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Environmental Technology Verification Report

Removal of Dissolved Salts and Particulate Contaminants from Seawater

Village Marine Tec.
Expeditionary Unit Water Purifier, Generation 1

Prepared by

NSF International

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**ULTRAFILTRATION AND REVERSE OSMOSIS**
APPLICATION:	**REMOVAL OF DISSOLVED SALTS AND PARTICULATE CONTAMINANTS FROM SEAWATER**
PRODUCT NAME:	**EXPEDITIONARY UNIT WATER PURIFIER (EUWP)**
VENDOR:	**VILLAGE MARINE TEC.**
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NSF International (NSF) manages the Drinking Water Systems (DWS) Center under the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program. The DWS Center evaluated the performance of the Village Marine Tec. Generation 1 Expeditionary Unit Water Purifier (EUWP). The EUWP, designed under U.S. Military specifications for civilian use, employs ultrafiltration (UF) and reverse osmosis (RO) to produce drinking water from a variety of sources. This document provides the verification test results for the EUWP system using seawater at Naval Base Ventura County in Port Hueneme, California.

EPA created the ETV Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups (consisting of buyers, vendor organizations, and permitters), and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

PRODUCT DESCRIPTION

The following technology description was provided by the manufacturer and has not been verified.

The EUWP was developed to treat challenging water sources with variable turbidity, chemical contamination, and very high total dissolved solids (TDS), including seawater, during emergency situations when other water treatment facilities are incapacitated. The EUWP components include feed pumps, a UF pretreatment system, a one or two pass RO desalination system with an energy recovery device, storage tanks, and product pumps. It has chemical feed systems for optional pretreatment coagulation and post treatment chlorination. Clean-in-place systems are included with the UF and RO skids. During this verification test, coagulation pretreatment was employed, but chlorination was not.

Design specifications indicate that the UF system alone has a production capacity up to 250,000 gallons per day (gpd) from a fresh water source with up to 500 mg/L TDS and a temperature of 25°C. The combined UF and RO system is designed to produce from 98,000 gpd up to 162,000 gpd, depending on the TDS of the source water and the recovery settings of the RO process.

VERIFICATION TEST DESCRIPTION

Test Site

The testing site was the Seawater Desalination Test Facility (SDTF) operated by the Naval Facilities Engineering Service Center (NFESC) at Naval Base Ventura County (NBVC) in Port Hueneme, California. The source water was from an open ocean intake in the Port of Hueneme, a deep-water port. The port has no appreciable fresh water outlets; therefore, the water closely resembles that of the Pacific Ocean salinity.

Initial characterization samples of seawater were collected in April, June and September 2006, and again in April and August 2007. Highlights of the initial characterization data are presented in Table VS-i. In addition to the data presented in Table VS-i, nitrite, nitrate, total silica, fluoride, and 29 metals were analyzed and the concentrations were either below the laboratory reporting limits (not detected) or below the National Primary Drinking Water Regulations (NPDWR) limits and are presented in the final report. Samples for many of the metals were analyzed by EPA Method 1640, which achieved detection limits much lower than Method 200.7 and provided data on seawater that could be compared to the NPDWR.

Table VS-i. Initial Raw Water Characterization Sampling Results

	Sample Date			
Parameter	**04/01/06**	**06/08/06**	**09/05/06**	**04/24/07**
pH	7.77	7.96	7.8	
Conductivity (µmhos/cm)	50,000	50,000	51,100	
TOC (mg/L)			ND (0.3)	
UV254 (l/cm)			0.016	
TSS (mg/L)			30	
TDS (mg/L)	34,000	37,000	35,700	
Alkalinity (mg/L $CaCO_3$)			100	
Total Hardness (mg/L as $CaCO_3$)			6,580	
Sodium (mg/L)				11,000
Heterotrophic Plate Count (CFU/mL)			4	
Total Coliforms (CFU/100 mL)			80	

Methods and Procedures

The U.S Army Tank-Automotive Research, Development, and Engineering Center (TARDEC) conducted the EUWP test with assistance from the U.S. Bureau of Reclamation (USBR). Field testing was conducted from October 16, 2007 to November 12, 2007. The ETV test protocol calls for testing to run for 30 days with the intent to operate the equipment until at least one chemical cleaning is performed. NSF allowed TARDEC to stop testing two days early because over the course of testing, the UF system was cleaned four times. Per a requirement of the ETV test, a chemical cleaning was performed on the RO system at the end of the test, although the RO system had not yet reached its cleaning level criteria.

The testing activities followed a test/quality assurance plan (TQAP) prepared for the project. The TQAP was developed according to ETV Protocols *EPA/NSF Protocol for Equipment Verification Testing for Removal of Inorganic Constituents*, dated April 2002, and the *EPA/NSF Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants*, dated September 2005.

Turbidity and conductivity were selected as two key water quality parameters, as turbidity removal by the system indicated the ability to remove particulate related contaminants, and a reduction in conductivity (indicator of total dissolved solids content) showed the ability of the RO system to remove dissolved contaminants. Flow, pressure, conductivity, and temperature recordings were collected twice per day when possible to quantify membrane flux, specific flux, flux decline, and recovery. Grab sample turbidity and pH readings were also recorded twice per day when possible. The UF and RO skids also included in-line turbidimeters for the raw water, UF filtrate, and RO permeate streams. The in-line turbidimeters recorded measurements every 15 minutes. In addition, the UF skid was equipped with in-line particle counters that recorded particle counts every five minutes. Pressure decay tests were conducted daily on the UF system to verify membrane integrity.

Total dissolved solids (TDS) were measured once per day on samples collected from the UF raw water and the RO process streams and once per week on the UF discharge and RO feed water. Once per week samples collected from the UF and RO process streams were analyzed for alkalinity, bicarbonate, total hardness, boron, calcium, chloride, lithium, magnesium, barium, selenium, ortho-phosphate, phosphorus (total), potassium, sodium, Stiff and Davis Stability Index (S&DSI), sulfate, total suspended solids (TSS), UV absorbance at 254 nm (UV_{254}), and total coliforms. Samples were collected for *Bacillus* endospores once per day from the UF and RO process water.

VERIFICATION OF PERFORMANCE

Finished Water Quality

The UF system reduced turbidity from a mean of 1.34 NTU in the raw water to a mean of 0.06 NTU in the UF filtrate, as measured by the daily grab samples. This equates to a mean percent reduction of 94.9%. The 95% confidence interval shows that filtrate turbidity can be expected to be in the range of 0.05 to 0.07 NTU. The raw water turbidity, as measured by the in-line analyzer, had a mean value of 1.38 NTU. The in-line turbidity data for the UF filtrate had a mean of 0.019 NTU. The UF filtrate turbidity levels met the NPDWR of <0.3 NTU 95% of the time and all values below 1.0 NTU throughout the test. A second turbidity requirement is an action level of 0.l5 NTU in the EPA Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). This rule states that if the filtrate turbidity exceeds 0.15 NTU over any 15-minute period, the system must be shut down for a direct integrity test. Since the data logger recorded turbidity every 15 minutes, the evaluation criteria was two consecutive turbidity measurements exceeding 0.15 NTU. There were three single data points where the UF filtrate turbidity exceeded 0.15 NTU. In each instance, the previous and following turbidity values were significantly below the 0.15 NTU level. Based on these data and evaluation criteria, it appears that the UF system did not exceed the LT2ESWTR action level during the verification test. It should be noted that the EUWP was not set up to

be compliant with the LT2ESWTR, as the in-line turbidity meters were not tied to an automatic system shutdown if the turbidity level exceeded 0.15 NTU for any 15 minute period.

The RO system provided little additional reduction of the turbidity levels, with the RO permeate having a mean turbidity of 0.05 NTU, based on the grab samples collected each day. The in-line RO permeate turbidimeter measurements had a mean turbidity of 0.013 NTU. The final treated water, the RO permeate, also met the NPDWR turbidity requirements. In addition, the RO system produced permeate with turbidity below the LT2ESWTR action level of 0.15 NTU throughout the test. As with the UF system, there were only three single RO permeate data points above the action level, and at no time were there two consecutive 15-minute readings above the action level.

The RO system reduced the dissolved ions in the water, as measured by conductivity by a mean of 99%. The mean conductivity in the RO permeate was 592 µS/cm, while that for the RO feed was 51,380 µS/cm. The direct measurements of TDS also show 99% reduction, with the RO permeate in the 280-300 mg/L range, compared to 34,000-39,000 mg/L in the RO feed. Sodium was reduced by 98% and chloride was reduced by 99%. These data are consistent with the conductivity data. The other inorganic materials measured such as hardness, alkalinity, metals, sulfate, and phosphorus were also effectively reduced in the RO permeate.

The UF system had no impact on the pH of the water with the feed water having a mean pH of 7.78 and the filtrate having a mean pH of 7.73. The RO system did lower the pH, the permeate having a mean pH of 6.29.

UF Membrane Integrity

Pressure decay tests, microorganism reduction, and particle counts were used to document UF membrane integrity. *Bacillus* endospores and total coliforms were measured in the feed and filtrate to provide data on the microbial reduction achieved by the UF system. In-line analyzers also collected particle count data from the feed and filtrate streams as an additional indicator of membrane integrity and the capability of the system to remove particulate and microbial contaminants.

Pressure decay tests on the UF system were performed on most operating days during the verification test. The mean pressure decay rates ranged from 0.02 to 0.15 psig/min. The overall mean pressure decay rate was 0.08 psig/min. These direct integrity test results were indicative of membrane modules with no significant observable breaches.

The particle counters recorded the particle counts in the UF feed and UF filtrate every five minutes and stored the data for transfer to a personal computer. The mean 2-3 µm particle count for the feed water was 5,559/mL, with a range of 53-17,843/mL. The UF filtrate had a mean 2-3 µm particle count of 42/mL, with a range of 0-773/mL. The UF system reduced the 2-3 µm particles by a mean value of 2.3 $\log_{10}$. However, the maximum particle count of 773/mL may not be indicative of the typical UF separation performance. The UF system went through a backflush cycle every half-hour, and during these backflushes the particle counts were still being recorded. Consequently, the filtrate particle count data included numerous spikes. The backflushes were not time-stamped, so the spikes due to backflushes could not be identified with certainty and removed from the data set.

The mean 3-5 µm particle count for the UF feed was 3,616/mL, with a range of 1,355-9,505/mL. The filtrate had a mean 3-5 µm particle count of 22/mL, with a range of 1-352/mL. Again, spikes due to backflushes could not be identified with certainty. The UF system reduced the 3-5 µm particles by a mean value of 2.5 $\log_{10}$.

Bacillus endospores and total coliform levels in the seawater were low during the test, with geometric mean concentrations of 64 CFU/100 ml and 10 CFU/100 ml, respectively. The UF system reduced the *Bacillus* endospores to a geometric mean of 1.3 CFU/100 ml. The UF filtrate endospores counts were 1 or <1 CFU/100mL on all but two days. No total coliforms were found in any UF filtrate samples.

UF System Operation

The UF system performance operations data for the test are presented in Table VS-ii. The intake flow is the intake from the source water into the UF feed water tank.

Table VS-ii. UF System Operations Data

Parameter	Count	Mean	Median	Minimum	Maximum	Standard Deviation	95% Confidence Interval
UF Operation per day (hr)	19	18.6	19.8	7.3	22.7	4.11	± 1.85
Intake Flow (gpm)	74	287	288	272	296	4.98	± 1.13
Feed Flow (gpm)	74	249	251	212	279	11.4	± 2.60
Filtrate Flow (gpm)	74	222	225	187	252	10.9	± 2.48
Retentate Flow (gpm)	74	26	26	25	34	1.66	± 0.38
Backwash Flow (gpm)	900 gallons per backwash cycle*; Backwash every 30 minutes						
Feed Pressure (psig)	74	20.6	20.0	14.0	30.0	3.74	± 0.85
Retentate Pressure (psig)	74	16.3	16.0	10.0	23.0	2.89	± 0.66
Filtrate Temperature (°F)	74	58.3	59.0	55.0	61.0	1.62	± 0.37

*Volume not measured. It was provided by the manufacturer.

The mean UF feed water flow was 249 gpm. The UF water recovery was 89.2% based on the mean feed water and filtrate flows. The net UF filtrate production over the 28 calendar-day test period (27 – 24 hour periods) was 4,673 kilogallons (kgal), which represents an average production rate of 173.1 kgal/day. The total UF filtrate volume (including filtrate used for backwash) produced was 5,249 kgal, which gives an average total production rate of 194.4 kgal/day. This production rate includes the two days when the UF was not operated as part of the cleaning cycle and includes other days with limited production due to cleaning or system maintenance issues.

A chemical coagulant (ferric chloride) was added to the UF feed water to improve operation of the UF system and to lengthen run time between chemical cleanings. The coagulant addition was planned for a feed rate of 4.37 ml/min, which would yield an iron dose (as Fe) of 0.75 mg/L in the UF feed water (4.6 x 10^{-6} gallons of ferric per gallon of feed water). Based on the tank records, a total of 22.4 gallons of ferric chloride were fed into 5,259,625 gallons of feed water (4.3 x 10^{-6} gallons of ferric per gallon of feed water), which is approximately 10% less than the feed rate measured by the pump calibration.

RO System Operation

The RO system operations data for the test are presented in Table VS-iii. The mean feed water flows of 115 gpm for Array 1 and 63 gpm for Array 2 were very close to the target feed rates established in the test plan (Array 1 target 116 gpm and Array 2 target was 58 gpm) to achieve an overall RO target flowrate of 100,000 gpd. The Array 1 recovery of 61% exceeded the target specification of 50%. The Array 2 recovery of 50% also exceeded the target specification of 48%. These recoveries, in conjunction with the feed water targets, resulted in mean permeate flow rates of 70 gpm for Array 1 and 32 gpm for Array 2. At these flows, the RO unit would need to operate an average of approximately 16.3 hours/day to meet the target of 100,000 gpd.

Table VS-iii. RO System Operations Data

Parameter	Count	Mean	Median	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Array 1 Feed Flow (gpm)	74	115	115	112	117	0.74	± 0.17
Array 1 Permeate Flow (gpm)	74	70	70	68	72	0.82	± 0.19
Array 1 Concentrate Flow (gpm)	74	45	45	43	48	1.03	± 0.23
Array 2 Feed Flow (gpm)	74	63	63	56	68	2.05	± 0.47
Array 2 Permeate Flow (gpm)	74	32	32	25	37	2.11	± 0.46
Array 2 Concentrate Flow (gpm)	74	31	31	30	32	0.36	± 0.08
Array 1 Feed Pressure (psig)	74	954	960	860	977	19.5	± 4.44
Array 1 Concentrate Pressure (psig)	74	905	903	870	992	15.5	± 3.53
Array 2 Feed Pressure (psig)	74	902	900	880	995	15.4	± 3.51
Array 2 Concentrate Pressure (psig)	74	868	865	850	885	7.65	± 1.74
Array 1 and 2 Combined Permeate Pressure (psig)	74	23.4	23.5	21.0	28.5	1.34	± 0.31

Over the 28 calendar-day (27 24-hour periods) verification test, the RO feed water totalizer showed 4,673 kgal of water was fed to the RO unit. Based on the daily percent recoveries for each array (typically Array 1 at 61% and Array 2 at 50%), the total volume of permeate produced was approximately 2,671 kgal, giving an average of 98.9 kgal/day over the 28-day test.

The primary reason the RO system did not achieve or exceed the production goal of 100 kgal/day was a lack of feed water when the UF system was shut down for cleaning. The UF system also shutdown anytime the RO system feed water tank was full. The test was designed to evaluate the entire system with both UF and RO in operation. The UF system produced enough water to meet the 100 kgal/day production goal; however, because of limited UF filtrate storage capacity, long downtime periods for the UF system cleaning did impact the RO production. With more storage capacity for UF filtrate, the UF system would have been able to meet the feed requirements for the RO system to achieve the overall goal of producing 100 kgal/day, even with the more frequent cleaning schedule. Whenever, there was feed available, the RO system operated continuously producing permeate at a flow rate of 100 to 102 gpm. The RO system operated greater than 20 hours on 12 of the 25 actual operating days. During those days, when the UF was also operating most hours of the day, the RO system did meet and exceed the target production rate. The RO mean operating hours were 17.0 hours/day with a median of 19.0 hrs/day. These mean and median hours match closely to the UF hours (mean – 16.9 hrs and median 19.1 hrs). The maximum RO operating hours were 24 hours and the minimum was 4 hours.

Antiscalant was added to the RO feed water throughout the test. The mean dose rate was 5.7 mg/L versus a target feed of 5 mg/L. The RO system did not appear to experience any scaling or fouling problems during the test. The S&DSI varied from -0.71 to -0.84 during the test. This indicates that the concentrate was a non-scaling water (S&DSI <0.0 is non-scaling). The combination of non-scaling water and the addition of antiscalant reduced or eliminated the problems of scaling on the RO membranes.

The system operated consistently throughout the test with little change in flows or pressures. This would suggest that for this source, the RO could have met and exceeded production targets, if sufficient water could have been provided from the UF system. The buildup of solids on the UF system and need for frequent UF system cleaning was the limiting factor over the test period.

The RO system specific flux was consistent over the test period and indicates that the RO membranes were not being fouled over time. The membranes were still functioning at the end of the test at a specific flux that was 97% of the starting specific flux; therefore, it cannot be projected when the membranes would require cleaning. The RO system was chemically cleaned in place on November 13 and 14, 2007 at the end of the test. This cleaning was performed because it was a requirement of the verification test to demonstrate the cleaning process; however the RO system had not actually reached its target cleaning level criteria.

QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

NSF provided technical and quality assurance oversight of the verification testing as described in the verification report, including a review of 100% of the data. NSF QA personnel also conducted a technical systems audit during testing to ensure the testing was in compliance with the test plan. A complete description of the QA/QC procedures is provided in the verification report.

Original signed by Sally Gutierrez 08/12/10
Sally Gutierrez Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original signed by Robert Ferguson 05/18/10
Robert Ferguson Date
Vice President
Water Systems
NSF International

NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and NSF make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end-user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of corporate names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products. This report is not an NSF Certification of the specific product mentioned herein.

Availability of Supporting Documents
Copies of the test protocol, the verification statement, and the verification report (NSF report # NSF 09/29/EPADWCTR) are available from the following sources:

1. ETV Drinking Water Systems Center Manager (order hard copy)
   NSF International
   P.O. Box 130140
   Ann Arbor, Michigan 48113-0140
2. Electronic PDF copy
   NSF web site: http://www.nsf.org/info/etv
   EPA web site: http://www.epa.gov/etv

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Notice

The U.S. Environmental Protection Agency, through its Office of Research and Development, funded and managed, or partially funded and collaborated in, the research described herein. It has been subjected to the Agency's peer and administrative review and has been approved for publication. Any opinions expressed in this report are those of the author (s) and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Foreword

The EPA is charged by Congress with protecting the nation's air, water, and land resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

The Environmental Technology Verification (ETV) Program has been established by the EPA to verify the performance characteristics of innovative environmental technology across all media and to report this objective information to permitters, buyers, and users of the technology, thus substantially accelerating the entrance of new environmental technologies into the marketplace. Verification organizations oversee and report verification activities based on testing and quality assurance protocols developed with input from major stakeholders and customer groups associated with the technology area. ETV consists of six environmental technology centers. Information about each of these centers can be found on the internet at http://www.epa.gov/etv.

Under a cooperative agreement, NSF International has received EPA funding to plan, coordinate, and conduct technology verification studies for the ETV "Drinking Water Systems Center" and report the results to the community at large. The DWS Center has targeted drinking water concerns such as arsenic reduction, microbiological contaminants, particulate removal, disinfection by-products, radionuclides, and numerous chemical contaminants. Information concerning specific environmental technology areas can be found on the internet at http://www.epa.gov/nrmrl/std/etv/verifications.html.

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Abbreviations and Acronyms

ANGB	Air National Guard Base
BOD	Biochemical Oxygen Demand
°C	degrees Celsius
CFU	colony-forming unit
CIP	clean-in-place
cm	centimeter
DF2	diesel fuel, grade 2
DFA	diesel fuel, arctic grade
DWSC	Drinking Water Systems Center
EPA	United States Environmental Protection Agency
ETV	Environmental Technology Verification
EUWP	Expeditionary Unit Water Purifier
°F	degrees Fahrenheit
FRP	fiberglass reinforced plastic
ft	foot (feet)
gal	gallons
gfd	gallons per foot per day
gpd	gallons per day
gpm	gallons per minute
h	hour
HPC	Heterotrophic plate count
in	inch
JP8	jet propellent 8 (jet fuel)
kgal	kilogallon
kW	kilowatt
kWh	kilowatt hour
L	liter
lbs	pounds
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
m	meter
mg	milligram
mL	milliliter
mS	milliSiemens
MWCO	molecular weight cutoff
NBC	nuclear, biological, and chemical
ND	non-detect
NDP	net driving pressure
NFESC	Naval Facilities Engineering Service Center
NIST	National Institute of Standards and Technology
NM	not measured
NPDWR	National Primary Drinking Water Regulations
NRMRL	National Risk Management Research Laboratory
NSF	NSF International (previously known as the National Sanitation Foundation)
NSWCCD	United States Naval Surface Warfare Center – Carderock Division

Abbreviations and Acronyms (continued)

NTU	Nephelometric turbidity units
NBVC	Naval Base Ventura County
O&M	operations and maintenance
ONR	Office of Naval Research
ORD	Office of Research and Development
P&ID	piping and instrumentation diagram
PE	performance evaluation
PLC	programmable logic controller
ppm	parts per million
psi	pounds per square inch
psig	pounds per square inch, gauge
PVC	polyvinyl chloride
PX	pressure exchanger
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RO	reverse osmosis
RPD	relative percent difference
RPM	revolutions per minute
S&DSI	Stiff and Davis Stability Index
SDI	Silt Density Index
SDTF	Seawater Desalination Test Facility
SM	Standard Methods for the Examination of Water and Wastewater
SNL	Sandia National Laboratories
TARDEC	Tank-Automotive Research, Development, and Engineering Center
TDS	total dissolved solids
TOC	total organic carbon
TQAP	test/quality assurance plan
TQG	Tactical Quiet Generator
TSS	total suspended solids
TMP	transmembrane pressure
UF	ultrafiltration
USBR	United States Bureau of Reclamation
UV_{254}	ultraviolet absorbance at 254 nanometers
VOC	volatile organic chemicals
µm	micron
µS	microSiemens

Acknowledgements

The U.S. Army Tank-Automotive Research, Development, and Engineering Center (TARDEC) was the main field testing organization. TARDEC was supported by the U.S. Bureau of Reclamation (USBR). TARDEC and USBR were responsible for all elements of the tests, including operation of the equipment, collection of samples, instrument calibration, and data collection.

This verification report was authored by Mr. Dale Scherger of Scherger and Associates (3017 Rumsey Drive, Ann Arbor, MI 48105), Mr. Michael Blumenstein, Ms. Kristie Wilhelm, and Mr. C. Bruce Bartley of the NSF International ETV Drinking Water Systems Center (DWSC), Ms. Michelle Chapman of USBR, and Mr. Jeffrey Q. Adams of USEPA. The verification report was based on the project test/quality assurance plan authored by DWSC, USBR, and TARDEC.

The laboratory selected for the analytical work was:
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The engineers responsible for the daily operations of the field test were Mr. Mark Miller, Mr. Abel Juarez, Mr. Daniel Gonzalez, Mr. Andrew Tiffenbach, and Mr. Micah Ing. The USBR support staff included Ms. Michelle Chapman and Mr. Steve Dundorf.

The NSF DWSC project manager was Mr. Michael Blumenstein. The DWSC is managed by Mr. Bruce Bartley. Ms. Kristie Wilhelm of the DWSC provided valuable assistance with report preparation.

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Chapter 1
Introduction

1.1 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; with stakeholder groups consisting of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans responsive to the needs of stakeholders, conducting field demonstrations, collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The EPA has partnered with NSF International (NSF) under the ETV Drinking Water Systems Center (DWSC) to verify the performance of small drinking water systems that serve small communities. A goal of verification testing is to enhance and facilitate the acceptance of small drinking water treatment equipment by state drinking water regulatory officials and consulting engineers, while reducing the need for testing of equipment at each location where the equipment's use is contemplated. NSF meets this goal by working with manufacturers and NSF-qualified Field Testing Organizations (FTO) to conduct verification testing under the approved protocols. It is important to note that verification of the equipment does not mean the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the FTO.

The DWSC evaluated the performance of the Village Marine Tec. Generation 1 Expeditionary Unit Water Purifier (EUWP). The EUWP, developed for the U.S. Military, uses ultrafiltration (UF) and reverse osmosis (RO) to produce drinking water from a variety of sources. This document provides the verification test results for the EUWP system using seawater at Naval Base Ventura County (NBVC) in Port Hueneme, California.

1.2 Testing Participants and Responsibilities

EUWP design, construction, and testing was overseen by a federal multi-agency team composed of representatives from Office of Naval Research (ONR); Army Tank-Automotive Research, Development, and Engineering Center (TARDEC); Naval Surface Warfare Command – Carderock Division (NSWCCD); United States Department of Interior Bureau of Reclamation

(USBR); and Sandia National Laboratories (SNL). The manufacturer, Village Marine Tec., was contracted to design and build the EUWP to the team's Generation 1 specifications using 2004 state-of-the-art technology.

The organizations involved in the verification testing project were:

- EPA
- NSF
- ONR
- TARDEC
- USBR
- Village Marine Tec.

The following is a brief description of all of the ETV participants and their roles and responsibilities.

1.2.1 EPA

EPA, through its Office of Research and Development (ORD), has financially supported and collaborated with NSF under Cooperative Agreements R-82833301 and CR833980. This verification effort was supported by the DWSC operating under the ETV Program. This document has been peer-reviewed, reviewed by USEPA, and recommended for public release.

1.2.2 NSF International

NSF is an independent, not-for-profit testing and certification organization dedicated to public health and safety and to the protection of the environment. Founded in 1946 and located in Ann Arbor, Michigan, NSF has been instrumental in the development of consensus standards for the protection of public health and the environment. NSF also provides testing and certification services to ensure products bearing the NSF Name, Logo and/or Mark meet those standards. The EPA partnered with NSF to verify the performance of drinking water treatment systems through the EPA's ETV Program.

NSF authored the test plan and test report. NSF also served as the analytical laboratory for all water quality parameters not measured in the field. NSF also provided technical oversight during testing and conducted an audit of the field testing activities.

Contact Information:

NSF International
789 N. Dixboro Road
Ann Arbor, Michigan 48105
Contact: Mr. Bruce Bartley, Project Manager
Phone: (734) 769-8010
Fax: (734) 769-0109
Email: bartley@nsf.org

1.2.3 ONR

The U.S. Navy ONR provided oversight of the EUWP development program which involved developing high productivity water treatment units for land and shipboard military and civilian emergency preparedness applications. ONR also provided funding for the EUWP ETV testing project.

Contact Information:

Office of Naval Research
Logistics Thrust Program
Operations Technology Division
800 N. Quincy St.
Arlington, VA 22217
Contact: Major Alan Stocks
Phone: 703-696-2561
Email: stocksa@onr.navy.mil

1.2.4 TARDEC

TARDEC served as the FTO for this verification. TARDEC was responsible for all on-site testing activities, including operation of the test equipment, collection of samples, measurement of water quality parameters, calibration and check of instrumentation, and operational data collection.

Contact Information:

U.S. Army TARDEC/RDECOM
AMSRD-TAR-D/210, MS 110
6501 E. Eleven Mile Road
Warren, MI 48397
Contact: Mr. Bob Shalewitz, TARDEC EUWP Program Manager
Phone: 586-574-4128
Email: bob.shalewitz@us.army.mil

1.2.5 USBR

USBR functioned as a co-FTO, providing field operations support, and technical support for equipment operation.

Contact Information:

U.S. Bureau of Reclamation
Denver Federal Center (D-8230)
P.O. Box 25007
Denver, CO 80225
Contact: Ms. Michelle Chapman
Phone: 303-445-2264
Email: mchapman@do.usbr.gov

1.2.6 Village Marine Tec.

The EUWP manufacturer was Village Marine Tec. The manufacturer was responsible for supplying a field-ready treatment system equipped with all necessary components, including instrumentation and controls, and an operation and maintenance (O&M) manual. The manufacturer was responsible for providing logistical and technical support, as needed, as well as technical assistance to the FTO during operation and monitoring of the equipment undergoing field verification testing.

Contact Information:

Village Marine Tec.
2000 W. 135th St.
Gardena, CA 90249
Phone: 310-516-9911
Email: sales@villagemarine.com

1.3 Verification Testing Site

The EUWP was tested at the Seawater Desalination Test Facility (SDTF) operated by the Naval Facilities Engineering Service Center (NFESC) at NBVC in Port Hueneme, California. Port Hueneme is located on the coast of California approximately 60 miles northwest of Los Angeles. Raw seawater directly from the Port of Hueneme was used for ETV testing. The Port of Hueneme is the only deep water port between Los Angeles and San Francisco. It has no appreciable fresh water outlets; therefore the water closely resembles that of the Pacific Ocean with respect to salinity. Average water temperature ranges from 55°F in the winter months to approximately 62°F in the summer. The source water chemistry was profiled for the initial water characterization task. The water chemistry data is presented in Section 4.3.

The EUWP was situated on a concrete pad at the SDTF as shown in Figure 1-1.

Figure 1-1. Photo of the concrete pad used for EUWP testing.

Chapter 2
Equipment Capabilities and Description

The EUWP was designed to meet purified water needs in areas with challenging water sources of very high total dissolved solids (TDS), turbidity, or hazardous contamination during emergency situations when other water treatment facilities are incapacitated. The system uses UF and RO to produce potable water. It is not intended to meet general municipal water treatment needs in a cost effective manner. The design requirements – to produce 100,000 gal per day (gpd) and be C-130 transportable – forced the use of lightweight durable materials, such as titanium, that are more costly and would not usually be required for municipal water treatment. The requirements to treat source water with up to 60,000 milligrams per liter (mg/L) TDS and ensure removal of nuclear, biological, and chemical (NBC) contaminants to a safe limit, drove the design to two parallel arrays - with a 2^{nd} permeate pass resulting in a maximum of 65% recovery. Most municipal water treatment systems can easily attain much higher recovery levels. The EUWP is also intended as a demonstration of the state-of-the-art of desalination for emergency situations.

Key innovations applied in the EUWP are:

- High flux UF membrane cartridges;
- Innovative staging of RO membrane modules; and
- Small system energy recovery to pressurize a parallel array.

The EUWP was developed to meet the following objectives:

- Develop a high capacity drinking water purification unit to provide strategic water production capability with a focus on peacekeeping, humanitarian aid, and disaster relief missions that the military frequently supports.
- Further the state of desalination technology with a view toward reduced operational costs, size, and weight; improved reliability; and verifying emerging technologies.

2.1 Equipment Capabilities

The objective of this verification test was to document the ability of the EUWP to meet the following performance criteria:

The EUWP is capable of producing 100,000 gpd of water meeting EPA's National Primary Drinking Water Regulations (NPDWR) from raw Port Hueneme sea water based on contaminants found in the source water during the initial water characterization phase of ETV testing.

The EUWP is intended to meet purified water needs in areas with challenging water sources of very high TDS, turbidity, or hazardous contamination during emergency situations when other water treatment facilities are incapacitated. The unit was designed to meet or exceed Tri-Service Field Water Quality Standards for short-term consumption by healthy adults. However, the technology used is capable of exceeding the EPA NPDWR.

The EUWP, using the UF system only, can produce up to 250,000 gpd of potable water from a fresh water source with up to 500 mg/L TDS and a temperature of 77 degrees Fahrenheit (°F) (25 degrees Celsius, or °C), provided that contaminants not removed by UF are not present in the source water. Using the UF and RO system, it is designed to produce from 98,000 gpd up to 162,000 gpd depending on the TDS of the source water and the recovery settings of the RO system. Production is decreased to 125,000 gpd (50% recovery) for higher TDS waters. It can also produce 98,000 gpd from a NBC contaminated source with up to 45,000 mg/L TDS. NBC contaminant removal was not verified as part of the ETV test at Port .

2.2 General System Description

- Equipment name: Expeditionary Unit Water Purifier (EUWP)
- Model number: Generation 1
- Manufacturer: Village Marine Tec., 2000 W. 135th St., Gardena, CA 90249, (310) 324-4156.
- Power requirements: 480 volts, 250 Amp, 60 hertz, 3-phase electrical, or two 60 kilowatt (kW) diesel Tactical Quiet Generators (TQG).
  - UF Requirements – 125 amps maximum
  - RO Requirements – 125 amps maximum

The EUWP is composed of feed pumps, a UF pretreatment system, a 1 or 2 pass RO desalination system with energy recovery, storage tanks, and product pumps (Figure 2-1). It has chemical feed systems for pretreatment and post treatment. Clean-in-place (CIP) systems are included with the skids.

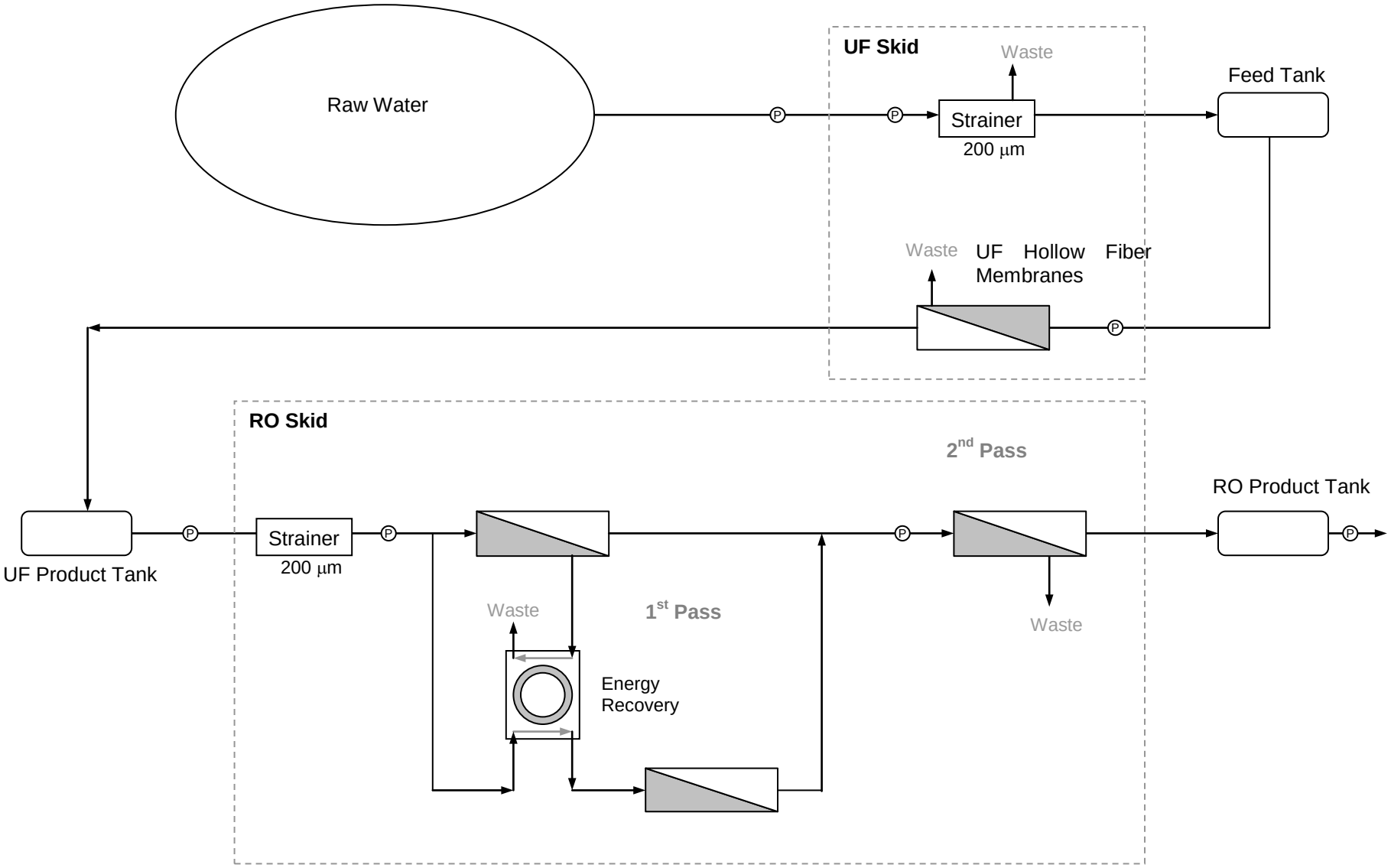


Figure 2-1. Process component diagram.

