Environmental Technology Verification Report

Removal of Arsenic in Drinking Water

Watts Premier
M-Series M-15,000 Reverse
Osmosis Treatment System

Prepared by

NSF.

NSF International

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

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

ETV ✓

EPA

U.S. Environmental Protection Agency

NSF

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**MEMBRANE FILTRATION USED IN DRINKING WATER TREATMENT SYSTEMS**
APPLICATION:	**REMOVAL OF ARSENIC**
TECHNOLOGY NAME:	**WATTS PREMIER M-SERIES M-15,000 REVERSE OSMOSIS (RO) TREATMENT SYSTEM**
COMPANY:	**WATTS PREMIER**
ADDRESS:	**1725 W. WILLIAMS DRIVE, #C-20** PHONE: **(623) 505-1514** **PHOENIX, ARIZONA 85027** FAX: **(623) 931-0191**
WEB SITE:	**www.wattspremier.com**
EMAIL:	**murphysp@wattsind.com**

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

NSF International (NSF) in cooperation with the EPA operates the Drinking Water Systems (DWS) Center, one of seven technology areas under the ETV Program. The DWS Center recently evaluated the performance of a membrane separations system for the reduction of arsenic in drinking water. This verification statement provides a summary of the test results for the Watts Premier M-Series M-15,000 Reverse Osmosis (RO) Treatment System. MWH, an NSF-qualified field testing organization (FTO), performed the verification testing. The verification report contains a comprehensive description of the test.

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ABSTRACT

Verification testing of the Watts Premier M-Series M-15,000 RO Treatment System was conducted over a 31-day period from April 26, 2004, through May 26, 2004. This test was conducted at the Coachella Valley Water District (CVWD) Well 7802 in Thermal, California. The source water was a chlorinated groundwater supply. Based on the manufacturer's recommendations, the unit was operated at an average inlet pressure of 135 pounds per square inch (psi), water recovery of 53%, flux of 34 gallons per square-foot per day (gfd), and a specific flux of approximately 0.36 gfd/psi at 25 degrees Celsius (ºC). The total arsenic (As) concentration in the feed water averaged 14 micrograms per liter (µg/L) during the testing period. The M-15,000 RO Treatment System reduced the arsenic levels to below detection (1.0 µg/L) for all but the last two samples, which were 1.4 and 1.2 µg/L. Six sets of samples were speciated and the dominant form of arsenic was As(V).

The system operated for 27 days of the 31-day verification period, with three system shut downs due to operational issues associated with the pre-filter. The verification study indicated that arsenic can be removed by the M-15,000 RO Treatment System, but depending on the source water characteristics, the appropriate pre-filter selection is important to prevent clogging of the pre-filters.

TECHNOLOGY DESCRIPTION

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

The M-15,000 RO Treatment System contains six pressure vessels, each containing one 4" x 40" membrane module. Each stainless steel pressure vessel is four inches (10 cm) in diameter and approximately 45 inches (110 cm) long. The M-15,000 RO Treatment System is a skid-mounted unit that is constructed with a carbon steel frame and powder coating. The verification unit is 37 ¾" (length) x 28 ¾" (depth) x 53 ½" (height) and requires a minimum of 18" clearance on all sides for servicing, 40" clearance on top, and a floor sink drain of 1 ¼" diameter within 10' of the processing unit. The main components of the RO unit are a 3 Hp feed pump, carbon bloc (for removal of chlorine) or sediment pre-filter pretreatment, six pressure vessels, and an in-line conductivity meter. The M-15,000 RO Treatment System unit may use either a carbon pretreatment for removal of chlorine or a sediment pre-filter as standard equipment for the system. The membranes are not tolerant of chlorine and, therefore, when the system is used on a chlorinated water source, the carbon pretreatment should be used.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification testing site was the CVWD Well 7802 located in Thermal, California. The feed water for the verification study was a chlorinated source, with an average free chlorine residual of 0.47 milligrams per liter (mg/L). The chlorine enters the distribution system at the discharge manifold, and was fed from a Hammond's tablet feeder using calcium hypochlorite tablets as the chlorine source. The average feed water quality during the verification testing is provided in the table below.

In addition to being a suitable fit for water quality, the site also had sufficient access (1 acre site); full electrical supply with backup diesel powered generator; 6' privacy/security wall; all utilities readily available including raw water supply, power, and a drain (blow-off structure) for the discharge of the water from the ETV verification testing; and safety facilities, including an emergency shower and eyewash.

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Average Feed Water Quality during Verification Testing

Parameter	Units	# of Samples	Average	Parameter	Units	# of Samples	Average
Total Arsenic	μg/L	27	14	Turbidity	NTU[3]	5	0.40
Dissolved Arsenic	μg/L	5	14	Conductivity	umoh/cm	54	231
As (III)	μg/L	5	3.7	TDS	mg/L	27	140
As(V)[1]	μg/L	5	11	TSS	mg/L	5	< 10
TOC	mg/L	5	< 0.50	Manganese	μg/L	5	< 2.0
Calcium	mg/L	5	4.8	Iron	mg/L	5	0.019
Chloride	mg/L	5	8.5	Barium	μg/L	5	7.1
Hardness	mg/L	5	18	Silica	mg/L	5	15
Alkalinity	mg/L	5	83	Fluoride	mg/L	5	0.80
Free Chlorine	mg/L	18	0.47	Sulfate	mg/L	5	20
Total Chlorine	mg/L	18	0.51	Chromium	μg/L	5	13
pH[2]	--	27	9.21[3]	Vanadium	μg/L	5	49
Temperature	°C	54	27.5				

[1] As (V) is a calculated value.
[3] pH is reported as the median, not the average.
[3] Nephelometric Turbidity Unit(s).

Methods and Procedures

Water quality was monitored from three water streams: feed water, permeate, and concentrate. Conductivity, pH, turbidity, chlorine (free and total), temperature, alkalinity, hardness analyses were conducted on-site, using equipment set up in the pump house at CVWD Well 7802 and in accordance with *Standard Methods for the Examination of Water and Wastewater, 20th edition*. Conductivity and feed water temperature were monitored twice per day, while pH was monitored once per day. Alkalinity, hardness, chlorine, and turbidity were monitored once per week on-site using methods approved by NSF. The following additional samples were sent to MWH Laboratories for analysis: arsenic (total, dissolved, and As^{+3}), total suspended solids (TSS), total dissolved solids (TDS), total organic carbon (TOC), silica, barium, calcium, chloride, sulfate, iron, manganese, fluoride, chromium, and vanadium. Total arsenic and TDS samples were collected once per day; dissolved arsenic, As^{+3}, TSS, TDS, TOC, silica, barium, calcium, chloride, sulfate, iron, manganese, fluoride, chromium, and vanadium samples were collected once per week. One sample was collected during the verification test for silt density index (SDI) analysis. Complete descriptions of the verification testing results and quality assurance/quality control procedures are included in the verification report.

VERIFICATION OF PERFORMANCE

System Operation

RO is a pressure-driven process, with the pressure used for separation by allowing fresh water to move through a membrane, leaving various dissolved constituents of the water behind. In the M-15,000 RO Treatment System, feed water is initially passed through a pre-filter (sediment filter or carbon bloc for chlorine removal) to remove particles that have the potential to damage the membrane. There is a sampling port just prior to the pre-filter to collect the feed water samples. After passing through the pre-filter, the feed water is blended with re-circulated concentrate water and is then referred to as the inlet water. The inlet water is then sent through a booster pump and after leaving the discharge side of the pump, the water line is split and feeds the two separate banks of membranes (six membranes in total), starting with membrane 1 and 4. For the first bank of membranes, concentrate from membrane 1 feeds membrane 2 and concentrate from membrane 2 feeds membrane 3. For the second bank of membranes, concentrate from membrane 4 feeds membrane 5 and concentrate from membrane 5 feeds membrane 6.

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Permeate from all membranes is collected from the bottom of the housing and exits the unit as drinking water. There is a permeate sample port for each of the six membranes, as well as the blended permeate from all six of the membranes. During the verification test, permeate samples were collected from the blended permeate sample port. Concentrate from membranes 3 and 6 is split, some being purged to waste and some re-circulating back to the head of the system, just after the pre-filter where it is blended with the feed water to create the inlet water. The concentrate that is re-circulated back to the head of the system is referred to as recycle water.

The M-15,000 RO Treatment System was set up in accordance with the manufacturer's recommendations the week prior to the verification test. The unit was tested to make sure all systems were operating in accordance with their recommended ranges. Based on discussions between the FTO and the manufacturer, the set points were adjusted to achieve a 50% permeate recovery. Once the set points were adjusted, the system flow rates were stable for the remainder of the verification period. The feed water pressure was stable throughout the testing period, however, the inlet pressure varied from 102 to 145 psi, due to clogging of the carbon bloc pre-filter. Once the pre-filter was replaced with a sediment filter, the inlet pressures stabilized (140 to 150 psi) for the remainder of the verification testing.

Water Quality Results

The M-15,000 RO Treatment System removed the feed water total arsenic from 14 µg/L (on average) to non-detectable levels (<1.0 µg/L) for all but the last two samples collected, which were 1.4 and 1.2 µg/L. As shown in the figure below, the unit was able to produce a consistent, high quality permeate with total arsenic levels below 1.0 µg/L in 95% of the samples over the range of feed water of 12 to 16 µg/L. Throughout most of the verification test, the total arsenic mass balance was very close, with the exception of April 29, 2004, and May 10, 2004, where the arsenic concentration in the concentrate stream was significantly higher (greater than the 95% confidence interval), at 84 µg/L and 38 µg/L respectively. The permeate conductivity and TDS slowly increased throughout the verification testing, starting around 6.4 umoh/cm and increasing to 76.6 umoh/cm for conductivity and starting at <10 mg/L and increasing to 45 mg/L for TDS. During the verification testing, a total of five weekly samples were collected for inorganic analyses. Based on these five samples, the M-15,000 RO Treatment System removed on average: >72% barium, >79% calcium, 85% fluoride, 85% chloride, >92% chromium, >90% sulfate, >93% vanadium, 38% iron, and 62% silica. Manganese was also sampled and analyzed during the verification testing, but the percent removal could not be determined due to non-detectable (<2 µg/L) levels for all of the feed water and permeate samples.
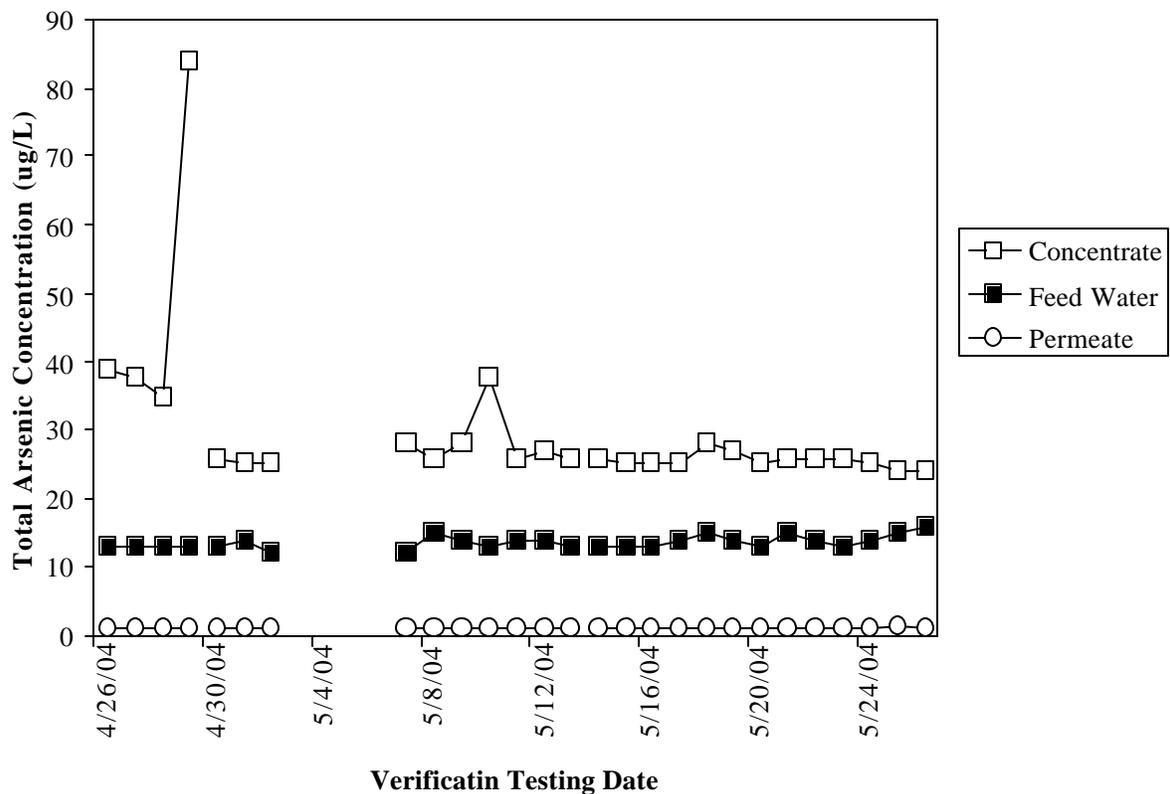
Temporal Plot of Total Arsenic

Operation and Maintenance Results

The system ran continuously for 27 of the 31-day verification testing period. For one 4-day period, the system was shut down due to operational issues. Clogging of the carbon bloc pre-filter is believed to be the cause of the shut down. The unit automatically shut down on two separate occasions, also believed to be related to clogging of the carbon bloc pre-filter. On May 13, 2004 the carbon bloc pre-filter was replaced with a 20-micron sediment pre-filter. The system ran continuously after the sediment filter was installed, until the end of the verification testing on May 26, 2004, when the system was manually shut down.

Quarterly maintenance was conducted upon completion of the verification testing. The maintenance procedure took approximately 45 minutes to change out the O-rings on the pre-filter and brine line, and replace the pre-filter and two of the six RO membranes. Upon completion of the maintenance procedures, the system was started back up and both water quality and operational conditions were recorded. The specific flux immediately prior to the maintenance was 0.34 gfd/psi and upon start up after the maintenance was 0.33 gfd/psi, thus a 97% recovery of specific flux was achieved upon completion of the maintenance procedures.

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Consumables and Waste Generation

There were no "consumable" chemical items used for the verification testing; however, the pre-filter to the system would be a consumable product and would have to be disposed of as solid waste. The concentrate waste stream produced from the verification test was blended back with the permeate water for an equivalent water quality to the feed water from the CVWD Well 7802. This water was then sent to a blow-off structure for disposal. The estimated concentrate production rate was 17,300 gallons per day, based on the targeted 50% permeate recovery.

Quality Assurance/Quality Control

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

Original Signed by		*Original Signed by*	
Lawrence W. Reiter	*09/30/04*	*Gordon Bellen*	*09/30/04*
Lawrence W. Reiter	Date	Gordon Bellen	Date
Acting Director		Vice President	
National Risk Management Research Laboratory		Research	
Office of Research and Development		NSF International	
United States Environmental Protection Agency			

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

Availability of Supporting Documents
Copies of the *ETV Protocol for Equipment Verification Testing for Arsenic Removal* dated September 2003, the *ETV Protocol for Equipment Verification Testing for Removal of Inorganic Constituents* dated April 2002, the verification statement, and the verification report (NSF Report # 04/16/EPADWCTR) are available from the following sources:
(NOTE: Appendices are not included in the verification report. Appendices are available from NSF upon request.)

1. ETV Drinking Water Systems Center Manager (order hard copy)
   NSF International
   P.O. Box 130140
   Ann Arbor, Michigan 48113-0140

2. NSF web site: http://www.nsf.org/etv (electronic copy)

3. EPA web site: http://www.epa.gov/etv (electronic copy)

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Environmental Technology Verification Report

Removal of Arsenic in Drinking Water

Watts Premier M-Series
M-15,000 Reverse Osmosis Treatment System

Prepared for:

NSF International
Ann Arbor, Michigan 48105

Prepared by:

MWH
Pasadena, CA 91101

Under a cooperative agreement with the U.S. Environmental Protection Agency

Jeffrey Q. Adams, Project Officer
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Notice

The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development, has financially supported and collaborated with NSF International (NSF) under Cooperative Agreement No. R-82833301. This verification effort was supported by the Drinking Water Systems (DWS) Center, operating under the Environmental Technology Verification (ETV) Program. This document has been peer reviewed, reviewed by NSF and EPA, and recommended for public release.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water 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, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Lawrence W. Reiter, Acting Director
National Risk Management Research Laboratory

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Abbreviations and Acronyms

AM	morning
As	arsenic
As (III)	arsenite
As (V)	arsenate
ASTM	American Society of Testing and Materials
°C	degree Celsius
CVWD	Coachella Valley Water District
°F	degree Fahrenheit
EPA	Environmental Protection Agency
ETV	environmental technology verification
Ft	feet
FTO	field testing organization
gfd	gallons per square-foot per day
gfd/psi	gallons per square-foot per day per pounds per square inch
gpd	gallons per day
gpm	gallon per minute
LCS	laboratory control sample
LFM	laboratory fortified matrix
LSI	Langelier Saturation Index
MB	method blank
mL	milliliter
mg/L	milligram
MRL	minimum reporting limit
NDP	net driving pressure
NELAC	National Environmental Laboratory Accreditation Conference
NIST	National Institute of Standards and Technology
NRMRL	National Risk Management Research Laboratory
NSF	NSF International (formerly known as the National Sanitation Foundation)
NTU	nephelometric turbidity unit(s)
O&M	operation and maintenance
p	pressure
PM	evening
psi	pounds per square inch
psig	gauge pressure
PSTP	Product Specific Test Plan
Q	flow rate
QAPP	Quality Assurance Project Plan
RO	reverse osmosis
RPD	Relative percent difference
SDI	silt density index
T	temperature
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
µg	microgram

Acknowledgments

The field testing organization (FTO), MWH, was responsible for all elements in the testing sequence, including collection of samples, calibration and verification of instruments, data collection and analysis, data management, data interpretation, and the preparation of this report.

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 (FTOs) 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 ETV DWS Center evaluated the performance of the Watts Premier M-Series M-15,000 Reverse Osmosis (RO) Treatment System, which is a membrane technology used in drinking water treatment system applications. The verification test evaluated the ability of the RO system to remove arsenic from drinking water under specific feed water quality and conditions. This document provides the verification test results for the M-15,000 RO Treatment System.

1.2 Testing Participants And Responsibilities

The ETV testing of the M-15,000 RO Treatment System was a cooperative effort among the following participants:

> NSF International
> MWH

Watts Premier
        MWH Laboratories
        U.S. Environmental Protection Agency

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

1.2.1 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 provided technical oversight of the verification testing and conducted an audit of the field analytical data gathering and recording procedures. NSF also provided review of the Product Specific Test Plan (PSTP) as well as this report.

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

1.2.2 Field Testing Organization

MWH, an environmental engineering consulting firm, conducted the verification testing of the M-15,000 RO Treatment System. MWH is an NSF-qualified FTO for the ETV DWS Center.

The FTO was responsible for conducting the verification testing for 31 calendar days. The FTO provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. The FTO was responsible for ensuring the testing location and feed water conditions were such that the verification testing could meet its stated objectives. The FTO prepared the PSTP; oversaw the pilot testing; managed, evaluated, interpreted, and reported on the data generated by the testing; and evaluated and reported on the performance of the technology.

FTO employees conducted the on-site analyses and data recording during the testing. The FTO's project engineer and project manager provided oversight of the daily tests.

Contact Information:
    MWH
    300 N. Lake Avenue, Suite 1200
    Pasadena, CA 91101
    Phone: (626) 568-6010
    Fax: (626) 568-6015
    Contact Person: Thomas Gillogly, Ph.D
    Email: Thomas.Gillogly@MWHGlobal.com

1.2.3   Manufacturer

The treatment system is manufactured by Watts Premier, a water treatment equipment manufacturer and supplier. The manufacturer was responsible for supplying a field-ready M-15,000 RO Treatment System equipped with all necessary components, including treatment equipment, 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:
    Watts Premier
    1725 W. Williams Drive, #C-20
    Phoenix, Arizona 85027
    Phone: (623) 505-1514
    Fax: (623) 931-0191
    Contact Person: Shannon Murphy
    Email: murphysp@wattsind.com

1.2.4   Analytical Laboratory

The specific responsibilities of the water quality analytical staff, MWH Laboratory, were to provide all off-site water quality analyses prescribed in the PSTP according to the Quality Assurance/Quality Control (QA/QC) and the protocols contained therein, provide reports with the analytical results to the data manager, and provide detailed information on the analytical procedures implemented.

Contact Information:
    MWH Laboratories
    750 Royal Oaks, Suite 100
    Monrovia, CA 91016
    Phone: (626) 386-1100
    Fax: (626) 386-1101
    Contact Person: Andrew Eaton, Ph.D.
    Email: Andrew.Eaton@MWHGlobal.com

1.2.5   U.S. Environmental Protection Agency

The EPA, through its Office of Research and Development, 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 NSF and EPA, and recommended for public release.

1.3   Verification Testing Site

The test site selected for the verification testing of the M-15,000 RO Treatment System was the Coachella Valley Water District's (CVWD) Well 7802 located in Thermal, California. The following sections provide additional information on the test site (source water characteristics and discharge method).

1.3.1   Source Water

The feed water used during the verification study was a chlorinated source, with an average free chlorine residual of 0.47 milligrams per liter (mg/L). The chlorine enters the distribution system at the discharge manifold, and was fed from a Hammond's tablet feeder using calcium hypochlorite tablets as the chlorine source. A summary of the average feed water quality values from the 27 days of operation during the verification testing is presented in Table 1-1. Complete descriptions of the verification testing results and quality assurance/quality control procedures are included in Chapters 3 and 4.

Table 1-1: Average Feed Water Quality during Verification Testing

Parameter	Units	Number of Samples	Average	Parameter	Units	Number of Samples	Average
Total Arsenic	µg/L	27	14	Turbidity	NTU[3]	5	0.40
Dissolved Arsenic	µg/L	5	14	Conductivity	umoh/cm	24	231
Arsenite (As (III))	µg/L	5	3.7	Total Dissolved Solids (TDS)	mg/L	27	140
Arsenate (As(V))[1]	µg/L	5	11	Total Suspended Solids (TSS)	mg/L	5	< 10
Total Organic Carbon (TOC)	mg/L	5	< 0.50	Manganese	µg/L	5	< 2.0
Calcium	mg/L	5	4.8	Iron	mg/L	5	0.019
Chloride	mg/L	5	8.5	Barium	µg/L	5	7.1
Hardness	mg/L	5	18	Silica	mg/L	5	15
Alkalinity	mg/L	5	83	Fluoride	mg/L	5	0.80
Free Chlorine	mg/L	18	0.47	Sulfate	mg/L	5	20
Total Chlorine	mg/L	18	0.51	Chromium	µg/L	5	13
pH[2]	--	27	9.21	Vanadium	µg/L	5	49
Temperature	°C	54	27.5				

[1] As (V) is a calculated value.
[2] pH is reported as the median, not the average.
[3] Nephelometric Turbidity Unit(s).

1.3.2   Pilot Effluent Discharge

All treated water (RO permeate) and waste (RO concentrate) were blended back together and sent to a blow-off drain for disposal, see clear 1-inch flexible tubing in Photograph 1.   The blended water produced from the equipment being tested was not anticipated to adversely impact the environment, as the quality of the blended water was equivalent to the well's raw water quality, with the exception of chlorine. The blow-off drain had sufficient capacity to accept the blended water (treated and concentrate) flow rate for the duration of the study. De-chlorination tablets were added to the drain where the water from the verification unit was discharging.
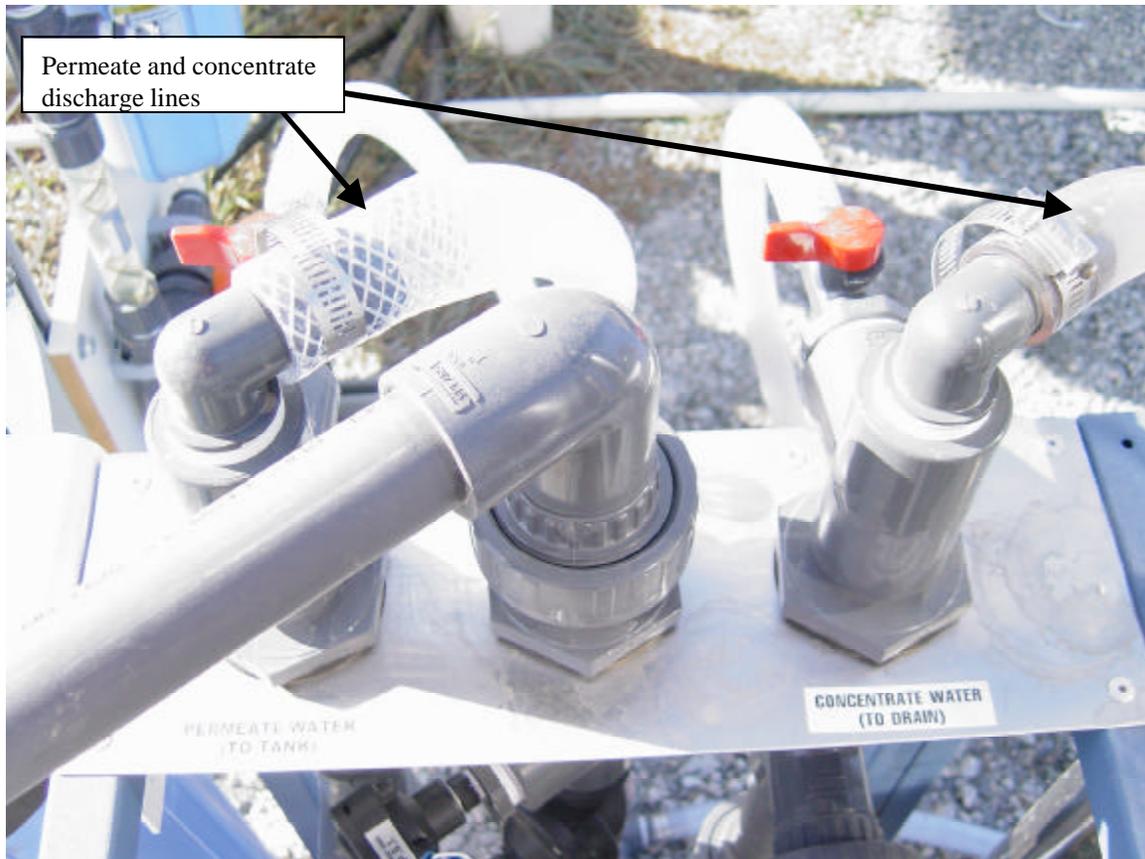
Photograph 1: Permeate and Concentrate Discharge Lines

1.3.3 Discharge Permits

No discharge permits were necessary for this verification study.

Chapter 2
Equipment Description and Operating Processes

2.1   Equipment Description

The equipment tested in the ETV was the M-15,000 RO Treatment System. The M-15,000 RO Treatment System verification unit contains six pressure vessels, each containing one 4" x 40" membrane module. Each stainless steel pressure vessel is 4 inches (10 cm) in diameter and approximately 45 inches (110 cm) long. A schematic of the system is shown in Figure 2-1 and a photograph of the unit is shown in Photograph 2, which specifically shows the panel mounted flow meters, pressure gauges, recirculation needle valve, and individual membrane sample ports.
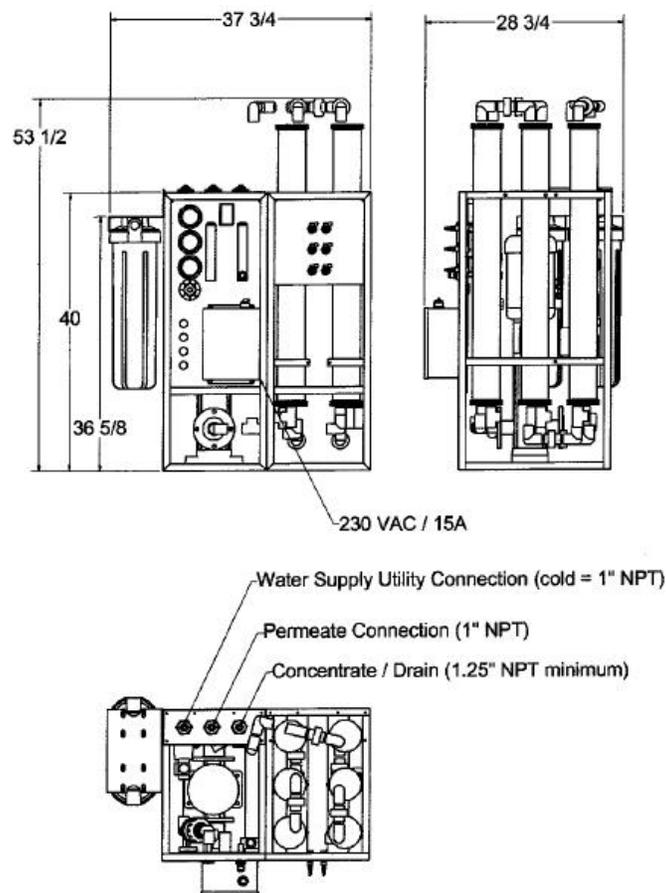
Figure 2-1: Watts Premier M-Series M-15,000 RO Treatment System.

The feed water is initially passed through a pre-filter (sediment filter or carbon bloc for chlorine removal) to remove particles that have the potential to damage the membrane. There is a sampling port just prior to the pre-filter to collect the feed water samples. After passing through the pre-filter, the feed water is blended with re-circulated concentrate water and is then referred to as the inlet water. The inlet water is then sent through a booster pump and after leaving the discharge side of the pump, the water line is split and feeds the two separate banks of membranes

(three membranes per bank, six membranes in total), starting with membrane 1 and 4. For the first bank of membranes, concentrate from membrane 1 feeds membrane 2 and concentrate from membrane 2 feeds membrane 3. For the second bank of membranes, concentrate from membrane 4 feeds membrane 5 and concentrate from membrane 5 feeds membrane 6. Permeate from all membranes is collected from the bottom of the housing and exits the unit as drinking water. There is a permeate sample port for each of the six membranes, as well as the blended permeate from all six of the membranes. During the verification test, permeate samples were collected from the blended permeate sample port. Concentrate from membranes 3 and 6 is split, some being purged to waste and some re-circulating back to the head of the system, just after the pre-filter where it is blended with the feed water to create the inlet water. The concentrate that is re-circulated back to the head of the system is referred to as recycle water. A process flow diagram of the flow streams through the M-15,000 RO Treatment System is presented in Figure 2-2.
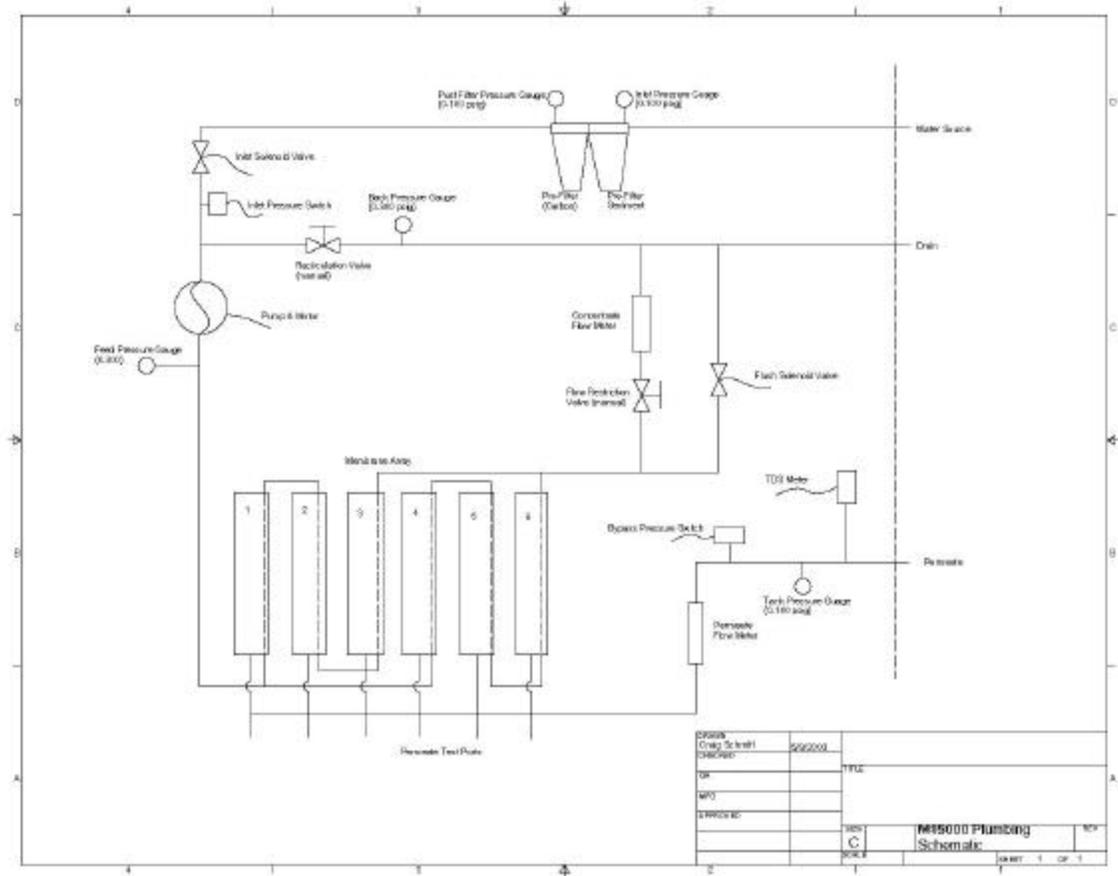
Figure 2-2: Watts Premier M-15,000 RO Treatment System process flow diagram and sample locations.

