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Environmental Technology Verification Report

Removal of Inorganic, Microbial, and Particulate Contaminants from Secondary Treated Wastewater

Village Marine Tec.
Expeditionary Unit Water Purifier, Generation 1

Prepared by

NSF International

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

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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 INORGANIC, MICROBIAL, AND PARTICULATE CONTAMINANTS FROM SECONDARY TREATED WASTEWATER**
PRODUCT NAME:	**EXPEDITIONARY UNIT WATER PURIFIER (EUWP), GENERATION 1**
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 evaluated using secondary wastewater effluent from the Gallup, New Mexico wastewater treatment plant (WWTP).

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 voluntary 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.

The accompanying notice is an integral part of this verification statement.

PRODUCT DESCRIPTION

The following technology description was provided by the manufacturer for informational purposes only 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 are designed to operate with a generator and 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. The first pass part of the RO system has two arrays. One of the arrays is driven by the normal RO feed pump and the other array is driven by the energy saving device. There is only one array in the second pass part of the RO system. The EUWP 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, ferric chloride coagulation pretreatment was used at a dose of 5 mg/L as Fe. There was no post-treatment chlorination.

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 test was performed at the City of Gallup WWTP at 800 Sweetwater Place, Gallup, New Mexico. The WWTP treats an average of 3 million gallons per day (MGD) of wastewater with a peak of 5.5 MGD in the summer. The source water for testing was secondary wastewater effluent prior to chlorination. Initial characterization samples, which consisted of six grab samples, were collected in May and June of 2006. Highlights of the source water characterization are presented in Table VS-i. Parameters in the source water that exceed the EPA’s National Primary Drinking Water Regulations (NPDWR) included nitrate, bromide, gross alpha, and biological components. Secondary drinking water standards were exceeded for color, sulfate, TDS, surfactants, aluminum, and odor. The source of the city’s drinking water is high in TDS and sulfate with some radioactivity. The rest of the exceedances are caused by municipal use and the wastewater treatment process. Detailed results of the source water characterization can be found in the report.

Table VS-i. Source Water Characterization Data

Parameter	Background Samples, 2006					
	5/25	**6/01**	**6/08**	**6/15**	**6/22**	**6/28**
Color (color units)	35	30	75	40	40	35
Bromide (mg/L)	<0.20	<0.20	0.21	<0.20	0.20	<0.20
Sulfate (mg/L)	320	340	330	340	310	340
Nitrate (as Nitrogen) (mg/L)	19.5	13.8	N/A	10.9	10.8	8.7
TDS (mg/L)	1100	1100	1100	1100	1200	1100
Surfactants (mg/L)	0.75	0.75	0.75	0.50	0.50	0.75
Aluminum (µg/L)	<100	N/A	310	130	110	130
Odor (Threshold Odor Number)	12	12	17	17	12	17
Gross Alpha (pCi/L)	9.8	0	30	7.5	1.9	16
Total Coliform (MPN/100 mL)	N/A	24,000	≥160,000	70,000	1,600,000	4,000
Fecal Coliform (MPN/100 mL)	N/A	5,000	140,000	70,000	900,000	<2,000
Heterotrophic Plate Count (HPC) (CFU/mL)	N/A	6,600	≥160,000	11,000	190,000	11,000

Methods and Procedures

The EUWP verification test was conducted from July 12 to August 16, 2006 by the U.S. Bureau of Reclamation (USBR), with assistance from the U.S Army Tank-Automotive Research, Development, and Engineering Center (TARDEC). The test was intended to determine if the EUWP could produce 100,000 gpd of finished water meeting the NPDWR from secondary treated wastewater, based on contaminants found in the source water during the initial water characterization phase of ETV testing (see Table VS-i).

The testing activities followed a test/quality assurance plan (TQAP) prepared for the project. The TQAP was developed according to 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 system was shut down for two days (July 24 and 25, 2006) for RO cleaning and for two days (July 30 and 31, 2006) for UF cleaning. An additional RO cleaning was performed from August 7 to August 8, when the system was down for approximately 24 hours. The system was in operation on 32 calendar days, which met the test plan goal for collecting operating data for a minimum of 30 days. The system was operated as continuously as possible. Shut downs occurred each day to perform a pressure decay test on the UF system, to calibrate sensors, clean the strainers, etc. The RO system also shut down periodically for various maintenance activities, or when alarms occurred and shut the system down. When alarms and shutdown occurred during unattended operation at night, the entire system would remain shut down until an operator arrived in the morning. Turbidity and conductivity were selected as two key parameters. 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. 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. 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.

Once per week samples were collected from the UF and RO process streams for alkalinity, hardness, sulfate, total silica, dissolved organic carbon (DOC), TDS, total organic carbon (TOC), total suspended solids (TSS), ultraviolet light absorbance at 254 nanometers (UV_{254}), dissolved metals, total metals, total and fecal coliforms, *Escherichia coli* (*E. coli*), and HPC. Samples were also collected from the UF system weekly for color, biological oxygen demand (BOD) and chemical oxygen demand (COD).

VERIFICATION OF PERFORMANCE

Finished Water Quality

The UF system reduced turbidity from a mean of 11.1 Nephelometric Turbidity Units (NTU) in the feed water to a mean of 0.74 NTU in the UF filtrate as measured by the daily grab samples. The 95% confidence level shows that filtrate turbidity can be expected to be in the range of 0.62 to 0.86 NTU. The operators manually recorded in-line turbidity measurements at least once per day. The feed water turbidity, as recorded from the in-line analyzer, showed a mean value of 8.7 NTU. The UF filtrate in-line analyzer showed a mean turbidity of 0.69 NTU. Statistics for in-line turbidity measurements were not calculated for the test because the in-line turbidity data for the process streams was inadvertently erased for the period July 27 through the end of the test.

The RO permeate had a mean turbidity of 0.15 NTU based on the handheld meter readings. The 95% confidence interval for the handheld meter results showed an expected range of 0.13 to 0.17 NTU for the RO permeate. The RO permeate turbidity, as manually recorded from the in-line analyzer, had a mean value of 0.016 NTU.

The UF system was found to have faulty seals, which is discussed in the verification report. This may explain why the turbidity reductions by the UF system did not meet the NPDWR of <0.3 NTU 95% of the time. While the UF system alone did not meet the NPDWR, the RO system which followed it sufficiently reduced the turbidity to the meet NPDWR. The RO permeate turbidity levels manually recorded from the in-line meter show that the system did meet the NPDWR of <0.3 NTU 95% of the time, with all values below 1.0 NTU.

A second turbidity requirement is an action level of 0.15 NTU in the EPA Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). The rule states that if the in-line turbidity measurement exceeds 0.15 NTU over any 15-minute period, the system must be shut down and a direct integrity test performed. Throughout the period for which in-line turbidity data exists (July 12-27), the RO system produced permeate with turbidity meeting the LT2ESWTR action level criteria. There were a few single data points that exceeded 0.15 NTU, but never two readings in a row, which would indicate that the turbidity did not exceed the action level over an entire 15-minute period. All of the manually recorded turbidity data was 5 to 10 times lower than the 0.15 NTU action level.

The RO system reduced the dissolved ions in the feed water, as measured by conductivity, by a mean of 99.3%. The mean conductivity in the RO permeate was 11 µS/cm compared to the mean conductivity in the RO feed water of 1,600 µS/cm. The direct measurement of TDS shows that the mean concentration in the RO permeate was <10 mg/L compared to a mean RO feed water level of 1,100 mg/L. The overall TDS rejection was 99.5%.

The UF system had no impact on the pH of the water with the feed water having a mean pH of 7.53 and the filtrate having a mean pH of 7.54. The RO system did lower the pH of the permeate. The pH in the permeate ranged from 5.38 to 7.30 with a mean of 6.27. The UF and RO systems did not have an effect on the temperature of the water as it passed through the systems.

After RO treatment, the RO permeate met all primary and secondary drinking water standards measured during the verification test. The RO unit served as an effective treatment system for removing inorganic and organic constituents present in the secondary wastewater. To be acceptable for transmission or drinking, the RO permeate would need stabilization and residual chlorination.

UF and RO Membrane Integrity

Daily pressure decay tests were used to document UF membrane integrity. Turbidity, fecal and total coliforms, *E. coli*, and HPC were measured in the UF feed and filtrate as indirect membrane integrity indicators.

During the test audit, representatives from Koch Membrane Systems, Village MarineTec., NSF, and USBR were present to observe the pressure decay test. During that test the filtrate side of the membranes was drained and both arrays were simultaneously pressurized to 20 pounds per square inch, gauge (psig). The feed valve and retentate valves were in their operating positions. The filtrate valves were closed. After 15 minutes the system had lost 1.5 psig. This rate of pressure decline was acceptable to Koch.

As pressure testing continued, it became apparent that the procedure was not giving an accurate test of the system. After further inspection of the system, USBR realized that the check valve on the feed side and the long run of piping filled with water on the retentate side would not allow air to escape from the system at 20 psig. In effect the system was completely closed. Opening a sample port on the feed side remedied this, but also revealed that the system had lost integrity, as was apparent from the turbidity readings and biological analysis results that had started arriving by this time.

As discussed above, the UF filtrate turbidity was much higher than expected. None of the remedies of chemically cleaning the system, cleaning the turbidimeter, and recalibration of the turbidimeter solved the problem. The leakage was so severe that it was believed to be more than broken fibers. However, the testing schedule had to be maintained, as the City of Gallup needed the space and the EUWP had to be off-site by the scheduled end of the test period.

Biological analyses were performed for fecal and total coliform, *E. coli*, and HPC. Virus counts were measured for one set of UF feed, filtrate, and RO permeate. The enteric virus results showed 176 MPN/100 mL in the RO feed and <1 MPN in the RO permeate. Coliform species were present in the feed water in great enough numbers to allow for a log reduction value (LRV) greater than 3 from the UF filtrate to the RO permeate.

Dye-marker direct integrity tests were performed on the RO system at the start and end of the test period. The RO membranes rejected the dye at a rate higher than 99%. The rejection rate improved at the end of the test. These results, supported by the high rejection rate for conductivity, the low turbidity in the permeate, and the 3 LRV for coliform samples, indicate that the RO membranes maintained integrity throughout the verification test. Although the UF membrane unit had lost integrity, the subsequent RO array provided a barrier to microorganisms, turbidity and other contaminants.

UF System Operation

UF process operations data for the test are presented in Table VS-ii. The mean UF operating hours during the verification test was 14 hours per day. The mean RO operating hours during the verification test was 18 hours per day. The UF operating hours were lower than the RO because the system is designed for the UF to operate at a higher filtrate flow rate than the RO feed rate to keep the RO feed tank full. Whenever the RO feed rate tank was at maximum level, the UF was automatically shut down until the RO feed tank level dropped to the pre-set level to restart the UF system. The intake flow is defined as the source water pumped into the UF feed water tank. The mean UF feed water flow rate of 250 gallons per minute (gpm) was slightly below the target feed flow rate of 259 gpm specified for the system. The mean filtrate flow rate of 229 gpm corresponds to a flow rate of 14.3 gpm for each of the 16 UF membrane modules. The UF water recovery was 91.6% based on the mean feed water and filtrate flow rates.

The UF system flow rate objective was 200,000 gpd for this test. Based on the mean net filtrate production of 178,000 gpd over the verification period, the UF system did not achieve the objective. The reason was that the unit did not operate a sufficient number of hours per day to meet the production goal. At a mean filtrate flow rate of 229 gpm, and accounting for a backwash volume of 900 gallons every 30 minutes, the UF system would need to operate an average of 17 hours per day to meet the objective. The UF system operated an average of only 14 hours of per day during the test.

Table VS-ii. UF Operations Productivity Data

Parameter	Count	Mean	Median	Minimum	Maximum	Standard Deviation	95% Confidence Interval
UF operation (hr/day)	30	14	15	4	20	4.1	±1.5
Intake flow (gpm)	53	281	288	217	301	21.0	+5.65
Feed flow (gpm)	53	250	251	179	314	24.3	±6.55
Filtrate flow (gpm)	53	229	229	154	289	25.0	±6.74
Retentate flow (gpm)	49	24	25	19	30	4.4	±1.2
Backwash flow (gpm)	Not measured. 900 gallons per backwash cycle(1); Backwash every 30 minutes						
Feed pressure (psig)	53	22	21	16	30	3.9	±1.1
Retentate pressure (psig)	53	19	19	0	28	5.4	±1.5
Filtrate temperature (°F)	54	78	78	76	82	1.5	±0.4

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

RO System Operation

The RO process operations data are presented in Table VS-iii. The RO system did not achieve the permeate production of 100,000 gpd claimed in the statement of performance. The mean permeate production for the 32 calendar days of operation was 78,000 gpd. The mean feed water flows of 107 gpm for Array 1 and 41 gpm for Array 2 were below the target feed rates established in the test plan (Array 1 target 116 gpm and Array 2 target was 58 gpm). The percent recovery for Array 1 of 50% equaled the target specification of 50%. The Array 2 percent recovery of 42% was below the target specification of 48%. These recoveries, with the feed water flows, resulted in mean permeate flow rates of 53 gpm for Array 1 and 17 gpm for Array 2. At these flow rates, the RO unit would need to operate an average of approximately 24 hours per day to meet the target of 100,000 gpd. The RO unit averaged 18 hours per day of operation during the test.

It was apparent during the test that the UF treated secondary wastewater was putting a heavier load on the RO than expected. For this type of application, lower percent recoveries and lower flows were achieved compared to design specifications for groundwater and seawater. During the last few days of testing the recovery was set to 40% to protect the system from heavy loading from the WWTP. While this may not have been necessary, it explains the drop in flows and pressure near the end of the test.

It should be noted that while the RO only achieved approximately 78% of the performance objective for permeate production, additional operating time each day would have increased the total production. As noted in the UF system discussion, operators were only present during daylight hours and there was no coverage over night. Therefore, if an alarm sounded and shutdown the unit, the system remained off-line until an operator arrived the next morning. While it may not be realistic to operate the RO unit continuously 24 hours per day for several days, additional operator coverage could increase operating hours and achieve permeate production closer to the target.

Table VS-iii. RO System Operations Productivity Data

Parameter	Count	Mean	Median	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Array 1 feed flow (gpm)	54	107	107	104	110	1.29	±0.34
Array 1 permeate flow (gpm)	54	53	55	42	64	5.44	±1.45
Array 1 concentrate flow (gpm)	54	54	53	43	67	5.52	±1.47
Array 2 feed flow (gpm)	54	41	41	32	48	4.14	±1.10
Array 2 permeate flow (gpm)	54	17	18	11	22	2.74	±0.73
Array 2 concentrate flow (gpm)	54	24	23	20	29	1.70	±0.45
Array 1 feed pressure (psig)	54	290	293	222	366	26.1	±6.96
Array 1 concentrate pressure (psig)	53	197	199	134	263	24.8	±6.67
Array 2 feed pressure (psig)	54	193	195	133	261	23.6	±6.28
Array 2 concentrate pressure (psig)	54	138	138	91	182	19.0	±5.06
Array 1 and 2 combined permeate pressure (psig)	54	20	19	9	42	5.82	±1.55

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.

In-line field meters for particle counts were factory calibrated and certificates were provided as required in the TQAP. However, incorrect calibration certificate data for bin voltages was entered into the software program for the particle counters. This resulted in rendering the particle count data inaccurate and not meeting the Data Quality Objectives. Because of this problem, particle count data could not be used for documenting system performance for particle count and the data are not included in this report.

Samples were collected for *Cryptosporidium* and *Giardia* enumeration, but the analyses did not meet the QA/QC objectives for the ETV test. Therefore, these data are not included in the verification report.

A complete description of the QA/QC procedures is provided in the verification report.

Original signed by Sally Gutierrez 01/31/11	*Original signed by Robert Ferguson 01/17/11*
Sally Gutierrez Date	Robert Ferguson Date
Director	Vice President
National Risk Management Research Laboratory	Water Systems
Office of Research and Development	NSF International
United States Environmental Protection Agency	

NOTICE: Verifications are based on 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 10/27/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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Village Marine Tec.
Expeditionary Unit Water Purifier, Generation 1

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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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Appendices

Abbreviations and Acronyms

ANGB	Air National Guard Base
bhp	brake horsepower
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
DOC	dissolved organic carbon
DQO	data quality objectives
DWS	Drinking Water Systems
EPA	United States Environmental Protection Agency
ERI	Energy Recovery, Inc.
ETV	Environmental Technology Verification
EUWP	Expeditionary Unit Water Purifier
°F	degrees Fahrenheit
FRP	fiberglass reinforced plastic
ft	foot (feet)
gal	gallons
gfd	gallons per square foot per day
g/mol	grams per mole
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
LLD	lower limit of detection
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
m	meter
MDL	method detection limit
mg	milligram
mL	milliliter
MPN	most probable number
mS	milliSiemens
MWCO	molecular weight cutoff
NA	not applicable
NBC	nuclear, biological, and chemical

NC	not calculated
ND	non-detect
NDP	net driving pressure
NFESC	Naval Facilities Engineering Service Center
NIST	National Institute of Standards and Technology
NM	not measured
nm	nanometers
NPDWR	National Primary Drinking Water Regulations
NR	not recorded
NSF	NSF International (previously known as the National Sanitation Foundation)
NSWCCD	United States Naval Surface Warfare Center – Carderock Division
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
ORP	oxidation reduction potential
pCi	picocuries
PE	performance evaluation
P&ID	piping and instrumentation diagram
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
PQL	practical quantification limit
psi	pounds per square inch
psi	pounds per square inch, gauge
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	United States Army Tank-Automotive Research, Development, and Engineering Center
TDS	total dissolved solids
TOC	total organic carbon
TON	total organic nitrogen
TQAP	test/quality assurance plan
TQG	Tactical Quiet Generator
TSS	total suspended solids
TMP	trans-membrane pressure

UF	ultrafiltration
USBR	United States Bureau of Reclamation
UV_{254}	ultra violet absorbance at 254 nanometers
VOC	volatile organic chemicals
VSS	volatile suspended solids
whp	water horsepower
µg	micrograms
µm	micron

Acknowledgements

The U.S. Bureau of Reclamation (USBR) was the main field testing organization. USBR was supported by the U.S. Army Tank-Automotive Research, Development, and Engineering Center (TARDEC). USBR and TARDEC 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 Michelle Chapman of USBR, Dale Scherger of Scherger Associates (3017 Rumsey Drive, Ann Arbor, MI 48105), and Michael Blumenstein and C. Bruce Bartley of the NSF International ETV Drinking Water Systems Center (DWSC). The verification report was based on the project test/quality assurance plan authored by DWSC, USBR, and TARDEC.

The authors would like to thank Jeff Adams of the EPA Water Quality Division for his assistance in the ETV process.

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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.

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 (DWS) Center 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 DWS Center 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 secondary wastewater effluent from the Gallup, New Mexico wastewater treatment plant (WWTP) as the source water for the test.

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.
- City of Gallup, New Mexico

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 Agreement No. R-82833301. This verification effort was supported by the DWS Center 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

The U.S. Army TARDEC provided oversight of EUWP design, construction, and testing.

Contact Information:
US 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 was the FTO for the ETV test and 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. 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

1.2.7 The City of Gallup, New Mexico

City of Gallup provided a portion of the funding for the wastewater testing phase, the testing location, and operational assistance. The funding was provided by the City of Gallup through a grant from the state of New Mexico.

Contact Information:
Lance Allgood
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Fax: 505-726-1278
Email: lallgood@ci.gallup.nm.us

1.3 Verification Testing Site

The ETV test of the EUWP Generation 1-1 was performed at the City of Gallup WWTP at 800 Sweetwater Place, Gallup, New Mexico. Gallup is located 140 miles west of Albuquerque. Gallup is on a high desert plateau at 6,500 ft. The climate is temperate (average low of 16ºF, average high of 87ºF) and dry (11 in. of rain per year). In 2005, the population of Gallup was approximately 20,000 residents. The water chemistry data is presented in Section 4.3.

The City of Gallup WWTP provided secondary treated wastewater for the ETV test. During most of the operation the secondary effluent is filtered through pressure media filters prior to chlorination providing tertiary treated effluent. Figure 1-1 presents a flow diagram of the WWTP and the location of the EUWP Generation 1-1 equipment.

The WWTP treats an average of 3 million gallons per day (MGD) of wastewater with a peak of 5.5 MGD in the summer. The facility was in the midst of expansion to 3.5 MGD during ETV testing. The WWTP has enough hydraulic capacity to handle the peak loads without significant change in effluent water quality. Wastewater is discharged into the Rio Puerco of the West, a dry riverbed.

The EUWP Generation 1-1 was situated on a gravel pad at the north side of the facility as shown in the photograph provided in Figure 1-2. Rio Puerco of the West runs along the north end of the facility (on left side in Figure 1-2). All water produced during the verification test, including clean-in-place (CIP) waste, was discharged to the oxidation ditch at the head of the WWTP. Chemical waste from CIP operations was neutralized prior to discharge to the oxidation ditch.

Figure 1-3 provides a diagram of the general layout of the major components of the EUWP Generation 1-1 equipment.

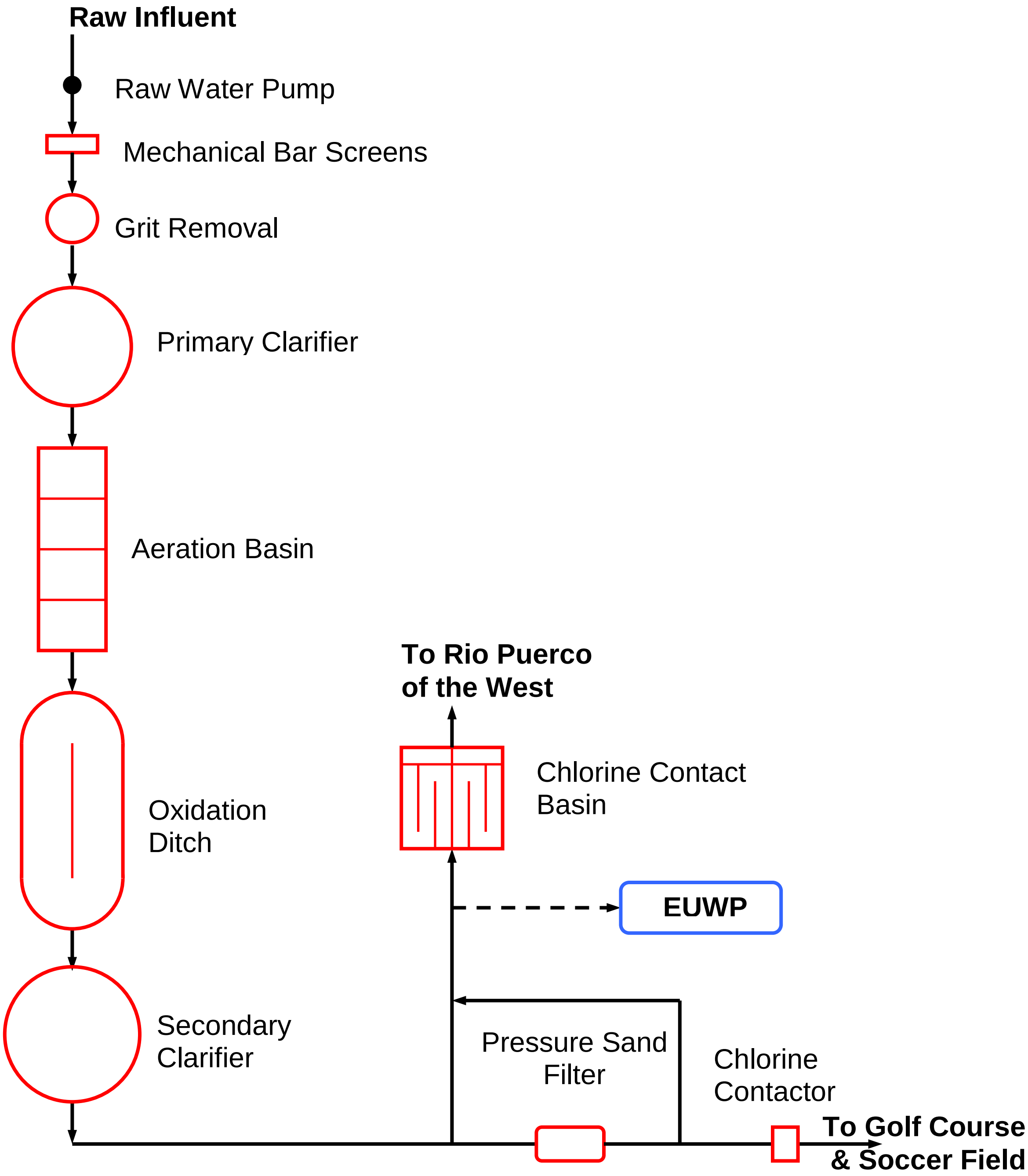


Figure 1-1. Existing WWTP and EUWP location.

Figure 1-2. Gallup Wastewater Treatment Plant with EUWP indicated by the circle.

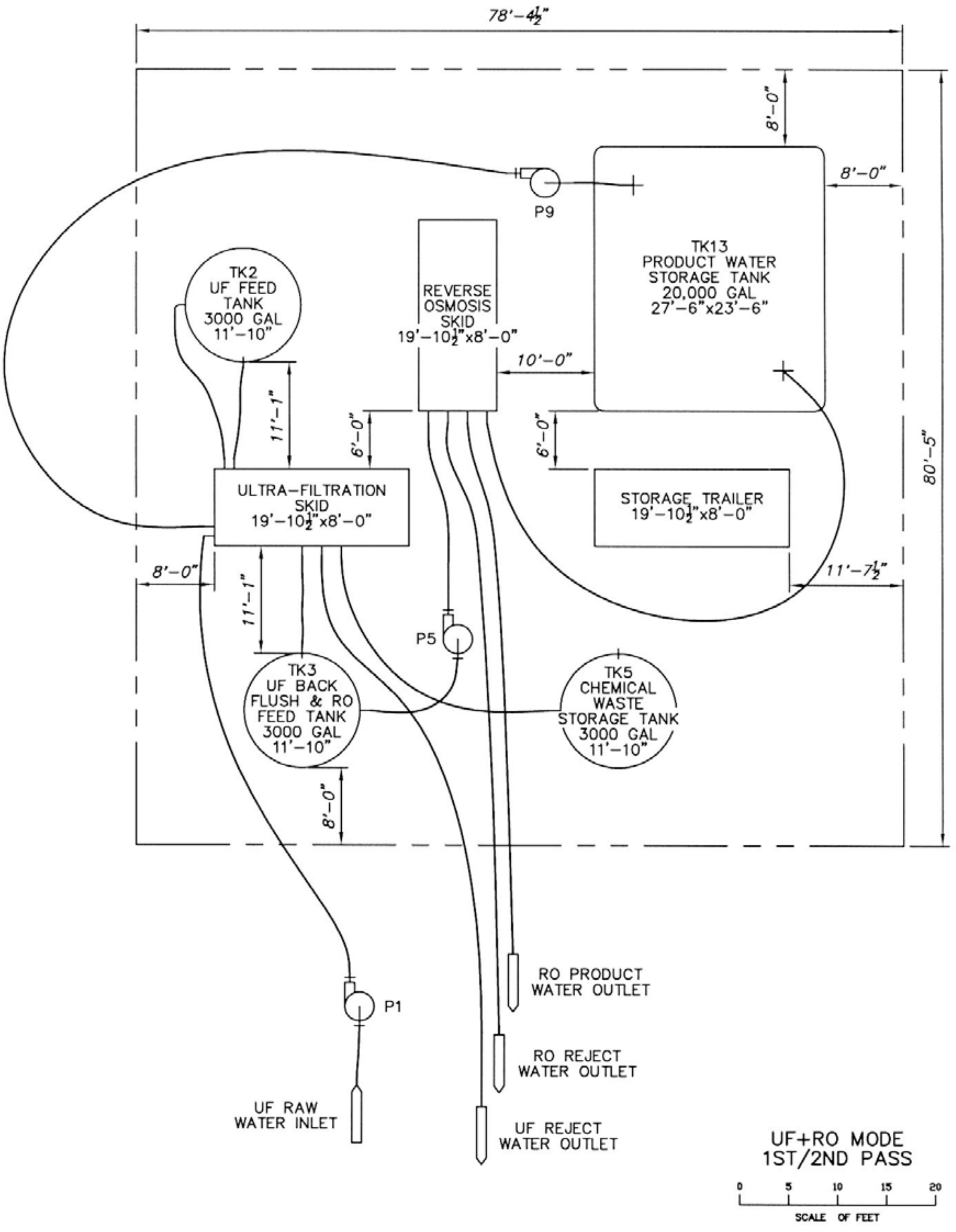


Figure 1-3. General layout of EUWP equipment.

Chapter 2
Equipment Capabilities and Description

The EUWP was designed to meet purified water needs in areas with challenging water sources of 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 gallons 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 second 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 while removing as much as 99.7% of dissolved salts and meeting EPA's National Primary Drinking Water Regulations (NPDWR) from secondary treated wastewater 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.

According to the system designers, 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 the Gallup WWTP.

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.

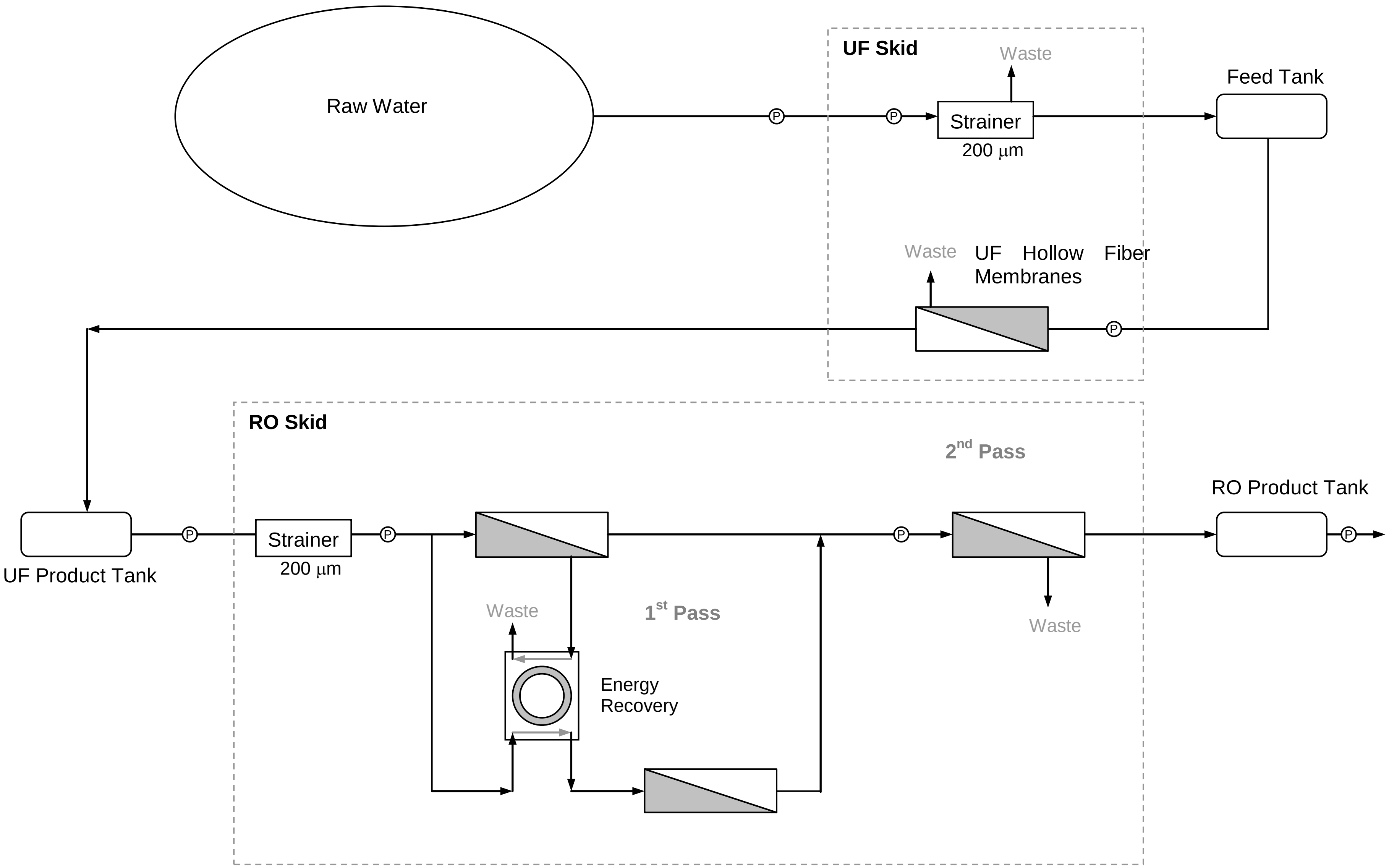


Figure 2-1. Process component diagram.