2.3 Concept of Treatment Processes

2.3.1 UF Pretreatment/Suspended Solids Filtration

UF is a low-pressure (5–90 pounds per square inch, gauge, or psig) membrane process that separates particulates based on size exclusion. The UF process retains oils, particulate matter, bacteria, and suspended solids that contribute to turbidity and a high silt density index (SDI). Feed water to RO systems should have turbidity less than 0.1 Nephelometric Turbidity Units (NTU) and a SDI less than 3. UF membranes pass water, dissolved salts, and most dissolved organic compounds. UF pore sizes range from 0.002 to 0.1 micron (µm) (1,000–500,000 molecular weight cutoff, or MWCO). Koch Membrane Systems Targa-10 hollow fiber UF membranes are used in the EUWP. Water flows from the inside of the fiber to the outside causing suspended solids to collect on the inside of the fiber. Periodically, the system must be vigorously backwashed to remove this material from the system. Figure 2-2 shows example UF cartridges, a single fiber, and the flow pattern used in this system.

The key operating parameters for a UF system are the instantaneous flux and the overall productivity taking into account the volume required for backwash. Generally, the higher the instantaneous flux, the more often backwashing will be required. There is an optimum flux point where overall productivity is maximized, called the critical flux. For municipal systems, it is economical to operate the system at the critical flux. The EUWP is an emergency supply system with extreme weight restrictions to enable transport. The weight restrictions drove design of the UF system to operate at a maximum flux with more frequent backwashes.

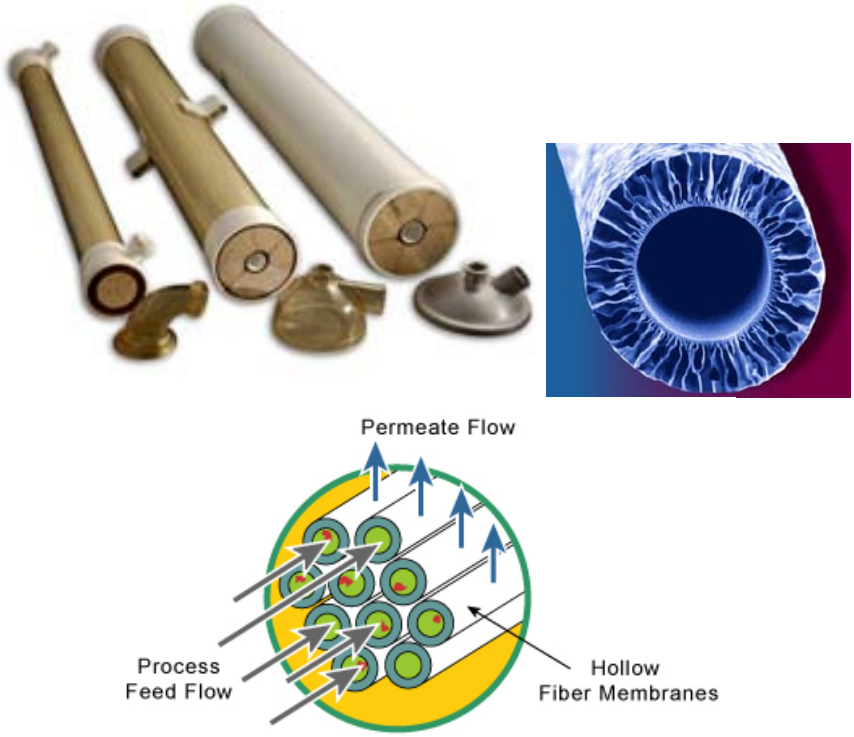


Figure 2-2. Koch UF hollow fiber modules, a single fiber, and the process flow through the module.

2.3.2 RO Desalination

Dissolved salts and larger molecular weight organic molecules can be removed by RO. Osmosis is a naturally occurring phenomenon in which pure water is transported down a chemical potential gradient across a semi-permeable membrane from a low concentration solution to a high concentration solution. One measure of the chemical potential is the osmotic pressure. Osmotic pressure is dependent on the concentration of ions and dissolved compounds. It can be measured by pressurizing the concentrated solution until osmotic induced flow stops. If this pressure is exceeded, then osmotic flow reverses from concentrated solution to the dilute solution.

RO is a moderate to high-pressure (80 – 1,200 psig) membrane separation process. The membranes in the EUWP are spiral wound with up to seven modules in a vessel. Figure 2-3 shows the construction of a spiral wound element. They are operated under cross-flow conditions at a pressure above the osmotic pressure of the bulk solution, plus additional pressure to overcome resistance of the modules. Water passing through the RO membrane is called permeate, and the concentrated discharge stream is called concentrate.

The separation model is of solution and diffusion of material through the polymer of the membrane. Dissolved salts are transported very slowly compared to water and other un-charged molecules. Uncharged molecules may be rejected based on size exclusion, depending on their mass and geometry.

2.4 Detailed System Description

This section provides a detailed system description. See the system operation manual in Appendix A for further details about the system and operation. Note that the system was designed and manufactured prior to promulgation of the final EPA Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). The EUWP, as tested, was not designed to comply with the LT2ESWTR indirect integrity monitoring requirement that calls for the system to shut down pending a direct integrity test, if two consecutive turbidity readings exceed 0.15 NTU. The EUWP does have in-line turbidity meters to monitor the feed and filtrate streams for the UF skid, but the programmable logic controller (PLC) was not programmed to automatically shut down the system, if necessary. The RO system has an in-line turbidity meter for the RO permeate process stream. The RO system also includes in-line conductivity meters to monitor performance. The system process schematic and detailed layout are shown in Figures 2-3 and 2-4, respectively.

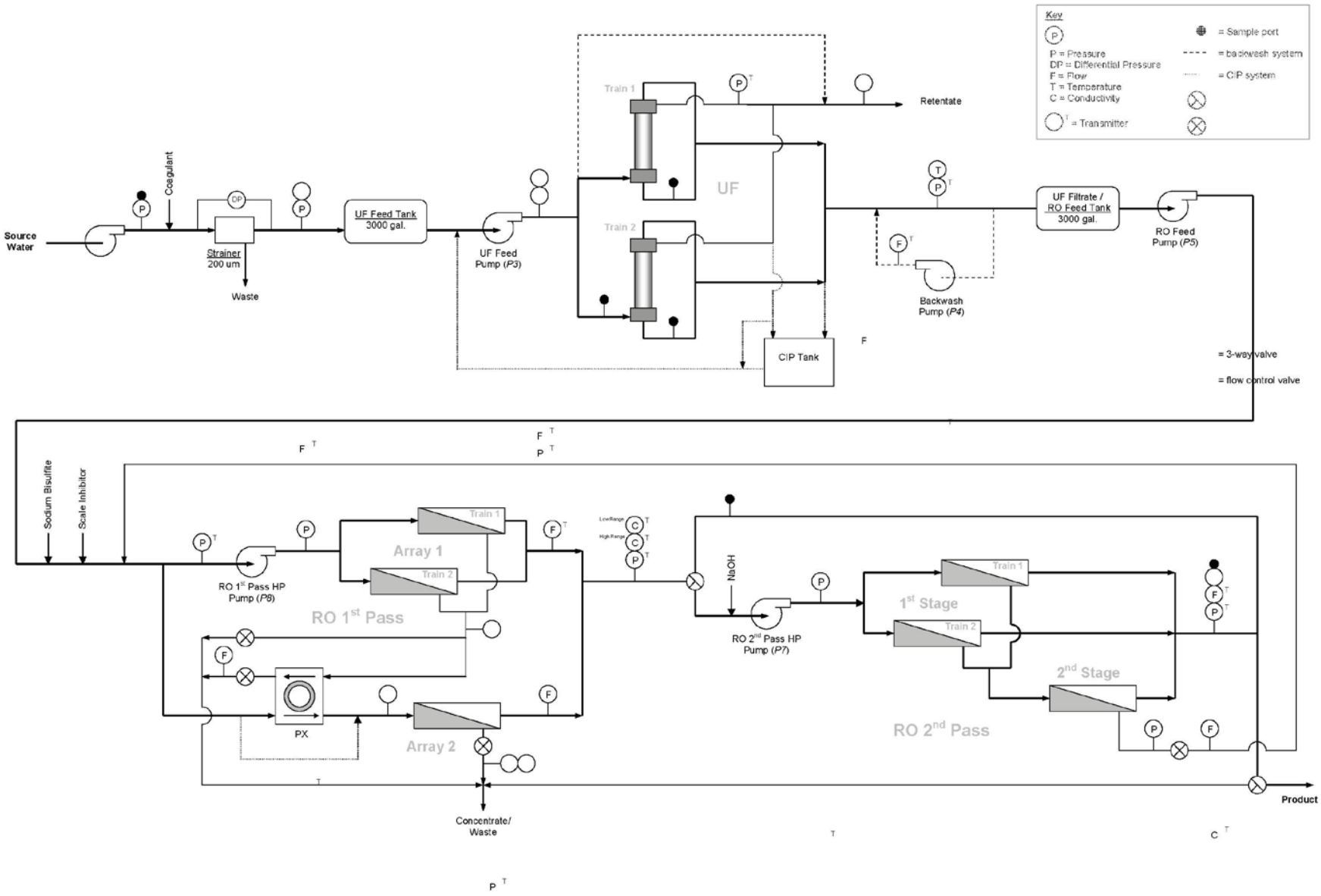


Figure 2-3. EUWP system process schematic.

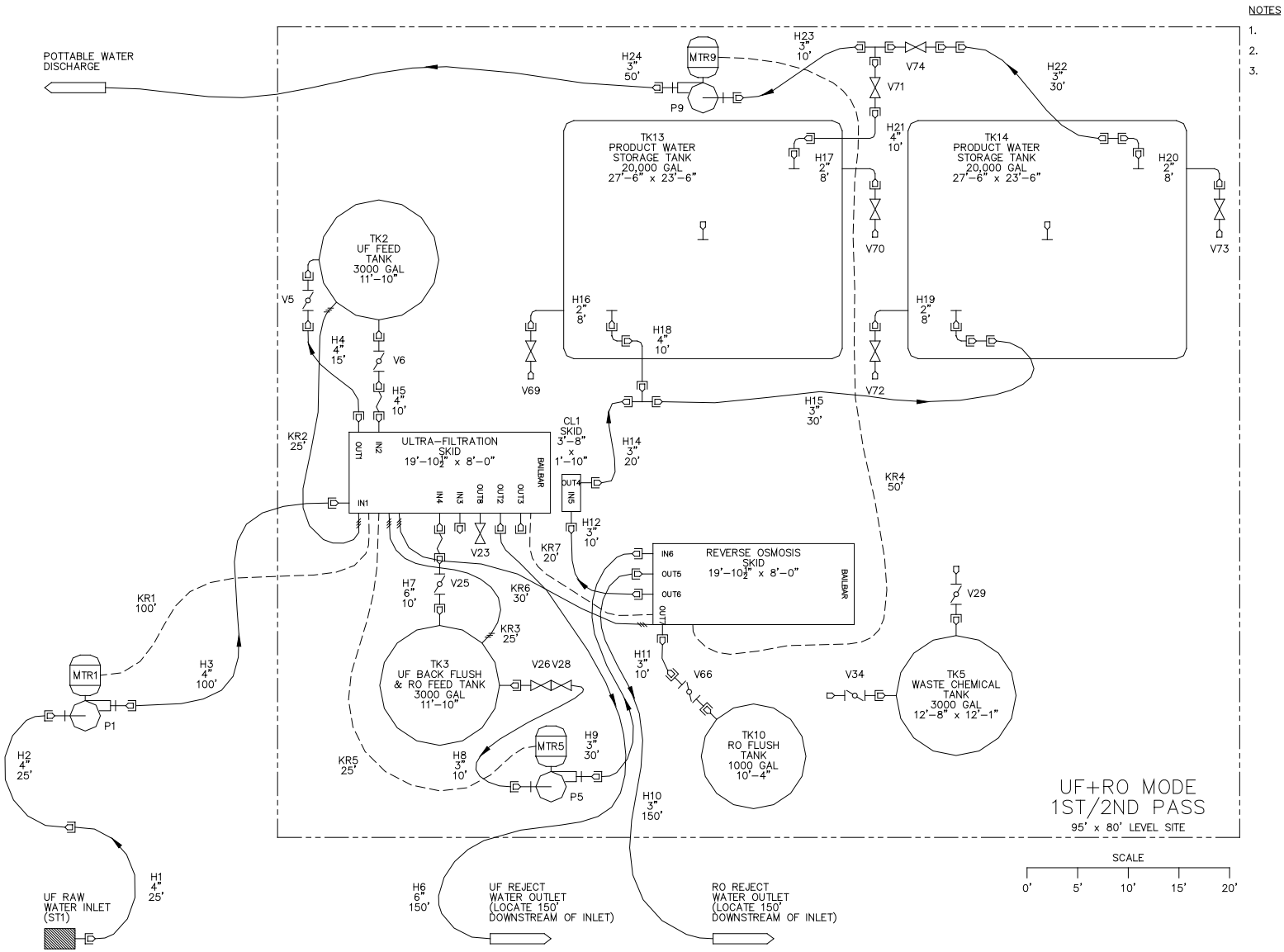


Figure 2-4. Schematic of typical EUWP layout.

2.4.1 Raw Water Intake

Raw seawater was drawn from the Port of Hueneme at a point approximately halfway into the port from the open sea. An intake strainer was used to keep large pieces of debris from being drawn up. Before the raw water reached the UF feed tank, ferric chloride was injected as a coagulant, and the water was strained again through dual Amiad Filtration Systems, Ltd. model TAF-750 strainers, operated in parallel. Each strainer was equipped with a 200 µm weave-wire screen. The strainers did not remove any ferric chloride floc, since there was not enough time for particles larger than 200 µm to form between the injection point and the strainer. The 3,000 gallon (gal) UF feed tank provides at least 12 minutes of retention time for floc formation.

2.4.2 UF System Description

The UF membranes used in the EUWP are model TARGA® 10-48-35-PMC, manufactured by Koch Membrane Systems. The UF cartridge specifications are presented in Table 2-1. The UF membranes are configured in two parallel trains of eight cartridges each, all of which are operated in parallel. The membranes are operated such that 10% of the feed flow exits the cartridges as retentate. Statistics of the UF skid are presented in Table 2-2. Photos of the UF skid are shown in Figure 2-5 and Figure 2-6.

Table 2-1. Koch Membrane Systems Targa 10-48-35-PMC Cartridge Specifications

Parameter	Value
Nominal Molecular Weight Cut-off	100,000
Max. Recommended Flow (per cartridge)	32.2 gpm(1)
Maximum Pressure	45 psig
Maximum Transmembrane Pressure (TMP)	30 psig
Maximum Backflush TMP	20 psig
Inner Fiber Diameter	0.035 in(2)
Membrane Area	554 ft2(3)
Cartridge Diameter	10.75 in
Cartridge Length	48 in

(1) gallons per minute
(2) inch(es)
(3) square feet

Table 2-2. UF Skid Statistics

Parameter	Value
Production Capacity	250,000 gpd
Maximum Pressure to Membranes	45 psig
Maximum Transmembrane Pressure	30 psig
Water Temperature Range	34–104 ^{o}F
Turbidity Range	0–150 NTU
Dimensions	20’ L x 8’ H x 8’ W
Weight	15,500 lbs dry, fully paced out for deployment, less fuel
Basic Metals	UF System Piping: Fiberglass, Titanium, Nylon Air System Piping: Nylon Tubing
Operating Ambient Temperature Range	32°F–120°F
Storage and Transport Air Temperature Range	32°F–120°F
Relative Humidity:	3%–95%
Maximum slope of unit when deployed for operation	5 degrees side to side, 2 degrees end to end
Power Source Requirement	60 kW Generator (self contained) or power grid connection consisting of 480 volts, 125 amps. UF system and external pumping power requirements are 2.1 kWh/kgal(1)
Fuel Type	DF2 (Diesel Fuel, Grade 2) DFA (Diesel Fuel, Arctic Grade) JP8 (jet propellent 8)
Fuel Capacity (60 kW Generator)	43 gal

(1) kilowatt-hours per kilogallon

Figure 2-5. Photo of the UF skid.

Figure 2-6. Photo of the UF cartridges mounted in the UF skid.

2.4.2.1 UF System Operation

The following is a basic description of the flow path and functional description of the UF system in normal operation for an open surface water source. The operation manual provides a full description of UF operation. Figure 2-7 is a piping and instrumentation diagram of the UF system.

1. Pump #1 (P1) brings water through the intake strainer #1 (ST1) (if an open intake is used) to the UF skid. Before entering the UF feed tank, water is strained (ST2) again to 200 µm on the UF skid. The strainers serve to eliminate debris that would clog the membrane fibers. Water exits strainer #2 and is stored in the UF feed tank (TK2) which serves as a break tank between the feed water supply and the UF feed.
2. If necessary, ferric chloride coagulant from Chemical Pump #1 (CP1) can be added to the feed stream before entering ST2 to enhance UF performance. The decision to use ferric chloride is site-specific, based on the raw water quality, if known, and/or the results of a jar test.
3. Pump #3 (P3) moves water from TK2 to the UF membranes.
4. The UF filtrate flows to tank #3 (TK3). TK3 acts as a break tank between the UF skid and the RO skid and a back flush reservoir for the UF skid.

5. Pump #5 (P5) pumps water from TK3 to the RO skid or directly through the disinfection system (CL1 – calcium hypochlorite) to the distribution system when RO is not required. The disinfection system will not be used for this verification.

2.4.2.2 UF Cleaning Procedure

The UF system must be cleaned when the TMP exceeds 35 psig after a normal backflush cycle. This cleaning cycle is required approximately every 30 days, depending on the water source. The CIP procedure typically uses citric acid as the low pH cleaning agent, and sodium hydroxide as the high pH cleaning agent. Note that different cleaning agents may need to be used for certain foulants. Citric acid, sodium hydroxide, and sodium hypochlorite (bleach) were used during the UF system CIP procedures during the ETV test.

If system operation requires the use of ferric chloride as a coagulant, then a low pH clean must be performed first, followed by a high pH clean. If ferric chloride is not being used, then a high pH clean must be performed first, then a low pH clean. Ferric chloride was used during testing at Port Hueneme. The following is a basic description of the flow path and functional description of the UF system in normal operation. The operation manual provides a full description of UF operation, including an operational summary described below.

1. Prior to CIP, perform a fresh back flush.
2. Following backwash, set up system for UF normal mode of operation. Activate UF drain mode on the screen.
3. Wait for the system to drain.
4. Connect the hose from the CIP tank to the system.
5. Touch the CIP button on the screen. Select CIP Mode ON. The programmable logic controller (PLC) will automatically move the pneumatically operated valves to the correct positions.
6. Enable heaters to maintain CIP solution to between 96 and 100°F.
7. Turn tank mixer on using CIP display screen
8. Add the appropriate amount of chemical to achieve the desired pH.
9. Check the pH of the mixture in tank 4 at sample port V22 every 15 minutes. Use citric acid to lower the pH to 3 or use sodium hydroxide to raise the pH to 11.
10. With high pH only, add an appropriate amount of calcium hypochlorite.
11. Start CIP by touching the CIP button at the top left of the CIP screen then start to pump the solution using P3.
12. Allow the chemical to circulate through the selected array for 20 to 30 minutes.
13. Let the system soak for several hours after recirculation if needed to remove tough fouling.
14. Repeat recirculation with the desired chemicals.
15. Following chemical recirculation, rinse the system as necessary with clean water.

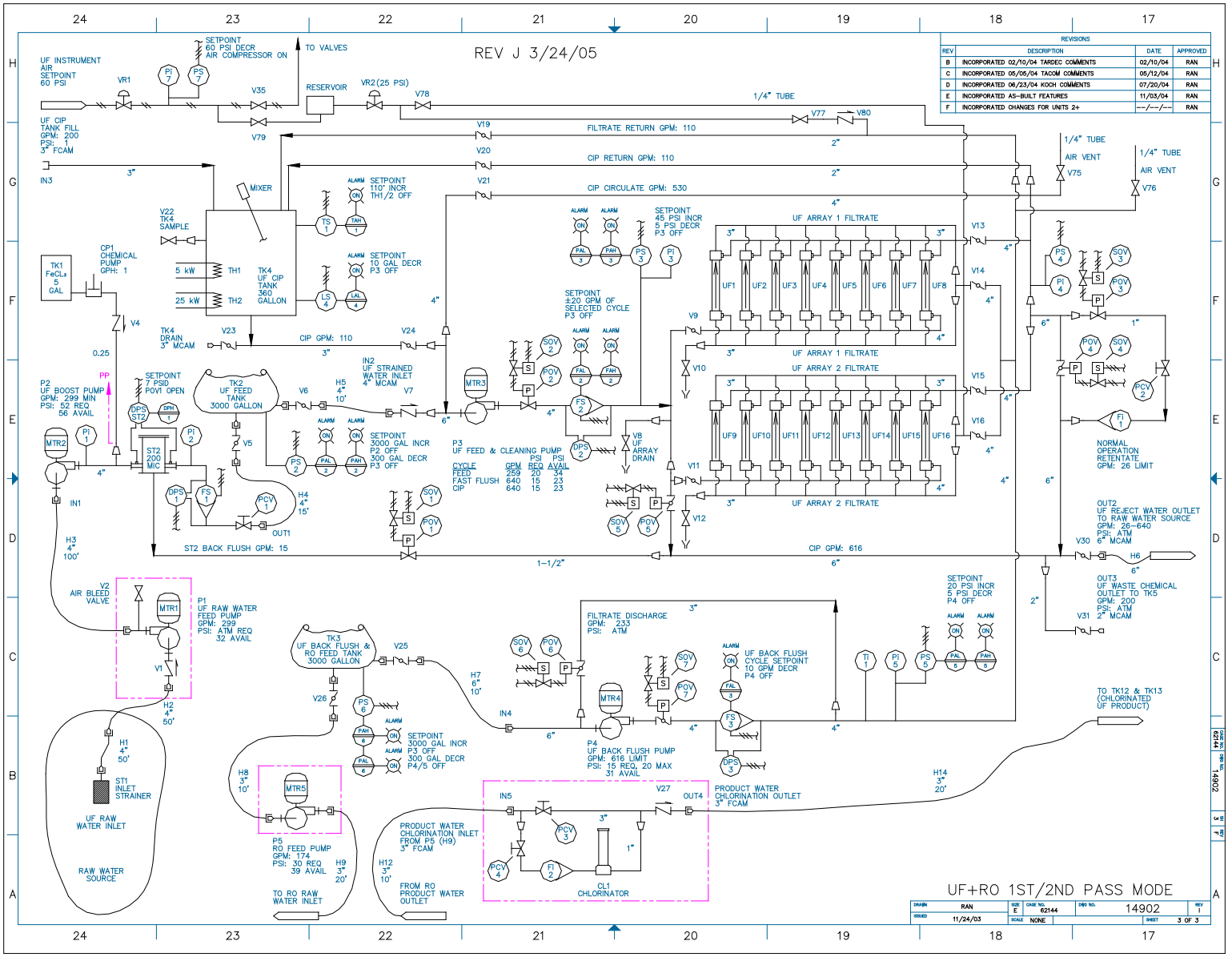


Figure 2-7. Piping and instrumentation diagram of UF skid.

2.4.3 RO System

The RO skid is shown below in Figures 2-8 and 2-9.

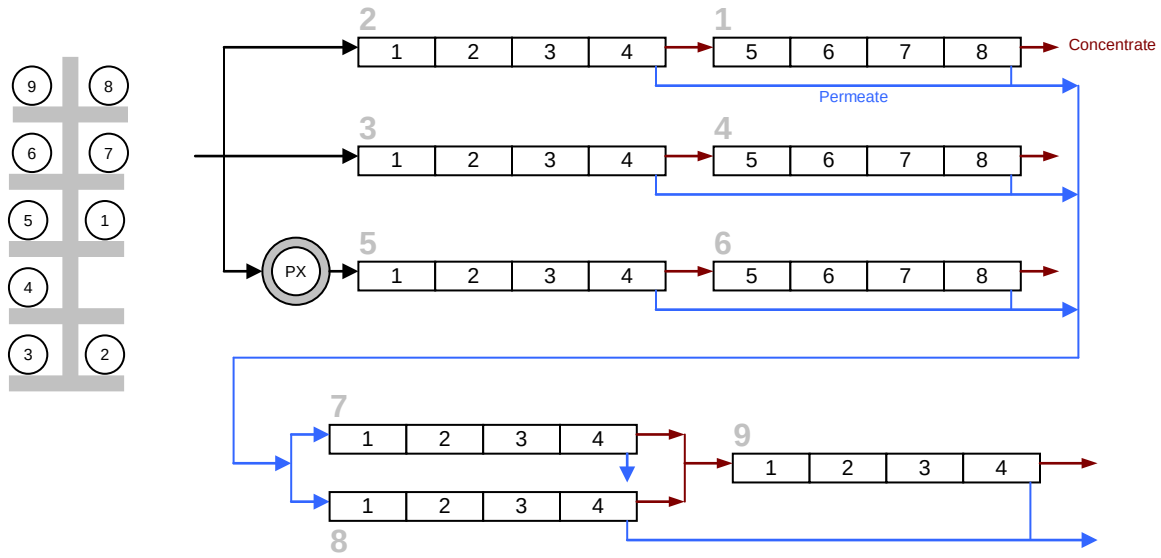
The RO system has the capability to operate in single-pass or double-pass mode if necessary (the double-pass mode was not used for this ETV test). The first pass of the RO system consists of a unique combination of moderate rejection/high productivity and high rejection/moderate productivity membranes. The first pass is composed of two parallel arrays (Figure 2-10). The first array is fed by the high-pressure pump and has two parallel trains with two four-element vessels each (Vessels 1, 2, 3, and 4 in Figure 2-10). The energy from the brine of this array is used to pressurize feed water via a pressure exchanger energy recovery device to feed a second array consisting of a single train of two four-element vessels (Vessels 5 and 6 in Figure 2-10).

The second pass RO system consists of a 2→1 array, where a second high -pressure pump boosts permeate pressure from the first pass feeding two parallel four-element vessels (Vessels 7 and 8 in Figure 2-10). The brine from these vessels then feeds one additional four-element vessel (Vessel 9 in Figure 2-10).

The RO design incorporates an internally staged RO element configuration on the first pass (Figure 2-11). This configuration consists of two Dow Chemical Company FILMTEC™ SW30-HR LE-400 elements, followed by two FILMTEC SW30-XLE400 elements, which are in turn followed by four FILMTEC SW30-HR-12000 ultra-low-energy experimental membranes. All membranes are polyamide thin-film composite type. The second pass RO system uses AquaPro LE-8040UP membrane elements. Table 2-3 provides performance data for the elements used in the system.

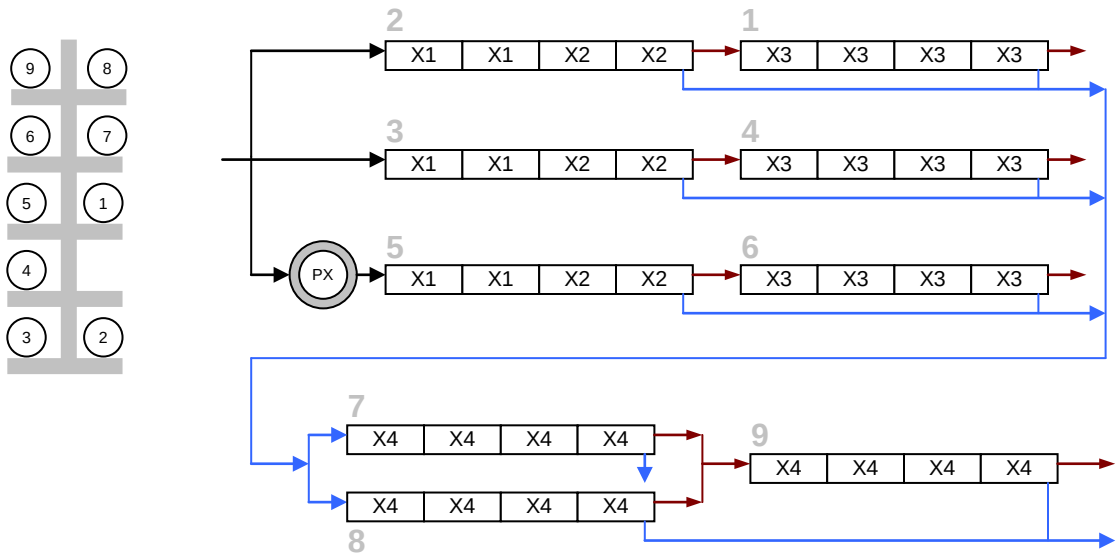
Figure 2-8. Photo of the RO skid.

Figure 2-9. Photo of the RO skid membrane vessels.



Numbers indicate pressure vessels

Figure 2-10. Vessel arrangement schematic.



Numbers indicate pressure vessels

Figure 2-11. Membrane arrangement schematic.

Table 2-3. RO System Membrane Element Characteristics

Vessel	Product	Designator	Nominal Active Surface Area ft^2 (m^2)	Permeate Flowrate gpd (m^3/d)	Stabilized Salt Rejection (%)
1st Pass 2, 3, 5	FILMTEC SW30-HR LE-400	X1	380 (35)	6000 (26)	99.8
1st Pass 2, 3, 5	FILMTEC SW30-XLE-400	X2	400 (37)	9000 (34)	99.7
1st Pass 1, 4, 6	FILMTEC SW30-HR -12000 (experimental)	X3	400 (37)	12,000 (45)	99.7
2nd Pass 7, 8, 9	AquaPro LE-8040UP *	X4	400 (37)	10,200 (38)	99.7

* Toray membrane assembled by AquaPro/Village Marine

2.4.3.1 RO skid statistics

Table 2-4 presents statistics of the RO skid.

Table 2-4. RO Skid Statistics

Parameter	Value
Production Capacity	~ 125,000 gpd for single pass on surface water above 25,000 mg/L TDS or groundwater above 2,500 mg/L TDS ~162,000 gpd for other lower TDS waters ~98,000 gpd in double pass mode
Water Temperature Range	34–104°F
Dimensions	20’ L x 8’ H x 8’ W
Weight	15,500 lbs dry, fully paced out for deployment, less fuel
Basic Metals	High Pressure Piping: Titanium Production Piping: 316L Stainless Steel and fiberglass reinforced plastic (FRP)
Operating Ambient Temperature Range	32°F–120°F
Storage and Transport Air Temperature Range	32°F–120°F
Relative Humidity	3%–95%
Maximum slope of unit when deployed for operation	No Restrictions
Power Source Requirement	Power for all but high-pressure pump is supplied from UF skid. HP pump requirements are 480 Volts and 125 Amps. The operational power use is 7.4 kWhr/kgal for the RO system only.
Fuel Type (if using RO Pump Engine)*	DF2, DFA, JP8
Fuel Capacity (if using RO Pump Engine)*	60 gal

* Electric RO pump was used for ETV testing

2.4.3.2 RO System Operation

The following is a basic description of the flow path and functional description of the RO system in normal operation. The RO system has the capacity to operate in either a one or two pass mode. The second pass is only used if sufficient treatment is not achieved with the first pass (especially for NBC contamination). The operation manual provides a full description of RO operation. Figure 2-12 is a P&ID of the RO system.

1. The UF filtrate is supplied to the RO 1st pass through P5 from TK3.
2. The RO 1st pass includes two arrays. The RO feed water (from the UF filtrate) flows into vessels 2 and 3 (PV2, PV3). The concentrate from vessels 2 and 3 flow into vessels 1 and 4 (PV1, PV4), respectively. The combined concentrate from vessels 1 and 4 flows through the energy recovery device, which boosts raw water pressure and feeds vessel 5 (PV5) of the second array. The concentrate from PV5 flows into vessel 6 (PV6). High pressure pump #6 (P6) supplies pressure for the 1st pass 1st and 2nd arrays and the pressure exchanger #8 (P8) supplies pressure for the 1st pass 3rd array.

3. Sodium metabisulfite from chemical pump #2 (CP2) and tank #7 (TK7) can be added after P5 to remove chlorine, if necessary. Free chlorine can damage RO membranes. The maximum allowable chlorine level is membrane specific with the minimum chlorine tolerance being non-detect.
4. Anti-scalant from chemical pump #3 (CP3) and tank #8 (TK8) is added after P5 to minimize RO membrane scaling.
5. P6 increases the pressure to the required 1st pass 1st array operating pressure (800-1,200 psig depending on water conditions).
6. Concentrate from the 1st pass 1st array flows through the pressure exchanger P8. P8 exchanges energy from the high pressure, high salinity 1st pass concentrate to the lower pressure, lower salinity UF filtrate feed water. The UF filtrate pressurized by P8 flows into the 2nd array.
7. Pressure control valves #5, #6, and #7 (PCV5, PCV6, PCV7) are used to adjust pressure within the RO 1st pass piping. When PCV5 is fully open, P8 is bypassed. When restricted, PCV5 provides backpressure for P6.
8. As PCV6 is restricted, water is forced through P8.
9. When open, PCV7 prevents P8 overflow during start up. When restricted, it provides additional backpressure for P6.
10. Second pass operation is optional and will not be verified in this testing. During NBC operations or when the 1st pass permeate quality does not meet requirements, the 2nd pass is required.
11. The 2nd pass has one array with 12 membranes (PV7, PV8, PV9). The 1st pass permeate feeds the 2nd pass. If the raw water source does not contain NBC, concentrate from the 2nd pass (which is lower concentration because 2nd pass feed is 1st pass permeate) is recycled back to the raw water source to reduce the salinity of the inlet water.
12. Sodium hydroxide from chemical pump #4 (CP4) is added at the 2nd pass inlet to adjust pH to improve the rejection of certain contaminants that are ionized at high pH such as Boron.
13. Pump #7 (P7) pressurizes the 1st pass permeate. Pressure control valve #8 (PCV8) provides the backpressure for pump #7 (P7).
14. The 1st pass permeate is monitored by and displayed on conductivity sensors #1 and #2 (CS1, CS2), which determine if the permeate purity meets requirements. Permeate salinity is affected by temperature, TDS, and age of the RO membranes. If the permeate purity does not meet requirements, CS1 de-energizes solenoid valve #1, which then dumps the undesirable permeate back to the feed source. If the permeate purity meets requirements, CS2 activates solenoid valve #1, allowing the handle on the dump valve to be latched, causing the high purity permeate to flow from the RO skid to the product water storage tanks. This diversion feature is disabled during 2nd pass operation.
15. Prior to distribution, RO permeate flows through the calcium hypochlorite disinfection system to the product water storage tanks. This system will not be operated during this test phase.