Photograph 2: Watts Premier M-15,000 RO Treatment System at CVWD Well 7802

The recycle rate was determined during the initial shake down period, but was expected to be 75% at 130 to 150 pounds per square inch (psi) (based on the manufacturer's experience) and was manually adjusted through a recirculation needle control valve. For a standard M-15,000 RO Treatment System, recycle ratio is not a measured operational parameter. For the verification study, the recycle flow rate was monitored through a flow meter (not a standard part) located on the recycle water line in order to calculate the recycle ratio and determine the true osmotic gradient across the membranes.

The qualitative, quantitative and cost factors of the tested equipment were identified, in so far as possible, during the verification testing. The relatively short duration of the study created difficulty in reliably identifying some of these factors. The qualitative factors examined during the verification were operational aspects of the M-15,000 RO Treatment System; for example, susceptibility to changes in environmental conditions, operational requirements and equipment safety, as well as other factors that might impact performance. The quantitative factors examined during the verification testing process were costs associated with the system, such as power, filter cartridge replacement, cost of operation and disposal costs. The operating conditions were recorded in the project logbook. Specific information regarding the membrane plant design criteria and membrane element characteristics may be found on Table 2-1 and Table 2-2.

Table 2-1: Membrane Plant Design Criteria Reporting Items

Parameter	Value
Number of Stages	2
Number of Pressure Vessels in Stage 1	1
Number of Pressure Vessels in Stage 2	6
Number of Membrane Elements per Pressure Vessel	1
Recovery per Stage (%)	NA[1]
Recovery for System	50%
Design Flux	12 gfd[2]
Pressure Loss per Element	6 psi
Pressure Loss in Stage Entrance and Exit	150 psi
Feed Stream TDS (mg/L)	Based on Influent Water Quality
TDS rejection	95-99%
Rejection of Specific Inorganic Constituents	80-99%

[1] NA = Not available.
[2] Gallons per square-foot per day.

Table 2-2: Membrane Element Characteristics

Parameter	Value
Membrane Manufacturer	Applied
Membrane Element Model Number	M-T4040 ALE
Size of Element Used in Study	4" X 40"
Active Membrane Surface Area per Element	82 ft^2
Molecular Weight Cut-Off	80 – 100 Daltons
Membrane Material Construction	Dow Filmtec
Membrane Hydrophobicity	Hydrophobic
Reported Membrane Charge	Negative
Spacer Thickness	31 mil
Scroll Width	38 inches
Design Pressure	150 psi
Design Flux at Design Pressure	34 gfd
Variability of Design Flux	± 15%
Design Specific Flux at 25°C	0.24 gfd/psi
Standard Testing Recovery	50-75%
Standard Testing pH	8
Standard Testing Temperature	25°C
Design Cross-Flow Velocity	0.6 ft/s
Maximum Flow Rate to an Element	16 gallons per minute (gpm)
Minimum Flow Rate to an Element	4 gpm
Required Feed Flow to Permeate Flow Ratio	1:5
Maximum Element Recovery	75%
Rejection of Reference Solute and Conditions of Test (e.g., Solute type and concentration)	80-99%
Variability of Rejection of Reference Solute	-0%, +1%
Acceptable Range of Operating Pressures (psi, bar)	Dependent on Water Temperature
Acceptable Range of Operating pH Values	2 – 11
Typical Pressure Drop across a Single Element	6 psi
Maximum Permissible Silt Density Index (SDI)	4
Maximum Permissible Turbidity	1 NTU
Chlorine/Oxidant Tolerance	With Carbon Pre-Filter
Suggested Cleaning Procedures	M-15,000 RO Treatment System has a self-flush procedure.

2.2   Operating Process

RO is a pressure-driven process, with the pressure used for separation by allowing fresh water to move through a membrane, leaving various dissolved constituents of the water behind. Scientists have explored this concept since the turn of the century, but commercialization for desalting water for municipal purposes has occurred in only the last 30 to 40 years.

For this separation process, water from a pressurized saline solution is separated from the dissolved inorganic and organic compounds by flowing through a membrane. No heating or phase change is necessary for this separation. The major energy required for desalting is for pressurizing the feed water. The saline feed water is pumped into a closed vessel where it is pressurized against the membrane. As a portion of the water passes through the membrane, the remaining feed water increases in salt content. At the same time, a portion of this feed water is discharged without passing through the membrane.

The amount of water that can be passed through the membrane is frequently controlled to avoid problems with precipitation of super-saturated salts and increased osmotic pressure across the membranes. The amount of the feed water discharged to waste in the concentrate stream varies from 15 to 70% of the feed flow, depending on the inorganic composition of the feed water, pressure, and type of membrane. The RO membranes vary in their ability to reject the passage of inorganics, including the various arsenic compounds detected in the environment.

As this treatment does not destroy arsenic, the total mass of arsenic exiting the system equals the mass entering the system. Consequently, the amount of arsenic that has been "removed" from the permeate (treated water) can be found in the wasted concentrate.

Referring to Figure 2-1, the M-15,000 RO Treatment System used in the verification testing included:

- 3 Hp single phase motor and stainless steel centrifugal pump,
- Pre-filter for removal of small debris (sediment, rust, and other suspended solids) and residual chlorine (first 18 days of testing) and a cartridge pre-treatment filter (last 13 days of testing) (see Photograph 3),
- Panel mounted flow meters (to monitor permeate, concentrate, and recycle flow),
- Recycled water flow meter (not a standard part for the M-15,000 RO Treatment System) located on the recycle line prior to cartridge pre-filter,
- Manual recirculation needle control valve,
- Panel mounted digital conductivity meter (permeate water),
- Membrane test ports,
- Glycerin filled pressure gages (used to monitor inlet and feed water pressure),
- Six stainless steel pressure vessels, and
- Six 4" x 40" RO modules.

Photograph 3: Pre-Filter to Watts Premier M-15,000 RO Treatment System

The inlet and feed water pressure were monitored by the glycerin filled pressure gages that had a range of 0 to 300 psi. The permeate and concentrate flow rates were measured by the panel mounted flow meters that had a range of 0-20 gpm. The recycle flow meter also had a range of 0 to 20 gpm.

Specific feed water operating parameters, electrical and drain requirements, as well as additional specifications for the M-15,000 RO Treatment System are presented in Table 2-3.

Table 2-3: Watts Premier M-15,000 RO Treatment System Specifications

Specifications	M-15,000 RO System
Dry Weight	950 lbs
Wet Weight	4900 lbs
Feed Water Parameters	
Temperature	35 to 100°F
Max Feed Flow Rate	24 gpm
pH	2 to 11
Maximum Hardness	290 mg/L
Maximum TDS	2500 mg/L
Maximum Iron	0.1 mg/L
Pressure	50 to 150 gauge pressure (psig)
Drain Connection Requirements	
Floor Sink Minimum within 10' of RO system	1 ¼" connection
Electrical Requirements	
RO Processor Optional 220V	220 volts/11.5 amps
Delivery Pump	115 volts/12.4 amps

The flow rate was regulated by a flow meter and control valve to maintain a constant flow, which were mounted on the RO control panel. Raw water was supplied to the verification testing unit

using a pressurized feed line (approximately 80 to 90 psi) and a 3 Hp centrifugal pump was used to increase the pressure to the RO operating conditions of ~150 psi. The raw water (approximately at 24 gpm) was first passed through a 20" carbon bloc pre-filter to remove any small debris, other suspended solid particles, and residual chlorine. The carbon pre-filter was replaced with a 20-micron sediment pre-filter (20 inch, Watts Premier Big Blue pleated sediment filter; the Watts Premier poly spun sediment filter model number WP204020 may also be used) after 18 days of operation, due to a high replacement rate (approximately every 7 days) of the carbon pre-filter.

Chapter 3
Methods and Procedures

3.1 Quantitative and Qualitative Evaluation Criteria

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

- Performance relative to the manufacturer's (Watts Premier) stated range of equipment capabilities,
- The impacts on performance of variations in feed water quality (such as TDS, hardness, temperature, pH, alkalinity and iron),
- The logistical, human and economic resources necessary to operate the equipment, and
- The reliability, ruggedness, cost factors, range of usefulness and ease of operation of the equipment.

In order to address these objectives, the ETV employed the quantitative and qualitative factors listed in Table 3-1 in evaluating the RO equipment performance.

Table 3-1: Quantitative and Qualitative Evaluation Criteria

Quantitative Factors	Qualitative Factors
• Flux	• Ease of operation
• Feed water recovery	• Safety
• Finished water quality	• Susceptibility to environmental conditions
• Range of feed water quality that were treated successfully	• Ruggedness
	• Impact of operator experience on successful
• Power consumption	operation
• Maintenance requirements	• Portability of equipment
• Required level of operator attention	• Modular nature of equipment (ease of capacity
• Spatial requirements	expansion)
• Feed flow requirements	
• Discharge requirements	
• Waste disposal	

The primary applications of RO are the removal of dissolved inorganic and organic contaminants. In the case of this ETV test, the primary application was arsenic removal.

3.2 Key Treated Water Quality Parameters

3.2.1 *Key Groundwater Quality Parameters the Equipment is Designed to Address*

The operating range of the manufacturer's RO membrane is summarized in Table 3-2.

Table 3-2: Operating Range of Watts Premier RO Membrane

Parameter	Range
Arsenic	Less than 350 µg/L[1]
TDS	Less than 2,500 mg/L
Hardness	Less than 290 mg/L
Iron	Less than 0.1 mg/L
pH	2 to 11
Chlorine exposure	Not chlorine tolerant without a carbon filter (which was included during a portion of the study)

[1] For verification testing, the range of arsenic was anticipated to be < 50 µg/L.

3.2.2 Key Treated Water Quality Parameters for Evaluating Equipment Performance

Key treated water quality parameters that were employed for evaluation of the manufacturer's RO system equipment are listed in Table 3-3.

Table 3-3: Key Treated Water Quality Parameters

Water Quality	Inorganic Parameters	Other Parameters
Temperature	Arsenic	Langelier Saturation Index (LSI)
Alkalinity	Conductivity	SDI
Hardness	Silica	
pH	Fluoride	
Turbidity	Iron	
TOC	Manganese	
Chloride	Sulfate	
Free and Total Chlorine	Chromium	
	Vanadium	
	TDS	
	TSS	
	Calcium	
	Barium	

3.3   Calculations

3.3.1 Calculation of Statistical Uncertainty

The count, average, minimum, and maximum values were tabulated for all data sets. For the water quality parameters described above, 95% confidence intervals were calculated for parameters with more than eight data points. The following equation was used for confidence interval calculation:

$$\text{Confidence Interval} = \overline{X} \pm t_{n-1,1-\frac{\alpha}{2}}\left(\frac{S}{\sqrt{n}}\right)$$

where: X = sample mean;
         S = sample standard deviation;

n = number of independent measurements included in the data set; and
t = Student's t distribution value with n-1 degrees of freedom;
α = significance level, defined for 95% confidence as: 1 - 0.95 = 0.05.

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

$$95\% \text{ Confidence Interval} = \overline{X} \pm t_{n-1,0.975}\left(\frac{S}{\sqrt{n}}\right)$$

With input of the analytical results for pertinent water quality parameters into the 95% confidence interval equation, the output is presented as the sample mean value plus or minus the second term. The results of this statistical calculation are presented as a range of values falling within the 95% confidence interval.

3.3.2 Calculation and Definition of Operational Parameters

The following are definitions used in the calculations presented within this section:

Permeate water is defined as the water produced by the RO membrane process.

Feed water is defined as the water introduced to the membrane element (no recycled water).

Inlet water is the combination of the feed water and the recycled concentrate water.

Concentrate water is the concentrated waste stream produce by the RO membrane process.

Recycled water is a portion of the concentrate water recirculated back through the RO membrane process, blended with feed water entering into membranes 1 and 4.

Permeate flux is the flow of permeate divided by the surface area of the membrane.

Permeate flux was calculated according to the following formula:

$$J_t = \frac{Q_p}{S} \tag{3.1}$$

where: J_t = permeate flux at time t (gfd)
  Q_p = permeate flow (gallons per day (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:

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

(3.2)

where: J_t = permeate flux at time t (gfd, $L/(h\text{-}m^2)$)
       Q_p = permeate flow (gpd, L/h)
       S   = membrane surface area (ft^2, m^2)
       T   = temperature of the feed water (°C)

Net Driving Pressure: The Net Driving Pressure is the pressure available to drive water through the membrane, equal to the average feed pressure (average of feed pressure and concentrate pressure) minus the differential osmotic pressure, minus the permeate pressure:

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

(3.3)

where: NDP = net driving pressure for solvent transport across the membrane (psi, bar)
      P_f = inlet pressure to the feed side of the membrane (psi, bar)
      P_c = concentrate pressure on the concentrate side of the membrane (psi, bar)
      P_p = permeate pressure on the treated water side of the membrane (psi, bar)
      $\Delta\pi$ = 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 TDS concentrations on either side of the membrane:

$$\Delta p = \left(\left[\frac{(TDS_I + TDS_c)}{2}\right] - TDS_p\right) \cdot \left(\frac{1\,psi}{100\frac{mg}{L}}\right)$$

(3.4)

where: TDS_I = inlet water (feed water + recycled water) TDS concentration (mg/L)
      TDS_c = concentrate TDS concentration (mg/L)
      TDS_p = permeate TDS concentration (mg/L)

The inlet water (feed water plus recycled water) characteristics were calculated based on the feed water, permeate, and concentrate TDS and conductivity.

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. In contrast, for TDS composed of multivalent ions, the ratio is closer to 0.5 psi per 100 mg/L TDS. This was accounted for during verification testing.

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 discussed with use of flux values that have been temperature-adjusted to 25°C:

$$J_{tm} = \frac{J_t}{NDP} \qquad (3.5)$$

where: NDP = net driving pressure for solvent transport across the membrane (psi, bar)
J_t = permeate flux at time t (gfd, L/(h·m^2)). Temperature-corrected flux values were employed.

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

$$\% \text{ System Recovery} = 100 \cdot \left[\frac{Q_p}{Q_f} \right] \qquad (3.6)$$

where: Q_f = feed water flow to the membrane (gpm, L/h)
Q_p = permeate flow (gpm, L/h)

Recycle Ratio: The recycle ratio represents the ratio of the recycle flow from the membrane concentrate to the total flow of water that is used as feed water flow to the membrane. This ratio provides an idea of the recirculation pumping that is applied to the membrane system to reduce membrane fouling and specific flux decline.

$$\text{Recycle Ration} = \frac{Q_r}{Q_r + Q_f} \qquad (3.7)$$

where: Q_r = recycle water flow rate (gpm)
Q_f = feed water flow rate (gpm)

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 were calculated by the following equation:

$$\% \text{ Solute Rejection} = 100 \cdot \left[\frac{C_f - C_p}{C_f} \right] \tag{3.8}$$

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

Note: the feed water concentration does not include the recycled water.

Solvent and Solute Mass Balance: Calculation of solvent mass balance was performed during Task 1 in order to verify the reliability of flow measurements through the membrane. Calculation of solute mass balance across the membrane system was performed as part of Task 3 in order to estimate the concentration of total arsenic at the membrane surface.

$$Q_f = Q_p + Q_{cw} \tag{3.9}$$

$$Q_f\, C_f = Q_p\, C_p + Q_{cw}\, C_c \tag{3.10}$$

where: Q_f = feed water flow to the membrane (gpm, L/h)
         Q_p = permeate flow (gpm, L/h)
         Q_{cw} = concentrate (wastewater) flow (gpm, L/h)
         C_f = feed water concentration of specific constituent (mg/L)
         C_p = permeate concentration of specific constituent (mg/L)
         C_f = concentrate concentration of specific constituent (mg/L)

Solubility Product: Calculation of the solubility product of selected sparingly soluble salts was performed to determine if there were operational limitations caused by the accumulation of limiting salts at the membrane surface. Textbook equilibrium values of the solubility product were compared with solubility values calculated from the results of experimental verification testing, as determined from use of the following equation:

$$K_{sp} = \mathbf{g}_A^x \left[A^{y-} \right]^x \mathbf{g}_B^y \left[B^{x+} \right]^y \tag{3.11}$$

where: K_{sp} = solubility product for the limiting salt being considered
         γ = free ion activity coefficient for the ion considered (i.e., A or B)
         $[A]$ = molar solution concentration of the anion A for sparingly soluble salt A_xB_y
         $[B]$ = solution concentration of the anion B
         x, y = stiochiometric coefficients for the precipitation reaction of A and B

Mean Activity Coefficient: The mean activity coefficients for each of the salt constituents were estimated for the concentrated solutions as a function of the ionic strength:

$$\log \boldsymbol{g}_{A,B} = -0.509 \cdot Z_A Z_B \sqrt{\boldsymbol{m}} \qquad (3.12)$$

where: γ = free ion activity coefficient for the ion considered (i.e., A or B)
  Z_A = ion charge of anion A
  Z_B = ion charge of cation B
  μ = ionic strength

Ionic Strength: A simple approximation of the ionic strength was calculated based upon the concentration of the TDS in the feed water stream:

$$\boldsymbol{m} = (2.5 \cdot 10^{-5}) \cdot (TDS) \qquad (3.13)$$

where: μ = ionic strength
  TDS = total dissolved solids concentration (mg/L)

3.4 Testing Schedule

The ETV schedule is presented in Figure 3-1. The testing took place over a total period of approximately eight weeks beginning during the second week of April 2004, and ending in late May 2004. The five tasks are described in further detail in Sections 3.7 and 4.1.

Task	Description	Year - 2004							
		12-Apr	19-Apr	26-Apr	3-May	10-May	17-May	24-May	7-Jun
-	Preparation, Coordination, and Setup	███	███						
1	Membrane Operation			███	███	███	███	███	
2	Cleaning Efficiency								███
3	Feedwater and Treated Water Quality Monitoring			███	███	███	███	███	
4	Data Handling Protocol	███	███	███	███	███	███	███	
5	Quality Assurance Project Plan	███	███	███	███	███	███	███	

Figure 3-1: RO verification testing schedule.

Verification testing activities included equipment set-up, initial operation, verification operation, membrane cleaning, and sampling and analysis. Initial operations were conducted so that equipment could tested and to be sure it is functioning as intended.

3.5 Operation and Maintenance

The manufacturer's operation and maintenance (O&M) documentation for the M-15,000 RO Treatment System was reviewed prior to the verification testing. The O&M manual for the M-15,000 RO Treatment System may be found in Appendix A of this report. In addition, the following aspects of operability are addressed in this report:

- Fluctuation of flow rates and pressures through membrane unit – the time interval at which resetting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?)
- Presence of devices to aid the operator with flow control adjustment?
- Was transmembrane pressure measurement provided?
- Was recycle ratio measurement provided?
- Was feed water recovery measurement provided?
- Was rate of flow of raw water measured?
- Did the plant have an indicator if the sediment pre-filter was changed ahead of scheduled quarterly maintenance schedule?
- Did the carbon pre-filter adequately remove chlorine?

3.6 Field Operations Procedures

Testing of the M-15,000 RO Treatment System was conducted by an NSF-qualified FTO, MWH. Water quality analytical work that was carried out as a part of the verification testing plan, was conducted by MWH Laboratories. All arsenic analyses were conducted by MWH Laboratory. Field analytical work was performed by MWH field personnel using field laboratory equipment and procedures for pH, temperature, conductivity, chlorine, turbidity, alkalinity, and hardness.

The verification unit was operated 24 hours a day, seven days a week with staff on-site each day to operate the verification unit and collect water quality data during one eight-hour shift. Tasks performed by the operations staff are described in detail below.

3.7 Environmental Technology Verification Testing Plan

The following section provides a brief overview of the tasks included in the initial characterization tests and the tasks included in the M-15,000 RO Treatment System verification testing plan. The verification tasks included:

Task 1: Membrane Operation
Task 2: Cleaning Efficiency
Task 3: Feed water and Treated Water Quality Monitoring
Task 4: Data Handling Protocol
Task 5: Quality Assurance Project Plan (QAPP)

Verification testing activities included equipment set-up, initial operation, verification operation, and sampling and analysis. Initial operations were conducted so that equipment could be tested

to be sure it was functioning as intended. An overview of each task is provided below with detailed information following this section of the report.

3.7.1   Task 1: Membrane Operation

The objective of this task was to evaluate the RO membrane system operation. System performance was evaluated relative to the stated water quality goals specified by the manufacturer. Membrane productivity, rate of specific flux decline, and rejection capabilities were evaluated at one set of operating conditions for the testing period.

3.7.2   Task 2: Cleaning Efficiency

The objective of this task was to evaluate the efficiency of the membrane cleaning procedures recommended by the manufacturer. Watts Premier recommends replacement of the RO modules based upon efficiencies of TDS reduction per module. TDS reduction of the membranes would need to be monitored in order to determine if replacement of the membranes is necessary. Watts has stated that the M-15,000 RO Treatment System has a built in flushing procedure; however, since the verification test was run continuously, the system did not go through this flushing procedure. However, at the conclusion of the testing period, the cartridge sediment pre-filter and RO module O-rings were replaced according to the manufacturer's recommended quarterly maintenance procedures. While not part of the quarterly maintenance procedures, two of the membranes (membrane number 5 and 6) were also replaced during the maintenance procedures. The operational performance following these maintenance procedures was recorded and presented in Chapter 4 of this report.

3.7.3   Task 3: Feed Water and Treated Water Quality Monitoring

The objective of this task was to evaluate the quality of water produced by the membrane system and the removal of inorganic chemical contaminants achieved by the membrane system at the specified operational conditions. Monitoring of the water quality parameters included the following: arsenic (total, dissolved and As (III)), pH, feed water temperature, chloride, conductivity, calcium, barium, hardness, chlorine, TDS, alkalinity, LSI, turbidity, TSS, silica, fluoride, iron, manganese, sulfate, chromium, vanadium, TOC and SDI. Water quality produced was evaluated in relation to feed water quality and operational conditions. Mass balances were calculated to determine the accumulation of limiting salts on the membrane surface. Post-treatment capabilities of the equipment were also evaluated for arsenic (total, As^{+3}, and dissolved), pH adjustment, corrosion control, and removal of carbon dioxide from the permeate.

An overview of the equipment operational and production characteristics evaluated for each task of the verification testing is provided in Table 3-4.

Table 3-4: Equipment Operational Characteristics to be Evaluated in Each Task

Equipment Operational Characteristic to be Evaluated	Task
1. Feed water flow rate	1
2. Permeate flow rate	1
3. Concentrate flow rate	1
4. Inlet and Outlet pressures to membrane element	1
5. Permeate pressure	1
6. Feed water temperature	1
7. Recycle Ratio	1
8. Power consumption	1
9. Permeate stream characterization	3
10. Calculation of limiting salt concentrations	3
11. Waste stream characterization and range of waste stream flow rates	1 and 3

3.7.4   Task 4: 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 the FTO and NSF during verification testing.   Prior to the beginning of field testing, the database or spreadsheet design were developed by the FTO and reviewed and approved by NSF. This insured that the required data was collected during the testing, and that results could be effectively transmitted to NSF for review.

3.7.5   Task 5: Quality Assurance Project Plan (QAPP)

An important aspect of verification testing is the Quality Assurance Project Plan (QAPP) 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.

3.8 Task 1: Membrane Operation

Membrane operation was evaluated in Task 1, with quantification of temperature-corrected rate of specific flux decline and water recoveries. The rates of specific flux decline were used to demonstrate membrane performance at the specific operating conditions to be verified. Monitoring in Task 1 was focused on determination of the system operational characteristics (e.g., arsenic removal, flux, temperature-corrected specific flux, recovery, etc.). An NSF field inspection of equipment operations, sampling, and field analysis procedures was carried out during the initial test runs in Task 1 (results presented in Chapter 4).

Rate of temperature-corrected specific flux decline is a function of water quality and operational strategy. Many additional factors influence specific flux decline with RO membranes including membrane compaction, inorganic scaling, particulate or organic fouling, biofouling, and other factors.   In this task, specific flux decline was monitored to evaluate operational trends. Chemical characterization of the feed waters and permeate water stream with calculation of membrane rejection capabilities were performed as part of Task 3. Additionally, calculation of the operational limitations caused by limiting salt concentrations was also performed in Task 3.

3.8.1 Experimental Objectives

The objectives of Task 1 were to demonstrate the following: 1) the appropriate operational conditions for the membrane equipment; 2) the feed water recovery achieved by the membrane equipment at the designated operational conditions; and 3) the rate of specific flux decline observed over extended membrane filtration operation during the testing period. This task was also intended to provide operational power consumption information that could be used to develop cost estimates for O&M of the equipment. Complete chemical and physical characterization of the feed waters and treated waters produced by the system, with calculation of limiting salt concentrations, were performed as part of Task 3.

It should be noted that the objective of this task was not process optimization, but rather verification of membrane operation at the operating conditions specified by the FTO, as pertains to permeate flux and transmembrane pressure.

3.8.2 Work Plan

Site preparation, coordination, mobilization and start-up of equipment were performed prior to the initiation of Task 1 testing. Furthermore, the RO membrane treatment system had achieved a condition of steady-state operation prior to the start of Task 1 testing.

After set-up and shakedown of the membrane equipment, RO operation was established at a specific flux of 0.38 gfd/psi with a feed water recovery of 69%. It was intended that the membrane system would be operated continuously for a minimum of one month. However, the system automatically shut itself down twice during the verification testing, and was not in operation for a total of four days during the verification testing period. The system was operated for a total of 27 days during the verification test. A summary of the operational parameters recorded during Task 1 and the minimum frequency of monitoring are presented in Table 3-5. A summary of the water recovery and specific flux may be found in Tables 4-3 (Section 4.2.1.3) and Table 4-6 (Section 4.2.1.5) respectively.

Samples were collected from lab valves mounted on the panel coming from ¼" ball valves teed into the permeate line (permeate), 1" bulk fittings mounted on the top of the unit (concentrate), 1" port on the top of the unit (inlet), and a 1" housing on the side of the panel (feed water). The inlet and feed water pressure were monitored by the glycerin filled pressure gages that have a range of 0 to 300 psi, and the permeate and concentrate flow rates were measured by the panel mounted flow meters that have a range of 1 to 20 gpm. For a standard M-15,000 RO Treatment System, the recycle ratio is not a measured operational parameter. However, for the purpose of verification testing, a flow meter was placed on the recycle line to calculate the recycle ratio.

Table 3-5: Frequency and Type of Operating Data

Operational Parameter	Action, Monitoring Frequency
Feed Water, Permeate, Recycle, and Concentrate Flow Rates	Checked and recorded twice daily. Adjusted when 10% above or below target. Recorded both before and after adjustment. The feed water flow rate was monitored twice daily by summing the permeate and concentrate flow rates.
Membrane Element Inlet and Feed Water Pressures	Checked and recorded twice daily.
Recovery	Calculated and recorded twice daily. Adjusted when 10% above or below target.
Recycle Ratio	Calculated and recorded twice daily. Adjusted when 10% above or below target.
TDS Concentration in Feed water, Concentrate, Permeate	Calculation of osmotic pressure gradient on a daily basis.
Feed water Temperature	Recorded twice daily.
Horsepower and Efficiency of Motors, and Consumed Amperage for RO Treatment	Provided record of pumping requirements, current draw to motors on cumulative basis, power factor and recorded daily from a power totalizer.
Concentrate Composition For Disposal	Sampled waste stream once per week during the 31-day testing period.

When a specific flux decline of 20% occurred before the operating period was completed, adjustments to the operational strategy were made (such as a decrease in nominal flux or recovery). Decisions on which adjustments were made were based upon the manufacturer's experience and consultation with the FTO conducting the study.

3.8.3 Analytical Schedule

Measurement of membrane performance parameters were monitored a minimum of 2 times per day, as indicated in Table 3-5. Temperature measurements were made on a daily basis in order to provide data for temperature correction of specific flux and for reporting of solute rejection (addressed in Task 3).

Power use for the operation of the RO system was monitored with a power totalizer. Power measurements were recorded daily by MWH during the verification test.

The characteristics of feed waters used during the testing period were explicitly reported with the compiled results from membrane flux, specific flux and recovery monitoring. The TDS concentrations in the inlet water (combined feed water and recycled water), permeate and concentrate streams were used to calculate the osmotic pressure gradient (Equation 3.4) across the membrane on a daily basis. Osmotic pressure gradient value was used to calculate net driving pressure and specific flux on a daily basis.

3.8.4 Evaluation Criteria and Minimum Reporting Criteria

- General operational performance (provided in Chapter 4):
  - $\Rightarrow$ Graph of specific flux normalized to 25°C (Equation 3.5) vs. time over the verification testing period.

- ⇒ Temporal profile of net driving pressure normalized to 25°C (Equation 3.3) over the verification testing period.
- ⇒ Temporal profile of water recovery (Equation 3.6) over the verification testing period. One temporal profile graph has been provided for the water quality evaluated.
- ⇒ Temporal profile of the concentrate flow and other waste stream flows produced during the verification testing period.
- Power consumption (provided in Chapter 4):
  - ⇒ A table of horsepower requirements, motor efficiency and consumed amperage for the testing period has been provided, as measured for the set of operational conditions during the verification testing period.
- Concentrate stream characterization (See Chapter 4, Task 3 for the water quality characteristics of the concentrate, permeate, and feed water):
  - ⇒ A table of concentrate stream quality parameters measured during the verification testing period has been provided.

3.9 Task 2: Cleaning Efficiency

While no chemical cleaning procedure was provided by the manufacturer, regularly scheduled maintenance of the system includes quarterly replacement of the pre-filter and RO module O-rings, and replacement of the RO modules based on efficiencies of TDS reduction per filter module. At the end of the testing period, the cartridge sediment pre-filter and RO module O-rings were replaced. In addition to replacing the pre-filter and RO module O-rings, two of the membranes were replaced (membrane number 5 and 6). Measurement of membrane performance parameters following this maintenance were recorded and presented in Chapter 4.