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 psi) 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.

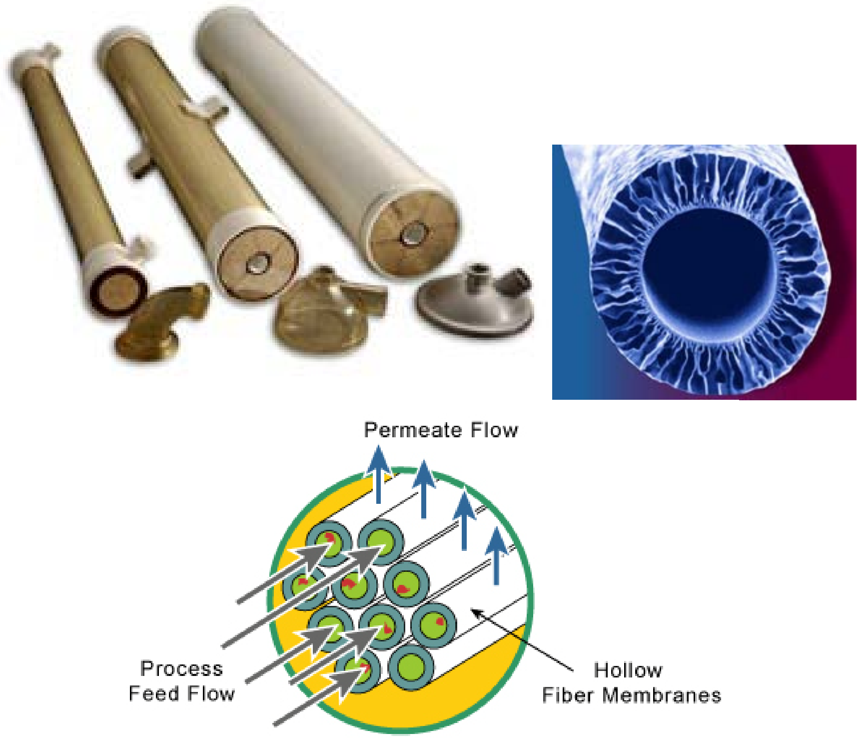


Figure 2-2. Koch UF hollow fiber modules, a single fiber, and the process flow through the module.

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.

Osmotic pressure can be estimated by the following equation:

$$\pi = inRT \tag{2-1}$$

where:

π = osmotic pressure;
i = e dissociation constant;
n = number of moles of ions;
R = Universal Gas Constant; and
T = temperature in degrees Kelvin.

A simpler approximation is 1 psi per 100 mg/L TDS.

RO is a moderate to high-pressure (80-1,200 psi) membrane separation process. The membranes in the EUWP are spiral wound with up to seven modules in a vessel. 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

The system process schematic and detailed layout are shown in Figures 2-3 and 2-4, respectively.

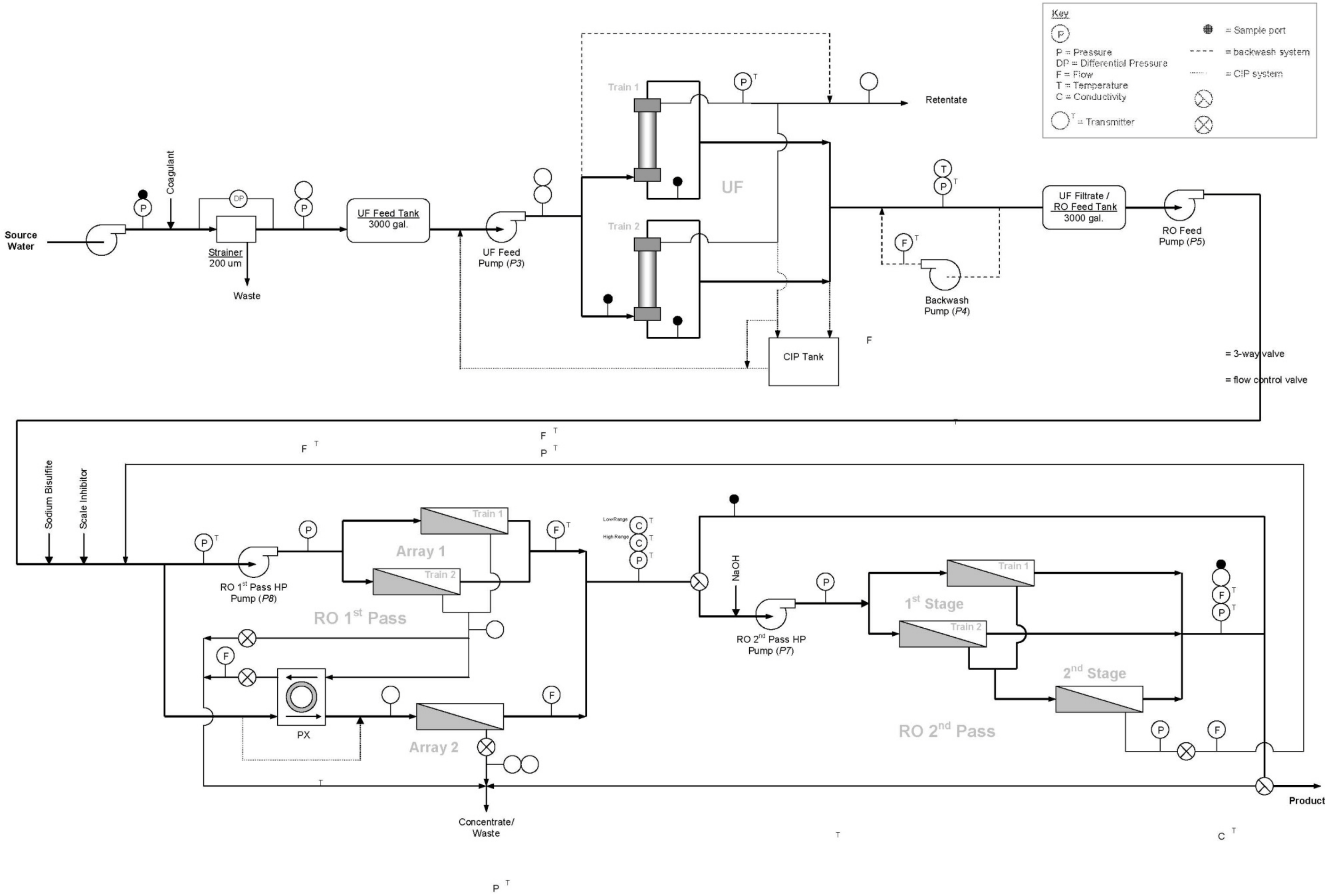


Figure 2-3. EUWP system process schematic.

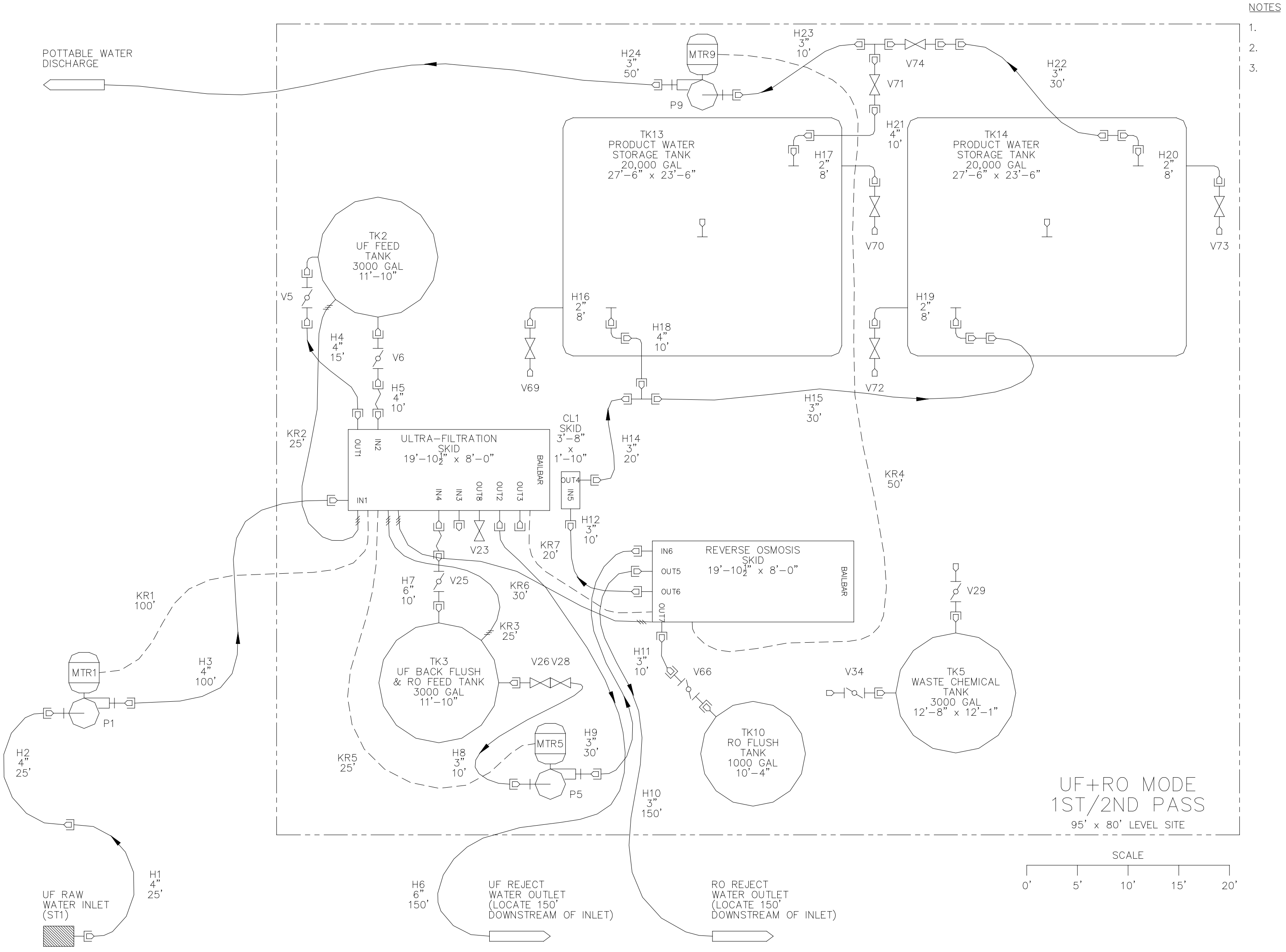


Figure 2-4. Schematic of typical EUWP layout.

2.4.1 Raw Water Intake

The intake strainer was buoyed behind a weir before the WWTP chlorination system and detention tank. The intake pump draws water from this source to the UF skid where ferric chloride is injected as a filter aid before the dual 200 µm Amiad strainers. The strainers aid in mixing the coagulant since there is not enough time to form particles larger than 200 µm between the injection point and the strainer. The 3,000 gal UF feed tank provides 12 min of retention time. Ferric chloride is dosed to create a micro-floc under these conditions. Ferric chloride was used during the ETV test at a dose rate of 5 mg/L as Fe, as described in Section 4.4.

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. A photo of the UF skid is shown in Figure 2-5. The onion tank in the right foreground of the photograph is for the UF feed source after the ferric chloride addition and strainer.

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
Maximum Pressure	45 psi
Maximum Transmembrane Pressure (TMP)	30 psi
Maximum Backflush TMP	20 psi
Inner Fiber Diameter	0.035 in
Membrane Area	554 ft^2
Cartridge Diameter	10.75 in
Cartridge Length	48 in
Maximum Free Chlorine at 25^oC	200 mg/l at 9.5 pH
Maximum Total Cholorine Contact	200,000 ppm hrs cumulative

Table 2-2. UF Skid Statistics

Parameter	Value
Production Capacity	250,000 gpd
Maximum Pressure to Membranes	45 psi
Maximum Transmembrane Pressure	30 psi
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 kWhr/kilogallon (kgal)
Fuel Type	DF2 (Diesel Fuel, Grade 2) DFA (Diesel Fuel, Arctic Grade) JP8 (Kerosene type, military jet fuel)
Fuel Capacity (60 kW Generator)	43 gal

Figure 2-5. Photo of 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 2-6 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. Ferric chloride was used during the ETV test at a dose rate of 5 mg/L as Fe, as described in Section 4.4.
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 trans-membrane pressure (TMP) exceeds 35 psi 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 the Gallup WWTP. The following is a basic description of the flow path and functional description of the UF CIP 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 PLC will automatically move the pneumatically operated valves to the correct positions.

6. Enable heaters to maintain CIP solution to between 96 - 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.

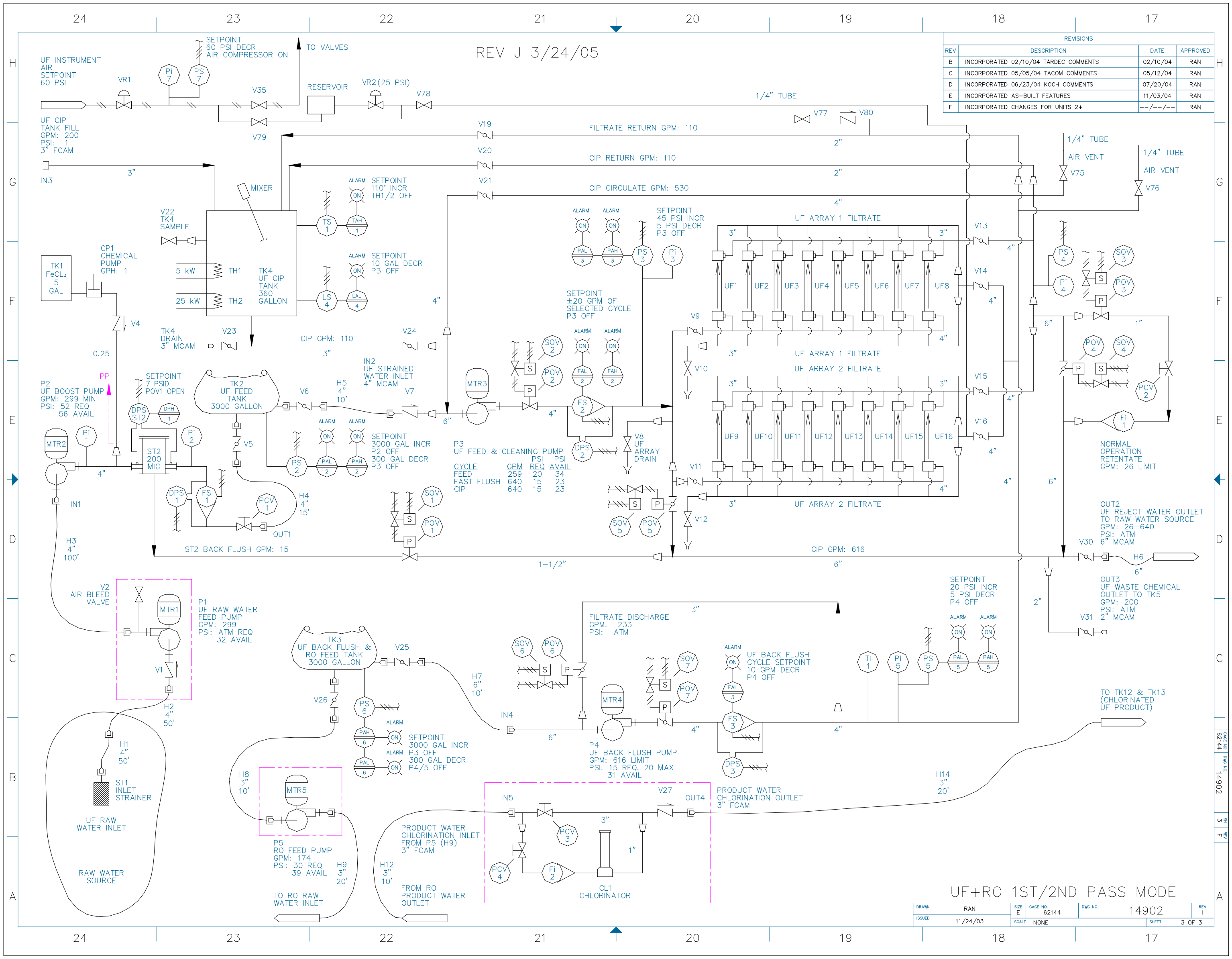


Figure 2-6. Piping and instrumentation diagram of UF skid.

2.4.3 RO System

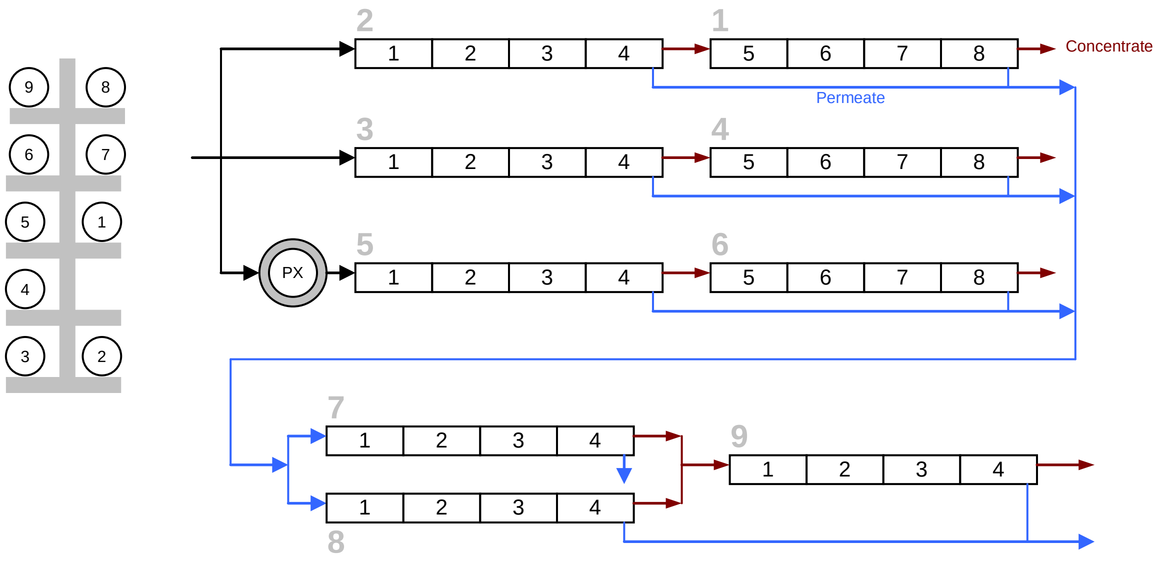
The RO skid is shown below in Figures 2-7 and 2-8.

Figure 2-7. Photo of the RO skid.

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 2-9). 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 2-9). 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 2-9).

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 2-9). The brine from these vessels then feeds one additional four-element vessel (Vessel 9 in Figure 2-9).

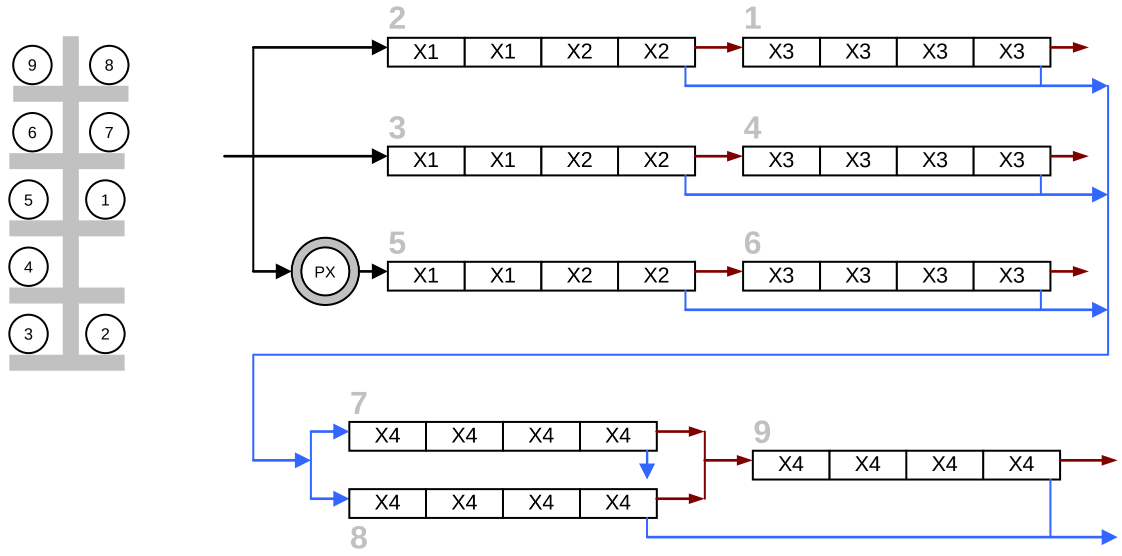
Figure 2-8. Photo of the RO skid membrane vessels.



Numbers indicate pressure vessels

Figure 2-9. Vessel arrangement schematic.

The RO design incorporates an internally staged RO element configuration on the first pass (Figure 2-10). 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.



Numbers indicate pressure vessels

Figure 2-10. Membrane arrangement schematic.

Table 2-3. RO System Membrane Element Characteristics

Vessel	Product	Designator	Nominal Active Surface Area ft^2 (m^2)	Permeate Flow 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 and 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 2-11 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 psi 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 water 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 min.
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.

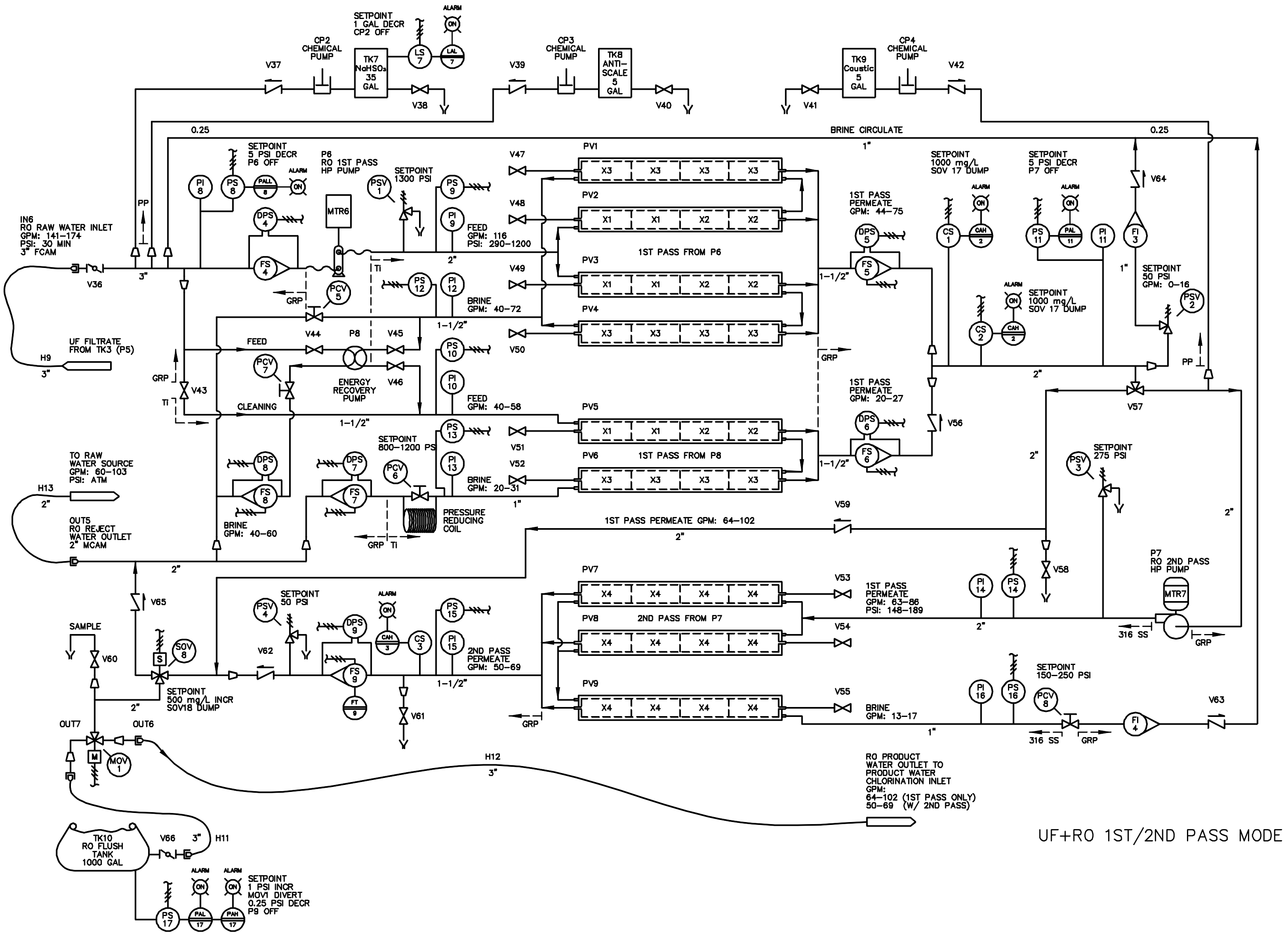
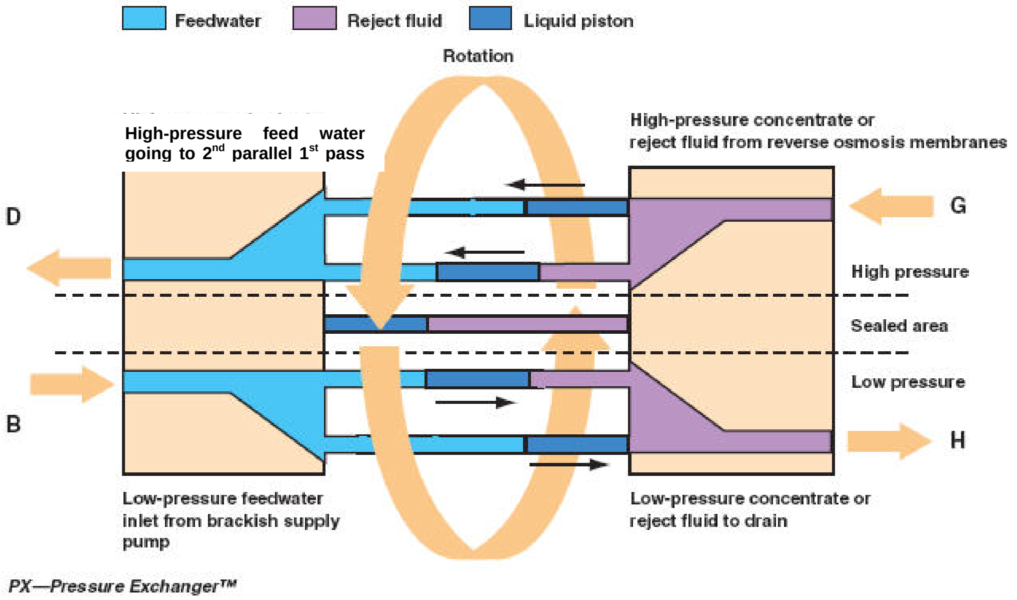


Figure 2-11. P&ID of RO skid.

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 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 2-12). 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.

In a typical system, the pressurized feed water 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).



http://www.energy-recovery.com/pdf/PX45SPX70SPX90S.pdf

Figure 2-12. 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 for 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 required	7 psi
	Backpressure required for strainer auto flushing	35 psi
UF	Pretreatment requirements	200 µm strainer
	Feed pressure (maximum)	45 psi
	Ambient temperature range	32 – 120°F
	Water temperature range	34 – 104°F
	Control air pressure	60 psi
	Damaging chemicals	Grease, Oil, Silicon
	TMP following back flush (maximum) before CIP required	35 psi
	Pressure surges	Must be minimized by closing and opening valves slowly
UF Membranes	Stagnation time (maximum) before preservation required with 1,000 – 5,000 mg/L sodium bisulfite (see operations manual for details)	14 days (somewhat temperature dependent)
	See Table 2.6 for more details.	
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 psi
	Maximum Air Pressure	15 psi
	Temperature range	32°F to 120°F
	Filtered	500 µm prior to entering the UF system
	All water must be free of particulate matter such as rust, scale, flake sandy, granular material, slurries, scum, algae, etc.	
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 treatment - 200 µm strainer on RO skid
	Operating concentrate pressure after backpressure valve (maximum)	200 psi
	Operating permeate pressure (maximum)	100 psi

Table 2-6 (cont'd). Equipment Limitations

System	Parameter	Value
RO	2nd pass inlet pressure (maximum)	300 psi
	RO high pressure pump #6 maximum speed	600 revolutions per minute (RPM)
	RO high pressure pump #6 minimum inlet pressure	30 psi
	Stagnation time (maximum) before preservation required with 1% sodium bisulfite (see operations manual for details)	1 week (somewhat temperature dependent)
RO Membranes	(see Table 2-6 for details)	

(1) Non-detect

Table 2-7. Membrane Limitations

Membrane	Pressure (Max.) – psi	Temperature (Max.) - °F	SDI (Max.)	Chlorine (Max.) – mg/L	pH range – feed, continuous	pH range – feed, CIP	Pressure drop (Max.) per element - psi	Pressure drop (Max.) per vessel - psi	Production TMP (Max.) - psi	Backwash TMP (Max.) - psi
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 psi 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 and RO CIP

A CIP cycle for the UF or RO system involves filling the 300 gal CIP tank with an acid cleaning solution followed by a basic solution with chlorine. Each cleaning cycle is followed by a rinse cycle from the UF filtrate tank. A second base cleaning may be required. The total volume generated with two cleaning steps using the 300 gal tank plus 200 gal piping/membrane volume each followed by a thorough rinse is approximately 2,500 gal for a total waste volume of 12,500 gal for the whole ETV test. All CIP waste was returned to the head of the WWTP.

2.6.2 RO Concentrate

All product water and concentrate was recombined and returned to the head of the WWTP. A total of 5.8 million gal was processed and returned to the head of the WWTP during the test.

2.6.3 UF Backwash and Retentate

The UF system on the EUWP automatically initiates a backwash every 30 min to remove contaminants from the membrane surface. Each backwash consists of backflushing the membrane with UF filtrate for 60 sec followed by a forward flush using UF feed water to remove the contaminants dislodged from the membranes during the backflush. In addition to the backwash, the UF system also discharges a continuous stream referred to as retentate. All backwash and retentate was returned to the head of the WWTP and is included in the total of 5.8 million gal processed during the test period.