2.4.3.3 RO Cleaning Procedure

The RO elements should be cleaned whenever the temperature corrected product water output drops by 10 to 15% from the initial baseline established at the beginning of operation or from the expected output. The RO elements should also be cleaned when the TDS level of the product

water exceeds 500 mg/L. Prior to cleaning the membranes, verify that any reduction in product output is not the result of a corresponding variation in raw water inlet temperature or salinity by normalizing the data to a set of initial conditions. The following is a summarization of the operating instructions from the operations manual:

1. Set RO system in normal operation mode. Verify that valves are in the correct startup position. Make sure that the system output is being discharged to waste.
2. Select RO clean mode on main display screen.
3. Fill tank 4 with about 300 gal of fresh, un-chlorinated water to within 12 in of the top.
4. If ferric chloride is used in the system, perform the low pH adjustment first. If ferric chloride is not used, perform high pH adjustment first. (ETV note: ferric chloride was used during ETV test.)
5. Dissolve the appropriate amount of alkaline detergent or citric acid in a bucket of water.
6. Check the pH of the mixture in tank 4 and adjust as needed. Use citric acid to lower pH to 3 or use sodium hydroxide to raise the pH to 11.
7. Start P5 and allow chemical solution to circulate for 3 minutes. Check and adjust pH as needed.
8. Allow the cleaning solution to circulate for 15 minutes.
9. Touch “RO Clean” on the screen. Then touch “Enable RO Clean.”
10. Allow system to soak for 1 to 15 hours.
11. After soaking for the desired length of time, re-circulate the cleaning solution for 30 minutes.
12. Drain system and dispose of cleaning agents.
13. Repeat above steps for each desired chemical solution.
14. Rinse the RO system with fresh water.

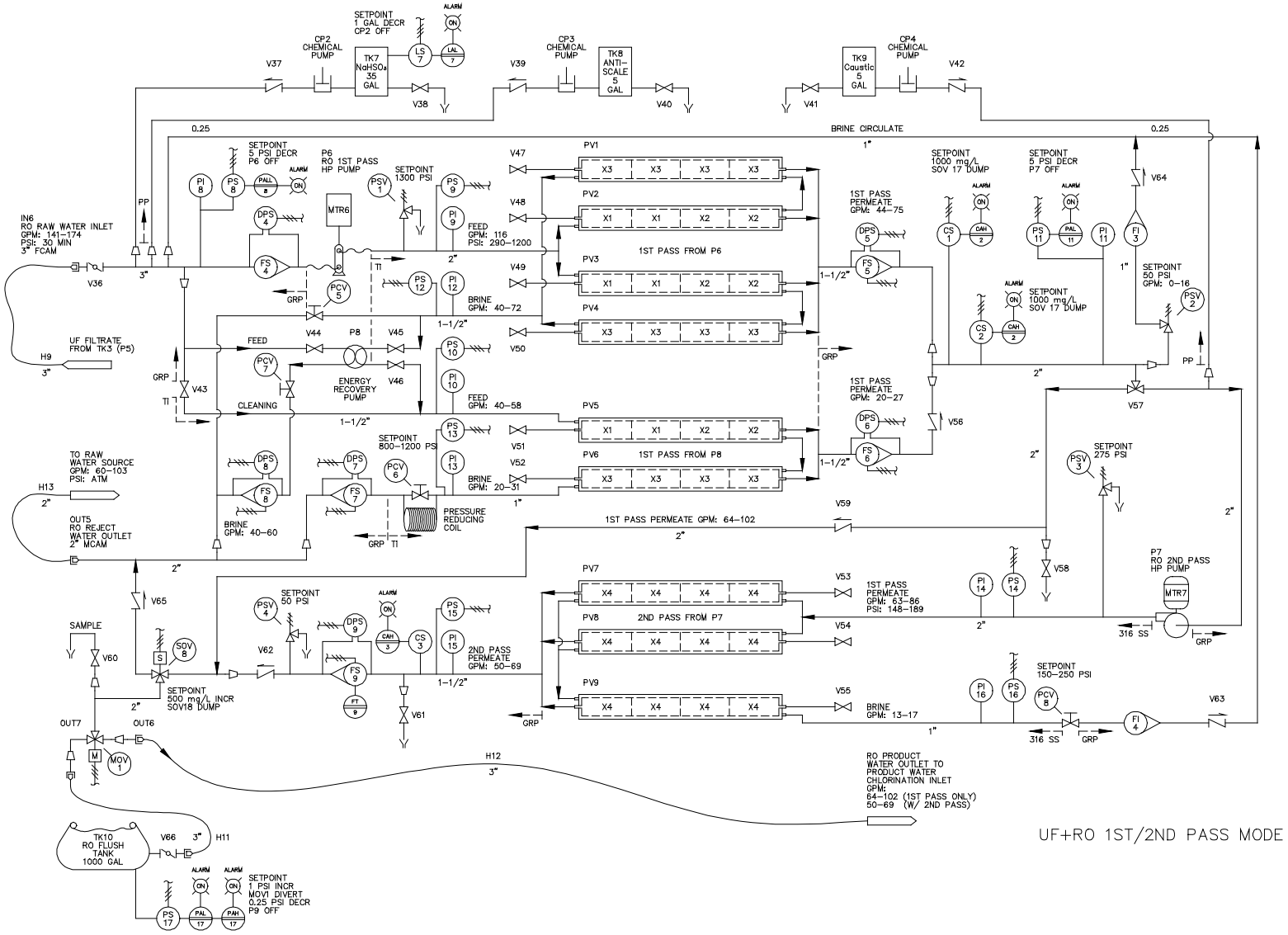


Figure 2-12. P&ID of RO skid.

2.4.3.4 Pressure Exchanger

RO is an inherently power intensive process. Historically, energy from the high-pressure brine was wasted through the utilization of a control valve to the control the process. Today, several systems are available to recover the energy contained in the high-pressure brine to help offset the energy required. The EUWP uses the PX® Pressure Exchanger® (Model 90S) from Energy Recovery, Inc (Figure 2-13). The PX operates on the principle of positive displacement to allow incoming raw water to be pressurized by direct contact with the concentrate from a high-pressure membrane system. It uses a cylindrical rotor with longitudinal ducts parallel to its axis to transfer the pressure energy from the concentrate stream to the feed stream. The rotor fits into a ceramic sleeve between two ceramic end covers with precise clearances that, when filled with high-pressure water, create an almost frictionless hydrodynamic bearing. At any given time, half of the rotor ducts are exposed to the high-pressure stream and half of the ducts are exposed to the low-pressure stream. As the rotor turns, the energy is transferred to the low-pressure stream, pushing the feed water on to the booster pump. This type of energy device has been shown to be 90% efficient in transferring energy. During previous EUWP testing in Alamogordo, New Mexico, the average observed efficiency of the energy recovery device was 78 ± 8 %.

In a typical system, the pressurized feed from the PX goes to a booster pump, which restores the pressure lost in the exchange and feeds a second RO vessel. However, the EUWP utilizes a parallel pass 1 train operation at approximately 10% lower pressure than the train operating directly off the high pressure pump. PX dimensions are 24 in long x 6.5 in diameter. Wetted materials are duplex stainless steel, ceramics, polyvinyl chloride (PVC), and fiberglass reinforced plastic (FRP).

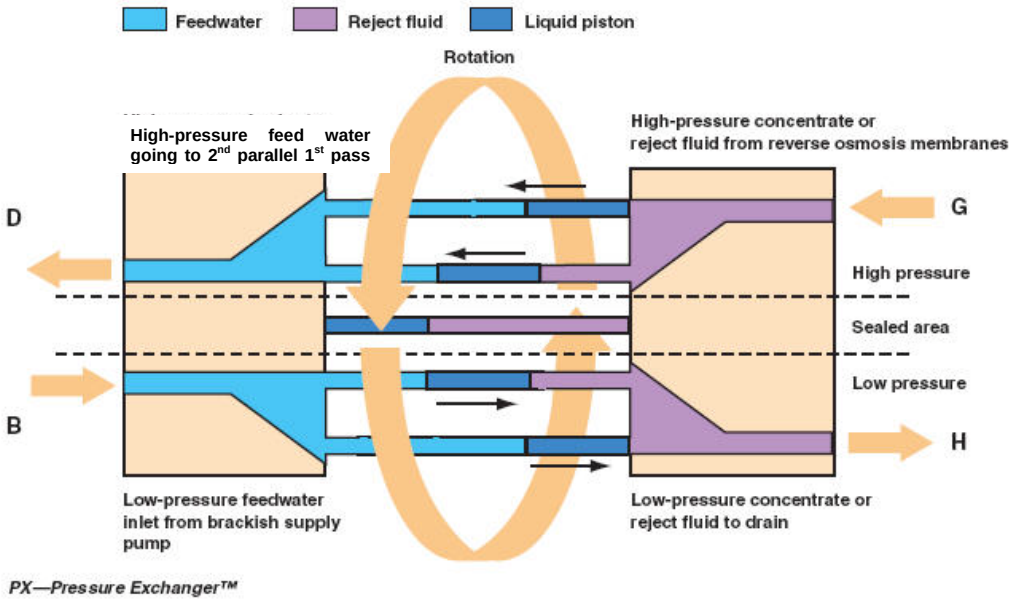


Figure 2-13. PX pressure exchanger.

2.5 General Requirements and Limitations

Table 2-5 lists the general environmental requirements for setup and operation of the EUWP.

Table 2-5. EUWP Site Considerations and Dimensions

Site Considerations	Site Dimensions
Drive-in access for on-road equipment	At least 10 ft wide
Work area required for equipment maneuvering and setup	At least 75 ft x 100 ft
Fairly smooth, level, and clear ground surface	Grade not to exceed 5° side to side and 2° end to end for UF configured platform or skid. No restriction f-r the RO skid. Ensure the elevation of tank #3 is equal to or higher than the UF skid (higher is better).
Cleared path to water source	Wide enough to move equipment
Work area elevation above pump #1	Maximum 25 ft vertical and 100 ft horizontal
Elevation/distance of pump #1 above the water source	Maximum 15 ft vertical and 50 ft horizontal
Distance of pump #1 from inlet strainer #1 in water source	Maximum 50 ft
Water depth from the inlet strainer #1 to the bottom of the raw water source	3 ft minimum; 5 ft or more preferred
Distance of distribution tanks from EUWP	Limited by hose length. Check hoses to determine distance.
Distance of distribution tanks from adjacent distribution tank	Limited by hose length. Check hoses to determine distance.
Distance of distribution pump #9 from tee adaptors	Limited by hose length. Check hoses to determine distance.
Cleaning waste storage tank	Less than 50 ft from the waste out connection

The EUWP was designed to be transported by air using a C-130 aircraft, or by land using any number of commercial and military haul transporters. The skids have forklift pockets that allow handling with an appropriately sized forklift.

Volume and type of consumables are site-specific depending on raw source water quality. As recommended by the membrane manufacturer, calcium hypochlorite, citric acid, or sodium hydroxide may be required to perform a CIP. Also as recommended by the membrane manufacturer, citric acid, sodium hydroxide, and/or a membrane detergent may be required to perform an RO cleaning. Depending on the raw water source quality, chemical additions may be needed for protection of the membranes during operation. Ferric chloride may be added at the UF skid to prevent clogging of the membranes by natural organic matter or high suspended solids in the feed water. Antiscalant and/or sodium meta-bisulphite may be added at the RO skid to prevent scaling and remove chlorine present in the feed water; and sodium hydroxide may be added to raise the pH to aid rejection of constituents during the 2nd pass. Calcium hypochlorite in granular or tablet form containing 65–70% free chlorine may be added prior to filtrate or permeate storage as a disinfectant (this did not occur as part of this ETV test). Table 2-6 covers equipment limitations and Table 2-7 presents membrane limitations.

Table 2-6. Equipment Limitations

System	Parameter	Value
Inlet Pump #1	Suction head (maximum)	25 ft
Strainer	Differential pressure (maximum) before manual backwash	7 psig
	Backpressure required for strainer auto flushing	35 psig
UF	Pretreatment requirements	200 µm strainer
	Feed pressure (maximum)	45 psig
	Ambient temperature range	32 – 120°F
	Water temperature range	34 – 104°F
	Control air pressure	60 psig
	Damaging chemicals	Grease, Oil, Silicon
	TMP (maximum) before CIP required	35 psig
	Pressure surges	Minimize by operating valves slowly
UF Membranes	Stagnation time (maximum) before preservation required with 1,000 – 5,000 mg/L sodium bisulfite (see operations manual for details) (see Table 2-1 for more details)	14 days (somewhat temperature dependent)
UF CIP Water	Turbidity	<1.0 NTU
	Iron	<0.05 mg/L
	Manganese	<0.05 mg/L
	Aluminum	<0.5 mg/L
	Reactive silica	ND(1)
	Colloidal silica	ND
	Total silica	<10 mg/L
	Calcium sulfate	< saturated at 50°C (122°F)
	Calcium carbonate	< saturated
	Microbiological	no living or dead material
	SDI	<3.0
	pH range	1.5 – 13
	Maximum feed pressure	45 psig
	Maximum Air Pressure	15 psig
	Temperature range	32°F to 120°F
	Filtered All water must be free of particulate matter	500 µm prior to entering UF
RO	Water Temperature Range	34 – 104°F
	SDI (maximum)	5 (membrane dependent)
	Operating Ambient Temperature Range	32°F to 120°F
	Storage and Transport Air Temperature Range	32°F to 120°F
	Relative Humidity	3% to 95%
	Pretreatment requirements	UF or 200 µm strainer on RO skid
	Operating concentrate pressure after backpressure valve (maximum)	200 psig
	Operating permeate pressure (maximum)	100 psig
	2nd pass inlet pressure (maximum)	300 psig
	RO high pressure pump #6 maximum speed	600 revolutions per minute (RPM)
	RO high pressure pump #6 minimum inlet pressure	30 psig
	Stagnation time (maximum) before preservation required	1 week (somewhat temperature
RO Membranes	(see Table 2-6 for details)	

(1) Non-detect

Table 2-7. RO Membrane Limitations

Membrane	Pressure (Max.) – psig	Temperature (Max.) - °F	SDI (Max.)	Chlorine (Max.) – mg/L	pH range	pH range – feed, CIP	Pressure drop (Max.) per element - psig	Pressure drop (Max.) per vessel - psig	Production TMP (Max.) - psig	Backwash TMP (Max.) - psig
TARGA® 10 - 48 - 35 – PMC	45	104		200					30	20
FILMTEC™ SW30HR LE-400	1,000[1]	113	5	<0.1	2-11	1-12	15	50		
FILMTEC™ SW30 XLE-400	1,200	113	5	<0.1	2-11	1-12	15			
FILMTEC™ SW30HR -12000 (experimental)	1,200	113	5	<0.1	2-11	1-12	15			
AquaPro LE-8040UP[2]	600	113	5	ND	2-11	1-12	20	60		

(1) May go up to 1,200 psig under certain conditions specified by Dow Chemical
(2) Toray membrane assembled by AquaPro/Village Marine

2.6 Waste Generation and Permits

The waste streams for the EUWP consist of the following:

- Cleaning waste from UF system (UF CIP);
- Cleaning waste from the RO system (RO CIP);
- Concentrate from the RO system; and
- Backwash waste and retentate from the UF system.

2.6.1 UF CIP

The UF system CIP cycle involves use of the 300-gal CIP tank with the following chemical cleaning cycles: acid, rinse, base with chlorine, rinse. A second base cleaning may be required. The total volume generated with five cleaning cycles (worst case, assuming a second base cleaning) at 300 gal each, plus 200 gal for piping/membrane volume is approximately 2,500 gal. For this ETV verification, all cleaning solutions were captured in a storage tank. The contents of the storage tank were pumped into the sanitary sewer.

2.6.2 RO CIP

The CIP procedure for the RO system is similar to that of the UF and uses the same 300-gal CIP tank to dispense the cleaning solutions. The cleaning cycles consist of an acid clean followed by a rinse, then a high pH clean with membrane cleaner followed by a final rinse. The approximate volume of waste generated from all of the cleaning cycles is 1,200 gal of cleaning solutions, plus 200 gal of piping/membrane volume for each cycle, for a total of approximately 2,000 gal.

2.6.3 RO Concentrate

The RO concentrate was blended with the RO permeate, UF backwash, and UF retentate, and the resulting mixture was discharged back into the port.

2.6.4 UF Backwash and Retentate

The UF system automatically initiates a backwash every 30 minutes to remove captured material from the membrane surface. Each backwash cycle consists of backflushing the membranes with UF filtrate for a short period followed by a forward "fast flush" using feed water. In addition to the backwash, the UF system also discharges a continuous retentate stream. Both waste streams exited the system using a common discharge line that was routed to a settling tank. The settling tank effluent was discharged into the port.

2.6.5 Discharge Permits

SDTF operates under a waiver from the South Coast Regional Water Quality Control Board. This waiver covers the operation of desalination and filtration equipment for evaluation purposes. The waiver stipulates that concentrate and filtrate/permeate streams be recombined and returned to the port.

2.7 Discussion of the Operator Requirements

The following information on operator requirements is supplied by the manufacturer for informational purposes only. A team of four water treatment specialists, with proper site validation, layout planning and using a 10,000-lb forklift, should be able to have the EUWP setup and producing potable water within eight hours. Depending on the distribution connection requirements and availability of the connections, distribution of the produced potable water may take longer.

Except for periodic O&M and data collection, once set up and operational, the EUWP is capable of operating unattended. Staffing requirements are based on the O&M or data collection efforts being performed. Due to the use of high pressure, electricity or diesel, and chemicals, O&M on the equipment and piping should be performed by a minimum of two persons. Data collection requires only one person.

The EUWP requires a skilled operator familiar with water treatment processes, equipment, and concepts to perform O&M and collect data. A skilled operator could meet any of a variety of requirements as discussed below. Operation of the EUWP should be performed by an individual with similar experience, knowledge, or training as provided within these programs.

A U.S. military water treatment specialist (classified as skill level 4 through 1) supervises or performs installation, operation of water purification equipment, water storage, and distribution operations and activities.

The minimum skill level 4 requires the specialist to:

- Assist in water reconnaissance, site preparation, and setup of water treatment activity;
- Operate and maintain water treatment equipment;
- Receive, issue, and store potable water; and
- Perform water quality analysis testing and verification.

Although remote operation is not available, the EUWP can be monitored remotely 24 hours per day by use of the water system management tool, WaterEye™ (www.watereye.com). WaterEye provides timely, critical operations monitoring information utilizing colored indicators to either confirm system status or alert potential problems. In addition, WaterEye can assist with managing daily, monthly, and yearly compliance requirements by monitoring compliance data and automatically creating reports. WaterEye maintains a database of monitored instrument readings, which are read every 15 min and uploaded to their server every 30 min. Alarm conditions are immediately uploaded for response. WaterEye can also display/store information calculated from uploaded instrument readings. Data must be either uploaded directly from the PLC on the EUWP or be able to be calculated from that data.

Chapter 3
Methods and Procedures

3.1 Quantitative and Qualitative Evaluation Criteria

The objectives of the verification test were to evaluate equipment in the following areas:

- The actual results obtained by the equipment as operated under the conditions at the test site;
- The impacts on performance of any variations in feed water quality or process variation;
- The logistical, human, and other resources necessary to operate the equipment; and
- The reliability, ruggedness, ranges of usefulness, and ease of operation of the equipment.

There are three main components of the EUWP that were evaluated at the same time: the UF system, the RO system, and the energy recovery system. All three components must function successfully to meet the performance objectives. To address these objectives, the verification test employed the quantitative and qualitative factors listed below.

Qualitative factor:

- Waste discharge requirements.

Quantitative factors:

- Water quality data
- Physical operations data – flow, membrane flux, recovery, and pressure.
- Power usage
- Chemical usage
- Waste stream generation
- Operating cycle length

3.2 Key Treated Water Quality and Operational Parameters

Treated product water must meet EPA NPDWR, and should meet EPA secondary Standards whenever possible. As discussed in Section 2.1, the objective of this ETV verification was to demonstrate that the EUWP can provide water that meets the requirements of the EPA NPDWR. As such, a list of key treated water parameters was developed based the EPA regulations, and other water quality parameters of interest. Regulated contaminants not present in raw water samples analyzed during the characterization of feed water task were excluded from the list. The final list is presented in Table 3-1.

Note that the test/quality assurance plan (TQAP) called for also measuring strontium and total organic carbon (TOC), and also conducting a silt density index (SDI) test on the RO feed, but these parameters were dropped. Strontium was to be measured for the Stiff and Davis Stability Index (S&DSI) calculations, but it was found in the raw seawater at such a low concentration compared to other cations that it did not need to be included in the S&DSI

Table 3-1. Key Treated Water Quality Parameters

Parameter	
pH	Magnesium
Temperature	Ortho-Phosphate
Specific Conductance	Total Phosphorus
Turbidity	Potassium
Particle Counts	Selenium
Stiff and Davis Stability Index (S&DSI)	Sodium
Alkalinity	Sulfate
Barium	Total Dissolved Solids (TDS)
Bicarbonate	Total Hardness
Boron	Total Suspended Solids (TSS)
Calcium	Ultraviolet light absorbance at 254 nm (UV_{254})
Chloride	Total Coliforms
Lithium	*Bacillus* Endospores

analysis. TOC was dropped because it was measured in the raw seawater at a less than detectible concentration (<0.3 mg/L). The SDI test was not dropped intentionally, the FTO forgot to run it. However, this test is of questionable importance for RO feed water when the feed has been treated by UF. The SDI test uses a 0.45 µm filter to capture and measure silt in the feed water. The UF membrane pore size is less than 0.1 µm, so the UF should remove all of the silt that would be captured by the SDI filter. A portion of the water quality and operational parameters were measured continuously via in-line instrumentation, as listed in Table 3-2.

Table 3-2. Water Quality and Operational Parameters Measured In-Line

Membrane	**UF Feed**	**UF Retentate**	**UF Filtrate**	**RO Feed**	**RO 1st Array Concentrate**	**RO 1st Array Permeate**	**RO 2nd Array Permeate**	**RO Permeate**
Flow	X	X		X	X	X	X	
Pressure	X	X	X	X	X	X		
Conductivity						X	X	
Temperature			X					
Turbidity	X		X					X
Particle Count	X		X					

3.3 Operations and Maintenance

Village Marine Tec. provided an operations and maintenance manual for the EUWP, which is included in Appendix A. The ETV test protocols call for review of the manual in regards to the ability of the user to successfully operate the system armed with only the information in the manual. An objective review of the manual by the field operators was not possible, because they already had intimate knowledge of the EUWP prior to the test. Therefore, a review of the O&M manual is not included in this report.

The following aspects of operability are addressed in Chapters 2 and 4, and in the appendices:

- Fluctuation of flow rates and pressures through unit (the time interval at which resetting is needed);
- Presence of devices to aid the operator with flow control adjustment;
- Availability of pressure measurement;
- Measurement of raw water rate of flow;
- Pace of chemical feed with raw water; and
- Operation of the PLC control system.

3.4 Field Operations

Acting as the FTO, TARDEC conducted the testing of the EUWP as described below. TARDEC and USBR field personnel performed field analytical work using field laboratory equipment and procedures for pH, temperature, conductivity, and turbidity. NSF performed water quality analytical work for samples not analyzed on site. Field staff were on site each day to operate the system and collect water quality data during the verification test.

The test plan called for the EUWP to be operated 24 hours per day, seven days per week, excluding regular backwashes and cleaning periods. This was the case for most of the test period, except when the system shut down during the night due to an alarm, and field personnel were not present to restart the system. System shutdowns that occurred during the ETV test are discussed in Chapter 4.

3.5 Overview of ETV Testing Plan

A test/quality assurance plan (TQAP) was prepared for the EUWP verification test in accordance with the ETV Protocols *EPA/NSF Protocol for Equipment Verification Testing for Removal of Inorganic Constituents* – April 2002, and the *EPA/NSF Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants* – September 2005. The TQAP divided the work into three main tasks (A, B, C) with Task C, the verification test itself, divided into six subtasks. These tasks are:

Task A: Characterization of Feed Water
Task B: Equipment Installation, Initial Test Runs, and Initial System Integrity Tests
Task C: Verification Test
    Task C1: Membrane Flux and Recovery
    Task C2: Cleaning Efficiency

Task C3: Finished Water Quality
Task C4: Membrane Module Integrity
Task C5: Data Handling Protocol
Task C6: Quality Assurance/Quality Control (QA/QC)

The TQAP, which included a Quality Assurance Project Plan (QAPP), specified procedures to be used to ensure the accurate documentation of both water quality and equipment performance. An overview of each task is provided below with detailed information on testing procedures presented in later sections.

3.5.1 Task A: Characterization of Feed Water

The objective of this initial operations task was to obtain a chemical, biological, and physical characterization of the feed water prior to testing.

3.5.2 Task B: Equipment Installation, Initial Test Runs, and Initial System Integrity Tests

The objective of this initial operations task was to evaluate equipment operation and determine the treatment conditions that result in effective treatment of the feed water. This task was considered shakedown testing and was carried out prior to performing Task C.

3.5.3 Task C: Verification Test

The verification test itself consisted of six tasks described as follows:

3.5.3.1 Task C1: Membrane Flux and Recovery

Task C1 evaluated membrane operation and entailed quantification of membrane flux decline rates and product water recoveries. The rates of flux decline demonstrate membrane performance at the specific operating conditions established during Task B.

3.5.3.2 Task C2: Cleaning Efficiency

An important aspect of membrane operation is the restoration of membrane productivity after membrane flux decline has occurred. The objective of this task was to evaluate the efficiency of the membrane cleaning procedure. The fraction of specific flux restored following a chemical cleaning and after successive filter runs was determined.

3.5.3.3 Task C3: Finished Water Quality

The objective of this task was to evaluate the quality of water produced by the EUWP. Treated water quality was evaluated in relation to feed water quality and operational conditions. The monitored water quality parameters are listed in Table 3-1.

3.5.3.4 Task C4: Membrane Module Integrity

The objective of this task was to demonstrate the methodology for monitoring membrane integrity and to verify the integrity of membrane modules.

3.5.3.5 Task C5: Data Handling Protocol

The objective of this task was to establish an effective field protocol for data management at the field operations site and for data transmission between TARDEC and NSF.

3.5.3.6 Task C6: Quality Assurance and Quality Control

An important aspect of verification testing is the protocol developed for QA/QC. The objective of this task was to assure accurate measurement of operational and water quality parameters during membrane equipment verification testing.

3.6 Task A: Characterization of Feed Water

The objective of this task was to determine the chemical, biological, and physical characteristics of the feed water. Grab samples for seawater analysis were collected on four separate occasions during 2006 and 2007. The samples were collected from the existing seawater intake line at SDTF.

3.7 Task B: Equipment Installation, Initial Test Runs, and Initial System Integrity Tests

The objective of this task was to properly install the equipment and begin equipment operation, then evaluate operation and determine whether the operating conditions resulted in effective treatment of the water. In this task, a preliminary assessment of the treatment performance of the equipment was made. This task was considered a shakedown testing period and was completed before Task C. This task also included pressure decay testing of the UF membranes. See Section 3.8.4.1 for further discussion about this test.

3.8 Task C: Verification Testing

The verification test ran from October 16, 2007 to November 12, 2007. Note that the ETV test protocol referenced in Section 3.5 calls for testing to run for at least 30 days. However, the main intent of the test period length is to operate the equipment until at least one chemical cleaning is required. NSF allowed TARDEC to stop testing two days early because over the course of testing, four UF system cleanings were conducted. Per a requirement of the ETV test, a CIP was performed on the RO system at the end of the ETV although the RO system had not yet reached its cleaning level criteria.

The TQAP describes six tasks to be performed to achieve a successful verification test. Each of these tasks is described in detail in this section.

3.8.1 Task C1: Membrane Flux and Operation

The purpose of this task was to evaluate membrane flux during extended operation to demonstrate membrane performance. The objectives of this task were to demonstrate the feed

water recovery achieved by the membrane equipment, and the rate of flux decline observed over extended membrane operation. Flow, pressure, conductivity, and temperature data were collected daily in order to quantify the loss of productivity in terms of specific flux decline.

3.8.1.1 Work Plan

At least twice per day the operator checked the flow rates and recovery and made adjustments as necessary to put the system on target. Thirty minutes after resetting target flow and recovery, the operator recorded the appropriate water quality and operational data, as outlined in Table 3-3. The set points for key operating parameters are listed in Table 3-4. Chemical usage was monitored by recording the concentration and tank level on a daily basis.

Table 3-3. Operational Parameter Sampling Locations

Parameter	Raw	UF Feed	UF Filtrate	UF Retentate	UF Backwash	RO Feed	RO 1st Pass Permeate	RO 1st Pass Concentrate	UF Skid	RO Skid
Flow	X	X		X	X	X	X	X		
Pressure		X	X	X		X		X		
Conductivity						X	X	X		
Temperature		X	X			X	X	X		
Power usage									X	X
Operating Hours									X	X

Table 3-4. Key Operating Parameters

Parameter	Set Point
UF Feed Flow (gpm)	259
UF Recovery (%)	90
RO Feed Flow 1st Pass Array 1 (gpm)	116
RO Feed Flow 1st Pass Array 2 (gpm)	58
RO Recovery Levels (%)	50 (1st array) and 48 (2nd array)

3.8.1.2 Evaluation Criteria

Completion of this task involved quantification of membrane flux decline rates and product water recoveries. Summaries of the data collected for Task C1 are presented in tabular format in Chapter 4 for both the RO and UF systems.

The plots listed in Table 3-5 are also presented in Chapter 4 to illustrate equipment operation for Task C1. Note that all plots are of the parameter over time.

Table 3-5. Operational Data Plots Appearing in Chapter 4

UF Skid	RO Skid
Filtrate Production	Flow Rates
Flow Rates	Percent Recovery
Operating Presssures	Operating Pressures
Trans-Membrane Pressures	Specific Flux
Specific Flux	Power Consumption
Loss of Specific Flux	
Power Consumption	

3.8.1.3 Equations

UF System

The following are the definitions and equations used for the verification report for the UF system:

Filtrate: Treated water produced by the UF process.

Retentate: Water rejected by the UF system.

Feed water: Water introduced to the membrane elements after all chemical additions.

Raw water: The source water supply.

Membrane flux: The average flux across the UF membrane surface calculated by dividing the flow rate of filtrate by the surface area of the membrane.

Membrane flux is calculated as follows:

$$J_t = \frac{Q_p}{S}$$

where:

J_t = filtrate flux at time t (gallons per square foot per day (gfd))
Q_p = filtrate flow (gpd)
S = membrane surface area (ft^2)

Temperature Adjustment for Flux Calculation: Temperature corrections to 20°C for filtrate flux and specific flux are made to correct for the variation of water viscosity with temperature. The following empirically derived equation was used to provide temperature corrections for specific flux calculations:

$$J_t = \frac{Q_p \times e^{-0.0239(T-20)}}{S}$$

where:

J_t = filtrate flux at time t (gfd)
Q_p = filtrate flow (gpd)
S = membrane surface area (ft^2)
T = temperature of the feed water (°C)

Transmembrane Pressure: The pressure across the membrane, equal to the average feed pressure on the membrane (average of inlet pressure and outlet pressure) minus the filtrate (permeate) pressure:

$$TMP = \left[\frac{(P_f + P_c)}{2}\right] - P_p$$

where:

TMP = transmembrane pressure (psig)
P_f = inlet pressure to the feed side of the membrane (psig)
P_c = outlet pressure on the retentate side of the membrane (psig)
P_p = filtrate pressure on the treated water side of the membrane (psig)

Specific flux: The filtrate flux that has been normalized for the TMP. The equation used for calculation of specific flux is given by the formula provided below. Specific flux is usually discussed with use of flux values that have been temperature-adjusted to 20°C per equation above:

$$J_{tm} = \frac{J_t}{TMP}$$

where:

TMP = Transmembrane pressure across the membrane (psig)
J_t = filtrate flux at time t (gfd) (temperature-corrected flux values were employed)
J_{tm} = specific flux at time t (gfd/psig)

RO System

Permeate: Water produced by the RO membrane process.

Feed Water: Water introduced to the membrane element.

Concentrate: Water rejected by the RO membrane system.

Permeate Flux: The average permeate flux is the flow of permeate divided by the surface area of the membrane. Permeate flux is calculated according the following formula:

$$J_t = \frac{Q_p}{S}$$

where:

J_t = permeate flux at time t (gpd))
Q_p = permeate flow (gpd)
S = membrane surface area (ft^2)

Temperature Adjustment for Flux Calculation: Temperature corrections to 25 °C for permeate flux and specific flux were made to correct for the variation of water viscosity with temperature. The following empirically-derived equation were used to provide temperature corrections for specific flux calculations:

$$J_t \text{ (at } 25^\circ \text{ C)} = \frac{Q_p \times e^{-0.0239 \cdot (T-25)}}{S}$$

where:

J_t = permeate flux at time t (gfd)
Q_p = permeate flow (gpd)
S = membrane surface area (ft^2)
T = temperature of the feed water (°C)

Net Driving Pressure: For this test, a temperature conversion chart provided by the manufacturer was used for all temperature correction. Net Driving Pressure (NDP) is the total average pressure available to force water through the membrane into the permeate stream. Net driving pressure is calculated according to the following formula:

$$NDP = \left[\frac{\left(P_f + P_c\right)}{2}\right] - P_p - \Delta\pi$$

where:

NDP = net driving pressure for solvent transport across the membrane (psig)
P_f = feed water pressure to the feed side of the membrane (psig)
P_c = concentrate pressure on the concentrate side of the membrane (psig)
P_p = permeate pressure on the treated water side of the membrane (psig)
$\Delta\pi$ = osmotic pressure (psig)

Osmotic Pressure Gradient: The term osmotic pressure gradient refers to the difference in osmotic pressure generated across the membrane barrier as a result of different concentrations of dissolved salts. The following equation provides an estimate of the osmotic pressure across the semi-permeable membrane through generic use of the difference in TDS concentrations on either side of the membrane:

$$\Delta\pi = \left[\frac{\left(TDS_f + TDS_c\right)}{2}\right] - TDS_p \quad \begin{matrix} 0.6 \ psi \\ 100 \ \frac{mg}{L} \end{matrix}$$

where:

$\Delta\pi$ = osmotic pressure (psig)
TDS_f = feed water TDS concentration (mg/L)
TDS_c = concentrate TDS concentration (mg/L)
TDS_p = permeate TDS concentration (mg/L)

Note that the different proportions of monovalent and multivalent ions composing the TDS will influence the actual osmotic pressure, with lower unit pressures resulting from multivalent species. The osmotic pressure ratio of 1 psig per 100 mg/L is based upon TDS largely composed of sodium chloride or other monovalent ions. In contrast, for TDS composed of multivalent ions, the ratio is closer to 0.5 psig per 100 mg/L TDS. Osmotic pressure was estimated using the ionic strength of the feed and concentrate based on the weekly data for cations and anions (Ca, Mg, Na, K, Li, Cl, SO4, HCO_3). The ratio of 1 psig per 100 mg/L TDS gave a much higher osmotic pressure and the ratio of 0.5 psig per 100 mg/L TDS gave a lower osmotic pressure. It was determined that the equation for TDS using a factor 0.6 psig per 100 mg/L TDS most closely approximates the osmotic pressure calculated based on the ionic strength data available for this water.

Specific Flux: The term specific flux is used to refer to permeate flux that has been normalized for the net driving pressure. The equation used for calculation of specific flux is given by the formula provided below. Specific flux is usually calculated with use of flux values that have been temperature-adjusted to 25 °C:

$$J_{tm} = \frac{J_t}{NDP}$$

where:

J_{tm} = specific flux (gfd/psig)
NDP = net driving pressure for solvent transport across the membrane (psig)
J_t = permeate flux at time t (gfd). Temperature-corrected flux values should be employed.

Water Recovery: The recovery of feed as permeate is given as the ratio of permeate flow to feed flow:

$$\%\ System\ Recovery = 100 \left[\frac{Q_p}{Q_f}\right]$$

where:

Q_f = feed flow to the membrane (gpm)
Q_p = permeate flow (gpm)

Loss of Original Specific Flux:

$$Percent\ Loss = 100 \cdot \left(1 - \frac{J_s}{J_{so}}\right)$$

where:

J_{so} = specific flux (gfd/psig) at time zero point of membrane testing.
J_s = specific flux (gfd/psig) at time T of membrane testing.