3.9.1 Experimental Objectives

The objective of this task was to evaluate the manufacturer's recommended maintenance procedures for ensuring reasonable operational parameters are maintained during throughout the treatment life of the membrane modules. This task was considered a "proof of concept" effort, not an optimization effort.

3.9.2 Work Plan

The membrane system has the potential to experience specific flux decline during the membrane test run conducted for Task 1. If a 20% decline of specific flux were detected, the modules were to be replaced and the system would then undergo the recommended maintenance procedures specified by the manufacturer. Following the maintenance procedures, the system was restarted and the initial conditions of specific flux, recovery and inorganics (arsenic) rejection capabilities were tested.

As the manufacturer recommends replacement of fouled modules, no chemical cleaning procedures were provided. Furthermore, since chemical cleanings are not recommended, disposal of spent cleaning agents is not relevant.

3.9.3 Analytical Schedule

Flow rates, pressures, recovery, and temperature data were collected immediately prior to and immediately after performing any manufacturer's scheduled quarterly or annual maintenance procedures. Based on this information, any changes in the temperature adjusted specific flux were determined. Two primary indicators of conventional cleaning efficiency and restoration of membrane productivity were examined in this task:

1) The immediate recovery of membrane productivity, as expressed by the ratio between the final specific flux value of the current filtration run (J_{tmf}) and the initial specific flux (J_{tmi}) measured for the subsequent filtration run:

$$\% \text{ Recovery of specific Flux} = 100 \cdot \left[\frac{J_{tm_i}}{J_{tm_f}} \right] \tag{3.14}$$

where: J_{tmf} = Final specific flux (gfd/psi, L/(h·m^2)/bar) at end of the previous run
J_{tmi} = Initial specific flux (gfd/psi, L/(h·m^2)/bar) at the beginning of the current run.

2) The loss of specific flux capabilities, as expressed by the ratio between the initial specific flux for any given filtration run (J_{tmi}) divided by the original specific flux measured at the initiation of operation for the first filtration run in a series (J_{tmio}):

$$\% \text{ Loss of Original specific Flux} = 100 \cdot \left[1 - \frac{J_{tm_i}}{J_{tm_{io}}} \right] \tag{3.15}$$

where: J_{tmio} = Original Specific flux (gfd/psi, L/(h·m^2)/bar) measured at the initiation of membrane testing.

3.9.4 Evaluation Criteria and Minimum Reporting Requirements

The minimum reporting requirements include presentation of the following results
- Specific flux recovery:
  - ⇒ A table is provided in Chapter 4 of post maintenance specific flux recoveries during the period of operation.
- Maintenance efficiency:
  - ⇒ A table is provided in Chapter 4 of the maintenance efficiency indicators described above for the maintenance procedures performed during the period of operation.
- Assessment of irreversible loss of specific flux and estimation of usable membrane life for costing purposes.

3.10 Task 3: Water Quality Monitoring

The water quality data for the feed water (chlorinated groundwater), the membrane permeate and concentrate streams were collected during the verification testing as part of Task 1. A list of the water quality parameters monitored during equipment verification testing is provided in Table 3-6.

Table 3-6: Sampling Schedule and Methods for Feed, Permeate, & Concentrate Water

Parameter	Frequency[1]	Facility	Standard Method[2]	EPA Method[3]	Hach Method
Arsenic (total)	1/day	Laboratory		200.8	
Arsenic (As^{+3} and dissolved)	1/week	Laboratory		200.8	
pH	1/day	On-site	4500-H$^+$ B		
Conductivity	2/day	On-site	2510 B		
TDS	1/day	Laboratory	2540 C		
Alkalinity	1/week	On-site			8221
Hardness	1/week	On-site			8226
LSI	1/month	By Calculation			
Turbidity	1/week	On-site	2130 B		
Temperature (feed only)	2/day	On-site	2550		
TSS	1/week	Laboratory	2540 D		
Silica	1/week	Laboratory		200.7	
Calcium	1/week	Laboratory		200.7	
Barium	1/week	Laboratory		200.8	
Fluoride	1/week	Laboratory	4500 FC		
Iron	1/week	Laboratory		200.7	
Manganese	1/week	Laboratory		200.8	
Sulfate	1/week	Laboratory		300.0	
Chloride	1/week	Laboratory		300.0	
Chromium	1/week	Laboratory		200.8	
Vanadium	1/week	Laboratory		200.8	
TOC	1/week	Laboratory	5310 C		
SDI[4]	1/month	Laboratory	ASTM D4189-95		
Chlorine (total and free)[5]	4/week	On-site			8167 (total) 8021 (free)

[1] The verification plant was staffed seven days per week.
[2] *Standard Methods* 20th Edition.
[3] "Methods for the Determination of Metals in Environmental Samples-Supplement I", EPA/600/R-94/111, May 1994. Available at (NTIS) PB95-125472.
[4] SDI was analyzed on the feed water only.
[5] Total and free chlorine were monitored prior to the pre-filter and after the first membrane to monitor the chlorine removal.

3.10.1 *Experimental Objectives*

The objective of this task was to assess the treatment capability of the membrane equipment to remove arsenic based on water quality conditions at the site. Mass balances were performed as part of this task in order to evaluate the concentration of rejected species at the membrane surface during membrane operation. Calculation of the recovery limitation caused by limiting salts was performed to determine the impact of feed water quality on membrane operation. The count, average, minimum, and maximum values were tabulated for all data sets. Statistical analysis (standard deviation and confidence intervals), were performed on all analytes with eight

or more discrete samples collected over the verification period. The median, minimum, maximum, and count were presented for each pH data set.

3.10.2 Work Plan

Monitoring of water quality parameters in the feed water, permeate and concentrate water streams allowed the calculation of percent rejection of the measured parameters and targeted inorganic chemical contaminants for the specific operational conditions evaluated. Estimation of the percent rejection of arsenic (total) was based upon the equation for solute rejection provided in the Section 3.3.2, Equation 3.8.

Many of the water quality parameters described in this task were measured on-site by the NSF-qualified FTO. Analysis of the remaining water quality parameters were performed by MWH Laboratories, a state certified laboratory. The methods used for measurement of water quality parameters are identified in Table 3-6. A number of the analytical methods utilized in this study for on-site monitoring of feed, permeate, and concentrate water qualities are further described in Task 5, Quality Assurance Project Plan. These analytical methods include pH, conductivity, turbidity, alkalinity, hardness, chlorine, and temperature.

For the water quality parameters submitted to MWH Laboratories, water samples were collected in appropriate containers (containing necessary preservatives as applicable) prepared by MWH Laboratories. These samples were then preserved, stored, shipped, and analyzed in accordance with appropriate procedures and holding times.

3.10.3 Analytical Schedule

Feed Water, Permeate and Concentrate Characterization
During the testing period, the feed water, permeate and concentrate water streams were characterized at a single set of operating conditions. The water quality monitoring requirements are provided in Table 3-6.

Water Quality Sample Collection
Water quality data were collected at the specified intervals during each testing period. The monitoring frequency for the water quality parameters is provided in Table 3-6. To the extent possible, analyses for inorganic water quality parameters were performed on water sample aliquots obtained simultaneously from the same sampling location, in order to ensure the maximum degree of comparability between water quality analytes.

The TDS concentrations in the feed water, permeate and concentrate streams were used to calculate the ionic strength of the feed water and concentrate streams, as well as osmotic pressure gradient across the membrane on a daily basis (see Chapter 4). Osmotic pressure gradient value was then used for calculation of net driving pressure and specific flux on a daily basis. Mass balances for specified water quality parameters [arsenic (total, As^{+3}, and dissolved), silica, fluoride, iron, manganese, chloride, barium, calcium and sulfate] were then calculated once per week. Calculation of the potential for recovery limitation based upon limiting salt concentrations was performed once per week.

3.10.4 Evaluation Criteria and Minimum Reporting Criteria

- Percent removal of inorganic chemical constituents were developed and the following are presented in Chapter 4:
    - ⇒ A temporal plot showing concentrations of target inorganic constituents (arsenic, silica, fluoride, iron, chloride and sulfate) and TDS in the feed water, permeate and concentrate water streams over the period of operation is presented. A temporal plot of the manganese concentrations was not presented as all results (feed water, permeate, and concentrate) were below the minimum reporting limit (MRL) of 2.0 µg/L.
    - ⇒ A table with weekly values of percent removal of target inorganic constituents [arsenic (total, As^{+3}, As^{+5} and dissolved), silica, fluoride, iron, manganese, chloride, barium, calcium and sulfate] and other pertinent water quality parameters (chromium and vanadium) for the period of operation is presented. The equations shown in Section 3.3.2 were used to determine percent removal of all pertinent water quality parameters for verification testing.
    - ⇒ Mass balances through the membrane testing system for total arsenic were conducted. The mass balance equation presented in the Section 3.3.2 was used to calculate the mass of inorganic constituents in different water streams.
    - ⇒ Limiting salt concentrations (via solubility product calculation Equation 3.11) were calculated for specific water quality constituents ($CaCO_3$, $BaSO_4$, and $CaSO_4$) once per week. The equation for solubility product calculation as presented in Section 3.3.2 (Equation 3.11) were used to compare with standard Solubility Product values to determine if the salt concentration is posing a limitation to operational system recovery.
- Individual water quality and removal goals specified by the manufacturer:
    - ⇒ Feed, permeate and concentrate concentrations of any measured water quality parameters are provided in tabular form for the period of operation.
- Removal of TSS and Turbidity:
    - ⇒ A table of feed, permeate, and concentrate water measurements are presented for TSS during the period of operation.
    - ⇒ A table of feed, permeate, and concentrate water turbidity measurements are presented for the period of operation.

3.11 Task 4: Data Handling Protocol

The data management system used in the verification testing involved the use of both computer spreadsheets and manual recording (on-site logbook) of operational parameters for the membrane equipment on a daily basis. All field activities were thoroughly documented. Field documentation included field notebooks, photographs, field data sheets, and chain-of-custody forms. The following guidelines were followed:

- Field notes were kept in a bound logbook,
- Field logbook was used to record all water treatment equipment operating data,
- Each page was sequentially numbered,
- Each page was labeled with the project name and number,

- Completed pages were signed and dated by the individual responsible for the entries, and
- Errors had one line drawn through them and this line was initialed and dated.

All photographs were logged in the field logbook. These entries included the time, date, and subject of the photograph, and identified the photographer.

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

3.11.1 Experimental Objectives

The objectives of this task were: 1) to establish a viable structure for the recording and transmission of field testing data such that the FTO provided sufficient and reliable data to NSF for verification purposes, and 2) to develop a statistical analysis of the data, as described in the document "EPA/NSF ETV Protocol for Equipment Verification Testing for Removal Of Inorganic Constituents: Requirements For All Studies" and "EPA/NSF ETV Protocol for Equipment Verification Testing for Arsenic Removal: Requirements For All Studies."

3.11.2 Work Plan

FTO operators recorded data and calculations by hand in laboratory notebooks. Daily measurements were recorded on specially prepared data log sheets as appropriate. The original notebooks were stored on-site; and electronic copies were forwarded to the project manager of the FTO at least once per week during the testing period. Operating logs included a description of the membrane equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions were provided in addition to experimental calculations and other items.

A database for the project was set up in the form of custom-designed spreadsheets. The spreadsheets were capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebook and data log sheets were entered into the appropriate spreadsheet. Data entry was conducted on-site by the designated field testing operators. All recorded calculations were also checked at this time. Following data entry, the spreadsheets were printed out and the printouts were checked against the handwritten data sheet. Any corrections were noted on the hard copies and corrected on the screen, and then a corrected version of the spreadsheet was printed out. Each step of the verification process was initialed by the field testing operator performing the entry or verification step.

Data from MWH Laboratory were received and reviewed by the field-testing operator. These data were entered into the data spreadsheets, corrected, and verified in the same manner as the field data. As available, electronic data storage and retrieval capabilities were employed in order to maximize data collection and minimize labor hours required for monitoring.

3.12 Task 5: Quality Assurance Project Plan (QAPP)

QA/QC of the operation of the membrane equipment and the measured water quality parameters were maintained during verification testing through a quality assurance project plan (QAPP) as described in this section.

3.12.1 Experimental Objectives

The objective of this task was to maintain strict QA/QC methods and procedures during verification testing. Maintenance of strict QA/QC procedures was important, in that if a question arose when analyzing or interpreting data collected for a given experiment, it was possible to verify exact conditions at the time of testing. The elements of the Quality Assurance Project Plan for the ETV included:

- Work Plan,
- Monthly QA/QC Verifications,
- Data Correctness,
- Calculation of Indicators of Data Quality, and
- Corrective Action Plan.

3.12.2 Work Plan

Equipment flow rates were measured and recorded on a daily basis. A routine daily walk through during testing was established to verify that each piece of equipment or instrumentation was operating properly. In-line monitoring equipment such as flow meters, etc. were checked to confirm that the readout matches with the actual measurement (i.e. flow rate).

3.12.3 Monthly QA/QC Verifications

The monthly QA/QC verifications included:

- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter) and
- Tubing (verify good condition of all tubing and connections; replace if necessary).

3.12.4 Data Correctness

Data correctness refers to data quality, for which there are five indicators:

- Representativeness,
- Statistical Uncertainty,
- Precision,
- Accuracy, and
- Completeness.

3.12.4.1 Representativeness

As specified by NSF, representativeness of water quality samples for the ETV were ensured by executing consistent sample collection procedures, including:

- Sample locations,
- Timing of sample collection, and
- Analytical methods, sampling procedures, sample preservation, packaging and transport.

Sample Locations
Sample locations for the M-15,000 RO Treatment System included the feed water, permeate (treated water), and concentrate. Only one specific sample tap was used at each of these sample locations.

Timing of Sample Collection
In the RO verification study, the timing of sample collection was not as critical as in, for example, a granular media filtration verification study in which the filter run time can influence the quality of water produced by the filter. For the RO verification study, there is no filter maturation time, stable period of filter operation, or turbidity breakthrough period. To the extent possible, analyses for inorganic water quality parameters were performed on water sample aliquots obtained simultaneously from the same sampling location, in order to ensure the maximum degree of comparability between water quality analytes.

Analytical Methods, Sampling Procedures, Sample Preservation, Packaging and Transport
The analytical methods and sampling procedures utilized in the verification testing plan for collecting laboratory samples and for on-site monitoring of feed water, permeate and concentrate water quality are described below. Field analyses were performed using portable field analytical equipment. Laboratory samples were collected in bottles prepared by MWH Laboratories with the appropriate preservative for the analyte.   Once collected, the samples were stored in a refrigerator (4°C) until ready for transport to MWH Laboratories, and the temperature of the refrigerator were logged daily. The samples were transported in coolers packed with ice. With the exception of those samples noted in Chapter 4, the samples were analyzed within the *Standard Methods* or EPA recommended holding times, if not analyzed on-site.

Samples were collected from lab valves mounted on the panel coming from ¼" ball valves teed into the permeate line (permeate), 1" bulk fittings mounted on the top of the unit (concentrate), and a 1" housing on the side of the panel (feed water). To the extent possible, analyses for water quality parameters were performed on water sample aliquots obtained simultaneously from the same sampling location, in order to ensure the maximum degree of comparability between water quality analytes.

> Arsenic (Total)
> Samples were collected headspace free into polyethylene or borosilicate glass bottles provided by the analytical laboratory, capped tightly and stored refrigerated. The sample bottles from the laboratory included the preservative (HNO_3) for a holding period of up to

six months. The samples were analyzed using EPA Method 200.8 within the holding period of the preserved samples.

Arsenic (As (III) and Dissolved)
Samples were collected on-site and speciated using the procedures (see Appendix B) and resin columns provided by NSF. The samples were collected in polyethylene bottles provided by MWH Laboratories (preserved in accordance with the NSF procedures). The samples were analyzed using EPA Method 200.8 within the holding period of the preserved samples (six months).

pH
Analyses for pH were performed according to *Standard Method* 4500-H$^+$B. Samples were collected and analyzed on-site immediately and the temperature at which the pH readings were made was recorded. Sample agitation and prolonged exposure to air were avoided. A three-point calibration of the pH meter used in this study was performed once per day when the instrument was in use. Certified pH buffers (4.0, 7.0, and 10.0) were used for the daily calibration. The probe was stored in the appropriate solution defined in the instrument manual.

Conductivity
Analyses for conductivity were performed according to *Standard Method* 2510 B. Samples were collected and analyzed on-site immediately. Sample agitation and prolonged exposure to air were avoided. A three-point calibration of the conductivity meter used in verification testing was performed once per day when the instrument is in use. Certified conductivity solutions (184, 1000, and 1990 umoh/cm) and were used. The probe was stored in the appropriate solution defined in the instrument manual.

Turbidity
Due to the relatively short holding period of 48-hours, these samples were analyzed on-site using *Standard Method* 2130 B with a bench-top turbidimeter. All glassware used for turbidity measurements were cleaned and handled using lint-free tissues to prevent scratching. Sample vials were stored inverted to prevent deposits from forming on the bottom surface of the cell.

The bench-top turbidimeter was calibrated within the expected range of sample measurements at the beginning of equipment operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 5.0 Nephelometric Turbidity Units (NTU). The turbidity meter has a range of 0 to 199 NTU. Secondary turbidity standards were obtained and checked against the primary standards. Secondary standards were used (4.5, 45.9, and 448 NTU) on a weekly basis to verify calibration of the turbidimeter and to re-calibrate when more than one turbidity range was used.

The method for collecting grab samples was performed according to the following protocol: 1) running a slow, steady stream from the sample tap, 2) triple-rinsing a dedicated sample beaker in this stream, 3) allowing the sample to flow down the side of the beaker to minimize bubble entrainment, 4) double-rinsing the sample vial with the sample, 5) carefully pouring from the beaker down the side of the sample vial, 6) wiping

the sample vial clean, 7) inserting the sample vial into the turbidimeter, and 8) recording the measured turbidity. There were no issues associated with fogging of the glass vials.

Chlorine

Free and total chlorine were analyzed in the feed water (before the pre-filter) and after the pre-filter to monitor for chlorine removal. There was no sample port between the pre-filter and the first membrane; therefore, chlorine was tested after the first membrane. Analyses for both free and total chlorine were conducted on-site immediately upon collection of the samples, using Hach's DPD method of analysis, 8167 for total chlorine and 8021 for free chlorine (both EPA approved methods).

Alkalinity and Hardness

Alkalinity (bicarbonate) and hardness were not target contaminants for arsenic removal by RO. Thus, they were measured on-site by properly calibrated test kits provided by Hach. Total alkalinity was measured on-site immediately using Hach's 0.1600 N sulfuric acid with Hach's titration method (Hach method 8221) with a detection range of 0 to 5,000 mg/L as CaCO3. Total hardness was measured on-site immediately using Hach's titration method prepared titrants (EDTA Hach method 8226), with a range of 0 to 25,000 mg/L as CaCO3.

All test kits used on-site were calibrated when the equipment was in use, utilizing known standards at two or more concentration levels. Data obtained with test kits, which utilize non-standard methods were not used to determine if the system met the applicable performance criteria.

Temperature

Readings for temperature were conducted on-site immediately after collection in accordance with *Standard Method* 2550. Raw water temperatures were obtained twice daily. The thermometer was a precision thermometer certified by the National Institute of Standards and Technology (NIST).

TDS

Plastic sample bottles were used, as provided by the analytical laboratory. Analyses were made as soon as possible due to impracticality of preserving samples, as specified in *Standard Method* 2540. Samples were refrigerated until the time of analysis.

TSS

Plastic sample bottles were used, as provided by the analytical laboratory. Analyses were made as soon as possible due to impracticality of preserving samples, as specified in *Standard Method* 2540 D. Samples were refrigerated until the time of analysis.

TOC

Amber glass bottles preserved with H_2SO_4 were used, as provided by the analytical laboratory. Analyses were made as soon as possible according to *Standard Method* 5310 C. Samples were refrigerated until the time of analysis, prior to the 28-day holding period.

Iron

Samples were collected headspace free into polyethylene bottles provided by the analytical laboratory, capped tightly and stored refrigerated. The sample bottles from the laboratory included the preservative (HNO_3) for a holding period of up to six months. All iron samples were analyzed using EPA Method 200.7 within the holding period of the preserved samples.

Manganese

Samples were collected headspace free into polyethylene bottles provided by the analytical laboratory, capped tightly and stored refrigerated. The sample bottles from the laboratory included the preservative (HNO_3) for a holding period of up to six months. All manganese samples were analyzed using EPA Method 200.8 within the holding period of the preserved samples.

Sulfate

Samples were collected headspace free into polyethylene bottles provided by the analytical laboratory, capped tightly and stored refrigerated. All sulfate samples were analyzed using EPA Method 300.0 within the holding period of the preserved samples.

Chloride

Samples were collected headspace free into polyethylene bottles provided by the analytical laboratory, capped tightly and stored refrigerated. All chloride samples were analyzed using EPA Method 300.0 within the holding period of the preserved samples.

Silica

Samples were collected headspace free into polyethylene bottles provided by the analytical laboratory, capped tightly and stored refrigerated. The sample bottles from the laboratory included the preservative (HNO_3) for a holding period of up to six months. All silica samples were analyzed using EPA Method 200.7 within the holding period of the preserved samples.

Chromium

Samples were collected headspace free into polyethylene bottles provided by the analytical laboratory, capped tightly and stored refrigerated. The sample bottles from the laboratory included the preservative (HNO_3) for a holding period of up to six months. All chromium samples were analyzed using EPA Method 200.8 within the holding period of the preserved samples.

Fluoride

Samples were collected headspace free into polyethylene bottles provided by the analytical laboratory, capped tightly and stored refrigerated. All fluoride samples were analyzed using *Standard Method* 4500 FC within the holding period of the preserved samples (28 days).

Vanadium

Samples were collected headspace free into polyethylene bottles provided by the analytical laboratory, capped tightly and stored refrigerated. The sample bottles from the

laboratory included the preservative (HNO_3) for a holding period of up to six months. All vanadium samples were analyzed using EPA Method 200.8 within the holding period of the preserved samples.

Barium

Samples were collected headspace free into polyethylene bottles provided by the analytical laboratory, capped tightly and stored refrigerated. The sample bottles from the laboratory included the preservative (HNO_3) for a holding period of up to six months. All barium samples were analyzed using EPA Method 200.8 within the holding period of the preserved samples.

Calcium

Samples were collected headspace free into polyethylene bottles provided by the analytical laboratory, capped tightly and stored refrigerated. The sample bottles from the laboratory included the preservative (HNO_3) for a holding period of up to six months. All calcium samples were analyzed using EPA Method 200.7 within the holding period of the preserved samples.

SDI

Sample water was collected in a 5-gallon polyethylene cube-container, headspace free and shipped overnight to the laboratory for analysis. The American Society of Testing and Materials (ASTM) test number 4189-95 procedures were followed for the SDI calculation.

Representativeness of Operational Parameters

As specified by NSF, representativeness for operational parameters entails collecting a sufficient quantity of data during operation to be able to detect a change in operations. As specified by NSF, detecting a ±10% change in an operating parameter, such as pressure, is sufficient. Operational parameters including flow and pressure were recorded twice per day, which NSF specifies as sufficient for tracking changes in operational conditions that exceed this 10% range.

Flow Rates

The permeate and concentrate flow rates were verified daily using a calibrated container and stopwatch method to manually verify the flow rates from the system. While no adjustments to the panel mounted flow meters was possible, the manual "check" could verify if the panel mounted flow meters were accurate.

3.12.4.2 Statistical Uncertainty

Statistical uncertainty of the water quality parameters analyzed were evaluated through calculation of the 95% confidence interval around the sample mean for parameters with eight or more samples. Description of the confidence interval calculation is provided in Section 3.12.5.

3.12.4.3 Methodology for Measurement of Precision and Accuracy

Precision and Accuracy for Water Quality Parameters
Tables 3-7 and 3-8 summarize the methodology used in the ETV for the measurement of precision and accuracy for each water quality analysis performed for the verification study. Arsenic speciation columns were QA/QC checked by NSF and were provided by NSF for the verification testing. The sampling location for each duplicate sample was alternated between the feed water, permeate, and concentrate.

Precision and Accuracy for Operational Parameters
The operational parameters in the ETV included flow rates and pressures. Water flow rates were verified for all flow meters (located on the permeate and concentrate lines) daily by using a calibrated container and a stopwatch. The duration of the bucket tests were one minute or longer, depending on the magnitude of the flow rate.

Spiked Samples
Spiked samples were utilized at MWH laboratory, as presented in Table 3-8. Spiked samples were applicable for the analyses performed on-site at the treatment system at a 10% frequency, as presented in Table 3-9.

Table 3-7: Methodology for Measurement of Precision and Accuracy

Parameter	MRL	On-site Duplicate Frequency	Acceptable Precision	Accuracy
Arsenic (Total)[1] (report to nearest 1 µg/L)	1.0 µg/L	Seven measurements per week in duplicate (33% of samples)	30%	See procedures of MWH Laboratory (see Table 3-8)
pH (report to nearest 0.1 pH unit)	0-14 pH units	Seven measurements per week in duplicate (33% of samples)	10%[2]	Daily[2] 3-point calibration with certified pH buffers in range of measurements (4.0, 7.0 and 10.0)
Silica (report to nearest 0.1 mg/L)	0.05 mg/L	One sample per week in duplicate (33% of samples)	30%	See procedures of MWH Laboratory (see Table 3-8)
Fluoride (report to nearest 0.1 mg/L)	0.1 mg/L	One sample per week in duplicate (33% of samples)	20%	See procedures of MWH Laboratory (see Table 3-8)
Chromium (report to nearest 1 µg/L)	2 µg/L	One sample per week in duplicate (33% of samples)	30%	See procedures of MWH Laboratory (see Table 3-8)
Vanadium (report to nearest 1 µg/L)	10 µg/L	One sample per week in duplicate (33% of samples)	30%	See procedures of MWH Laboratory (see Table 3-8)
TOC (report to nearest 0.5 mg/L)	0.5 mg/L	One sample per week in duplicate (33% of samples)	30%	See procedures of MWH Laboratory (see Table 3-8)
Chloride (report to nearest 1 mg/L)	1 mg/L	One sample per week in duplicate (33% of samples)	20%	See procedures of MWH Laboratory (see Table 3-8)

Table 3-7: Methodology for Measurement of Precision and Accuracy (continued)

Parameter	MRL	On-site Duplicate Frequency	Acceptable Precision	Accuracy
Iron (report to nearest 0.5 mg/L)	0.5 mg/L	One sample per week in duplicate (33% of samples)	30%	See procedures of MWH Laboratory (see Table 3-8)
Manganese (report to nearest 0.5 mg/L)	0.015 mg/L	One sample per week in duplicate (33% of samples)	30%	See procedures of MWH Laboratory (see Table 3-8)
Sulfate (report to nearest 1 mg/L)	2 mg/L	One sample per week in duplicate (33% of samples)	20%	See procedures of MWH Laboratory (see Table 3-8)
Temperature (report to nearest 0.1°C)	NA	Two measurements per week in duplicate (20% of samples)	10% [3]	Initial and weekly verification against a NIST thermometer.
Alkalinity (report to nearest 1 mg/L as $CaCO_3$)	10 mg/L	One sample per week in duplicate (33% of samples)	30% [3]	Weekly calibration verification using known standards at two concentration levels
Hardness (report to nearest 1 mg/L as $CaCO_3$)	10 mg/L	One sample per week in duplicate (33% of samples)	30% [3]	Weekly calibration verification using known standards at two concentration levels
Turbidity (report to nearest 0.05 mg/L)	0.05 NTU	One sample per week in duplicate (33% of samples)	30% [3]	Initial and weekly calibration with primary standards. Daily [2] calibration verification with secondary standards.
Conductivity (report to nearest 0.1 μmho/cm)	4 μmho/cm	Eight samples per week in duplicate (20% of samples)	10% [3]	Daily [2] calibration verification using known standards at three concentration levels
Barium (report to nearest 0.5 mg/L)	2 μg/L	One sample per week in duplicate (33% of samples)	30%	See procedures of MWH Laboratory (see Table 3-8)
Calcium (report to nearest 0.5 mg/L)	1 mg/L	One sample per week in duplicate (33% of samples)	30%	See procedures of MWH Laboratory (see Table 3-8)
TSS (report to nearest 1 mg/L)	4 mg/L	One sample per week in duplicate (33% of samples)	30%	See procedures of MWH Laboratory (see Table 3-8)
SDI (report to nearest 1 mg/L)	1	One sample per month in duplicate (100% of samples)	30%	Use procedures of the American Society of Testing and Materials (ASTM) test number 4189-95.
TDS (report to nearest 1 mg/L)	10 mg/L	Four samples per week in duplicate (20% of samples)	30%	See procedures of MWH Laboratory (see Table 3-8)

Table 3-7: Methodology for Measurement of Precision and Accuracy (continued)

Parameter	MRL	On-site Duplicate Frequency	Acceptable Precision	Accuracy
Chlorine (report to nearest 0.1 mg/L)	0.02 mg/L	Four samples per week in duplicate (25% of samples)	30%	Use Hach 8167 (total) and Hach 8021 (free) procedures for accuracy using Hach standard solutions.

[1] As^{+3} and dissolved arsenic samples were prepared on-site using arsenic speciation procedures developed by Battelle for the EPA (see Appendix B). The laboratory method used to measure the arsenic is EPA 200.8, and will measure total arsenic (after on-site preparation).

[2] "Daily" refers to each day the verification plant is staffed (7 days a week).

[3] For all on-site duplicate analyses, the first analysis is considered the sample and that result is reported. The duplicate analysis is used for calculating precision per Section 6.3.4 in Chapter 1 of the *EPA/NSF ETV Protocol for Equipment Verification Testing for Arsenic Removal* (EPA/NSF, 2003).

Table 3-8: Laboratory Water Quality Analyses Indicators

Parameter	Laboratory Fortified Matrix (LFM), i.e. spike sample	LFM Duplicate	LFM Acceptance Limits (% Recovery)	Method Blank (MB)	MB Acceptance Limits	Lab Control Sample (LCS), i.e. standards	LCS Acceptance Limits
Arsenic (Total)	10% (1 per 10 samples)	10%	± 30	5% (1 per 20 samples or less)	< MRL[1]	5% (1 per 20 samples or less)	± 15
TDS	10%	10%	< 5% RPD	5%	< MRL[1]	5%	± 15
TSS	10%	10%	< 20% RPD	5%	< MRL[1]	5%	± 20
Silica	10%	10%	± 30	5%	< MRL[1]	5%	± 15
Fluoride	10%	10%	± 20	5%	< MRL[1]	10%	± 10
Iron	10%	10%	± 30	5%	< MRL[1]	5%	± 15
Manganese	10%	10%	± 30	5%	< MRL[1]	5%	± 15
Sulfate	10%	10%	± 20	10%	< MRL[1]	10%	± 10
Chloride	10%	10%	± 20	10%	< MRL[1]	10%	± 10
Chromium	10%	10%	± 30	5%	< MRL[1]	5%	± 15
Vanadium	10%	10%	± 30	5%	< MRL[1]	5%	± 15
Barium	10%	10%	± 30	5%	< MRL[1]	5%	± 15
Calcium	10%	10%	± 30	5%	< MRL[1]	5%	± 15
TOC	10%	10%	± 10	run after each sample	< MRL[1]	5%	± 10

[1] MRL is the minimum reporting limit (See Table 3-7).

2 RPD is the relative percent difference.

Table 3-9: On-Site Water Quality Analyses Indicators

On-Site Parameters	On-site Spike Frequency	Acceptable Accuracy (% Recovery)
Alkalinity	10%	$\pm$ 30
Hardness	10%	$\pm$ 30
Chlorine	10%	+ 30
Turbidity	NA[1]	NA[1]
pH	NA[1]	NA[1]
Temperature	NA	NA[2]
Conductivity	NA[1]	NA[1]

[1] Accuracy documented by proper instrument setup and calibration with buffers or standards.
[2] Accuracy established by using a NIST traceable thermometer on a weekly basis.