2.6.4 Discharge Permits

The City of Gallup has an NPDES permit for the discharge of their wastewater. The permit limits the increase in TDS between their source water and their discharge to 500 mg/L. If the product and concentrate flow streams are combined for discharge, the permit requirements are not exceeded. All product water and concentrate was recombined and returned to the head of the WWTP.

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^{TM}. 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; and
- Labor hours.

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 on the EPA regulations, and other water quality parameters of interest. Regulated contaminants and unregulated troublesome components analyzed are listed in Table 3-1, which also lists the laboratory responsible for analysis. Contaminants such as pharmaceuticals and hormones have recently emerged as a concern with municipal wastewater. Pharmaceuticals and hormones compounds monitored are listed in Table 3-2. They pose at least a public perception problem and at most a health problem, and deserve consideration for removal. In addition to the analytical water quality parameters, the Langelier Saturation Index (LSI) was calculated for the RO feed and permeate according to ASTM Method D 3739.

Table 3-1. Raw Water Quality Sampling Schedule and Analysis Locations

Water Quality Parameter Type			Parameter	Initial	Analysis Location				
					STL	Gallup	CSM	Field	Other
Unregulated Constituents	General		pH	x	x		q		
			Temperature	x	q	q	q	x	q
			Conductivity	x	x			x	
			ORP	x				x	
			Dissolved Organic Carbon (DOC)	x	x				
			Total Organic Carbon (TOC)	x	x				
			UV_{254}	x			x		
			Color	x	x				
			Odor	x					Weck
			Biochemical Oxygen Demand (BOD)	x		x			
			Chemical Oxygen Demand (COD)	x	x				
			Total Suspended Solids (TSS)	x	x				
			TDS	x	x				
			Volatile Suspended Solids (VSS)	x	x				
			Alkalinity (total) [as $CaCO_3$]	c/x	c/x				
			Carbonate (CO_3^{-2})	x	x				
			Bicarbonate (HCO_3^-)	x	x				
			Hardness (total) [as $CaCO_3$]	c/x	c/x				
			Nitrogen (total)	x	x				
			Nitrogen (total Kjeldahl)	x	x				
			Surfactants	x	x				
			Silica (SiO_2) (total and dissolved)	x	x				
			Silt Density Index (SDI)	x				x	
	Dissolved Gases		Ammonia (NH_3) (as N)	x					Weck
			Soluble Sulfide	x					Weck
	Cations	total	Iron (Fe)	x	x				
			Manganese (Mn)	x	x				
			Phosphorous (total) (P)	x	x				
		Dissolved – (0.45 µm)	Aluminum (Al^{+3})	x	x				
			Boron (B^{+3})		x				
			Calcium (Ca^{+2})	x	x				
			Magnesium (Mg^{+2})	x	x				
			Iron (Fe^{+2})	x	x				
			Manganese (Mn^{+2})	x	x				
			Nickel (Ni)	x	x				
			Phosphorous (total) (P)	x	x				
			Potassium (K^+)	x	x				
			Silver (Ag)	x	x				
			Sodium (Na^+)	x	x				
			Strontium (Sr^{+2})	x	x				
			Zinc (Zn^{+2})	x	x				
	Anions	Dissolved – (0.45 µm)	Bromide (Br^-)	x	x				
			Chloride (Cl^-)	x	x				
			Orthophosphate (PO_4^{-3})	x	x				
			Sulfate (SO_4^{-2})	x	x				
			Sulfide (as S_2^-)	x	x				

c = performed by calculation
c/x = by calculation and measurement
q = will be performed only as a quality check
STL = Severn Trent Labs
CSM = Colorado School of Mines

ACZ = ACZ Laboratories
BioVir =BioVir Laboratory
Weck = Weck Laboratory
Anatek = Anatek Laboratory

Table 3-1 (cont'd). Raw Water Quality Sampling Schedule and Analysis Locations

Water Qualty Parameter Type			Parameter	Initial	Analysis Location				
					STL	Gallup	CSM	Field	Other
Regulated Primary Contaminants	Inorganic	Total (regulations apply to Total)	Antimony (Sb)	x	x				
			Arsenic (As)	x	x				
			Barium (Ba)	x	x				
			Beryillium (Be)	x	x				
			Cadmium (Cd)	x	x				
			Chromium (total) (Cr)	x	x				
			Copper (Cu)	x	x				
			Cyanide (free) (CN^{-})	x	x				
			Fluoride (F^{-})	x	x				
			Lead (Pb)	x	x				
			Mercury (inorganic) (Hg)	x	x				
			Nitrate (NO^{-3}) (as N)	x	x				
			Nitrite (NO^{-2}) (as N)	x	x				
			Selenium (Se)	x	x				
			Thallium (Tl)	x	x				
		dissolved (0.45 μm)	Copper (Cu)	x	x				
			Lead (Pb)	x	x				
			Nitrate (NO^{-3}) (as N)	x	x				
			Nitrite (NO^{-2}) (as N)	x	x				
	Radionuclides		Radium 226	x					ACZ
			Radium 228	x					ACZ
			Gross Alpha (excluding Ra & U)	x					ACZ
			Beta Particle & Photon Emitters	x					ACZ
			Uranium (U)	x					ACZ
	DBPs		Bromate (BrO^{-3})	x					Weck
			Chlorite (ClO^{-2})	x					Weck
			Haloacetic Acids (5 species)	x					Anatek
			Total Trihalomethanes (4 species)	x					Anatek
	Biological & Fouling Potential		Turbidity					x	
			Cryptosporidium	x					BioVir
			Giardia	x					BioVir
			Heterotrophic Plate Count (HPC)	x	x				BioVir
			Total Coliforms	x	x				BioVir
			Fecal Coliforms	x	x				BioVir
			E. coli		x				BioVir

c = performed by calculation
c/x = by calculation and measurement
q = will be performed only as a quality check
STL = Severn Trent Labs
CSM = Colorado School of Mines

ACZ = ACZ Laboratories
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Weck = Weck Laboratory
Anatek = Anatek Laboratory

Table 3-1 (cont'd). Raw Water Quality Sampling Schedule and Analysis Locations

Water Qualty Parameter Type		Parameter	Initial	Analysis Location				
				STL	Gallup	CSM	Field	Other
Regulated Constituents	Organic Chemicals	Alachlor	x	x				
		Benzene	x	x				
		Carbofuran	x	x				
		Carbon tetrachloride	x	x				
		Chlordane	x	x				
		Chlorobenzene	x	x				
		2,4-D (2,4-dichlorophenoxyacetic acid)	x	x				
		Dalapon (2,2-Dichloropropionic acid)	x	x				
		1,2-Dibromo-3-chloropropane (DBCP)	x	x				
		o-Dichlorobenzene (1,2-dichlorbenzene)	x	x				
		p-Dichlorobenzene (1,4-dichlorbenzene)	x	x				
		1,2-Dichloroethane	x	x				
		1,1-Dichloroethylene	x	x				
		cis-1,2-Dichloroethylene	x	x				
		trans-1,2-Dichloroethylene	x	x				
		Dichloromethane	x	x				
		1,2-Dichloropropane	x	x				
		Di(2-ethylhexyl) adipate						
		Di(2-ethylhexyl) phthalate	x	x				
		Diquat	x					Anatek
		Endothall	x					Anatek
		Endrin	x	x				
		Ethylbenzene	x	x				
		Glyphosate	x					Anatek
		Heptachlor	x	x				
		Heptachlor epoxide	x	x				
		Lindane	x	x				
		Methoxychlor	x	x				
		Picloram	x	x				
		Simazine	x	x				
		Styrene	x	x				
		Tetrachloroethylene	x	x				
		Toluene	x	x				
		Toxaphene	x	x				
		2,4,5-TP (Silvex)	x	x				
		1,2,4-Trichlorobenzene	x	x				
		1,1,1-Trichloroethane	x	x				
		1,1,2-Trichloroethane	x	x				
		Trichloroethylene	x	x				
		Vinyl chloride	x	x				
		Xylenes (total)	x	x				

c = performed by calculation
c/x = by calculation and measurement
q = will be performed only as a quality check
Accuracy reported as "Recovery Limits"
Precision reported as "RPD" or "Relative Percent Difference"
STL = Severn Trent Labs

CSM = Colorado School of Mines
ACZ = ACZ Laboratories
BioVir =BioVir Laboratory
Weck = Weck Laboratory
Anatek = Anatek Laboratory

Table 3-2. Unregulated Organic Chemicals of Concern Analyzed by Colorado School of Mines

Group	Name	Category 1	Category 2	Description	EPA Toxicity Class	Major Concern
Indicator 1: Hydrophilic Ionic	Dichlorprop (2-(2,4-dichlorophenoxy) propanoic acid)	Herbicide		Various sources	Slightly	
	Diclofenac	Pharmaceutical		Anti-inflammatory		
	Gemfibrozil	Pharmaceutical		Blood lipid regulator		
	Ibuprofen	Pharmaceutical		Anti-inflammatory – OTC		Public perception
	Ketoprofen	Pharmaceutical		Anti-inflammatory		
	Mecoprop (2-(2-Methyl-4-chlorophenoxy) propanoic acid)	Herbicide		Various sources	Slightly	Public perception
	Naproxen	Pharmaceutical		Anti-inflammatory		
	Propyphenazone	Pharmaceutical		Analgesic		
Indicator 2: Hydrophilic Non-Ionic	Caffeine	Pharmaceutical		Stimulant - Coffee, soda		Public perception
	Primidone	Pharmaceutical		Anticonvulsant (seizures)		
	Phenacetine	Pharmaceutical		Analgesic		
	Tris(1,3-dichloro-2-propyl) phosphate - (TDCPP)	Flame retardant	Carcinogen			
	Tris(2-chloroethyl) phosphate - (TCIPP)	Flame retardant	Carcinogen	Often in flexible foams	Slightly	
	Tris(1,3-dichloroisopropyl) phosphate - (TCEP)	Flame retardant				
Indicator 3: Hydrophobic Non-Ionic	Bisphenol A	Industrial Chemical	Endocrine disruptor	Plasticizer		
	Carbamazepine	Pharmaceutical				
	17β-estradiol	Natural Hormone	Endocrine disruptor	Estrogen		Health
	Testosterone	Natural Hormone	Endocrine disruptor			

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, USBR conducted the testing of the EUWP as described below. USBR field personnel performed field analytical work using field laboratory equipment and procedures for pH, temperature, conductivity, and turbidity. Six laboratories performed water quality analytical work for samples not analyzed on site. The laboratories included Severn Trent Labs, Colorado School of Mines, ACZ Laboratories, BioVir Laboratory, Weck Laboratory and Anatek Laoratory. 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 a 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: 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. As mentioned previously, this ETV test at Gallup, New Mexico, was specifically performed on wastewater effluent.

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

The objective of this initial operations task was to evaluate equipment operation and determine the treatment conditions that resulted 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 USBR 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. Since sufficient historic data was not available for the feed water source for the ETV test at Gallup, an initial full water quality analysis of the feed water was performed. This consisted of six grab samples, one each on the following dates: May 25, June 1, 8, 15, 22 and 28, 2006. The samples were collected between the hours of 12:30pm and 3:30pm. The initial sampling event also included the full analysis of regulated organic chemicals.

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 included pressure decay testing of the UF membranes and a dye challenge test of the RO system. See Section 3.8.4.1 for further discussion about this test.

3.8 Task C: Verification Testing

The verification test ran from July 12, 2006 to August 16, 2006. 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

Table 3-3 lists the water quality and operational parameters measured continuously via online instrumentation. Conductivity, turbidity, and temperature were also verified with manual measurements. Flows were corroborated with total flow readings or by monitoring fill time on tanks. Elapsed run time was also recorded daily based on RO high pressure pump and UF feed pump hours. All continuously measured online data were recorded automatically approximately every 15 minutes. The set points for key operating parameters are listed in Table 3-4.

Table 3-3. Water Quality and Operational Parameters Measured Online

	UF Feed	**UF Retentate**	**UF Filtrate**	**RO Feed**	**RO 1st Array Concentrate**	**RO 2nd Array Concentrate**	**RO 1st Array Permeate**	**RO 2nd Array Permeate**	**RO 2nd Pass Feed**	**RO 2nd Pass Concentrate**	**RO 2nd Pass Permeate**	**RO Permeate**
Flow	FS2			FS4	FS8	FS7	FS5	FS6			FS9	
Pressure	PS3	PS4	PS5	PS9	PS12	PS13	PI11		PI15	PS16	PS14	
Conductivity							CS1	CS2			CS3	
Temperature			TI1									
Turbidity	X											
Turbidity (low range)			X									X
Particle Count	X		X									

Table 3-4. Key Operating Parameters

Parameter	Set Point
UF Feed Flow (gpm)	259
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 Pressures	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:

$$J_t = \frac{Q_p}{S} \tag{3-1}$$

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:

$$J_t = \frac{Q_p \times e^{-0.0239(T-20)}}{S} \tag{3-2}$$

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 water pressure on the membrane (average of inlet pressure and outlet pressure) minus the filtrate (permeate) pressure:

$$TMP = \left[\frac{(P_f + P_c)}{2} \right] - P_p \tag{3-3}$$

where:

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

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:

$$J_{tm} = \frac{J_t}{TMP} \tag{3-4}$$

where:

TMP = Transmembrane pressure across the membrane (psi)
J_t = filtrate flux at time t (gfd). Temperature-corrected flux values were employed. Temperature correction is to 20 °C.
J_{tm} = specific flux at time t (gfd/psi)

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:

$$J_t = \frac{Q_p}{S} \tag{3-5}$$

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 was used to provide temperature corrections for specific flux calculations:

$$J_t \text{ (at } 25^\circ \text{ C)} = \frac{Q_p \times e^{-0.0239 \cdot (T-25)}}{S} \tag{3-6}$$

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:

$$NDP = \left[\frac{(P_f + P_c)}{2}\right] - P_p - \Delta\pi \tag{3-7}$$

where:

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

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 total dissolved solids (TDS) concentrations on either side of the membrane:

$$\Delta\pi = \left(\left[\frac{(TDS_f + TDS_c)}{2}\right] - TDS_p\right)\left(\frac{0.6\ psi}{100\ \frac{mg}{L}}\right) \tag{3-8}$$

where:

$\Delta\pi$ = osmotic pressure (psi)
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 psi 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 psi 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 psi per 100 mg/L TDS gave a much higher osmotic pressure and the ratio of 0.5 psi per 100 mg/L TDS gave a lower osmotic pressure. It was determined that the equation for TDS using a factor 0.6 psi 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:

$$J_{tm} = \frac{J_t}{NDP} \tag{3-9}$$

where:

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

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

$$\%\ System\ Recovery = 100 \left[\frac{Q_p}{Q_f}\right] \tag{3-10}$$

where:

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

Loss of Original Specific Flux: The loss of original specific flux is given as the ratio of specific flux at membrane testing time zero divided by the specific flux at time T, and is calculated using the following equation:

$$Percent\ Loss = 100 \cdot \left(1 - \frac{J_s}{J_{so}}\right) \tag{3-11}$$

where:

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

Solute Rejection: 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:

$$Percent\ Solute\ Rejection = 100 \cdot \left(\frac{C_f - C_p}{C_f} \right) \tag{3-12}$$

where:

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

Break Horse Power:

$$bhp = \frac{Q \cdot P}{1715 \cdot eff} \tag{3-13}$$

where:

Q = total feed flow to hydraulic array plus the Energy Recovery, Inc. (ERI) array
P = feed pressure to the hydraulic array
Eff = efficiency of the high pressure pump motor
1715 is a conversion factor.

Water Horse Power:

$$whp = \frac{Q \cdot h}{3960} \tag{3-14}$$

where:

Q = total feed flow to hydraulic array plus the ERI array
h = feet of head (pressure)
3960 is a conversion factor.

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 psi, even after a backwash. The manufacturer specified that the RO system be cleaned when there is a 10 to 15% decrease in normalized permeate flow, 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 3-1 were monitored during the testing period. Some parameters in this table would not normally be measured at some locations (e.g. UF filtrate, RO feed, total and dissolved silica for the RO permeate), but are in place as quality assurance checks.

In addition to the water quality parameters and manual sample collection listed in Table 3-1, the following in-line measurements were recorded at 5 to 15 minute intervals (most intervals were around ten minutes) with the data acquisition software:

- Turbidity readings recorded for UF feed and filtrate (RO feed) and RO permeate;
- Particle count readings recorded for UF feed and filtrate; and
- Conductivity readings recorded for RO filtrate.

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 was 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.

3.8.4.1 Direct Integrity Testing

3.8.4.1.1 Pressure Decay Test

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. The pressure decay test was also performed after each UF system cleaning.

Pressure decay testing was performed on the UF system daily. The product side of the membranes was drained, both arrays were pressurized to 20 psi with compressed air as shown in Figure 3-1. The feed valve and retentate valves were left in their operating positions. The filtrate valves were closed. Pressure indicator P5 was monitored for 15 minutes. A pressure decline of 0.1 psi/min was determined to be acceptable based on the feed side pipe volume.

In the case that there was a failure of the system, it is necessary to perform a pressure hold test on individual cartridges using the setup shown in Figure 3-2. The cartridge must be removed from the unit. The filtrate connectors were plugged on one side and pressurized with compressed air on the other side. The rate of pressure decline was measured with a gauge attached to the pressurized line. The cartridge was partly submerged in water, rotating the cartridge periodically so that any leaking fibers could be detected and plugged.

As described later in Section 4.5.4, the daily pressure hold test did not provide an accurate reading due to the configuration of the system that was used for the test. The individual cartridge pressure test, described above, was performed at the end of the ETV test. All cartridges were found to be in good condition. However, it was found that the end caps did not fit properly which allowed leakage to occur.

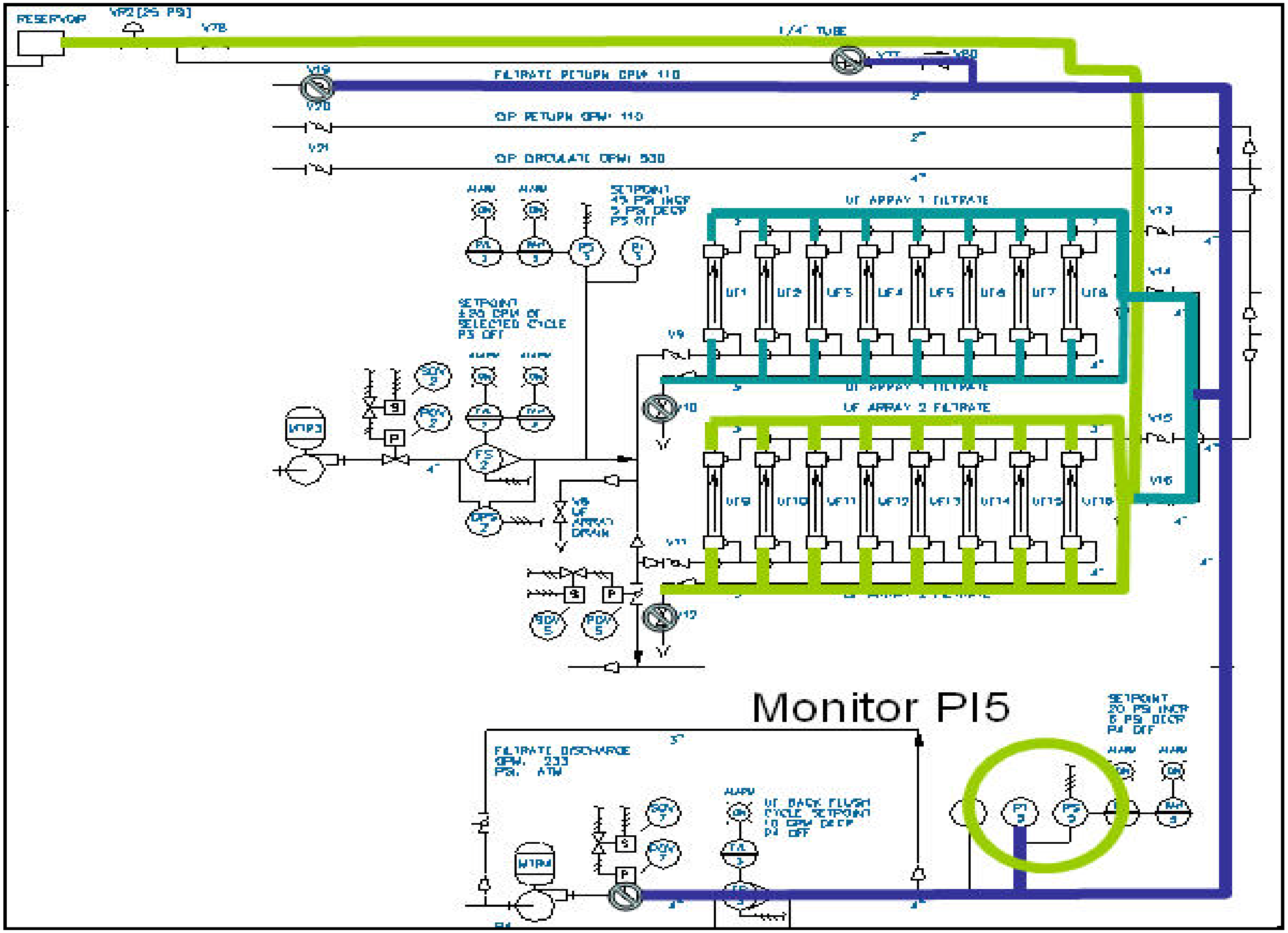

Figure 3-1. Pressurized Lines for Filtrate Side Pressure Hold Test.

Figure 3-2. Individual UF Cartridge Pressure Hold Test.

3.8.4.1.2 Dye Challenge Test

The direct integrity testing method employed on the RO system was a dye challenge test. Florescent Water Tracing (FWT) Red 25 Liquid dye, a formulation of Rodamine WT, was used as a challenge dye for the RO system. It was obtained from Bright Dyes, Division of Kingscote Chemicals, 3334 South Tech Blvd., Miamisburg, Ohio 45342. Table 3-6 lists the properties of the dye.

Table 3-6. Properties of FWT Red 25 Liquid Powder Dye

Property	**FWT Red 25 Liquid**
Detectability of Active ingredient[1]	Visual <100 ppb
Maximum absorbance wavelength [2]	550/588 nm
Appearance	clear dark red aqueous solution
NSF Approved maximum concentration for potable water	0.8 ppb
Molecular Weight	479.02 g/mol
Specific Gravity	1.03±0.05 @25°C
Viscosity [3]	1.3 centipoises (cps)
pH	8.7±0.05 @25°C
Coverage of Product	**One Pint Liquid**
Light Visual	31,250 gallons
Strong Visual	3,125 gallons

1 In deionized water in 100 mL flask. Actual detectability and coverage in the field will vary with specific water condition.

2 No significant change in fluorescence between 6 and 11 pH.

3 Measured on a Brookfield viscometer, Model LV, UL adapter, 60 rpm @25°C.

To determine the concentration that would be required to detect a 99% or greater reduction in concentration between the feed and product during the challenge, first an absorption response curve and then a concentration response curve were developed. Figures 3-3 and 3-4 show the absorbance of a concentration of 2 mL/L of dye solution and the change in absorbance as the dye was diluted from 2 mL/L to 0.005 mL/L.

The FWT Red absorbance is saturated above 1 mL/L. Absorbance at 1 mL/L is 2.922 while the lowest that can be detected reproducibly is 0.005 mL/L with an absorbance of 0.005. Therefore, the maximum detectable log removal was 2.77 $\log_{10}$. A solution was prepared in the RO feed tank to attain an absorbance of approximately 2.9. After monitoring the concentrate until the dye was detected, samples of the product and concentrate were collected at one minute intervals for ten minutes. Absorbance was measured at a wavelength of 560 nm. The concentrate sample was diluted with RO permeate and concentration calculated from absorbance.

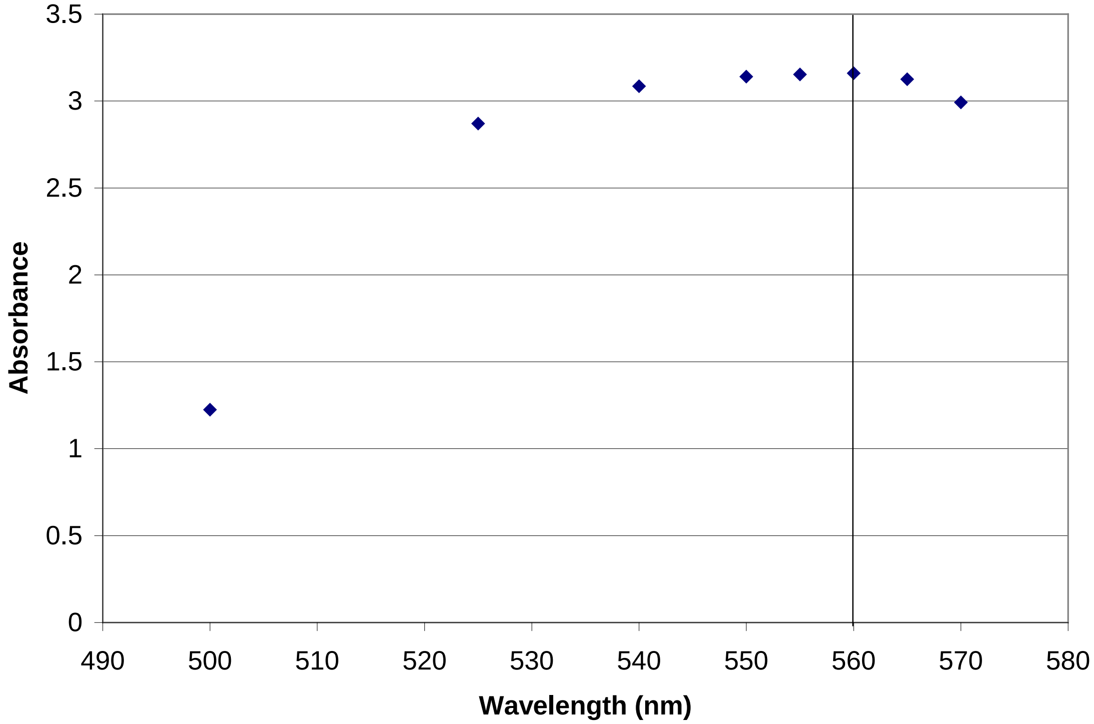

Figure 3-3. Absorbance of 2 mL/L FWT Red Liquid Dye with Maximum Absorbance at Wavelength 560 nm.

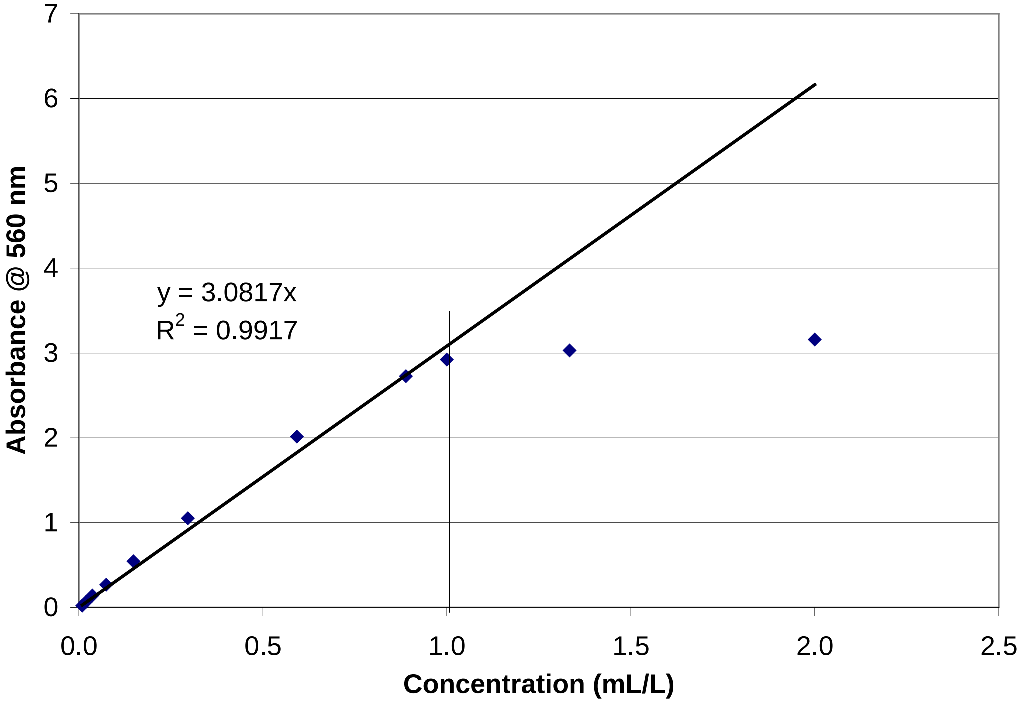

Figure 3-4. Absorbance has a linear correlation to concentration below 1mL/L.

3.8.4.2 Continuous Indirect Integrity Monitoring

The continuous indirect integrity monitoring method used on both the UF and RO membrane systems was turbidity monitoring. Turbidity was monitored continuously on the UF filtrate (RO feed) and RO permeate using a Hach l720E Low Range Process Turbidimeter with sc100 controller. The UF feed was monitored continuously with the Hach FilterTrak 660^{TM} sc Laser Nephelometer. Turbidity was also measured twice daily from each process stream using a Hach 2100P Portable Turbidimeter. Data was downloaded by WaterEye and also saved locally on the controllers. As a backup, WaterEye readings were manually documented twice per day.

In addition to turbidity monitoring, 2200 PCX Particle Counters were installed on the UF feed, filtrate, and RO permeate. Data was written to a dedicated computer at five to 15 minute intervals with most of the data collected at ten minute intervals.

Results of the direct integrity tests and indirect integrity monitoring are presented in Chapter 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 USBR 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 3-3) were recorded automatically by the automated system. The remaining required measurements were recorded by hand by the field operator on-site.

All field activities were documented. Field documentation included field logbooks, photographs, field data sheets, and chain-of-custody forms. USBR was responsible for maintaining all field documentation. Field notes were kept in bound logbooks with each page numbered sequentially. Field data sheets were used to record all operating data as backup and check of data recorded inline by WaterEye.

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

Chain-of-custody forms accompanied all samples shipped to the analytical laboratory. Copies of field sheets and chain-of-custody forms are included in the Appendix.

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.

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.

Table 3-7. On-Site Analytical Equipment 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 flow
	Turbidimeter – in-line	Verified with portable turbidimeter
	pH meter – portable	3-point calibration (4,7,10)
	Turbidimeter – in-line	Volumetrically checked flow
	Particle Counters – in-line	Volumetrically checked flow
	Conductivity meter – portable	Calibrated at 2 points
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 precision thermometer
	Turbidimeter – portable	Calibrated using <0.1, 20, 100, and 800 NTU standards
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

3.8.6.4.1.1 Sampling Locations

Sampling locations are detailed in Table 3-9.

Table 3-9. Water Sampling Locations for Water Quality Samples

Sample Stream	Location
Raw	Grab sample from feed pipe side tap, upstream of any pre-UF chemical addition, or source water near intake
UF Filtrate	UF filtrate sample tap
UF Retentate and Backwash (combined)	Outfall
RO Feed	V90 - Valve immediately after RO strainer
RO 1st Pass Permeate	V58 – *only available during 1st Pass only operation*
RO 1st Pass Concentrate	V91 - Temporary valve off the RO unit
RO 2nd Pass Permeate	V61
RO 2nd Pass Concentrate	V91 - Temporary valve off the RO unit

3.8.6.4.1.2 On-Site Analytical Methods

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

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 compared to the readings from the hand-held turbidimeter daily. In addition to calibration, the lens was cleaned before each calibration using lint-free paper to prevent any particle or microbiological build-up that could produce inaccurate readings. If the comparison suggested inaccurate readings, the in-line turbidimeter was recalibrated. A volumetric check on the sample flow was performed daily.