<u>*Solute Rejection*</u>: Solute rejection is controlled by a number of operational variables that must be reported at the time of water sample collection. Bulk rejection of a targeted inorganic chemical contaminant may be calculated by the following equation:

$$Percent\ Solute\ Rejection = 100 \cdot \left(\frac{C_f - C_p}{C_f} \right)$$

where:

C_f = feed concentration of specific constituent (mg/L)
C_p = permeate concentration of specific constituent (mg/L).

3.8.2 Task C2: Cleaning Efficiency

An important aspect of membrane operation is the restoration of membrane productivity after specific flux decline has occurred. The effectiveness of chemical cleaning to restore membrane productivity was evaluated.

3.8.2.1 Work Plan

The manufacturer specified that the UF cleaning procedure should be executed when the TMP drop exceeds 35 psig, even after a backwash. The manufacturer specified that the RO system be cleaned when there is a 10 to 15% decrease in normalized permeate flowrate, 15% increase in TMP drop or permeate TDS concentration.

Flow, pressure, and temperature data were recorded immediately before the system was shut down for cleaning and immediately upon return to membrane operation after cleaning procedure was complete.

Two primary indicators of cleaning efficiency and restoration of membrane productivity were examined in this task:

- Immediate recovery of membrane productivity (percent recovery of specific flux); and
- Long term maintenance of specific flux over an equivalent time period.

The pH, temperature, conductivity, and TOC of each cleaning solution were measured after the cleaning. Flow, pressure, and temperature data were also collected during the cleaning procedure. Following the cleaning procedure, the specific membrane flux was calculated at the same operating conditions used prior to the cleaning. This value was compared to the pre-cleaning specific flux to determine the efficiency of the cleaning procedure. See Section 2.4.2.2 for the UF cleaning procedure, Section 2.4.3.3 for the RO cleaning procedure, and also the User's Manual (Appendix A) for details on the cleaning procedures employed.

3.8.2.2 Evaluation Criteria

The outputs for this task are post-cleaning flux recoveries and the cleaning efficacy indicators described above (including flow, pressure, and temperature data).

3.8.3 Task C3: Finished Water Quality

The objective of this task was to assess the ability of the membrane equipment (both UF and RO) to meet the water quality goals specified by the manufacturer.

3.8.3.1 Work Plan

The water quality parameters in Table 3-6 were measured as indicated during the testing period. To the extent possible, scheduled on-site analyses for each sampling point were performed on water samples collected at the same time as the samples shipped off site.

Table 3-6. Water Quality Sampling Schedule

Parameter	Raw Water	UF Filtrate	UF Discharge(1)	UF Cleaning Solution	RO Feed	RO 1st Pass Permeate	RO 1st Pass Concentrate
pH	D_1		W	E	D_1	D_1	D_1
Temperature	D_1	D_1		E	D_1	D_1	D_1
Specific Conductance	D_1		W		D_1	D_1	D_1
Turbidity	D_1	D_1	W			D_1	D_1
Particle Counts	D_1	D_1			D_1	D_1	D_1
General Mineral(2)	W				W	W	W
Regulated Metals(3)	W				W	W	W
TDS	D_2		W		W	D_2	D_2
TOC				E			
TSS	W	W	W		W	W	W
UV_{254}	W				W	W	W
Total Coliform	W	W	W			W	W
Bacillus endospores	D_2	D_2	D_2			D_2	D_2

D_1 = Twice per day, Mon. – Fri., once daily on Sat. and Sun.
D_2 = Once per day, Mon. – Thurs.
E = At every cleaning event.
O = Optional analysis, parameters may be measured for operation optimization purposes.
W = once per week.
(1) UF discharge is UF retentate and UF backwash combined.
(2) General Mineral Analysis includes alkalinity, bicarbonate, boron, calcium, chloride, lithium, magnesium, ortho-phosphate, pH, phosphorus (total), potassium, sodium, S&DSI, sulfate, and total hardness.
(3) Regulated Metals Analysis includes only barium and selenium.

In addition to manual sample collection for the water quality parameters listed in Table 3-6, in-line particle counters recorded particle counts for the UF feed and UF filtrate streams every five minutes. Note that particle count data is not presented in the water quality discussion of Chapter 4, but rather in the membrane integrity section (Section 4.5.4), since the primary purpose of the particle counters is serve as a monitor of membrane integrity.

3.8.3.2 Evaluation Criteria

All water quality data generated during the test periods is presented in a tabular format in Chapter 4. In addition, the UF feed and filtrate turbidity data, and the RO conductivity data is presented in a graphical format.

3.8.4 Task C4: Membrane Integrity Testing

The objective of this task is to demonstrate the methodology to be employed for direct integrity testing of the UF system and indirect integrity monitoring of both the RO and UF systems. Direct testing and indirect monitoring methods were used together to provide consistent and sensitive evaluation of membrane system integrity.

3.8.4.1 Direct Integrity Testing:

The direct integrity testing method employed on the UF system was a pressure decay test, similar to that described in ASTM International (ASTM) Standard D6908 – Standard Practice for Integrity Testing of Water Filtration Membrane Systems. A pressure decay test was performed during Task B to establish a baseline pressure decay rate for the UF system. During testing, the pressure decay test was performed daily. The pressure decay test was also performed after each UF system cleaning.
Note that the TQAP called for conducting a marker dye test on the RO system as a direct integrity evaluation, but this test was not conducted.

3.8.4.2 Continuous Indirect Integrity Monitoring:

Continuous indirect integrity monitoring methods were employed on both the UF and RO systems. Turbidity was monitored continuously on the UF feed, UF filtrate, and RO permeate. In addition to turbidity monitoring, particle counts were continuously monitored on the UF system, and conductivity was monitored on the RO permeate stream. Turbidity readings were recorded every fifteen minutes, while particle counts were recorded every five minutes, and conductivity readings were recorded hourly.

Results of the direct integrity tests, and the indirect integrity monitoring data are presented in Section 4.5.4.

3.8.5 Task C5: Data Handling Protocol

The objectives of this task were to: 1) establish an effective structure for the recording and transmission of test field test data, such that TARDEC provided sufficient and reliable data; and 2) develop an effective and accurate statistical analysis of the data.

3.8.5.1 Work Plan

The EUWP test system was equipped with a computer monitoring system. Some of the required measurements (see Table 3-2) were recorded automatically by the automated system. The remaining required measurements were recorded by hand by the field operator on-site. The data was recorded onto specially prepared bench sheets, which are included as Appendix B. Miscellaneous operational notes were recorded in a data logbook with numbered pages. All

errors were crossed out with one line, and the error was initialed and dated. Completed pages were signed, dated, and numbered by the individual responsible for the entries.

The database for the project was set up in the form of custom-designed spreadsheets. A spreadsheet containing the operational data, including calculations, was developed by USBR. A spreadsheet containing the water quality data was developed by NSF. Following data entry, 100% of the data in the spreadsheets was checked against the numbers on the field log sheets or laboratory analysis outputs.

3.8.6 Task C6: Quality Assurance Project Plan

QA/QC of the operation of the equipment and the measured water quality parameters was maintained through a QAPP, as described in this section.

3.8.6.1 Experimental Objectives

The objective of this task was to maintain strict QA/QC methods and procedures during the verification test. This included maintaining instrument calibration and operation within the ranges specified by the manufacturer.

The elements of the QAPP for this verification test included:

- work plan;
- QA/QC verifications;
- data correctness;
- calculation of indicators of data quality; and
- corrective action plan

3.8.6.2 Work Plan

A routine daily walk-through during testing was conducted to verify that each piece of equipment or instrumentation was operating properly. Chemical addition rates and receiving stream flows were checked to verify that they flowed at the expected rates. Values recorded by the automated data acquisition program were checked daily against those displayed on the instrument displays and those measured on-site.

3.8.6.3 QA/QC Verifications

Tables 3-7 and 3-8 give the on-site QA and on-site QC activities, respectively, for the verification test. NSF Laboratory analytical QA and QC activities followed those specified in the NSF Laboratory Quality Assurance Manual.

Table 3-7. On-Site Analytical Equpment QA Activities

	Equipment	Action Required
Initial	Flowmeters – electronic	Verified calibration volumetrically
	Turbidimeter – in-line (1720E)	Provided factory calibration certificate
	Turbidimeter – in-line (FilterTrak)	Provided factory calibration certificate
	Particle counter – in-line	Provided factory calibration certificate
	UV Spectrophotometer	Provided factory calibration certificate
Daily	Chemical Feed Pump	Volumetrically checked flowrate
	Turbidimeter – in-line	Verified with portable turbidimeter
	pH meter – portable	3-point calibration (4,7,10)
	Turbidimeter – in-line	Volumetrically checked flowrate
	Particle Counters – in-line	Volumetrically checked flowrate
Weekly	Rotameters	Inspected for buildup of algae, salt, etc.
	UF filtrate flow	Verified volumetrically
	Particle counter - in-line	Cleaned sensors
	Temperature – portable	Verified calibration with NIST-certified thermometer
	Turbidimeter – portable	Calibrated using <0.1, 20, 100, and 800 NTU standards
	Conductivity meter – portable	Calibrated at 2 points
Every Two Weeks	Flowmeters – electronic	Verified calibration volumetrically
Prior to Test	Tubing	Checked condition, checked for leaks
	Particle Counter - in-line	Factory Calibration
	Turbidimeter – in-line (1720E)	Cleaned and calibrated using 20 NTU standard
	Turbidimeter – in-line (FilterTrak)	Cleaned and calibrated using 0.8 NTU standard

Table 3-8. On-Site Data Generation QC Activities

	Item	Action Required
Daily	Data	Reviewed system performance data since previous day
Weekly	Data	Compared field and lab water quality results when available

3.8.6.4 Data Correctness

There are five indicators of data quality that were used for this verification test:

- representativeness;
- statistical uncertainty;
- precision;
- accuracy; and
- completeness.

These five indicators are discussed in detail in the sections that follow.

3.8.6.4.1 Representativeness

Representativeness of the data for this verification test was ensured by executing consistent sample collection and data collection procedures, including:

- Consistency of sample locations;
- Timing of sample collection;
- Analytical methods; and
- Sampling procedures, sample preservation, packaging, and transport.

3.8.6.4.1.1 On-Site Analytical Methods

The analytical methods for on-site monitoring of raw and treated water quality are described in the sections below.

pH

Analyses for pH were performed according to *Standard Method* 4500-H^+ using a Myron L Ultrameter II Model 6P or an Accumet Model 50. Three-point calibration (using pH 4, 7, and 10 buffer solutions) was performed daily.

Temperature

Readings for temperature were conducted in accordance with *Standard Method* 2550 using a Myron L Ultrameter II Model 6P. A calibration check was performed weekly with a NIST-traceable thermometer.

Turbidity

Turbidity was measured at all sampling points using a hand-held turbidimeter. In addition, in-line turbidimeters were used for measurement of UF feed and filtrate. All measurements were conducted according to EPA Method 180.1.

Hand Held Turbidimeters: A Hach 2100P portable turbidimeter (range 0 to 1000 NTU) was used to measure the turbidity of the appropriate grab samples. The turbidimeter was calibrated weekly using formazin turbidity standards of <0.1, 20, 100, and 800 NTU.

In-line Turbidimeters: In-line Hach turbidimeters were used for measurement of turbidity in the feed (Hach 1720 E – Low Range) and UF filtrate water (Hach FilterTrak 660). The Hach 1720E has a range from 0 to 100 NTU and uses a 20 NTU calibration standard. The Hach FilterTrak has a range from 0.005 to 5.00 NTU and uses a 0.8 NTU calibration standard. These turbidimeters were calibrated at the start of the test. In-line readings were periodically compared to the readings from the hand-held turbidimeter. If the comparison suggested inaccurate readings, the in-line turbidimeter was recalibrated. A volumetric check on the sample flowrate was performed daily.

Conductivity

Analyses for conductivity were performed according to manufacturer's instructions using a Myron L Ultrameter II Model 6P. A two-point calibration was performed daily.

Particle Count

In-line particle counters were employed for measurement of particle concentrations in UF membrane unit feed and filtrate waters. The Hach 2200 PCX in-line particle sensor selected is able to measure particles with a range of 2 μm to 750 μm in up to 32 user-defined bins. The particle counters were calibrated by the manufacturer prior to the ETV test.

3.8.6.4.1.2 Sample Collection, Shipment, and Storage for Laboratory Analyses

Samples were collected in bottles prepared by NSF and shipped to the test site. All samples were preserved, if required, according to the proper analytical method. Bottles for parameters requiring preservation were shipped to the test site containing the preservative. All samples were kept on ice in coolers and shipped overnight to NSF. Chain of custody forms accompanied all samples.

3.8.6.4.1.3 Laboratory Analytical Methods

A comprehensive list of laboratory analytical methods used can be found in Table 3-9. TDS from the lab analysis was correlated to conductivity for calculation of normalized permeate flow and rejection trends over time. TDS was used to calculate osmotic pressure gradient needed for net driving pressure calculations.

Table 3-9. Analytical Methods for Laboratory Analyses

Parameter	Analytical Method	Method Detection Limit[(1)]
Alkalinity (total, as $CaCO_3$)	EPA 310.2	5 mg/L
Barium	EPA 200.8	1 µg/L
Bicarbonate (as $CaCO_3$)	EPA 310.2	5 mg/L
Boron	EPA 200.7	1 µg/L
Calcium	EPA 200.7	20 µg/L
Chloride	EPA 300.0	0.5 mg/L
TDS	SM 2540 C[(2)]	5 mg/L
Hardness (total, as $CaCO_3$)	SM 2340 B	2 mg/L
Lithium	EPA 200.8	1 µg/L
Magnesium	EPA 200.7	20 µg/L
Phosphate (ortho)	SM 4500-P E	0.020 mg/L
Phosphate (total)	EPA 200.7	0.050 mg/L
Potassium	EPA 200.7	0.5 mg/L
Selenium	EPA 200.8	2 µg/L
Sodium	EPA 200.7	0.5 mg/L
Sulfate	EPA 300.0	0.5 mg/L
TOC	SM 5310 B	0.1 mg/L
TSS	SM 2540 D	2 mg/L
UV_{254}	SM 5910B	0.000 Absorbance/cm (A/cm)
Bacillus Endospores	SM 9218	1 CFU/L
Total Coliforms	SM 9222	1 CFU/100 mL

(1) The listed detection limits may not apply for some samples, especially the feed water samples, due to matrix interference from the high TDS.
(2) SM=Standard Methods

3.8.6.4.2 Statistical Uncertainty

For the water quality parameters monitored, 95% confidence intervals were calculated for data sets of eight values or more. The following equation was used for confidence interval calculation:

$$\text{Confidence Interval} = \overline{X} \pm [t_{n-1,1-(\alpha/2)} \times (S/\sqrt{n})]$$

where:

$\overline{X}$ = sample mean
S = sample standard deviation
n = number of independent measurements included in the data set
t = Student's t distribution value with n-1 degrees of freedom
α = significance level, defined for 95% confidence as: 1 - 0.95 = 0.05

According to the 95% confidence interval approach, the α term is defined to have the value of 0.05, thus simplifying the equation for the 95% confidence interval in the following manner:

$$95\%\ \text{Confidence Interval} = \overline{X} \pm [t_{n-1,0.975} \times (S/\sqrt{n})]$$

3.8.6.4.3 Accuracy

The accuracy of on-site analytical equipment was periodically verified according to the schedule in Table 3-7. The calibration records for the analytical equipment were recorded on bench sheets (Appendix B). All calibrations were performed at the frequency required. All calibration data were within the specified QC objectives on all days analyses were performed.

Accuracy for the laboratory analyses was quantified as the percent recovery of a parameter in a sample to which a known quantity of that parameter was added. The following equation was used to calculate accuracy:

$$\text{Percent Recovery} = 100 \times [(X_{known} - X_{measured}) \div X_{known}]$$

where:

X_{known} = known concentration of measured parameter
$X_{measured}$ = measured concentration of parameter

Accuracy also incorporates calibration procedures and use of certified standards to ensure the calibration curves and references for analysis are near the "true value." Accuracy of analytical readings was measured through the use of spiked samples and lab control samples. Table 3-10 presents the control sample frequency and accuracy limits for each parameter.

Table 3-10. Accuracy and Precision Limits for Laboratory Analyses

Parameter	LFM[1] (spike sample) Frequency	LFM Acceptance Limits (% Recovery)	MB[2] Frequency	MB Acceptance Limits	Standards Frequency	Standards Acceptance Limits	LFM Duplicate or Field Duplicate Frequency	Field Duplicate Precision Acceptance Limits
Alkalinity	10%	70-130%	10%	< RL[3]	10%	85-115%	10%	30%
Barium	10%	70-130%	10%	< RL	10%	85-115%	10%	30%
Bicarbonate	10%	70-130%	10%	< RL	10%	85-115%	10%	30%
Boron	10%	70-130%	10%	< RL	10%	85-115%	10%	30%
Calcium	10%	70-130%	10%	< RL	10%	85-115%	10%	30%
Chloride	10%	80-120%	10%	< RL	10%	85-115%	10%	30%
TDS	10%	90-110%	10%	< RL	10%	85-115%	10%	30%
Total Hardness	10%	70-130%	10%	< RL	10%	85-115%	10%	30%
Lithium	10%	70-130%	10%	< RL	10%	85-115%	10%	30%
Magnesium	10%	70-130%	10%	< RL	10%	85-115%	10%	30%
Manganese	10%	70-130%	10%	< RL	10%	85-115%	10%	30%
Phosphate (ortho)	10%	70-130%	10%	< RL	10%	85-115%	10%	30%
Phosphate (total)	10%	70-130%	10%	< RL	10%	85-115%	10%	30%
Potassium	10%	70-130%	10%	< RL	10%	85-115%	10%	30%
Selenium	10%	70-130%	10%	< RL	10%	85-115%	10%	30%
Sodium	10%	70-130%	10%	< RL	10%	85-115%	10%	30%
Sulfate	10%	80-120%	10%	< RL	10%	85-115%	10%	30%
TSS	10%	N/A	10%	< RL	10%	85-115%	10%	30%
UV_{254}	N/A	N/A	N/A	N/A	(4)	(4)	N/A	N/A

(1) Laboratory Fortified Matrix
(2) Method Blank
(3) Laboratory Reporting Limit
(4) QC Standard is analyzed daily, acceptance limits are assigned by standard manufacturer.

3.8.6.4.4 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. To quantify precision, the relative percent difference (RPD) of duplicate analyses was calculated. RPD was measured by use of the following equation:

$$RPD = \left| \frac{S_1 - S_2}{S_1 + S_2} \right| \times 200$$

where:

S_1 = sample analysis result; and

S_2 = sample duplicate analysis result.

The required duplicate analysis frequency, and maximum allowable percent difference for each analyte are listed in Table 3-10. For the field analysis parameters, acceptable analytical precision was set at an RPD of 30%. Field duplicates were collected at a frequency of 10% for each parameter.

3.8.6.4.5 Completeness

Completeness refers to the amount of valid, acceptable data collected from a measurement process compared to the amount expected to be obtained. Completeness was quantified according to the following equation:

$$\%C = (V/T) \times 100$$

where:

%C = percent completeness
V = number of measurements judged valid
T = total number of measurements

The completeness objective for data generated during this verification test was based on the number of samples collected and analyzed for each parameter and/or method. Table 3-11 presents the completeness requirements based on the sampling frequency spelled out in the test/QA plan.

Table 3-11. Completeness Requirements

Number of Samples per Parameter and/or Method	Percent Completeness
0-10	80%
11-50	90%
> 50	95%

3.8.6.5 Operation and Maintenance

The EUWP was operated and maintained according to limits stated in Chapter 2 and the EUWP Operation and Maintenance Manual.

Chapter 4
Results and Discussion

4.1 Introduction

This chapter presents a summary of the water quality and operating data collected during the verification test. Operating data are presented to describe the flow rates, volume of treated water produced, backwash volumes and frequency, pressure differential across the UF and RO skids, and related operating information. Water quality data are presented for the key parameters. Information on the membrane integrity testing, microbial results, and particle counts are also included in this Chapter. QA/QC information, as described by the QAPP in the TQAP for this verification test, is presented at the end of the chapter.

4.2 Equipment Installation, Start-up, and Shakedown

The EUWP unit tested is maintained and stored at the NBVC. Therefore, the unit was already at the testing site and required only minimal installation time. A series of calibrations checks and UF integrity tests were performed prior to starting the verification test (see Section 4.4). Startup and shakedown testing was started on September 27, 2007. The verification test began on October 16, 2007, and ended on November 12, 2007. A post-test cleaning of the RO system occurred on November 13 and 14, 2007.

4.3 Task A: Raw Water Characterization

Raw seawater directly from the Port of Hueneme was used for ETV testing, as discussed in Section 1.3. The Port of Hueneme is the only deep-water port between Los Angeles and the San Francisco. It has no appreciable fresh water outlets; therefore the water closely resembles that of the Pacific Ocean with respect to salinity. Average water temperature ranges from 55 °F in the winter months to approximately 62 °F in the summer. Raw seawater samples were collected in 2006 and 2007 for this task. The data for these samples are shown in Table 4-1.

Note that the metals were measured by both EPA Methods 200.7 and 200.8, and EPA Method 1640. Method 1640 includes a pre-concentration step that allows for lower detection limits in seawater samples. The seawater detection limits for 200.7 and 200.8 are higher than those for drinking water samples due to interferences from the high levels of sodium.

Table 4-1. Initial Raw Water Characterization Sampling Results

Parameter	Sample Date 04/01/06	06/08/06	09/05/06	04/24/07	08/28/07
pH	7.77	7.96	7.8		
Conductivity (µmhos/cm)	50,000	50,000	51,100		
TOC (mg/L)			ND (0.3)		
UV_{254} (Absorbance/cm)			0.016		
TSS (mg/L)			30		
TDS (mg/L)	34,000	37,000	35,700		
Alkalinity (mg/L as $CaCO_3$)			100		
Total Hardness (mg/L as $CaCO_3$)			6,580		
Nitrate (mg/L of N)			ND(40)		
Nitrite (mg/L of N)			ND(10)		
Total Silica (mg/L as SiO_2)			ND(2)		
Fluoride (mg/L)			ND(0.1)		
Heterotrophic Plate Count (CFU/mL)			4		
Total Coliforms (CFU/100 mL)			80		
Metals by EPA 200.7 (all mg/L)					
Calcium				420	
Iron				0.040	
Magnesium				1,300	
Manganese				ND(0.050)	
Potassium				400	
Sodium				11,000	
Metals by EPA 200.8 (all µg/L)					
Antimony	ND(20)	ND(10)	ND(25)	ND(25)	
Arsenic (total)	42	5.2	ND(50)	ND(50)	
Barium	7.6	6.1	6	ND(50)	
Beryllium	ND(10)	ND(5)	ND(5)	ND(250)	
Cadmium	ND(20)	ND(5)	ND(5)	ND(100)	
Chromium	ND(30)	ND(15)	ND(25)	ND(50)	
Copper	21	16	ND(10)	ND(50)	
Lead	0.64	ND(5)	8	ND(50)	
Lithium				180	
Mercury	ND(0.2)	0.02	ND(0.02)	ND(100)	
Rubidium				110	
Selenium	160	ND(50)	120	ND(100)	
Strontium				7,800	
Tin				110	
Thallium	ND(10)	0.26	ND(5)	ND(10)	
Vanadium				110	
Zinc				750	
Metals by EPA 1640 (all µg/L)					
Aluminum					ND (6)
Antimony					0.18
Arsenic					1.41
Beryllium					ND (0.01)
Cadmium					0.03
Chromium					ND (0.05)
Cobalt					0.04
Copper					1.2
Iron					20.7
Lead					0.05
Manganese					2.25
Molybdenum					9.64

Table 4-1. Initial Raw Water Characterization Sampling Results (continued)

Parameter	Sample Date 04/01/06	06/08/06	09/05/06	04/24/07	08/28/07
Nickel					0.24
Selenium					0.02
Silver					ND (0.04)
Thallium					ND (0.01)
Tin					ND (0.01)
Titanium					0.81
Vanadium					1.69
Zinc					3.49

4.4 Task B: Equipment Installation, Initial Test Runs and Initial System Integrity Tests

The objective of this task was to evaluate equipment operation and determine whether the operating conditions result in effective treatment of the water. In this task, a preliminary assessment of the treatment performance of the equipment was made. This task is considered a shakedown testing period and was completed before the start of the verification test.

Initial equipment checks, UF integrity tests, required calibration checks, and initial test runs took place between September 27, 2007 and the beginning of the official ETV test on October 16, 2007. During this period, sensors were calibrated, communications were established with the particle counters and turbidimeters, and the PLC was operated to confirm programming and data collection were operating properly. The in-line turbidimeters and conductivity meters were calibrated. Handheld analyzers for pH, turbidity, and conductivity were checked and calibrated. The system flow meters and pressure gauges were also calibrated during this pretest period.

A pressure decay test (integrity test) of the UF system was an important part of the initial test runs to verify that the UF membranes and the connections were properly sealed. The first pressure decay test of the UF system was performed on September 27. A pressure drop of 4 psig occurred over a 20 minute period indicating that there was a leak or broken fibers in one or more of the UF cartridges. Closer inspection found that air was leaking from Cartridge #7. This was identified by the audible sound of air bubbles within the cartridge. Cartridge #7 was removed from the skid and placed in a trough of water to perform a low-pressure decay test. This test identified one broken fiber in Cartridge #7, which was repaired by plugging both ends of the fiber.

On October 9, pressure decay tests were performed on each cartridge individually. These tests were performed with the cartridges in place on the skid, and with the end caps in place. The filtrate and feed outlets were capped and the cartridges filled with water. Each cartridge was then pressurized to between 4.8 and 6.0 psig and the pressure monitored for 5 minutes. The pressure drop over the five minutes ranged between 0.01 psig/min to 0.03 psig/min, except for Cartridge #14, which showed a drop of 0.72 psig/min. This cartridge was removed from the system and pressure tested in a trough with water. The identified leaks were pinned and the cartridge reinstalled on the skid. Cartridge #14 was pressure decay tested again, and the decay rate was measured at only 0.02psig/min. Table 4-2 shows the results of the individual cartridge low pressure test.

On October 10, the entire UF system was pressure decay tested once again. The system was pressurized to 14.7 psig and the pressure drop recorded over a twenty minute period. The results are shown in Table 4-3. These data were reviewed by NSF, and it was determined the UF system was ready for testing.

Table 4-2. Results of Low Pressure Integrity Test on Individual UF Cartridges

Time	Applied Pressure (psig)						
(minutes)	UF1	UF2	UF3	UF4	UF5	UF6	UF7
0	6.01	5.21	5.83	5.13	5.65	5.33	5.34
1	5.94	5.19	5.81	5.10	5.61	5.29	5.31
2	5.91	5.18	5.80	5.08	5.58	5.27	5.28
3	5.88	5.17	5.79	5.06	5.56	5.25	5.26
4	5.86	5.16	5.78	5.04	5.54	5.23	5.25
5	5.84	5.16	5.77	5.03	5.53	5.21	5.24
Avg. pressure drop/min	0.03	0.01	0.01	0.02	0.02	0.02	0.02

Time	Applied Pressure (psig)						
(minutes)	UF8	UF9	UF10	UF11	UF12	UF13	UF14a[(1)]
0	4.82	5.00	5.26	5.14	5.06	4.94	5.45
1	4.80	4.98	5.24	5.10	5.05	4.92	4.26
2	4.79	4.96	5.22	5.06	5.04	4.91	3.34
3	4.78	4.94	5.21	5.03	5.04	4.90	2.63
4	4.77	4.93	5.19	5.00	5.03	4.89	2.15
5	4.76	4.92	5.17	4.98	5.02	4.88	1.85
Avg. pressure drop/min	0.01	0.02	0.02	0.03	0.01	0.01	0.72

Time	Applied Pressure (psig)			
(minutes)	UF14b	UF14c	UF15	UF16
0	5.18	5.19	5.23	5.27
1	4.75	5.17	5.22	5.26
2	4.37	5.14	5.21	5.24
3	4.03	5.12	5.20	5.23
4	3.74	5.11	5.20	5.22
5	3.44	5.09	5.19	5.21
Avg. pressure drop/min	0.35	0.02	0.01	0.01

(1) Cartridge #14 was tested prior to repair, which is shown as UF14a. After repair, the cartridge was tested a second time (UF14b), which it again failed. It was repaired a second time resulting in a successful test (UF14c).

Table 4-3. October 10, 2007 UF Full System Integrity Test Results

Time (min)	Applied Pressure (psig)	Pressure Drop (psig/min)
0	14.74	NA
1	14.65	0.09
2	14.56	0.09
3	14.49	0.07
4	14.42	0.07
5	14.36	0.06
6	14.31	0.05
7	14.26	0.05
8	14.22	0.04
9	14.17	0.05
10	14.14	0.03
11	14.10	0.04
12	14.07	0.03
13	14.03	0.04
14	14.00	0.03
15	13.97	0.03
16	13.94	0.03
17	13.91	0.03
18	13.89	0.02
19	13.86	0.03
20	13.83	0.03

The UF and RO system were run for short periods of time during the pretest period, as part of the calibration and equipment checks for the flow meters, conductivity and turbidimeters, and particle counters. On October 11, the entire system was operated for several hours to ensure all systems were fully operational. There were no additional lengthy runs made prior to the start of the verification test on October 16. The RO system was operated to ensure the target flows could be attained, but no additional checks or pretest membrane integrity tests were performed on the RO membranes. The in-line conductivity meters were monitored at the start of the verification test to confirm the rejection rate of the RO membranes. The conductivity measurements made on the first day of testing showed a salt rejection rate of 98.8%.

It was known from past experience that the treatment of seawater would require the use of a coagulant prior to the UF system and the use of an antiscalant to reduce scaling on the RO membranes. While it is often necessary and helpful to run jar tests to determine the optimal coagulant dose, in this case, no jar tests were performed prior to the verification test. Ferric chloride was selected as the coagulant based on previous pilot testing experience. In 2004 a pilot study was performed at Port Hueneme by TARDEC, in conjunction with Koch Membrane Systems to investigate the use of UF membranes for seawater pretreatment upstream of RO treatment. This study also evaluated the use of ferric chloride to improve UF performance. The results from this study were used to set the initial target dosage of ferric chloride at 0.75 mg/L as Fe. The antiscalant selected for use at this test site was ONDEO (Nalco) PermaTreat® PC-191. The initial target dose rate was 5 mg/L.

On October 15, the day before the verification test was scheduled to start, TARDEC scheduled a final preliminary run with all systems operational; however, the high pressure RO pump would not start. A service person was called and arrived at the site the same day. A problem was found with the fuel pump. A replacement fuel pump was obtained the next morning and the system was up and running by 11:00 a.m. on October 16.

4.5 Task C: Verification Test

The verification test was started on October 16, 2007 and ran for 28 calendar days (27 24-hour periods), to November 12, 2007. The test had been scheduled to run for thirty days, or until the UF system required at least two CIPs. The continuous operation portion of the verification test was stopped on November 12, as the UF system had been cleaned four times as of November 9. On November 13 and 14, the RO membranes were cleaned and post-cleaning operational data was collected.

The UF system was operated each day on continuous basis, except for shutdowns for integrity testing and routine maintenance. The UF system also automatically shut down when the RO feed tank was full. The biggest impact on overall UF operating hours was the need to perform chemical cleaning of the UF membranes four times during the test. A typical operating day for the UF system was 19 to 22 hours. The mean UF operating hours per day over the entire test was 18.6 hours with a median of 19.8 hours, as shown in Table 4.4. Note that the count in Table 4-4 for the hours per day figures is only 19. For the first two weeks of the test, and also the last two days, the operators did not record the operation hours on most of the sheets for daily operation data.

The RO system was also setup to operate continuously, except for routine maintenance periods and times when the UF was shutdown for integrity testing, maintenance, or cleaning. A typical operating day for the RO system with no significant maintenance issues was 21 to 23 hours. The mean RO operating hours per day over the entire test was 17.1 hours with a median of 19.0 hours. When alarms and shutdown occurred during unattended operation at night, the entire system would remain shut down until an operator arrived in the morning.

The on-site operators typically collected operating data and on site water quality samples a minimum of twice per day in accordance with the test plan schedule. The following sections present the operating data and water quality data.

4.5.1 Task C1: Membrane Flux and Operation

The purpose of this task was to evaluate system performance during operation. The objectives of this task were to demonstrate the appropriate operational conditions for the system, the feed recovery achieved by the UF and RO membranes, and the rate of flux decline observed over the operation period.

Operational data were collected and on-site water quality measurements were made two or more times per day throughout the test, except for three days associated with UF cleaning when only one set of data was obtained. The data were summarized for presentation and discussion in this

section. The complete set of data sheets can be found in Appendix B. The data spreadsheet with the calculations is Appendix C.

4.5.1.1 UF Operating Data

4.5.1.1.1 UF Flow Rate, Filtrate Production, and TMP Results

The UF operational statistics are presented in Table 4-4. The UF skid does not have a filtrate flow meter or filtrate pressure gauge. Therefore, the total filtrate flow was calculated as the UF feed flow rate minus the UF retentate flow. The intake flow is the intake from the source water into the UF feed tank. The intake pump is technically not part of the UF skid, but the intake flow is included here as part of the overall UF treatment process. The intake pump ran at a higher flow rate than the UF system to ensure that the UF feed water tank always contained sufficient water to operate the UF system.

Table 4-4. UF Operational Data Statistics

Parameter	Count	Mean	Median	Minimum	Maximum	Standard Deviation	95% Confidence Interval
UF Operation per day (hr)	19	18.6	19.8	7.3	22.7	4.11	± 1.85
Raw Intake Flow (gpm)	74	287	288	272	296	4.98	± 1.13
Feed Flow (gpm)	74	249	251	212	279	11.4	± 2.60
Filtrate Flow (gpm)	74	222	225	187	252	10.9	± 2.48
Retentate Flow (gpm)	74	26	26	25	34	1.66	± 0.38
Backwash Flow (gpm)	900 gal per backwash cycle(1); Backwash every 30 minutes						
Feed Pressure (psig)	74	20.6	20.0	14.0	30.0	3.74	± 0.85
Retentate Pressure (psig)	74	16.3	16.0	10.0	23.0	2.89	± 0.66
Filtrate Temperature (°F)	74	58.3	59.0	55.0	61.0	1.62	± 0.37

(1) Volume not measured. It was provided by the manufacturer.

The mean UF feed flow of 249 gpm was below the design feed flow of 259 gpm specified for the system (See Table 3-4). The mean filtrate flow of 222 gpm corresponds to a flow of 13.9 gpm for each of the 16 UF membrane modules. The UF water recovery was 89.2% based on the mean feed and filtrate flows.

Figure 4-1 shows the UF system flow rates over the duration of the verification test. The retentate flow remained steady throughout the test. The feed flow and filtrate flow dropped as the membranes became fouled with solids and TMP increased. Manual adjustment of the flow control valve was made to hold the feed and filtrate flows as steady as possible.