Method Blanks

The methodology for use of method blanks is summarized in Table 3-10. Field blanks were submitted with each set of samples submitted to MWH Laboratories. One field blank was collected for each parameter submitted for analysis.

Table 3-10: Methodology for Use of Method Blanks

Method	Methodology for Blanks
Arsenic	Blanks were used in accordance with the procedures of MWH Laboratory[1].
pH	Purchased certified pH buffers; no use of blanks.
Temperature	No use of blanks.
Alkalinity	Purchased reagent-grade ultra-pure water and kept in stock at the verification plant for use as a blank on a weekly basis to verify proper operation of the instrument.
Total Hardness	Purchased reagent-grade ultra-pure water and kept in stock at the verification plant for use as a blank on a weekly basis to verify proper operation of the instrument.
Turbidity	Purchased reagent-grade ultra-pure water and kept in stock at the verification plant for use as a blank on a daily basis to verify proper operation of the instrument.
Conductivity	No use of blanks.
TDS	Blanks were used in accordance with the procedures of MWH Laboratory[1].
Other Inorganics	Blanks were used in accordance with the procedures of MWH Laboratory[1].

[1] See Table 3-8.

Proficiency Testing Samples

Proficiency Testing (PT) samples were analyzed in accordance with the procedures of the MWH Laboratory, which performed all laboratory analyses. External PT samples (single blind) were analyzed approximately twice a year for each analysis for which National Environmental Laboratory Accreditation Conference (NELAC) requires PT samples. Additionally, a laboratory control sample (typically second source) is analyzed with each analytical batch.

3.12.4.4 Completeness

Completeness refers to the number of valid, acceptable samples collected from a measurement process compared to the number of samples expected to be obtained. The completeness objective for data generated during this verification test is based on the number of samples collected and analyzed for each parameter and/or method. Table 3-11 illustrates the completeness objectives for performance parameter and/or method based on the sample frequency:

Table 3-11: Completeness Objectives Based on Sample Frequency

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

3.12.5 Calculation of Indictors of Data Quality

Statistical Uncertainty

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

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

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

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

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

Calculation of Precision

As specified in *Standard Methods* (Method 1030 C), precision is specified by the standard deviation of the results of replicate analyses. The overall precision of a study includes the random errors involved in sampling as well as the errors in sample preparation and analysis.

$$\text{Precision} = \text{Standard Deviation} = \sqrt{\left[\sum_{i=1}^{n} (\overline{X}_i - \overline{X})^2 \div (n - 1)\right]}$$

where:
$\overline{X}$ = sample mean
$\overline{X}_i$ = ith data point in the data set

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n = number of data points in the data set

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. Analytical precision is a measure of how far an individual measurement may be from the mean of replicate measurements. The standard deviation and relative standard deviation recorded from sample analyses were recorded as a means to quantify sample precision. The percent relative standard deviation was calculated in the verification study in the following manner:

$$\%\text{Relative Standard Deviation} = S(100)/X_{average}$$

where   S = Standard Deviation
         $X_{average}$ = the arithmetic mean of the recovery values

Calculation of Accuracy
Accuracy is quantified as the percent recovery of a parameter in a sample to which a known quantity of that parameter was added.

$$\text{Accuracy} = \text{Percent Recovery} = 100 \times [1- (X_{known} - X_{measured}) \div X_{known}]$$

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

Calculation of Completeness
Completeness is defined as the following for all measurements:

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

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

3.12.6 Corrective Action Plan

The corrective action plan for water quality parameters is summarized in Table 3-12.

Table 3-12: Corrective Action Plan

Parameter	Acceptance Criteria	Sequence of Steps for Corrective Action
Any Duplicate Analysis	See Table 3-7	• Re-sample duplicates • Check instrument calibration; re-calibrate instrument
Any Method Blank	See Table 3-8; criteria set by MWH Laboratory	• See Table 3-8; perform procedures specific to each analysis as determined by MWH Laboratory
Any Performance Evaluation (PE) or Proficiency Sample	Within recovery specified for each PE or proficiency sample	• Check and verify all steps in sample collection and analysis • Re-do PE or proficiency sampling and analysis
pH	≤10% difference from previous day	• Check for change in feed water source or supply • Check instrument calibration • Re-calibrate instrument
Temperature	≤20% difference from previous day	• Check for change in feed water source or supply
Turbidity (Bench-top)	No increasing or decreasing trend indicated by results of proficiency samples	• Check/verify system operating conditions • Verify turbidimeter operation and status of sample tap • Perform routine maintenance/cleaning of instrument • Verify calibration using secondary standards • Re-calibrate using primary standards
Alkalinity, Total Hardness, Calcium Hardness, TDS	≤20% difference from previous reading	• Verify change in feed water source or supply

3.13 Operation and Maintenance

The following sections provide O&M criteria that were necessary for a safe and successful operation of the M-15,000 RO Treatment System.

3.13.1 Operation

Start-Up Procedures
The start-up sequence, as provided by the manufacturer, for the M-15,000 RO Treatment System is:

1. Ensure power switch (located on top of control box) is in the off position.
2. Plug the unit into an appropriate power supply.
3. If installing a pressure tank system, open the ball valve on the bulkhead.
4. Turn the blending valve to coldest setting [90°].
5. Fully open the concentrate needle valve by turning it counter clockwise.
6. Fully close recirculate needle valve by turning it clockwise.
7. Turn the incoming water supply on the RO processor to the "on" position.
    • The water inlet solenoid valve will open.
    • There is a 5-second delay before the pump starts.

- The system will cycle on and off automatically during initial start up as air is purged from system.
- Allow the unit to run for five minutes while excess air is being purged from system.

8. Close the concentrate needle valve until the feed pressure gauge reaches a max. of 150 psig.
9. Open the recirculation needle valve until the unit feed pressure gauge drops to 140 psig.
10. Close the concentrate needle valve until 150 psig is again achieved on the pump feed pressure gauge.

Shut Down Procedures
1. Turn incoming feed water off while unit is running.
2. System will automatically turn off due to lack of feed water pressure.
3. Turn power switch to the OFF position.

3.13.2 Maintenance

Quarterly maintenance for the M-15,000 RO Treatment System requires replacement of the cartridge sediment pre-filter and RO module O-rings.

Pre-filter Replacement Procedure
1. Turn incoming feed water off while unit is running.
2. System will automatically turn off due to lack of feed water pressure.
3. Turn power switch to the OFF position.
4. Close ball valve on permeate line connection on bulkhead
5. Unplug unit from power supply.
6. Place bucket under pre-filter to catch the water from the filter housing.
7. Using supplied filter wrench, loosen filter housing.
8. Replace with new 20-micron sediment filter and replace filter housing using wrench to tighten securely. (o-rings and bowls need to be lubricated with a water-soluble lubricant such as KY jelly).
9. Follow "start-up procedure".

Maintenance requires the replacement of the RO membrane modules based on efficiencies of TDS reduction per module. To simulate this procedure, two of the six membranes were replaced during the simulated maintenance procedures performed at the end of the testing period.

Module Replacement Procedure
1. Replace RO membrane by loosening retaining clamp at top of stainless steel membrane vessel.
2. Carefully pry loose PVC end cap from stainless steel vessel.
3. Pull membrane from vessel using pliers if necessary and discard.
4. Take note of location of black BRINE SEAL located approximately 1/2" from one end of membrane, so the new membrane is installed in the proper direction.
5. Lubricate O-Rings on both ends of the membrane and PVC vessel cap with KY Jelly or other water-soluble lubricant. Vaseline or other petroleum-based lubricants will damage rubber o-ring and cause leaks.

6. Insert new membrane into vessel with the brine seal on same position as the old one just removed. Replace PVC end cap and tighten clamp evenly.
7. Follow "start-up procedure".

3.13.3 Operability

During verification testing, attention was given to equipment operability aspects. Among the factors that were considered were:

*   Fluctuation of flow rates and pressures through membrane unit -- the time interval at which resetting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?)
*   Was there a device present to aid the operator with flow control adjustment?
*   Was a continuous particle counter provided for monitoring of membrane permeate?
*   Was a continuous conductivity meter provided for monitoring of membrane permeate?
*   Was transmembrane pressure measurement provided?
*   Was feed water recovery provided?
*   Was recycle flow rate provided?
*   Was rate of flow of raw water measured?

This report addresses the above questions. The issues of operability were dealt with in the portion of the reports that are written in response to Tasks 1 & 2 of the verification testing plan and may be found in Chapter 4.

Chapter 4
Results and Discussion

4.1 Introduction

The verification testing of the M-15,000 RO Treatment System performed at the CVWD Well 7802 in Thermal, California, commenced on April 26, 2004, and concluded on May 26, 2004. The system ran continuously with the exception of two brief system shut downs, and one extended shut down period of approximately four days. The shut downs occurred on April 29, May 3-6, and on May 13, 2004. In total, the system was in operation for 27 days.

Quarterly and a portion of annual (replacement of two RO membranes) O&M procedures were performed after completion of the verification testing, on May 26, 2004. Results and discussion of the membrane operation, cleaning efficiency (substituted by quarterly/annual O&M), finished water quality, and data management are presented in this chapter as the following five tasks:

Task 1: Membrane Operation
Task 2: Cleaning Efficiency
Task 3: Feed water and Treated Water Quality Monitoring
Task 4: Data Handling Protocol
Task 5: Quality Assurance Project Plan (QAPP)

The field data (operational and water quality) was maintained in a field logbook per Section 3.11 (Task 4) and may be found in Appendix C. The corresponding off-site laboratory data may be found in Appendix D.

4.2 Task 1: Membrane Operation

The objective of this task was to evaluate the M-15,000 RO Treatment System operation, not to optimize the system. System performance was evaluated relative to the stated raw water quality ranges specified by the manufacturer in Chapter 3 (Table 3-2). For verification testing purposes, the equipment was operated for 27 days. During the testing period the membrane productivity, rate of specific flux decline, and rejection capabilities were evaluated.

The objectives of Task 1 were to:

- Evaluate the operational conditions for the membrane equipment relative to the stated water quality goals,
- Determine the feed water recovery achieved by the membrane equipment under the operational conditions evaluated during the one month verification period, and
- Determine the rate of specific flux decline observed over the testing period.

The following evaluation and reporting criteria for Task 1 enabled the objectives to be met:

- General operational performance,
- Power consumption,

- Consumables and waste generation, and
- Concentrate stream characterization.

4.2.1 General Operational Performance

The purpose of this test was to evaluate the general operational performance of the M-15,000 RO Treatment System. Operational information regarding this task was collected throughout the length of the verification testing according to the frequency presented in Chapter 3 (see Table 3-5). Specifically, the following operational parameters were monitored:

- Feed water, permeate, concentrate, and recycle flow rates,
- Membrane element inlet and feed water pressures,
- Discharge tank pressure (permeate line) and back pressure (concentrate line),
- Water recovery and recycle ratio,
- Feed water temperature,
- Specific flux (flux and temperature-corrected specific flux),
- Net driving pressure, and
- Osmotic pressure gradient.

4.2.1.1 Feed Water, Permeate, Concentrate, and Recycle Flow Rates

The M-15,000 RO Treatment System was equipped with panel mounted flow meters to read permeate and concentrate flow rates and to make adjustments as necessary. The feed water flow rate was recorded as the sum of the permeate and the concentrate flow rates. The recycle flow rate was documented from a digital flow meter installed on the recycle line prior to the feed water line. Each of these four flow streams (feed water, permeate, concentrate, and recycle – see Figure 2-2 in Section 2.1) was monitored twice per day during the verification testing. This data is graphically presented in Figure 4-1 with the corresponding data presented in Table 4-1. Included in this table are the average, minimum, maximum, count, standard deviation, and 95% confidence interval data calculated for each of the flow streams. Since there were two different types of pre-filters used during the study (carbon bloc and sediment), Table 4-1 has been subdivided into two sections, each representing the type of pre-filter used during the verification test.

The vertical lines in Figure 4-1 represent each time the pre-filter was changed and the break in the data represents the four days the system was down (May 3-6) due to operational issues. The feed water flow rate between April 26, 2004 and May 13, 2004 continued to decrease. Steps to recover the feed flow rate included changing out the carbon bloc pre-filter, which served to temporarily improve the feed flow rate. Once it was discovered that the periodic operation of the CVWD Well 7802 introduced a slug of solids with each start-up (approximately every three days), the carbon bloc pre-filter was replaced with a sediment pre-filter on May 13, 2004. After this modification to the system, a relatively constant feed flow rate (25 gpm on average) was achieved. The initial decreasing feed water flow rates (approximately 20 gpm decreasing to 17 gpm with the carbon bloc pre-filter) led to varied flow rates in the concentrate, permeate and recycle flows, which were also stabilized after replacing the carbon bloc pre-filter with a sediment pre-filter. While the carbon bloc pre-filter was originally determined necessary due to

the chlorine levels in the feed water, the operational issues caused by the pre-filter clogging led the manufacturer to recommend the use a sediment pre-filter in place of the carbon bloc and risk damage to the membranes due to exposure to chlorine for the remaining limited ETV operation period. The system ran continuously for 27 of the 31-day verification testing period. For one four-day period, the system was shut down due to operational issues. Clogging of the carbon bloc pre-filter is believed to be the cause of the shut down. Ideally at this test sight, the vendor has indicated that a separate granular activated carbon tank would be used to remove the chlorine prior to the M-15,000 RO Treatment System. The pre-filter on the M-15,000 RO Treatment System would then consist of a sediment filter to further reduce the amount of particulates prior to the water entering the RO.
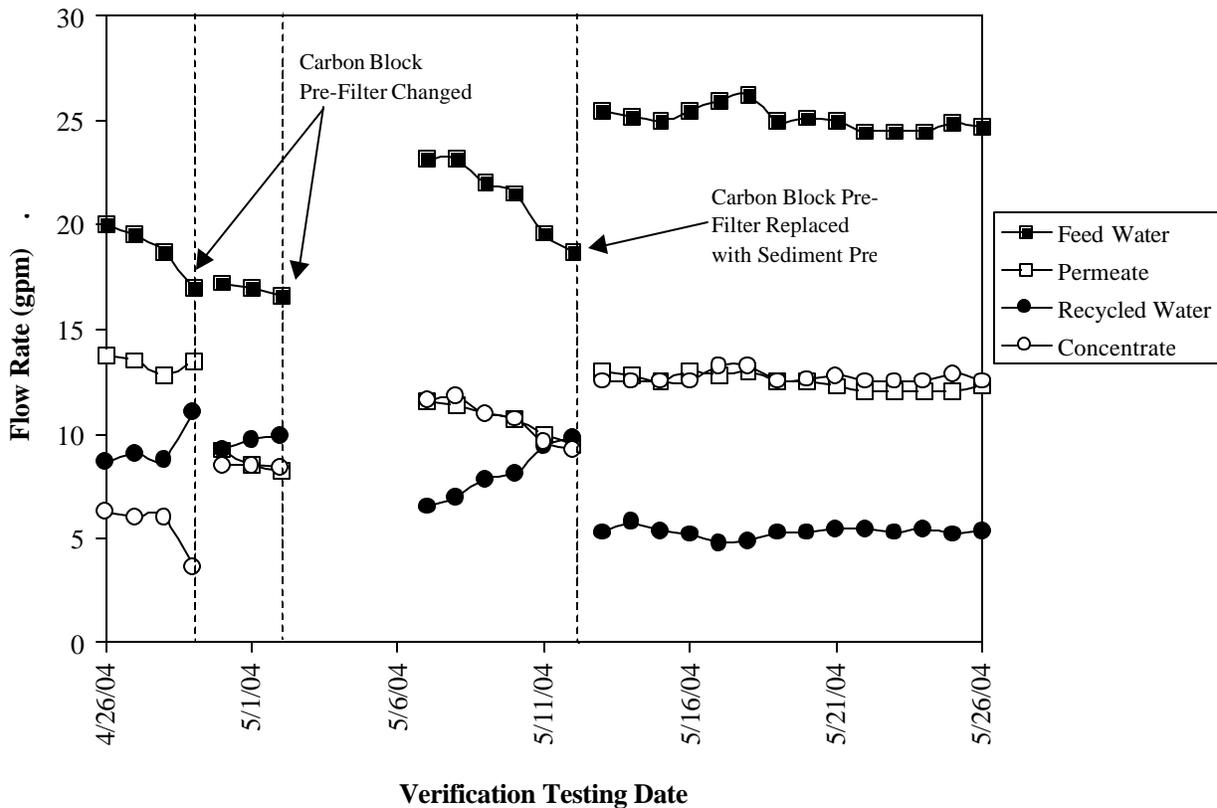
Figure 4-1: Temporal plot of feed water, permeate, recycle and concentrate flow rates.

Table 4-1: Feed Water, Permeate, Concentrate and Recycle Flow Rates

Carbon Bloc Pre-filter Date	Feed Water (gpm)[1] AM	PM	Ave	Permeate (gpm) AM	PM	Ave	Concentrate (gpm) AM	PM	Ave	Recycle (gpm) AM	PM	Ave
4/26/04	20.50	19.50	20.00	14.00	13.50	13.75	6.50	6.00	6.25	8.53	8.85	8.69
4/27/04	19.50	19.50	19.50	13.50	13.50	13.50	6.00	6.00	6.00	9.00	9.07	9.04
4/28/04	19.00	18.50	18.75	13.00	12.50	12.75	6.00	6.00	6.00	9.14	8.34	8.74
4/29/04	18.00	16.00	17.00	12.80	14.00	13.40	5.20	2.00	3.60	10.16	11.96	11.06
4/30/04	B[2]: 13.00 A[2]: 17.00	B: 16.50 A: 17.50	AM: 15.00 PM: 17.00	B: 11.00 A: 9.50	B: 9.00 A: 9.00	AM: 10.25 PM: 9.00	B: 2.00 A: 8.50	B: 7.50 A: 8.50	AM: 5.25 PM: 8.00	B: 12.84 A: 8.90	B: 9.91 A: 9.56	AM: 10.87 PM: 9.74
5/1/04	17.00	17.00	17.00	8.50	8.50	8.50	8.50	8.50	8.50	9.65	9.72	9.69
5/2/04	16.75	16.50	16.63	8.25	8.25	8.25	8.50	8.25	8.38	9.84	9.89	9.87
5/7/04	23.00	23.25	23.13	11.50	11.50	11.50	11.50	11.75	11.63	6.30	6.76	6.53
5/8/04	23.25	23.00	23.13	11.50	11.25	11.38	11.75	11.75	11.75	6.94	6.95	6.95
5/9/04	22.00	22.00	22.00	11.00	11.00	11.00	11.00	11.00	11.00	7.80	7.89	7.85
5/10/04	21.50	21.50	21.50	10.75	10.75	10.75	10.75	10.75	10.75	8.05	8.06	8.06
5/11/04	19.75	19.50	19.63	10.00	10.00	10.00	9.75	9.50	9.63	9.42	9.43	9.43
5/12/04	19.00	18.50	18.75	9.50	9.50	9.50	9.50	9.00	9.25	9.70	9.85	9.78
5/13/04 (before)	17.75	NA	17.75	9.25	NA	9.25	8.50	NA	8.50	10.68	NA	10.68
Average	19.57	19.40	19.43	10.93	11.02	10.91	8.71	8.38	8.55	8.87	8.95	8.97
Minimum	16.75	16.00	16.63	8.25	8.25	8.25	5.20	2.00	3.60	6.30	6.76	6.53
Maximum	23.25	25.25	23.13	14.00	14.00	13.75	11.75	11.75	11.75	10.68	11.96	11.06
Number of Samples	14	13	14	14	13	14	14	13	14	14	13	14
Standard Dev.	2.21	2.41	2.27	1.87	1.94	1.88	2.15	2.81	2.40	1.24	1.39	1.30
95% Confidence Interval	(18.08, 21.07)	(17.69, 21.12)	(17.89, 20.96)	(9.67, 12.20)	(9.64, 12.40)	(9.64, 12.19)	(7.25, 10.17)	(6.39, 10.38)	(6.93, 10.18)	(8.03, 9.70)	(7.96, 9.93)	(8.09, 9.85)
Sediment Pre-filter	Feed Water (gpm)			Permeate (gpm)			Concentrate (gpm)			Recycle (gpm)		
5/13/04 (after)	25.50	25.50	25.50	13.00	13.00	13.00	12.50	12.50	12.50	5.27	5.31	5.29
5/14/04	25.25	25.25	25.25	12.75	12.75	12.75	12.50	12.50	12.50	5.75	5.81	5.78
5/15/04	25.00	25.00	25.00	12.50	12.50	12.50	12.50	12.50	12.50	5.35	5.37	5.36
5/16/04	25.50	25.50	25.50	13.00	13.00	13.00	12.50	12.50	12.50	5.19	5.21	5.20
5/17/04	26.00	26.00	26.00	13.00	12.50	12.75	13.00	13.50	13.25	4.88	4.62	4.75
5/18/04	26.50	26.00	26.25	13.00	13.00	13.00	13.50	13.00	13.25	4.58	5.14	4.86
5/19/04	25.00	25.00	25.00	12.50	12.50	12.50	12.50	12.50	12.50	5.24	5.27	5.26
5/20/04	25.00	25.25	25.13	12.50	12.50	12.50	12.50	12.75	12.63	5.38	5.19	5.29
5/21/04	25.00	25.00	25.00	12.25	12.25	12.25	12.75	12.75	12.75	5.37	5.45	5.41
5/22/04	24.50	24.50	24.50	12.00	12.00	12.00	12.50	12.50	12.50	5.48	5.48	5.48
5/23/04	24.50	24.50	24.50	12.00	12.00	12.00	12.50	12.50	12.50	5.30	5.29	5.30
5/24/04	24.50	24.50	24.50	12.00	12.00	12.00	12.50	12.50	12.50	5.39	5.46	5.43
5/25/04	25.00	24.75	24.88	12.00	12.00	12.00	13.00	12.75	12.88	5.16	5.21	5.19
5/26/04	24.75	24.75	24.75	12.25	12.25	12.25	12.50	12.50	12.50	5.36	5.34	5.35
Average	25.14	25.11	25.13	12.48	12.45	12.46	12.66	12.66	12.66	5.26	5.30	5.28
Minimum	24.50	24.50	24.50	12.00	12.00	12.00	12.50	12.50	12.50	4.58	4.62	4.75
Maximum	26.50	26.00	26.25	13.00	13.00	13.00	13.50	13.50	13.25	5.75	5.81	5.78
Number of Samples	14	14	14	14	14	14	14	14	14	14	14	14
Standard Dev.	0.58	0.51	0.54	0.41	0.38	0.39	0.30	0.29	0.27	0.27	0.26	0.25
95% Confidence Interval	(24.75, 25.53)	(24.76, 25.45)	(24.76, 25.49)	(12.20, 12.76)	(12.19, 12.71)	(12.20, 12.73)	(12.45, 12.87)	(12.47, 12.86)	(12.47, 12.85)	(5.08, 5.45)	(5.12, 5.47)	(5.11, 5.45)

[1] Feed water flow rates are calculated values and are the sum of the permeate and concentrate flow rates.

[2] B= Before and A= After manual adjustments made to system.

Note: Only the 'after' values and averages on April 30, 2004 are used in the statistical calculations.

AM = First sample daily collection.

PM = Second sample daily collection.

NA = Not Applicable.

4.2.1.2 Membrane Element Inlet and Feed Water Pressures

Pressure gauges were panel mounted for the inlet (feed water plus recycled water) pressure, back pressure (pressure on the concentrate line), and tank pressure (pressure on the permeate line which was open to drain for the purpose of this testing). The feed water pressure gauge was installed on the feed water line between the raw (chlorinated groundwater) line and the inlet to the M-15,000 RO Treatment System. Pressure was monitored and recorded twice daily [morning (AM) and evening (PM)], with the average daily (AM and PM) data presented in Figure 4-2 and the corresponding data presented in Table 4-2. Additionally, Table 4-2 presents the pressure data as two data sets, with the carbon bloc pre-filter and with the sediment pre-filter, to evaluate the operational impact (with regard to pressure) of using different types of pre-filters. Throughout the verification test, there was a limited amount of variability in the feed water pressure, ranging from 78 to 85 psi. There was, however, a larger range of pressure readings on the inlet pressure (ranging from 102 to 150 psi), believed to be related to clogging of the carbon bloc pre-filter (discussed in additional detail in Section 4.2.1.1). While the carbon bloc pre-filter was in place, the inlet pressure ranged from 102 to 147 psi. Once the sediment pre-filter replaced the carbon bloc pre-filter, the inlet pressure ranged from 140 to 150 psi.

In addition to monitoring the feed water and inlet pressures, the back pressure (concentrate line) and the tank pressure (permeate line) were monitored twice daily for use in calculating the daily net driving pressure. During the verification test, both the permeate and concentrate lines discharged to a drain under atmospheric conditions. The recorded back pressures ranged from 18 to 75 psi, and the tank pressures ranged from 0 to 7 psi. There was large variability in the back pressure while the carbon bloc pre-filter was in use (i.e. prior to May 13, 2004) with a steady back pressure realized once the sediment pre-filter was in use.
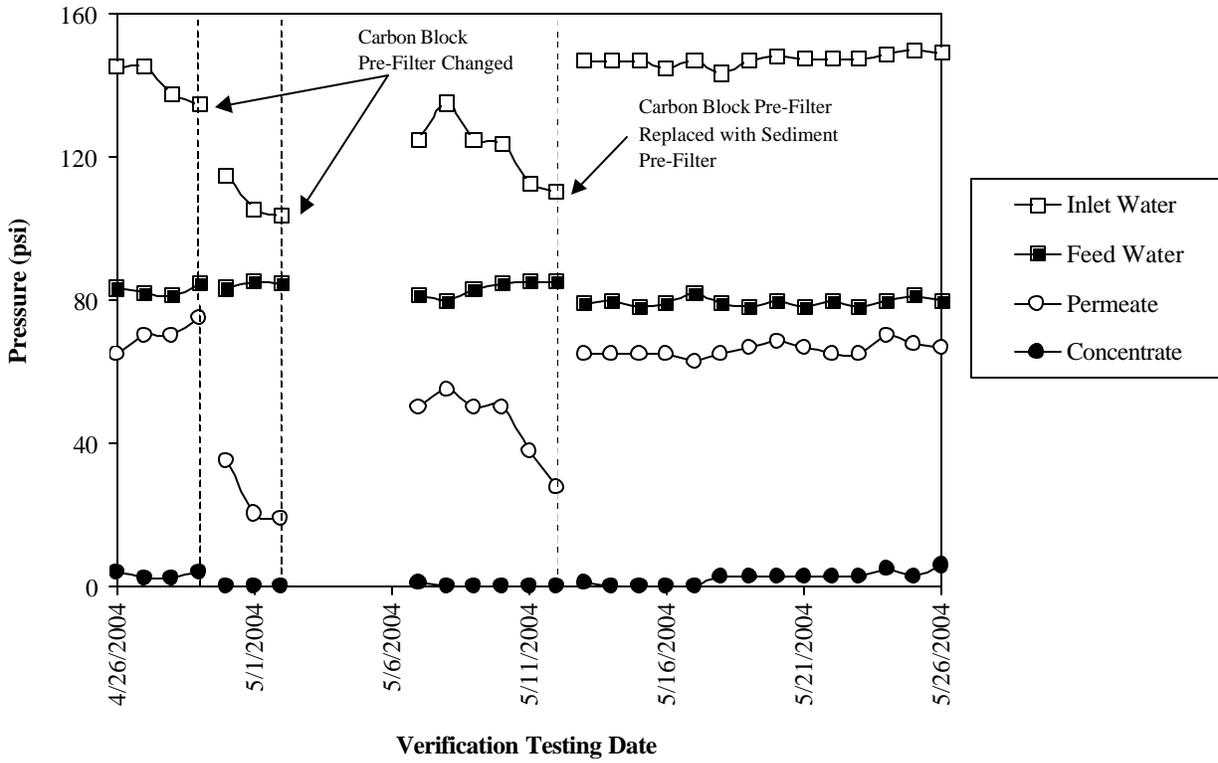
Figure 4-2: Average daily feed water, inlet, back pressure, and tank pressures.

Table 4-2: Feed Water, Inlet, Back Pressure, and Tank Pressures

Carbon Bloc Pre-filter Date	Feed Water Pressure (psi)			Inlet Pressure (psi)			Back Pressure, Concentrate Line psi)			Tank Pressure, Permeate Line (psi)		
	AM	PM	Ave	AM	PM	Ave	AM	PM	Ave	AM	PM	Ave
4/26/04	85	82	84	145	145	145	65	65	65	4	4	4
4/27/04	82	82	82	145	145	145	70	70	70	2	2	2
4/28/04	80	82	81	135	140	138	70	70	70	2	2	2
4/29/04	84	85	85	125	144	135	75	75	75	4	4	4
4/30/04	B[1]: 85 A[1]: 82	B: 85 A: 85	AM: 84 PM: 85	B: 148 A: 125	B110 A: 105	AM: 137 PM: 108	B: 90 A: 50	B: 35 A: 20	AM: 70 PM: 28	B: 2 A: 0	B: 0 A: 0	AM: 1 PM: 0
5/1/04	85	85	85	105	105	105	20	20	20	0	0	0
5/2/04	84	85	85	105	102	104	20	18	19	0	0	0
5/7/04	82	80	81	115	135	125	45	55	50	2	0	1
5/8/04	80	80	80	135	135	135	55	55	55	0	0	0
5/9/04	84	82	83	125	125	125	50	50	50	0	0	0
5/10/04	85	84	85	125	122	124	50	50	50	0	0	0
5/11/04	85	85	85	115	110	113	40	35	38	0	0	0
5/12/04	85	85	85	110	110	110	30	25	28	0	0	0
5/13/04 (before)	85	NA	85	102	NA	102	20	NA	20	0	NA	0
Average	83	83	83	122	125	123	47	47	46	1	1	1
Minimum	80	80	80	102	102	102	20	18	19	0	0	0
Maximum	85	85	85	145	145	145	75	75	75	4	4	4
Number of Samples	14	13	14	14	13	14	14	13	14	14	13	14
Standard Deviation	2	2	2	14	17	15	19	21	20	2	2	1
95% Confidence Interval	(82, 85)	(82, 85)	(82, 85)	(113, 132)	(113, 137)	(113, 133)	(34, 60)	(32, 62)	(33, 59)	(0, 2)	(0, 2)	(0, 2)

Sediment Pre-filter	Feed Water Pressure (psi)			Inlet Pressure (psi)			Back Pressure, Concentrate Line psi)			Tank Pressure, Permeate Line (psi)		
5/13/04 (after)	78	80	79	147	147	147	65	65	65	2	0	1
5/14/04	80	80	80	147	147	147	65	65	65	0.0	0	0
5/15/04	78	78	78	147	147	147	65	65	65	0.0	0	0
5/16/04	78	80	79	147	142	145	65	65	65	0.0	0	0
5/17/04	82	82	82	147	147	147	65	60	63	0.0	0	0
5/18/04	78	80	79	140	147	144	65	65	65	5.0	0	3
5/19/04	78	78	78	147	147	147	68	65	67	5.0	0	3
5/20/04	78	82	80	147	149	148	68	69	69	5.0	0	3
5/21/04	78	78	78	148	147	148	68	65	67	5.0	0	3
5/22/04	80	80	80	148	147	148	65	65	65	5.0	0	3
5/23/04	78	78	78	147	148	148	65	65	65	5.0	0	3
5/24/04	80	80	80	149	148	149	70	70	70	5.0	5	5
5/25/04	82	80	81	150	150	150	70	65	68	5.0	0	3
5/26/04	80	80	80	149	149	149	68	65	67	7.0	4	6
Average	79	80	79	147	147	147	67	65	66	4	1	2
Minimum	78	78	78	140	142	144	65	60	63	0	0	0
Maximum	82	82	82	150	150	150	70	70	70	7	5	6
Number of Samples	14	14	14	14	14	14	14	14	14	14	14	14
Stand. Dev.	2	1	1	2	2	2	2	2	2	3	2	2
95% Confidence Interval	(78, 80)	(79, 81)	(79, 80)	(146, 149)	(146, 149)	(146, 148)	(65, 68)	(64, 67)	(65, 67)	(2, 5)	(0, 2)	(1, 3)

[1] B= Before and A= After manual adjustments made to system.
Note: Only the 'after' values and averages on April 30, 2004 are used in the statistical calculations.
NA = Not Applicable.
AM = First sample daily collection.
PM = Second sample daily collection.

