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Environmental Technology Verification Report

Removal of Chemical Contaminants in Drinking Water

Watts Premier Incorporated WP-4V Drinking Water Treatment System

Prepared by



NSF International

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

ET ✓ ET ✓ ET ✓

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM



U.S. Environmental Protection Agency



NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	POINT-OF-USE DRINKING WATER TREATMENT SYSTEM
APPLICATION:	REMOVAL OF CHEMICAL CONTAMINANTS IN DRINKING WATER
PRODUCT NAME:	WATTS PREMIER WP-4V
COMPANY:	WATTS PREMIER, INC.
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NSF International (NSF) manages the Drinking Water Systems (DWS) Center under the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program. The DWS Center recently evaluated the performance of the Watts Premier WP-4V point-of-use (POU) drinking water treatment system. NSF performed all of the testing activities, and also authored the verification report and this verification statement. The verification report contains a comprehensive description of the test.

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

ETV works in partnership with recognized standards and testing organizations, stakeholder groups (consisting of buyers, vendor organizations, and permittees), 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.

ABSTRACT

The Watts Premier WP-4V POU drinking water treatment system was tested for removal of aldicarb, benzene, cadmium, carbofuran, cesium, chloroform, dichlorvos, dicotophos, fenamiphos, mercury, mevinphos, oxamyl, strontium, and strychnine. The WP-4V employs a reverse osmosis (RO) membrane, a sediment filter, and activated carbon filters to treat drinking water. The system was first tested with only the RO membrane component in place. The target challenge concentration for each chemical for the RO membrane tests was 1 mg/L. Following the RO membrane challenges, the post-membrane carbon filter component was challenged alone with each chemical the RO membrane did not remove to below 30 µg/L. Based on this criterion, the carbon filter was challenged with benzene, chloroform and mercury. The target challenge concentration for the carbon filter tests was the maximum effluent level measured during the RO membrane tests.

A total of 20 RO membrane components were tested, divided into ten pairs. Only one pair of membranes was tested for removal of each chemical. Each RO membrane chemical challenge was conducted over a one-day period. Influent and effluent samples were collected during the operation period, and also the next morning. The post-membrane carbon filter challenges were conducted over a 15-hour duration. Two filters were tested for each chemical challenge, and each pair was only used for one challenge. Influent and effluent samples were collected at the beginning, middle, and end of the challenge period.

The WP-4V as a whole, considering both the RO membrane challenge and post-membrane carbon filter challenge results combined, reduced all of the challenge chemicals 98% or more.

TECHNOLOGY DESCRIPTION

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

The WP-4V is a four-stage POU drinking water treatment system, using sediment filtration, activated carbon filtration, and reverse osmosis. Treated water is stored in a three-gallon storage tank. The WP-4V is certified by NSF to NSF/ANSI Standard 58 – *Reverse Osmosis Drinking Water Treatment Systems*. It has a certified production rate of 9.06 gallons per day.

Incoming water first passes through a sediment filter to remove particulate matter, such as rust and silt, and then through a carbon filter to remove chlorine or other contaminants. The third stage of treatment is the reverse osmosis membrane, which removes a wide variety of inorganic and larger molecular weight organic contaminants, and also protozoan cysts such as cryptosporidium and Giardia. The permeate water is sent to a 3-gallon maximum capacity storage tank. Upon leaving the storage tank, the water passes through a second carbon filter to remove organic chemicals and other taste and odor causing substances before dispensing through the faucet. The pre-membrane carbon and sediment filters were not tested, because they are only designed to remove chlorine and particulate matter to protect the RO membrane.

VERIFICATION TESTING DESCRIPTION

Test Site

The testing site was the Drinking Water Treatment Systems Laboratory at NSF in Ann Arbor, Michigan. A description of the test apparatus can be found in the test/QA plan and verification report. The testing was conducted November 2004 through March 2005.