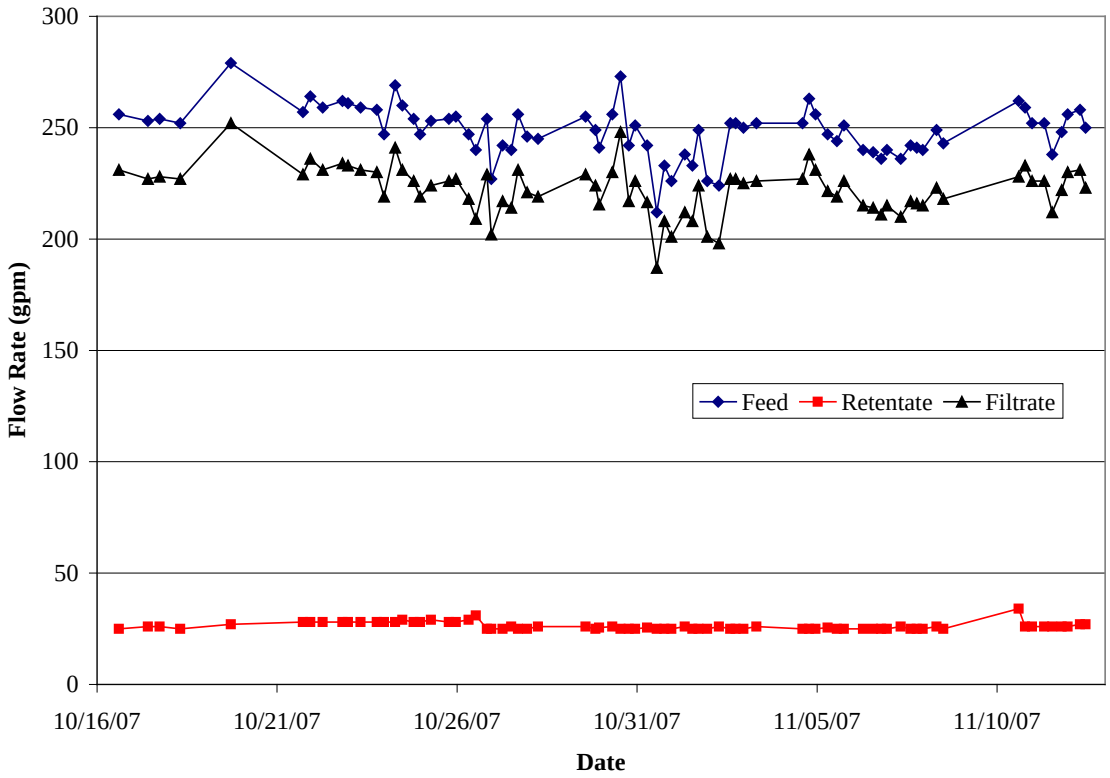


Figure 4-1. Plot of UF system flow rates through the testing period.

Total UF filtrate production was tracked using the RO feed totalizer. This production volume was the actual filtrate used for the RO feed and does not include the filtrate used for backwash water. The net filtrate production over the 27-day test period was 4,673 kgal, which represents an average production rate of 173 kgal/day. The total UF filtrate volume (including filtrate used for backwash) produced was 5,249 kgal, which gives an average total production rate of 194.4 kgal/day. This production rate includes the two days when the UF was not operated due to cleanings, and includes the other days with limited production due to cleaning or system maintenance issues. Figure 4-2 shows the cumulative total and net filtrate production for the UF system over the duration of the verification test.

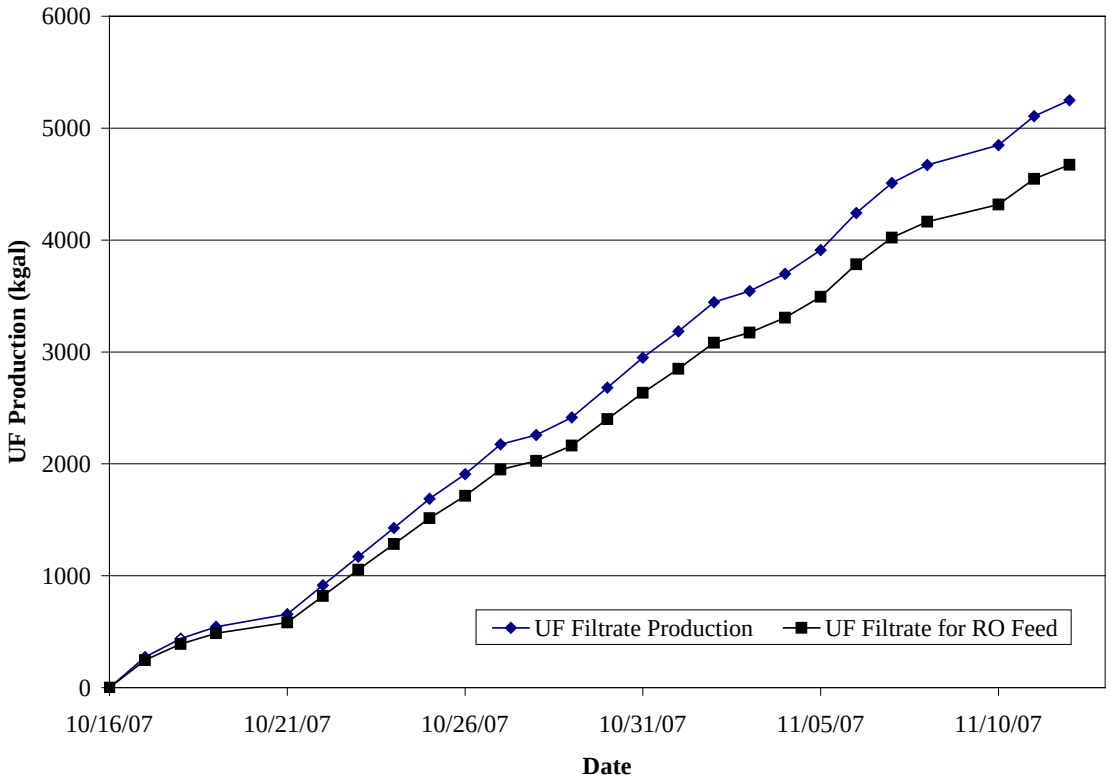


Figure 4-2. UF system filtrate production through the testing period.

Figure 4-3 shows the feed and retentate pressures during the test and Figure 4-4 shows the calculated TMP results. These figures depict the impact of solids build up on the UF membranes during operation.

A chemical coagulant (ferric chloride) was added to the UF feed to improve operation of the UF system and to lengthen run time between chemical cleanings. The coagulant addition was planned for a feed rate of 4.37 ml/min (0.07 gal/h), which would yield an iron dose (as Fe) of 0.75 mg/L in the UF feed (4.6×10^{-6} gal ferric chloride per gal of feed). The chemical feed pump stroke and speed were calibrated and checked daily. In addition, the level in the ferric chloride feed tank was recorded at least twice per day and records were maintained of the ferric chloride added to the feed tank. Based on the tank records, a total of 22.4 gal of ferric chloride were fed into 5,259,625 gal of feed (4.3×10^{-6} gal ferric per gal of feed), which is approximately 10% less than the feed rate measured by the pump calibration.

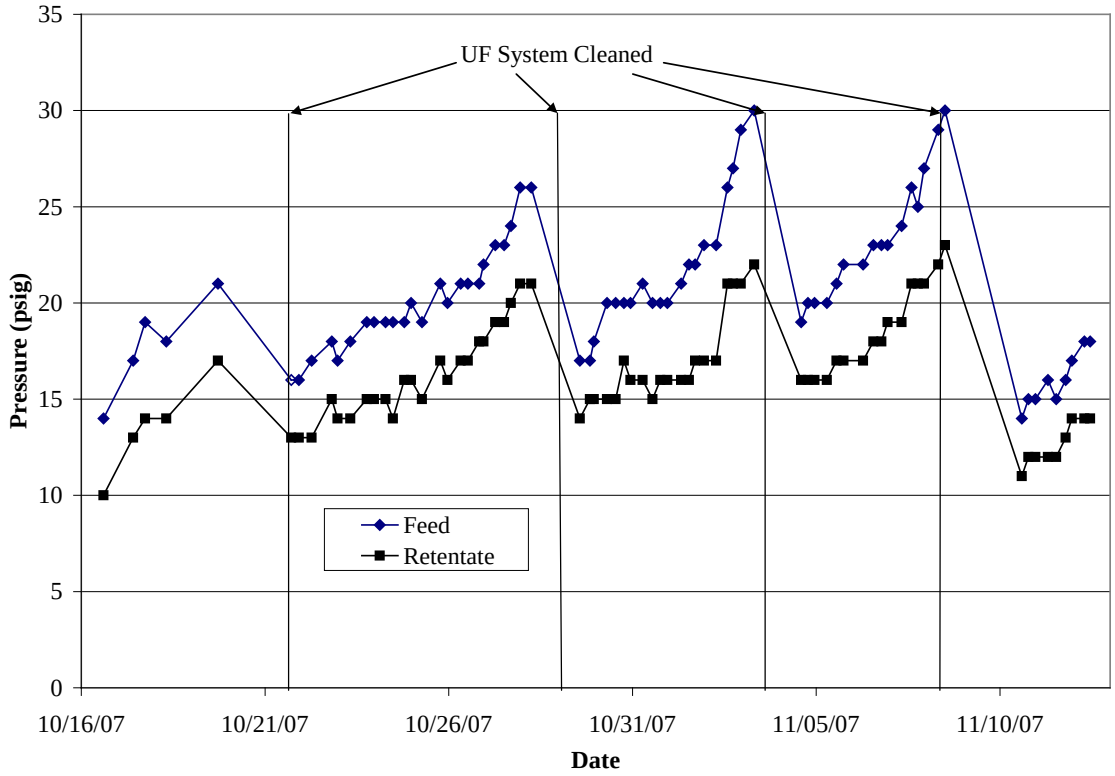


Figure 4-3. Plot of UF system feed and retentate pressures over the testing period.

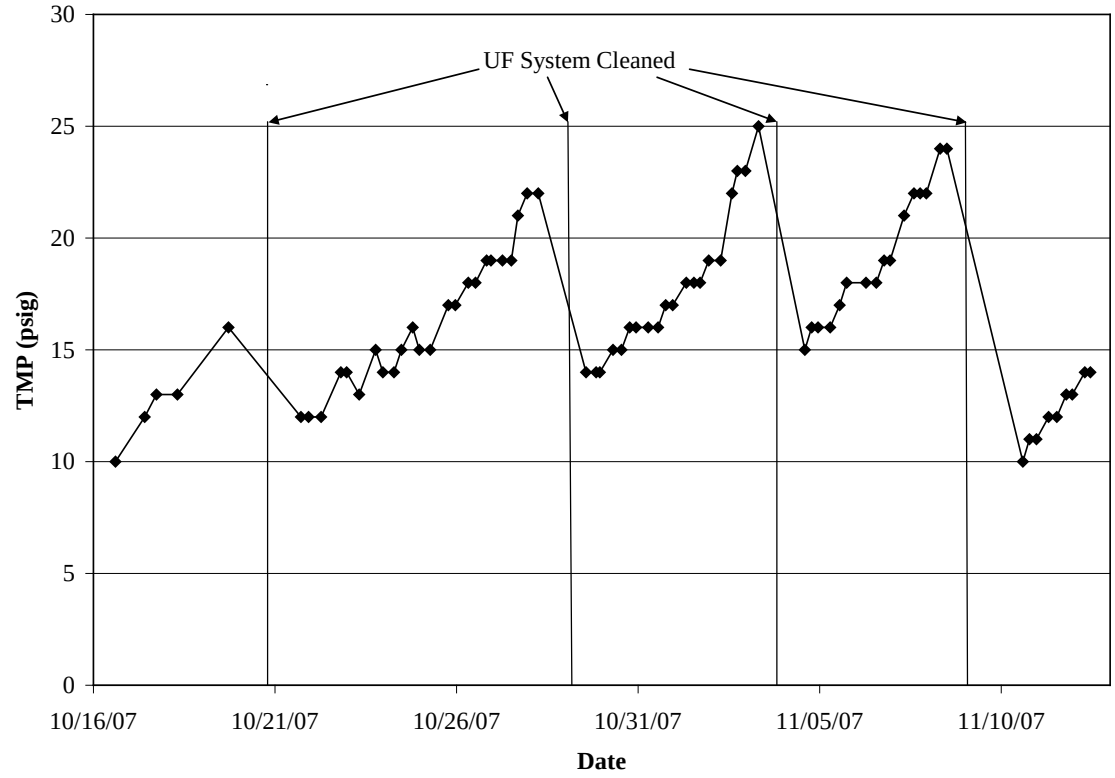


Figure 4-4. Plot of UF system TMP over the testing period.

4.5.1.1.2 Discussion - UF Flow Rate, Filtrate Production, and TMP

As discussed in Section 2.1, the maximum UF production rate is 250,000 gpd (not including backwash water). Based on the net filtrate production over the 27-day verification period, the UF system produced on average 173 kgal/day.

The EUWP included a totalizer to track the hours of UF system operation. The primary impact on total operating hours over the 27-day test was the need to clean the UF membranes four times during the test. There were two cleaning periods when the unit was down for more than one day, yielding two days out of 27 with no operation. The other two cleaning periods resulted in the daily operating hours averaging approximately 9 hours per day for the two-day cleaning periods (each cleaning requires an overnight soak, so the cleaning covers two days). The hours of operation varied widely, from 7.3 to 22.7 hrs, depending on the downtime for various maintenance activities and verification related testing. The UF system was operated an average of 18.6 hours per day with a median of 19.8 hours per day. However, a typical operation day with no significant maintenance issues netted 21-23 hours of operation.

The first UF cleaning occurred when the TMP had only increased to 16 psig compared to a target of 20 psig (Note: actual equipment specification says to clean when TMP exceeds 30- 35 psig). The operators had noted an increase in feed pressure and read by mistake a backwash TMP readout that was above 20 psig. Thus, this first cleaning was performed earlier than required. Subsequently, as shown in Figure 4-4, the TMP increased over the next 5 to 7 days and the UF membranes required another chemical cleaning, as the normal backwash cycle was not sufficiently cleaning the UF membranes. After each cleaning was completed, flow rates and TMP returned to normal ranges and similar to the values measured at the beginning of the test.

4.5.1.1.3 UF Specific Flux Results and Discussion

Figure 4-5 shows the specific flux calculations for the UF system during the test. The impact of solids buildup on the system is clear, especially for the last three cleaning cycles. The CIPs were successful, as the specific flux was improved after each cleaning event, but they were not able to restore the specific flux to that at time 0. For the last cleaning event on November 9 the FTO added an overnight soak with the low pH solution in addition to the standard overnight soak with the high pH solution. This bolstered cleaning procedure returned the membranes to a specific flux of 4.23 gfd/psig, which was identical to that at time 0.

Figure 4-6 shows the change in specific flux over the duration of the verification test. The change in specific flux is calculated by comparing the specific flux on a given day to the value calculated at the start of the test. This data shows the impact of cleaning and backwashing by comparing a given day's specific flux to the start of the test. As can be seen, there was a steady loss of specific flux between cleanings.

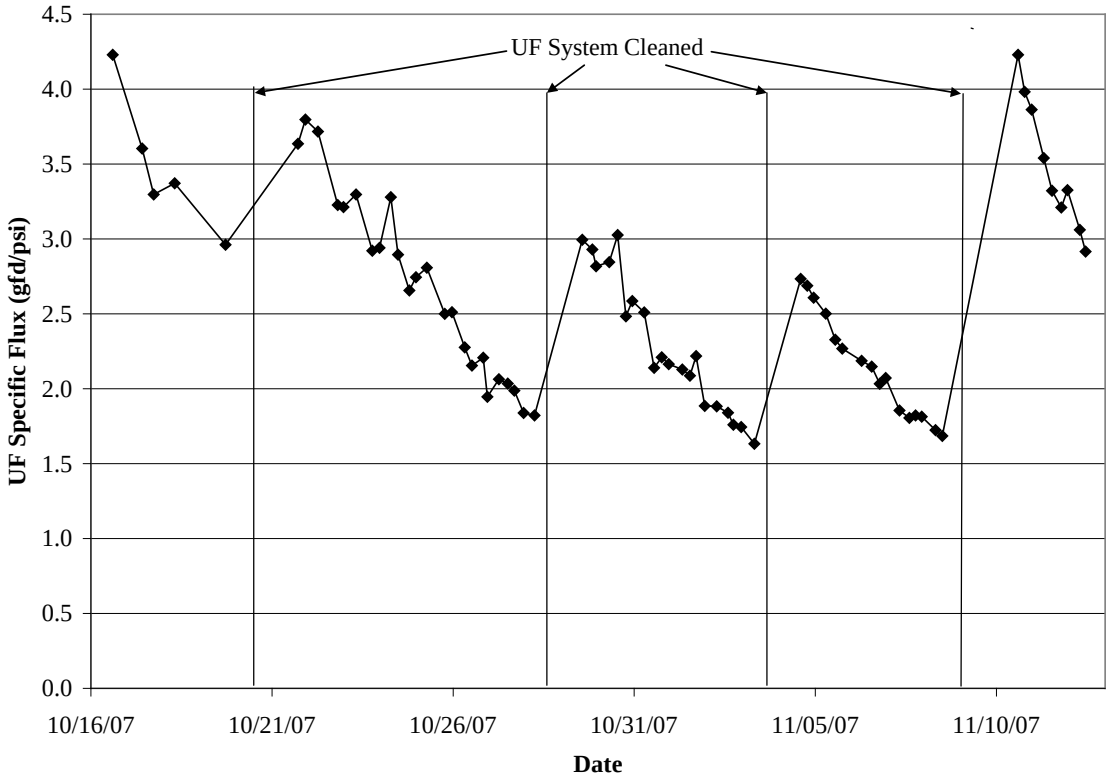


Figure 4-5. UF system specific flux over testing period.

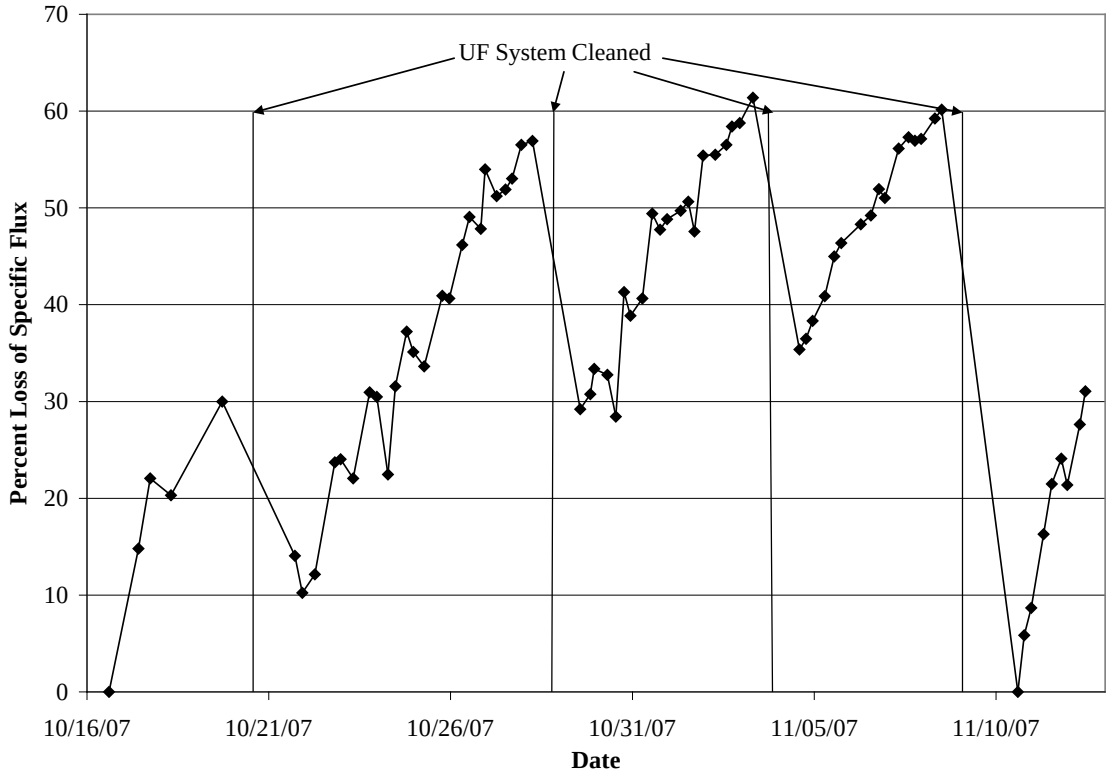


Figure 4-6. Change in specific flux over time.

4.5.1.1.4 Power Supply – Fuel Consumption

For this verification test, the generator that is part of the field portable system was used to demonstrate that the generator could sustain UF operation on a regular basis. The diesel powered 60 kWh generator supplies power to the UF skid and to the ancillary systems on the RO skid. The RO high-pressure pump has its own diesel engine, or can operated with an electric pump. The diesel fueled RO pump was used for this test.

The UF power requirements are stated as approximately 31 kWh when operating at full capacity or 2.1 kWh/kgal. The generator operated throughout the test and provided adequate power for the UF system and ancillary systems on the RO skid. Figure 4-7 shows the fuel consumption during the test. The total fuel consumption was 3,091 gal of diesel fuel over the 27-day test. The generator and the high pressure RO engine used the same fuel tank, so fuel usage figures are total usage for both systems. The EUWP was actually operated for 25 of the 27 days, yielding an average fuel consumption of 124 gpd with peak usage of 180 gpd.

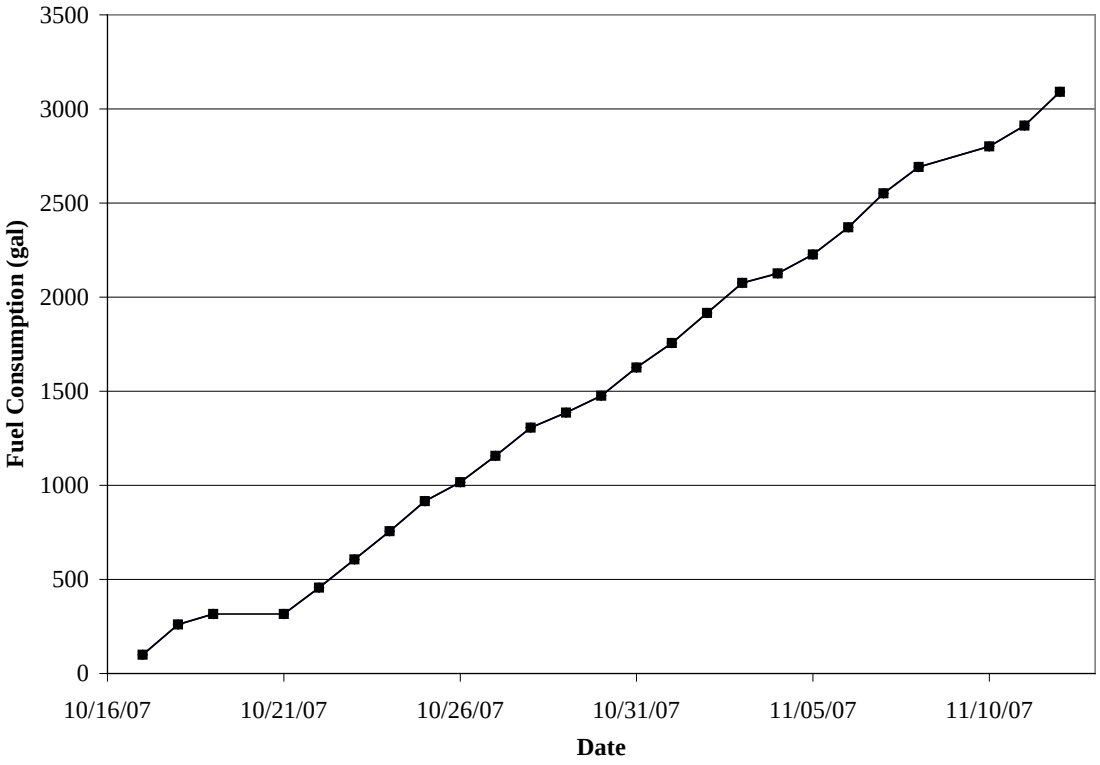


Figure 4-7. Diesel fuel consumption.

4.5.1.2 RO System Operational Data

4.5.1.2.1 Flow rates, Operating Pressures and Percent Recovery Results

The RO operational statistics for the verification test are presented in Table 4-5. The RO system has flow meters and pressure gauges to monitor the feed and permeate for Array 1. The concentrate flows for Array 1 were calculated as the difference between the feed flow and

permeate flow. Array 2 has flow meters for the permeate and concentrate, and gauges to monitor pressure for the feed, permeate, and concentrate. The feed flow for Array 2 was calculated by adding the permeate and concentrate flows. The UF system supplied all of the feed for the RO system.

Table 4-5. RO System Operational Measurement Statistics

Parameter	Count	Mean	Median	Min.	Max.	Standard Deviation	95% Confidence Interval
RO Operation Hours per Day (h)	25	17.1	19.0	4	24	6.12	±2.40
Array 1 Feed Flow (gpm)	74	115	115	112	117	0.74	± 0.17
Array 1 Permeate Flow (gpm)	74	70	70	68	72	0.82	± 0.19
Array 1 Concentrate Flow (gpm)	74	45	45	43	48	1.03	± 0.23
Array 2 Feed Flow (gpm)	74	63	63	56	68	2.05	± 0.47
Array 2 Permeate Flow (gpm)	74	32	32	25	37	2.11	± 0.46
Array 2 Concentrate Flow (gpm)	74	31	31	30	32	0.36	± 0.08
Array 1 Feed Pressure (psig)	70	957	960	927	977	10.8	± 2.39
Array 1 Concentrate Pressure (psig)	74	905	903	870	992	15.5	± 3.53
Array 2 Feed Pressure (psig)	70	901	900	880	936	11.0	± 2.58
Array 2 Concentrate Pressure (psig)	74	868	865	850	885	7.65	± 1.74
Array 1 and 2 Combined Permeate Pressure (psig)	74	23.4	23.5	21.0	28.5	1.34	± 0.31

The RO system maintained a steady permeate flow rate for both arrays throughout the verification test. Figure 4-8 shows the daily flows for permeate and concentrate for both arrays. Figure 4-9 shows the feed and concentrate pressures for both arrays. Feed pressure remained steady over the duration of the test. The concentrate pressure from Array 1 was used by the energy recovery device to provide the feed pressure for Array 2. This energy saving device eliminated the need for a high pressure pump for the Array 2 flow, which was approximately 55% of Array 1. Without the energy saving device, additional pumping capacity and the associated energy use would be required. The energy saving device achieved feed pressures that were similar to the Array 1 pressures throughout the test. Based on the permeate flows from Array 2 representing 31% of the RO water production (mean of 32 gpm out of an average of 102 gpm total), it can be roughly estimated that the energy conservation device saved 31% of the energy that would have been required if all the permeate was produced by high pressure pumps.

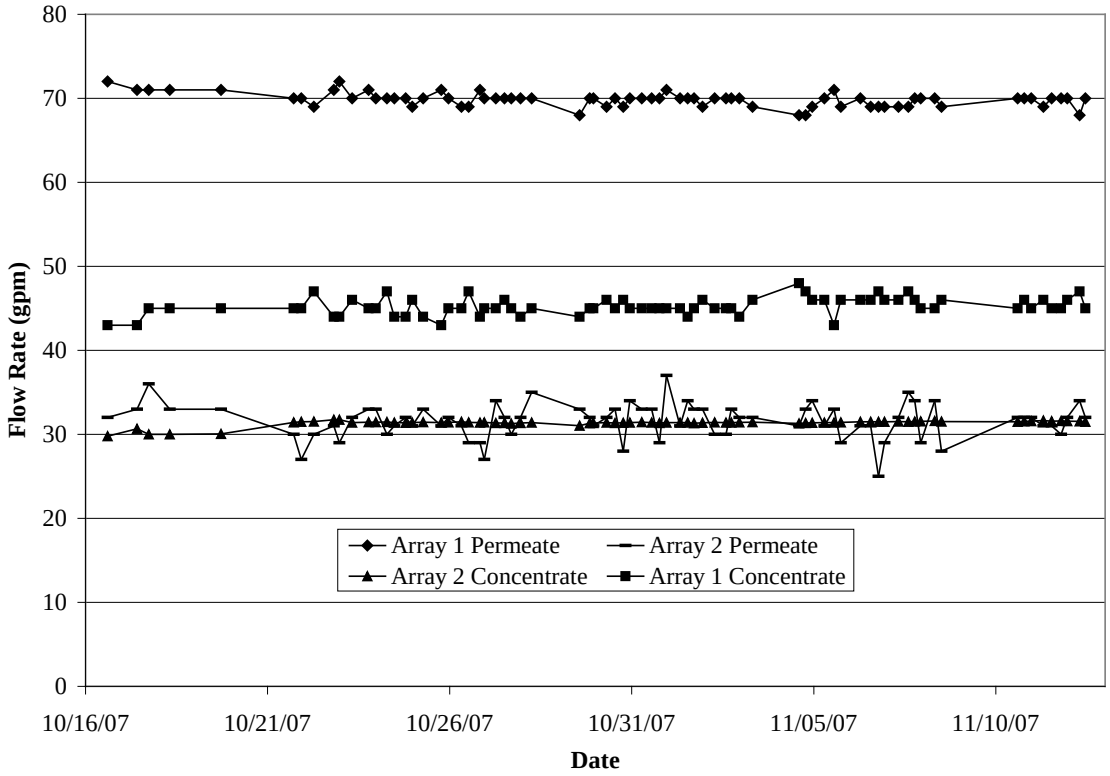


Figure 4-8. RO system flow rates.

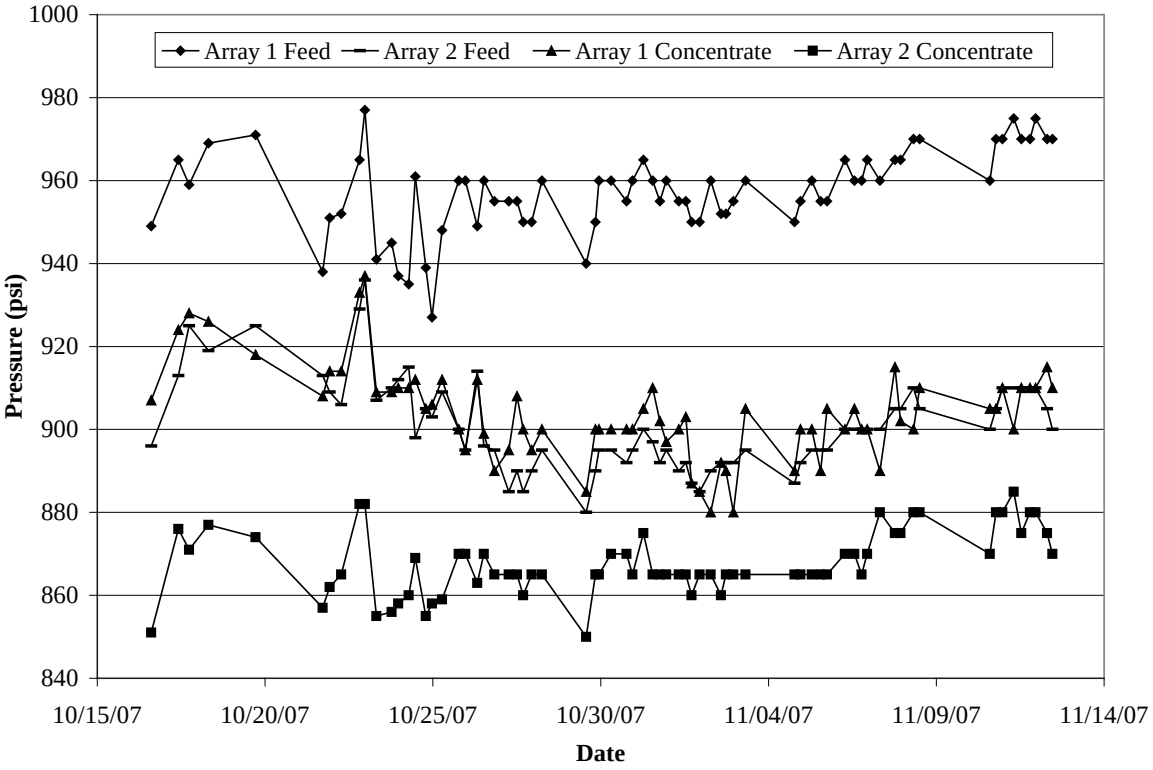


Figure 4-9. RO system operating pressures.

Figure 4-10 shows the percent recoveries achieved by the RO system. Recoveries, calculated as the permeate flow divided by the feed flow, were consistent throughout the test. The average percent recovery for Array 1 was 61% with a median of 61%. The mean recovery for Array 2 was 50% with a median of 50%. As expected, the recoveries for Array 2 were lower than for Array 1, as Array 2 operates at a lower feed pressure.

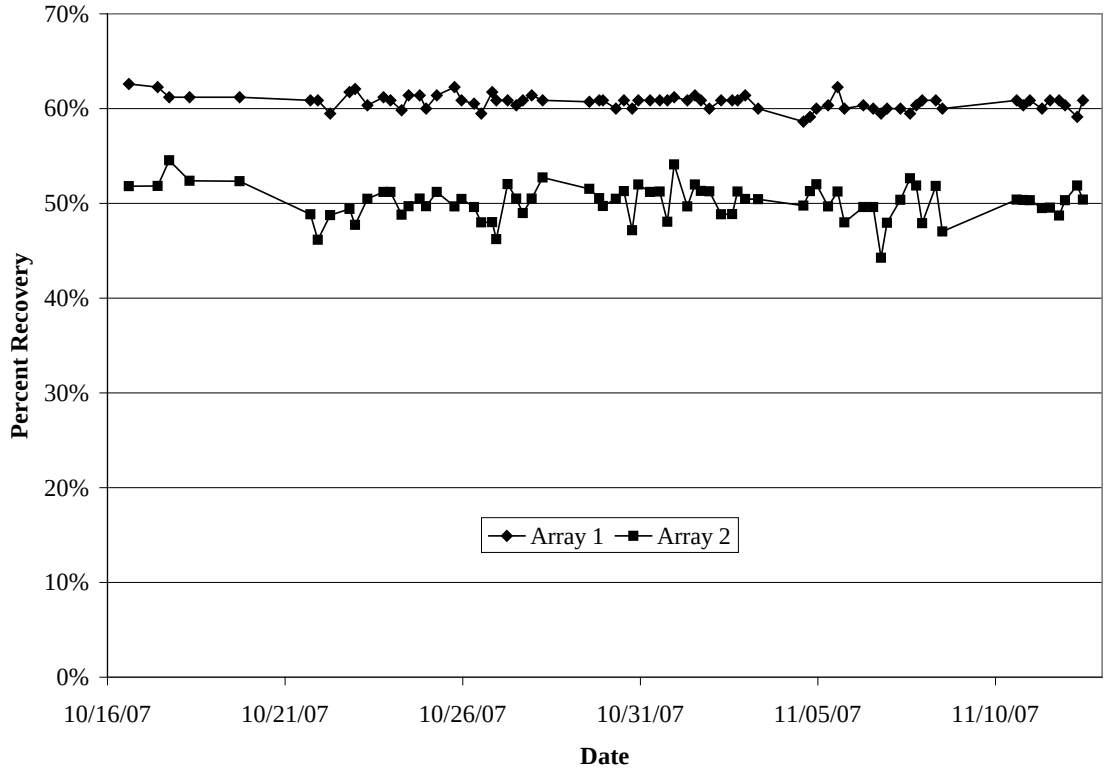


Figure 4-10. RO system percent recoveries.

4.5.1.2.2 Flow rates, Operating Pressures and Percent Recovery Discussion

The mean feed flows of 115 gpm for Array 1 and 63 gpm for Array 2 were close to the target feed rates of 116 gpm for Array 1, and 58 gpm for Array 2 listed in Table 3-4. The Array 1 recovery of 61% exceeded the target specification of 50%. The Array 2 recovery of 50% also exceeded the target specification of 48%. These recoveries, in conjunction with the feed targets, resulted in mean permeate flows of 70 gpm for Array 1 and 32 gpm for Array 2. At these flows, the RO unit would need to operate an average of approximately 16.3 hours per day to meet the claimed target of 100,000 gpd.

Over the 27-day verification test, the RO feed totalizer showed 4,673.3 kgal was fed to the RO unit. Based the daily recoveries for each Array (typically Array 1 at 61% and Array 2 at 50%), the total volume of permeate produced was approximately 2,671 kgal, giving an average of 98.9 kgal/day over 27-day test. This was close to the target production rate of 100,000 gpd.