4.2.1.3 Water Recovery and Recycle Ratio

The temporal profile of the percent water recovery over the verification testing period is presented in Figure 4-3. The range of water recovery experienced during the verification testing was 48% to 88% with an average of 53%. The manufacturer selected this range of water recovery after examination of the initial operating data. Higher recovery rates occurred from April 26, 2004 to April 29, 2004, until the time the unit shut down for the first time. Per the manufacturers recommendations, the flow rates were adjusted, thus effecting the percent recoveries. The data from April 30, 2004 through May 26, 2004 indicates a relatively constant system recovery.
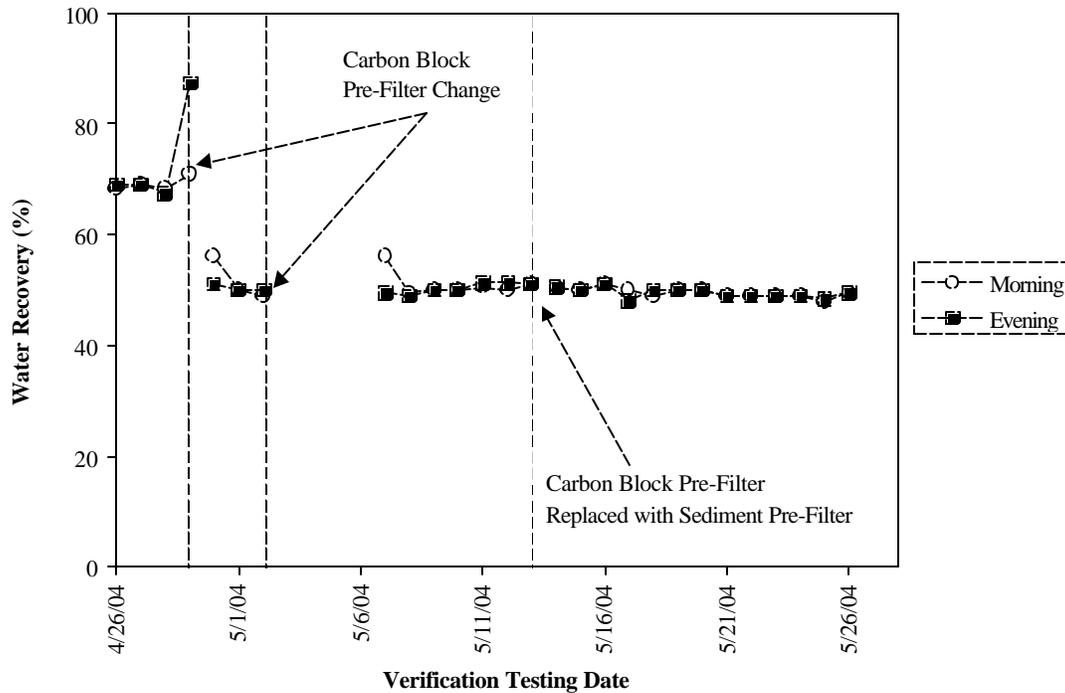
Figure 4-3: Percent water recovery.

The calculated water recovery and recycle ratios for the 27-days of operation during the verification testing were recorded daily in the field log sheets and are presented in Table 4-3. There was a wide range in percent water recovery over the operating period, ranging of 48 to 88% with an average of 53%. The wide range of percent recovery was primarily related to operating conditions associated with the type of pre-filter used. Once the sediment pre-filter was placed online (May 13, 2004), the range of percent recovery was 48 to 51%.

The range of recycle ratio during the verification testing was 0.15 to 0.43, with an average of 0.24. The recycle ratio during the verification testing was higher during the initial days of testing (April 26, 2004 through May 12, 2004) and was adjusted downward through the manually controlled needle valve on May 13, 2004 after replacement of the carbon bloc pre-filter with the sediment pre-filter, following discussions between the manufacturer and FTO to maintain approximately 50% recovery. After adjustment of the recycle valve, the average recycle ratio was 0.17 and prior to the adjustment the recycle ratio was almost double at 0.28. The data

presented in Table 4-3 indicates that both the percent water recovery and the recycle ratio (both influences by system flow rates) are influenced by the type of pre-filter used with the M-15,000 RO Treatment System.

Table 4-3: Water Recovery and Recycle Ratio

Carbon Bloc Pre-filter	Water Recovery (%)			Recycle Ratio		
Date	AM	PM	Ave	AM	PM	Ave
4/26/04	68	69	69	0.29	0.31	0.30
4/27/04	69	69	69	0.32	0.32	0.32
4/28/04	68	68	68	0.32	0.31	0.32
4/29/04	71	88	79	0.36	0.43	0.39
4/30/04	B[1]: 85 A[1]: 56	B: 55 A: 51	AM: 71 PM: 53	B:0.50 A:0.34	B:0.38 A:0.35	AM:0.42 PM:0.37
5/1/04	50	50	50	0.36	0.36	0.36
5/2/04	49	50	50	0.37	0.37	0.37
5/7/04	56	49	53	0.24	0.23	0.23
5/8/04	49	49	49	0.23	0.23	0.23
5/9/04	50	50	50	0.26	0.26	0.26
5/10/04	50	50	50	0.27	0.27	0.27
5/11/04	51	51	51	0.32	0.33	0.32
5/12/04	50	51	51	0.34	0.35	0.34
5/13/04 (before)	52	NA	52	0.38	NA	0.38
Average	56	57	57	0.32	0.32	0.32
Minimum	49	49	49	0.23	0.23	0.23
Maximum	71	88	79	0.38	0.43	0.39
Number of Samples	14	13	14	14	13	14
Standard Dev.	9	12	10	0.05	0.06	0.05
95% Confidence Interval	(51, 62)	(49, 66)	(50, 63)	(0.28, 0.35)	(0.28, 0.36)	(0.28, 0.35)
Sediment Pre-filter	Water Recovery (%)			Recycle Ratio		
5/13/04 (after)	51	51	51	0.17	0.17	0.17
5/14/04	50	50	50	0.19	0.19	0.19
5/15/04	50	50	50	0.18	0.18	0.18
5/16/04	51	51	51	0.17	0.17	0.17
5/17/04	50	48	49	0.16	0.15	0.15
5/18/04	49	50	50	0.15	0.17	0.16
5/19/04	50	50	50	0.17	0.17	0.17
5/20/04	50	50	50	0.18	0.17	0.17
5/21/04	49	49	49	0.18	0.18	0.18
5/22/04	49	49	49	0.18	0.18	0.18
5/23/04	49	49	49	0.18	0.18	0.18
5/24/04	49	49	49	0.18	0.18	0.18
5/25/04	48	48	48	0.17	0.17	0.17
5/26/04	49	49	49	0.18	0.18	0.18
Average	50	50	50	0.17	0.17	0.17
Minimum	48	48	48	0.15	0.15	0.15
Maximum	51	51	51	0.19	0.19	0.19
Number of Samples	14	14	14	14	14	14
Standard Dev.	1	1	1	0.01	0.01	0.01
95% Confidence Interval	(49, 50)	(49, 50)	(49, 50)	(0.17, 0.18)	(0.17, 0.18)	(0.17, 0.18)

[1] B= Before and A= After manual adjustments made to system.
Note: Only the 'after' values and averages on April 30, 2004 are used in the statistical calculations.
NA = Not Applicable
AM = First sample daily collection
PM = Second sample daily collection

4.2.1.4 Feed Water Temperature

Feed water temperature measurements were made twice daily using a NIST thermometer. Temperatures were taken with each set of morning and evening analyses and ranged from 25.0°C to 29.0°C with the morning samples and 27.0°C to 30.5°C with the evening samples (see Table 4-4). The feed water temperature variance was taken into consideration when calculating the temperature adjusted flux values presented in the following section, Section 4.2.1.5 Specific Flux.

Table 4-4: Feed Water Temperature

| Date | Temperature (°C) | | |
	AM	PM	Daily Average
4/26/04	29.0	28.5	28.8
4/27/04	26.5	30.5	28.5
4/28/04	25.0	30.5	27.8
4/29/04	27.0	27.5	27.3
4/30/04	26.0	27.5	26.8
5/1/04	27.0	27.5	27.3
5/2/04	26.5	27.5	27.0
5/7/04	26.0	27.5	26.8
5/8/04	26.0	27.0	26.5
5/9/04	27.5	28.0	27.8
5/10/04	27.0	28.0	27.5
5/11/04	27.0	28.5	27.8
5/12/04	26.5	28.5	27.5
5/13/04	27.0	28.5	27.8
5/14/04	27.5	28.5	28.0
5/15/04	28.0	27.5	27.8
5/16/04	28.0	28.5	28.3
5/17/04	27.0	28.0	27.5
5/18/04	27.0	28.5	27.8
5/19/04	27.0	28.0	27.5
5/20/04	26.0	28.0	27.0
5/21/04	27.0	28.0	27.5
5/22/04	27.5	28.0	27.8
5/23/04	26.5	27.5	27.0
5/24/04	27.0	27.5	27.3
5/25/04	26.0	27.5	26.8
5/26/04	27.0	28.0	27.5
Average	26.9	28.1	27.5
Minimum	25.0	27.0	26.5
Maximum	29.0	30.5	28.8
Number of Samples	27	27	27
Standard Deviation	0.8	0.8	0.5
95% Confidence Interval	(26.5, 27.2)	(27.7, 28.5)	(27.2, 27.7)

AM = First sample daily collection.
PM = Second sample daily collection.

4.2.1.5 Flux, Specific Flux, Net Driving Pressure, and Osmotic Pressure

Flux is a method of expressing permeate flow through the membranes. The flux was monitored and recorded daily throughout the verification testing period, and the data is graphically presented in Figure 4-4 with the corresponding data presented in Table 4-5. There are noticeable declines in the flux, just prior to changing out the carbon bloc pre-filter. While the carbon bloc pre-filter was in place, the flux ranged from 24 to 41 gfd, with an average of 32 gfd, standard deviation of 5 gfd, and a 95% confidence interval of 28 to 36 gfd. Once the sediment pre-filter was put on-line, the flux stabilized with an average 37 gfd, a range of 35 to 28, a standard deviation of 1 gfd, and a 95% confidence interval of 36 to 37 gfd.
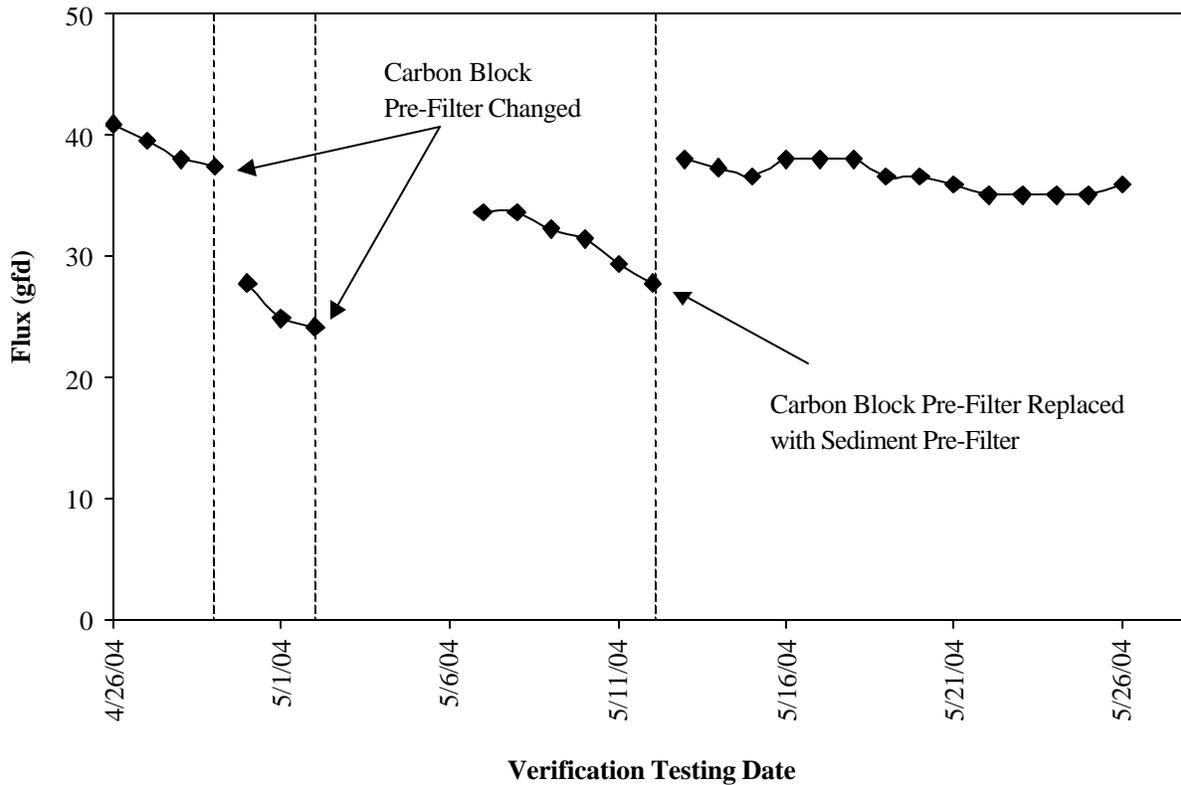
Figure 4-4 Temporal plot of flux verses time.

Table 4-5: Daily Flux Data

Date	Flux (gfd) with Carbon Bloc Pre-filter	Date	Flux (gfd) with Sediment Pre-filter
4/26/04	41	5/13/04	38
4/27/04	40	5/14/04	37
4/28/04	38	5/15/04	37
4/29/04	37	5/16/04	38
4/30/04	28	5/17/04	38
5/1/04	25	5/18/04	38
5/2/04	24	5/19/04	37
5/7/04	34	5/20/04	37
5/8/04	34	5/21/04	36
5/9/04	32	5/22/04	35
5/10/04	31	5/23/04	35
5/11/04	29	5/24/04	35
5/12/04	28	5/25/04	35
5/13/04	27	5/26/04	36
Average	32	Average	37
Minimum	24	Minimum	35
Maximum	41	Maximum	38
Number of Samples	14	Number of Samples	14
Standard Deviation	5	Standard Deviation	1
95% Confidence Interval	(28, 36)	95% Confidence Interval	(36, 37)

Specific flux is used as an indicator of general operational performance. Specific Flux is calculated by flux at a constant temperature (in this case, normalized to 25°C) divided by the net driving pressure. Normalizing the flux to a constant temperature helps to account for the effects of viscosity of water at varying temperatures on the permeate flow through the membranes. The osmotic pressure data was calculated using daily TDS data and the pressures recorded during the verification testing.

The specific flux normalized to 25°C (Equation 3.5) verses time over the verification testing period is presented in Figure 4-5 and Table 4-6. In Table 4-6, the specific flux is presented as two data sets: with the carbon bloc pre-filter and the sediment pre-filter. The specific flux while using the carbon bloc pre-filter ranged from 0.32 gfd/psi to 0.44 gfd/psi, a 27% difference during the 14-days of operation. The specific flux ranged from 0.32 gfd/psi to 0.38 gfd/psi, a 16% difference, while the sediment pre-filter was utilized. The modules were to be replaced if a 20% decline in the specific flux was detected. However, since the study began at a specific flux of 38 gfd, the manufacturer was confident the testing should continue without replacing the modules. Initial decreases in the specific flux may be attributed to the aggressive operational parameters. Once the system was stabilized by replacing the carbon bloc pre-filter with a sediment pre-filter, a steady specific flux was achieved.
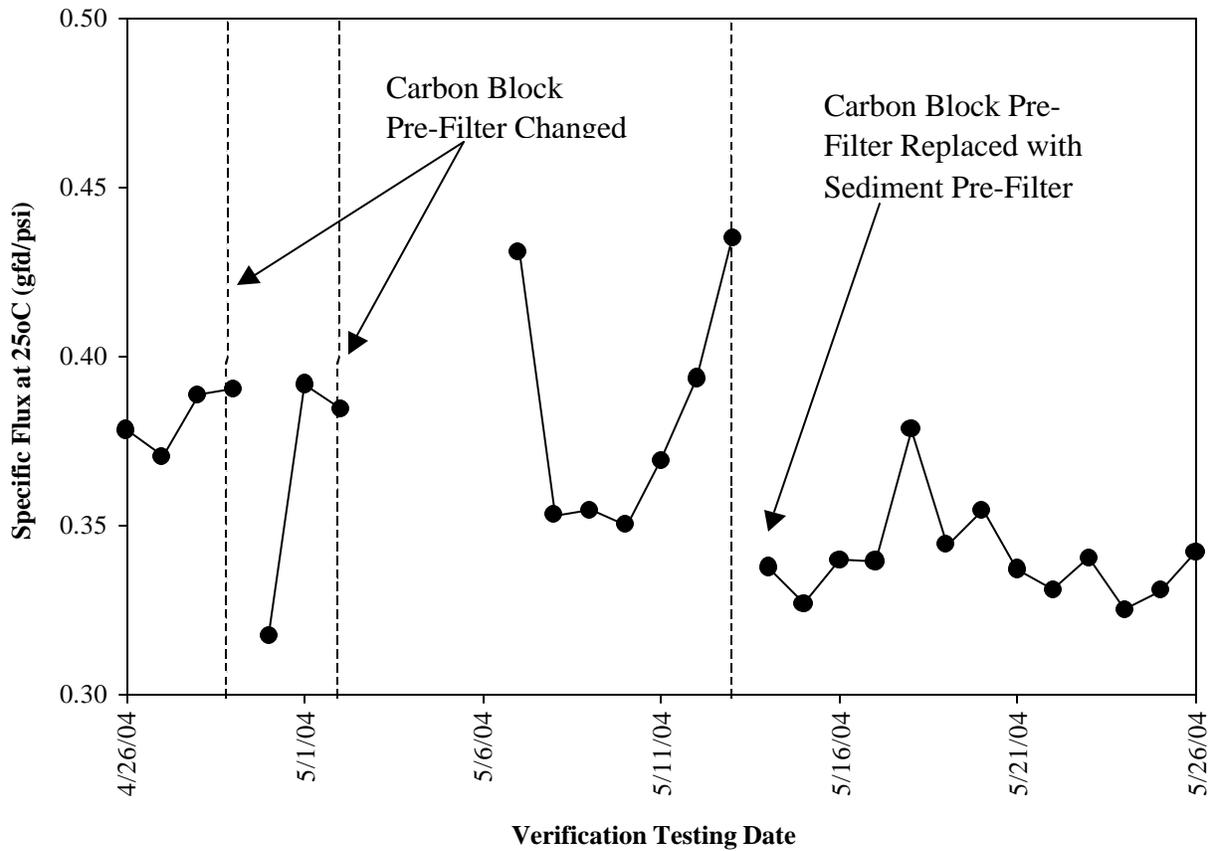
Figure 4-5: Specific flux at 25ºC verses time.

Table 4-6: Daily Specific Flux Data at 25ºC

Date	Specific Flux (gfd/psi) with Carbon Bloc Pre-filter	Date	Specific Flux (gfd/psi) with Sediment Pre-filter
4/26/04	0.38	5/14/04	0.34
4/27/04	0.37	5/15/04	0.33
4/28/04	0.39	5/16/04	0.34
4/29/04	0.39	5/17/04	0.34
4/30/04	0.32	5/18/04	0.38
5/1/04	0.39	5/19/04	0.34
5/2/04	0.38	5/20/04	0.35
5/7/04	0.43	5/21/04	0.34
5/8/04	0.35	5/22/04	0.33
5/9/04	0.35	5/23/04	0.34
5/10/04	0.35	5/24/04	0.32
5/11/04	0.37	5/25/04	0.33
5/12/04	0.39	5/26/04	0.34
5/13/04	0.44		
Average	0.38	Average	0.34
Minimum	0.32	Minimum	0.32
Maximum	0.44	Maximum	0.38
Number of Samples	14	Number of Samples	13
Standard Deviation	0.03	Standard Deviation	0.03
95% Confidence Interval	(0.36, 0.40)	95% Confidence Interval	(0.32, 0.36)

The osmotic pressure gradient is the difference in osmotic pressure generated across the membrane barrier as a result of different concentrations of dissolved salts. TDS concentrations were used as the constituent to calculate the daily osmotic pressure gradient from the verification testing (see Equation 3-4). This data is graphically presented in Figure 4-6 with the corresponding data shown in Table 4-7. The range of osmotic pressure while the carbon bloc pre-filter was in use was 1.7 to 4.5 psi. When the carbon bloc pre-filter was replaced by the sediment pre-filter, the range of osmotic pressure was 1.3 to 1.8 psi.
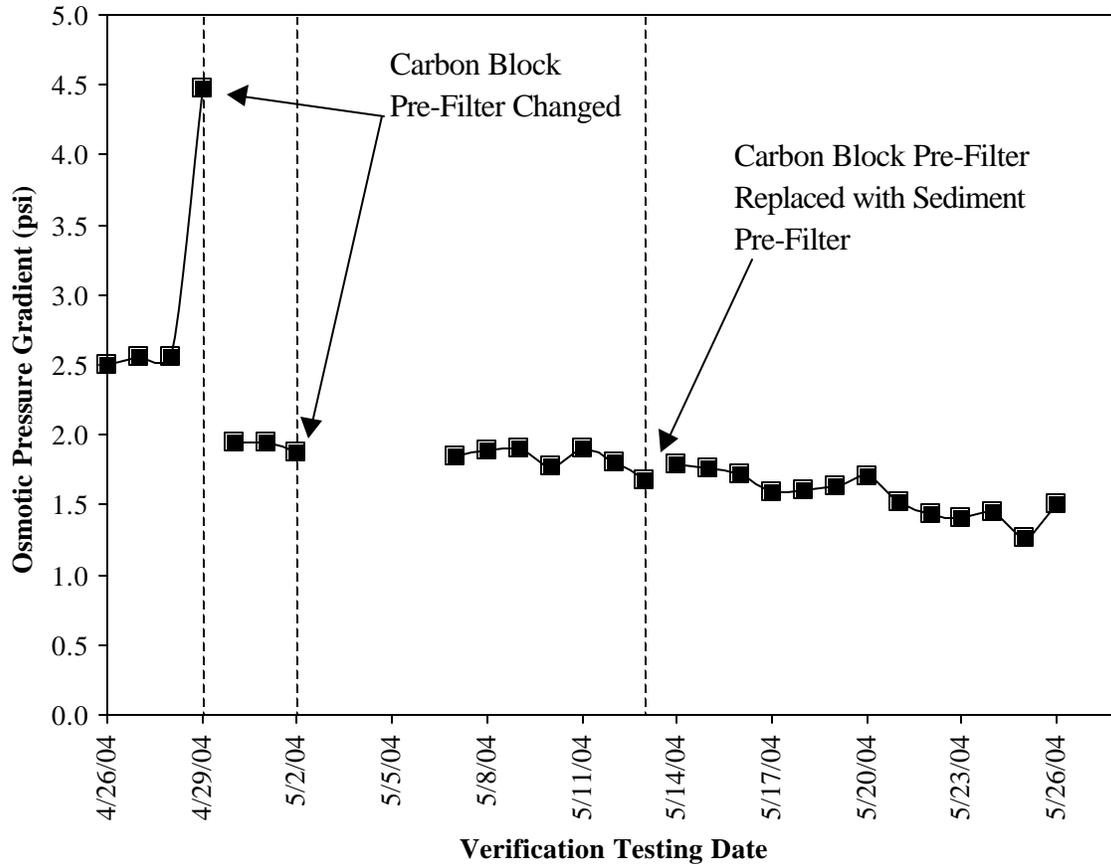
Figure 4-6: Osmotic pressure gradient verses time.

Table 4-7: Osmotic Pressure Gradient

Date	Osmotic Pressure (psi) with Carbon Bloc Pre-filter	Date	Osmotic Pressure (psi) with Sediment Pre-filter
4/26/04	2.5	5/14/04	1.8
4/27/04	2.6	5/15/04	1.8
4/28/04	2.6	5/16/04	1.7
4/29/04	4.5	5/17/04	1.6
4/30/04	1.9	5/18/04	1.6
5/1/04	2.0	5/19/04	1.6
5/2/04	1.9	5/20/04	1.7
5/7/04	1.8	5/21/04	1.5
5/8/04	1.9	5/22/04	1.4
5/9/04	1.9	5/23/04	1.4
5/10/04	1.8	5/24/04	1.5
5/11/04	1.9	5/25/04	1.3
5/12/04	1.8	5/26/04	1.5
5/13/04	1.7		
Average	2.2	Average	1.6
Minimum	1.7	Minimum	1.3
Maximum	4.5	Maximum	1.8
Number of Samples	14	Number of Samples	13
Standard Deviation	0.7	Standard Deviation	0.2
95% Confidence Interval	(1.7, 2.7)	95% Confidence Interval	(1.5, 1.7)

Net driving pressure was calculated daily from the recorded feed water and concentrate streams pressure, and is the average of the feed water and concentrate pressure readings minus the permeate pressure and the osmotic pressure (see Equation 3-3). The net driving pressure during the verification testing period is graphically presented in Figure 4-7 with the corresponding data provided in Table 4-8. As with other operating parameters, there was a noticeable difference in the net driving pressure while the carbon bloc pre-filter was in use, and what appears to be stabilization of the net driving pressure once the sediment pre-filter was installed. The average net driving pressure with the carbon bloc filter was 83 psi, compared to 102 psi with the sediment pre-filter. Additionally, the standard deviation of the net driving pressure while the carbon bloc pre-filter was in use was 14 psi, and was 2 psi while the sediment pre-filter was in use.
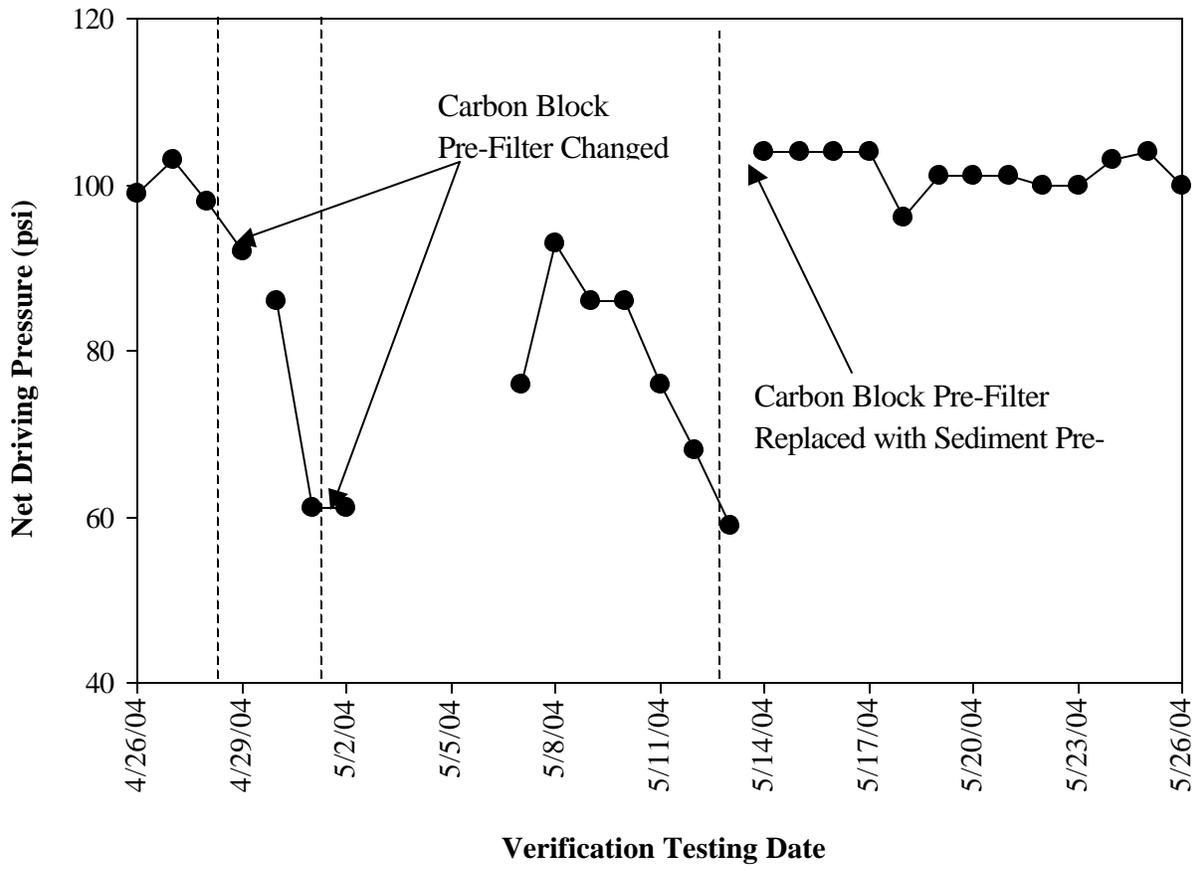
Figure 4-7: Temporal profile of net driving pressure.

Table 4-8: Net Driving Pressure

Date	Net Driving Pressure (psi) with Carbon Bloc Pre-filter	Date	Net Driving Pressure (psi) with Sediment Pre-filter
4/26/04	99	5/14/04	104
4/27/04	103	5/15/04	104
4/28/04	98	5/16/04	104
4/29/04	92	5/17/04	104
4/30/04	86	5/18/04	96
5/1/04	61	5/19/04	101
5/2/04	61	5/20/04	101
5/7/04	76	5/21/04	101
5/8/04	93	5/22/04	100
5/9/04	86	5/23/04	100
5/10/04	86	5/24/04	103
5/11/04	76	5/25/04	104
5/12/04	68	5/26/04	100
5/13/04	59		
Average	82	Average	102
Minimum	59	Minimum	96
Maximum	103	Maximum	104
Number of Samples	14	Number of Samples	13
Standard Deviation	15	Standard Deviation	3
95% Confidence Interval	(71, 92)	95% Confidence Interval	(100, 104)

4.2.2 Power Consumption

The M-15,000 RO Treatment System required 220 volts/11.5 amperage.   The power consumption in kilowatt-hours (KWH) to the system was 33 KWHs (on average) per day in operation. The power consumption was monitored and recorded daily, as presented in Table 4-9. The total power consumed for the 27 days of operation was 880 KWHs. The cost of electricity was the primary consumable O&M cost for operating the system.

Table 4-9: Power Totalizer for M-15,000 RO Treatment System

Date	Cumulative Power Totalizer Reading (KWH)
4/26/04	0
4/27/04	26
4/28/04	61
4/29/04	96
4/30/04	128
5/1/04	165
5/2/04	197
5/7/04	231
5/8/04	253
5/9/04	288
5/10/04	320
5/11/04	357
5/12/04	392
5/13/04	428
5/14/04	464
5/15/04	494
5/16/04	533
5/17/04	564
5/18/04	602
5/19/04	634
5/20/04	670
5/21/04	702
5/22/04	745
5/23/04	772
5/24/04	811
5/25/04	845
5/26/04	880

4.2.3 Consumables and Waste Generation

There were no "consumable" chemical items used for the verification testing; however, the pre-filter to the system would be a consumable product and additional solid waste for disposal. The concentrate waste stream produced from the verification test was blended back with the permeate water for an equivalent water quality to the feed water from the CVWD Well 7802. This water was then sent to a blow-off structure for disposal. The estimated concentrate production rate was 17,300 gallons per day, based on the targeted 50% recovery. The concentrate stream water quality characteristics are discussed in additional detail in Section 4.4 (Task 3).