Methods and Procedures

Verification testing followed the procedures and methods detailed in the *Test/QA Plan for Verification Testing of the Watts Premier WP-4V Point-of-Use Drinking Water Treatment System for Removal of Chemical Contamination Agents*. Because any contamination event would likely be short-lived, the challenge period for each chemical lasted only one day. Long-term performance over the life of the membrane was not evaluated.

The system was first tested with only the RO membrane component in place. A total of 20 RO membranes were challenged with the chemicals in Table 1. The target challenge concentration for each chemical was 1 mg/L. The 20 membrane test units were divided into ten pairs. One pair of systems was tested for removal of each chemical. The reduction of TDS was also measured during the challenges to evaluate whether any organic chemicals damaged the membrane material or membrane seals.

Table 1. Challenge Chemicals

Organic Chemicals	Inorganic Chemicals
Aldicarb	Cadmium Chloride
Benzene	Cesium Chloride (nonradioactive isotope)
Carbofuran	Mercuric Chloride
Chloroform	Strontium Chloride (nonradioactive isotope)
Dicrotophos	
Dichlorvos	
Fenamiphos	
Mevinphos	
Oxamyl	
Strychnine	

Each RO membrane chemical challenge was conducted over a one-day period. The systems were operated for six tank-fill periods, and then were allowed to rest overnight. Influent and effluent samples were collected at start-up, after the 3rd tank fill, after 15 hours of operation, and the next morning after the membranes rested under pressure overnight. During the chloroform, dichlorvos, and fenamiphos challenges, the systems were still in operation for the 3rd tank fill at 15 hours, so the 3rd tank-fill samples were not collected.

Following the RO membrane challenges, the post-membrane carbon filters were challenged with the chemicals that the RO membranes did not remove to below 30 µg/L. The filters were attached to a separate manifold that was of the same design as the manifold in the full RO system. Two carbon filters were tested for each chemical challenge, and each filter was only used for one challenge. The target challenge concentrations were the maximum effluent levels measured during the RO membrane tests.

Prior to testing, each carbon filter was service-conditioned by feeding water containing chloroform to simulate the possible contaminant loading on the carbon halfway through the filter's effective lifespan.

The post-membrane carbon filter challenges were 15 hours in duration. Influent and effluent samples were collected at the beginning, middle, and end of the challenge period. The carbon filters were operated at 0.3 gallons per minute on an operating cycle where the "on" portion was 19 minutes (the time required to empty the system storage tank when full), and the "off" portion was 3 hours and 45 minutes (the time required to fill the storage tank).

VERIFICATION OF PERFORMANCE

The results of the RO membrane challenges are presented in Table 2. The RO membrane treatment process removed 98% or more of all challenge chemicals but mercury, benzene, and chloroform. The membranes removed 44% of mercury, 85% of benzene, and 84% of the chloroform challenge.

The TDS reduction by each membrane component for all challenge tests was 95% or higher. The TDS reduction data does not indicate that any of the membranes or membrane seals were adversely affected by exposure to the challenge chemicals.

The post-membrane carbon filter components were challenged with benzene, chloroform, and mercury.

Table 2. RO Membrane Challenge Data

Chemical	Mean Influent (µg/L)	Mean Effluent (µg/L)	Percent Reduction (%)
Cadmium	910	0.4	> 99
Cesium	660	11	99
Mercury	1200	670	44
Strontium	920	1	> 99
Aldicarb	1100	10	> 99
Benzene	1100	160	85
Carbofuran	1100	5	> 99
Chloroform	1100	180	84
Dichlorvos	560	10	98
Dicrotophos	840	10	99
Fenamiphos	1200	11	> 99
Mevinphos	1200	16	99
Oxamyl	1100	4	> 99
Strychnine	1000	6	> 99

The carbon challenge results are shown below in Table 3. The carbon filter removed 98% or more of all three substances. The RO membrane and carbon challenge data combined shows that the two treatment technologies working in concert within the WP-4V system removed 98% or more of all challenge chemicals.

Complete descriptions of the verification testing results are included in the verification report.