The primary reason the RO system did not meet the production goal of 100 kgal/day was lack of feed when the UF system was shut down for cleaning. It should be noted that in addition to the impact that frequent cleaning had on the overall UF system water production, the UF system also shutdown anytime the RO system feed tank was full. The test was designed to verify the entire system with both UF and RO in operation. The UF system produced enough water to meet the 100 kgal per day production goal, but because of limited UF filtrate storage capacity, long downtime periods for the UF system cleaning did impact the RO production. With more storage capacity for UF filtrate, the UF system would have been able to meet the feed requirements for the RO system to achieve the overall goal of producing 100 kgal/day, even with the more frequent cleaning schedule.

Whenever, there was feed available, the RO system operated continuously producing permeate at a flow rate of 100 to 102 gpm. The RO system operated for more than 20 hours on 12 of the 25 actual operating days. The mean RO operating hours per day was 17.1, with a median of 19.0 hours per day. These mean and median hours match closely to the UF hours (mean 16.9 h and median 19.1 h). The maximum RO operating hours was 24 hours and the minimum was 4 hours.

Antiscalant was added to the RO feed throughout the test. The mean dose rate was 5.7 mg/L versus a target feed of 5 mg/L. The RO system did not seem to experience any scaling or fouling problems during the test. The S&DSI for the concentrate water was calculated in accordance with ASTM procedure D4582. This index can be used to determine the need for calcium carbonate scale control measures in the operation of an RO system. Direct measurements of the ions (Ca, Mg, Na, K, Cl, SO_4, Alkalinity) and pH of the concentrate stream provided data for the calculation without the need to estimate these concentrations from the feed data. The S&DSI varied from –0.71 to –0.84 during the test. This indicates that the concentrate was a non-scaling water (S&DSI <0.0 is non-scaling). The S&DSI results for each week of the test and the supporting water quality data are presented later in Table 4-12 in Section 4.5.3.2. The combination of non-scaling water and the addition of antiscalant reduced or eliminated the problems of scaling on the RO membranes.

As shown by the flow rate and pressure results, the system operated consistently throughout the test with little change in flows or pressures. This would suggest that for this water source, the RO could have met and exceeded the production feed targets, if sufficient water could have been provided from the UF system. The buildup of solids on the UF system and need for frequent UF system cleaning was the limiting factor over the verification test period.

4.5.1.2.3 RO Specific Flux – Results and Discussion

A common method of evaluating RO membrane performance is to calculate the specific flux, which normalizes the permeate flux based on net driving pressure. The calculation of net driving pressure (NDP) that is used in the determination of specific flux includes the calculation of osmotic pressure. A correlation between TDS and conductivity was calculated, and this correlation was then used with the daily conductivity measurements to calculate TDS values for the osmotic pressure equation. The equation for the line determined for this correlation was:

$$y(\text{TDS}) = 733.98x(\text{conductivity}), (R^2 = 0.9936)$$

Figure 4-11 shows the specific flux for the two RO system arrays based on NDP and adjusted to a temperature of 25 ^{o}C. The consistency of the specific flux over the test period further indicates that the RO membranes were not being fouled over the time. Given that the membranes were still functioning at the end of the test at a specific flux that was 97% of the starting specific flux, it cannot be projected when the membranes would require cleaning.

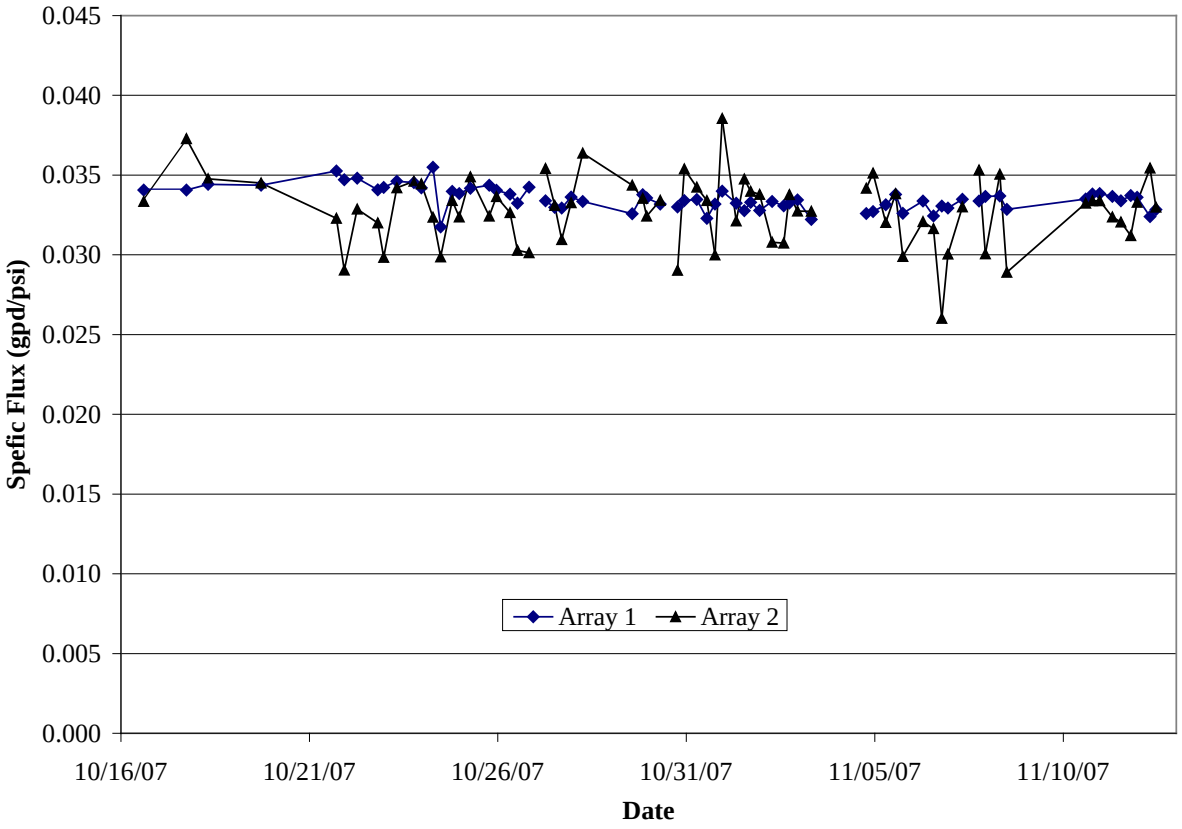


Figure 4-11. RO system specific flux.

The RO system was chemically cleaned at the end of the test on November 13 and 14. This cleaning was performed because it was a requirement of the verification test to demonstrate the cleaning process; even though the RO system had not actually reached its target cleaning level criteria. Data on the cleaning is provided in Section 4.5.2.2.

4.5.1.2.4 RO System Power

The RO system uses either an electric high-pressure pump or a diesel fuel high-pressure pump engine to pressurize the RO feed. The UF power generator described earlier provides all other power for the RO system. For this test, the diesel fuel high-pressure pump engine was used. As described in Section 4.5.1.1 under the *Power Supply - Fuel Consumption* heading, a common fuel tank provided fuel to both the generator and the RO engine. A total of 3,091 gal of diesel fuel was used through November 12, 2007, which was the end of the continuous flow portion of

the test. An additional 100 gal of diesel fuel was used on the last two days when the RO membranes were cleaned. Figure 4-7 shows the cumulative fuel usage over the verification test.

4.5.2 Task C2: Cleaning Efficiency

An important aspect of membrane operation is the ability to achieve long run times between chemical cleanings (to maintain operation time and minimize chemical use) and to restore membrane production after flux decline due to buildup of solids on the membrane and in the membrane pores. The objective of this task was to evaluate the membrane cleaning procedures and determine the fraction of specific flux restored following chemical cleaning.

4.5.2.1 UF Backwash and Cleaning Frequency and Performance

The UF system is designed to be backwashed automatically after every 30 minutes of operation. The backwash is designed to remove solids that have accumulated on and within the membrane. Frequent effective backwashes provide restoration of water production and lengthen the time until chemical cleaning is required. The automatic backwash system reverses the flow through the membrane to remove material accumulated on the membrane surface, and then a fast forward flow flush is performed to clear the membrane. The system uses UF filtrate water for the backwash cycle.

The automatic backwash system functioned properly during the verification test. The automatic cycle initiated on schedule once every 30 minutes, as programmed, and the entire process was automated. The backwash cycle counter tracked the number of backwashes performed during the test. The backwash system used 900 gal of filtrate for each backwash cycle (volume provided by the manufacturer). Based on the number of backwashes performed and the flow rates achieved in the verification test, the backwash system used approximately 11-12% of the filtrate produced by the UF system

It had been expected that the UF system would require chemical cleaning about every 15 to 30 days. However, the UF system actually was cleaned four times during the four-week test.

The first CIP for the UF system occurred on October 20, four days after startup. The specific flux had dropped from 4.23 gpd/psig to 2.96 gpd/psig and the TMP had increased from 10 psig to 16 psig. The UF system was still producing filtrate at an acceptable rate and TMP had not reached the target cleaning level of 20 psig. The operators had noted an increase in feed pressure and read by mistake a backwash TMP readout that was above 20 psig. The FTO decided to clean the unit. Thus, this first cleaning was performed earlier than required. Both a low pH and high pH cleaning were performed. Following an overnight soaking with the high pH solution, the UF was restarted. The specific flux increased to 3.64 gpd/psig and the TMP decreased to 12 psig. The CIP was considered successful with an 86% recovery of specific flux.

The UF system ran from October 21 to October 28, but showed steady decrease in specific flux and increase in TMP, as shown in Figures 4-4 and 4-5. At the end of the seven days the specific flux had decreased to 1.82 gpd/psig and TMP had increased to 22 psig. A CIP was started on October 28, and after an overnight high pH soaking of the membranes, the procedure was completed on October 29. The CIP restored specific flux to 2.99 gpd/psig (71% recovery) and decreased TMP to 14 psig.

Two additional cleanings were required to maintain the UF system, on November 3-4 after five more days of operation and on November 8-10 after four more days of operation. The CIP on November 3-4 showed a specific flux recovery of only 65% and lowered the TMP to 15 psig. The gradual decrease in cleaning performance was a concern so the procedure for the November 8-10 CIP was changed to add a low pH overnight soak followed by a regular low pH cleaning and then a high pH over night soak. This resulted in increased down time, but it was felt that the membranes needed to be restored closer to the original operating conditions. The November 8-10 CIP resulted in a specific flux recovery of 100%. Figures 4-4 and 4-5 show the TMP and specific flux before and after these cleaning procedures.

Figure 4-6 shows the change in specific flux over the duration of the verification test. The change in specific flux is calculated by comparing the specific flux on a given day to the value calculated at the start of the test. This type of data shows the impact of cleaning and backwash by comparing any given day's specific flux to the start of the test. As can be seen, the UF system was being consistently fouled every five to six days. As discussed in the previous section on UF production, this frequent cleaning resulted in significant down time for the system and reduced the capacity for the UF system for filtrate production and subsequent RO production.

The UF CIP procedure uses three chemicals, citric acid for the low pH cleaning, and sodium hydroxide and sodium hypochlorite (bleach) for the high pH cleaning. The amount of citric acid and sodium hydroxide needed to make a pH 3 or pH 11 cleaning solution varied for each cleaning. Additional chemical was added as needed during the recirculation step to maintain the pH and chlorine concentration. The target chlorine concentration was 100 to 200 mg/L. Table 4-6 shows the amount of each chemical that was used for each cleaning. The CIP mixing tank contained 270 to 300 gal.

The UF cleaning solution was heated in the CIP tank with the low pH solution ranging from 35 to 39 ^{o}C and the high pH solution 32 to 37 ^{o}C. Each bank of modules was circulated with each solution for 20 to 30 minutes. The membranes were then soaked overnight with the high pH solution.

Table 4-6. UF System CIP Cleaning Solution – Chemical Use

Date	Citric Acid (Solid, Lb.)	Sodium Hydroxide (0.5%, L)	Bleach (12.5%, L)
Oct. 20 to 21	4	2.4	12.6
Oct. 28 to 29	6	2.0	12.
Nov. 3 to 4	10	3.8	21.
Nov. 8 to 10	11.2/11.2(1)	3.8	29.

(1) Two low pH cleanings were performed with an overnight soak for each.

4.5.2.2 RO Cleaning Frequency and Performance

The RO system was cleaned on November 13 at the end of the verification test using both a low pH and high pH cleaning. This cleaning was not required based on the system operating data, as the specific flux for Array 1 had only decreased from an initial value of 0.0313 gpd/psig to 0.0303 gpd/psig (3% drop), and the Array 2 specific flux had only decreased from 0.0304

gpd/psig to 0.0302 gpd/psig (1% drop). The verification test, however, required a demonstration of the cleaning process, so it was performed at the end of the test. Figure 4-11 showed the specific flux for the two RO system arrays over the duration of the test. These data show no indication that the membranes were being fouled or that scaling was occurring. Based on these data it is not possible to project when a cleaning would be required, but clearly the RO system could sustain long run times, in excess of 30 days, in this specific application with the given water supplied from the UF system.

The RO cleaning was performed using Avista RO Cleaner P303 for the low pH cleaning. Fifty-four pounds of the RO cleaner were added to the 300-gal CIP tank, which resulted in a solution with pH 3.24. The system was circulated for one hour and then the system was flushed in preparation for the high pH cleaning. Avista RO Cleaner P111 was used for the high pH cleaning solution, with 54 pounds of P111 added to 300 gal, yielding a pH of 10.2. The high pH cleaning solution was circulated for two and a half hours and then the RO system was flushed and shutdown for the night.

Table 4-7 shows the specific flux results for Arrays 1 and 2 before and after the CIP procedure. The CIP restored Array 1 from a time 0 specific flux of 0.0341 before the cleaning, to a mean post-cleaning flux of 0.0334, which is a recovery of 99%. For Array 2, the CIP actually restored the membranes to an average specific flux of 0.0352, which was higher than the initial value of 0.0334, yielding a recovery of 105%.

Table 4-7. RO System Specific Flux Before and After CIP

Date	Time	Array 1 Specific Flux (gpd/psig)	Array 2 Specific Flux (gpd/psig)
10/16/07	Day 0 of test	0.0341	0.0334
11/12/07	Last Day of test	0.0328	0.0330
11/13/07		RO System Cleaned	
11/14/07	9:30	0.0332	0.0365
11/14/07	10:50	0.0335	0.0340
11/14/07	12:05	0.0335	0.0340
11/14/07	13:20	0.0333	0.0372
11/14/07	14:30	0.0336	0.0343
11/14/07	15:45	0.0335	0.0353
Mean post-cleaning specific flux		**0.0334**	**0.0352**

4.5.3 Task C3: Water Quality Results

The primary objective of this task was to assess the ability of the membrane equipment to meet the water quality goals, which were established as producing water that meets the USEPA NPDWR. Several water quality parameters were selected as indicator parameters to demonstrate the performance of the UF and RO membranes. Turbidity and conductivity were selected as two key parameters, as turbidity removal by the system would indicate the ability to remove particulate related contaminants, and a reduction in conductivity (indicator of total dissolved solids content) would show the ability of the RO system to remove dissolved contaminants. Both turbidity and conductivity were continuously monitored using in-line meters in the EUWP, and

grab samples were also measured onsite with portable equipment at least twice per day. Temperature and pH were also measured onsite at least twice per day. Other water quality parameters were monitored by collecting grab samples on a weekly basis. These parameters included TDS, TSS, Alkalinity, Hardness, Bicarbonate, Chloride, Sulfate, Calcium, Magnesium, Sodium, Potassium, Lithium, Boron, Barium, Selenium, Total phosphorus, Ortho-phosphate, and UV 254 absorbance.

This section presents the water quality results for the verification test. Data on the bacteriological samples (total coliforms and *Bacillus* endospores) are presented and discussed in Section 4.5.4, Task C4: Membrane Module Integrity.

4.5.3.1 Water Quality Results – Turbidity, Conductivity, pH, and Temperature

Figures 4-12 and 4-13 graphically present the grab sample turbidity results for the raw water and UF filtrate over the duration of the test. Table 4-8 shows this data in a tabular format, as well as the turbidity summary statistics. Note that the data set begins on October 17, which was the second day of the test. The October 16 turbidity readings are not included in the table because there was a problem with the turbidimeter on that day. Over the course of the test, the UF system reduced turbidity from a mean of 1.34 NTU in the raw water to a mean of 0.06 NTU in the UF filtrate. The 95% confidence level shows that filtrate turbidity can be expected to be in the range of 0.05 to 0.07 NTU. Turbidity in the raw water was reduced by a mean value of 94.9%, with a median reduction of 95.6% through the UF system. Turbidity levels met the NPDWR requirements of <0.3 NTU 95% of the time and all values below 1.0 NTU, except for the first day of testing as noted above.

As discussed above, the EUWP includes in-line turbidity meters that measured the turbidity of the raw water, UF filtrate, and RO permeate every 15 minutes as a means of monitoring membrane integrity. The raw water and UF filtrate readings are graphed in Figure 14. Note that there are two y-axes (different scales) in the figure, one for the raw water, and one for the UF filtrate. Also, the gaps in the data correspond to when the system was down for UF cleanings. The raw water turbidity, as measured by the in-line analyzer, had a mean value of 1.38 NTU, and a median of 1.32 NTU. The in-line turbidity data for the UF filtrate had a mean of 0.019 NTU, and a median of 0.018 NTU. Table 4-9 shows the summary statistics for the raw, UF filtrate, and RO permeate in-line turbidity readings. All of the individual measurements from in-line turbidity meters are listed in Appendix D.

The LT2ESWTR states that if the turbidity exceeds 0.15 NTU over any 15-minute period, the system must be shut down and a direct integrity test performed. Since the data logger recorded turbidity readings every 15 minutes, the evaluation criterion was two consecutive turbidity measurements exceeding 0.15 NTU. There were only three single data points where the UF filtrate turbidity exceeded 0.15 NTU. In each instance, the previous and following turbidity values were significantly below the 0.15 NTU level. Based on these data, it appears that the UF system did not exceed the LT2ESWTR action level during the verification test. It should be noted that the EUWP was not setup to be compliant with the LT2ESWTR, as the in-line turbidity meters were not tied to an automatic system shutdown if the turbidity level exceeded 0.15 NTU for any 15 minute period. The in-line turbidity data was logged onto a laptop computer, which was not connected to the EUWP for the purpose of shutting down the system. Also, it should be

noted that the in-line turbidity meters continued to operate during UF backwash periods, and thus, the spikes in turbidity have been caused by measurements of backwash water. The three instances during the test when turbidity exceeded 0.15 NTU for one 15 minute reading, the readings before and after the elevated reading were typically ten times lower, suggesting the single high turbidity readings were most likely due to a backwash occurring at the same time that the in-line turbidity unit reading was being recorded.

The RO system had little additional impact on the turbidity levels, with the RO permeate having a mean turbidity of 0.05 NTU, based on the grab samples collected each day. The in-line RO analyzer showed a mean turbidity of 0.013 NTU with a median of 0.012 NTU. The final treated water, the RO permeate, met the NPDWR turbidity requirements (<0.3 NTU 95% of the time and all values below 1.0 NTU), except for the first day of testing as noted above. Similar to the UF system, the RO system produced permeate with turbidity below the LT2ESWTR action level of 0.15 NTU throughout the test. There were only three single data points above the action level, and at no time were there two consecutive 15-minute readings above the 0.15 NTU action level.

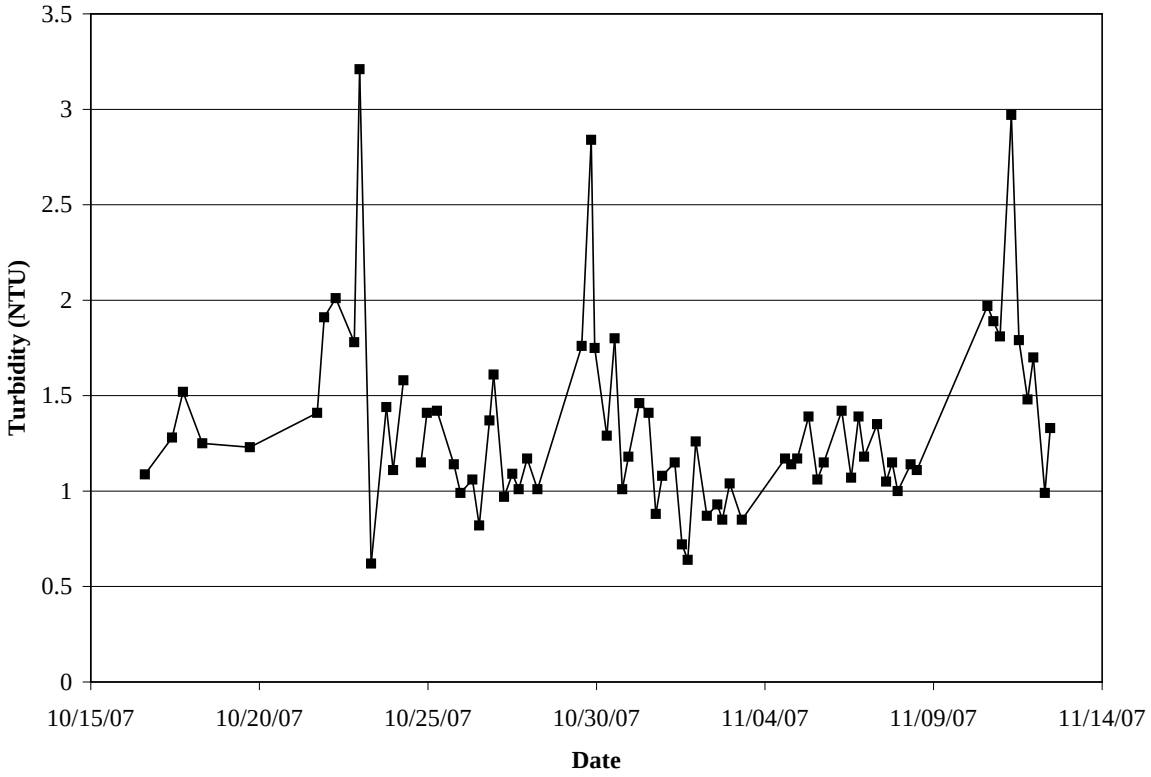


Figure 4-12. Grab sample UF feed turbidity data

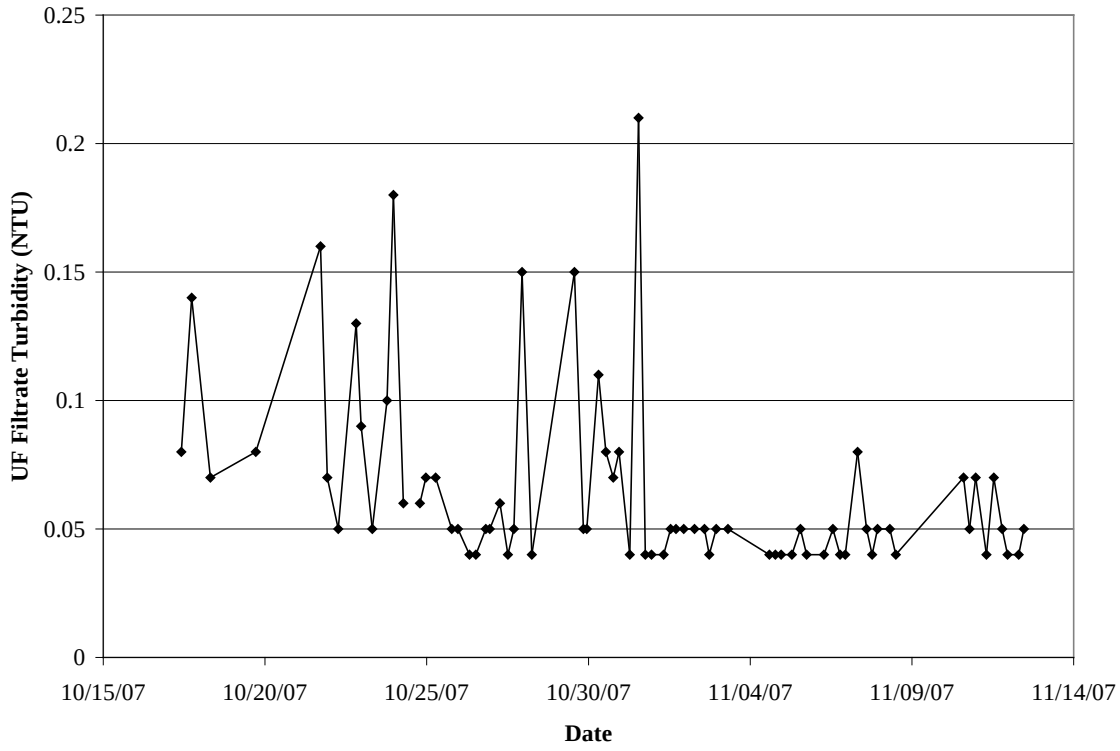


Figure 4-13. Grab sample UF filtrate turbidity data.

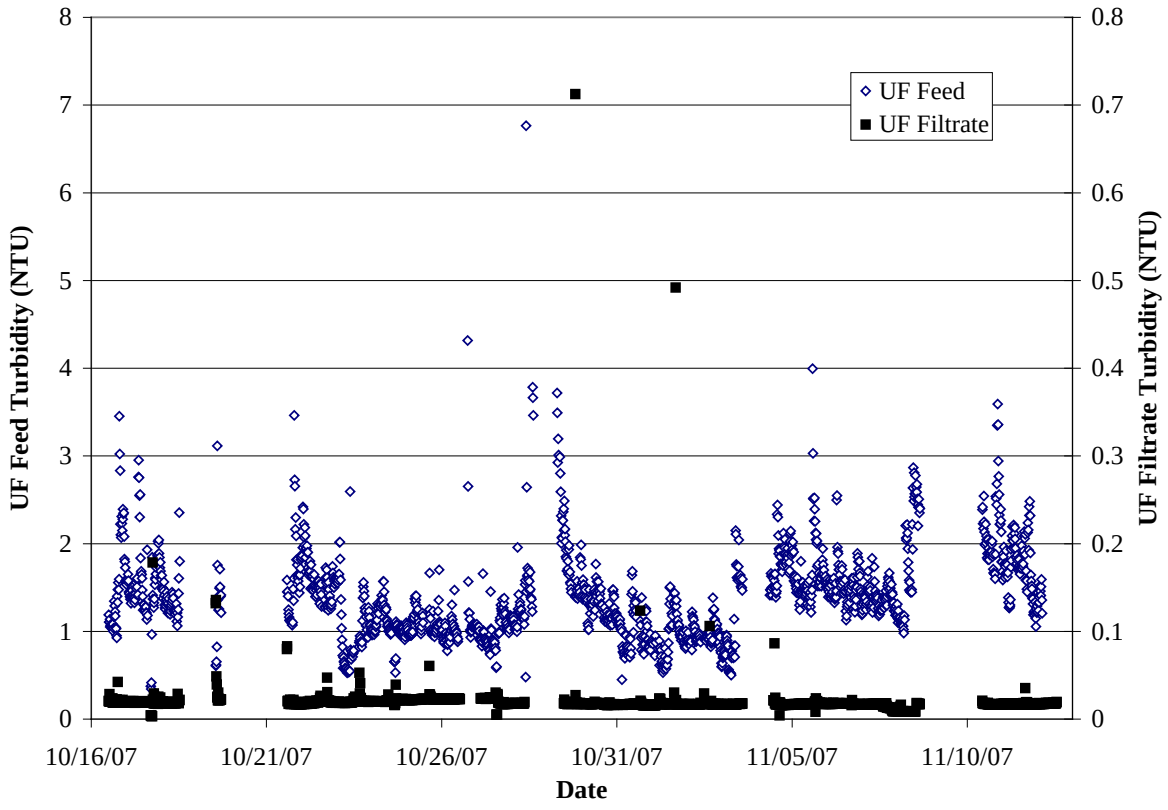


Figure 4-14. UF feed and UF filtrate in-line turbidity readings.

Table 4-8. Turbidity Results, On-Site Bench Top

Date	Raw Water (NTU)	UF Filtrate (NTU)	RO Feed (NTU)	RO Permeate (NTU)	RO Concentrate (NTU)	UF Turbidity Reduction (%)
10/17/07	1.28	0.08	0.05	0.24	1.58	93.8
10/17/07	1.52	0.14	0.10	0.05	0.88	90.8
10/18/07	1.25	0.07	0.03	0.04	0.09	94.4
10/19/07	1.23	0.08	0.12	0.06	0.34	93.5
10/21/07	1.41	0.16	0.05	0.04	1.13	88.7
10/21/07	1.91	0.07	0.12	0.05	0.16	96.3
10/22/07	2.01	0.05	0.06	0.06	0.55	97.5
10/22/07	1.78	0.13	0.05	0.04	0.12	92.7
10/22/07	3.21	0.09	0.06	0.04	0.77	97.2
10/23/07	0.62	0.05	0.05	0.06	0.18	91.9
10/23/07	1.44	0.10	0.06	0.05	0.15	93.1
10/23/07	1.11	0.18	0.05	0.07	0.08	83.8
10/24/07	1.58	0.06	0.06	0.05	0.06	96.2
10/24/07	1.15	0.06	0.07	0.04	0.08	94.8
10/24/07	1.41	0.07	0.05	0.04	0.05	95.0
10/25/07	1.42	0.07	0.05	0.04	0.19	95.1
10/25/07	1.14	0.05	0.05	0.04	0.06	95.6
10/25/07	0.99	0.05	0.05	0.05	0.10	94.9
10/26/07	1.06	0.04	0.04	0.04	0.06	96.2
10/26/07	0.82	0.04	0.07	0.06	0.07	95.1
10/26/07	1.37	0.05	0.15	0.04	0.31	96.4
10/26/07	1.61	0.05	0.04	0.04	0.18	96.9
10/27/07	0.97	0.06	0.04	0.04	0.12	93.8
10/27/07	1.09	0.04	0.07	0.06	0.05	96.3
10/27/07	1.01	0.05	0.04	0.04	0.17	95.0
10/27/07	1.17	0.15	0.04	0.04	0.06	87.2
10/28/07	1.01	0.04	0.04	0.04	0.05	96.0
10/29/07	1.76	0.15	0.05	0.01	0.04	91.5
10/29/07	2.84	0.05	0.04	0.04	1.01	98.2
10/29/07	1.75	0.05	0.04	0.04	0.83	97.1
10/30/07	1.29	0.11	0.04	0.06	0.06	91.5
10/30/07	1.80	0.08	0.06	0.06	0.13	95.6
10/30/07	1.01	0.07	0.05	0.04	0.42	93.1
10/30/07	1.18	0.08	0.05	0.05	0.90	93.2
10/31/07	1.46	0.04	0.04	0.05	0.05	97.3
10/31/07	1.41	0.21	0.17	0.06	0.56	85.1
10/31/07	0.88	0.04	0.06	NR	0.07	95.5
10/31/07	1.08	0.04	0.04	0.04	0.05	96.3
11/01/07	1.15	0.04	0.05	0.04	0.07	96.5
11/01/07	0.72	0.05	0.05	0.04	0.05	93.1
11/01/07	0.64	0.05	0.04	0.04	0.06	92.2
11/01/07	1.26	0.05	0.04	0.04	0.05	96.0
11/02/07	0.87	0.05	0.04	0.04	0.13	94.3
11/02/07	0.93	0.05	0.05	0.04	0.08	94.6
11/02/07	0.85	0.04	0.05	0.04	0.05	95.3
11/02/07	1.04	0.05	0.04	0.04	0.04	95.2

Table 4-8 Turbidity Results, On-Site Bench Top (continued)

Date	Raw Water (NTU)	UF Filtrate (NTU)	RO Feed (NTU)	RO Permeate (NTU)	RO Concentrate (NTU)	UF Turbidity Reduction (%)
11/03/07	0.85	0.05	0.05	0.04	0.13	94.1
11/04/07	1.17	0.04	0.05	0.01	0.05	96.6
11/04/07	1.14	0.04	0.05	0.04	0.04	96.5
11/04/07	1.17	0.04	0.04	0.03	0.05	96.6
11/05/07	1.39	0.04	0.04	0.04	0.04	97.1
11/05/07	1.06	0.05	0.06	0.04	0.06	95.3
11/05/07	1.15	0.04	0.04	0.03	0.05	96.5
11/06/07	1.42	0.04	0.05	0.04	0.04	97.2
11/06/07	1.07	0.05	0.05	0.04	0.05	95.3
11/06/07	1.39	0.04	0.04	0.03	0.05	97.1
11/06/07	1.18	0.04	0.04	0.03	0.05	96.6
11/07/07	1.35	0.08	0.06	0.06	0.32	94.1
11/07/07	1.05	0.05	0.04	0.04	0.04	95.2
11/07/07	1.15	0.04	0.04	0.04	0.05	96.5
11/07/07	1.00	0.05	0.04	0.03	0.04	95.0
11/08/07	1.14	0.05	0.04	0.04	0.13	95.6
11/08/07	1.11	0.04	0.05	0.04	0.07	96.4
11/10/07	1.97	0.07	0.02	0.04	0.06	96.4
11/10/07	1.89	0.05	0.05	0.05	0.05	97.4
11/10/07	1.81	0.07	0.05	0.05	0.06	96.1
11/11/07	2.97	0.04	0.04	0.04	0.05	98.7
11/11/07	1.79	0.07	0.04	0.04	0.05	96.1
11/11/07	1.48	0.05	0.04	0.04	0.06	96.6
11/11/07	1.70	0.04	0.04	0.05	0.04	97.6
11/12/07	0.99	0.04	0.05	0.04	0.05	96.0
11/12/07	1.33	0.05	0.02	0.04	0.05	96.2
Mean:	1.34	0.06	0.05	0.05	0.19	94.9
Median:	1.18	0.05	0.05	0.04	0.06	95.6
Minimum:	0.62	0.04	0.02	0.01	0.04	83.8
Maximum:	3.21	0.21	0.17	0.24	1.58	98.7
Count:	72	72	72	71	72	72
Std. Dev.:	0.48	0.04	0.02	0.03	0.30	2.73
95% CI:	0.11	0.01	0.01	0.01	0.07	0.63

Table 4-9. In-Line Turbidity Measurement Statistics

	Raw Water (NTU)	UF Filtrate (NTU)	RO Permeate (NTU)
Mean	1.38	0.019	0.013
Median	1.26	0.018	0.012
Minimum	0.34	0.003	0.001
Maximum	6.76	0.712	0.333
Count	1835	1807	1854
Std. Dev.	0.50	0.021	0.012
95% CI	±0.02	±0.001	±0.0005

The conductivity of the process streams was measured daily through bench-top analysis. In addition, an in-line conductivity meter continuously monitored the RO permeate stream, and a data logger recorded measurements once per hour through the test. Table 4-10 shows the bench-top conductivity measurement data and summary statistics for the UF and RO systems. Note that the RO permeate data is in units of microSiemens per centimeter (µS/cm), while the data for the rest of the process streams is in units of milliSiemens per centimeter (mS/cm). Figure 4-15 graphically presents the bench-top conductivity measurements for the RO process streams over the duration of the test. Figure 4-16 shows the in-line meter RO permeate conductivity measurements captured by the data logger. The in-line meter conductivity data can be found in Appendix D. The mean conductivity in the RO permeate, as measured by the bench-top conductivity meter, was 592 µS/cm. The mean conductivity of the RO feed was 51,380 µS/cm. The mean RO permeate conductivity for the hourly data logger measurements was 587 µS/cm. The RO unit reduced the conductivity by a mean value of 98.9%. The direct measurement of TDS, presented in Table 4-13, shows that the TDS concentration in the RO permeate was in the 280 to 300 mg/L range compared to the feed in the 34,000 to 39,000 mg/L range. These numbers translate to TDS reduction of approximately 99% or greater.