The LED readout was also recorded in the logbook to ensure a back-up record of the in-line data acquisition system.

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 counter manufacturer provided calibration certificates documenting that the inline particle sensors meet these criteria. The particle counter manufacturer provided the methods for demonstration of coincidence error.

3.8.6.4.1.3 Sample Collection, Shipment, and Storage for Laboratory Analyses

Samples were collected in bottles prepared and shipped to the test site by the laboratories identified in Table 3-1. 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 during storage and shipment to the laboratories. Chain of custody-like forms accompanied all samples.

3.8.6.4.1.4 Laboratory Analytical Methods

A comprehensive list of laboratory analytical methods used can be found in Table 3-10. 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 3-10. Analytical Methods for Laboratory Analyses

Parameter	Analytical Method
Bicarbonate	EPA 310.1
Carbonate	EPA 310.1
BOD	SM(1) 5210 B
COD	EPA 410.4
Color	EPA 110.2
Ammonia	EPA 350.1
Bromide	EPA 300.0
Bromate	EPA 300.1
Chloride	EPA 300.0
Chlorite	EPA 300.1
Odor	EPA 140.1
DOC	EPA 415.1
UV_{254}	SM 5910-B
Sulfate	EPA 300.0
Fluoride	EPA 300.0
Free Cyanide	SM 4500-CN-I
Hardness (total)	EPA 130.2
Nitrate	EPA 300.0
Nitrite	EPA 300.0
Conductivity	EPA 120.1
Alkalinity	EPA 310.1
TDS	EPA 160.1
TOC	EPA 415.1
TSS	EPA 160.2
VSS	EPA 160.4
Dissolved Ortho-Phosphate	EPA 300.0
Dissolved Sulfide	EPA 376.1 and SM 4500 S_2
Surfactants	Special Method
Total Kjeldahl Nitrogen	EPA 351.2
Total Nitrogen	EPA 300.0
Aluminum	SW 846 6010B
Boron	SW 846 6010B
Calcium	SW 846 6010B
Iron	SW 846 6010B
Potassium	SW 846 6010B
Magnesium	SW 846 6010B
Manganese	SW 846 6010B
Sodium	SW 846 6010B
Silica	SW 846 6010B
Strontium	SW 846 6010B
Zinc	SW 846 6010B
Phosphorous	SW 846 6010B
Silver	SW 846 6010B
Copper	SW 846 6010B
Nickel	SW 846 6010B
Lead	SW 846 6010B
Antimony	SW 846 6010B
Arsenic	SW 846 6010B
Barium	SW 846 6010B
Beryllium	SW 846 6010B
Cadmium	SW 846 6010B
Chromium (total)	SW 846 6010B

Table 3-10. Analytical Methods for Laboratory Analyses (continued)

Parameter	Analytical Method
Selenium	SW 846 6010B
Thallium	SW 846 6010B
1,2-Dibromoethane (EDB)	SW 846 8260B
Benzene	SW 846 8260B
Carbon Tetrachloride	SW 846 8260B
Chlorobenzene	SW 846 8260B
1,2-Dibromo-3-chloro propane (DBCP)	SW 846 8260B
1,2-Dichlorobenzene	SW 846 8260B
1,4-Dichlorobenzene	SW 846 8260B
1,2-Dichloroethane	SW 846 8260B
cis1,2-Dichloroethylene	SW 846 8260B
trans 1,2-Dichloroethylene	SW 846 8260B
1,1-Dichloroethylene	SW 846 8260B
1,2-Dichloropropane	SW 846 8260B
Ethylbenzene	SW 846 8260B
Methyl Chloride	SW 846 8260B
Styrene	SW 846 8260B
Tetrachloroethylene	SW 846 8260B
Toluene	SW 846 8260B
1,2,4-Trichlorobenzene	SW 846 8260B
1,1,1-Trichloroethane	SW 846 8260B
1,1,2-Trichloroethane	SW 846 8260B
Trichlorethylene	SW 846 8260B
Vinyl Chloride	SW 846 8260B
Xylenes (total)	SW 846 8260B
Lindane	SW 846 8081A
Chlordane	SW 846 8081A
Endrin	SW 846 8081A
Heptachlor	SW 846 8081A
Heptachlor Epoxide	SW 846 8081A
Methoxychlor	SW 846 8081A
Toxaphene	SW 846 8081A
Aroclor 1016	SW 846 8082
Aroclor 1221	SW 846 8082
Aroclor 1232	SW 846 8082
Aroclor 1242	SW 846 8082
Aroclor 1248	SW 846 8082
Aroclor 1254	SW 846 8082
Aroclor 1260	SW 846 8082
Simazine	SW 846 8141 A
2,4-D	SW 846 8151A
Dalapon	SW 846 8151A
Picloram	SW 846 8151A
2,4,5-TP (Silvex)	SW 846 8151A
Carbofuran	SW 846 8321A
N-Nitrosodimethylamine (NDMA)	EPA 1625M
Gross Alpha/Beta	EPA 900.0
Radium 226	EPA 903.1
Radium 228	EPA 904.0
Uranium	EPA 200.8
Chloroform	EPA 524.2
Bromodichloromethane	EPA 524.2

Table 3-10. Analytical Methods for Laboratory Analyses (continued)

Parameter	Analytical Method
Chlorodibromomethane	EPA 524.2
Bromoform	EPA 524.2
Monochloroacetic Acid	SM 6251 B
Dichloroacetic Acid	SM 6251 B
Trichloroacetic Acid	SM 6251 B
Monobromoacetic Acid	SM 6251 B
Dibromoacetic Acid	SM 6251 B
Endothall	EPA 548.1
Diquat	EPA 549.2
Glyphosate	EPA 547
Total Coliform	SM 9221 B
Fecal Coliform	SM 9221 E
HPC	SM 9216 A
Ibuprofen	(2)
Diclofenac	(2)
Ketoprofen	(2)
Naproxen	(2)
Gemfibrozil	(2)
Propylphenazone	(2)
Mecoprop	(2)
Diclorprop	(2)
Primidone	(2)
Phenacetine	(2)
Caffeine	(2)
Tris(1,3-dichloro-2-propyl)phosphate (TDCPP)	(2)
Tris(2-chloroethyl)-phosphate (TCIPP)	(2)
Tris(2-chloroisopropyl)- phosphate (TCEP)	(2)
17β-estradiol	(3)
Testosterone	(3)
Carbamazepine	(2)
Bisphenol A	(2)

(1) SM=Standard Methods for the Examination of Water and Wastewater
(2) Method described in Reddersen and Heberer (2003)
(3) Method described in Mansell and Drewes (2004)

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:

$$\text{Confidence Interval} = \overline{X} \pm [t_{n-1,1-(\alpha/2)} \times (S/\sqrt{n})] \qquad (3\text{-}13)$$

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:

$$\text{95\% Confidence Interval} = \overline{x} \pm [t_{n-1,0.975} \times (S/\sqrt{n})] \tag{3-14}$$

3.8.6.4.3 Accuracy

The accuracy of on-site analytical equipment was periodically verified according to the schedule in Table 3-5. 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. Accuracy of analytical readings was measured through the use of spiked samples and laboratory control samples. Accuracy also incorporates calibration procedures and use of certified standards to ensure the calibration curves and references for analysis are near the "true value."
Recoveries for spiked samples are calculated in the following manner:

$$\text{\% Recovery} = \frac{100 * (SSR - SR)}{SA} \tag{3-15}$$

where:

SSR = spiked sample result
SR = sample result
SA = spike amount added

Recoveries for laboratory control samples are calculated as follows:

$$\text{\% Recovery} = \frac{100 \cdot (\text{Found Concentration})}{\text{True Concentration}} \tag{3-16}$$

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 can be calculated. Every sampling event with samples shipped to the lab included 10% sample duplicates. RPD was measured by use of the following equation:

$$RPD = \left| \frac{S_1 - S_2}{S_1 + S_2} \right| \times 200 \tag{3-17}$$

where:

S_1 = sample analysis result; and
S_2 = sample duplicate analysis result.

RPD should be less than 30%.

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:

$$\%C = (V/T) \times 100 \qquad (3\text{-}18)$$

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 3-12 presents the completeness requirements based on the sampling frequency spelled out in the test/QA plan.

Table 3-12. 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 flows 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. QA/QC information, as described by the QAPP in the PSTP for this verification test, is presented at the end of the chapter.

4.2 Equipment Installation, Start-up, and Shakedown

The equipment installation, start-up and shakedown tests took place between June 28, 2006, and the beginning of the official ETV test on July 12, 2006. During this period all sensors were calibrated, communications were established with the particle counters and turbidimeters, and several programming issues were resolved. Handheld analyzers were calibrated and checked; colorimetric methods were tested; and the intake screen was installed. It was determined that ferric chloride coagulation would be necessary to keep the UF system running smoothly. Jar tests were performed to estimate the necessary dose rate for this water source.

Background sampling continued during the initial test runs, giving the operators experience in sampling, packaging, and shipping the water samples. A pressure hold test for UF system, and an initial dye test on the RO system were performed during this time.

4.3 Task A: Raw Water Characterization

The objective of this task was to determine the chemical, biological, and physical characteristics of the feed water. As described in the Section 1.5, the feed (raw) water for this ETV test is treated municipal wastewater collected prior to chlorination. Wastewater analysis data for the background samples are listed in Tables 4-1 through 4-9. Parameters that exceed primary drinking water standards included nitrate, haloacetic acids, bromate, gross alpha, and biological components. Secondary drinking water standards are exceeded for color, sulfate, TDS, surfactants, aluminum, and odor. The source of the city's drinking water is high in TDS and sulfate with some radioactivity. The rest of the exceedances are caused by municipal use and the wastewater treatment process.

Additional contaminants of concern found in the feed water (treated municipal wastewater), listed in Table 4-9, include:

- Naproxen - a nonsteroidal anti-inflammatory drug (NSAID) found in Aleve®;
- Gemfibrozil - a lipid regulating agent used to treat heart disease and high cholesterol;
- Primidone - an anticonvulsant used to treat epilepsy and neuralgia;
- Carbamazepine – also an anticonvulsant;
- Tris(1,3-dichloro-3-propyl)phosphate (TDCPP), Tris(2-chloroethyl)phosphate (TCIPP), tris(2-chloroisopropyl)phosphate(TCEP) – components of fire retardant;

- 17β-estradiol – female hormone;
- Testosterone – male hormone; and
- Bisphenol A - a degradation product of plastic and potential endocrine disruptor.

Table 4-1. Background Water Analyses -Severn Trent Results/CSM: General Chemistry

Parameter	Units	Reporting Limit	Date					
			5/25/06	6/01/06	6/08/06	6/15/06	6/22/06	6/28/06
pH	-	0.1	7.8	7.8	7.9	8.0	8.0	8.0
Bicarbonate	mg/L	5	260	270	300	280	290	270
Carbonate	mg/L	5	<5	<5	<5	<5	<5	<5
COD	mg/L	20	20	38	40	26	34	32
Color	Color Units	5	35	30	75	40	40	35
Ammonia	mg/L	0.10	0.12	<0.10	<0.10	<0.10	<0.10	0.11^{J}
Ammonia (CSM)	mg/L	0.10	0.48	NM	0.69	0.56	0.45	0.37
Bromide	mg/L	0.20	<0.20	<0.20	0.21	<0.20	0.20	<0.20
Chloride	mg/L	30	110^{JQ}	110^{Q}	100^{JQ}	110^{Q}	88	100^{Q}
DOC	mg/L	1.0	6.9^{J}	8.6^{J}	13.0	7.7	6.9	7.1
UV_{254} absorbance	(cm^{-1})	-	0.1745	NM	0.1700	0.1819	0.1759	0.1825
Sulfate	mg/L	50	320^{Q}	340^{JQ}	330^{JQ}	340^{Q}	310^{Q}	340^{Q}
Fluoride	mg/L	0.5	1.4	1.4	1.3^{J}	1.3	1.3	1.0
Free Cyanide	mg/L	0.01	NM	<0.01	<0.01	<0.01	<0.01	<0.01
Hardness (total, as $CaCO_3$)	mg/L	5	63	44	47	54	59	44
Nitrate	mg/L	1	13^{Q}	11^{Q}	10	10^{Q}	8.5	11^{Q}
Nitrite	mg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Conductivity	μS/cm	2.0	1700	1700	1700	1700	1700	1700
Conductivity (CSM)	μS/cm	2.0	1672	NM	1653	1642	1636	1659
Alkalinity (as $CaCO_3$)	mg/L	5.0	260	270	300	280	290	270
TDS	mg/L	10	1100	1100	1100	1100	1200	1100
TOC	mg/L	1.0	7.4	22	12	8.1	6.9	7.1
TSS	mg/L	4.0	10	7.6	21	11	15	<4.0
Volatile Suspended Solids	mg/L	4.0	7.6	5.2	14	8	11^{J}	<4.0
Dissolved Ortho-Phosphate	mg/L	0.5	3.1	4.4	<0.5	2.4	2.6	3.4
Dissolved Sulfide	mg/L	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Surfactants	mg/L	0.10	0.75	0.75	0.75	0.50	0.50	0.75
Total Kjeldahl Nitrogen	mg/L	0.50	0.84	2.2	3.1	2.2	2.3	1.6
Total Nitrogen	mg/L	0.50	14	14	14	13	11	13
Nitrate (as N)	mg/L	0.50	19.5	13.8	NM	10.9	10.8	8.7

J - Method blank contamination. The associated method blank contains the target analyte at a reportable level.

Q - Elevated reporting limit. The reporting limit is elevated due to high analyte levels.

NM - Not measured.

Table 4-2. Background Water Analyses –Severn Trent: Dissolved Metals

Dissolved Metals	Reporting Limit (µg/L)	5/25/06 (µg/L)	6/1/06 (µg/L)	6/8/06 (µg/L)	6/15/06 (µg/L)	6/22/06 (µg/L)	6/28/06 (µg/L)
Aluminum	100	<100	NM	310	130	110	130
Boron	100	320	320	310	320	320	300
Calcium	200	14,000 (J)	13,000	13,000	14,000 (J)	12,000 (J)	12,000 (J)
Iron	100	<100	<100	140	<100	<100	<100
Potassium	3,000	15,000	15,000 (L)	13,000 (L)	13,000	13,000	15,000
Magnesium	200	2,800	3,000	2,300	3,000	3,000	2,900
Manganese	10	<10	19	13	<10	<10	<10
Sodium	1,000	400,000	380,000	360,000 (J)	380,000 (J)	370,000	340,000
Silica	1,100	22,000	18,000	19,000	17,000	20,000	21,000
Strontium	10	170	140	160	170	170	150
Zinc	20	62 (J)	60	53 (J)	90	62 (J)	61 (J)
Phosphorus (total)	3,000	3,000	4,400	<3,000	<3,000	<3,000	3,200
Silver	10	<10	<10	<10	<10	<10	<10
Copper	15	<15	<15	<15	<15	<15	<15
Nickel	40	<40	<40	<40	<40	<40	<40
Lead	9.0	<9.0	<9.0	<9.0	<9.0	<9.0	<9.0

NM - Not measured.

J - Method blank contamination. The associated method blank contains the target analyte at a reportable level.

L - Serial dilution of a digestate in the analytical batch indicated that physical and chemical interferences are present.

Table 4-3. Background Water Analyses - Severn Trent: Total Metals

Total Metals	Reporting Limit (µg/L)	5/25/06 (µg/L)	6/1/06 (µg/L)	6/8/06 (µg/L)	6/15/06 (µg/L)	6/22/06 (µg/L)	6/28/06 (µg/L)
Antimony	10	<10	<10	<10	<10	<10	<10
Arsenic	15	<15	<15	<15	<15	<15	<15
Barium	10	<10	<10	10 (J,L)	<10	<10	<10
Beryllium	5	<5	<5	<5	<5	<5	<5
Cadmium	5	<5	<5	<5	<5	<5	<5
Chromium (total)	10	<10	<10	<10	<10	<10	<10
Copper	15	<15	<15	<15	<15	<15	<15
Iron	100	150	130	170 (J)	140	<100	<100
Lead	9	<9	<9	<9	<9	<9	<9
Manganese	10	11	30	17	12	<10	<10
Mercury	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Phosphorus	3,000	3,000	4,400	<3,000	<3,000	<3,000	3,300
Selenium	15	<15	<15	<15	<15	<15	<15
Silica	1,100	21,000	21,000	21,000	15,000	19,000	19,000
Thallium	15	<15	<15	<15	<15	<15	<15

J - Method blank contamination. The associated method blank contains the target analyte at a reportable level.

L - Serial dilution of a digestate in the analytical batch indicated that physical and chemical interferences are present.

Table 4-4. Background Water Analyses - Severn Trent: Volatile Organic Compounds

Volatiles	Reporting Limit (µg/L)	5/28/06 (µg/L)	6/1/06 (µg/L)	6/8/06 (µg/L)	6/15/06 (µg/L)	6/22/06 (µg/L)	6/28/06 (µg/L)
1,2-Dibromoethane (EDB)	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzene	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Carbon Tetrachloride	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Chlorobenzene	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
1,2-Dibromo-3-chloro propane (DBCP)	5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
1,2-Dichlorobenzene	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
1,4-Dichlorobenzene	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
1,2-Dichloroethane	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
cis1,2-Dichloroethylene	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
trans 1,2-Dichloroethylene	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
1,1-Dichloroethylene	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
1,2-Dichloropropane	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Ethylbenzene	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Methyl Chloride	5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Styrene	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Tetrachloroethylene	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Toluene	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
1,2,4-Trichlorobenzene	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
1,1,1-Trichloroethane	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
1,1,2-Trichloroethane	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Trichlorethylene	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Vinyl Chloride	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Xylenes (total)	2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0

Table 4-5. Background Water Analyses - Severn Trent: Semi-Volatile Organic Compounds

GC Semi Volatiles	Reporting Limit (µg/L)	6/1/06 (µg/L)	6/8/06 (µg/L)	6/15/06 (µg/L)	6/22/06 (µg/L)	6/28/06 (µg/L)
Lindane	0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Chlordane	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Endrin	0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Heptachlor	0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Heptachlor Epoxide	0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Methoxychlor	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Toxaphene	2.5	<2.5	<2.5	<2.5	<2.5	<2.5
Aroclor 1016	1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aroclor 1221	1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aroclor 1232	1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aroclor 1242	1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aroclor 1248	1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aroclor 1254	1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aroclor 1260	1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Simazine	10.0	<10.0	<10.0	<10.0	<10.0	<10.0
2,4-D	4.0	<4.0	<4.0	<4.0	<4.0	<4.0
Dalapon	2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Picloram	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2,4,5-TP (Silvex)	1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Carbofuran	1.0	<1.0	<1.0	<1.0	<1.0	<1.0

Table 4-6. Background Water Analysis - Weck and ACZ

	Analyte	Units	Reporting Limit	5/25/06	6/1/06	6/8/06	6/15/06	6/22/06	6/28/06
Weck	Bromate	µg/L	25	<25	<25	<25	<25	<25	<25
	Chlorite	µg/L	50	<50	<50	<50	<50	<50	<50
	Ammonia as N	mg/L	0.1	NM	<0.1	NM	<0.1	0.1	0.11
	Odor	TON	1	12	12	17	17	12	17
	Soluble Sulfide	mg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	NDMA	ng/L	2	<2	6.8	<2	<2	<2	<2
ACZ	Gross Alpha	pCi/L		9.8	0	30	7.5	1.9	16
	LLD(1)			4.4	4.9	4.4	4.4	4.7	4.8
	Gross Beta	pCi/L		18	11	11	14	12	29
	LLD			6.3	7.6	6.3	6.3	7.2	7
	Radium 226	pCi/L		0.09	0.06	0.16	0.1	0.16	0.05
	LLD			0.22	0.221	0.45	0.35	0.64	0.42
	Radium 228	pCi/L		0.34	1.6	1.1	0.15	0.86	1.6
	LLD			0.75	0.86	0.84	1.6	0.62	0.67
	Uranium	mg/L	MDL(2) = 0.0001 PQL(3) = 0.0005	0.0001	0.0001	0.0002	0.0001	0.0002	0.0001

(1) LLD - lower limit of detection
(2) MDL - method detection limit
(3) PQL - practical quantitation limit
NM – Not analyzed.

Table 4-7. Background Water Analyses - Anatek Labs: Disifection Biproducts and Pesticides

Analyte	MDL (µg/L)	5/25/06 (µg/L)	6/1/06 (µg/L)	6/8/06 (µg/L)	6/15/06 (µg/L)	6/22/06 (µg/L)	6/28/06 (µg/L)
Chloroform	0.05	0.46	0.39	0.33	0.32	0.52	0.5
Bromodichloromethane	0.05	<0.05	<0.05	<0.05	<0.05	0.08	0.06
Chlorodibromomethane	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Bromoform	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Monochloroacetic Acid	0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Dichloroacetic Acid	0.5	0.6	0.8	0.5	0.5	0.4	0.6
Trichloroacetic Acid	0.4	1	0.7	0.6	0.6	0.6	0.9
Monobromoacetic Acid	0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7
Dibromoacetic Acid	0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Endothall	1.9	<1.9	<1.9	<1.9	<1.9	<1.9	<1.9
Diquat	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Glyphosate	3.3	<3.3	<3.3	<3.3	<3.3	<3.3	<3.3

Table 4-8. Background Biological Analysis

Analyte	Units	6/1/06	6/8/06	6/15/06	6/22/06	6/28/06
Total Coliforms	MPN/100 mL	24,000	≥160,000	70,000	1,600,000	4,000
Fecal Coliforms	MPN/100 mL	5,000	140,000	70,000	900,000	<2,000
HPC	CFU/mL	6,600	≥160,000	11,000	190,000	11,000

Table 4-9. Background Water Analyses – Colorado School of Mines: Wastewater Contaminants of Concern

	Samples	Detection limit (ng/L)	05/25/06 (ng/L)	06/01/06 (ng/L)	06/08/06 (ng/L)	06/15/06 (ng/L)	06/22/06 (ng/L)	06/28/06 (ng/L)
Indicator 1: Hydrophilic, ionic	Ibuprofen	4	<4	<4	<4	<4	<4	<4
	Diclofenac	1	<1	NA	<1	<1	<1	<1
	Ketoprofen	2	<2	<2	<2	<2	<2	<2
	Naproxen	1	168	65	40	177	127	99
	Gemfibrozil	2	143	35	<2	NA	<2	<2
	Propylphenazone	20	<20	<20	<20	<20	<20	<20
	Mecoprop	2	<2	<2	<2	<2	<2	<2
	Diclorprop	1	<1	<1	<1	<1	<1	<1
ndicator 2: Hydrophilic, non-ionic	Primidone	1	287	277	286	195	283	341
	Phenacetine	40	<40	<40	<40	<40	<40	<40
	Caffeine	40	<40	<40	<40	<40	<40	<40
	TDCPP	50	1110	1185	760	1012	651	888
	TCIPP	50	989	558	520	1008	988	840
	TCEP	50	1055	1040	480	995	800	537
hobic, non-ionic	17β-estradiol	0.4	0.7	0.8	0.8	1	ND	1
	Testosterone	0.5	1	<0.5	<0.5	0.6	<0.5	0.8
	Carbamazepine	2	552	444	<2	<2	<2	NA
	Bisphenol A	5	462	<5	<5	<5	<5	<5

4.4 Task B Initial Test Runs

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 was considered a shakedown testing period and was completed before the main tasks.

Initial equipment checks, UF integrity tests, required calibration checks, and initial test runs took place between June 28, 2006 and the beginning of the official ETV test on July 12, 2006. 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 June 21, 2006. This test was a low pressure test demonstrating that the system held a pressure of 2.4 psi for greater than five (5) minutes. A second higher pressure test was performed on July 12, 2006. These results are presented in Table 4-10. The pressure loss was only 1.5 psi over a 15-minute period (0.1 psi/min). Later, during the verification test it was discovered that the UF pressure decay data was incorrect. Section 4.5.4.1 presents additional information on UF integrity testing.

Table 4-10. UF Full System Integrity Test Results, July 12, 2006

Time (min)	Pressure (psi)	Pressure Change (psi/min)
0	20.0	NA
1	19.8	0.2
2	19.7	0.1
3	19.7	0.0
4	19.5	0.2
5	19.5	0.0
6	19.3	0.2
7	19.2	0.1
8	19.2	0.0
9	19.1	0.1
10	18.9	0.2
11	18.9	0.0
12	18.8	0.1
13	18.7	0.1
14	18.7	0.0
15	18.5	0.2

A dye test to check the RO system was performed on July 10, 2006. A liquid tracing dye stock solution was prepared and then used to develop an absorbance calibration curve by serial dilution of the stock solution. RO feed water with dye added was pumped to the RO system and the RO permeate checked for absorbance. The RO permeate had low absorbance and dye rejection was

>99.4% both arrays. Data from the initial dye test and the dye test at the end of the verification test are presented in Section 4.5.4.2.

It was expected that ferric chloride coagulation would be necessary to keep the UF system running smoothly. Field screening tests were performed to identify the initial dose rate for this water source. Tests at ferric chloride feed rates of approximately 1.5 mg/L (as Fe) and 2.5 mg/L (as Fe) indicated by visual observation that the higher dose provided better floc formation and clearer water. As system shakedown proceeded, the target feed rate was increased to 5.0 mg/L (as Fe) for the start of the test.

4.5 Task C: Verification Test

The verification test was started on July 12, 2006 and ran until August 16, 2006, covering 36 calendar days. The system was shut down for two days (July 24 and 25, 2006) for RO cleaning and for two days (July 30 and 31, 2006) for UF cleaning. An additional RO cleaning was performed from August 7 to August 8, when the system was down for approximately 24 hours. The system was in operation on 32 calendar days, which met the test plan goal for collecting operating data for a minimum of 30 days. The EUWP was operated as continuously as possible. Shut downs occurred each day to perform the pressure hold test on the UF system, to calibrate sensors, clean the strainers, etc. Operators were on site only during the day light periods. 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 mean RO operating hours during the verification test was 18 hours per day. The mean UF operating hours during the verification test was 14 hours per day with a median of 15 hours. The UF operating hours were lower than the RO as the system is designed for the UF to operate at a higher filtrate flow rate than the RO feed rate in order to keep the RO feed tank full. Whenever the RO feed rate tank is at maximum level, the UF is automatically shut down until the RO feed tank level drops to the pre-set level to restart the UF system.

4.5.1 Task C1: Membrane Flux and Operation

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

Operational data were collected and on-site water quality measurements were made twice per day on most days of operation. Occasionally, only one set of measurements were obtained due to maintenance activities limiting the time available for operators to collect operating data. The data were summarized for presentation and discussion in this Section. The complete data set can be found in Appendix L.

4.5.1.1 UF Operating Data

4.5.1.1.1 UF flow Rate, Filtration Production, TMP Results, and Specific Flux Results

The UF operational statistics are presented in Table 4-11. The UF skid does not have a filtrate flow meter or filtrate pressure gauge. Therefore, the total filtrate flow rate was calculated as the UF feed water flow rate minus the UF retentate flow rate. The intake flow is the intake from the source water into the UF feed water 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 4-11. UF Operational Data Statistics

Parameter	Count	Mean	Median	Minimum	Maximum	Standard Deviation	95% Confidence Interval (CI)
UF Operation per day (hr)	30	14	15	4	20	4.1	±1.5
Intake Flow (gpm)	53	281	288	217	301	21.0	+5.65
Feed Flow (gpm)	53	250	251	179	314	24.3	±6.55
Filtrate Flow (gpm)	53	229	229	154	289	25.0	±6.74
Retentate Flow (gpm)	49	24	25	19	30	4.4	±1.2
Backwash Flow (gpm)	900 gallons per backwash cycle(1); Backwash every 30 minutes						
Feed Pressure (psi)	53	22	21	16	30	3.9	±1.1
Retentate Pressure (psi)	53	19	19	0	28	5.4	±1.5
Filtrate Temperature (°F)	54	78	78	76	82	1.5	±0.4

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

The mean UF feed water flow rate of 250 gpm was slightly below the target feed flow rate of 259 gpm specified for the system (See Table 3.5 Section 3.7). The mean filtrate flow rate of 229 gpm corresponds to a flow rate of 14.3 gpm for each of the 16 UF membrane modules. The UF water recovery was 91.6% based on the mean feed water and filtrate flow rates.

Figure 4-1 shows the UF system flow rates over the duration of the verification test. The retentate flow rate remained steady throughout the test. The feed water flow rate and filtrate flow rates dropped as the intake strainers and UF membranes became fouled with solids and TMP increased. Manual adjustment of the flow control valve was made to hold the feed water and filtrate flows as steady as possible. The increase in flow rates on July 18 occurred after the strainer on the feed line was cleaned, which provided more feed line pressure and flow to the UF system.

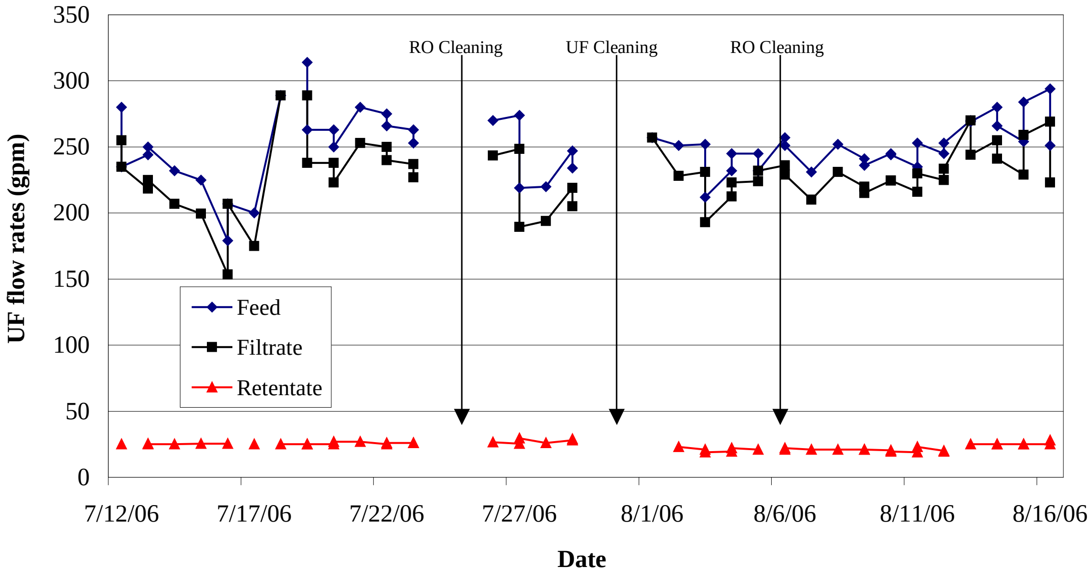

Figure 4-1. Plot of UF system flow rates throughout the testing period.

UF filtrate production was tracked using the RO feed totalizer plus the number of backwash cycles performed (900 gallons of UF filtrate used per backwash). The total UF filtrate volume produced was 5,693 kgal, which gives an average total production rate of 178 kgal per day. This daily production rate calculation excludes the four RO and UF cleaning days when the UF was not operated, but includes all other operating days. The net UF filtrate production, which also equals the RO feed water volume, was 5,089 kgal. Figure 4-2 shows the cumulative total and net filtrate production for the UF system over the duration of the verification test.