Table 3. Post-Membrane Carbon Filter Challenge Data

Chemical	Target Influent ⁽¹⁾ (µg/L)	Measured Mean Influent (µg/L)	Mean Effluent (µg/L)	Percent Reduction (%)
Benzene	290	300	0.5	> 99
Chloroform	300	300	ND (0.5)	> 99
Mercury	740	760	12	98

(1) Target influent level set at maximum single effluent level from RO challenge.

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Prepared by:

NSF International
Ann Arbor, Michigan 48105

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

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Notice

The U.S. Environmental Protection Agency (USEPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under Cooperative Assistance 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 USEPA, and recommended for public release.

Foreword

The U.S. Environmental Protection Agency (USEPA) 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, USEPA'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 USEPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

Table of Contents

Verification Statement	VS-i
Title Page	i
Notice	ii
Foreword	iii
Table of Contents	iv
List of Tables	vi
List of Figures	vi
Abbreviations and Acronyms	vii
Acknowledgements	viii
Chapter 1 Introduction	1
1.1 Environmental Technology Verification (ETV) Program Purpose and Operation	1
1.2 Purpose of Verification	1
1.3 Development of Test/Quality Assurance (QA) Plan	1
1.4 Challenge Chemicals	2
1.5 Testing Participants and Responsibilities	2
1.5.1 NSF International	2
1.5.2 Watts Premier Inc.	3
1.5.3 U.S. Environmental Protection Agency	3
Chapter 2 Equipment Description	4
2.1 Principals of Operation	4
2.1.1 Activated Carbon	4
2.1.2 RO Membrane	4
2.2 Equipment Capabilities	4
2.3 System Components	4
2.4 System Operation	5
2.5 Rate of Waste Production	7
2.6 Equipment Operation Limitations	7
2.7 Operation and Maintenance Requirements	7
Chapter 3 Methods and Procedures	8
3.1 Introduction	8
3.1.1 RO Membrane Challenges	8
3.1.2 Post-Membrane Carbon Filter Challenges	9
3.1.3 System Operation Scenarios	9
3.2 Verification Test Procedure	10
3.2.1 Challenge Protocol Tasks	10
3.2.2 Test Rig	10
3.2.3 Test Water	11
3.2.3.1 RO Membrane Conditioning and Challenge Test Water	11
3.2.3.2 Post-Membrane Carbon Filter Conditioning and Test Water	11

3.2.3.3	Chemical Challenges	12
3.2.4	Test System Installation and Conditioning	12
3.2.4.1	RO Membrane Test Units	12
3.2.4.2	Post-Membrane Carbon Filter Test Units	13
3.2.5	Challenge Protocols and Sampling Plans	13
3.2.5.1	TDS Reduction System Performance Check	13
3.2.5.2	RO Membrane Challenge Testing	14
3.2.5.3	Post-Membrane Carbon Filter Challenge Testing	16
3.3	Analytical Methods	18
3.3.1	Water Quality Analytical Methods	18
3.3.2	Challenge Chemical Analytical Methods	19
Chapter 4 Results and Discussion		20
4.1	RO membrane Conditioning	20
4.1.1	RO Membrane System Operation Data	20
4.2	Post-Membrane Carbon Filter Conditioning	20
4.3	TDS Reduction System Performance Check	20
4.4	RO Membrane Chemical Challenges.....	21
4.4.1	Inorganic Chemicals Challenges.....	21
4.4.2	Organic Chemical Challenges.....	22
4.5	Post-Membrane Carbon Filter Challenges.....	24
Chapter 5 QA/QC		26
5.1	Introduction.....	26
5.2	Test Procedure QA/QC	26
5.3	Sample Handling.....	26
5.4	Analytical Methods QA/QC	27
5.5	Documentation.....	27
5.6	Data Review	27
5.7	Data Quality Indicators	27
5.7.1	Representativeness.....	27
5.7.2	Accuracy	27
5.7.3	Precision.....	28
5.7.4	Completeness	29
5.7.4.1	Number of Systems Tested	29
5.7.4.2	Water Chemistry Measurements.....	29
5.7.4.3	Challenge Chemicals	30
Chapter 6 References		31