4.3 Task 2: Cleaning Efficiency

The objective of this task was to evaluate the efficiency of the membrane cleaning procedures recommended by the manufacturer. The manufacturer proposes replacement of RO membranes based on efficiencies of TDS reduction per module and quarterly maintenance procedures, which involve replacement of pre-filters and RO module O-rings, in lieu of a cleaning procedure. While not part of the quarterly maintenance procedures, two of the membranes (membrane number 5 and 6) were also replaced during the maintenance procedures to simulate a portion of annual maintenance procedures.

The total time to complete the O&M procedures was approximately 45 minutes. Visual inspection of the pre-filter and the membranes showed signs of red discoloration, assumed to be iron, sediment, and/or other suspended solids filtered out or precipitated onto the membranes. As previously discussed in Chapter 3, prior to the system being manually shut down for the O&M procedures, the unit automatically shut down on two prior occasions. It was believed that the booster pump was being starved of water due to solids accumulation on the carbon bloc pre-filter. Photograph 4 shows the three pre-filters used in the verification study. The first two are carbon bloc pre-filters and the third filter is a pleated, sediment pre-filter.

Photograph 4: Watts Premier M-15,000 RO Treatment System Pre-filters

Photograph 5 shows the condition of the RO membranes once removed from the system during the O&M procedures performed after the verification testing. There appeared to be "red" discoloration and the presence of solids on the surface of the membranes, similar to those seen on the pre-filters.
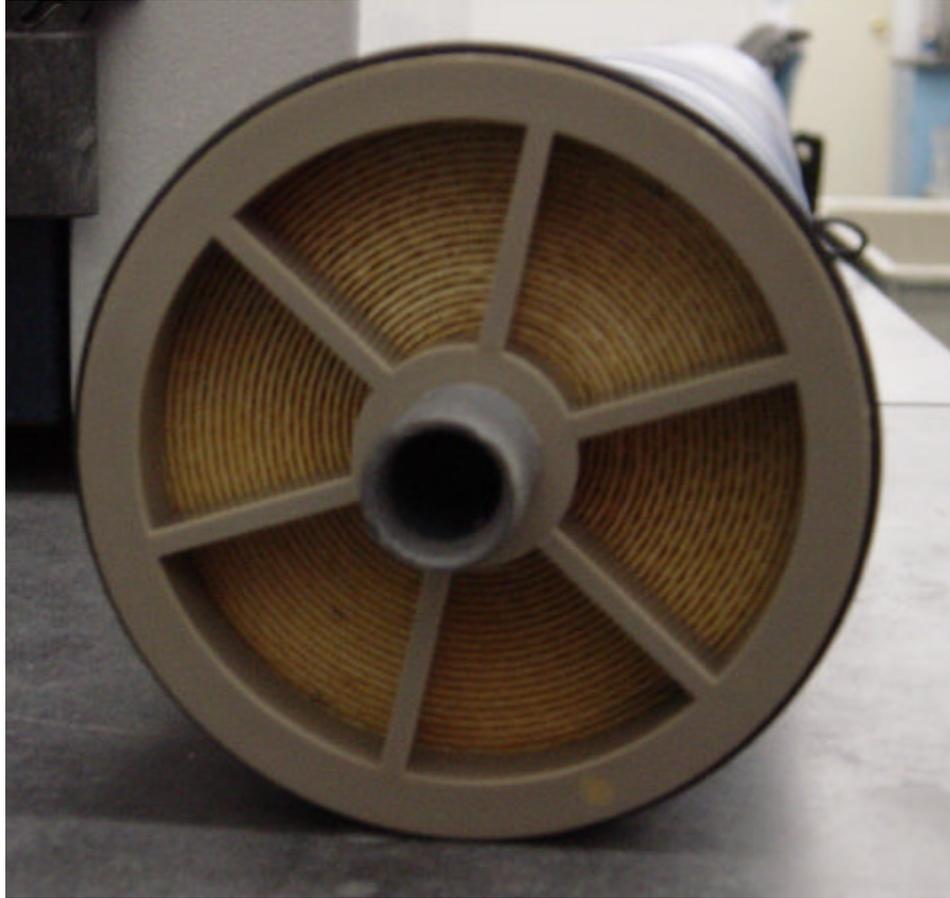
Photograph 5: Membrane RO Number 6 - Post Verification Testing

4.3.1 Measure of Membrane Performance – Post Quarterly O&M Procedures

After completion of the O&M procedures, the M-15,000 RO Treatment System was placed back on line to determine the effect of the O&M procedures on the model performance. Table 4-10 lists the specific flux recoveries and Table 4-11 list the maintenance efficiency indictors (performance indictors) prior to and after the O&M procedures. In Table 4-11, the percent recovery of specific flux was calculated using Equation 3.14, expressed as the ratio between the final specific flux (prior to the O&M procedures) and the initial specific flux (post O&M procedures). There was little deviation between the specific flux prior to and after the O&M procedures, with a percent recovery of 97%.

Table 4-10: Pre-and Post-Maintenance Specific Flux Recoveries

	Specific Flux (gfd/psi)	% Recovery of Specific Flux (%)	% Loss of Original Specific Flux (%)
Flux at Beginning of Verification Study (4/26/04)	0.38	97%	13%
Flux Immediately Prior to Quarterly O&M Procedures (5/26/04)	0.34		
Flux After Quarterly O&M Procedures (5/26/04)	0.33		

Table 4-11 Maintenance Efficiency Indicators

	Feed Water	Permeate	Concentrate	Recycle	Inlet
Flow Rate Prior to O&M Procedures, gpm	24.75	12.25	12.50	5.34	--
Flow Rate After O&M Procedures, gpm	25.00	12.50	12.50	5.28	--
Pressure Prior to O&M Procedures, psi	80	7	68	--	149
Pressure After to O&M Procedures, psi	78	2	65	--	147
Recovery Prior to O&M Procedures, psi	49	--	--	--	--
Recovery After to O&M Procedures, psi	50	--	--	--	--
Recycle Ratio Prior to O&M Procedures, psi	0.18	--	--	--	--
Recycle Ratio After to O&M Procedures, psi	0.17	--	--	--	--
Osmotic Pressure Prior to O&M Procedures, psi	1.5	--	--	--	--
Osmotic Pressure After to O&M Procedures, psi	1.5	--	--	--	--
Net Driving Pressure Prior to O&M Procedures, psi	100	--	--	--	--
Net Driving Pressure After O&M Procedures, psi	102	--	--	--	--
Temperature Prior to O&M Procedures, C	28.0	--	--	--	--
Temperature After to O&M Procedures, C	28.0	--	--	--	--

A set of water samples for water quality analysis was collected just prior to and after the O&M procedure. This data is presented in Table 4-12. From this table it appears that there is very little difference between the before and after O&M procedure water quality.

Table 4-12: Pre and Post O&M Feed Water, Permeate, and Concentrate Water Quality

Parameter	Units	Pre O&M May 24, 2004			Post O&M May 26, 2004		
		Feed Water	Permeate	Concentrate	Feed Water	Permeate	Concentrate
Total Arsenic	µg/L	14	< 1.0	25	15	< 1.0	30
Dissolved Arsenic	µg/L	14	1.1	23	16	1.0	33
As (III)	µg/L	14	< 1.0	30	< 1.0	< 1.0	< 1.0
As(V)[1]	µg/L	< 1.0	< 1.0	< 1.0	15	< 1.0	32
TOC	mg/L	0.50	0.50	0.50	< 0.50	< 0.50	< 0.50
Calcium	mg/L	4.7	< 1.0	8.4	4.7	< 1.0	8.7
Chloride	mg/L	8.2	2.1	15	8.7	1.7	15
Hardness	mg/L	4	0	18	4	0	10
Alkalinity	mg/L	84	34	136	82	26	132
Free Chlorine	mg/L	0.21	0.20	NA	0.35	0.32	NA
Total Chlorine	mg/L	0.22	0.18	NA	0.35	0.33	NA
pH	--	9.23	9.48	9.12	9.17	9.41	9.10
Turbidity	NTU	0.25	0.10	0.25	0.20	0.10	0.40
Conductivity[2]	umoh/cm	225	63.2	368	231	52.6	387
TDS	mg/L	150	45	230	140	34	230
TSS	mg/L	< 10	< 10	< 10	< 10	< 10	< 10
Manganese	µg/L	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
Iron	mg/L	0.023	< 0.010	0.023	0.039	< 0.010	0.043
Barium	µg/L	7.3	< 2.0	12	7.2	< 20[3]	13
Silica	mg/L	14	11	17	14	8.2	19
Fluoride	mg/L	0.78	0.29	1.2	0.80	0.24	1.3
Sulfate	mg/L	19	< 2.0	38	21	< 2.0	40
Chromium	µg/L	13	< 1.0	23	13	< 1.0	24
Vanadium	µg/L	51	5.3	88	51	5.1	90

[1] As (V) is a calculated value.
[2] Conductivity was measured twice per day. This value is the average of all the conductivity results.
[3] Note: EPA Method 200.7 was used for this one analysis with a MRL of 20 µg/L.
NA = Not applicable.

4.3.2 Review of Watts Premier Operation and Maintenance Manual

The Watts Premier O&M manual was previous discussed in Section 3.13. These procedures were followed on May 26, 2004, upon completion of the verification study to simulate the quarterly and a portion of the annual maintenance procedures. The O&M manual was very clear and the maintenance procedure was completed in approximately 45 minutes. Upon completion of the O&M procedures, the system was started back up and water quality data and operation data was collected for comparison with the first startup of the equipment on April 26, 2004. As with the maintenance procedures, the startup procedures were very clear and easy to follow as well.

4.4 Task 3: Feed Water And Treated Water Quality Monitoring

The objective of this task was to evaluate the quality of water produced by the membrane system and the removal of inorganic chemical contaminants achieved by the membrane system at the

specified operational conditions. Monitoring of the water quality parameters included the following: arsenic (total, As^{+3}, and dissolved), pH, temperature, chloride, calcium, barium, hardness, conductivity, chlorine (total and free), TDS, alkalinity, LSI, turbidity, TSS, silica, fluoride, iron, manganese, sulfate, chromium, vanadium, TOC and SDI. Water quality produced was evaluated in relation to feed water quality and operational conditions. The verification study indicated that arsenic can be removed by the M-15,000 RO Treatment System, but depending on the source water characteristics, the appropriate pre-filter selection is important to prevent clogging of the pre-filters.

In Figure 4-8, Temporal Plot of Total Arsenic, all permeate values were non-detect (ND) with a MRL of 1.0 µg/L, except on May 25, 2004, and May 26, 2004, which were 1.4 µg/L and 1.2 µg/L, respectively. There was a spike in the concentrate total arsenic (84 µg/L) just before the first pre-filter was changed out on April 29, 2004, but returned to approximately 26 µg/L for the remainder of the study. The cause of the concentrate arsenic spike is unknown, but was indirectly substantiated by a corresponding spike in the concentrate TDS. The data corresponding to Figure 4-8 is presented in Table 4-13. Mass balances were calculated to determine the accumulation of limiting salts on the membrane surface. Post-treatment capabilities of the equipment were also evaluated for arsenic (total, As^{+3}, and dissolved). Additional information on the mass balance for daily total arsenic (feed water, permeate, and concentrate streams) is presented in Section 4.4.2.1.

Figure 4-8 Temporal plot of total arsenic.

68
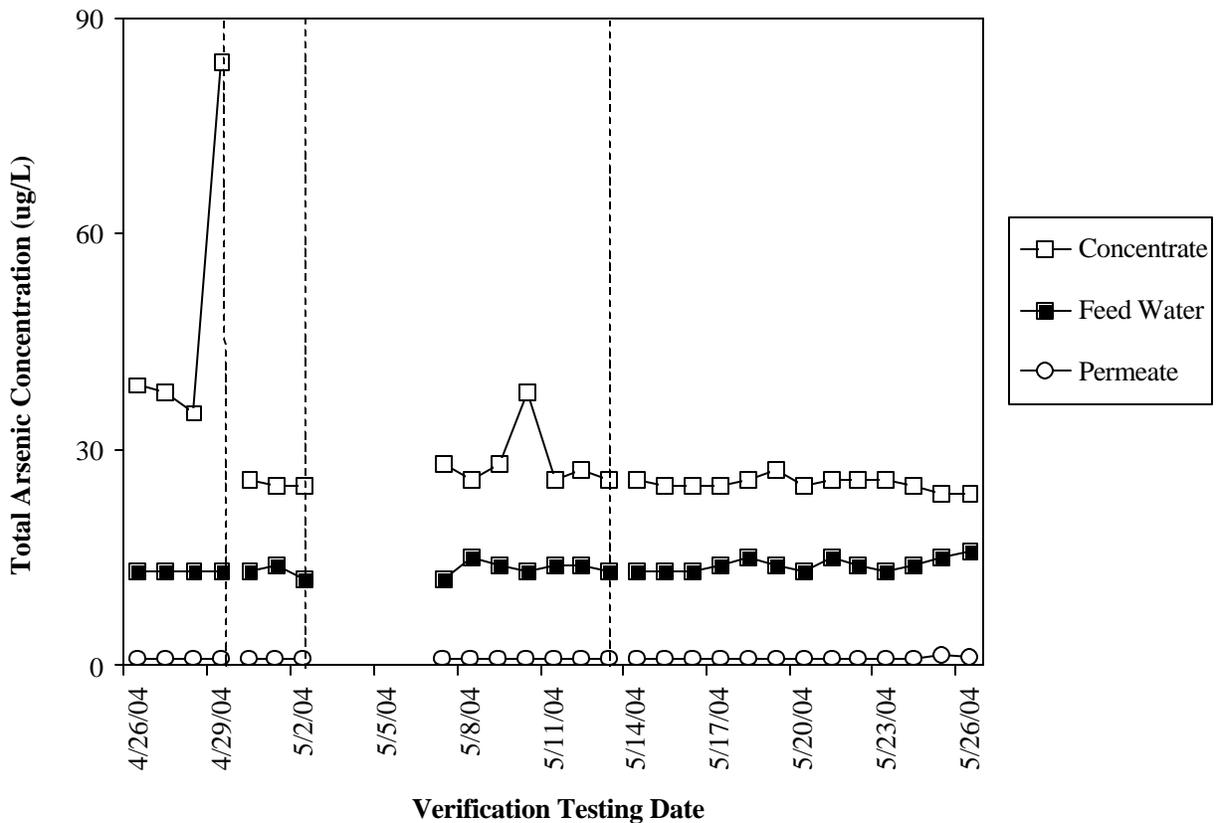
Table 4-13: Daily Feed Water, Concentrate, and Permeate Total Arsenic Data

Date	Feed Water Total Arsenic (mg/L)	Concentrate Total Arsenic (mg/L)	Permeate Total Arsenic (mg/L)
4/26/04	13	39	< 1.0
4/27/04	13	38	< 1.0
4/28/04	13	35	< 1.0
4/29/04	13	84	< 1.0
4/30/04	13	26	< 1.0
5/1/04	14	25	< 1.0
5/2/04	12	25	< 1.0
5/7/04	12	28	< 1.0
5/8/04	15	26	< 1.0
5/9/04	14	28	< 1.0
5/10/04	13	38	< 1.0
5/11/04	14	26	< 1.0
5/12/04	14	27	< 1.0
5/13/04	13	26	< 1.0
5/14/04	13	26	< 1.0
5/15/04	13	25	< 1.0
5/16/04	13	25	< 1.0
5/17/04	14	25	< 1.0
5/18/04	15	26	< 1.0
5/19/04	14	27	< 1.0
5/20/04	13	25	< 1.0
5/21/04	15	26	< 1.0
5/22/04	14	26	< 1.0
5/23/04	13	26	< 1.0
5/24/04	14	25	1.0
5/25/04	15	24	1.4
5/26/04	16	24	1.2
Average	14	30	< 1.0
Minimum	12	24	< 1.0
Maximum	16	84	1.4
Number of Samples	27	27	27
Standard Deviation	1	12	0.1
95% Confidence Interval	(13, 14)	(24, 35)	(< 1.0, 1.1)

In Figure 4-9, Temporal Plot of TDS, the feed water and permeate TDS show steady TDS levels throughout the verification testing, with standard deviations of 6 and 12 mg/L, respectively. The permeate TDS was below the detection limit of 10 mg/L at the beginning of the test, and slowly increased to 34 mg/L on the last day of testing. After the quarterly O&M procedures were performed, the permeate TDS was reduced by 26% to 34 mg/L (Table 4-12). Throughout the verification test, the TDS of the concentrate was less than 300 mg/L with the exception of the first 4 days of the verification testing where the TDS fluctuated as high as 790 mg/L. The data corresponding to Figure 4-9 is presented in Table 4-14.
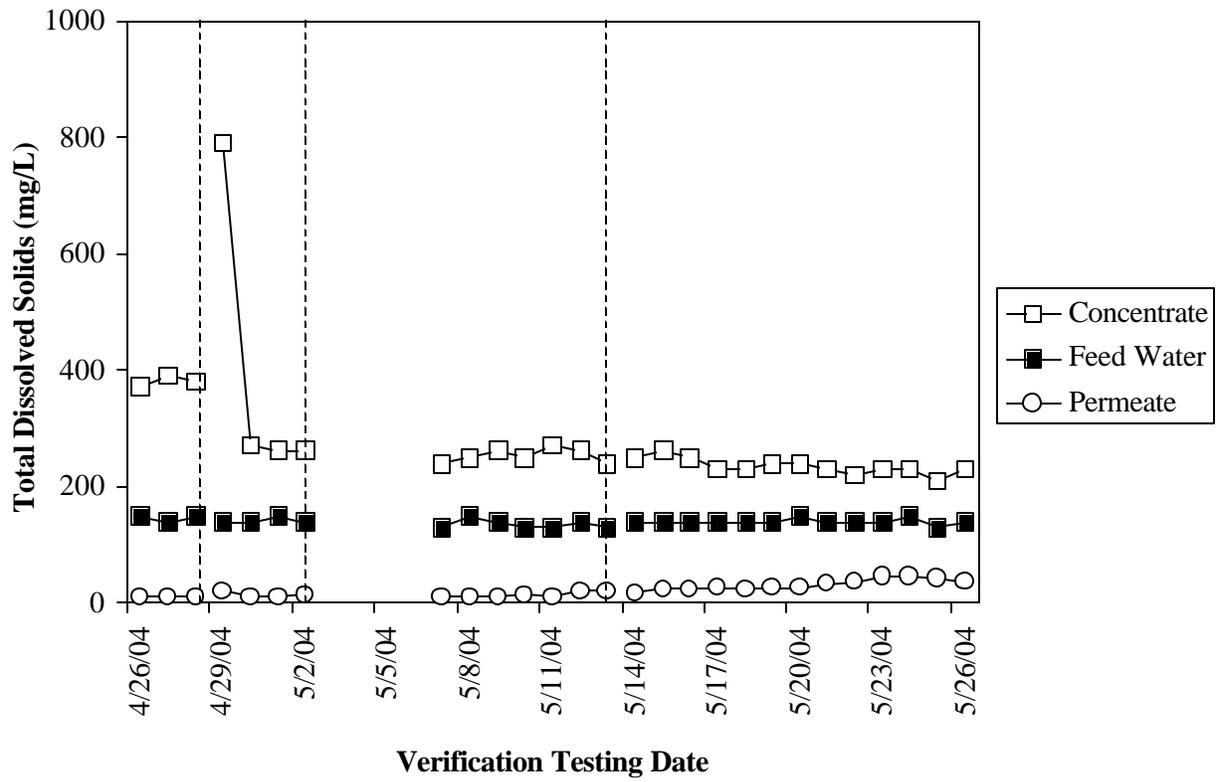
Figure 4-9 Temporal plot of TDS.

Table 4-14: Daily Feed Water, Concentrate, and Permeate TDS

Date	Feed Water TDS (mg/L)	Concentrate TDS (mg/L)	Permeate TDS (mg/L)
4/26/04	150	370	< 10
4/27/04	140	390	< 10
4/28/04	150	380	< 10
4/29/04	140	790[1]	18[1]
4/30/04	140[1]	270[1]	11[1]
5/1/04	150[1]	260[1]	< 10[1]
5/2/04	140	260[1]	12[1]
5/7/04	130	240	< 10
5/8/04	150	250	11
5/9/04	140	260	< 10
5/10/04	130	250	13
5/11/04	130	270	10
5/12/04	140	260	19
5/13/04	130	240	18
5/14/04	140[1]	250	16[1]
5/15/04	140	260	24
5/16/04	140	250	23
5/17/04	140	230	26
5/18/04	140	230	24
5/19/04	140	240	26
5/20/04	150	240	25
5/21/04	138	230	32
5/22/04	140	220	36
5/23/04	140	230	45
5/24/04	150	230	45
5/25/04	130[1]	210[1]	43[1]
5/26/04	140	230	34
Average	140	279	21
Minimum	130	210	< 10
Maximum	150	790	45
Number of Samples	27	27	27
Standard Deviation	7	112	12
95% Confidence Interval	(138, 143)	(277, 282)	(19, 23)

[1] Samples exceeded the laboratory RPD of 5%, as indicated in Table 3-8.

Additional water quality monitoring included daily on-site analysis of pH and twice a day on-site analysis of conductivity for the feed water, permeate, and concentrate streams. Additional weekly monitoring was conducted for hardness, alkalinity, and turbidity. Tables 4-15 and 4-16 present the data from the daily pH and conductivity measurements, and Table 4-17 presents the data from the weekly hardness, alkalinity, and turbidity. Free chlorine and total chlorine were monitored four times per week on the feed water (chlorinated groundwater) and the permeate from the first RO membrane (see Table 4-18). Data on additional inorganic constituents (barium, manganese, calcium, fluoride, chloride, chromium, sulfate, vanadium, iron, and silica) is presented in Section 4.4.1, which discusses the percent removal of these non-targeted inorganic chemical constituents.

Samples were analyzed daily for pH and twice daily for conductivity from each of the three sample streams (feed water, permeate, and concentrate). Due to the log nature of pH, the median value of the pH data has been present in lieu of the average. There was a short range (minimum to maximum value) of pH values for each of the samples sets with the concentrate having the greatest variability. The feed water pH ranged from 8.97 to 9.27, concentrate from 8.67 to 9.19 and permeate from 9.23 to 9.66.

Table 4-15: Daily pH Analysis

Date	Feed Water	Concentrate	Permeate
4/26/04	9.26	9.04	9.43
4/27/04	8.98	8.95	9.23
4/28/04	9.06	9.01	9.28
4/29/04	9.14	8.67	9.30
4/30/04	9.09	9.03	9.48
5/1/04	9.13	9.10	9.50
5/2/04	8.97	8.90	9.49
5/7/04	9.09	9.00	9.30
5/8/04	9.21	9.12	9.61
5/9/04	9.20	9.11	9.56
5/10/04	9.08	9.12	9.60
5/11/04	9.23	9.14	9.65
5/12/04	9.24	9.10	9.66
5/13/04	9.10	9.06	9.38
5/14/04	9.20	9.11	9.50
5/15/04	9.23	9.12	9.57
5/16/04	9.20	9.11	9.53
5/17/04	9.24	9.14	9.47
5/18/04	9.27	9.16	9.49
5/19/04	9.24	9.13	9.56
5/20/04	9.23	9.19	9.57
5/21/04	9.23	9.16	9.52
5/22/04	9.21	9.15	9.51
5/23/04	9.24	9.16	9.51
5/24/04	9.23	9.12	9.48
5/25/04	9.22	9.12	9.45
5/26/04	9.20	9.15	9.41
Median	9.21	9.12	9.50
Minimum	8.97	8.67	9.23
Maximum	9.27	9.19	9.66
Number of Samples	27	27	27

The permeate conductivity slowly increased over the 27 operating days of the verification testing, beginning at 6.7 umoh/cm and ending with 76.7 umoh/cm (see Table 4-16). This is an indicator of a decline in membrane system performance or membrane integrity. As this decline was observed even during constant operational conditions, it is suspected that the continued exposure to low levels of chlorine for the duration of the ETV testing period was leading to membrane integrity concerns. The conductivity data indicated a relatively steady state for the feed water and concentrate streams, with one exception on April 29, 2004 where the conductivity spiked to 1302 umoh/cm in the concentrate.

Table 4-16: Daily Conductivity Analysis

Date	Feed Water (umoh/cm)			Concentrate (umoh/cm)			Permeate (umoh/cm)		
	AM	PM	Ave	AM	PM	Ave	AM	PM	Ave
4/26/04	190	192	191	505	491	498	6.7	7.5	7.1
4/27/04	209	202	206	559	554	557	7.4	5.4	6.4
4/28/04	232	233	233	598	637	618	6.8	8.2	7.5
4/29/04	236	248	242	1302	1282	1292	11.3	12.2	11.8
4/30/04	239	227	233	431	412	422	11.7	B[1]: 11.2 A[1]: 7.1	AM: 11.7 PM: 9.2
5/1/04	245	243	244	449	440	445	14.1	11.2	12.7
5/2/04	233	228	231	434	424	429	11.1	12.2	11.7
5/7/04	238	244	241	423	426	425	23.3	15.2	19.3
5/8/04	245	214	230	428	425	427	15.7	13.2	14.5
5/9/04	245	239	242	424	430	427	16.2	15.9	16.1
5/10/04	237	224	231	426	433	430	18.9	18.3	18.6
5/11/04	242	246	244	439	439	439	22.3	22.8	22.6
5/12/04	240	244	242	437	437	437	23.2	23.5	23.4
5/13/04	243	239	241	414	417	416	25.8	24.7	25.3
5/14/04	241	244	243	411	414	413	25.6	25.8	25.7
5/15/04	240	241	241	420	421	421	31.0	32.3	31.7
5/16/04	241	231	236	416	409	413	38.1	35.1	36.6
5/17/04	244	237	241	408	398	403	42.8	39.8	41.3
5/18/04	224	222	223	401	398	400	39.2	39.1	39.2
5/19/04	234	227	231	398	391	395	44.0	40.6	42.3
5/20/04	230	222	226	387	374	381	41.3	43.3	42.3
5/21/04	224	227	226	381	378	380	49.2	50.0	49.6
5/22/04	228	224	226	377	375	376	55.5	53.3	54.4
5/23/04	226	228	227	371	374	373	58.3	60.1	59.2
5/24/04	225	227	226	368	370	369	63.2	64.1	63.7
5/25/04	230	228	229	393	391	392	72.8	74.1	73.5
5/26/04	230	228	229	362	361	362	76.5	76.7	76.6
Average	233	230	231	458	456	457	32	31	31
Minimum	190	192	191	362	361	362	6.7	5.4	6.4
Maximum	245	248	244	1302	1282	1292	76.5	76.7	76.6
Number of Samples	27	27	27	27	27	27	27	27	27
Standard Deviation	12	13	12	177	175	176	21	21	21
95% Confidence Interval	(231, 235)	(228, 232)	(229, 234)	(456, 460)	(453, 458)	(454, 459)	(29, 34)	(29, 33)	(29, 33)

[1] B= Before and A= After manual adjustments made to system.
Note: Only the 'after' permeate value and average on April 30, 2004 was used in the statistical calculations.
AM = First sample daily collection.
PM = Second sample daily collection.

Table 4-17 presents the weekly on-site hardness, alkalinity, and turbidity analyses. Feed water during the test was soft and the system completely removed any hardness present. Permeate hardness in all of the analyses was 0 mg/L, while the concentrate hardness was approximately double that of the feed water. Similarly, the alkalinity was reduced by approximately 72% in the permeate and almost doubled in the concentrate compared to the feed water alkalinity. The turbidity analysis ranged from 0.25 to 0.55 NTU in the feed water and 0.10 to 0.20 NTU in the permeate with an average percent turbidity removal of 63%.

Table 4-17: On-site Weekly Water Quality Monitoring

	Hardness (mg/L)				Alkalinity (mg/L)		
Date	Feed Water	Concentrate	Permeate		Feed Water	Concentrate	Permeate
4/26/04	20	40	0		74	206	12
5/7/04	22	44	0		88	140	18
5/10/04	20	44	0		82	144	22
5/18/04	22	34	0		88	130	28
5/24/04	4	18	0		84	136	34
Average	18	36	0		83	151	23
Minimum	4	18	0		74	130	12
Maximum	22	44	0		88	206	34
Number of Samples	5	5	5		5	5	5

	Turbidity (NTU)		
Date	Feed Water	Concentrate	Permeate
4/26/04	0.43	0.50	0.17
5/7/04	0.53	0.52	0.13
5/10/04	0.51	0.54	0.18
5/18/04	0.23	0.28	0.19
5/24/04	0.24	0.25	0.10
Average	0.40	0.40	0.15
Minimum	0.25	0.25	0.10
Maximum	0.55	0.55	0.20
Number of Samples	5	5	5

Table 4-18 presents the results of the free and total chlorine on-site analysis from the feed water and the permeate (note: permeate samples were collected immediately after the first membrane which was identified as the first available sample location downstream of the pre-filter).

Since the carbon bloc pre-filter was replaced with a sediment pre-filter, the data presented in Table 4-18 as been broken into two sets of data, one with the carbon bloc pre-filter and one set with the sediment pre-filter. The results of the first set of data indicate that the carbon bloc pre-filter removed 51% of the free chlorine and 53% of the total chlorine. This may have been due in part to the feed water flow rates not allowing sufficient contact time in the pre-filter for the carbon bloc to be 100% effective.

Once the sediment pre-filter was placed in service (in lieu of the carbon bloc pre-filter), there was still a small reduction in chlorine removal, 19% of the free chlorine and 21% of the total chlorine. It is evident that chlorine is breaking through the pre-filter (with either type of pre-filter). This may be a contributing factor to the decline in membrane performance during the verification test and may have a significant long-term impact, which cannot be determined by the data available from this verification test.

Table 4-18: On-Site Free and Total Chlorine Monitoring

Date	Free Chlorine (mg/L)		Total Chlorine (mg/L)	
	Feed Water	Permeate[1]	Feed Water	Permeate[1]
4/26/2004	0.51	0.27	0.94	0.27
4/27/2004	0.92	0.56	0.92	0.56
4/28/2004	0.98	0.29	0.98	0.29
4/30/2004	0.45	0.26	0.52	0.26
5/7/2004	0.45	0.36	0.43	0.20
5/8/2004	0.71	0.21	0.78	0.45
5/9/2004	0.30	0.12	0.40	0.18
5/10/2004	0.54	0.21	0.55	0.21
5/11/2004	0.56	0.30	0.56	0.30
5/12/2004	0.46	0.35	0.48	0.36
Average	0.59	0.29	0.66	0.31
Minimum	0.30	0.12	0.40	0.18
Maximum	0.98	0.56	0.98	0.56
Number of Samples	10	10	10	10
Standard Deviation	0.22	0.12	0.23	0.12
95% Confidence Interval	(0.40, 0.77)	(0.19, 0.39)	(0.46, 0.85)	(0.21, 0.41)
5/14/2004	0.68	0.52	0.73	0.48
5/17/2004	0.42	0.40	0.42	0.39
5/18/2004	0.38	0.30	0.39	0.31
5/19/2004	0.02	0.00	0.04	0.02
5/21/2004	0.43	0.19	0.44	0.37
5/24/2004	0.21	0.20	0.22	0.18
5/25/2004	0.03	0.02	0.04	0.02
5/26/2004	0.34	0.33	0.34	0.34
Average	0.31	0.25	0.33	0.26
Minimum	0.02	0.00	0.04	0.02
Maximum	0.68	0.52	0.73	0.48
Number of Samples	8	8	8	8
Standard Deviation	0.22	0.18	0.23	0.17
95% Confidence Interval	(0.09, 0.54)	(0.06, 0.43)	(0.10, 0.56)	(0.09, 0.44)

[1] Permeate chlorine samples were collected just after the first membrane.