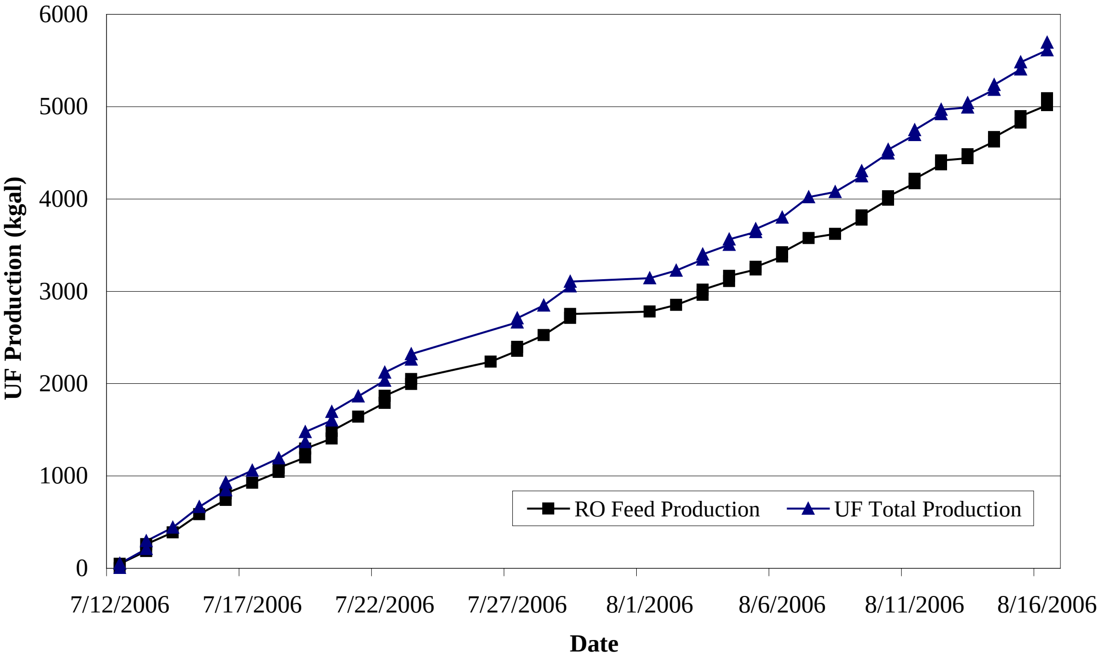

Figure 4-2. UF system filtrate production through the testing period.

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

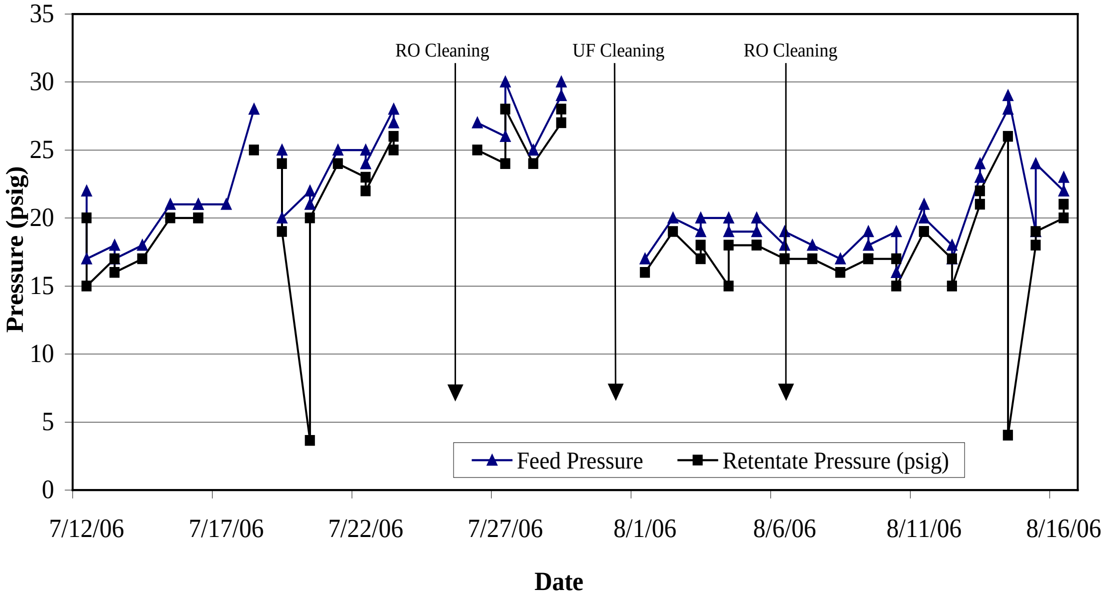

Figure 4-3. Plot of UF system feed and retentate pressures over the testing period.

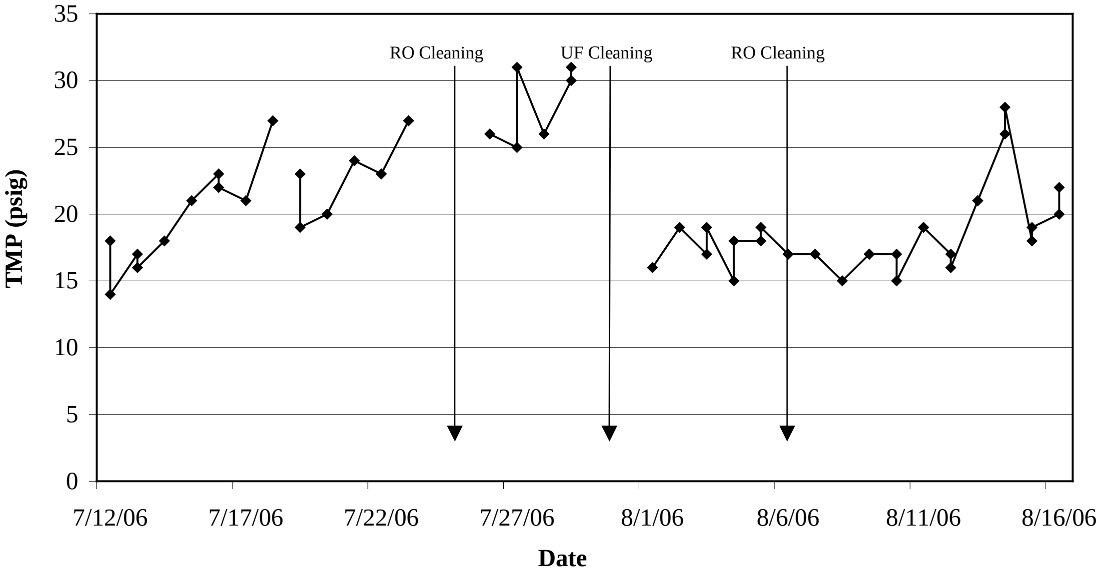

Figure 4-4. Plot of UF system TMP over testing period.

Water production for UF membrane systems is typically expressed in terms of flux (gfd) or specific flux (gfd/psi) adjusted to a standard temperature of 20 ^{o}C. The use of specific flux allows for comparison of filtrate production between various types of membranes and provides data for determining the number of membrane modules and pressure needed to produce the desired volume of water. The impact of temperature is accounted for by adjusting the data to a standard temperature. Figure 4-5 shows the specific flux calculated for the UF system during the test. The impact of solids buildup on the system between July 12 and July 29 is clear. As described further in Section 4.2, the CIP in late July was successful, as the specific flux was restored to a level equal to the start of the test.

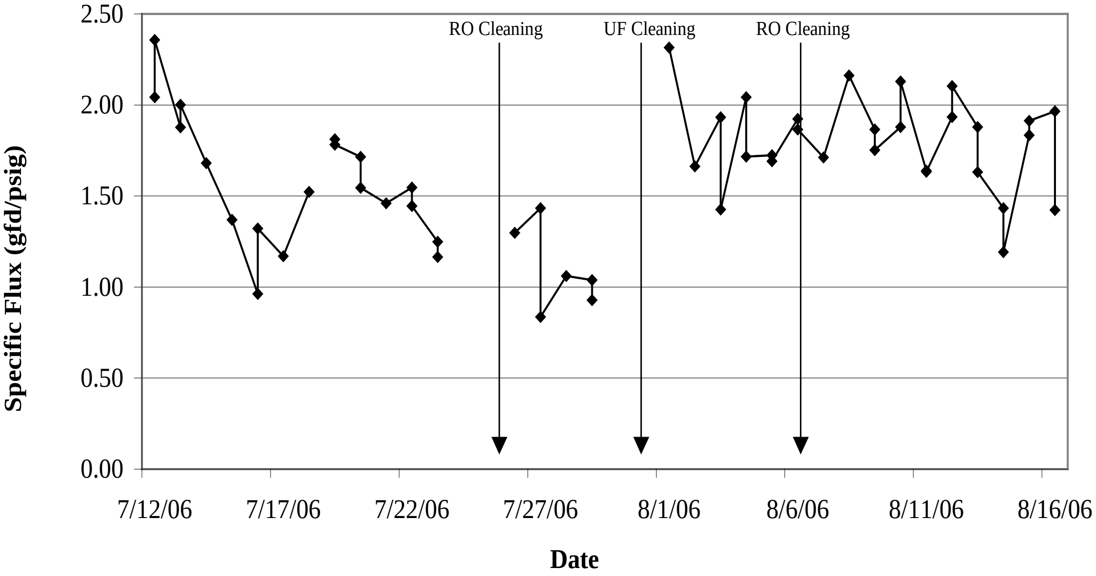

Figure 4-5. UF system specific flux over testing period.

4.5.1.1.2 UF Flow Rate, Filtrate Production, TMP, and Specific Flux Discussion

The EUWP stated that the net UF production design rate is 250,000 gpd (not including backwash water) and the performance objective stated for this verification (Section 2.8) was 200,000 gpd. Based on the mean net filtrate production of 178,000 gpd over the verification period, the UF system did not achieve the specified design production rate or the verification performance objective. The reason the specified production rate was not achieved was that the unit did not operate a sufficient number of hours per day to meet the production goal. At a mean filtrate flow rate of 229 gpm and accounting for a backwash volume of 900 gallons every 30 minutes, the unit would need to operate an average of 21.3 hours per day to achieve a net filtrate production of 250,000 gpd and 17 hours per day to meet the verification performance objective of 200,000 gpd. The UF system operated an average of 14 hours per day and the RO unit operated an average of 18.1 hours per day.

The primary reason the UF system did not achieve the design production rate is that the UF system automatically shutdown anytime the RO system feed water tank was full. The test was designed to verify the entire system with both UF and RO in operation. Since the RO system has less production capacity than the UF system, the UF system did not need to meet the stand alone design specification of 250,000 gpd or performance target of 200,000 gpd. The UF produced sufficient water to meet the RO system water requirements.

Occasionally, UF system downtime for maintenance and integrity testing, resulted in the RO system being shutdown as well. This was due to the limited UF filtrate storage capacity (RO feed water storage tank). With more storage capacity for UF filtrate, the UF system would have been able to meet the feed requirements for the RO system during the daily integrity testing and maintenance periods.

During the verification test, the operators were only on site during daytime periods. Therefore, any time there was an alarm during the unattended hours, which shutdown either the UF or the RO system, the units would remain shut down until an operator arrived the next morning. This situation further reduced the operating hours of the UF system.

The UF system operated with an average filtrate flux of 36.5 gfd (temperature adjusted normalized flux of 31.8 gfd). As shown in Figure 4-5, the specific flux started for the clean system at 2.04 gfd/psi and dropped to 0.93 gfd/psi prior to cleaning. Figure 4-6 shows the loss (or gain) of specific flux over the duration of the verification test. The loss (or gain) of 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 a given day’s specific flux to the start of the test. As can be seen, there was a steady loss of specific flux before the first cleaning on July 30. The cleaning was successful and resulted in the UF system having a specific flux after the cleaning similar to the start of the test.

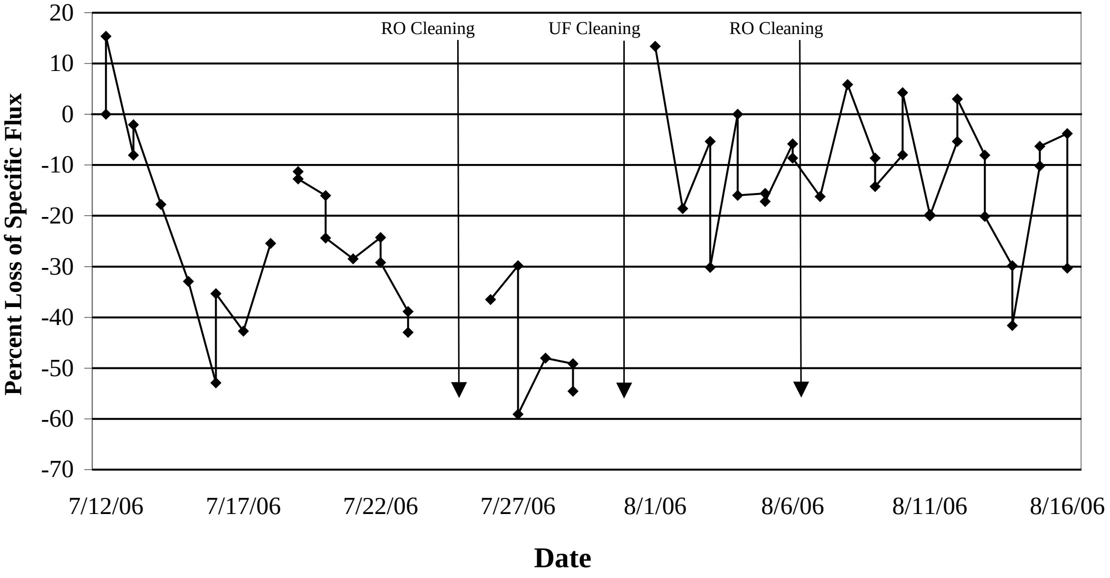

Figure 4-6. Loss of specific flux over time.

Figure 4-7 shows the backwash record during the testing period. The UF unit is programmed to perform a 205 second backwash cycle each 30 minutes if the Amiad strainers are not backwashing. The timer restarts after the backwash is completed. Based on the UF hour meter data, the backwash counter data, and the expected frequency of a backwash occurring every 33.42 minutes, it is apparent that the system was only achieving an average of 34% of the backwashes. The UF system was not achieving the backwash rate anticipated, because at the start of testing the Amiad strainers were attempting to backwash much more often to keep up with the high solids loading from the WWTP. This prevented as much as 68% of the scheduled backwashes. The PLC was set to skip UF backwashes if the Amiad strainer was backwashing. Declines in the UF performance during the first two weeks of testing appear to be caused by the increase in the time between backwashes. The backpressure on the Amiad Strainers was increased from 40 to 70 psi on August 6th on instruction from Village Marine. This improved the backwash frequency to 35% of scheduled, enabling a more consistent performance.

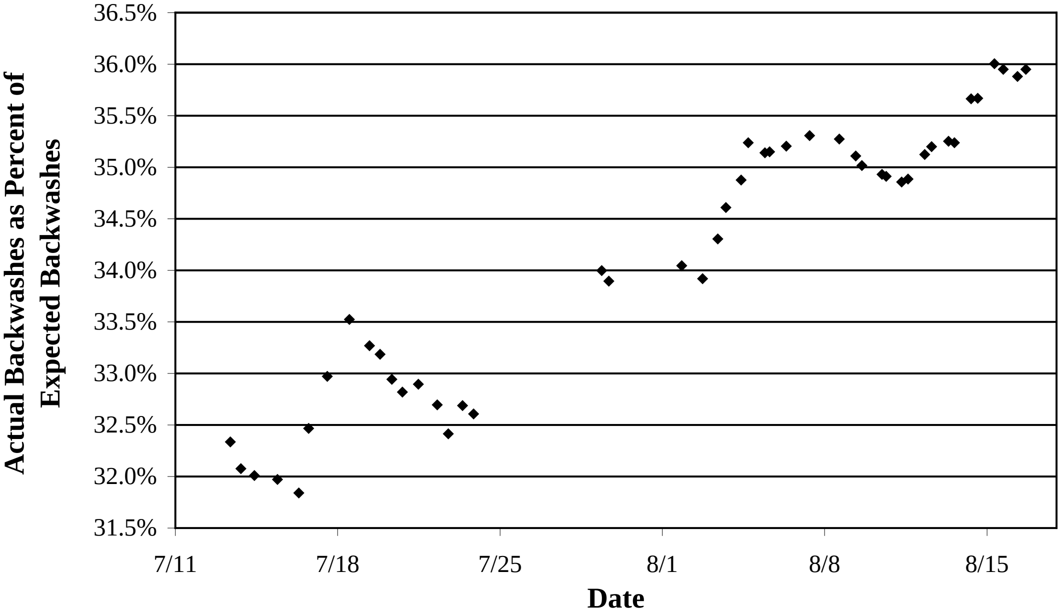

Figure 4-7. UF System Backwash Analysis.

4.5.1.2 RO System Operational Data

4.5.1.2.1 RO Flow Rates, Operating Pressures, Recovery, and Specific Flux Results

The RO operational statistics for the verification test are presented in Table 4-12. The RO system has flow meters and pressure gauges to monitor the feed water and permeate for Array 1. The concentrate flow rate for Array 1 reported in Table 4-12 is calculated as the difference between the feed water flow rate and the permeate flow rate. Array 2 has flow meters for the permeate and concentrate, and gauges to monitor pressure for the feed water, permeate, and concentrate. The feed flow rate for Array 2 was calculated by adding the permeate and concentrate flow rates. The UF system supplied all of the feed water for the RO system.

Table 4-12. RO System Operational Measurement Statistics

Parameter	Count	Mean	Median	Minimum	Maximum	Standard Deviation	95% CI
Array 1 Feed Flow (gpm)	54	107	107	104	110	1.29	±0.34
Array 1 Permeate Flow (gpm)	54	53	55	42	64	5.44	±1.45
Array 1 Concentrate Flow (gpm)	54	54	53	43	67	5.52	±1.47
Array 2 Feed Flow (gpm)	54	41	41	32	48	4.14	±1.10
Array 2 Permeate Flow (gpm)	54	17	18	11	22	2.74	±0.73
Array 2 Concentrate Flow (gpm)	54	24	23	20	29	1.70	±0.45
Array 1 Feed Pressure (psi)	54	290	293	222	366	26.1	±6.96
Array 1 Concentrate Pressure (psi)	53	197	199	134	263	24.8	±6.67
Array 2 Feed Pressure (psi)	54	193	195	133	261	23.6	±6.28
Array 2 Concentrate Pressure (psi)	54	138	138	91	182	19.0	±5.06
Array 1 and 2 Combined Permeate Pressure (psi)	54	20	19	9	42	5.82	±1.55

Figure 4-8 shows the daily flow rates for permeate and concentrate for both arrays. Figure 4-9 shows the feed water and concentrate pressures for both arrays. The RO system showed a decrease in permeate flow rate for both arrays during the first two weeks of the verification test. The feed water pressure to array 1 remained steady during this time, but the concentrate pressure on array 1, which also impacts the feed pressure to array 2, decreased during these first two weeks. Following the RO cleaning, flows and pressures returned to conditions similar to the start of the test and remained steady until near the end of the test, when operators reduced the recovery rate by lowering the feed pressure. This was done to reduce the loading to the RO. Feed flow and pressure were increased again on the last day of the test.

The concentrate pressure from Array 1 was used by the energy conservation device to provide the feed water pressure for Array 2. This energy saving device eliminated the need for a high pressure pump for the Array 2 flow rate, which was approximately 32% of the Array 1 flow rate. Without the energy saving device, additional pumping capacity and the associated energy use would be required. The energy saving device achieved array 2 feed pressures that were similar to the Array 1 concentrate pressures throughout the test. Based on the permeate flow rate from Array 2 representing 24% of the RO water production (mean feed flow rate of 17 gpm out of a mean 70 gpm total), it can be roughly estimated that the energy conservation device saved 25% of the energy that would have been required if all the permeate was produced by high pressure pumps.

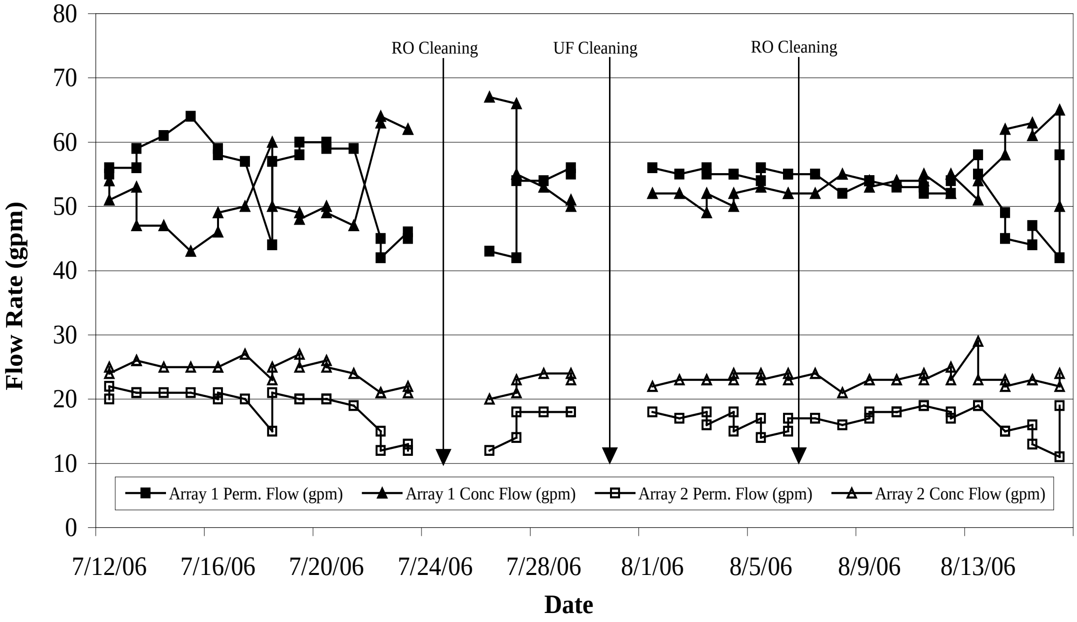

Figure 4-8. RO system flow rates.

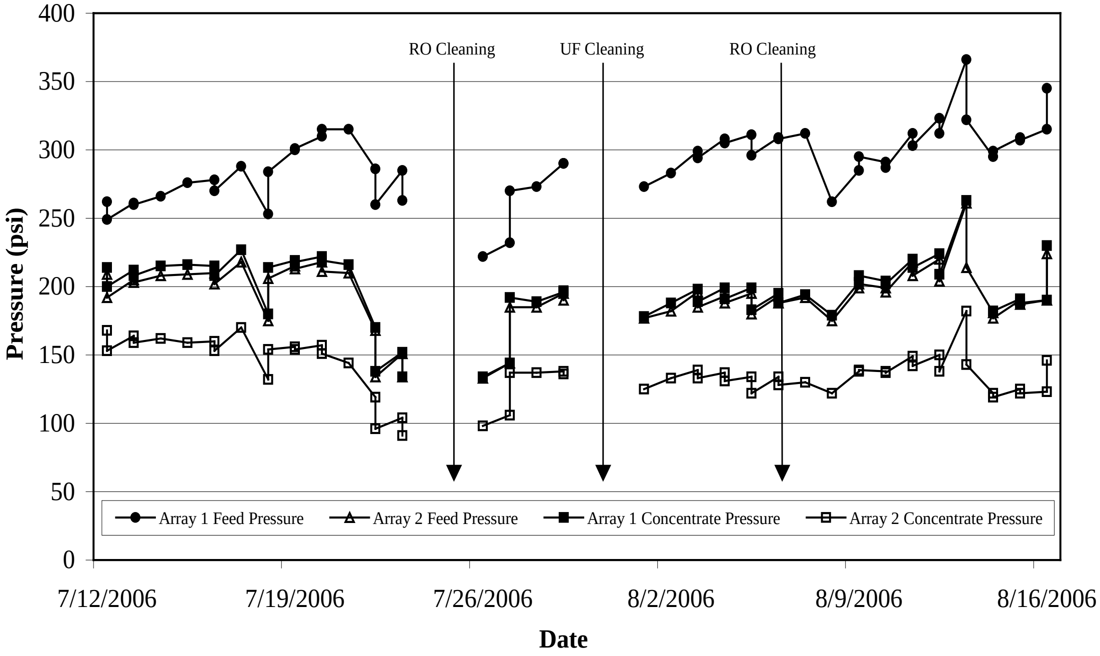

Figure 4-9. RO system operating pressures.

Figure 4-10 shows the percent recoveries achieved by the RO system. Recoveries, calculated as the permeate flow rate divided by the feed water flow rate, were consistent throughout the test. The mean percent recovery for Array 1 was 50% with a median of 51%. The mean recovery for Array 2 was 42% with a median of 43%. As expected, the recoveries for Array 2 were lower than for Array 1, as Array 2 operates at a lower feed water pressure.

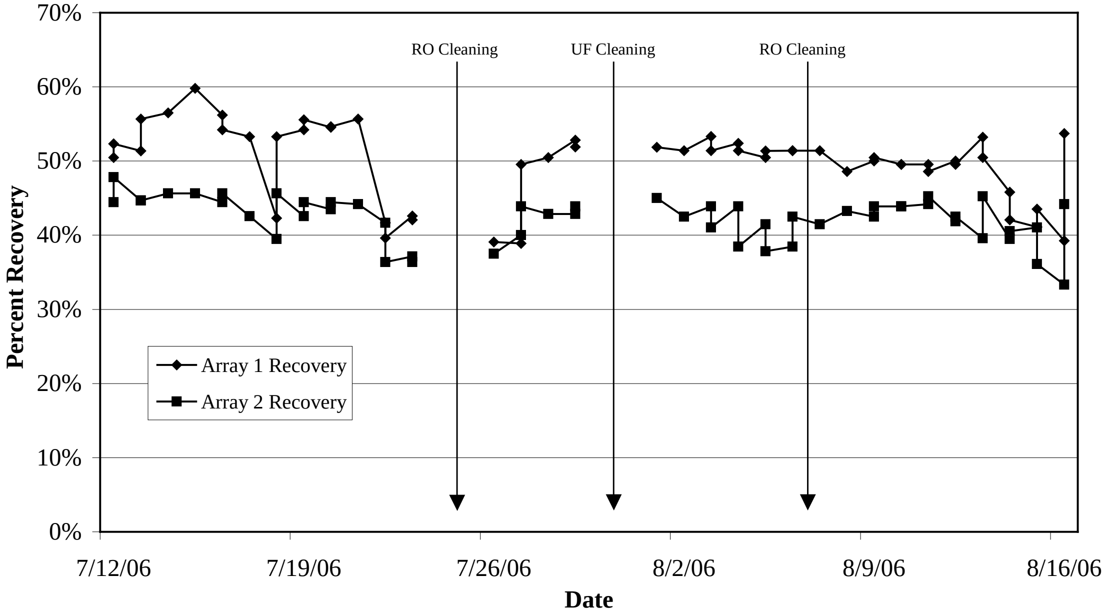

Figure 4-10. RO system percent recoveries.

Figure 4-11 shows the RO permeate production during the test and the total volume of feed water pumped to the RO system. The RO produced 2,419 kgal of permeate from a total RO feed water of 5,089 kgal. This yields an overall recovery of 48%.

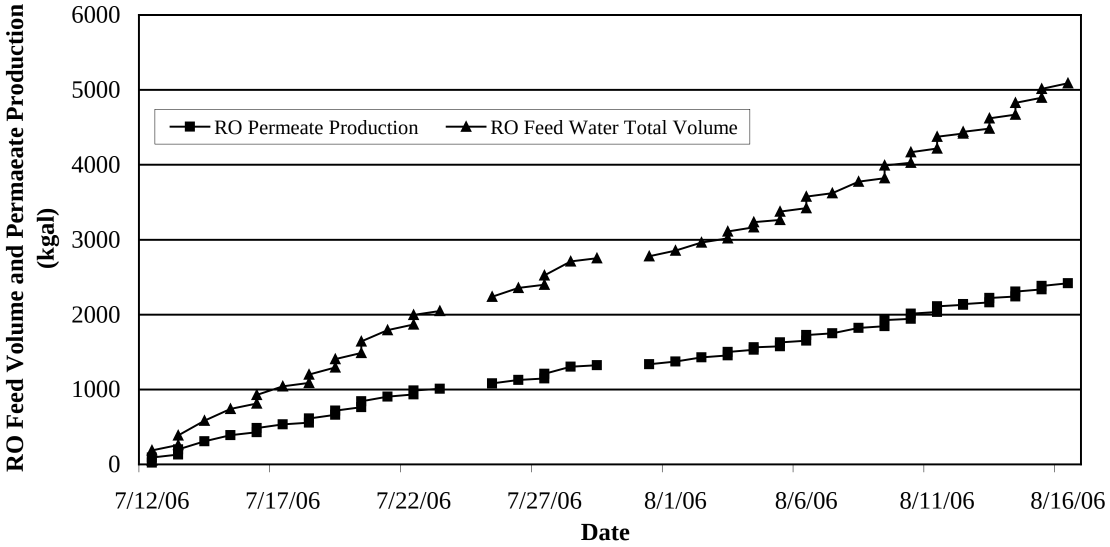

Figure 4-11. RO system permeate production and feed water volume.

A common method of evaluating RO membrane performance is to calculate the specific flux, which is based on the permeate flux and the 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. 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:

$$y(\text{TDS}) = 0.6014x(\text{conductivity}) \tag{4-1}$$

The permeate flux was also adjusted for temperature to 25 ^{o}C, as is the convention.

Figure 4-12 shows the specific flux for the two RO system arrays based on NDP and adjusted to a temperature of 25 ^{o}C. The decrease in the specific flux over the first two weeks of the test, further indicates that the RO membranes were being fouled over time. After cleaning on July 24 to July 25, the specific flux remained steady for the next two weeks and then began to decline once again near the end of the test. Based on the pattern established over the verification test period, it would appear that the RO system would require cleaning every two to three weeks in this type of application. If the leakage problem with UF system was resolved, then it would be expected that the RO cleaning frequency would be reduced.

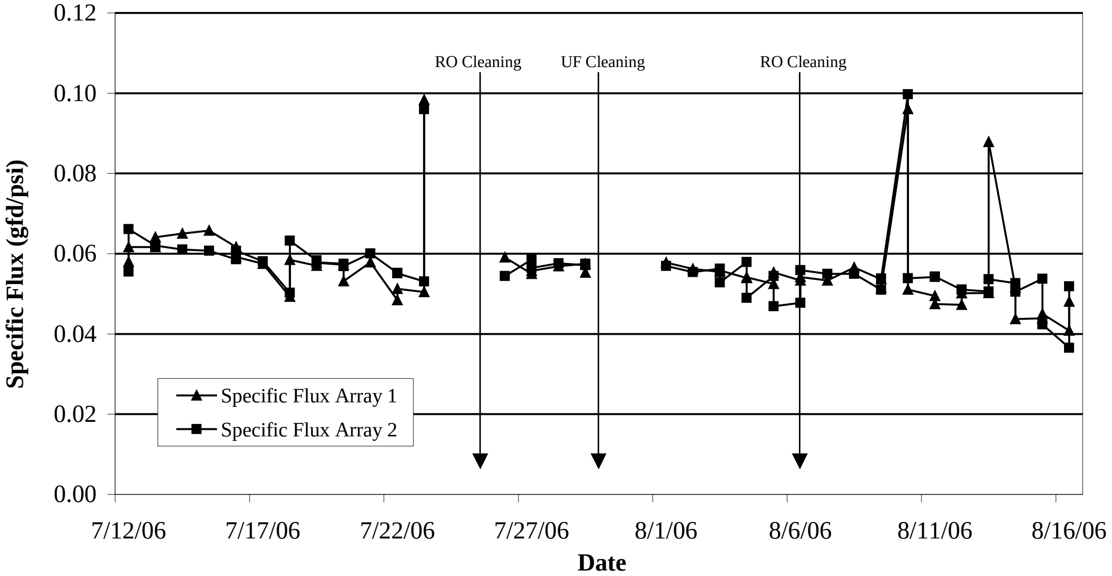

Figure 4-12. RO system specific flux.