Table 4-10. Conductivity Results, On-Site Benchtop

Date	Raw Water (mS/cm)	UF Filtrate (mS/cm)	RO Feed (mS/cm)	RO Permeate (µS/cm)	RO Concentrate (mS/cm)	RO % Conductivity Red.
10/16/07	52.91	53.05	53.00	642.0	90.72	98.8
10/17/07	NR	NR	50.80	602.0	34.61	98.8
10/17/07	1.49	3.07	50.88	625.7	87.90	98.8
10/18/07	NR	NR	51.03	571.6	87.76	98.9
10/19/07	52.66	52.68	52.69	619.9	89.23	98.8
10/21/07	51.74	51.78	51.77	585.6	88.28	98.9
10/21/07	51.82	51.88	51.80	565.9	88.25	98.9
10/22/07	52.81	52.62	52.60	552.8	89.67	98.9
10/22/07	50.41	50.70	50.66	558.5	86.37	98.9
10/22/07	50.56	50.72	50.84	549.4	86.57	98.9
10/23/07	53.89	53.68	53.33	588.3	90.48	98.9
10/23/07	50.84	50.78	50.79	576.0	86.65	98.9
10/23/07	50.78	50.68	50.76	583.2	86.36	98.9
10/24/07	53.67	53.43	53.49	561.5	90.55	99.0
10/24/07	50.83	50.77	50.85	595.0	86.64	98.8
10/24/07	50.78	50.66	50.72	599.5	86.46	98.8
10/25/07	51.27	51.54	51.46	565.6	87.31	98.9
10/25/07	51.08	51.23	51.21	590.3	87.79	98.8
10/25/07	51.08	51.16	51.23	579.9	87.56	98.9
10/26/07	51.22	51.36	51.38	556.3	87.82	98.9
10/26/07	50.99	51.20	51.20	576.6	87.69	98.9
10/26/07	51.28	51.28	51.30	619.3	88.16	98.8
10/26/07	51.10	51.25	51.31	614.9	87.03	98.8
10/27/07	51.12	51.28	51.32	618.6	88.03	98.8

Table 4-10. Conductivity Results, On-Site Benchtop (continued)

Date	Raw Water (mS/cm)	UF Filtrate (mS/cm)	RO Feed (mS/cm)	RO Permeate (µS/cm)	RO Concentrate (mS/cm)	RO Conductivity Reduction (%)
10/27/07	50.92	51.16	51.15	608.3	87.67	98.8
10/27/07	50.87	51.17	51.21	656.3	87.71	98.7
10/27/07	50.91	51.22	51.28	612.4	88.15	98.8
10/28/07	51.16	51.29	51.31	602.1	87.98	98.8
10/29/07	50.53	50.15	50.50	639.5	85.41	98.7
10/29/07	51.04	51.18	51.26	619.6	87.90	98.8
10/29/07	51.20	51.02	51.27	603.1	87.82	98.8
10/30/07	51.26	51.32	51.33	587.1	87.86	98.9
10/30/07	50.63	50.94	51.00	597.7	87.37	98.8
10/30/07	50.80	51.23	51.28	608.9	87.92	98.8
10/30/07	50.86	51.20	51.25	592.5	87.79	98.8
10/31/07	51.27	51.29	51.31	570.6	87.92	98.9
10/31/07	50.37	50.75	50.66	586.1	87.27	98.8
10/31/07	50.96	51.25	51.30	611.7	87.89	98.8
10/31/07	50.92	51.23	51.30	610.0	88.03	98.8
11/01/07	51.22	51.33	51.36	615.9	87.88	98.8
11/01/07	51.23	50.99	51.33	628.7	87.75	98.8
11/01/07	51.07	51.37	51.41	641.5	88.03	98.8
11/01/07	51.37	51.41	51.27	628.6	88.08	98.8
11/02/07	51.40	51.33	51.46	609.4	87.79	98.8
11/02/07	50.91	51.17	51.27	630.4	87.78	98.8
11/02/07	51.06	51.33	51.41	640.9	88.04	98.8
11/02/07	51.30	51.40	51.46	760.1	88.34	98.5
11/03/07	51.35	51.24	51.40	603.3	88.08	98.8
11/04/07	51.24	51.11	51.32	627.7	87.84	98.8
11/04/07	51.14	51.40	51.43	612.0	88.15	98.8
11/04/07	51.17	51.41	51.44	604.3	88.02	98.8
11/05/07	51.40	51.33	51.45	591.2	88.11	98.9
11/05/07	51.00	51.32	51.39	596.4	88.08	98.8
11/05/07	51.21	51.39	51.45	601.1	88.25	98.8
11/06/07	51.37	51.45	51.47	570.1	88.17	98.9
11/06/07	51.15	51.30	51.34	579.3	87.85	98.9
11/06/07	51.25	51.37	51.40	578.5	88.06	98.9
11/06/07	51.21	51.37	51.40	572.2	88.12	98.9
11/07/07	51.19	51.32	51.40	555.1	87.96	98.9
11/07/07	51.14	51.36	51.38	563.7	87.99	98.9
11/07/07	51.17	51.39	51.41	560.6	87.93	98.9
11/07/07	51.21	51.39	51.42	557.6	88.03	98.9
11/08/07	51.17	51.28	51.33	544.6	88.13	98.9
11/08/07	51.05	51.35	51.37	546.3	87.97	98.9
11/10/07	50.97	51.21	51.15	569.4	87.55	98.9
11/10/07	51.13	51.31	51.25	554.8	87.93	98.9

Table 4-10. Conductivity Results, On-Site Benchtop (continued)

Date	Raw Water (mS/cm)	UF Filtrate (mS/cm)	RO Feed (mS/cm)	RO Permeate (µS/cm)	RO Concentrate (mS/cm)	RO Conductivity Reduction (%)
11/10/07	51.23	51.31	51.36	547.7	87.82	98.9
11/11/07	51.41	51.45	51.49	534.3	87.73	99.0
11/11/07	51.23	51.24	51.19	547.6	87.56	98.9
11/11/07	51.23	51.24	51.28	553.8	87.63	98.9
11/11/07	51.16	51.18	51.41	545.3	87.63	98.9
11/12/07	51.54	51.55	51.49	559.1	87.92	98.9
11/12/07	51.19	51.34	51.35	577.2	87.96	98.9
Mean:	50.55	50.68	51.38	592.0	87.16	98.9
Median:	51.17	51.29	51.33	590.3	87.90	98.9
Minimum:	1.49	3.07	50.50	534.3	34.61	98.5
Maximum:	53.89	53.68	53.49	760.1	90.72	99.0
Count:	71	71	73	73	73	73
Std. Dev.:	5.94	5.76	0.52	35.27	6.29	0.07
95% CI:	1.38	1.34	0.12	8.09	1.44	0.02

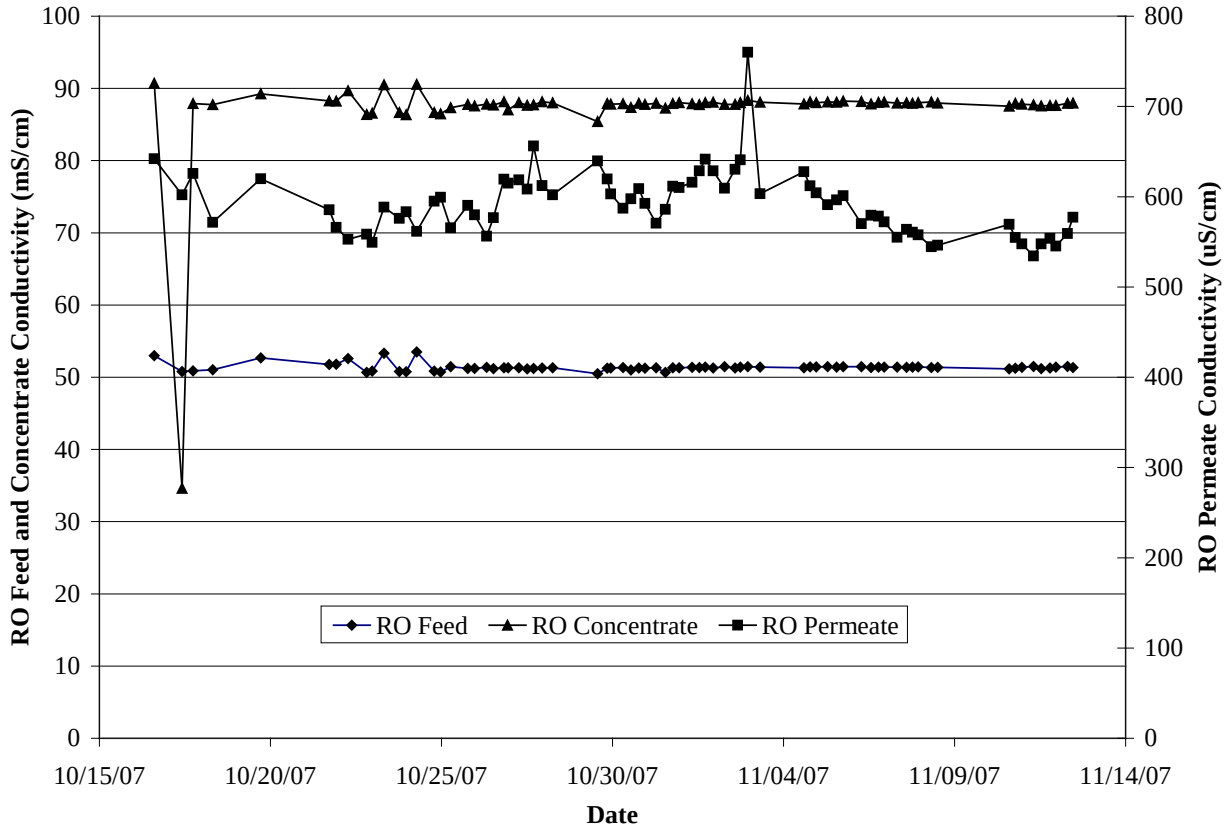


Figure 4-15. RO conductivity results.

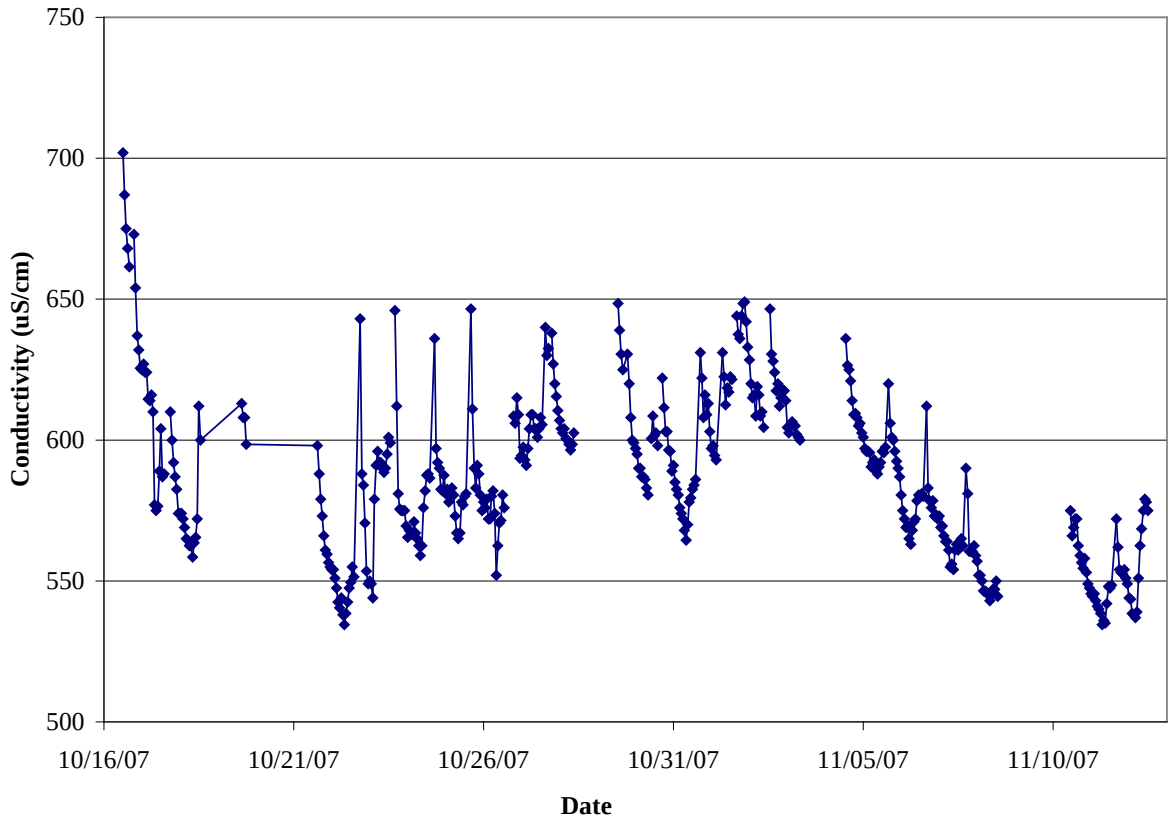


Figure 4-16. RO permeate conductivity readings from in-line meter.

Tables 4-11 and 4-12 present the pH and temperature data collected from the UF and RO systems. The UF system had no impact on the pH of the water with the feed having a mean pH of 7.78 (median 7.79) and the filtrate having a mean pH of 7.73 (median 7.73). RO treatment did lower the pH of the treated water. The pH of the RO permeate ranged from 6.11 to 6.49 with a mean of 6.29 (median 6.35). Note that there are only five reported pH values for the RO permeate. For most of the test, pH measurements were made using a Myron L Ultrameter II Model 6P, including RO permeate samples. However, this meter always reported the permeate pH in the 8.0 to 8.5 range, which is highly unlikely for an RO permeate stream due to the loss of dissolved ions. After a field technician realized that the RO permeate pH measurements were too high, the FTO began using an Accumet Model 50 meter to measure the RO permeate. This meter gave pH measurements in the expected range of 6.0 to 6.5. Only the five Accumet meter measurements are reported in Table 4-11. It is not known why the Ultrameter II 6P meter did not accurately measure the RO permeate pH. The meter was calibrated correctly every day at three points using buffers of pH 4, 7, and 10. Also, the Ultrameter's results for the other process streams agreed with confirmatory measurements made with the Accumet meter.

The UF and RO system had only a slight effect on the temperature of the water as it passed through the systems. Water temperature in the ocean feed at the beginning of the test was in the 12.8 °C to 16.2 °C range with a mean of 14.8 °C. The mean temperature of the RO permeate was 15.7 °C with a range of 13.3 °C to 17.0 °C. Temperature variation and impact on membrane

operating production (flux and specific flux) were accounted for in the operating section by adjusting the data to either 20 °C or 25 °C, as described in Sections 4.5.1.1.3 and 4.5.1.2.3, the temperature data in Table 4-12 served as the basis for the temperature adjustment calculations.

Table 4-11. pH Results

Date	Raw Water	UF Filtrate	RO Feed at Strainer	RO Permeate	RO Concentrate
10/16/07	7.76	7.81	7.40	NM	7.42
10/17/07	7.63	7.66	7.47	NM	7.25
10/17/07	7.50	7.69	7.72	NM	7.44
10/18/07	7.73	7.55	7.59	NM	7.25
10/19/07	7.87	7.83	7.75	NM	7.44
10/21/07	7.59	7.72	7.65	NM	7.37
10/21/07	7.79	7.74	7.61	NM	7.35
10/22/07	7.67	7.64	7.66	NM	7.36
10/22/07	7.68	7.71	7.60	NM	7.41
10/22/07	7.71	7.62	7.64	NM	7.32
10/23/07	7.86	7.79	7.80	NM	7.57
10/23/07	7.74	7.68	7.73	NM	7.36
10/23/07	7.80	7.73	7.71	NM	7.40
10/24/07	7.73	7.76	7.71	NM	7.41
10/24/07	7.78	7.72	7.71	NM	7.36
10/24/07	7.68	7.67	7.69	NM	7.39
10/25/07	7.79	7.72	7.73	NM	7.48
10/25/07	7.79	7.76	7.72	NM	7.43
10/25/07	7.81	7.74	7.76	NM	7.42
10/26/07	7.77	7.71	7.70	NM	7.47
10/26/07	7.78	7.70	7.73	NM	7.43
10/26/07	7.83	7.69	7.73	NM	7.41
10/26/07	7.82	7.76	7.76	NM	7.41
10/27/07	7.86	7.80	7.81	NM	7.54
10/27/07	7.75	7.75	7.75	NM	7.46
10/27/07	7.79	7.75	7.75	NM	7.43
10/27/07	7.79	7.74	7.73	NM	7.47
10/28/07	7.81	7.76	7.75	NM	7.47
10/29/07	7.80	7.72	7.73	6.35	7.43
10/29/07	7.82	7.78	7.78	NM	7.46
10/30/07	7.86	7.76	7.75	6.11	7.45
10/30/07	7.73	7.71	7.70	NM	7.43
10/30/07	7.79	7.75	7.74	NM	7.43
10/30/07	7.78	7.73	7.73	NM	7.49
10/31/07	7.79	7.73	7.70	NM	7.45
10/31/07	7.94	7.86	7.80	NM	7.52
10/31/07	7.71	7.69	7.68	NM	7.36
10/31/07	7.37	7.64	7.65	NM	7.34
11/01/07	7.76	7.69	7.67	6.49	7.39
11/01/07	7.84	7.70	7.76	6.14	7.45

Table 4-11. pH Results (continued)

Date	Raw Water	UF Filtrate	RO Feed at Strainer	RO Permeate	RO Concentrate
11/01/07	7.85	7.80	7.78	NM	7.45
11/01/07	7.81	7.75	7.72	NM	7.43
11/02/07	7.87	7.76	7.76	NM	7.49
11/02/07	7.77	7.73	7.73	NM	7.44
11/02/07	7.76	7.75	7.74	NM	7.44
11/02/07	7.79	7.74	7.74	NM	7.43
11/03/07	7.79	7.67	7.67	NM	7.40
11/04/07	7.77	7.61	7.69	NM	7.38
11/04/07	7.68	7.68	7.67	NM	7.34
11/04/07	7.74	7.71	7.69	NM	7.38
11/05/07	7.89	7.81	7.77	NM	7.46
11/05/07	7.79	7.73	7.72	NM	7.43
11/05/07	7.94	7.85	7.82	NM	7.53
11/06/07	7.93	7.84	7.80	NM	7.49
11/06/07	7.77	7.69	7.72	NM	7.42
11/06/07	7.70	7.60	7.58	NM	7.29
11/06/07	7.84	7.72	7.68	NM	7.38
11/07/07	7.86	7.87	7.83	NM	7.54
11/07/07	7.73	7.66	7.65	NM	7.39
11/07/07	7.84	7.69	7.66	NM	7.39
11/07/07	7.73	7.64	7.62	NM	7.34
11/08/07	7.85	7.74	7.70	NM	7.40
11/08/07	7.73	7.63	7.61	NM	7.34
11/10/07	7.65	7.70	7.73	NM	7.39
11/10/07	7.81	7.74	7.69	NM	7.40
11/10/07	7.78	7.69	7.66	NM	7.34
11/11/07	7.78	7.72	7.69	6.35	7.40
11/11/07	7.71	7.78	7.80	NM	7.41
11/11/07	7.79	7.67	7.63	NM	7.32
11/11/07	7.79	7.60	7.69	NM	7.38
11/12/07	7.91	7.82	7.82	NM	7.55
11/12/07	7.85	7.87	7.86	NM	7.57
Mean:	7.78	7.73	7.71	6.29	7.42
Median:	7.79	7.73	7.72	6.35	7.42
Minimum:	7.37	7.55	7.40	6.11	7.25
Maximum:	7.94	7.87	7.86	6.49	7.57
Count:	72	72	72	5	72
Std. Dev.:	0.09	0.07	0.08	NM	0.07
95% CI:	0.02	0.02	0.02	NM	0.02

Table 4-12. Temperature Results

Date	Raw Water (°C)	UF Filtrate (°C)	RO Feed (°C)	RO Permeate (°C)	RO Concentrate (°C)
10/16/07	14.4	15.5	16.4	16.0	16.9
10/17/07	13.9	14.1	14.7	15.2	16.1
10/17/07	14.2	14.0	14.0	14.7	15.8
10/18/07	13.1	13.4	13.3	14.1	15.0
10/19/07	14.1	14.1	14.3	15.3	16.1
10/21/07	13.1	13.3	13.5	14.2	15.2
10/21/07	13.0	13.2	13.5	14.1	15.1
10/22/07	12.8	13.0	13.1	13.7	14.7
10/22/07	13.3	13.4	13.7	14.2	15.3
10/22/07	13.1	13.4	13.5	14.1	15.0
10/23/07	14.4	14.6	14.8	15.5	16.5
10/23/07	14.0	14.4	14.3	14.9	15.8
10/23/07	13.9	14.2	14.3	14.9	15.9
10/24/07	13.8	13.8	13.9	14.6	15.7
10/24/07	14.3	14.8	14.8	15.4	16.3
10/24/07	14.3	14.6	14.7	13.3	16.2
10/25/07	14.0	14.1	14.2	14.9	15.9
10/25/07	14.7	14.7	14.7	15.3	16.3
10/25/07	14.4	14.6	14.6	15.2	16.2
10/26/07	13.8	13.9	14.1	14.8	15.7
10/26/07	14.7	14.8	14.9	15.6	16.6
10/26/07	15.4	15.4	15.4	15.9	16.8
10/26/07	14.9	15.0	15.1	15.7	16.6
10/27/07	15.5	15.6	15.7	16.4	17.3
10/27/07	15.6	15.7	15.7	15.5	17.3
10/27/07	16.0	15.9	16.2	16.7	17.7
10/27/07	15.5	15.5	15.6	16.2	17.1
10/28/07	15.3	15.4	15.4	16.3	17.0
10/29/07	15.2	16.0	15.8	16.4	17.4
10/29/07	15.1	14.9	15.2	15.8	16.8
10/29/07	15.0	15.0	15.1	15.8	16.6
10/30/07	14.9	14.8	15.0	15.6	16.6
10/30/07	15.2	15.3	15.6	16.2	17.2
10/30/07	15.5	15.3	15.4	16.1	17.0
10/30/07	15.1	15.2	15.3	15.9	16.8
10/31/07	14.6	14.7	14.9	15.5	16.4
10/31/07	15.5	15.7	16.2	16.6	17.6
10/31/07	15.4	15.5	15.7	16.3	17.2
10/31/07	15.4	15.3	15.3	15.3	16.9
11/01/07	15.4	15.5	15.7	16.3	17.3
11/01/07	15.8	16.1	16.1	16.8	17.7
11/01/07	16.2	16.3	16.3	17.0	17.9

Table 4-12. Temperature Results (continued)

Date	Raw Water (°C)	UF Filtrate (°C)	RO Feed (°C)	RO Permeate (°C)	RO Concentrate (°C)
11/01/07	16.1	16.2	16.4	17.0	17.9
11/02/07	15.9	16.1	16.1	16.8	17.7
11/02/07	16.1	16.1	16.3	17.0	18.0
11/02/07	16.2	16.1	16.2	16.9	17.8
11/02/07	16.0	16.0	16.2	16.7	17.6
11/03/07	15.9	16.1	16.1	16.7	17.7
11/04/07	15.8	15.9	16.0	16.7	17.6
11/04/07	15.8	15.8	15.9	16.6	17.5
11/04/07	15.8	15.8	15.8	16.5	17.4
11/05/07	15.5	15.7	15.7	16.4	17.3
11/05/07	15.8	15.9	16.0	16.6	17.6
11/05/07	15.7	15.7	15.8	16.4	17.4
11/06/07	15.1	15.1	15.3	16.0	16.9
11/06/07	15.5	15.6	15.8	16.4	17.4
11/06/07	15.0	15.1	15.2	15.8	16.8
11/06/07	15.1	15.1	15.2	15.8	16.8
11/07/07	14.8	14.9	15.0	15.6	16.5
11/07/07	15.0	15.1	15.2	15.9	16.9
11/07/07	14.6	14.6	14.7	15.3	16.3
11/07/07	14.7	14.7	14.8	15.5	16.4
11/08/07	14.5	14.5	14.7	15.3	16.3
11/08/07	14.6	14.6	14.8	15.5	16.4
11/10/07	14.4	14.7	15.0	15.7	16.5
11/10/07	14.2	14.2	14.3	15.0	15.9
11/10/07	14.0	14.1	14.1	14.9	15.8
11/11/07	13.6	13.7	13.9	14.6	15.5
11/11/07	14.3	14.6	14.6	15.2	16.3
11/11/07	14.1	14.1	14.2	14.8	15.8
11/11/07	14.0	14.0	14.2	14.8	15.8
11/12/07	14.5	14.5	14.6	15.4	16.2
11/12/07	14.8	15.2	15.4	16.6	17.0
Mean:	14.8	14.9	15.1	15.7	16.6
Median:	14.9	15.0	15.1	15.7	16.6
Minimum:	12.8	13.0	13.1	13.3	14.7
Maximum:	16.2	16.3	16.4	17.0	18.0
Count:	73	73	73	73	73
Std. Dev.:	0.86	0.84	0.84	0.87	0.80
95% CI:	0.20	0.19	0.19	0.20	0.18

4.5.3.2 Water Quality Results – Other Water Quality Parameters

Table 4-13 presents the other water quality data collected on a weekly basis during the verification test. For an unknown reason, the suspended solids levels in the UF filtrate were higher than expected. The TSS reduction through the UF skid was only 1-5 mg/L, with one set of measurements when the TSS was actually higher in the filtrate compared to the feed. These data are in conflict with the daily turbidity results, which show 95% reduction in turbidity (Table 4-9) and a low turbidity in the UF filtrate (mean of 0.5 NTU). The UF system was definitely retaining suspended solids, as evidenced by the TMP increases and four UF cleanings that were required during the test run. Also, the steady operation of the RO system indicates that any suspended solids in the UF filtrate (the RO feed) did not impact RO operation.

The RO system reduced the TSS in the RO feed to less than detectible levels (<2.0 mg/L) in the RO permeate. While this good (and expected) from a final water quality perspective, if suspended solids are getting to the RO membranes, they can build up and eventually could cause a decrease in specific flux, and a membrane plugging issue. Membrane plugging did not occur during this test, as shown by the minimal change in RO specific flux.

The UF system did not impact the other water quality parameters, as would be expected. These other parameters, such as hardness, alkalinity, TDS, etc., primarily represent dissolved inorganic constituents that are not removed by UF.

The RO system did remove many of the dissolved inorganic species, as shown by the results in Table 4-13 for the RO permeate. Total dissolved solids were reduced by 99%, as was chloride. Sodium was reduced by 98%. These data are consistent with the conductivity data presented earlier, which shows a salt rejection/reduction through the RO of 98.9%. The other inorganic materials measured, such as hardness, alkalinity, metals, sulfate, and phosphorus were also reduced in the RO permeate. The RO concentrate increased in concentration for these parameters above the feed levels, as would be expected. The RO membranes, at these operating conditions, rejected the dissolved salts present in the feed throughout the test.

The TQAP called for calculating mass balances of sodium, calcium, magnesium, sulfate, carbonate, and chloride ions, and also total dissolved solids, to determine if significant scale formation occurred in the RO system. However, as described in Section 4.5.1.2.2, the Stiff and Davis Stability Index was calculated, and the RO feed was found to be non-scaling. Therefore, the mass balance exercise was not performed for this report.

Table 4-13. Other UF System Water Quality Data

	TSS (mg/L)					
Date	Raw Water	UF Filtrate	UF Retentate	RO Feed	RO Permeate	RO Concentrate
10/17/07	7	5	10	5	ND (2)	8
10/24/07	5	4	7	4	ND (2)	10
10/30/07	9	7	10	5	ND (2)	7
11/05/07	6	7	11	7	ND (2)	9
11/12/07	8	3	9	4	ND (2)	9

ND – not detected (detection limit)

	TDS (mg/L)				
Date	Raw Water	UF Retentate	UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/16/07	35000	NM(1)	NM	340	67000
10/17/07	NM	34000	39000	300	67000
10/18/07	35000	NM	NM	290	67000
10/22/07	35000	NM	NM	260	67000
10/23/07	35000	NM	NM	280	67000
10/24/07	33000	36000	33000	280	67000
10/25/07	38000	NM	NM	280	66000
10/29/07	35000	NM	NM	330	66000
10/30/07	34000	34000	33000	300	64000
10/31/07	34000	NM	NM	280	65000
11/01/07	34000	NM	NM	300	64000
11/05/07	33000	33000	34000	290	65000
11/06/07	34000	NM	NM	280	65000
11/07/07	34000	NM	NM	270	65000
11/08/07	34000	NM	NM	270	66000
11/12/07	NM	34000	34000	NM	NM

(1) Note that as listed in Table 3-4, samples of the UF feed, RO permeate, and RO concentrate streams were collected for TDS analysis on most days of the test, for the purpose of establishing the conductivity to TDS correlation discussed in Section 4.5.1.2.3.
NM – not measured

	Hardness (mg/L as $CaCO_3$)			
Date	Raw Water	UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	6200	7200	4	12000
10/24/07	6500	6500	3	12000
10/30/07	5400	6000	4	11000
11/05/07	5800	5600	3	11000
11/12/07	5500	5500	3	11000

	Alkalinity (mg/L as $CaCO_3$)			
Date	Raw Water	UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	110	110	ND (5)	200
10/24/07	110	110	ND (5)	200
10/30/07	110	110	ND (5)	200
11/05/07	110	110	ND (5)	220
11/12/07	110	120	ND (5)	220

Table 4-13. Other UF System Water Quality Data (continued)

Date	Raw Water	Chloride (mg/L) UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	27000	21000	180	44000
10/24/07	20000	26000	180	41000
10/30/07	20000	21000	170	42000
11/05/07	20000	21000	180	39000
11/12/07	20000	20000	170	42000

Date	Raw Water	Sulfate (mg/L) UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	2600	2800	1.7	5100
10/24/07	2800	2800	1.6	5100
10/30/07	2700	2800	1.9	5000
11/05/07	2600	2700	1.6	5100
11/12/07	2700	2700	1.4	5000

Date	Raw Water	Calcium (mg/L) UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	380	440	0.24	750
10/24/07	410	410	0.21	740
10/30/07	340	380	0.26	730
11/05/07	360	370	0.21	680
11/12/07	360	350	0.19	690

Date	Raw Water	Magnesium (mg/L) UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	1300	1500	0.72	2500
10/24/07	1300	1300	0.58	2400
10/30/07	1100	1200	0.88	2300
11/05/07	1200	1100	0.71	2200
11/12/07	1100	1100	0.63	2200

Date	Raw Water	Sodium (mg/L) UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	9300	9900	110	19000
10/24/07	11000	11000	100	20000
10/30/07	10000	10000	110	19000
11/05/07	10000	11000	120	19000
11/12/07	10000	10000	110	19000

Date	Raw Water	Potassium (mg/L) UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	380	400	3.9	780
10/24/07	450	430	4.0	800
10/30/07	290	340	4.1	710
11/05/07	430	290	4.0	610
11/12/07	370	400	11.0	910

Table 4-13. Other UF System Water Quality Data (continued)

Lithium (mg/L)				
Date	Raw Water	UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	0.002	0.110	0.009	0.036
10/24/07	0.011	0.041	0.009	0.140
10/30/07	0.160	0.150	0.002	0.300
11/05/07	0.180	0.180	0.003	0.370
11/12/07	0.190	0.170	0.003	0.290

Boron (mg/L)				
Date	Raw Water	UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	6.2	6.0	1.0	9.4
10/24/07	6.6	6.3	1.1	9.2
10/30/07	4.2	4.9	1.2	7.9
11/05/07	4.6	4.5	1.1	7.6
11/12/07	4.9	5.1	1.5	8.4

Total Phosphorus (mg/L)				
Date	Raw Water	UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	ND (0.05)	ND (0.05)	ND (0.05)	0.16
10/24/07	0.05	0.38	ND (0.05)	0.46
10/30/07	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
11/05/07	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)
11/12/07	ND (1.0)	ND (1.0)	ND (1.0)	ND (1.0)

UV_{254} Absorbance				
Date	Raw Water	UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	0.0086	0.0029	ND (0)	0.0131
10/24/07	0.0478	0.0120	ND (0)	0.0073
10/30/07	0.0115	0.0076	ND (0)	0.0057
11/05/07	0.0166	0.0086	0.012	0.0333
11/12/07	0.0122	ND (0)	0.015	0.0092

Ortho-Phosphate (mg/L)[(1)]				
Date	Raw Water	UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	ND (0.02)	ND (0.02)	ND (0.02)	ND (0.02)
10/24/07	0.02	ND (0.02)	ND (0.02)	0.03

(1) Note that this parameter was dropped from the sampling plan after the first two weeks of the test, due to the less than detectible levels.

Barium (mg/L)[(1)]				
Date	Raw Water	UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	0.003	0.003	ND (0.001)	0.004
10/24/07	0.002	0.003	ND (0.001)	0.004

(1) Note that this parameter was dropped from the sampling plan after the first two weeks of the test, due to low and less than detectible levels.

Table 4-13. Other UF System Water Quality Data (continued)

	Selenium (mg/L)[1]			
Date	Raw Water	UF Filtrate/ RO Feed	RO Permeate	RO Concentrate
10/17/07	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)
10/24/07	ND (0.020)	ND (0.020)	ND (0.020)	ND (0.020)

(1) Note that this parameter was dropped from the sampling plan after the first two weeks of the test, due to the less than detectible levels.

	Stiff and Davis Stability Index			
Date	RO Concentrate pH	RO Concentrate pH	S&DSI Calculation[1]	S&DSI Nomagraph[2]
10/17/07	7.60	8.43	-0.83	-0.14
10/24/07	7.66	8.39	-0.73	-0.09
10/30/07	7.62	8.46	-0.84	-0.13
11/05/07	7.66	8.37	-0.71	0.08
11/12/07	7.70	8.44	-0.74	0.04

(1) Calculations in column 3 use equations from ASTM D4582
(2) S&DSI based on interpolation of nomagraphs in ASTM D4582.

4.5.3.3 Total Organic Carbon Results for Cleaning Solution

Samples of the cleaning solutions from the UF system CIP were collected from two cleaning periods. These samples were analyzed for TOC to provide basic water quality information as required in the ETV test protocol. The TOC results for the UF system cleaning solution are presented in Table 4-14.

Samples of the RO cleaning solutions were also collected for TOC analyses. These results are also shown in Table 4-14. Note that the RO cleaning solutions had higher TOC levels than the UF cleaning solutions. This was most likely caused by the additives in the commercial RO cleaning product that was used at the site.

Table 4-14. Cleaning Solution TOC Results

Cleaning Solution	Date	TOC (mg/L)
Low pH UF solution	11/03/07	360
High pH UF solution	11/04/07	260
Low pH UF solution	11/09/07	600
High pH UF Solution	11/10/07	140
Low pH RO solution	11/13/07	2100
High pH RO solution	11/14/07	770

4.5.4 Task C4: Membrane Module Integrity

The objective of this task was to demonstrate the methodology for integrity testing of the UF and RO membranes and also to document system integrity. Pressure decay tests, microorganism removal, and particulate reduction were all used to document UF membrane integrity. *Bacillus* endospores and total coliforms were monitored to provide data on the microbial reduction

achieved by the UF and RO membranes. In-line analyzers also collected particle count data, as an additional measurement/indicator of membrane integrity and the capability of the system to remove particulate and microbial contaminants.

As discussed in Section 4.4, the initial UF pressure decay test on September 27, 2007 showed that pressure was being lost from the system at a higher than desirable rate. The problem was investigated, and one UF cartridge was found to have a broken fiber, which was repaired. On October 9, each cartridge was tested individually. One additional cartridge was found to have a broken fiber and it was also repaired. As shown in Table 4-3, the final UF integrity test on October 11 before the verification test started showed an acceptable pressure decay rate. Subsequently, the UF system was tested on a frequent basis during the verification test. The results of those tests are presented in this section. The *Bacillus* endospore, total coliform, and particle count data are also presented.

The RO system was not dye tested during this verification test. The continuous conductivity measurements and microbial data were used as the indicator that the RO membranes were operating properly.