4.4.1 Percent Removal of Inorganic Chemical Constituents

Speciated arsenic data is presented in Table 4-19. Three forms of arsenic were evaluated on a weekly basis: total, dissolved, and arsenite. The majority of the arsenic appears to be in the dissolved form. There is a noticeable discrepancy on the May 24, 2004 sampling date with respect to the concentrate samples, where the arsenite is greater than both the dissolved and the total arsenic. This may be due to a number of issues, including sampling error, laboratory interference, or other unknown causes of interference.

The arsenate data are calculated values by subtracting the arsenite value from the dissolved arsenic value. From the data presented, the majority of the arsenic was in the arsenate form, with the exception of the May 24, 2004 sample where the feed water appears to be primarily in the arsenite form.

Table 4-19: Weekly Speciated Arsenic Analysis

Date[1]	Total Arsenic (µg/L)			Dissolved Arsenic (µg/L)			Arsenite (µg/L)			Arsenate (µg/L) [1]		
	Feed Water	Conc.	Perm.	Feed Water	Conc.	Perm.	Feed Water	Conc.	Perm.	Feed Water	Conc.	Perm.
4/26/04	13	39	< 1.0	16	39	< 1.0	< 1.0	1.7	1.3	15	37.3	< 1.0
5/7/04	12	28	< 1.0	14	26	< 1.0	< 1.0	< 1.0	1.5	13	25	< 1.0
5/10/04	13	38	< 1.0	13	31	< 1.0	< 1.0	1.4	< 1.0	12	29.6	< 1.0
5/18/04	15	28	< 1.0	14	26	< 1.0	1.3	1.4	< 1.0	12.7	24.6	< 1.0
5/24/04	14	25	1.0	14	23	1.1	14	30	< 1.0	< 1.0	< 1.0	< 1.0
Average	13	32	< 1.0	14	29	< 1.0	3.7	7.1	1.2	11	24	< 1.0
Minimum	12	25	< 1.0	13	23	< 1.0	< 1.0	< 1.0	<1.0	< 1.0	< 1.0	< 1.0
Maximum	15	39	< 1.0	16	39	1.1	14	30	1.5	15	37.3	< 1.0
Number of Samples	5	5	5	5	5	5	5	5	5	5	5	5

[1] Arsenate results are calculated values.

The results of the weekly sampling of inorganic constituents and the percent removal of the inorganic constituents are presented Table 4-20 followed by temporal plots for each significant inorganic constituent (Figures 4-10 to 4-14). Manganese was not plotted as the feed water, permeate, and concentrate analyses were all below the MRL of 2.0 µg/L. The testing unit was effective at reducing the following inorganic constituents to non-detectable levels: barium, calcium, iron, chromium, and sulfate. Significant levels of fluoride, chloride, and vanadium were also removed. Silica had a declining rate of removal, beginning with 91% removal and ending with 21% removal. The level of manganese removal could not be determined, as both the feed water and permeate concentrations were below the detection limit.

Table 4-20: Weekly Analytical Parameters and Percent Removal

Date	Barium (mg/L) Feed Water	Concen-trate	Permeate	Percent Removal	Manganese (mg/L) Feed Water	Concen-trate	Permeate	Percent Removal
4/26/04	6.4	18	< 2.0	> 69%	< 2.0	< 2.0	< 2.0	NA
5/7/04	7.6	14	< 2.0	> 74%	< 2.0	< 2.0	< 2.0	NA
5/10/04	8.1	13	< 2.0	> 75%	< 2.0	< 2.0	< 2.0	NA
5/18/04	6.3	12	< 2.0	> 68%	< 2.0	< 2.0	< 2.0	NA
5/24/04	7.3	12	< 2.0	> 73%	< 2.0	< 2.0	< 2.0	NA
Average	7.1	14	< 2.0	> 72%	< 2.0	< 2.0	< 2.0	NA
Minimum	6.3	12	< 2.0	> 68%	< 2.0	< 2.0	< 2.0	NA
Maximum	8.1	18	< 2.0	> 75%	< 2.0	< 2.0	< 2.0	NA
Number of Samples	5	5	5	5	5	5	5	NA
Calcium (mg/L)					**Fluoride (mg/L)**			
4/26/04	5.1	13	< 1.0	> 80%	0.82	2.2	< 0.050	> 94%
5/7/04	4.8	9.1	< 1.0	> 79%	0.79	1.4	< 0.050	> 94%
5/10/04	4.8	9	< 1.0	> 79%	0.80	1.4	0.06	93%
5/18/04	4.4	8	< 1.0	> 77%	0.80	1.4	0.16	80%
5/24/04	4.7	8.4	< 1.0	> 79%	0.78	1.2	0.29	63%
Average	4.8	9.5	< 1.0	> 79%	0.80	1.5	0.12	85%
Minimum	4.4	8	< 1.0	> 77%	0.78	1.2	< 0.050	63%
Maximum	5.1	13	< 1.0	> 80%	0.82	2.2	0.29	> 94%
Number of Samples	5	5	5	5	5	5	5	5
Chloride (mg/L)					**Chromium (mg/L)**			
4/26/04	8.9	25	< 1.0	> 89%	13	36	< 1.0	> 92%
5/7/04	8.4	16	< 1.0	> 88%	13	23	< 1.0	> 92%
5/10/04	8.7	17	< 1.0	> 89%	13	23	< 1.0	> 92%
5/18/04	8.2	15	1.1	87%	13	24	< 1.0	> 92%
5/24/04	8.2	15	2.1	74%	13	23	< 1.0	> 92%
Average	8.5	18	1	85%	13	26	< 1.0	> 92%
Minimum	8.2	15	< 1.0	74%	13	23	< 1.0	> 92%
Maximum	8.9	25	2.1	> 89%	13	36	< 1.0	> 92%
Number of Samples	5	5	5	5	5	5	5	5
Sulfate (mg/L)					**Vanadium (mg/L)**			
4/26/04	21	60	< 2.0	> 90%	45	130	< 3.0	> 93%
5/7/04	20	39	< 2.0	> 90%	51	80	< 3.0	> 94%
5/10/04	21	41	< 2.0	> 90%	51	84	< 3.0	> 94%
5/18/04	20	39	< 2.0	> 90%	49	90	< 3.0	> 94%
5/24/04	19	38	< 2.0	> 89%	51	88	5.3	90%
Average	20	43	< 2.0	> 90%	49	94	< 3.0	> 93%
Minimum	19	38	< 2.0	> 89%	45	80	< 3.0	90%
Maximum	21	60	< 2.0	> 90%	51	130	5.3	> 94%
Number of Samples	5	5	5	5	5	5	5	5
Iron (mg/L)					**Silica (mg/L)**			
4/26/04	0.012	< 0.010	< 0.010	> 17%	14	39	1.2	91%
5/7/04	0.033	0.028	< 0.010	> 70%	15	24	3.4	77%
5/10/04	0.019	0.018	< 0.010	> 47%	17	24	4.2	75%
5/18/04	0.010	< 0.010	< 0.010	> 0 %	15	20	8.4	44%
5/24/04	0.023	0.023	< 0.010	> 57%	14	17	11	21%
Average	0.019	0.018	< 0.010	38%	15	25	5.6	62%
Minimum	0.010	< 0.010	< 0.010	> 0 %	14	17	1.2	21%
Maximum	0.033	0.028	< 0.010	> 70%	17	39	11	91%
Number of Samples	5	5	5	5	5	5	5	5

[1] The ">" symbol in the percent removal column indicates that the analysis was below the MRL.

[2] NA = Not Applicable; Feed water and permeate were both below the detection limit;
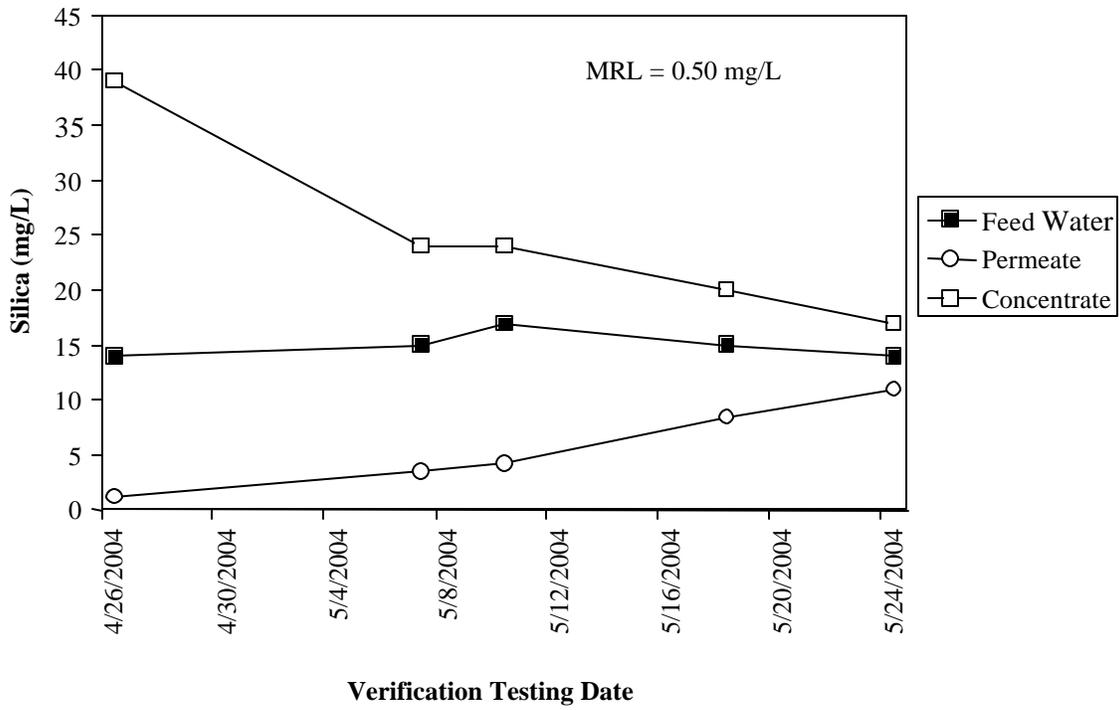
Figure 4-10: Temporal plot of silica.
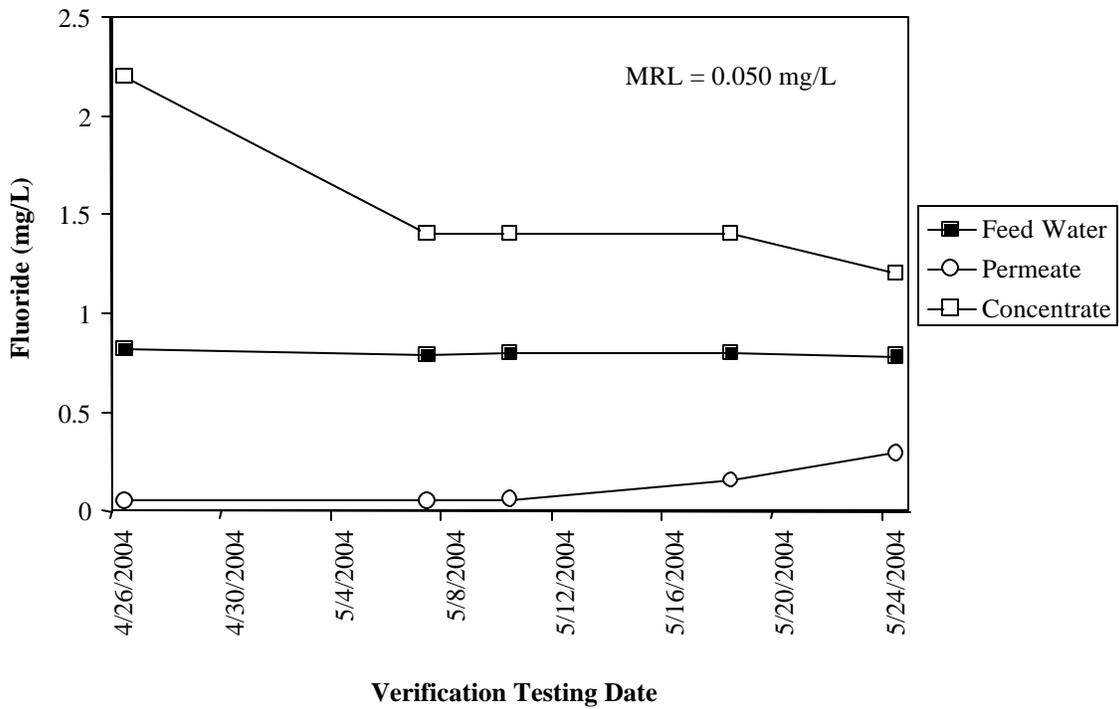
Figure 4-11: Temporal plot of fluoride.
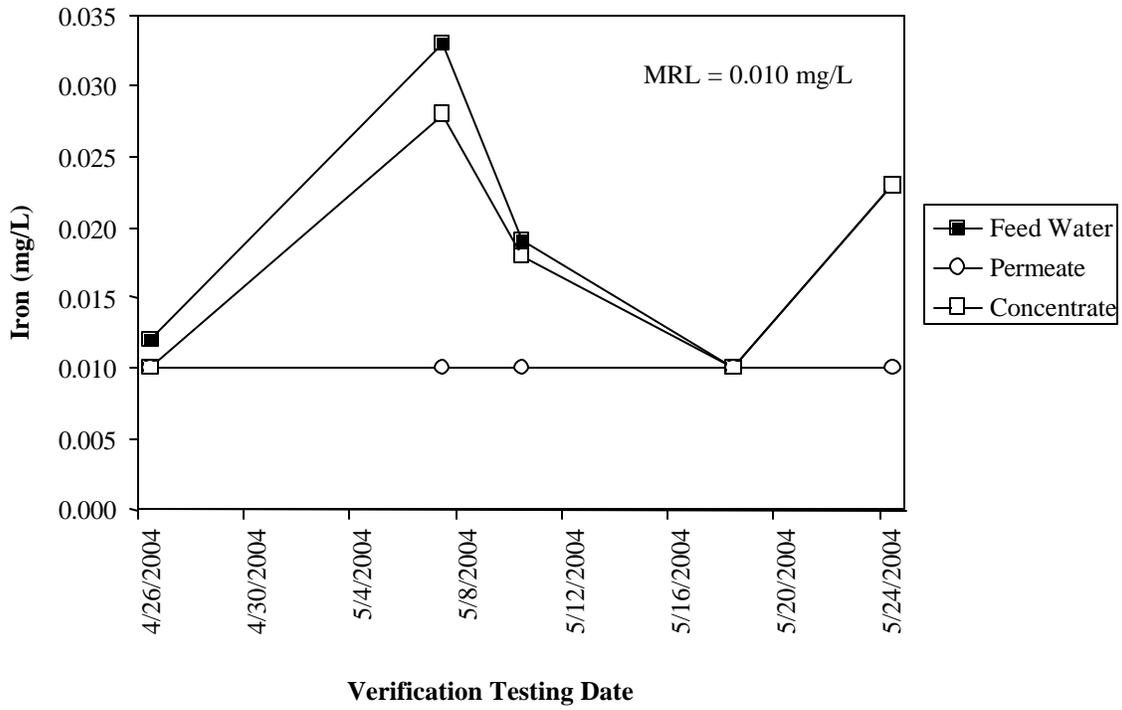
Figure 4-12: Temporal plot of iron.
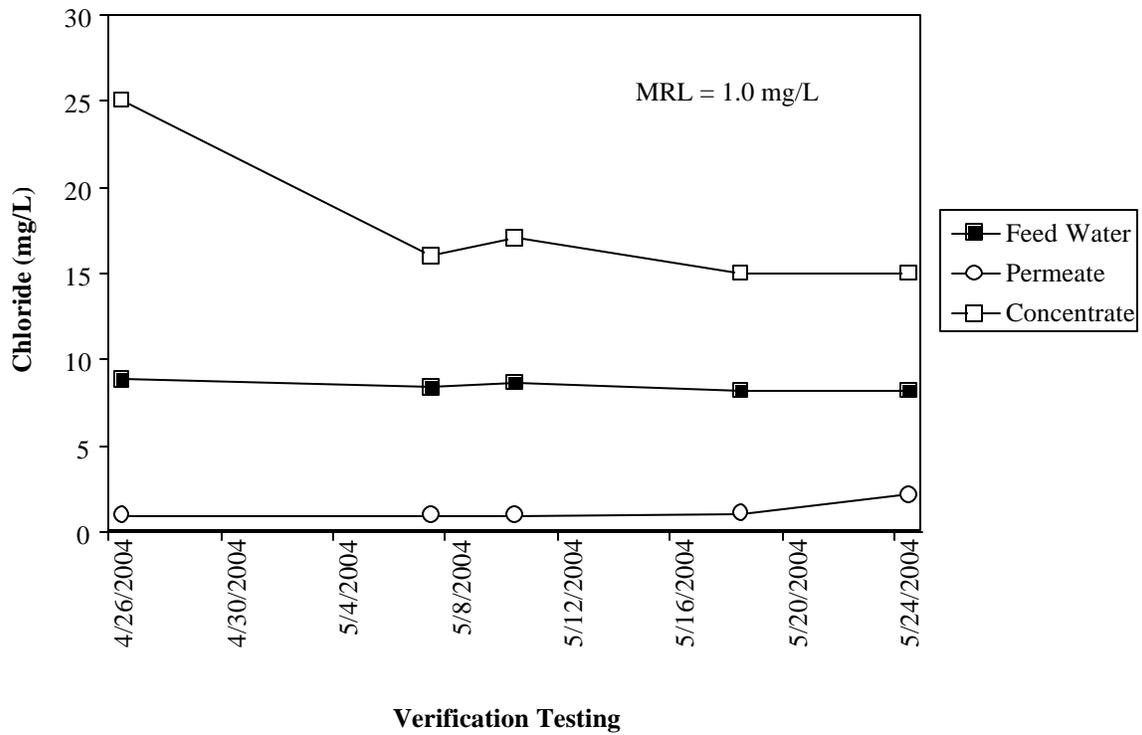
Figure 4-13: Temporal plot of chloride.
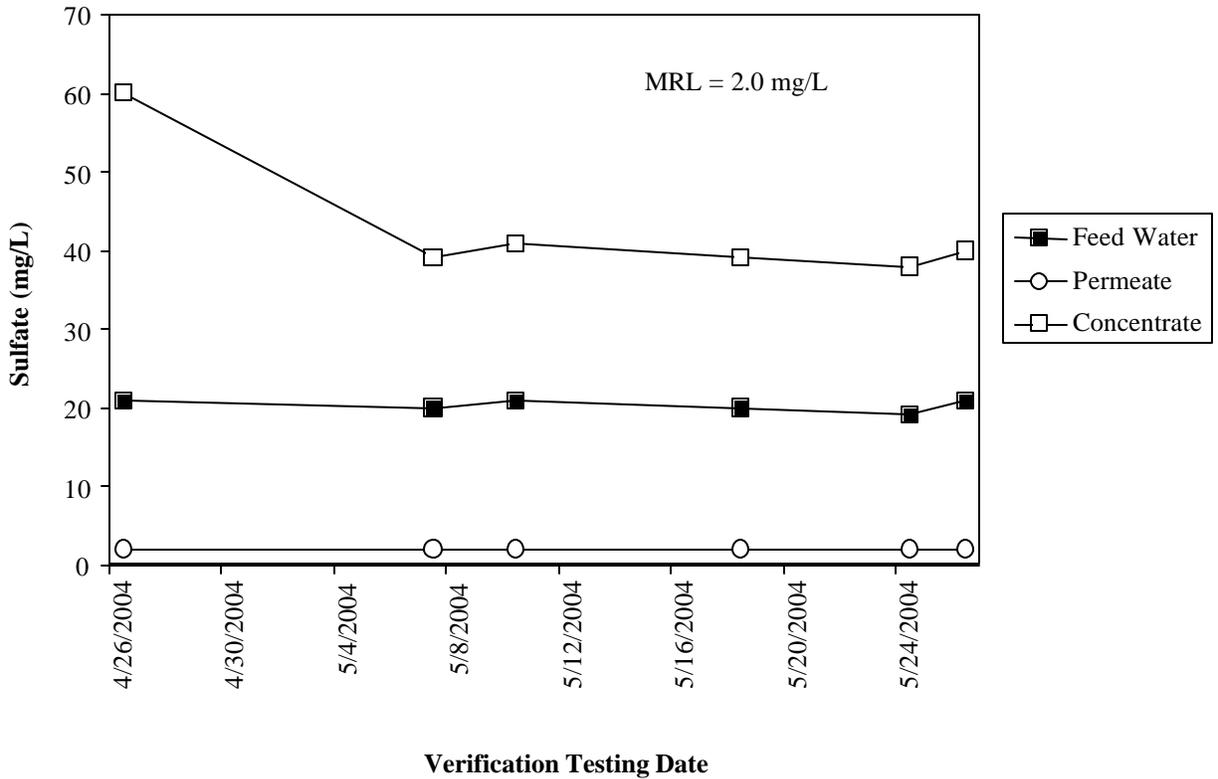
Figure 4-14: Temporal plot of sulfate.

4.4.2 Percent Removal of Organic Constituents

Samples for TOC were also collected on a weekly basis. The results of the sampling indicated that for this water source, the feed, concentrate and permeate had non-detectable levels of TOC, see Table 4-21.

Table 4-21: Percent Removal of Organic Constituents

	Total Organic Carbon (mg/L)			Percent
Date	Feed Water	Concentrate	Permeate	Removal
4/26/04	< 0.50	< 0.50	< 0.50	NA[1]
5/7/04	< 0.50	< 0.50	< 0.50	NA
5/10/04	< 0.50	< 0.50	< 0.50	NA
5/18/04	< 0.50	< 0.50	< 0.50	NA
5/24/04	< 0.50	< 0.50	< 0.50	NA
Average	< 0.50	< 0.50	< 0.50	NA
Minimum	< 0.50	< 0.50	< 0.50	NA
Maximum	< 0.50	< 0.50	< 0.50	NA
Number of Samples	5	5	5	5

[1] NA = Not applicable as all samples contained non-detectable levels of TOC.

4.4.2.1 Mass Balance for Total Arsenic

A mass balance through the M-15,000 RO Treatment System for total arsenic was conducted. The equation used for the mass balance was previously presented in Equation 3-10: $Q_fC_f = Q_pC_p + Q_{cw}C_{cw}$. In this equation, Q_fC_f represents the feed water flow rate multiplied by the feed water total arsenic concentration, Q_pC_p represents the permeate flow multiplied by the permeate total arsenic concentration, and lastly, $Q_{cw}C_{cw}$ represents the concentrate flow rate multiplied by the concentrate total arsenic concentration. The total arsenic mass balance was calculated for each day the M-15,000 RO Treatment System was in operation during the verification test. The data is graphically presented in Figure 4-15 and the corresponding data is provided in Table 4-22. Throughout most of the verification test, the total arsenic mass balance was very close, with the exception of April 29, 2004, and May 10, 2004, where the arsenic concentration in the concentrate stream was significantly higher (greater than the 95% confidence interval), at 84 μg/L and 38 μg/L respectively.
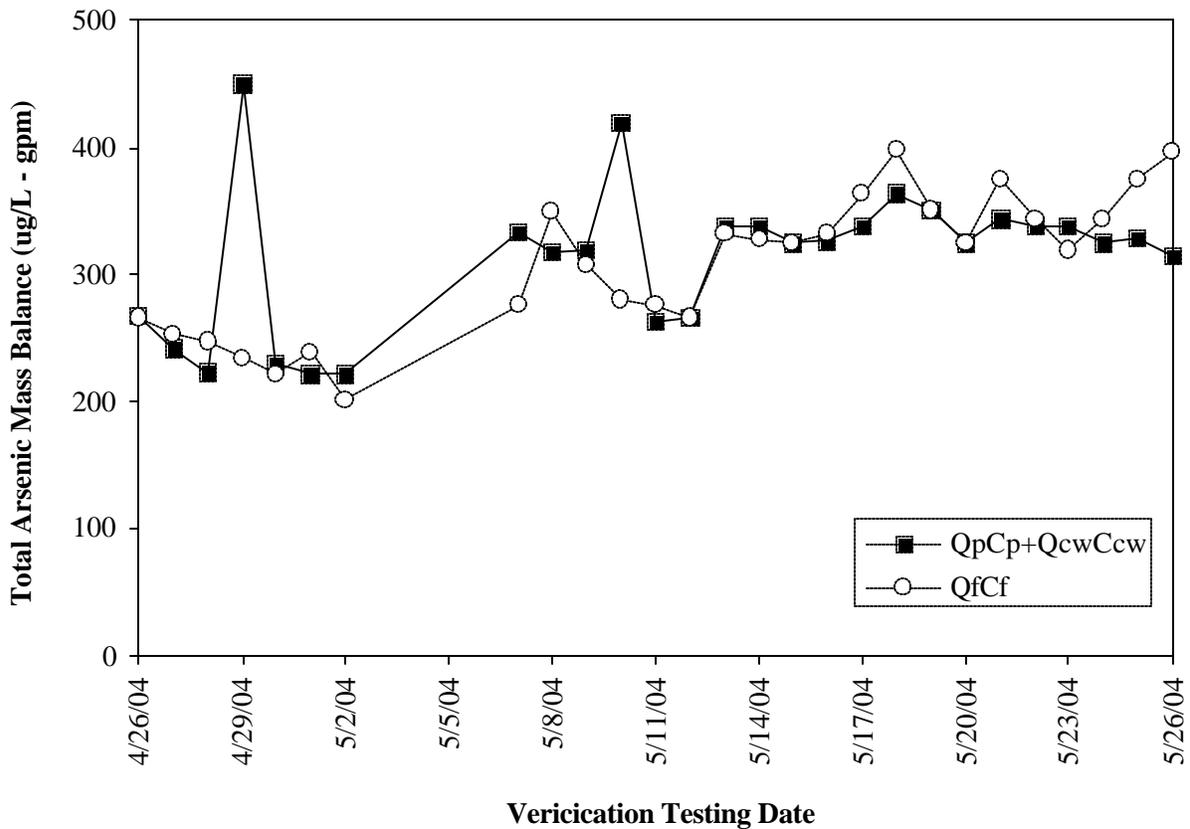
Figure 4-15: Daily total arsenic mass balance.

Table 4-22: Daily Total Arsenic Mass Balance

Date	Q_fC_f (gpm-μg/L)	$Q_pC_p + Q_{cw}C_{cw}$ (gpm-μg/L)
4/26/04	267	268
4/27/04	254	242
4/28/04	247	223
4/29/04	234	450
4/30/04	234	231
5/1/04	238	221
5/2/04	201	221
5/7/04	276	334
5/8/04	349	317
5/9/04	308	319
5/10/04	280	419
5/11/04	277	264
5/12/04	266	266
5/13/04	332	338
5/14/04	328	338
5/15/04	325	325
5/16/04	332	326
5/17/04	364	338
5/18/04	398	364
5/19/04	350	350
5/20/04	325	325
5/21/04	375	344
5/22/04	343	337
5/23/04	319	337
5/24/04	343	325
5/25/04	375	329
5/26/04	396	315
Average	309	313
Minimum	201	221
Maximum	398	450
Number of Samples	27	27
Standard Deviation	54	56
95% Confidence Interval	(284, 333)	(288, 339)

4.4.2.2 Limiting Salt Concentrations

The limiting salt concentrations were calculated using Equation 3.11 once per week and compared to standard Solubility Product values to determine if the salt concentrations were posing a limitation to operational system recovery, presented in Table 4-23. The salts that were evaluated were calcium carbonate ($CaCO_3$), barium sulfate ($BaSO_4$), and calcium sulfate ($CaSO_4$).

Barium Sulfate
As shown in Table 4-23, the solubility product of barium sulfate in the feed water, permeate, and concentrate was less than the theoretical solubility product, indicating that barium sulfate would remain in a soluble state.

Calcium Carbonate
Each of the calcium carbonate samples (feed water, permeate, and concentrate) samples had solubility products greater than the theoretical solubility product. Thus, it is expected that calcium carbonate would precipitate out of each of the three streams. This is a concern for the long-term operation of the membranes, as the precipitation of salts on the membranes could lead to fouling resulting in a decline in system performance.

Calcium Sulfate
Each of the calcium sulfate samples (feed water, permeate, and concentrate) samples had solubility products less than the theoretical solubility product. Thus, calcium sulfate would remain in solution for of each of the three streams.

Table 4-23: Solubility Products of Limiting Salt Concentrations

Theoretical Solubility Product	Feed Water	Permeate	Concentrate	Theoretical Solubility Product	Feed Water	Permeate	Concentrate
Barium Sulfate				**Calcium Carbonate**			
	5.8E-12	1.7E-13	4.7E-11		5.4E-08	1.7E-09	3.8E-07
	6.6E-12	1.7E-13	2.4E-11		6.0E-08	2.6E-09	1.8E-07
1.1E-10	7.6E-12	1.8E-13	2.4E-11	8.7E-9	5.8E-08	3.2E-09	1.9E-07
	5.5E-12	1.8E-13	2.1E-11		5.6E-08	4.1E-09	1.5E-07
	6.0E-12	1.7E-13	2.0E-11		5.6E-08	4.8E-09	1.6E-07
	6.7E-12	1.8E-13	2.3E-11		5.6E-08	1.9E-08	9.7E-08
Calcium Sulfate							
	1.6E-08	3.0E-10	1.2E-07				
	1.4E-08	3.0E-10	5.2E-08				
6.1E-5	1.5E-08	3.1E-10	5.7E-08				
	1.3E-08	3.0E-10	4.7E-08				
	1.3E-08	3.0E-10	4.7E-08				
	1.5E-08	3.0E-10	5.2E-08				

4.4.3   Removal of TSS

TSS was monitored on a weekly basis, as presented in Table 4-24. The source water for the verification testing was chlorinated groundwater, and not anticipated to have high-suspended solids. The feed water, concentrate, and permeate samples collected during the verification testing all had non-detectable levels of TSS, with a detection limit of 10 mg/L.

Table 4-24: Removal of Total Suspended Solids

Date	Total Suspended Solids (mg/L)			
	Feed Water	Concentrate	Permeate	Percent Removal
4/26/04	< 10	< 10	< 10	NA[1]
5/7/04	< 10	< 10	< 10	NA
5/10/04	< 10	< 10	< 10	NA
5/18/04	< 10	< 10	< 10	NA
5/24/04	< 10	< 10	< 10	NA
Average	< 10	< 10	< 10	NA
Minimum	< 10	< 10	< 10	NA
Maximum	< 10	< 10	< 10	NA
Number of Samples	5	5	5	5

[1] NA = Not applicable as all samples contained non-detectable levels of TOC.

4.4.4 SDI

SDI is the measurement of the quantity of suspended solids in a water supply that could potentially foul RO membranes. A 5-gallon sample of the feed water was collected on the last day of the verification testing. The SDI measurements were run in duplicate from this sample and found to be 3.12 and 3.10. The SDI results reveal relatively solids free water, which is consistent with the TSS analyses (all TSS samples were below the MDL of 10 mg/L). The filter volume for each test was 250 milliliter (mL) and Pall Acrodisk 25-mm syringe filters (0.45 µm diameter) were used for study. A blank SDI was run using de-ionized (DI) water, with a result of 2.57. The results of the SDI test and the method are available in Appendix E.

4.4.5 LSI

The LSI was calculated at the beginning of the verification testing (April 26, 2004) with the following equation: $LSI = pH - pH_s$, where pH is the measured pH of the water and pH_s is the pH at saturation (calcium carbonate).

$$pH_s = (9.3 + A + B) - (C + D).$$

where: $A = (Log_{10} [TDS] - 1) / 10$
  $B = -13.12 \times Log_{10} (°C + 273) + 34.55$
  $C = Log_{10} [Ca^{2+} \text{ as } CaCO_3] - 0.4$
  $D = Log_{10} [\text{alkalinity as } CaCO_3]$

The LSI is an indictor of how corrosive or scaling a water may be primarily based on the TDS, calcium, water temperature, and alkalinity. On April 26, 2004 the LSI of the feed water, permeate, and concentrate was calculated and the data is presented in Table 4-25. From the calculation, the feed water is at equilibrium, the permeate is slightly corrosive and the concentrate is in a slightly scaling state.