4.5.1.2.2 RO Flow Rate, Pressures, and Specific Flux Discussion

The RO system did not achieve the permeate production of 100,000 gpd claimed in the statement of performance. The mean permeate production for the 32 calendar days of operation was 78,000 gpd. The mean feed water flows of 107 gpm for Array 1 and 41 gpm for Array 2 were below the target feed rates established in the test plan (Array 1 target 116 gpm and Array 2 target was 58 gpm). The percent recovery for Array 1 of 50% equaled the target specification of 50%. The Array 2 percent recovery of 42% was below the target specification of 48%. These recoveries in conjunction with the feed water flows resulted in mean permeate flow rates of 53 gpm for Array 1 and 17 gpm for Array 2. At these flow rates, the RO unit would need to operate an average of approximately 24 hours per day to meet the claimed target of 100,000 gpd. The RO unit averaged 18 hours per day of operation during the test.

It was apparent during the test that the UF treated secondary wastewater was putting a heavier load on the RO than initially expected. For this type of application, it appears that lower percent recoveries and lower flows were achieved as compared to design specifications based on groundwater and seawater. During the last few days of testing the recovery was set to 40% to protect the system from heavy loading from and poor performance of the WWT. While this may not have been necessary, it explains the drop in flows and pressure near the end of the test.

It should be noted that while the RO only achieved approximately 78% of the performance objective for permeate production, additional operating time each day would have increased the total production. As noted in the UF system discussion, operators were only present during daylight hours and there was no coverage over night. Therefore, if an alarm sounded and shutdown the unit, the system remained off-line until an operator arrived the next morning. While it is not realistic to operate the RO unit continuously 24 hrs per day for several days, additional operator coverage could increase operating hours and achieve permeate production closer to the specified target.

4.5.1.3 Power Requirements and Efficiency

Figures 4-13 and 4-14 show the UF and RO system power requirements per hour and per volume of water produced from the UF and RO. The values are comparable to those for water recycled using RO presented by the Affordable Desalination Collaboration (ADC News Release May 4, 2006).

The efficiency of the high pressure RO pump motor is labeled as 92%. There are a variety of ways to verify actual performance, one is to calculate the brake horse power (bhp) and/or water horse power (whp), calculate the theoretical energy needed, and compare to the actual energy used. The efficiency of the ERI device was calculated as the ratio of the Array 1 concentrate pressure to the Array 2 feed pressure. The results of all three methods are shown in Figure 4-15. Considering that the system is designed to operate at 800 – 1000 psi, rather than 300 psi, the pump and energy recovery device did very well. Efficiencies greater than 1 are possible due to the additional work by the ERI device.

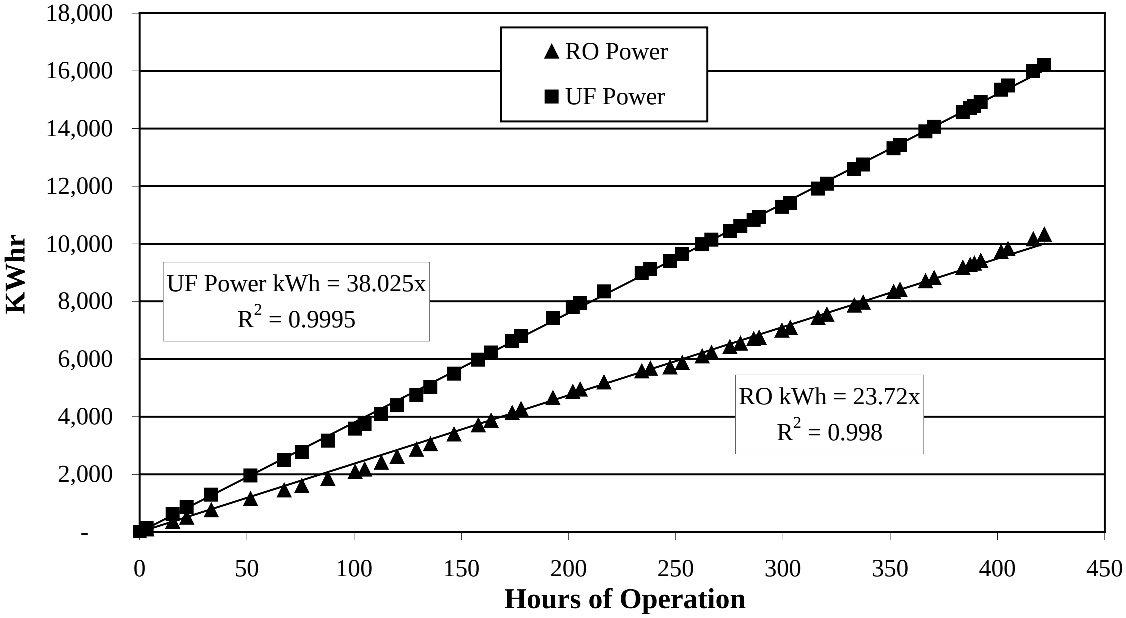

Figure 4-13. RO and UF power consumption over time.

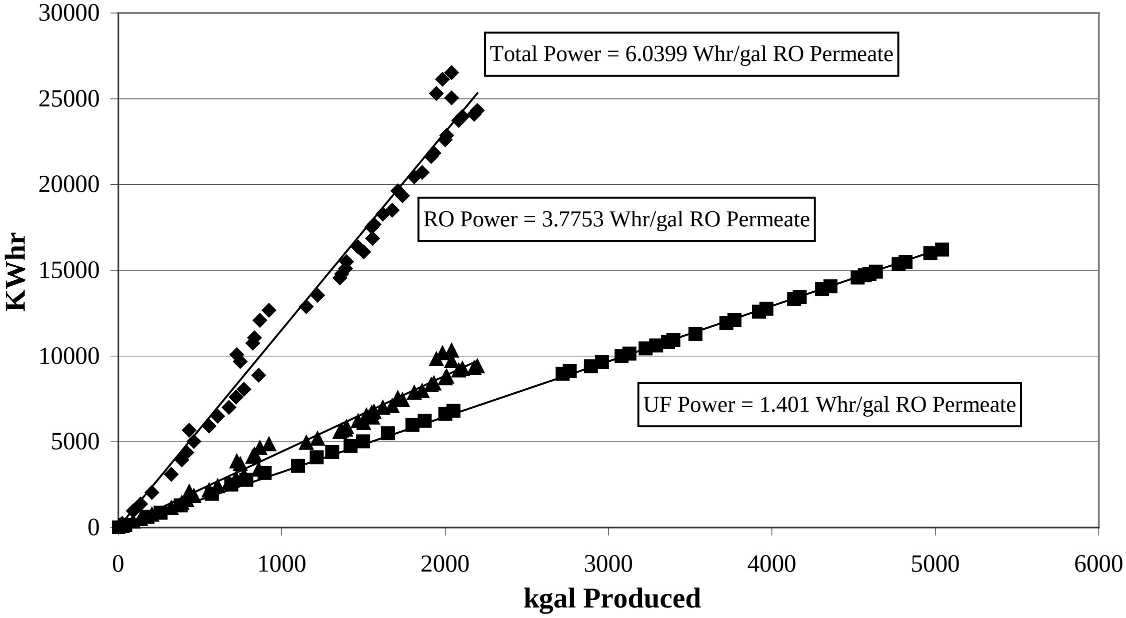

Figure 4-14. RO and UF power requirements per kgal of RO permeate.

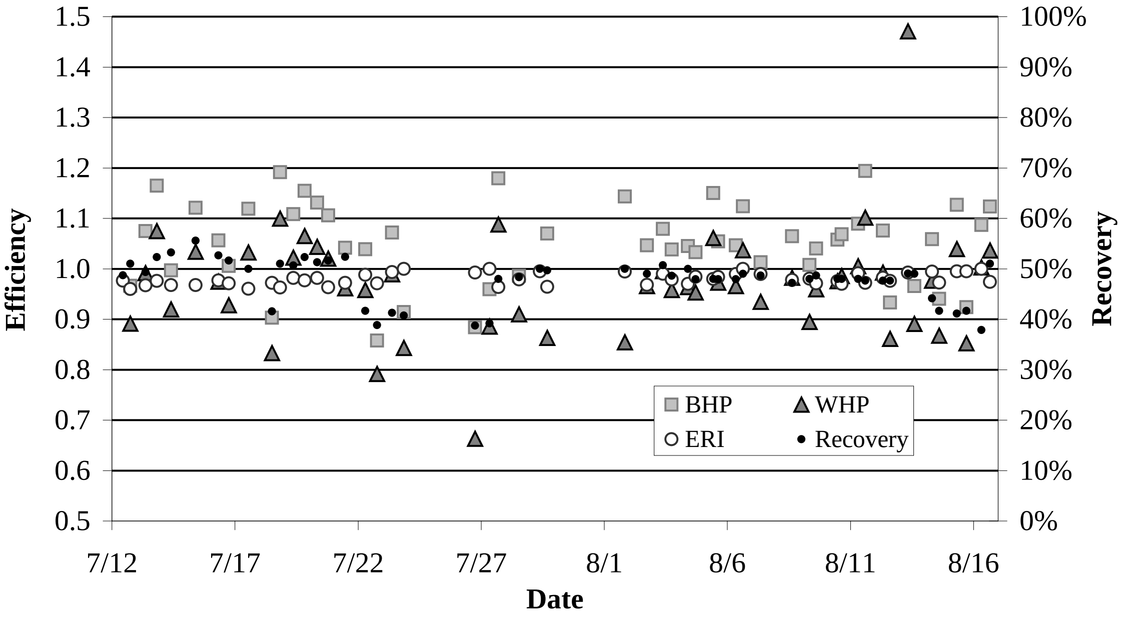

Figure 4-15. RO system energy efficiency calculated from bhp, whp, and energy recovery based on total feed flow compared to the overall water recovery.

4.5.2 Task C2: Cleaning Efficiency

An important aspect of membrane operation is the ability to achieve long run times between chemical cleanings (maintain up 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.

As shown in Figure 4-7 and discussed in Section 4.5.1.1.2, the automatic backwash system was only operating between 30 and 35% of the time. This was due to frequent backwashing of the Amiad filter ahead of the UF system. The PLC was programmed to not allow a UF system backwash to occur if the Amiad strainer was in backwash mode. Adjustments were made to the pressure setting on the Amiad strainer during the test to reduce the time it was in backwash mode and increase the number of successful UF system backwashes.

The UF system was expected to require CIP chemical cleaning about every 15 to 30 days. The UF system was only cleaned once, after 15 calendar days of operation and then ran without additional cleaning for 16 days until the end of the test. There were indications that the UF would need cleaning again at the end of the test, as TMP was increasing.

The CIP for the UF system started on July 30 and continued through July 31, 2006. The specific flux had dropped from 2.04 gpd/psi to 0.93 gpd/psi and the TMP had increased to 31 psi. The UF system was still producing filtrate at an acceptable rate for overall system operation, but the TMP had reached the target cleaning level of 30 psi and the specific flux had dropped by more than 50%. The operators were also informed that the wastewater facility had not activated a secondary clarifier at increased flows, and that the secondary effluent was elevated in TSS. Based on these facts, the CIP was initiated.

As shown in Figure 4-6 and Table 4-13, the CIP was successful in restoring the specific flux and lowering the TMP of the UF system. The initial specific flux started at 2.04 gfd/psi and was restored to 2.18 gfd/psi after the cleaning. TMP started at 18 psi, had increased to 31 psi, and was restored to 16 psi after the cleaning.

Table 4-13. UF System Performance Parameter Values at Key Intervals

Date Range	Specific Flux (gfd/psi)	Transmembrane pressure (psi)
7/12	2.04	18
7/17	1.17	21
7/19	1.81	19
7/29	0.93	31
8/1	2.18	16
8/16	1.42	22

Table 4-14 provides a summary of the performance parameters for the UF system and also a history of the strainer and UF cleaning based on the operator logs and operating data.

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. Citric acid and sodium hydroxide were added to water in the cleaning solution tank to make a pH 3 or pH 11 cleaning solution. 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 4-14 shows the amount of each chemical that was used for the cleaning. The CIP mixing tank contained 270 to 300 gal. Each bank of modules was circulated with the each solution for 20 to 30 minutes. The membranes were then soaked overnight with the high pH solution.

Table 4-14. Change in UF Performance with Cause and Action Taken

Date Range	Change in Specific Flux	Change in Transmembrane pressure	Action	Chemical Usage
7/13 – 7/17	-42%	+16%	Cleaned & Adjusted backpressure on Amiad strainer	
7/17 – 7/19	-11%	+6%	Improved Strainer performance	
7/19 – 7/29	-54%	+72%	Cleaned UF System	6.5 lbs. Citric Acid @ 40°C/ 2.3 L NaOH pH 14 plus 11.6 L bleach, 39°C
8/1	+7%	-11%	After Cleaning	
8/1 – 8/15	-30%	+22%	End of Testing	

4.5.2.2 RO Cleaning Frequency and Performance

The RO system had initially been expected to operate for 30 or more days before cleaning was required. However, the operators were noticing difficulty maintaining the flows and recoveries on the RO system. On July 24, the Gallup wastewater plant needed to perform maintenance activities that interrupted the availability of treated effluent to the EUWP, so it was decided to perform a RO CIP. The cleaning began on July 25 and was completed the afternoon of July 26, 2006.

The RO cleaning was performed using citric acid for a low pH cleaning and MemClean detergent cleaner for an alkaline cleaning. Citric acid was added to the 300 gallon CIP tank to achieve a pH of 3.03. The acid solution was circulated through the RO and then it was allowed to soak for approximately one hour. The ending pH was 4.07. A total of 7 kg of MemClean detergent was then added directly into the CIP tank. The system was circulated for a total of 18 minutes and then allowed to soak overnight (15 hours). The ending pH was 11.14. After the overnight soak, the RO was circulated for 30 minutes and then flushed with permeate. Citric acid (10 ounces) was then added to the CIP tank and circulated through the system to neutralize the unit. Finally, the system was then flushed with permeate for 1.5 hours and readied for return to operation.

Table 4-15 shows the specific flux results for Arrays 1 and 2 before and after the CIP procedure. The CIP restored Array 1 from a specific flux of 0.057 gfd/psi before the cleaning to 0.063 gfd/psi, which is a recovery of 98%. For Array 2, the CIP restored the membranes to a specific flux of 0.064 gfd/psi from 0.060 gfd/psi, also yielding a recovery of 98%.

Table 4-15. RO System Performance Intervals

	Specific Flux (gfd/psi)		Pressure Difference (Feed to Concentrate) (psi)			
Date	Array 1	Array 2	Array 1	Array 2	Event	Chemical Usage
7/12	0.064	0.065	50.5	40.5	Baseline	
7/23	0.058	0.063	130.5	67.5	Before Product Flush (@59% Recovery)	
7/23	0.059	0.068	129.5	40.5	After Product Flush	
7/24	0.057	0.060	126.5	38.5	RO Cleaning	1.2 kg Citric/ 7 kg MemClean
7/26	0.063	0.064	81.5	37	After Cleaning	
8/2	0.057	0.058	91	54	After UF Cleaning	
8/7	0.058	0.060	124	58.5	RO Cleaning	6.3 kg MemClean
8/8	0.059	0.060	86.5	53	After Cleaning	
8/15	0.049	0.045	116.5	60.5	Final Value	

The RO was cleaned with detergent only on August 7 to 8, 2006. The system was soaked overnight. As shown in Table 4-15, this cleaning did not change the specified flux. However, the pressure differential between the feed pressure and the concentrate pressure did decrease and improve operation.

The operators noted that the RO system cleaning appeared to be more effective for Array 1 than for Array 2, the ERI array. It is not possible to clean the two arrays separately. The RO forwarding pump (P5) is used for RO cleaning, not the high pressure pump (P6). The maximum flow possible is 25-30 gallons per minute. This is not enough for a good cleaning cycle as is possible with the UF system that uses its production pump for the cleaning cycle. Also the cleaning tank thermometer is in the recycle line for the UF system, not in the tank. It was moved to provide an operating temperature reading. Unfortunately, this action disabled heating capability when cleaning the RO system.

Table 4-16 shows additional information on the chemicals use and time for the CIP.

Table 4-16. RO and UF System Cleanings

Date	System	Chemical	Temp (°C)	pH	Flow (gpm)	Duration (hr:min)
7/25/06	RO	Citric 1.18 kg	21.6-30.1	3.03-4.07	N/A	N/A
7/25/06	RO	MemClean 7 kg	37	11.3	N/A	17:15*
8/1/06	UF	Citric 2.95 kg	37-40	2.92 – 3.06	516-564	1:20
8/1/06	UF	Chlorine 11.6 L and NaOH 2.28 L	37.8-40.3	9.9-10.73	520-566	2:10
8/7/06	RO	MemClean 6.3 kg	23.2-24.2	10.2-11.46	N/A	15:05*

* System left to soak overnight. Flow data are not available during cleaning cycle.

4.5.3 Task C3: Finished Water Quality

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 USEPA National Drinking Water Regulations. 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 measured with in-line meters in the EUWP and were measured with portable equipment on site. In addition, pH and temperature were measured on site. Other water quality parameters were monitored by collecting samples on a weekly basis.

Samples were also collected for bacteriological analyses. Data for the bacteriological samples (total coliform, fecal coliform, *E. coli*, and HPC) are also presented in this section.

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

Figures 4-16 and 4-17 present the grab sample turbidity results for the UF feed, UF filtrate, and RO permeate over the duration of the test. Table 4-17 shows a summary of the daily turbidity results for the grab samples taken during the verification test. Based on the grab samples, the UF system reduced turbidity from a mean of 11.1 NTU in the feed water to a mean of 0.74 NTU in the UF filtrate. The 95% confidence level shows that filtrate turbidity can be expected to be in the range of 0.62 to 0.86 NTU. As discussed Section 4.5.1, the UF system was found to have faulty seals, which may explain the lower than expected reductions of contaminants.

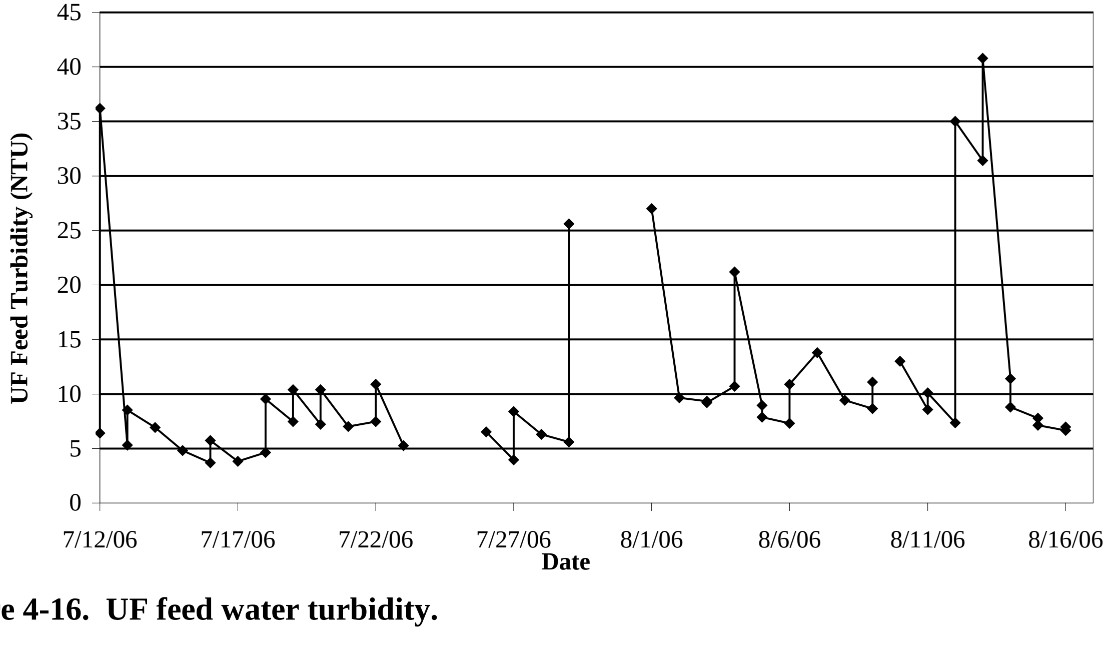

Figure 4-16. UF feed water turbidity.

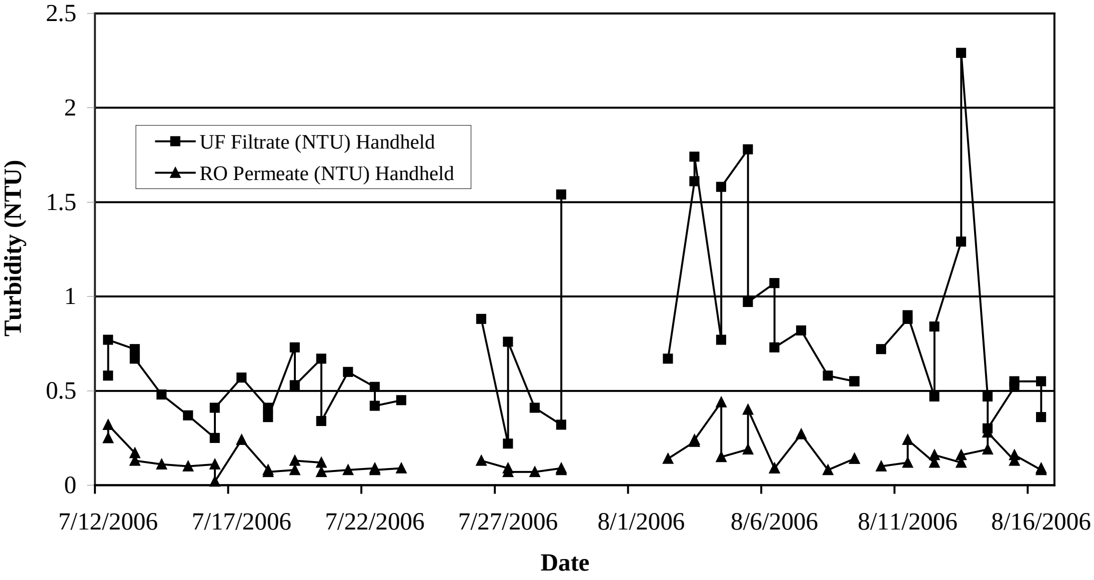

Figure 4-17. UF filtrate and RO permeate turbidity handheld meter.

Table 4-17. Summary Statistics for Handheld Turbidity Meter Results

Parameter	UF Feed (NTU)	UF Filtrate (NTU)	RO Feed (NTU)	RO Permeate (NTU)
Mean:	11.1	0.74	0.80	0.15
Median:	8.55	0.58	0.58	0.12
Minimum:	3.7	0.22	0.11	0.02
Maximum:	41	2.3	3.7	0.44
Count:	52	51	52	51
Std. Dev.:	8.6	0.44	0.62	0.09
95% CI:	2.3	0.12	0.17	0.02

The RO permeate had a mean turbidity of 0.15 NTU based on the handheld meter readings. The 95% confidence interval for the handheld meter results showed expected ranges of 0.13 to 0.17 NTU for the RO permeate. The RO permeate turbidity levels based on the handheld meter results, did not quite meet the National Primary Drinking Water Regulation (NPDWR) (<0.3 NTU 95% of the time and all values below 1.0 NTU). All results were less than 1.0 NTU, but three results out of 51 data points recorded were above 0.3 NTU, giving 94% of the data being less than 0.3 NTU. As described below, the handheld meter turbidity results for the UF feed and filtrate were similar to the in-line turbidimeters results, however, the in-line results for the RO permeate showed much lower turbidity levels. The in-line meters were more sensitive and had a lower detection limit. Additional discussion of the turbidity detection limits and sensitivity is presented in the QC Section 4.6.

The operators manually recorded in-line turbidity measurements at least once per day. The feed water turbidity, as recorded from the in-line analyzer, showed a mean value of 8.7 NTU with a median of 7.5 NTU. The UF filtrate in-line analyzer recorded readings showed a mean turbidity of 0.69 NTU with a median value of 0.53 NTU. The RO permeate turbidity, as manually recorded from the in-line analyzer had a mean value of 0.016 NTU and a median value of 0.015 NTU. Figure 4-18 shows UF feed and UF filtrate in-line turbidity readings. Note that there are two y-axes (different scales) in the figure, one for the feed and one for the filtrate. Figure 4-19 shows the RO feed and permeate in-line analyzer results. It should be noted that only the manually recorded UF filtrate, RO feed and RO permeate in-line analyzer results are shown in the figures after July 27. Unfortunately, the in line turbidity data for these process streams was inadvertently erased for the period July 27 through the end of the test. Table 4-18 shows the summary statistics for the UF feed, UF filtrate, and RO permeate in-line turbidity readings, as recorded on a daily basis by the operators.

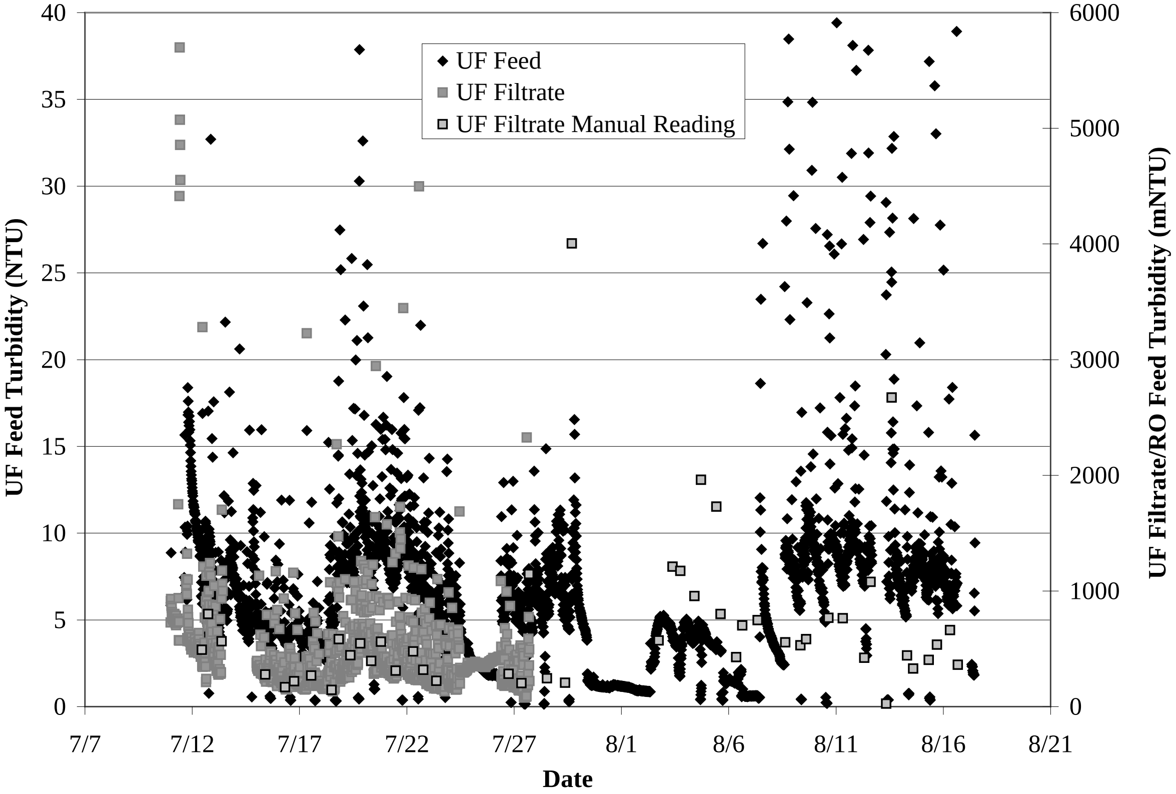

Figure 4-18. UF feed and UF filtrate/RO feed turbidity in-line meter.

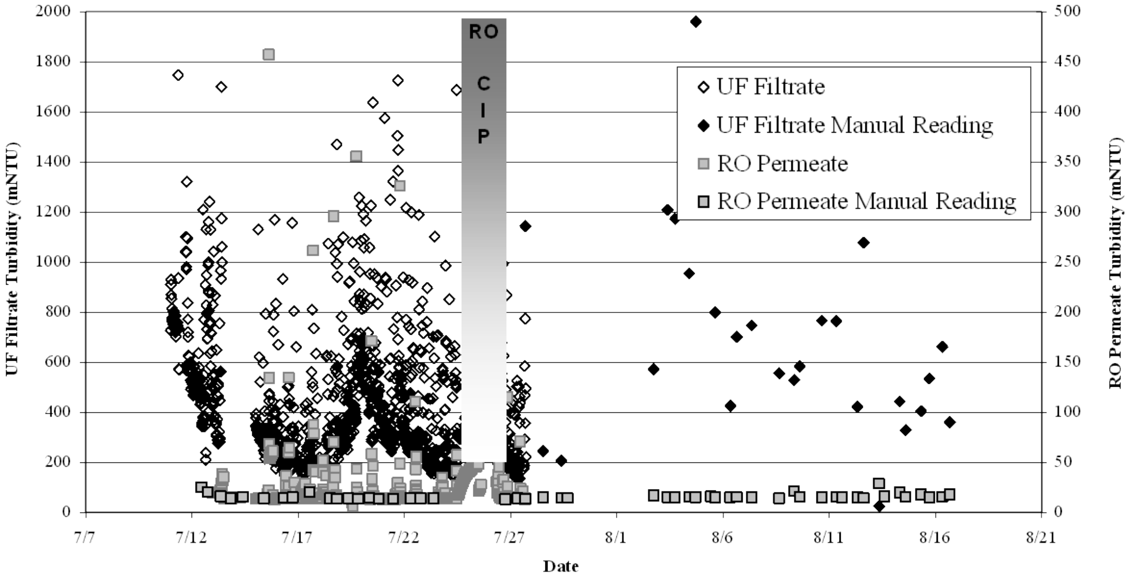

Figure 4-19. UF filtrate and RO permeate in-line turbidity readings.

Table 4-18. Summary Statistics for In-line Turbidity Meter Manually Recorded Results

Date	UF Feed (NTU)	UF Filtrate (NTU)	RO Permeate (NTU)
Mean:	8.8	0.69	0.016
Median:	7.5	0.53	0.015
Minimum:	0.62	0.026	0.013
Maximum:	39	4.0	0.029
Count:	52	48	51
Std. Dev.:	7.5	0.69	0.003
95% CI:	2.0	0.20	0.001

While the UF system did not achieve the results expected, the RO system handled the increased loading and did serve as the ultimate barrier to ensure low turbidity product water was produced. The RO permeate turbidity levels based on the manually recorded in-line meter results show that the system did meet the National Primary Drinking Water Regulation (NPDWR) (<0.3 NTU 95% of the time and all values below 1.0 NTU).

The Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) states that if the filtrate turbidity exceeds 0.15 NTU over any 15-minute period, the system must be shut down and a direct integrity test performed. The EUWP was not set up to be compliant with the LT2ESWTR, as the in-line turbidity meters are not tied to an automatic system shutdown if the turbidity level exceeds 0.15 NTU for any 15-minute period. The in-line turbidity data was logged onto a laptop computer, and the computer is not connected to the EUWP for the purpose of shutting down the system. The EUWP was designed and built before LT2ESWTR and did not have the necessary control equipment to be compliant with the LT2 monitoring requirements.