4.5.4.1 UF System Pressure Decay Results

Pressure decay tests on the UF system were performed on most operating days during the verification test. Table 4-15 presents the pressure decay data from the verification test. Data was actually collected every minute during the pressure decay tests, but has been summarized into 2-minute increments for ease of presentation. Figure 4-16 shows the pressure decay results on a minute-by-minute basis in graphical format.

As shown in Table 4-15, the mean pressure decay rate on a daily basis ranged from 0.02 to 0.15 psig/min. The overall mean pressure decay rate was 0.08 psig/min. After the initial membrane breaks found before the start of the test, there was no indication of any further problems with membrane integrity, based on these pressure decay rate results.

Most of the pressure decay rates measured during this verification test were lower than those measured during ETV laboratory tests on two UF cartridges from the sister EUWP unit to the one tested for this verification (see ETV report *Removal of Microbial Contaminants in Drinking Water, Koch Membrane Systems, Inc. Targa® 10-48-35-PMC™ Ultrafiltration Membrane, as Used in the Village Marine Tec. Expeditionary Unit Water Purifier*). Each of the two cartridges underwent four pressure decay tests over the course of lab testing activities. Cartridge 1 had decay rates of 0.35, 0.74, 0.6 and 0.4 psig/min, while Cartridge 2 had decay rates of 0.09, 0.1, 0.25, and 0.2 psig/min. These two cartridges had pressure decay rates ranging from 0.09 to 0.74 psig/min over four separate pressure decay tests per cartridge. These two cartridges were challenged with *Cryptosporidium parvum* oocysts, and removed greater than 4 $\log_{10}$.

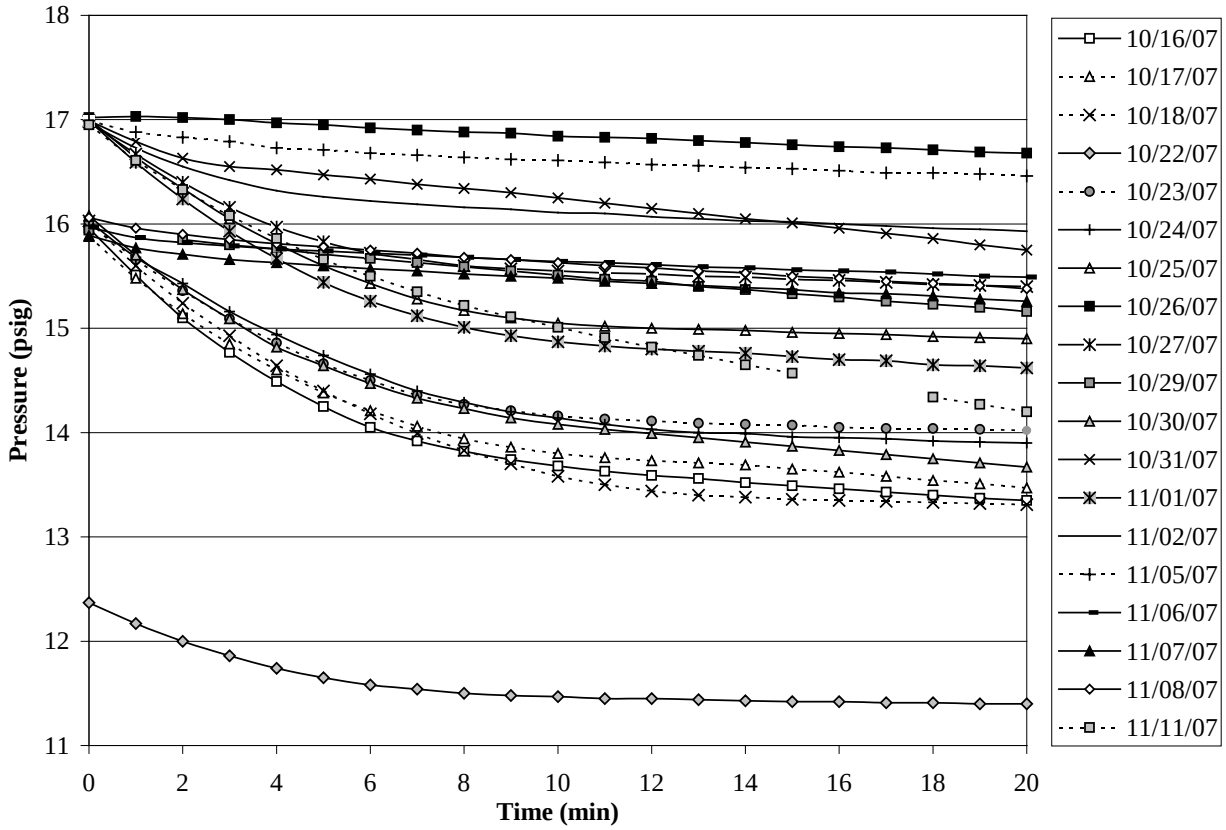


Figure 4-16. Pressure decay over time.

Table 4-15. Pressure Decay Data

Date	Pressure Readings (psig) 0 Min	2 Min	4 Min	6 Min	8 Min	10 Min	12 Min	14 Min	16 Min	18 Min	20 Min	Mean Decay Rate (psig/min)
10/16/07	15.96	15.10	14.49	14.05	13.82	13.68	13.59	13.52	13.46	13.40	13.35	0.13
10/17/07	15.88	15.14	14.60	14.21	13.94	13.80	13.73	13.69	13.62	13.54	13.47	0.12
10/18/07	16.03	15.24	14.64	14.18	13.83	13.58	13.44	13.38	13.35	13.33	13.31	0.14
10/22/07	12.37	12.00	11.74	11.58	11.50	11.47	11.45	11.43	11.42	11.41	11.40	0.05
10/23/07	16.02	15.36	14.86	14.50	14.27	14.16	14.11	14.08	14.05	14.04	14.02	0.10
10/24/07	16.03	15.43	14.94	NM	14.29	14.14	14.03	13.99	13.95	13.92	13.90	0.11
10/25/07	17.01	16.34	15.81	15.43	15.17	15.05	15.00	14.98	14.95	14.92	14.90	0.11
10/26/07	17.02	17.02	16.97	16.92	16.88	16.84	16.82	16.78	16.74	16.71	16.68	0.02
10/27/07	16.98	16.40	15.97	15.72	15.60	15.55	15.52	15.49	15.46	15.42	15.40	0.08
10/29/07	15.94	15.85	15.76	15.67	15.59	15.51	15.45	15.37	15.30	15.23	15.16	0.04
10/30/07	16.08	15.37	14.82	14.47	14.23	14.08	13.99	13.91	13.83	13.75	13.67	0.12
10/31/07	16.99	16.63	16.52	16.43	16.34	16.25	16.15	16.05	15.96	15.86	15.75	0.06
11/01/07	16.99	16.24	15.67	15.26	15.01	14.87	14.80	14.76	14.70	14.65	14.62	0.12
11/02/07	16.97	16.55	16.32	16.22	16.16	16.11	16.07	16.03	16.00	15.96	15.93	0.05
11/05/07	16.99	16.83	16.73	16.68	16.64	16.61	16.57	16.54	16.51	16.49	16.46	0.03
11/06/07	15.97	15.82	15.76	15.72	15.68	15.64	15.61	15.58	15.55	15.52	15.49	0.02
11/07/07	15.89	15.71	15.63	15.57	15.52	15.48	15.43	15.39	15.34	15.31	15.26	0.03
11/08/07	16.06	15.90	15.81	15.75	15.68	15.63	15.58	15.53	15.48	15.43	15.38	0.03
11/11/07	16.95	16.33	15.86	15.50	15.22	15.01	14.82	14.65	NM	14.34	14.20	0.15
											Mean:	0.08
											Median:	0.08
											Minimum	0.02
											Maximum	0.15

NM = not measured.

4.5.4.2 Bacillus Endospores and Total Coliform Results

The *Bacillus* endospores data are shown in Table 4-16. The UF system had a mean log reduction of 1.68 log_{10}, with a range of 0.68 to 1.92 log_{10}. The cumulative mean log reduction after RO treatment was 1.73 log_{10}, with a range of 0.73 to 1.98 log_{10}. The UF system removed *Bacillus* endospores to 1 CFU/100mL or <1 CFU/100mL on all but two days, October 22 and 23. Similarly, the RO permeate only had one day, October 23, with *Bacillus* endospores above 1 CFU/100mL. It was noted in the logbook that on October 22 there was windy conditions at the test site with smoke and ash in the air due to nearby wild fires. With the presence of high winds and the smoke and ash, it was possible that the samples were contaminated when they were collected. Similar conditions were reported on October 23 as well.

The concentration of *Bacillus* endospores present in the feed was low, with a geometric mean 64 CFU/100mL and a range of 33 to 96 CFU/100mL. Thus, with a detection limit of 1 CFU/100mL, the maximum log reduction that could be demonstrated was 1.5 to 2.0 log_{10}.

Table 4-16. *Bacillus* Endospore Counts and Log Reduction Calculations

	***Bacillus* Endospores (CFU/100mL)**						
Sample Date	**Raw Water**	**UF Filtrate**	**UF Log Reduction**	**UF Retentate**	**RO Permeate**	**UF + RO Log Reduction**	**RO Concentrate**
10/16/2007	56	1	1.8	50	<1	1.8	46
10/17/2007	60	<1	1.8	59	<1	1.8	51
10/18/2007	66	1	1.8	56	<1	1.8	4
10/22/2007	96	20	0.7	97	1	2.0	18
10/23/2007(1)	65	4	1.2	77	12	0.7	15
10/24/2007(1)	84	<1	1.9	119	<1	1.9	35
10/25/2007	81	1	1.9	79	<1	1.9	5
10/29/2007	66	1	1.8	52	<1	1.8	8
10/30/2007	61	<1	1.8	45	<1	1.8	6
10/31/2007	62	<1	1.8	49	<1	1.8	5
11/01/2007	33	1	1.5	35	<1	1.5	8
11/05/2007	58	1	1.8	67	<1	1.8	6
11/06/2007	54	<1	1.7	50	<1	1.7	3
11/07/2007	73	<1	1.9	91	1	1.9	5
11/08/2007	65	<1	1.8	48	<1	1.8	14
Geometric Mean	64	1.3(2)	1.6	61	1.2(2)	1.7	10
Median	65	2.5	1.7	65	1.7	1.7	15
Maximum	96	20	1.9	119	12	2.0	51
Minimum	33	<1	0.7	35	<1	0.7	3

(1) Sample holding time exceeded, see Section 4.7.4 for further discussion

(2) Values below detection limits (<1) set equal to 1 for geometric mean calculation.

The total coliform data collected during the verification test are shown in Table 4-17. The UF system reduced the total coliform concentration to <1 CFU/100mL for all days tested. The feed was low in total coliform count, ranging from 5 to 16 CFU/100mL. Therefore, the range of log_{10} reduction that could be demonstrated was only 0.7 to 1.2 log_{10}.

Table 4-17. Total Coliform Counts and Log Reduction Calculations

	Total Coliforms (CFU/100mL)						
Date	Raw Water	UF Filtrate	UF Log Reduction	UF Discharge	RO Permeate	UF + RO Log Reduction	RO Concentrate
10/18/2007	12	<1	1.1	4	<1	1.1	<1
10/22/2007	6	<1	0.8	16	<1	0.8	<1
10/23/2007	5	<1	0.7	2	<1	0.7	<1
10/24/2007	16	<1	1.2	13	<1	1.2	<1

4.5.4.3 UF System Particle Count Data

The in-line particle counters measured the particle counts in the raw water and UF filtrate every five minutes, and stored the data for transfer to a personal computer. Particle count data can be helpful in evaluating the integrity and performance of membrane systems and in predicting the reduction of microbial contaminants.

The particle count data was condensed from five-minute increments to one-hour averages for graphical presentation. The data were separated to provide information on various size ranges (e.g. 2-3 µm, 3-5 µm), as these sizes correspond to the sizes of various microbial contaminants of interest in drinking water, such as *Cryptosporidium* (3 to 5 µm)

Figure 4-17 shows the hourly averages for the raw water and UF filtrate 2-3 µm particle counts. Some notes about this figure and the particle count data presented:

- The y-axis is in logarithmic scale.
- There is no particle count data for the first two days, and last three days of testing. The particle count data supplied by the field operators begins at 8:30 a.m. on August 1. The data ends at 3:35 p.m. on August 21 because the computer logging the data crashed.
- The gaps in the data are the periods when the UF system was shut down for membrane cleanings.
- There were numerous single time point spikes in the particle counts that increased some of the hourly averages. These spikes were likely due to the automatic backwashes executed every half hour.

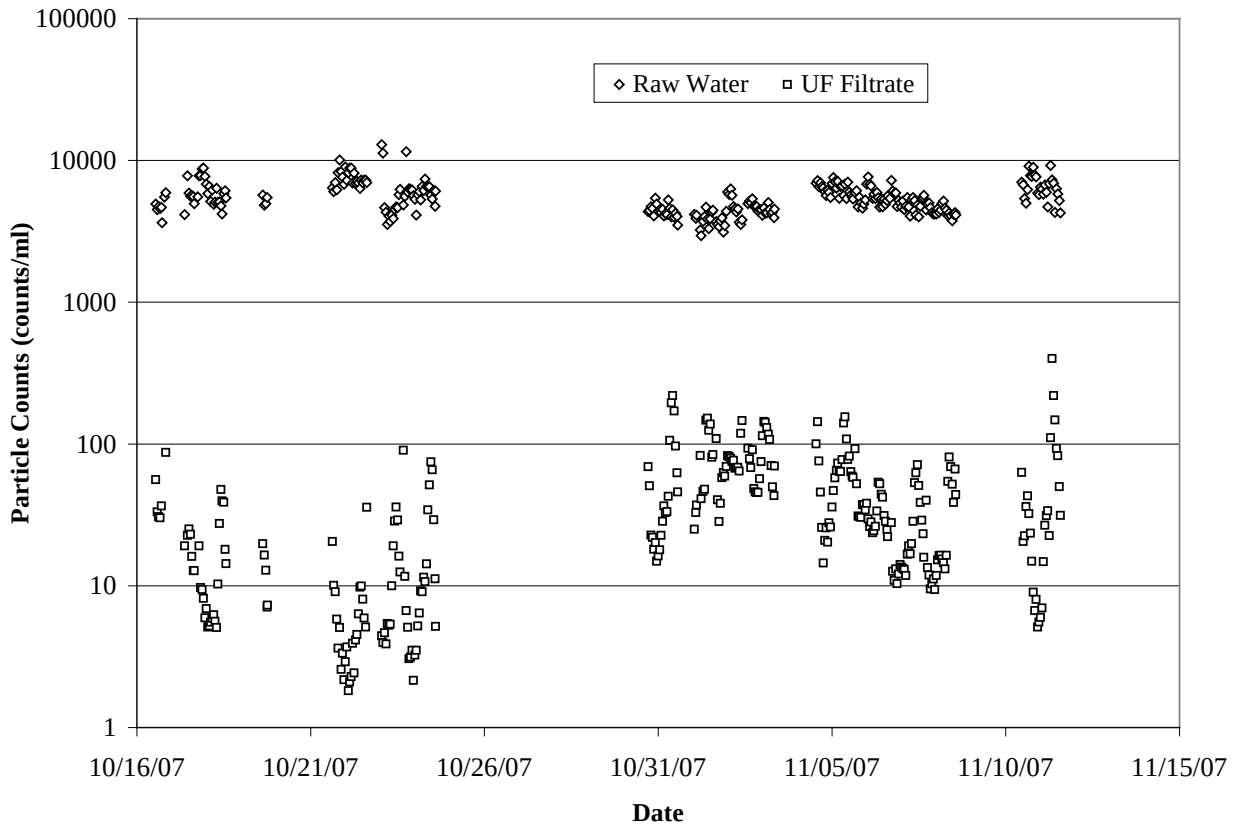


Figure 4-17. Particle count hourly averages – 2-3 µm.

The mean 2-3 µm particle count for the raw water was 5,559/mL with a median value of 5,533/mL. The range of particle counts for the raw water was from 53/mL to 17,843/mL. The filtrate had a mean 2-3 µm particle count of 42/mL with a median of 25/mL and a range of 0 to 773/mL. Note that these statistics are based on individual counts, not the hourly averages presented in the graphs. Both the mean and median 2-3 µm particle log reduction was 2.3 $\log_{10}$.

As evidenced by the difference between the mean and median particle counts, the particle count distribution is skewed toward the low side of the mean, as shown in the filtrate particle count distribution bar graph in Figure 4-18. Of the 3,464 individual particle counts used for this analysis, 2,270 were 40/mL or less. The mean was skewed upward by a few high counts that may have been measured during a backwash cycle.

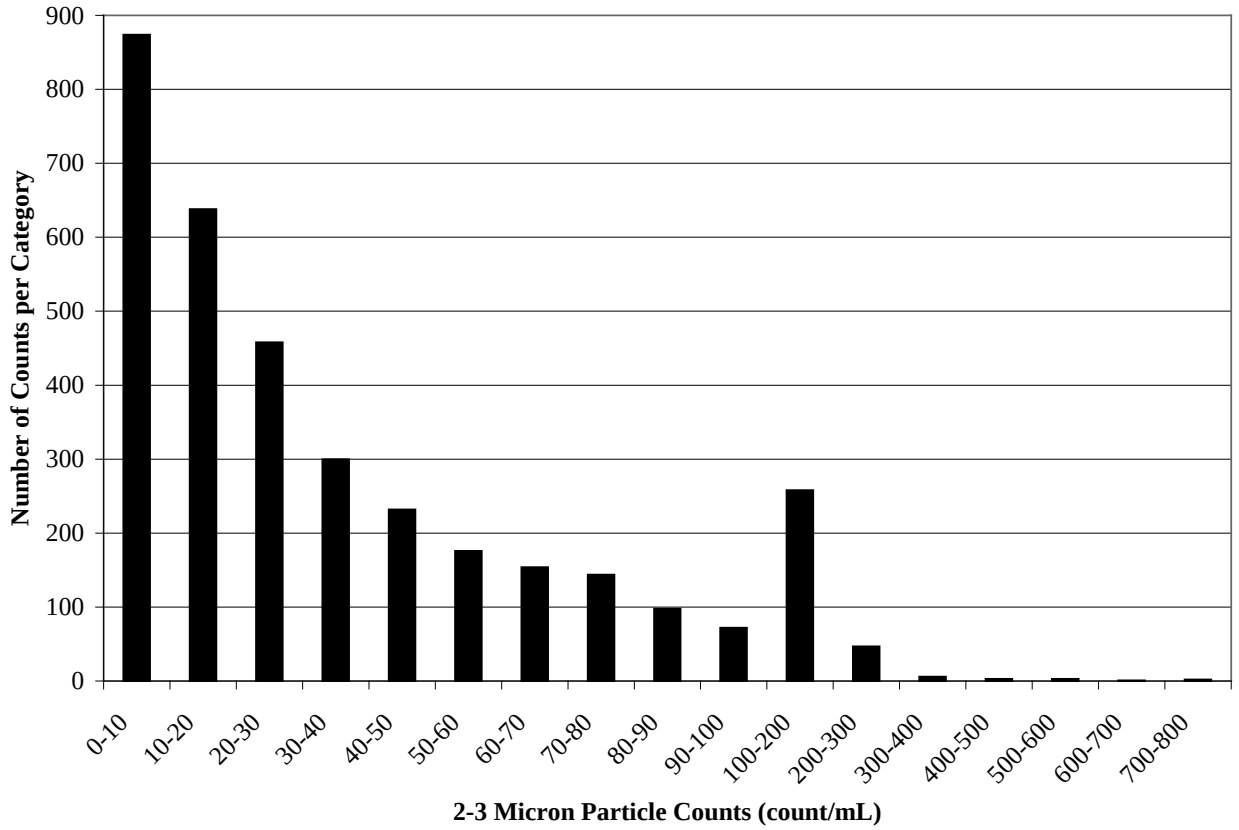


Figure 4-18. UF filtrate 2-3 µm particle count size distribution.

Figure 4-19 shows the hourly averages for the raw water and UF filtrate 3-5 µm particle counts. The notes about Figure 4-16 also apply to this graph. The mean particle count for the raw water was 3,662/mL with a median value of 3,551/mL. The range of particle counts for the feed was from 34 to 14,750/mL. The filtrate had a mean 3-5 µm particle count of 22/mL with a median of 10/mL and a range of 0 to 620/mL. The 3-5 µm particle counts were also skewed to the low end of the range (data not shown). As with the 2-3 µm particle counts, both the mean and median 3-5 µm particle counts were 2.5 $\log_{10}$.

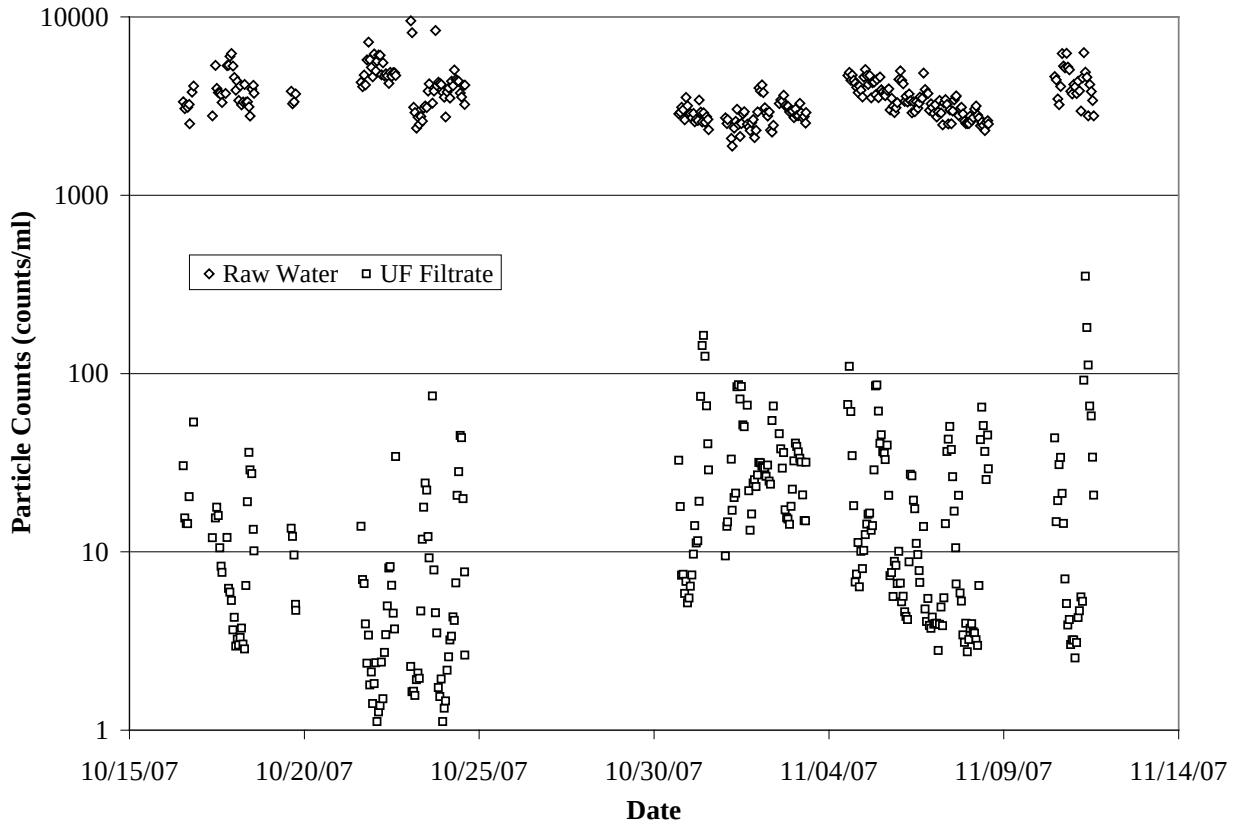


Figure 4-19. Particle count hourly averages – 3-5 µm.

As can be seen, the UF system was effective in reducing the particle count in these size ranges. The reduction of particulate matter in the smaller size range support the pressure decay tests in showing that the UF system maintained integrity throughout the test. Further, a 2.3 to 2.5 $\log_{10}$ reduction would tend to predict a similar or larger reduction in equal and larger size microbial contaminants. Combined with the pressure decay tests, these results would tend to support that the UF system should give at least 2-3 $\log_{10}$ reduction, if not better control of these contaminants.

Unfortunately, due to the low level of *Bacillus* endospores in the feed, the direct measurement of *Bacillus* endospores could not confirm the results of these indicator tests of UF system performance for microbial contaminants. These data do confirm, in conjunction with the turbidity data, that the UF system maintained good system integrity throughout the ETV test.

4.6 Chemical Consumption

Ferric chloride was fed to the UF feed at a rate of 4.37 mL/min, or approximately 0.07 gal per operating hour. The ferric chloride solution contained 13% iron (Fe) by weight. This yielded an approximate dose rate of 0.75 mg/L as Fe in the feed to the UF system. Near the end of the test, the feed pump rate was increased to 5.83 mL/min, increasing the iron dose rate to 1.0 mg/L as Fe. The higher dose rate was only run for five operating days.

The ferric chloride feed rate was checked on most operating days by direct measurement of the pumping rate. The quantity of ferric chloride used was also recorded each time ferric chloride was added to the feed tank. These measurements provided two checks on coagulant use during the test. Based on the feed tank records, a total of 22.4 gal of ferric chloride solution was used over the duration of the test. A total of 5,259,625 gal of feed was treated with coagulant, so the dose rate over the entire test was 4.3 X 10^{-3} gal ferric chloride per 1000 gal of water treated or 0.77 mg/L as Fe.

The RO system is designed to allow addition of a scale inhibitor, if needed. For this test, the scale inhibitor ONDEO (Nalco) PermaTreat® PC-191 was fed at target dose rate of 5 mg/L. The antiscalant was fed as a full strength solution (1.16 specific gravity). The target pump rate, based upon a RO feed flow rate of 174 gpm, was 2.84 mL/min (0.045 gal per hour). The average pump rate based on daily calibration records showed an average antiscalant feed rate of 3.22 mL/min, which yields an antiscalant dose rate of 5.7 mg/L. The quantity of antiscalant used was also recorded each time product was added to the feed tank. Based on the feed tank records, a total of 23.5 gal of antiscalant was used over the duration of the test. A total of 4,673,300 gal of RO feed was treated with antiscalant, so the dose rate over the entire test was 5.0 X 10^{-3} gal antiscalant per 1000 gal of water treated, or 5.8 mg/L.

The chemicals needed for the UF CIP were citric acid, sodium hydroxide (0.5%), and sodium hypochlorite (12.5% bleach). Citric acid was used to lower the pH of the cleaning solution for the low pH cleaning cycle, and sodium hydroxide was used for the high pH cleaning cycle. Section 4.5.2.1 and Table 4-7 described and showed the details on the quantities of chemicals used for each UF cleaning. Citric acid use ranged from 4 to 11.2 pounds per cleaning cycle; bleach use ranged from 12 to 29 L per cleaning cycle; and sodium hydroxide use ranged from 2.0 to 3.8 L per cycle.

The RO cleaning was performed using Avista RO Cleaner P303 for the low pH cleaning, and Avista RO Cleaner P111 for the high pH cleaning. Fifty four (54) pounds of each RO cleaner were used for the cleaning performed at the end of the test. It should be noted again here that the RO cleaning was performed at the end of the test, as it is a requirement of the ETV protocol to demonstrate the cleaning process. However, the RO unit did not actually require cleaning at that time. Because the specific flux had only decreased slightly at the end of the test, it is not possible to project the cleaning frequency actually required for the RO in this application with this seawater.

4.7 Quality Assurance/Quality Control

4.7.1 Introduction

An important aspect of verification testing is the QA/QC procedures and requirements. As described in Task C6 of the methods and procedures (Section 3.8.6), a structured QAPP was implemented to ensure the quality of collected data. Careful adherence to the procedures ensured that the data presented in this report were of sound quality, defensible, and representative of the equipment performance. The primary areas of evaluation were representativeness, accuracy, precision, and completeness.

4.7.2 Documentation

The field technicians recorded on-site data and calculations in a field logbook and on specially prepared field log sheets. The operating logsheets include calibration records for the field equipment used for on-site analyses. Copies of the daily data log sheets and calibration log sheets are in Appendix B.

Data from the on-site laboratory and data log sheets were entered into Excel spreadsheets. These spreadsheets were used to calculate various statistics (average, mean, standard deviation, etc.). NSF DWSC staff checked 100% of the data entered into the spreadsheets to confirm the information was correct. The spreadsheets are presented in Appendix C.

Samples collected and delivered to the NSF Laboratory for analysis were tracked using chain-of-custody forms. Each sample was assigned a location name, date, and time of collection. The laboratory reported the analytical results using the NSF Chemistry Laboratory management system reports. These reports were received and reviewed by NSF DWSC staff. These laboratory data were entered into the data spreadsheets, corrected, and verified in the same manner as the field data. Lab reports and chain-of-custody forms are included in Appendix F.

4.7.3 Quality Audits

The NSF QA officer performed an on-site audit on October 16, 2007, which was Day 1 of testing. The audit focused on review the field procedures, including the collection of operating data and performance of on-site analytical methods. The TQAP requirements were used as the basis for the audit. All deficiencies were corrected immediately.

The NSF QA Department reviewed the NSF laboratory analytical results for adherence to the QA requirements for calibration, precision, and accuracy detailed in the project QAPP and for compliance with the laboratory quality assurance requirements. No deficiencies were found. The laboratory raw data records (run logs, bench sheets, calibrations records, etc.) are maintained at NSF and are available for review.

4.7.4 Test Procedure QA/QC

The testing engineers conducted the field monitoring, measurements, and sample collection and handling in accordance with the EPA-approved TQAP created specifically for this verification. NSF testing laboratory staff conducted the chemical and microbiological analyses by following the TQAP. NSF QA Department staff performed audits during testing to ensure the proper procedures were followed. The audit yielded no significant findings.

4.7.5 Sample Handling

All samples analyzed by the NSF Chemistry and Microbiology Laboratories were labeled with unique ID numbers. These ID numbers appear in the NSF laboratory reports for the tests. All chemistry samples were analyzed within allowable holding times. The *Bacillus* endospores samples collected on October 23 and 24 were received late due to shipping problems, so they were not processed for analysis until two days after collection. However, exceeding the holding time for these samples should not bias the results, since the bacteria are in a spore state, thus are stable. As shown in Table 4-16, the endospore counts for these days were all above the means for

the process stream, with the exception of the <1 UF filtrate count for October 24. In fact, the maximum UF retentate count for the entire test was from the October 24 sample. Also, the late samples were received both days at a temperature of 33 °F, so the shipping delays did not result in the sample temperatures rising above 50 °F (10 °C), which is the maximum suggested holding temperature in Standard Methods.

4.7.6 Physical and Chemical Analytical Methods QA/QC

The calibrations of all NSF laboratory analytical instruments and the analyses of all parameters complied with the QA/QC provisions of the NSF Laboratories Quality Assurance Manual.

Bench top field instruments that measured turbidity, pH, temperature and specific conductance were calibrated daily in accordance with the data quality objectives, except that the daily calibration check lists do not indicate that the pH/temperature meter was calibrated on October 16, 17, and 21. In-line particle counters and turbidimeters were factory calibrated, and certificates were provided as required in the TQAP.

4.7.7 Microbiology Laboratory QA/QC

4.7.7.1 Growth Media Positive Controls

All media were checked for sterility and positive growth response when prepared and when used for microorganism enumeration. The media was discarded if growth occurred on the sterility check media, or if there was an absence of growth in the positive response check.

4.7.7.2 Negative Controls

For each sample batch processed, an unused membrane filter and a blank with 100 mL of sterile buffered deionized water filtered through the membrane were also placed onto the appropriate media and incubated with the samples as negative controls. No growth was observed on any blanks.

4.7.8 Laboratory Documentation

All laboratory activities were documented using specially prepared laboratory bench sheets and NSF laboratory reports. Data from the bench sheets and laboratory reports were entered into Excel spreadsheets. These spreadsheets were used to calculate average feeds and filtrates, and $\log_{10}$ reductions for each challenge. One hundred percent of the data entered into the spreadsheets was checked by NSF DWSC staff to confirm all data and calculations were correct.

4.7.9 Data Review

NSF QA/QC staff reviewed the raw data records for compliance with QA/QC requirements. NSF ETV staff checked 100% of the data in the NSF laboratory reports against the lab bench sheets.

4.7.10 Data Quality Indicators

The quality of data generated for this ETV was established through four indicators of data quality: representativeness, accuracy, precision, and completeness.

4.7.10.1 Representativeness

Representativeness refers to the degree to which the data accurately and precisely represent the expected performance of the EUWP system under conditions expected for use in an emergency response situation, or theater of war. The EUWP was operated similar to conditions of deployment in an emergency. As stated in Chapter 2, the raw water source was seawater, representing a possible application for the EUWP during deployment.

Representativeness was ensured by consistent execution of the test protocol and TQAP for the test, including timing of sample collection, sampling procedures, and sample preservation. Representativeness was also ensured by using each analytical method at its optimum capability to provide results that represent the most accurate and precise measurement it is capable of achieving.

4.7.10.2 Accuracy

Accuracy was quantified as the percent recovery of the parameter in a sample of known quantity. Accuracy was measured through use of both matrix spikes of a known quantity and certified standards during calibration of an instrument. For chemical analyses performed by the NSF laboratory, certified QC standards and/or matrix spikes were run with each batch of samples. The percent recoveries of all matrix spikes and standards were within the allowable limits for all analytical methods.

The TQAP called for the FTO and NSF Chemistry Laboratory to analyze PE samples and report the results to the NSF QA Department for review. This did not happen as part of the ETV test, but the NSF Chemistry Laboratory regularly participates in PE studies as part of the ongoing QA/QC program.

4.7.10.3 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. Precision of duplicate analyses was measured through calculation of RPD. For the water quality analyses conducted at the NSF laboratory, precision was measured in two ways. One set of field duplicates was collected for every ten samples sent to NSF. In addition, the NSF QA program calls for one sample per analytical batch to be analyzed in duplicate. The duplicate analysis results and RPD calculations for the field duplicates are presented in Appendix F. The NSF internal duplicate analysis data is not presented. The samples from this test were batched with samples from other NSF work, so most of the internal duplicates were from samples not affiliated with the ETV test. For the field measurements, one process stream was analyzed in duplicate every day. The field measurement duplicate analysis results and RPD calculations are also presented in Appendix G.

All RPD were within the allowable limit of 30% for each parameter with the following exceptions:

- Of 57 field turbidity duplicates, seven had RPD above 30%. However, five of the seven were measurements below 0.1 NTU, so as little as 0.02 NTU difference caused the RPD to be above 30%.
- Of the October 24 weekly sampling duplicates, the barium and lithium samples had RPD of 40% and 48.3%, respectively.
- Of the November 5 weekly sampling duplicates, the UV_{254} and Potassium samples had RPD of 44.1% and 45.7%, respectively.

4.7.10.4 Completeness

Completeness is the proportion of valid, acceptable data generated using each method as compared to the requirements of the test/QA plan. The completeness objective for data generated during verification testing is based on the number of samples collected and analyzed for each parameter and/or method, as presented in Table 3-13.

The completeness goals were met for all water quality parameters. Note that even though most of the RO permeate pH measurements are not reported (see Section 4.5.3.1 for further discussion), the completeness percentage for pH measurements was still met because the FTO collected more daily operation and water quality data than was required by the TQAP. The TQAP specified that pH measurements would be collected twice daily during the week, and once daily during the weekend. On most days three or four sets of measurements were collected. A total of 240 pH measurements were to be made, but there were actually 293 measurements over the course of the test.

References

EPA and NSF International (2002). *EPA/NSF Protocol for Equipment Verification Testing for Removal of Inorganic Constituents.* NSF International.

EPA and NSF International (2005). *EPA/NSF Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants.*