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Table 4-25: LSI Calculations (April 26, 2004)

	Feed water	Permeate	Concentrate
A	0.1176	0.0000	0.1568
B	2.0218	2.0218	2.0218
C	0.3076	-0.4000	0.7139
D	1.8692	1.0792	2.3139
pH	9.26	9.43	9.04
pH_s	9.26	10.64	8.45
LSI	0.00	-1.21	0.59

4.5 Task 4: 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 the FTO and NSF during verification testing. Prior to the beginning of field testing, the database or spreadsheet design was developed by the FTO and reviewed and approved by NSF. This ensured that the required data was collected during the testing, and that results could be effectively transmitted to NSF for review. The FTO followed all data handling procedures that were presented in Chapter 3. Additional details on data handling were previously discussed in Section 3.11.

4.6 Task 5: Quality Assurance/Quality Control Results

An important aspect of verification testing is the Quality Assurance Project Plan (QAPP) developed for QA/QC, as described in Section 3.12. The objective of this task was to assure accurate measurement of operational and water quality parameters during membrane equipment verification testing.   The primary areas of evaluation were precision, accuracy, statistical uncertainty, and completeness. Statistical uncertainty was discussed in Section 3.12.4.2 and presented in tables containing eight or more data sets, presented in Chapter 4 as the 95% confidence interval.

Each day the tubing, fittings, and general condition of the M-15,000 RO Treatment System were inspected to verify that there were no leaks or needed repairs. There were no leaks to report from tubing, however daily inspection of the membrane housings revealed intermittent leaks, which alternated between each of the six housings, as noted in the field logbook.

4.6.1 Precision

Precision refers to the degree of mutual agreement among individual measurements, and was discussed in Section 3.12.5 and 3.12.6. The percent acceptable precision among duplicate samples was previously presented in Table 3-7 and the calculated precision for each analytical parameter is presented in the following tables. The precision calculations of the weekly off-site duplicate analyses are presented in Table 4-26 and the weekly on-site duplicate analyses are presented in Table 4-27. Note that only the feed water and permeate samples were taken in duplicate for the on-site duplicate analysis of chlorine (free and total) and that only the feed water was taken in duplicate for temperature (twice weekly). All analyses presented in Tables 4-

26 and 4-27 were within the acceptable precision percentage, with the exception of one free chlorine sample collected on May 19, 2004 (47% precision), which had very low levels of chlorine (0.02 and 0.01 mg/L in the sample and duplicate, respectively), and eight of the twenty-seven pH duplicate samples. Analytical precision was calculated for pH based on duplicate samples that were collected seven times per week. The pH values were converted to hydrogen ion concentrations and the percent precision was calculated from the hydrogen ion concentration. For the data presented in Table 4-27, the hydrogen ion concentration was calculated as:

$$pH = - \log [\text{Hydrogen ion concentration}]$$

TDS duplicates were collected four times per week and the data is presented in Table 4-28. All TDS duplicate analyses were within the acceptable precision percentage of 30%. Conductivity duplicates were collected eight times per week and the data is presented in Table 4-29. Total arsenic duplicates were collected daily, with the results of the duplicate precision analysis presented in Table 4-30. The percent precision values for all the conductivity and total arsenic data sets were within the acceptable limits. An SDI measurement was required once during the verification testing period. The water for this analysis was collected in duplicate on May 26, 2004, with a percent precision of 0.6%.

Precision checks performed by the MWH Laboratory were within the acceptable limits outlined in Table 3-8, except for some TDS samples, as indicated in Table 4-14.

Table 4-26: Weekly Off-Site Analytical Precision

	Barium (mg/L)				Manganese (mg/L)			
Date	Sample Location	Sample	Duplicate	Percent Precision	Sample Location	Sample	Duplicate	Percent Precision
4/26/04	permeate	< 2.0	< 2.0	0.0%	permeate	< 2.0	< 2.0	0.0%
5/7/04	concentrate	14	14	0.0%	concentrate	< 2.0	< 2.0	0.0%
5/10/04	feed water	8.1	7.4	6.0%	feed water	< 2.0	< 2.0	0.0%
5/18/04	permeate	< 2.0	< 2.0	0.0%	permeate	< 2.0	< 2.0	0.0%
5/24/04	concentrate	12	12	0.0%	concentrate	< 2.0	< 2.0	0.0%
		Acceptable Precision		30%		Acceptable Precision		30%
	Calcium (mg/L)				Fluoride (mg/L)			
4/26/04	permeate	< 1.0	< 1.0	0.0%	permeate	< 0.050	< 0.050	0.0%
5/7/04	concentrate	9.1	9.1	0.0%	concentrate	1.4	1.4	0.0%
5/10/04	feed water	4.8	4.8	0.0%	feed water	0.80	0.8	0.0%
5/18/04	permeate	< 1.0	< 1.0	0.0%	permeate	0.16	0.16	0.0%
5/24/04	concentrate	8.4	8.5	1.0%	concentrate	1.2	1.2	0.0%
		Acceptable Precision		30%		Acceptable Precision		20%
	Chloride (mg/L)				Chromium (mg/L)			
4/26/04	permeate	< 1.0	< 1.0	0.0%	permeate	< 1.0	< 1.0	0.0%
5/7/04	concentrate	16	17	4.0%	concentrate	23	22	3.0%
5/10/04	feed water	8.7	8.7	0.0%	feed water	13	13	0.0%
5/18/04	permeate	1.1	1.1	0.0%	permeate	< 1.0	< 1.0	0.0%
5/24/04	concentrate	15	15	0.0%	concentrate	23	23	0.0%
		Acceptable Precision		20%		Acceptable Precision		30%
	Sulfate (mg/L)				Vanadium (mg/L)			
4/26/04	permeate	< 2.0	< 2.0	0.0%	permeate	< 3.0	< 3.0	0.0%
5/7/04	concentrate	39	39	0.0%	concentrate	80	80	0.0%
5/10/04	feed water	21	21	0.0%	feed water	51	45	9.0%
5/18/04	permeate	< 2.0	< 2.0	0.0%	permeate	< 3.0	< 3.0	0.0%
5/24/04	concentrate	38	38	0.0%	concentrate	88	87	1.0%
		Acceptable Precision		20%		Acceptable Precision		30%
	Iron (mg/L)				Silica (mg/L)			
4/26/04	permeate	< 0.010	< 0.010	0.0%	permeate	1.2	1.2	0.0%
5/7/04	concentrate	0.028	0.042	28%	concentrate	24	24	0.0%
5/10/04	feed water	0.019	0.019	0.0%	feed water	17	15	9.0%
5/18/04	permeate	< 0.010	< 0.010	0.0%	permeate	8.4	8.4	0.0%
5/24/04	concentrate	0.023	0.022	3.0%	concentrate	17	17	0.0%
		Acceptable Precision		30%		Acceptable Precision		30%
	TOC (mg/)				TSS (mg/L)			
4/26/04	permeate	< 0.50	< 0.50	0.0%	permeate	< 10	< 10	0.0%
5/7/04	concentrate	< 0.50	< 0.50	0.0%	concentrate	< 10	< 10	0.0%
5/10/04	feed water	< 0.50	< 0.50	0.0%	feed water	< 10	< 10	0.0%
5/18/04	permeate	< 0.50	< 0.50	0.0%	permeate	< 10	< 10	0.0%
5/24/04	concentrate	< 0.50	< 0.50	0.0%	concentrate	< 10	< 10	0.0%
		Acceptable Precision		30%		Acceptable Precision		30%

Table 4-27: On-Site Analytical Precision

	Hardness (mg/L)				Alkalinity (mg/L)			
Date	Sample Location	Sample	Duplicate	Percent Precision	Sample Location	Sample	Duplicate	Percent Precision
4/26/04	permeate	0	0	0.0%	permeate	12	12	0.0%
5/7/04	concentrate	44	42	3.0%	concentrate	140	138	1.0%
5/10/04	feed water	20	22	7.0%	feed water	82	84	2.0%
5/18/04	permeate	0	0	0.0%	permeate	28	30	5.0%
5/24/04	concentrate	18	20	7.0%	concentrate	136	134	1.0%
		Acceptable Precision		30%		Acceptable Precision		30%
	Free Chlorine (mg/L)				Total Chlorine (mg/L)			
4/26/2004	permeate	0.27	0.28	2.6%	permeate	0.27	0.28	2.6%
4/28/2004	feed water	0.98	0.97	0.7%	feed water	0.98	0.98	0.0%
4/30/2004	feed water	0.45	0.46	1.6%	feed water	0.52	0.50	2.8%
5/2/2004	permeate	0.13	0.14	5.2%	permeate	0.14	0.15	4.9%
5/7/2004	feed water	0.45	0.45	0.0%	feed water	0.43	0.46	4.8%
5/9/2004	permeate	0.12	0.16	20%	permeate	0.18	0.20	7.4%
5/10/2004	feed water	0.54	0.50	5.4%	feed water	0.55	0.52	4.0%
5/12/2004	permeate	0.35	0.29	13%	permeate	0.36	0.30	13%
5/14/2004	permeate	0.52	0.51	1.4%	permeate	0.48	0.51	4.3%
5/18/2004	permeate	0.30	0.39	18%	permeate	0.31	0.40	18%
5/19/2004	feed water	0.02	0.01	47%	feed water	0.04	0.04	0.0%
5/21/2004	feed water	0.43	0.44	1.6%	feed water	0.44	0.44	0.0%
5/24/2004	feed water	0.21	0.20	3.4%	feed water	0.22	0.19	10%
5/26/2004	permeate	0.33	0.33	0.0%	permeate	0.34	0.33	2.1%
		Acceptable Precision		30%		Acceptable Precision		30%
	Temperature (°C)[1]				Turbidity (NTU)			
4/26/04	feed water	29.0	29.0	0.0%	permeate	0.17	0.16	4.0%
4/30/04	feed water	27.5	27.5	0.0%				
5/7/04	feed water	27.5	27.5	0.0%	concentrate	0.52	0.54	3.0%
5/10/04	feed water	27.0	27.0	0.0%	feed water	0.51	0.52	1.0%
5/14/04	feed water	28.5	28.5	0.0%				
5/18/04	feed water	27.0	27.0	0.0%	permeate	0.19	0.20	4.0%
5/21/04	feed water	28.0	28.0	0.0%				
5/24/04	feed water	27.0	27.0	0.0%	concentrate	0.25	0.24	3.0%
		Acceptable Precision		10%		Acceptable Precision		30%

Table 4-27: On-Site Analytical Precision (continued)

Date	Sample Location	pH Sample	Duplicate	Percent Precision
4/26/04	permeate	9.43	9.44	2%
4/27/04	concentrate	8.95	9.01	14% [2]
4/28/04	feed water	9.06	9.12	14% [2]
4/29/04	permeate	9.30	9.26	9%
4/30/04	concentrate	9.03	9.04	2%
5/1/04	feed water	9.13	9.19	14% [2]
5/2/04	permeate	9.49	9.44	12% [2]
5/7/04	concentrate	9.00	9.07	16% [2]
5/8/04	feed water	9.21	9.19	5%
5/9/04	permeate	9.56	9.58	5%
5/10/04	feed water	9.08	9.10	5%
5/11/04	permeate	9.65	9.60	12% [2]
5/12/04	concentrate	9.10	9.11	2%
5/13/04	feed water	9.10	9.00	23% [2]
5/14/04	permeate	9.50	9.52	5%
5/15/04	concentrate	9.12	9.11	2%
5/16/04	feed water	9.20	9.20	0%
5/17/04	concentrate	9.14	9.12	5%
5/18/04	permeate	9.49	9.52	7%
5/19/04	feed water	9.24	9.24	0%
5/20/04	permeate	9.57	9.52	12% [2]
5/21/04	concentrate	9.16	9.15	2%
5/22/04	feed water	9.21	9.21	0%
5/23/04	permeate	9.51	9.51	0%
5/24/04	concentrate	9.12	9.12	0%
5/25/04	feed water	9.22	9.20	5%
5/26/04	permeate	9.41	9.42	2%
		Acceptable Precision		10%

[1] Temperature duplicates were taken twice weekly and only on the feed water.
[2] Exceeded the precision limit of 10%, as defined in Table 3-7.

Table 4-28: TDS Analytical Precision

Date	Sample Location	Sample TDS (mg/L)	Duplicate TDS (mg/L)	Percent Precision
4/26/04	permeate	<10	<10	0%
4/28/04	feed water	150	140	5%
4/30/04	concentrate	270	260	3%
5/2/04	permeate	12	13	6%
5/7/04	concentrate	240	250	3%
5/9/04	permeate	<10	14	24%
5/10/04	feed water	130	130	0%
5/12/04	concentrate	260	250	3%
5/14/04	permeate	16	12	20%
5/16/04	feed water	140	140	0%
5/18/04	permeate	24	25	3%
5/19/04	feed water	140	130	5%
5/20/04	permeate	25	26	3%
5/21/04	concentrate	230	230	0%
5/23/04	permeate	45	37	14%
5/24/04	concentrate	230	230	0%
5/26/04	permeate	34	34	0%
			Acceptable Precision	30%

Table 4-29: Daily Conductivity Precision Analysis

Date	Sample Location	Sample Conductivity (umoh/cm)	Duplicate Conductivity (umoh/cm)	Percent Precision
4/26/04	permeate	6.7	6.7	0.00%
4/27/04	concentrate	554	556	0.25%
4/28/04	feed water	232	230	0.61%
4/29/04	permeate	11.3	11.5	1.24%
4/30/04	concentrate	412	431	3.19%
5/1/04	feed water	245	247	0.57%
5/2/04	permeate	11.1	12.2	6.68%
5/2/04	permeate	11.1	12.1	6.10%
5/7/04	concentrate	426	425	0.17%
5/8/04	feed water	245	244	0.29%
5/9/04	permeate	16.2	16.4	0.87%
5/10/04	feed water	237	235	0.60%
5/11/04	permeate	22.8	22.7	0.31%
5/12/04	concentrate	437	436	0.16%
5/13/04	concentrate[1]	417	438	3.47%
5/14/04	permeate	25.8	25.8	0.00%
5/15/04	concentrate	420	421	0.17%
5/16/04	feed water	241	240	0.29%
5/16/04	feed water	241	241	0.00%
5/17/04	concentrate	398	406	1.41%
5/18/04	permeate	39.2	39.6	0.72%
5/19/04	feed water	234	234	0.00%
5/20/04	permeate	41.3	41.4	0.17%
5/21/04	concentrate	378	380	0.37%
5/22/04	feed water	228	229	0.31%
5/23/04	permeate	58.3	58.2	0.12%
5/23/04	permeate	58.3	58.4	0.12%
5/24/04	concentrate	368	369	0.19%
5/25/04	feed water	230	230	0.00%
5/26/04	permeate	76.5	76.6	0.09%
5/26/04	permeate	76.5	76.8	0.28%
			Acceptable Precision	10%

[1] The duplicate conductivity value was taken on the concentrate water and not the feed water, as indicated in the logbook.

Table 4-30: Daily Total Arsenic Precision Analysis

Date	Sample Location	Sample Arsenic (µg/L)	Duplicate Arsenic (µg/L)	Precision
4/26/04	permeate	< 1.0	< 1.0	0%
4/27/04	concentrate	38	36	4%
4/28/04	feed water	13	12	6%
4/29/04	permeate	< 1.0	< 1.0	0%
4/30/04	concentrate	26	26	0%
5/1/04	feed water	14	14	0%
5/2/04	permeate	< 1.0	< 1.0	0%
5/7/04	concentrate	28	27	3%
5/8/04	feed water	15	14	5%
5/9/04	permeate	< 1.0	< 1.0	0%
5/10/04	feed water	13	13	0%
5/11/04	permeate	< 1.0	< 1.0	0%
5/12/04	concentrate	27	26	3%
5/13/04	feed water	13	14	5%
5/14/04	permeate	< 1.0	< 1.0	0%
5/15/04	concentrate	25	24	3%
5/16/04	feed water	13	13	0%
5/17/04	concentrate	25	26	3%
5/18/04	permeate	< 1.0	< 1.0	0%
5/19/04	feed water	14	14	0%
5/20/04	permeate	< 1.0	< 1.0	0%
5/21/04	concentrate	26	24	6%
5/22/04	feed water	14	14	0%
5/23/04	permeate	< 1.0	< 1.0	0%
5/24/04	concentrate	25	24	3%
5/25/04	feed water	15	15	0%
5/26/04	permeate	1.2	< 1.0	0%
			Acceptable Precision	30%

4.6.2 Accuracy

Arsenic Speciation and Analysis

Total arsenic samples were collected daily according to EPA Method 200.8. Additional arsenic samples were collected weekly for As^{3+} and dissolved arsenic. The field speciation columns were provided by NSF. QA/QC evaluations of the speciation columns using known concentrations of As^{3+} and As^{5+} were conducted by the NSF laboratory prior to the verification test.

One concentrate sample (collected May 24, 2004) indicated higher As^{3+} than total arsenic. While it is not reasonable for a single species of arsenic to have a higher concentration than the total, it is further perplexing to measure a detectable concentration of As^{3+} as this water source is chlorinated. There is currently no explanation for these results. Furthermore, 10% of the samples showed slightly higher dissolved arsenic concentrations than total arsenic. However, these samples were just slightly higher than the total arsenic and primarily found in the concentrate samples. On April 26, 2004 the dissolved arsenic concentration in the concentrate was 16 µg/L, with a total arsenic of 13 µg/L, and on May 7 the dissolved arsenic concentration in the concentrate was 14 µg/L, with a total arsenic of 12 µg/L. On May 24, 2004, the dissolved

arsenic of 1.1 µg/L with a total arsenic of <1.0 µg/L. Accuracy checks for arsenic samples performed by the MWH Laboratory were within the acceptable limits outlined in Table 3-8.

Other Laboratory Parameters
Accuracy checks performed by the MWH Laboratory for all samples analyzed by the laboratory were within the acceptable limits outlined in Table 3-8.

pH Meter
The pH meter was calibrated daily using certified pH solutions (4.0, 7.0 and 10.0) from Hach. Analyses were made daily according to *Standard Method* 4500-H$^+$B.

Temperature
Table 3-7 indicates that temperature was to be verified weekly against a NIST-certified thermometer. Since the feed water temperature was measured twice daily using a NIST-certified thermometer, no accuracy checks were necessary.

Alkalinity
Two sets of four known samples were analyzed during the verification test to verify the accuracy of the onsite test method. The accuracy checks are discussed in additional detail in Section 4.6.3 with corresponding data provided in Table 4-32, with all results being within the acceptable accuracy range of ± 30% recovery.

Hardness
Two sets of four known samples were analyzed during the verification test to verify the accuracy of the onsite test method. The accuracy checks are discussed in additional detail in Section 4.6.3 with corresponding data provided in Table 4-32, with all results being within the acceptable accuracy range of ± 30% recovery.

Turbidity Instrumentation
The turbidity meter was calibrated each day the instrument was in use. Calibrations were made using both primary and secondary standards provided by Hach. Each calibration was also checked against standards in the anticipated turbidity range of the samples (0.1, 0.5 and 5 NTU).

Conductivity Meter
The handheld conductivity meter was used according to *Standard Method* 2510 B. A three-point calibration with certified conductivity solutions (184, 1000, and 1990 umoh/cm) was made each day the meter was in use.

Chlorine Meter
The chlorine meter was checked for accuracy through the use of known spike samples provided by Hach with the Hach 8167 method for total chlorine and Hach 8021 method for free chlorine, at a frequency of three times during the verification testing. The accuracy of the free and total chlorine spikes is discussed in additional detail in Section 4.6.3 with corresponding data provided in Table 4-32, with all results being within the acceptable accuracy range of ± 30% recovery.

<u>Flow Monitoring</u>
The M-15,000 RO Treatment System was equipped with panel mounted flow meters to read the permeate and concentrate flow rates and were checked daily using the "calibrated container and stopwatch" method. The flow meters appeared to be accurate according to this method of calibration, with an average accuracy of 98% for both the concentrate and permeate flow rates. The flow meters were not designed to allow adjustment or calibration, so the differences (when present) were recorded, however, no adjustments could be made to "calibrate" the flow meters. Table 4-31 presents the results of the daily permeate and concentrate flow rate checks and the percent accuracy of the panel mounted flow meters.

<u>Pressure Gauges</u>
Watts Premier indicated that the pressure gauges installed were factory-calibrated; no additional accuracy checks were performed.

Table 4-31: Daily Permeate and Concentrate Flow Rate Checks (Calibration)

Date	Known Permeate Flow Rate (gpm)[1]	Measured Permeate Flow Rate (gpm)	% Accuracy of Panel Mounted Permeate Flow Meter	Known Concentrate Flow Rate (gpm)	Measured Concentrate Flow Rate (gpm)	% Accuracy of Panel Mounted Concentrate Flow Meter
4/26/04	14.00	14.00	100%	6.50	6.50	100%
4/27/04	13.50	13.50	100%	6.00	6.00	100%
4/28/04	13.00	12.50	96%	6.00	6.00	100%
4/29/04	12.80	12.50	98%	5.20	5.25	99%
4/30/04	9.50	9.00	95%	8.50	8.50	100%
5/1/04	8.50	8.50	100%	8.50	8.50	100%
5/2/04	8.25	8.25	100%	8.50	8.25	97%
5/7/04	11.50	10.25	89%	11.50	10.25	89%
5/8/04	11.50	11.50	100%	11.75	11.75	100%
5/9/04	11.00	11.00	100%	11.00	11.00	100%
5/10/04	10.75	10.50	98%	10.75	10.75	100%
5/11/04	10.00	10.00	100%	9.75	9.50	97%
5/12/04	9.50	9.50	100%	9.50	9.50	100%
5/13/04	13.00	9.25	71%	12.50	8.50	68%
5/14/04	12.75	12.50	98%	12.50	12.50	100%
5/15/04	12.50	12.50	100%	12.50	12.50	100%
5/16/04	13.00	13.00	100%	12.50	12.50	100%
5/17/04	13.00	13.00	100%	13.00	13.00	100%
5/18/04	13.00	13.00	100%	13.50	13.00	96%
5/19/04	12.50	12.50	100%	12.50	12.50	100%
5/20/04	12.50	12.50	100%	12.50	12.50	100%
5/21/04	12.25	12.50	98%	12.75	12.50	98%
5/22/04	12.00	12.00	100%	12.50	12.50	100%
5/23/04	12.00	12.00	100%	12.50	12.50	100%
5/24/04	12.00	12.00	100%	12.50	12.50	100%
5/25/04	12.00	12.00	100%	13.00	13.00	100%
5/26/04	12.25	12.50	98%	12.50	12.50	100%
		Average	98%		Average	98%
		Minimum	71%		Minimum	68%
		Maximum	100%		Maximum	100%

Table 4-32: Spike Data for Free and Total Chlorine, Hardness, and Alkalinity

Date	Free Chlorine Spike (mg/L)	Value (mg/L)	Accuracy	Total Chlorine Spike (mg/L)	Value (mg/L)	Accuracy
5/2/04	0	0	0.0%	0	0.02	0.0%
	0.25	0.25	0.0%	0.25	0.23	8.0%
	0.50	0.49	2.0%	0.50	0.45	10.0%
	0.75	0.74	1.3%	0.75	0.72	4.0%
6/16/04	0	0	0.0%	0	0	0.0%
	0.25	0.25	0.0%	0.25	0.24	4.0%
	0.50	0.50	0.0%	0.50	0.50	0.0%
	0.75	0.75	0.0%	0.75	0.75	0.0%
5/24/04	0	0	0.0%	0	0	0.0%
	0.25	0.25	0.0%	0.25	0.24	4.0%
	0.50	0.49	2.0%	0.50	0.49	2.0%
	0.75	0.74	1.3%	0.75	0.73	2.7%
	Acceptable Accuracy		30%	Acceptable Accuracy		30%

Date	Hardness Spike (mg/L)	Value (mg/L)	Accuracy	Alkalinity Spike (mg/L)	Value (mg/L)	Accuracy
5/2/04	0	0	0.0%	0	0	0.0%
	1.0	1.0	0.0%	3.0	3.0	0.0%
	2.0	2.0	0.0%	5.5	5.5	0.0%
	3.0	3.0	0.0%	7.0	8.0	13%
5/16/04	0	0	0.0%	0	0.0	0.0%
	1.0	1.1	9.1%	3.0	2.5	17%
	2.0	2.1	4.8%	5.5	5.0	9.1%
	3.0	3.2	6.3%	7.0	7.4	5.4%
	Acceptable Accuracy		30%	Acceptable Accuracy		30%

4.6.3 Off-Site Analysis of Samples

4.6.3.1 Inorganic Samples

Inorganic samples were collected in accordance with the *Standard Methods* and EPA methods listed in Table 3-6. All samples were stored in a refrigerator, held at 4°C until shipment to the off-site analytical lab (MWH Laboratories). Samples were shipped with chain-of-custody in coolers packed with blue ice. All samples were analyzed within the required holding times.

4.6.3.2 Organic Samples

TOC was sampled six times throughout the verification testing. All samples were collected in amber glass bottles, stored at 4°C, and shipped in coolers packed with blue ice. All samples were analyzed according to *Standard Method* 5310C within the required holding times. All results were below the MDL of 0.50 mg/L. All spikes, duplicates, and precision analyses were within the required testing parameters, as presented in Table 3-8.

4.6.4 Completeness

Calculation of data completeness was made for on-site water quality measurements and MWH Laboratory water quality measurements, as explained in Section 3.12.4.4. During the verification test, duplicate samples were collected in a rotating manner (i.e., duplicates were taken of the feed water during one round of duplicate analysis, then permeate samples, and finally concentrate samples). Based on the completeness goals defined in Table 3-11 and the completeness results in Table 4-33, all parameters were within the stated completeness goals.

Table 4-33: Completeness

Parameter	Proposed[1] Results	Duplicates	Actual Results	Duplicates	Completeness (%) Results	Duplicates	Completeness Goal[2] Results	Duplicates
Arsenic (Total)	81	27	81	27	100%	100%	95%	90%
Arsenic (Speciated)	15	NA	15	NA	100%	NA	90%	NA
pH	81	27	81	27	100%	100%	95%	90%
Silica	15	5	15	5	100%	100%	90%	80%
Fluoride	15	5	15	5	100%	100%	90%	80%
Chromium	15	5	15	5	100%	100%	90%	80%
Vanadium	15	5	15	5	100%	100%	90%	80%
TOC	15	5	15	5	100%	100%	90%	80%
Chloride	15	5	15	5	100%	100%	90%	80%
Iron	15	5	15	5	100%	100%	90%	80%
Manganese	15	5	15	5	100%	100%	90%	80%
Sulfate	15	5	15	5	100%	100%	90%	80%
Temperature	54	10	54	8	100%	80%	95%	80%
Alkalinity	15	5	15	5	100%	100%	90%	80%
Hardness	15	5	15	5	100%	100%	90%	80%
Turbidity	15	5	15	5	100%	100%	90%	80%
Conductivity	162	33	162	31	100%	94%	95%	90%
Barium	15	5	15	5	100%	100%	90%	80%
Calcium	15	5	15	5	100%	100%	90%	80%
TSS	15	5	15	5	100%	100%	90%	80%
SDI	1	1	1	1	100%	100%	80%	80%
TDS	81	17	81	17	100%	100%	95%	90%
Free Chlorine	36	9	36	17	100%	>100%	90%	90%
Total Chlorine	36	9	36	17	100%	>100%	90%	90%

[1] Based on 27 days of testing.
[2] Based on completeness guidelines outlined in Table 3-11.

4.6.5 NSF Field Inspection

On May 13, 2004, NSF conducted a field inspection of the verification test and found the practices in place on-site to be in accordance with the PSTP that was approved prior to beginning the testing.

Chapter 5
References

The following references were used in the preparation of this report:

Methods for Chemical Analysis of Water and Wastes (MCAWW) EPA/600/4-79-202 - Revised March 1983.

Methods for Determination of Organic Compounds in Drinking Water - EPA/600/4-88/039-December 1988 (Revised July 1991).

Standard Methods for the Examination of Water and Wastewater. 1999. 20th edition. APHA, AWWA, and WEF, Washington D.C.

U.S. EPA/NSF International. *EPA/NSF ETV Protocol for Equipment Verification Testing for Arsenic Removal*, September 2003.

U.S. EPA/NSF International. *EPA/NSF ETV Protocol for Equipment Verification Testing for Removal of Inorganic Constituents*, April 2002.

Chapter 6
Vendor Comments

Watts Premier submitted the following comments concerning the ETV test and report. These statements were not validated in the verification test and are the opinion of Watts Premier:

"*4.2.1 General Operational Performance*

Just prior to the commencement of the ETV project and installation of the M-15,000 RO system it was discovered that the water entering the reverse osmosis unit would be chlorinated. At this time based upon the water parameters that were provided, and given the consideration that this would be a one month duration test, a 4" x 20" carbon filter was used as pre-filtration for the RO unit. It was agreed that under these conditions this testing would certainly provide a "worst case" arsenic reduction test protocol for the M-15,000 RO unit.

Seven days in to the arsenic reduction testing of the RO unit, the motor on the M-15,000 seized. It was discovered during the replacement of the pump that the pre filter to the M-15,000 unit was completely plugged. Upon further investigation by MWH field staff, it was discovered that the periodic operation of the CVWD Well 7802 introduced a significant slug of solids with each start-up, which then plugged the carbon pre-filter. With the plugging of the carbon prefilter, the pump seized due to loss of water to the motor.

Once the pump was replaced and the pre filtration switched to a 20 micron sediment filter, RO system operation stabilized.

Due to the tight time line and the relatively short duration of the test, Watts Premier suggested the use of a sediment pre filter to the RO unit. With only a few weeks remaining in the project testing phase, this chlorine contact on the RO membrane would represent an even further "worst-case" evaluation of reduction capabilities. This would provide valuable information to Watts Premier and the industry in regards to the operation of the M-15,000 RO unit.

Looking at several parameters with in this report, including feed water flow rate decreasing, flux reduction, increase in permeate conductivity it is evident that the chlorine did in fact have a negative effect on the overall reduction capabilities of the membranes. Permanent installation and operation of the M-15,000 unit would include a thorough review of the water system operation, which would have revealed the solids that CVWD Well 7802 introduced in to the system. Based upon this information, and the presence of chlorine, permanent installation of an M-15,000 would include proper filtration prior to the M series reverse osmosis unit to remove the chlorine and sufficient sediment filtration capabilities to efficiently handle the frequent slug of solids that the CVWD Well 7802 discharged to the water treatment system.

4.3 Task 2: Cleaning Efficiency

M series of RO units are available for systems that feed both in to a pressure tank, as well as a float tank apparatus. Each system is designed to go through a self initiated rinse cycle of the RO membranes. This rinse cycle occurs at either the unit shut down for units operating on short duty

cycles or on timed periodic schedule for those systems operating on extended duty cycles. This cleaning cycle is used in order to remove solids and other salts from the membrane, therefore prolonging the life of each membrane module. During normal operation where water is being discharged to a permanent tank, this flushing procedure would commence each time the tank is filled, and the M-15,000 system goes in to standby mode. During this ETV test, the M-15,000 unit was on continuously for the duration of the testing. Based upon this quantity of water being treated, this flushing cycle would have occurred more frequently under normal operation procedures than what was conducted during this evaluation.

Based upon the results obtained through this ETV testing protocol, the M series of commercial reverse osmosis systems has proven to be a viable means of processing water for the intent of domestic or industrial use.

Watts Premier would like to thank the hard work of all participants from MWH and NSF in completing this ETV project. All of their hard work on this project has been greatly appreciated."