However, the RO system produced permeate with turbidity below the LT2ESWTR action level of 0.15 NTU most of the time. However, there are few data points recorded from the in-line meters (during the period July 12-27) when single data points exceeded the 0.15 NTU action level. It is not possible to determine if the action level was exceeded after the CIP was performed on July 25-26, as the 15-minute increment data for the remainder of the test was erased. All of the manually recorded data (once or twice per day) were 5 to 10 times lower than the 0.15 NTU action level. This would suggest that the RO permeate did meet the LT2ESWTR turbidity requirements, but it cannot be confirmed, because the computer file with the continuous (15-minute increment) data was erased.

The RO system reduced the dissolved ions in the feed water, as measured by conductivity. The mean conductivity in the RO permeate was 14.2 µS/cm compared to the mean conductivity in the RO feed water of 1,726 µS/cm. The RO unit reduced the conductivity by a mean value of 99.2%. Table 4-19 shows the conductivity results for the UF and RO systems, and the summary statistics for the verification test. The direct measurement of TDS, presented later in Table 4-27, shows that the mean TDS concentration in the RO permeate was 5.0 mg/L compared to the mean RO feed water TDS of 1,113 mg/L. The overall TDS rejection was 99.6%.

Table 4-19. Conductivity Results

Date	UF Feed (µS/cm)	UF Filtrate (µS/cm)	RO Feed (µS/cm)	RO Permeate (uS/cm)	RO Concentrate (µS/cm)	RO % Conductivity Red.
7/12/06	1733	1722	1719	9.34	3637	99.5
7/12/06	1726	1726	1729	9.81	3640	99.4
7/13/06	1747	1742	1745	9.2	3650	99.5
7/13/06	1739	1751	1755	9.81	3684	99.4
7/14/06	1779	1767	1769	9.41	3717	99.5
7/15/06	1729	1723	1728	9.1	3626	99.5
7/16/06	1729	1705	1714	9.22	3655	99.5
7/16/06	1714	1718	1711	9.51	3740	99.4
7/17/06	1663	1664	1658	9.47	3512	99.4
7/18/06	1926	nr	1857	8.55	3277	99.6
7/18/06	1927	1915	1918	73.69	3921	96.2
7/19/06	1952	1924	1932	69.13	3973	96.5
7/19/06	1768	1658	1758	11.48	3749	99.4
7/20/06	1787	1777	1774	10.25	3754	99.4
7/20/06	1760	1755	1760	11.15	3690	99.4
7/21/06	1860	1860	1850	22	3830	98.8
7/22/06	1850	1780	1773	39.4	3180	97.9
7/22/06	1705	1702	1715	21.72	2800	98.7
7/23/06	1700	1695	1694	10.5	2879	99.4
7/26/06	1741	1653	1647	15.4	2704	99.1
7/27/06	1682	1680	1676	10.5	2760	99.4
7/27/06	1672	1666	1669	10.12	3226	99.4
7/28/06	1669	1665	1664	10.4	3159	99.4
7/29/06	1677	1675	1663	10.55	3172	99.4
7/29/06	1667	1670	1667	10.01	3207	99.4
8/1/06	1665	1661	nr	nr	nr	nc

Table 4-19. Conductivity Results

Date	UF Feed (µS/cm)	UF Filtrate (µS/cm)	RO Feed (µS/cm)	RO Permeate (uS/cm)	RO Concentrate (µS/cm)	RO % Conductivity Red.
8/2/06	1771	1725	1720	10.85	3246	99.4
8/3/06	1734	1736	1725	10.85	3316	99.4
8/3/06	1721	1726	1721	10.6	3280	99.4
8/4/06	1739	1770	1754	10.62	3355	99.4
8/4/06	1752	1750	1751	14.75	3320	99.2
8/5/06	1717	1723	1721	10.04	3288	99.4
8/5/06	1710	1714	1711	9.75	3266	99.4
8/6/06	1721	1716	1715	9.37	3230	99.5
8/6/06	1708	1702	1706	11.02	3194	99.4
8/7/06	1660	1654	1656	9.08	3092	99.5
8/8/06	1700	1702	1699	11.15	3107	99.3
8/9/06	1730	1722	1721	9.96	3311	99.4
8/9/06	1727	1725	1719	10.96	3363	99.4
8/10/06	1716	1685	1688	10.85	3276	99.4
8/11/06	1709	1704	1710	10.02	3342	99.4
8/11/06	1707	1711	1713	10.87	3368	99.4
8/12/06	1677	1667	1672	9.34	3248	99.4
8/12/06	1626	1627	1631	9.87	3108	99.4
8/13/06	1718	1708	1701	16.73	3431	99.0
8/13/06	1798	1788	1766	21.58	3513	98.8
8/14/06	1717	1705	1706	10.2	2968	99.4
8/14/06	1691	1696	1693	11.05	3015	99.3
8/15/06	1732	1721	1723	10.2	3035	99.4
8/15/06	1715	1715	1715	12.33	3053	99.3
8/16/06	1414	1716	1715	10.94	3021	99.2
8/16/06	1706	1710	1712	10.72	3368	99.4
Mean:	1729	1721	1726	14.2	3338	99.2
Median:	1720	1715	1715	10.5	3288	99.4
Minimum:	1414	1627	1631	8.55	2704	96.2
Maximum:	1952	1924	1932	73.7	3973	99.6
Count:	52	51	51	51	51	51
Std. Dev.:	79.7	57.7	59.4	12.7	300	0.65
95% CI:	±21.7	±15.85	±16.3	±3.48	±82.4	±0.18

nr - not recorded
nc - not calculated

Tables 4-20 and 4-21 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 water having a mean pH of 7.53 (median 7.55) and the filtrate having a mean pH of 7.54 (median 7.55). The RO system did lower the pH of the permeate, with a mean of 6.27 (median 6.14), and a range of 5.38 to 7.30.

The UF and RO systems also did not have an effect on the temperature of the water as it passed through the EUWP. The feed water temperature ranged from 23.9 ^{o}C to 28.9 ^{o}C, with a mean of

26.6 ^{o}C. The mean temperature of the RO permeate was 26.8 ^{o}C, with a range of 20.7 ^{o}C to 31.3 ^{o}C. Temperature variation and impact on membrane production (flux and specific flux) were accounted for in the operating section by adjusting the data to either 20 ^{o}C or 25 ^{o}C, as described in Sections 4.5.1.1.1 and 4.5.1.2.1 The temperature data in Table 4-21 served as the basis for the temperature adjustment calculations.

Table 4-20. pH Results

Date	UF Feed	UF Filtrate	RO Feed at Strainer	RO 1st Pass Permeate	RO Concentrate
7/12/06	7.94	7.93	7.77	6.6	8.06
7/12/06	7.84	7.84	7.85	7.24	8.02
7/13/06	7.49	7.47	7.45	5.87	7.73
7/13/06	7.67	7.45	7.62	6.83	7.83
7/14/06	7.77	7.6	7.41	6.98	7.9
7/15/06	8.5	8.38	8.33	6.85	8.49
7/16/06	7.57	7.62	7.46	6.64	7.66
7/16/06	8.09	8.01	7.66	7.21	8.04
7/17/06	7.57	8.14	7.68	7.24	8.26
7/18/06	7.58	nr	7.4	6.62	7.4
7/18/06	7.4	7.4	7.4	6.75	7.69
7/19/06	7.23	7.2	7.27	6.52	7.34
7/19/06	7.45	7.38	7.3	5.79	7.55
7/20/06	7.62	7.6	7.52	5.82	7.75
7/20/06	7.31	7.36	7.31	5.67	7.55
7/21/06	7.75	7.72	7.44	6.07	7.8
7/22/06	7.8	7.8	7.6	6.2	7.8
7/22/06	7.68	7.62	7.43	6.15	7.65
7/23/06	7.71	7.45	7.6	6.05	7.75
7/26/06	7.46	7.64	7.43	6.19	7.65
7/27/06	7.6	7.55	7.6	6.3	7.72
7/27/06	7.6	7.61	7.49	6.55	7.56
7/28/06	7.66	7.55	7.55	6.21	7.72
7/29/06	7.61	7.58	7.42	6.2	7.73
7/29/06	7.58	7.6	7.33	6.0	7.62
8/1/06	7.47	7.59	7.08	Nr	nr
8/2/06	7.40	7.68	7.48	6.0	7.69
8/3/06	7.56	7.51	7.51	7.3	7.75
8/3/06	7.54	7.44	7.45	5.92	7.65
8/4/06	7.45	7.65	7.43	6.08	7.64
8/4/06	6.89	6.96	6.88	5.55	7.14
8/5/06	7.68	7.53	7.59	6.02	7.8
8/5/06	7.73	7.9	7.72	6.59	7.86
8/6/06	7.61	7.75	7.7	6.14	7.87
8/6/06	7.42	7.56	7.37	5.95	7.63
8/7/06	7.58	7.67	7.63	6.07	7.8
8/8/06	7.41	7.58	7.51	6.01	7.67
8/9/06	7.4	7.55	7.47	5.46	7.7
8/9/06	7.51	7.38	7.43	6.06	7.64

Table 4-20. pH Results

Date	UF Feed	UF Filtrate	RO Feed at Strainer	RO 1st Pass Permeate	RO Concentrate
8/10/06	7.42	7.44	7.37	6.01	7.61
8/11/06	7.49	7.52	7.46	5.52	7.65
8/11/06	7.41	7.39	7.34	6.28	7.47
8/12/06	7.44	7.49	7.42	6.1	7.61
8/12/06	7.47	7.44	7.37	6.04	7.56
8/13/06	7.15	7.22	7.09	5.75	7.31
8/13/06	5.99	6.13	6.17	5.38	6.46
8/14/06	7.56	7.45	7.26	6.55	7.44
8/14/06	7.34	7.39	7.3	6.13	7.52
8/15/06	7.69	7.43	7.36	7.21	7.58
8/15/06	7.46	7.43	7.29	5.82	7.55
8/16/06	7.54	7.38	7.49	6.75	7.61
8/16/06	7.47	7.4	7.34	6.61	7.58
Mean:	7.53	7.54	7.44	6.27	7.67
Median:	7.55	7.55	7.44	6.14	7.65
Minimum:	5.99	6.13	6.17	5.38	6.46
Maximum:	8.5	8.38	8.33	7.3	8.49
Count:	52	51	52	51	51
Std. Dev.:	0.32	0.31	0.28	0.49	0.28
95% CI:	±0.087	±0.084	±0.075	±0.135	±0.077

nr - not recorded

Table 4-21. Temperature Results

Date	UF Feed (°C)	UF Filtrate (°C)	RO Feed (°C)	RO Permeate (°C)	RO Concentrate (°C)
7/12/06	26.5	26.9	27.0	26.7	27.4
7/12/06	27.7	28	27.6	28.3	28.2
7/13/06	25.8	25.8	25.5	25.5	26.2
7/13/06	27.8	27.1	26.8	27	26.9
7/14/06	25.5	26	26.1	26.4	26.4
7/15/06	26.9	26.6	26.5	27.1	27.1
7/16/06	25.1	26.1	25.7	26.7	26.7
7/16/06	28.1	28.2	27.8	28.1	28.2
7/17/06	28.9	28.4	28.5	31.3	28.8
7/18/06	27.2	nr	27.9	28	28.2
7/18/06	26.7	26.6	26.1	27	27.1
7/19/06	25.2	25.4	25.9	26	26.5
7/19/06	26.4	26.3	26.7	26.6	27
7/20/06	25.3	26.3	25.9	26.2	26.4
7/20/06	28	28.2	28.1	28.9	28.4
7/21/06	25.2	24.8	24.9	25.8	25.4
7/22/06	26.5	26.7	26.6	27.3	26.6
7/22/06	27	26.8	26.7	26.2	27.3
7/23/06	27.8	27.1	27.3	27.6	27.7
7/26/06	27	26.6	26.9	26	26.9
7/27/06	26.2	26.2	26.4	26.7	27
7/27/06	28.2	28	28.2	28.4	28.5

Table 4-21. Temperature Results

Date	UF Feed (^oC)	UF Filtrate (^oC)	RO Feed (^oC)	RO Permeate (^oC)	RO Concentrate (^oC)
7/28/06	26.9	26.9	27.3	27	27.6
7/29/06	26.3	25.8	26	26.6	26.8
7/29/06	27.2	26.4	26.8	27.2	27.4
8/1/06	26.0	25.9	26.2	nr	nr
8/2/06	27.7	27.7	27.7	29.8	28.1
8/3/06	26.7	26.1	26.7	26.9	27.2
8/3/06	26.8	27.7	27	27.6	27.4
8/4/06	26.3	24.9	26	25.7	26.5
8/4/06	26.6	26.2	26.7	26.7	27.2
8/5/06	26	25.1	25.7	25.1	26.6
8/5/06	27.5	27.5	27.7	27.9	28.8
8/6/06	25.7	26.2	26.5	25.9	27
8/6/06	25.8	25.9	26.2	26.2	26.4
8/7/06	25.1	25.7	25.9	25.5	26.4
8/8/06	28.1	27.4	27.7	28.2	28.1
8/9/06	25.2	25.4	26.1	25.5	26.7
8/9/06	27.4	27.5	27.7	27.5	28.1
8/10/06	27.8	27.9	28.2	28.4	28.6
8/11/06	25.3	26	26	24.4	26.6
8/11/06	28.7	28.3	28.3	28.6	28.8
8/12/06	25.1	25.2	25.6	25.4	26
8/12/06	26.8	26.5	26.9	26.9	27.4
8/13/06	23.9	24.5	24.6	20.7	25.1
8/13/06	27.5	27.4	27.9	28.3	28.4
8/14/06	24.8	24.9	24.8	23.2	25.9
8/14/06	28.1	27.7	28	28.3	28.4
8/15/06	24.6	25.2	25.1	25.2	25.8
8/15/06	27.1	27.1	27.3	27.5	27.5
8/16/06	25.6	25.1	25.5	24.3	23.3
8/16/06	27.3	27.1	27.2	27.7	27.9
Mean:	26.6	26.5	26.7	26.8	27.2
Median:	26.7	26.5	26.7	26.9	27.1
Minimum:	23.9	24.5	24.6	20.7	23.3
Maximum:	28.9	28.4	28.5	31.3	28.8
Count:	52	51	52	51	51
Std. Dev.:	1.15	1.04	0.98	1.67	1.06
95% CI:	±0.31	±0.29	±0.27	±0.46	±0.29

nr - not recorded

4.5.3.2 Other Water Quality Results - UF System

UF feed and filtrate water general water quality statistics are shown in Table 4-22. Parameters that improved significantly by UF treatment, based on the 95% confidence intervals, are BOD, DOC, TOC, TSS, VSS, and iron.

Table 4-23 presents the biological analyses results for the UF system. Since the UF interconnectors were leaking, the removals across the UF system are not what would be expected. In most cases, there was less than one log removal of the various bacteriological indicators analyzed.

UF retentate TOC and TSS, and backwash TSS statistics are listed in Table 4-24. The variability of backwash TSS is due to the natural variation in TSS loading over time during a backwash. It is difficult to get a representative sample from the large backwash flows from this system.

Table 4-22. UF Feed and Filtrate General Water Quality Analysis

		UF Feed					UF Filtrate				
				Standard	95th Percentile				Standard	95th Percentile	
	Parameter	**Count**	**Mean**	**Deviation**	**Upper**	**Lower**	**Count**	**Mean**	**Deviation**	**Upper**	**Lower**
General Chemistry (mg/L)	pH (pH Units)	8	7.8	0.1	7.8	7.8	8	7.8	0.1	7.8	7.8
	Bicarbonate	8	250	9	256	244	8	240	12	248	232
	Carbonate	8	<5	NA	NA	NA	8	<5	NA	NA	NA
	BOD	8	6.2	1.8	7.5	4.9	8	<2.0	NA	NA	NA
	COD	8(1)	24	7.7	29	19	8(2)	20	7.3	25	15
	Color (Color Units)	8	71	50	106	36	8	34	5.6	38	30
	Ammonia	8	<0.10	NA	NA	NA	8	<0.10	NA	NA	NA
	Bromide	8(3)	0.21	0.02	0.22	0.20	8(3)	0.21	0.02	0.22	0.20
	Chloride	8	100	6.6	105	96	8	110	6.7	115	105
	DOC	8	7.3	0.7	7.8	6.8	8	4.9	2.7	6.8	3.0
	Sulfate	8	330	16	341	319	8	370	103	442	299
	Free Cyanide	8	<0.01	NA	NA	NA					
	Hardness	8	45	6.0	49	41	8	44	5.2	48	40
	Conductivity (μS/cm)	8	1,700	46	1,732	1,668	8	1,700	76	1,752	1,648
	Total Alkalinity	8	250	9.3	256	244	8	240	9.2	246	234
	TDS	8	1,100	35	1,125	1,076	8	1,100	46	1,132	1,068
	TOC	8	7.1	0.2	7.3	6.9	8	6.6	0.2	6.8	6.4
	TSS	8(3)	14	9.9	21	7.1	8	<4.0	NA	NA	NA
	VSS	8(1)	7.7	5.2	11.3	4.1	8	<4.0	NA	NA	NA

(1) Count and statistics include three estimated results below the reporting limit.
(2) Count and statistics include four estimated results below the reporting limit.
(3) Count and statistics include one estimated result below the reporting limit.

Table 4-22 (cont'd). UF Feed and Filtrate General Water Quality Analysis

		UF Feed					UF Filtrate				
				Standard	95th Percentile				Standard	95th Percentile	
	Parameter	**Count**	**Mean**	**Deviation**	**Upper**	**Lower**	**Count**	**Mean**	**Deviation**	**Upper**	**Lower**
Dissolved Metals (µg/L)	Aluminum	7	<100	NA	NA	NA	6	<100	NA	NA	NA
	Boron	7	310	14	320	300	7	310	19	324	296
	Calcium	7	13,000	690	13,511	12,489	7	13,000	976	13,723	12,277
	Iron	7(1)	110	64	157	63	7	<100	NA	NA	NA
	Potassium	7	14,000	787	14,583	13,417	7	14,000	900	14,667	13,334
	Magnesium	7	3,000	315	3,233	2,767	7	3,100	364	3,370	2,831
	Manganese	7(1)	8.5	4.4	12	5.2	6	13	3.9	16	10
	Sodium	7	350,000	13,452	359,965	340,035	7	350,000	7559	355,600	344,400
	Silica	7	20,000	900	20,667	19,334	7	20,000	1,134	20,840	19,160
	Strontium	6	150	26	171	130	7	140	16	152	128
	Zinc	7	67	29	89	45	7	52	5.9	56	48
Total Metals (µg/L)	Iron	7	1,600	1,498	2,710	490	7	240	179	373	107
	Manganese	7	17	9.2	24	10	7	14	5.1	18	10
	Phosphorus	7	4,400	872	5,046	3,754	7	3,800	931	4,490	3,111
	Silica	7	21,000	900	21,667	20,334	7	21,000	1,380	22,022	19,978

(1) Count and statistics include three estimated results below the reporting limit.

Table 4-23. Biological Analysis of UF System

		Fecal Coliform (MPN/100 mL)		
Date	**UF Feed**	**UF Filtrate**	**UF Retentate**	**UF Backwash**
07/13/06	5.0E+05	1.6E+04	1.6E+04	2.0E+04
07/17/06	4.0E+04	8.0E+04		
07/18/06	4.0E+04	2.3E+03		
07/20/06	2.0E+04	5.0E+03		
07/26/06	2.0E+04	2.2E+03	3.0E+04	2.0E+04
07/27/06	2.0E+04	4.0E+03		
08/02/06	2.6E+05	7.0E+03	1.6E+05	
08/03/06	2.3E+05	1.6E+04		
08/07/06	<2.0E+04	2.3E+03		
08/08/06	4.0E+04	3.0E+03		
08/10/06			2.4E+04	
08/14/06	5.0E+05			
08/15/06	1.1E+05			
08/16/06	4.0E+04	2.4E+04	1.6E+05	1.2E+05

		E. coli (MPN/100 mL)		
Date	**UF Feed**	**UF Filtrate**	**UF Retentate**	**UF Backwash**
07/13/06	3.0E+05	3.0E+03	1.6E+04	< 2.0E+04
07/20/06	2.0E+04	2.0E+04		
07/26/06	2.0E+04	2.0E+03	1.7E+04	2.0E+04
08/02/06	1.4E+05	1.4E+03	1.6E+05	
08/03/06	4.0E+04	4.0E+04		
08/10/06			2.4E+04	
08/16/06	<2.0E+04	<2.0E+04	1.3E+04	< 2.0E+04

		HPC (CFU/100 mL)		
Date	**UF Feed**	**UF Filtrate**	**UF Retentate**	**UF Backwash**
07/13/06	4.0E+07	1.2E+07	9.4E+06	2.1E+07
07/20/06	9.3E+06	3.8E+06		
07/26/06	5.3E+06	1.3E+06	9.6E+06	1.5E+07
07/27/06	7.2E+06	6.8E+05		
08/02/06	3.3E+07	2.1E+07	1.9E+07	
08/03/06	1.3E+07	6.2E+06		
08/10/06			1.8E+07	
08/16/06	2.0E+07	1.5E+07	2.0E+07	5.5E+07

		Total Coliform (MPN/100 mL)		
Date	**UF Feed**	**UF Filtrate**	**UF Retentate**	**UF Backwash**
07/13/06	1.6E+06	1.6E+04	1.6E+04	1.7E+05
07/17/06	8.0E+03	2.3E+03		
07/18/06	4.0E+04	2.3E+03		
07/20/06	1.3E+05	3.0E+04		
07/26/06	8.0E+04	1.4E+04	3.0E+04	1.1E+05
07/27/06	4.0E+04	5.0E+03		
08/02/06	2.2E+06	3.0E+04	1.6E+05	
08/03/06	7.0E+05	2.4E+04		
08/07/06	8.0E+04	1.3E+06		
08/08/06	8.0E+04	1.4E+04		
08/10/06			1.6E+05	
08/14/06	3.0E+04			
08/15/06	1.7E+05			
08/16/06	5.0E+05	9.0E+04	1.6E+05	3.3E+05

Table 4-24. UF Retentate and Backwash Analysis

	Count	Mean	Standard Deviation	95% CI	
				Upper	Lower
UF Retentate TOC	6	7.38	0.26	7.59	7.17
UF Retentate TSS	6	18.2	5.4	22.5	13.9
UF Backwash TSS	6	31	29	54.4	8.0

4.5.3.3 Other Water Quality Results - RO System

A summary of the water quality results and statistics for the RO system feed water, concentrate, and permeate are reported in Table 4-25. Most constituents were reduced in the permeate to below the reporting limit. Table 4-26 shows the rejection achieved for various water quality parameters, based on the mean concentrations. Some contaminants showed low rejection rates due to low concentrations in the RO feed water, and higher reporting limits resulting from the wastewater matrix.

After RO treatment, the final production water (RO permeate) met all primary and secondary drinking water standards. The RO unit served as the an effective treatment system for removing inorganic and organic constituents present in the secondary wastewater, based on meeting the objective of achieving a treated water that met primary and secondary drinking water standards. To be acceptable for transmission or drinking, the RO permeate would need stabilization and residual chlorination.

The LSI of the concentrate was 0.5 with 28% saturation of silica, 3% saturation of calcium sulfate, and 2% for strontium sulfate. Antiscalant is recommended. In this test, Nalco Permatreat PC-191 was used at a dose of 3.0 mg/L. RO permeate requires stabilization with 7 mg/L sodium bicarbonate, 7 mg/L sodium carbonate, and 7 mg/L of calcium hydroxide to attain an LSI of zero with a pH of 9.5.

Mass balances for selected inorganic constituents (Na, Ca, Mg, SO_4, HCO_3, Cl, and TDS) were calculated to evaluate possible buildup of salts in the membranes. The results are listed in Table 4-27. Inorganic mass balances indicate that outgoing salts were on average 8% higher concentration than the incoming salts. Therefore, there does not appear to have been a significant accumulation of salts in the RO system.

The results for the biological analysis of UF filtrate (RO Feed), RO permeate, and concentrate are listed in Table 4-28. Biological analyses were performed for fecal and total coliforms, *E. coli*, and HPC. Enteric virus counts were measured for one set of UF feed, UF filtrate, and RO permeate samples. The enteric virus results showed 176 MPN/100 mL in the RO feed and <1 MPN/100 mL in the RO permeate. Coliform species were present in the feed water in great enough numbers to allow for a log reduction value greater than 3 from the UF filtrate to the RO permeate.

Table 4-25. RO Feed, Permeate, and Concentrate - General Chemistry

Parameter (mg/L)	RO Feed					RO Permeate					RO Concentrate				
			Std.	95th Percentile				Std.	95th Percentile				Std.	95th Percentile	
	Count	Mean	Dev.	Upper	Lower	Count	Mean	Dev.	Upper	Lower	Count	Mean	Dev.	Upper	Lower
pH (pH units)	8	7.7	0.0	NA	NA	5	6.0	0.1	6.1	5.9	6	8.0	0.1	8.1	7.9
Bicarbonate	8	250	12	258	242	<5	NA	NA	NA	NA	6	500	60	548	452
Carbonate	8	<5	NA	NA	NA	5	<5	NA	NA	NA	6	<5	NA	NA	NA
Color (Color Units)	8	37	5.3	41	33	5	<5	NA	NA	NA	6	83	24	102	64
Ammonia	8	<0.10	NA	NA	NA	5	<0.10	NA	NA	NA	6(1)	0.13	0.05	0.17	0.09
Bromide	8(2)	0.21	0.02	0.22	0.20	5	<0.20	NA	NA	NA	6	0.42	0.10	0.50	0.34
Chloride	8	110	5.2	114	106	5	<30	NA	NA	NA	6	220	25	240	200
DOC	8	6.6	0.2	6.7	6.5	5	<1.0	NA	NA	NA	6	13	3.6	16	10
Sulfate	8	340	27	359	321	5	<50	NA	NA	NA	6	650	140	762	538
Fluoride	8	1.1	0.3	1.3	0.9	5	<0.5	NA	NA	NA	6	2.7	1.2	3.7	1.7
Free Cyanide	8	<0.01	NA	NA	NA	5	<0.01	NA	NA	NA	6	<0.01	NA	NA	NA
Hardness	8	69	69.0	117	21	5	<5	NA	NA	NA	6	84	22.2	102	66
Nitrate	8	18	1.8	19	17	5	<1	NA	NA	NA	6	37	5.9	42	32
Nitrite	8	<0.5	NA	NA	NA	5	<0.5	NA	NA	NA	6	<0.5	NA	NA	NA
Conductivity (µS/cm)	8	1,600	52	1,636	1,564	5(2)	11	5.4	16	5.1	6	3,300	288	3,530	3,070
Total Alkalinity	8	250	12	258	242	5	<5.0	NA	NA	NA	6	500	57	546	454
TDS	8	1,100	35	1,125	1,076	5	<10	NA	NA	NA	6	2,300	248	2,499	2,101
TOC	8	6.6	0.3	6.8	6.4	5	<1.0	NA	NA	NA	6	14	1.1	15	13
TSS	8	<4.0	NA	NA	NA	5	<4.0	NA	NA	NA	6	<4.0	NA	NA	NA

(1) Count and statistics include two estimated results below the reporting limit.

(2) Count and statistics include one estimated result below the reporting limit.

Table 4-25 (cont'd). RO Feed, Permeate, and Concentrate Inorganic Analysis

	Parameter (µg/L)	RO Feed					RO Permeate					RO Concentrate				
				Std	95th Percentile				Std	95th Percentile				Std	95th Percentile	
		Count	Avg.	Dev	Upper	Lower	Count	Avg.	Dev	Upper	Lower	Count	Avg.	Dev	Upper	Lower
Dissolved Metals	Aluminum	5	<100	NA	NA	NA	5	<100	NA	NA	NA	5	<100	NA	NA	NA
	Boron	7	300	17	313	287	5(2)	110	9.4	118	102	6	520	57	565	475
	Calcium	7	12.71	1.38	13.74	11.69	5	0.075	0.025	0.095	0.055	6	26.50	3.94	29.65	23.35
	Iron	7	<100	NA	NA	NA	5	<100	NA	NA	NA	6	200	95	276	124
	Potassium	7	14,000	900	14,667	13,334	5	<3,000	NA	NA	NA	6	30,000	4,622	33,699	26,301
	Magnesium	7	3,000	264	3,195	2,805	5	<200	NA	NA	NA	6	6,200	973	6,978	5,422
	Manganese	7	11(1)	6.3	16	6.4	5	<10	NA	NA	NA	6	22	9.3	29	15
	Sodium	7	350,000	7,559	355,600	344,400	5	2,200	261	2,429	1,971	6	730,000	82,624	796,112	663,889
	Silica	7	20,000	756	20,560	19,440	5	<1,100	NA	NA	NA	6	42,000	5,269	46,216	37,784
	Strontium	7	140	13	149	131	5	<0.10	NA	NA	NA	6	300	36	329	272
	Zinc	7	54	6.0	58	50	5	<20	NA	NA	NA	6	110	16	123	98
	Phosphorus	7	3,400	785	3,982	2,819	5	<3,000	NA	NA	NA	6	7,800	2,112	9,490	6,110
Total Metals	Lead	6	<100	NA	NA	NA	5	<100	NA	NA	NA	6	<100	NA	NA	NA
	Silica	6	20,000	983	20,787	19,213	5	<1,100	NA	NA	NA	6	40,000	3,933	43,147	36,853

Table 4-26. Rejection of Analytes in the RO Feed

Analyte	Percent Rejection*	Analyte	Percent Rejection*
Conductivity	99.3	Boron	63.3
DOC	>92.4	Calcium	>99.2
TOC	>92.4	Magnesium	>96.7
Alkalinity	>99.0	Potassium	>96.2
Hardness	>96.4	Sodium	99.4
TDS	99.5	Zinc	>81.5
Silica (SiO_2)	>97.3	Bromide	>52.4
Manganese	>>54.5	Chloride	>86.4
Phosphorous	>55.9	Sulfate	>92.6

* Components at or below the method detection limit indicate a rejection >X based on one half the method detection limit.

Table 4-27. RO System Mass Balance

Analyte	Process Stream	Date				
		7/19/2006	7/26/2006	8/2/2006	8/9/2006	8/16/2006
Sodium (mg/L)	Feed	360	350	350	350	340
	Concentrate	800	590	690	740	770
	Permeate	2	2.4	2.2	2.6	2.0
	MB	1.11	1.05	1.02	1.11	1.16
Calcium (mg/L)	Feed	13	13	10	13	12
	Concentrate	28	21	23	27	28
	Permeate*	0.1	0.1	0.1	0.1	0.1
	MB	1.07	1.00	1.19	1.09	1.19
Magnesium (mg/L)	Feed	3.1	3.1	2.4	3.2	3.0
	Concentrate	6.9	5.2	4.7	6.7	6.9
	Permeate*	0.1	0.1	0.1	0.1	0.1
	MB	1.12	1.05	1.03	1.11	1.19
Sulfate (mg/L)	Feed	310	340	360	320	390
	Concentrate◊	710	610	720	680	390
	Permeate*	25	25	25	25	25
	MB	1.18	1.14	1.07	1.15	0.54
Bicarbonate (mg/L)	Feed	250	240	250	230	240
	Concentrate	560	420	490	450	480
	Permeate*	2.5	2.5	2.5	2.5	2.5
	MB	1.12	1.09	1.02	1.03	1.02
Chloride (mg/L)	Feed	110	100	100	100	110
	Concentrate	250	180	210	220	220
	Permeate	15	15	15	15	15
	MB	1.20	1.17	1.16	1.22	1.09
TDS (mg/L)	Feed	1100	1100	1100	1100	1100
	Concentrate	2600	1900	2200	2300	2200
	Permeate*	5	5	5	5	5
	MB	1.18	1.07	1.04	1.10	1.02

*Permeate values were not detected and are assumed to be one half the reporting limits.

◊ Concentrate value is that reported by the lab. Its true value should be at least 750 mg/L for mass balance.

MB - Mass Balance - 1.00 would indicate a "perfect" mass balance.

Table 4-28. Biological Analyses of RO Process Streams

	Fecal Coliform (MPN/100 mL)			***E Coli* (MPN/100 mL)**		
Date	**RO Feed**	**RO Permeate**	**RO Concentrate**	**RO Feed**	**RO Permeate**	**RO Concentrate**
07/13/06	5.0E+05	<2	1.6E+03	3.0E+05	<2	1.6E+03
07/26/06	2.2E+03*	<2	2.4E+00	2.0E+04*	<2	8.0E+02
08/02/06	1.1E+04	<2	1.6E+04	5.0E+03	<2	9.0E+03
08/10/06		<2	1.3E+03		<2	
08/14/06	5.0E+05*	<2				1.3E+03
08/15/06	1.1E+05*	<2				
08/16/06	4.0E+04*	<2	3.0E+03	2.0E+04*	<2	2.4E+03

* - Sample from UF Filtrate - which was feed for RO.

	HPC (CFU/L)			**Total Coliform (MPN/100 mL)**		
Date	**RO Feed**	**RO Permeate**	**RO Concentrate**	**RO Feed**	**RO Permeate**	**RO Concentrate**
07/13/06	4.0E+07*	2.0E+05	1.4E+07	1.6E+06*	7	1.6E+03
07/26/06	5.3E+06*	1.0E+04	3.0E+07	8.0E+04*	<2	1.6E+04
08/02/06	8.9E+06	2.1E+06	1.1E+07	9.0E+04	2	1.6E+04
08/03/09	1.3E+07*	5.5E+03				
08/10/06			3.3E+06		<2	9.0E+03
08/14/06				3.0E+06*	<2	
08/15/06				1.7E+05*	<2	
08/16/06	2.0E+07*	1.8E+04	5.8E+06	5.0E+05	2	9.0E+03

* - Sample from UF Filtrate - which was feed for RO.

4.5.4 Task C4: Membrane Integrity Testing

4.5.4.1 UF System – Pressure Hold Test

Pressure hold testing was performed on the UF system each day. During the test audit representatives from Koch Membrane Systems, Village Marine, Inc., NSF, and USBR were present to observe the pressure hold test procedures. During that test the product side of the membranes was drained and both arrays were simultaneously pressurized to 20 psi. The feed valve and retentate valves were in their operating positions. The filtrate valves were closed. After 15 minutes the system had lost 1.5 psi. This rate of pressure decline was acceptable to Koch Membrane Systems.

As the verification test progressed, it became apparent that the pressure hold procedure being used was not providing an accurate evaluation of the UF system. After further inspection, it was discovered that the check valve on the feed side and the long run of piping filled with water on the retentate side would not allow air to escape from the system at 20 psi. In effect the system was completely closed. Opening a sample port on the feed side remedied the situation, but also revealed that the system was not intact, as was apparent from the turbidity readings and biological analysis results that had started arriving by this time.

Since the ETV test objectives require both the UF and RO systems for effective treatment, the testing was continued with the RO system as the ultimate barrier. After the completion of the test period, the UF cartridges were removed for individual cartridge pressure hold tests as described in Section 3.8. All the cartridges passed. However while re-installing the cartridges with new o-rings, the operators discovered that the end caps did not fit tightly over the filtrate connectors, see Figure 4-20. At this point the future tests were postponed while Village Marine constructed new interconnectors and endcaps.

Village Marine determined that the endcaps were 0.04 inches larger than the design specifications. The end caps on the EUWP are made from nylon according to Koch Membrane System's specifications. When the system was built, Koch did not sell seawater compatible endcaps. Apparently the nylon endcaps and interconnectors deformed over time with exposure to chlorine and sun light. However, Koch Membrane Systems has a seawater compatible endcap assembly made from Noryl® under development at this time. It is recommended that these new endcaps be procured for both EUWP systems if they are put into commercial production.

Figure 4-20. UF filtrate connector and leaking end cap.

4.5.4.2 RO System – Dye Challenge

Dye tests were performed on the RO system at the start and end of the test period. For the second dye test there was only enough dye left for a six minute test. Table 4-29 gives the results for each sample before and after the test period. As can be seen the RO membranes rejected the dye at a rate of higher than 99%. The rejection rate actually improved at the end of the test. These results, supported by the high rejection rate for conductivity, the low turbidity in the permeate, and the 3 log reduction calculated from the bacteriological samples, indicate that the RO membranes maintained integrity throughout the verification test.

Table 4-29. RO Permeate Absorbance after Injection

	Gallup Start Up				Gallup End Point	
Minutes after injection	**Permeate Sample 1**	**Rejection Sample 1**	**Permeate Sample 2**	**Rejection Sample 2**	**Permeate Sample 1**	**Rejection**
1	0.018	99.41%	0.020	99.35%	0.004	99.8%
2	0.014	99.54%	0.012	99.61%	0.004	99.8%
3	0.012	99.61%	0.013	99.58%	0.007	99.7%
4	0.015	99.51%	0.014	99.54%	0.003	99.8%
5	0.013	99.58%	0.016	99.48%	0.001	>99.9%
6	0.013	99.58%	0.014	99.54%	0.002	99.9%
7[1]	0.002	99.93%	0.003	99.90%		
8	0.001	99.97%	0.000	>99.99%		
9	0.000	>99.99%	0.001	99.97%		
10	0.003	99.90%	0.004	99.87%		
Feed (mean)	3.068				2.41	
Concentrate 1:1 Dilution	2.92				2.358	

1 Cleaned the product vials and applied silicone oil. The powder had adhered to the outside of the vials giving a higher reading than expected but still over the 99% rejection level.

4.5.4.3 Continuous Indirect Integrity Monitoring

Turbidity data is presented previously in Figures 4-18 and 4-19, and Table 4-18. RO permeate turbidity was well below 50 mNTU except for regular brief excursions to 50-60 mNTU during sampling. However, these excursions are an artifact of sampling. Sampling disrupts the flow to the turbidimeter.

Due to operator error, the on-line turbidity records were erased after July 27 for RO permeate and UF filtrate. The readings that were recorded on the data sheets are included in Figures 4-18 and 4-19.

UF filtrate turbidity was much higher than expected. None of the remedies of cleaning the system, cleaning the turbidimeter, and recalibration did anything to solve the problem. After the bacteria counts started coming in, it became apparent that the UF system had significant integrity problems. The UF filtrate water quality was so poor that USBR believed it had to be worse than just broken fibers. However, the schedule with the City of Gallup had to be maintained, as the City needed the space and the EUWP had to be off site by the scheduled end of this test period. Testing continued with reliance on the RO system as the ultimate barrier.

Particle counts for the UF filtrate were also high, with only about 50-75% retention of particles in all size ranges. Hach technical assistance was sought, but their technical representative could not explain the erratic and poor results. When the testing was complete, and the calibration data was verified, it was discovered that the particle counter software had been set up with erroneous calibration data. This means that none of the particle data is meaningful. Even if some of the ranges roughly correspond to configured ranges, there can be no confidence in any of the data. NSF agreed that since the test was based on the whole system, it was acceptable to disregard the erroneous particle count data and use turbidity and biological analysis as criteria for success.

4.5.5 Task C6: Qualitative Evaluations

The qualitative evaluation is based on events and observations. Information here should be taken as advice for those who would operate this equipment or design similar equipment.

4.5.5.1 Reliability or Susceptibility to Environmental Conditions

4.5.5.1.1 Protective Covers

One of the key requirements of this equipment is transportability. It is designed to be picked up and moved around. Before transport to Gallup, the unit was fitted with brand new, custom-made, Envelop© Protective Covers from Shield Technologies. When the equipment arrived it already had two tears in the covers from wind during transport. These tarps should be covered during transportation. They are mainly for protection while in storage and during operation.

4.5.5.1.2 PLC

The GE Fanuc PLC lost its memory during transportation. This resulted in a delay of four weeks while Village Marine attempted to replace it. They finally sent their programmer to correct issues resulting from loading the wrong program. Remote high speed telecommunication access to the PLC was not available at this remote site. If remote access could have been achieved, it would have quickened trouble shooting and software updates. Otherwise, it is critical to have the programming software and a programmer to participate in deployment of the system.

4.5.5.1.3 Intake Strainer

The intake strainer required frequent cleaning, sometimes daily. Although this is indicative of poor source water, it is also the effect of a relatively high velocity going through the screen. Larger surface area intake screens may be required to reduce cleaning frequency or in areas where cleaning is not practical.

4.5.5.1.4 Amiad Strainers

The Amiad Strainers were very difficult to extract from their mounting near the top of the UF system. It was necessary to remove them for cleaning every one to two days. They need to be mounted in a more accessible location. Also, the UF is disabled from backwashing while the Amiad is backwashing, and the Amiad strainers were backwashing much more often than assumed in the system design. As a result there was a loss of approximately 65% of all scheduled backwashes for the UF system, thereby decreasing their efficiency.

4.5.5.1.5 UF System Hoses

Several times during the backwash cycle hoses flew off the bottom of the UF cartridges. Hoses are secured with hose clamps on hose barb fittings. The barbs on the EUWP Gen 1-1 are not long enough for two hose clamps. The EUWP Gen 1-2 unit has longer hose barbs to accommodate two hose clamps. Both units should be equipped with the longer barbs.

4.5.5.1.6 UF System Interconnections

The filtrate tubes were too small or the caps were too large. This resulted in the failure of the UF system. Village Marine is redesigning the interconnections to prevent mixing of feed water with the filtrate.

4.5.5.1.7 Cleaning

The EUWP must be re-configured to accomplish cleaning either system. The longer time for the first cleaning of the RO and UF reflects the need to find more plumbing parts to get RO permeate to the Cleaning tank. The PLC did not allow operation of one of the pumps required for water transfer if it was not feeding the RO system. This required moving the pressure sensor on the outlet of the RO feed pump (P6) from the RO skid to the cleaning system line. This type of reconfiguration should not be standard procedure. The PLC program should be modified to include an RO cleaning cycle that disables the check on the P6 outlet pressure sensor.

4.5.5.1.8 Chemical Feed Pumps

The chemical feed pumps did not meter accurately. There was no correlation between pump speed, stroke length, and volume delivered. The FTO mixed the chemicals to match the observed delivery rate at an intermediate pump speed and stroke length setting. The coagulant chemical injection line was repeatedly blown off the injection fitting. The fitting was not the appropriate type for rigid 3/8” plastic tubing. This was later moved to the feed side of the pump to alleviate the problem, but this introduced suction issues where at certain pump settings, there would be free flow of coagulant. The pumps need to be replaced and/or properly installed to provide adequate backpressure.

4.5.5.1.9 Flow Measurement

There is not enough redundancy in flow measurement. The UF filtrate is not measured. The retentate flow is measured with a rotometer which appears to be as much as 30% low according to bucket and stop watch measurements. The filtrate flow was estimated using the pressure indicators for onion tank level. However the relation between pressure and volume depends on tank dimension measurements at various heights. Volume was derived from modeling sections of the tank. There was a 9-12% difference from the calculated flow in one instance and 2-5% in another.

4.5.5.1.10 Pumps

All the water pumps were 100% reliable. There were no pump failures during the test period.

4.5.5.1.11 RO System

The RO system ran extremely well for the challenge it received during this test.

4.5.5.2 Equipment Safety

There were no safety incidents during the test period.

4.5.5.3 Effect of Operator Knowledge, Skill, and Experience on Results

In addition to familiarity with the pilot process and data requirements, desirable skills for operators are:

- Positive attitude;
- Self confidence;
- Instrumentation skills for troubleshooting and calibration;
- Plumbing skills;
- Familiarity with electrical systems;
- Attention to detail; and
- Neat handwriting.

Successful operations teams own these skills among their members. The Gallup ETV test was carried out by a total of eleven operators who have been rated on a scale from 1-10 based on past experience with pilot systems, membrane processes, and general skills such as those listed above. With the exception of a couple of travel day disconnects, there were two operators on site each day. The minimum combined score for any team was 4 during a three day overlap of relatively in-experienced operators. The maximum score was 10 for two days at the start of testing. The average score was 7.1.

Teams were assigned a Quality Assurance (QA) Rating based on their completion of the several quality assurance activities that were required, such as writing down the operating conditions, field measurements, duplicate field measurements, completion of the daily, weekly, and bi-weekly calibrations and maintenance checks and, if there was a cleaning, whether the chemical usage was recorded either in the log book or on a cleaning record form. Each activity earned one point. Operator teams also got a point for recording activities in the log book. Actual daily production of RO permeate was used as a dependant parameter. Point score was divided by the number possible for the day resulting in a perfect QA Rating of 1. Table 4-30 lists operator codes, skill ratings, quality assurance scores, and the RO permeate production of the day.

There was no correlation between skill level and productivity or the number of quality assurance measures completed. This was a very challenging test for all of the operators. The UF system struggled with the waste water effluent, especially during the Fourth of July holiday when the tourist population was high. Maintenance was required for the Amiad filters, the hoses, and/or cleaning, most every day of the test, in addition to the extensive sampling program, and quality assurance activities. Most days, the operators were on site for 10-15 hours. All the operators dealt with the problems of the day in a professional manner.

Performance at any one period is dependent on the previous performance of all parts of the process. The responsibility for flux decline and the need for cleaning cannot be assigned to the current operator. The performance of the WWTP played a major role but the only true indicator available is the performance of the RO system. Even that is the combined result of the poor performance of both the WWTP and the UF system.

There was a fairly strong correlation between the QA score and productivity as shown in Figure 4-21. However, this may be an indication of the correlation between smooth operation and productivity which is indirectly the result of the operator's knowledge and skill. The wide range of productivity for a perfect score of 1 demonstrates that even conscientious operators have days when they need to shut the system down for maintenance.

Table 4-30. Evaluation of Skill, QA, and Productivity

Operator Team	Skill Rating	QA Rating	kgal/day produced	Activity
A/B	10	1.00	42	Audit/Sampling
A/B	10	1.00	121	
B/C	9	0.63	74	
B/C	9	0.62	84	
B/C	9	1.00	169	
B/D	9	0.67	83	
B/D	9	0.91	157	Sampling
B/D	9	1.00	162	
B/D	9	1.00	167	
D/E	5	0.67	86	
D/E	5	1.00	169	
D/E	5	0.78	168	
E/F	5	0.15	0	RO System Cleaning/ Sampling
E/F	5	0.20	0	
E/F	5	0.67	72	
E/F	5	1.00	144	Calibrations
F/G	7	1.00	72	
F/G	7	1.00	68	
F/G	7	0.35	0	UF System Cleaning
F/G	7	0.11	0	
G/H	4	0.59	59	Sampling
G/H	4	0.67	58	
G/H	4	1.00	118	
H/I	5	1.00	120	
H/I	5	1.00	119	
H/I	5	1.00	120	
H/I	5	1.00	61	RO System Cleaning/Sampling
I/J	8	0.50	59	
I/J	8	0.95	121	
I/J	8	0.78	124	
I/J	8	1.00	126	
I/J	8	1.00	128	Sampling
J/B	9	1.00	126	
J/B	9	1.00	126	
J/B	9	1.00	128	
B/C/K	9	1.00	129	
B/C/K	9	0.00	0	Dye Test/Cleaning

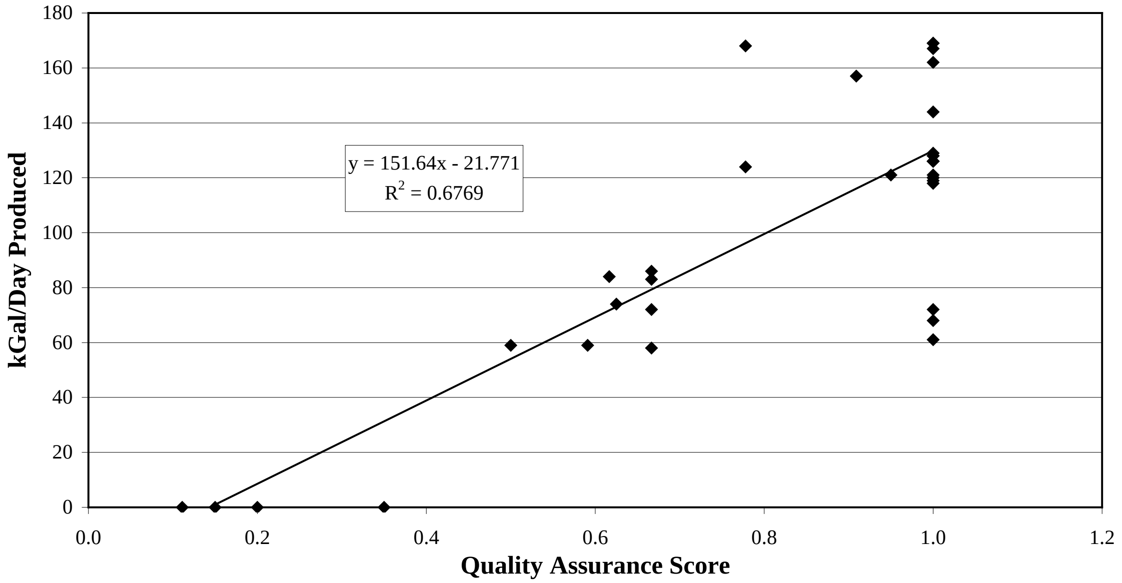

Figure 4-21. Relation between QA and actual productivity.

4.5.5.4 Effect of Operator's Technical Knowledge on System Performance and Robustness of Operation

The more an operator knows a system, the easier it will be to troubleshoot any problems. All the operators had access to the user manual for the system. All but two had prior experience operating the system. It is vital that operators understand the principles of the process they are operating so that they can detect changes – and know the probable cause and consequences of the change.

During the test period, changes in performance were related to the ability of the equipment to perform with poorly treated wastewater effluent as the feed. The first UF system decline in performance corresponds to a week of discussions with Village Marine about the efficiency of the UF backwash and how the Amiad Strainers were preventing UF backwash initiation. Unfortunately it took three weeks to get the backpressure on the Amiads increased high enough to allow more consistent UF performance. A thorough knowledge of the system would have brought the solution to light in a timelier manner. However, since the Amiads were only recently moved to their current position, this information would not be in the user manual.

4.5.5.5 Ease of Equipment Operation

The EUWP is very easy to operate. The touch screen control system shows what is on, flow rates, temperature, and pressures. All the pumps can be started from the control screen.

Cleaning is not easy. However if additional hoses were set in place and an extra pump was available to move water from the RO permeate tank, it would be simpler. The changes mentioned above need to be incorporated into the RO cleaning algorithm.

4.5.5.6 Waste Discharge Requirements

The design waste discharge from the EUWP is comprised of the UF system retentate, backwash, RO concentrate, and water for cleaning. Theoretically, the discharge should be the UF feed flow minus the RO permeate, or 3.46 million gallons for the 35.2 days of data or on average 97.8 kgal per day.

4.6 QA/QC

4.6.1 Introduction

An important aspect of verification testing is the QA/QC procedures and requirements. As described in Task 7 of the methods and procedures (Section 3.9.9) and the QAPP in the PSTP prepared for this ETV test, 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.

4.6.2 Documentation

The field technicians recorded on-site data and calculations in a field logbook and on specially prepared field log sheets. The operating logbook included calibration records for the field equipment used for on-site analyses. Copies of the logbook, 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 DWS Center staff checked 100% of the data entered into the spreadsheets to confirm the information was correct. The spreadsheets are presented in Appendix L.

Samples collected and delivered to the contract laboratories for analysis were tracked using chain-of-custody forms. Each sample was assigned a location name, date, and time of collection. The laboratories reported the analytical results in laboratory reports. These reports were received and reviewed by Bureau of Reclamation staff. These laboratory data were entered into the data spreadsheets, corrected, and verified in the same manner as the field data. Lab reports are presented in Appendices C through I.

4.6.3 Quality Audits

Representatives from NSF performed an audit of the QA plan at the start of the testing period on July 12-13, 2006. The audit focused on review of the field procedures, including the collection of operating data and performance of on-site analytical methods. The TQAP requirements and QAPP were used as the basis for the audit. The NSF representatives prepared an audit report. All deficiencies were corrected immediately.

The NSF QA Department reviewed the contract laboratory and field analytical results for adherence to the QA requirements for precision and accuracy detailed in the project QAPP and for compliance with the laboratory quality assurance requirements. The laboratory raw data records (run logs, bench sheets, calibrations records, etc.) are maintained at NSF and are available for review.

4.6.4 Test QA/QC Activities

The USBR staff conducted the field monitoring, measurements, and sample collection and handling in accordance with the USEPA-approved TQAP created specifically for this verification. The testing laboratory staff conducted the chemical and microbiological analyses by following the TQAP. NSF QA Department staff and representatives performed audits during testing to ensure the proper procedures were followed.

Table 4-31 lists a summary of QC activities that were performed in the field and Table 4-32 lists a summary of QA activities performed by field and project staff.

Table 4-31. Quality Assurance Activities

	Equipment	Action Required
Initial	Flowmeters – electronic	Verify calibration volumetrically
	Turbidimeter – online (1720E)	Provide factory calibration certificate
	Turbidimeter – online (FilterTrak)	Provide factory calibration certificate
	Particle counter – online	Provide factory calibration certificate
Daily	Chemical Feed Pump	Volumetrically check flow
	Turbidimeter – online	Verify with portable turbidimeter
	Turbidimeter – portable	Volumetrically check flow
	Particle Counters – online	Volumetrically check flow
	Myron pH meter	Calibrate – 3 point (4,7,10)
	UF System	Pressure hold test
	Particle counter – online	Clean sensors used to monitor feed
	Conductivity meter – portable	Calibrate - 2 points with certified conductivity buffers (required monthly)
Weekly	Rotameters	Check for algae & verify volumetrically
	UF filtrate flow	Verify volumetrically
	Temperature – portable	Verify calibration with NIST certified precision thermometer (required by ETV only)
	Turbidimeter – portable	Calibrate using <0.1, 20, 100, and 800 NTU standards (required quarterly)
	Tubing	Check for algae and leaks
	On-Line Pressure/flow indicators	Verify calibration

Table 4-32. Quality Control Activities

	Item	Action Required
Daily	Data	Review system performance data since previous day
Weekly	Data	Qualitative online data review & review field and Lab data when available.

4.6.5 Sample Handling

All samples analyzed by the laboratories were labeled with unique identification numbers. These identification numbers appear in the laboratory reports for the tests. All samples for chemical analytes were analyzed within required holding times.

Some microbiological samples for fecal coliform and HPC were not analyzed within 24 hours. It was necessary to ship all microbiological samples off site for analysis. Shipment was by overnight carrier for next- day delivery. In most cases samples collected in the afternoon arrived the next morning and the analysis was started within the 24 hour holding time. However, in a few cases, by the time the samples arrived at the laboratory and the test was started, that actual time was slightly more than 24 hours. All tests were started within a few hours of arrival at the laboratory. The exceedance of holding times by a couple of hours should not have a major impact on test results. It should be noted that fecal coliform has an 8 hour holding time requirement for compliance samples for drinking water, but has a 24 hour holding time for other data use. The 24 hour holding time was used for this ETV test as it was not a compliance test.

4.6.6 Physical and Chemical Analytical Methods QA/QC

4.6.6.1 Field Sample Analysis

Bench top field instruments that measured turbidity, pH, temperature and specific conductance (conductivity) were calibrated in accordance with the data quality objectives (DQO) in the TQAP. Procedures followed USEPA methods.

In-line field meters for particle counts and turbidity measurements were factory calibrated, and certificates were provided as required in the TQAP. However, the incorrect calibration certificate data for bin voltages was entered into the software program for the particle counters. This resulted in rendering the particle count data inaccurate and not meeting the DQO. Because of this problem, particle count data could not be used for documenting system performance for particle count and the data are not included in this report.

Turbidity was measured with two different approaches during the test. The in-line turbidity meters provided continuous data. Grab samples for turbidity were also collected either once or twice per day and analyzed using a field turbidimeter. The data presented in Section 4.5.3.1 showed that the feed water and UF filtrate results were similar between the methods. However, the RO permeate results from the in-line meter were an order of magnitude lower than the results from the handheld turbidimeter (mean of 0.15 NTU for grab samples versus a mean of 0.016 NTU for in-line measurements). It would be expected that the RO permeate would have a very low turbidity. The difference in the results is due to the better sensitivity and lower detection limit of the in-line meter. A reasonable detection limit for a standard turbidimeter with grab samples is typically in the 0.05 to 0.10 NTU range. This lower detection limit assumes the use of a very clean cuvette with no fogging of the glass due to temperature changes in the sample water. In the measurement of low turbidity levels, such as at 0.10 NTU, error trends are normally biased positive due to effects from such sources as bubbles, contamination and sample cell imperfections. While good results can be obtained, it is very difficult in field conditions to achieve reproducible results much below 0.10 NTU limit. All of the RO permeate readings were very close to the 0.1 to 0.2 NTU, with a 95% confidence level of 0.13 to 0.17 NTU (see Table 4-17)

The in-line meter used for the RO permeate was Hach FilterTrak 660™ laser nephelometer designed specifically to measure very low turbidity levels. The unit specifications show that it can detect changes in turbidity as low as 0.0005 NTU and has a rated limit of detection of 0.0004 NTU. The typical operating range is 0.001 to 5.0 NTU. Thus, this unit measures turbidity by passing a steady flow of water through the unit, which reduces problems of fogging due to water temperature, presence of air bubbles, and similar problems encountered when using grab samples and field or laboratory turbidimeters. It can be expected that a in-line laser unit, such as the one installed in the RO permeate line, properly calibrated and maintained, should provide more accurate data at the low turbidity levels expected in the RO permeate. Based on the evaluation of the procedures and equipment used for the turbidity measurements of the RO permeate, it is judged that the in-line meter results are of good quality and appropriate for the measurement of the RO permeates. Therefore, the lower results obtained from this unit should be the data used for evaluating the turbidity of the RO permeate water.

4.6.6.2 Laboratory Methods

All of the analytical methods used by the contract laboratories were EPA methods or Standard Methods. However, most of the EPA methods referenced by the laboratories, particularly for the background organics work and some of the general water quality measurements, were methods from EPA SW-846 and not the approved EPA methods for drinking water. The PSTP did not require that the methods being used for this technology evaluation test (this was not a drinking water compliance test) be EPA drinking water methods. The PSTP did require that the laboratories be certified laboratories (NELAC, State, or similar certification) and that proper methods for water/wastewater be used. In this case, the EPA SW-846 methods are very similar to the drinking water methods, and are published by EPA as appropriate for water/wastewater type testing. These methods have QA/QC procedures that met the requirements of the PSTP and QAPP. Review of the methods found that they were appropriate for this work and produced results that met the quality objectives.

Review of the microbiological results show that the proper procedures and QA/QC were followed for the fecal coliform, *E. coli*, total coliform, and HPC analyses. However, the *Cryptosporidium* and *Giardia* analyses did not meet the QA/QC objectives for the ETV test. Therefore, these data are not included in the report.

4.6.7 Documentation

The contract laboratories documented their activities using their prepared laboratory bench sheets and standard laboratory reports. Data laboratory reports were entered into Excel spreadsheets. These spreadsheets were used to calculate mean, median, and confidence intervals for feeds and filtrates when sufficient numbers of sample results were available (generally 8 or more). One hundred percent of the data entered into the spreadsheets was checked by a reviewer to confirm all data and calculations were correct.

4.6.8 Data Review

NSF QA/QC staff reviewed the data records for compliance with QA/QC requirements. NSF ETV staff checked at least 10% of the data in the laboratory reports against the Excel® spreadsheets.

4.6.9 Data Quality Indicators

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

4.6.9.1 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 a secondary wastewater, representing a possible application (highly contaminated surface water) for the EUWP during deployment. Two other ETV reports considered the EUWP performance when using sea water and normal surface water (lake water) as its feed.

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.

4.6.9.1.1 Sampling Locations

Samples were collected from the points listed in Table 3-9 for all analyses both by labs and by operators in the field.

4.6.9.1.2 Timing of Sample Collection

Automatic data acquisition of PLC inputs occurred every 15 minutes, which was adequate to catch the UF system at various stages of backwash and forward operation. Turbidity data was recorded by the turbidimeters every five minutes. Data was also recorded manually at the start and end of the workday. Weekly samples were collected on Wednesdays until July 13 when the batch of samples arrived too cold for analysis. Biological samples must be above zero degree C, however the lab maintains that the water temperature was below zero. Sampling was repeated on July 18 and thereafter sampling was performed on Tuesdays. Sampling was begun at approximately 1:00 pm to allow for the minimum transit time for samples with 24 hour hold times. Field measurements were performed twice per day in the morning and evening as other tasks allowed.

4.6.9.2 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, certified QC standards and/or matrix spikes were run with each batch of samples. Every sampling event with samples shipped to the lab included 10% sample duplicates, travel blanks, method blanks, matrix spikes (MS), and matrix spike duplicates (MSD) provided by the labs. For acceptable analytical accuracy, the recoveries must be within control limits for each analyte, where control limits are defined as the mean recovery plus or minus 3x the standard deviation. Recovery of matrix spike samples, duplicates and laboratory control samples are reported in Appendix M.

The percent recoveries of all matrix spikes and standards were within the allowable limits for all analytical methods.

For physical and chemical analyses performed in the field, certified QC standards (performance evaluation, or PE) for pH and turbidity were run once during the testing period. The reported values for pH and turbidity were within the acceptable range for the PE samples.

4.6.9.3 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. One sample per batch was analyzed in duplicate for the NSF Laboratory measurements. For field measurements, one process stream was analyzed in duplicate every day. Precision of duplicate analyses was measured through RPD.

The duplicate analysis RPD calculations are presented in Appendix M. All RPDs were within the allowable limit of 30% for each parameter with the following exceptions:

- 15 of the 48 turbidity measurements using grab samples and the field turbidimeter exceeded the 30% RPD. As discussed in Section 4.6.6.1, the field test is more susceptible to air bubbles, fogging, and other issues than the in-line measurements.

4.6.9.4 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 actual number of samples collected and analyzed for each parameter and/or method compared to the test plan requirements.

All planned water chemistry samples were collected and analyzed.

Initially total and fecal coliform were scheduled to be collected daily, Monday through Thursday, for each week of testing for the UF feed and filtrate. Full sets of feed and filtrate were obtained for 11 of 17 possible sampling days yielding a completeness of 65%. HPC and *E. coli* were scheduled for weekly analysis and were analyzed on 4 of the 5 weeks during the test for 80% completeness. As discussed earlier, the *Cryptosporidium* and *Giardia* analyses did not meet the QA/QC requirements, thus were not valid.

The field parameters, pH, temperature, conductivity, and turbidity were scheduled for twice daily analysis for a 30 day test yielding a projected 60 results. The actual number of results collected varied from a minimum of 48 UF filtrate turbidity measurements to a maximum of 52 UF feed water samples for pH, temperature, conductivity and turbidity. This yields a completeness of 80 to 87%.

4.7 References

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Appendices

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