Appendix

Appendix A Conditioning and Chemical Challenges Data Tables

List of Tables

Table 1-1. Challenge Chemicals	2
Table 3-1. Challenge Chemicals	9
Table 3-2. Summary of the Sampling Plan for RO Membrane Challenges.....	16
Table 3-3. Summary of the Sampling Plan for Post-Membrane Carbon Filter Challenges	17
Table 3-4. QC Limits and Method Reporting Limits for Analyses	18
Table 4-1. RO Membrane Inorganic Chemical Reduction Data.....	21
Table 4-2. RO Membrane Organic Chemical Challenge Data	22
Table 4-3. TDS Reduction Data for Organic Chemical Challenges	23
Table 4-4. Organic Chemical Challenges Reject Water Data.....	23
Table 4-5. Post-Membrane Carbon Filter Challenge Data	25
Table 5-1. Completeness Requirements	29

List of Figures

Figure 2-1. Photograph of the WP-4V	5
Figure 2-2. Schematic Diagram of the WP-4V	6
Figure 3-1. RO Membrane Test Units Installed at Test Station	14
Figure 3-2. Post-Membrane Carbon Filter Test Units Installed at Test Station	17

Abbreviations and Acronyms

ANSI	American National Standards Institute
°C	Degrees Celsius
DWS	Drinking Water Systems
DWTS	Drinking Water Treatment Systems
ETV	Environmental Technology Verification
°F	Degrees Fahrenheit
GC/MS	Gas Chromatography/Mass Spectrometry
gpd	Gallons Per Day
gpm	Gallons Per Minute
HCl	Hydrochloric Acid
HPLC	High Pressure Liquid Chromatography
ICP/MS	Inductively Coupled Plasma – Mass Spectrometry
L	Liter
LFB	Laboratory Fortified Blank
LFM	Laboratory Fortified Matrix
mg	Milligram
mL	Milliliter
NaOH	Sodium Hydroxide
ND	Non-detect
NRMRL	National Risk Management Research Laboratory
NSF	NSF International (formerly known as National Sanitation Foundation)
NTU	Nephelometric Turbidity Unit
POE	Point-of-Entry
POU	Point-of-Use
psi	Pounds per Square Inch
QA	Quality Assurance
QC	Quality Control
QA/QC	Quality Assurance/Quality Control
RO	Reverse Osmosis
RPD	Relative Percent Difference
RSD	Relative Standard Deviation
SOP	Standard Operating Procedure
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
µg	Microgram
USEPA	U. S. Environmental Protection Agency
VOC	Volatile Organic Chemical

Acknowledgments

NSF 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.

The manufacturer of the equipment was:

Watts Premier Incorporated
1725 West Williams Drive
Suite C-20
Phoenix, AZ 85027

NSF wishes to thank the members of the expert technical panel for their assistance with development of the test plan.

Chapter 1 Introduction

1.1 Environmental Technology Verification (ETV) Program Purpose and Operation

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

ETV works in partnership with recognized standards and testing organizations; with stakeholder groups consisting of buyers, vendor organizations, and permittees; 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, by conducting field or laboratory testing, collecting and analyzing data, and by 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 USEPA has partnered with NSF International (NSF) under the ETV Drinking Water Systems (DWS) Center to verify performance of drinking water treatment systems that benefit the public and small communities. It is important to note that verification of the equipment does not mean the equipment is “certified” by NSF or “accepted” by USEPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations under conditions specified in ETV protocols and test plans.

1.2 Purpose of Verification

The purpose of this verification was to evaluate treatment system performance under a simulated intentional or non-intentional chemical contamination event. Because any contamination event would likely be short-lived, the challenge period for each chemical lasted only one day. Long-term performance over the life of the membrane was not investigated.

1.3 Development of Test/Quality Assurance (QA) Plan

USEPA’s “Water Security Research and Technical Support Action Plan” (USEPA, 2004) identifies the need to evaluate point-of-use (POU) and point-of-entry (POE) treatment system capabilities for removing likely contaminants from drinking water. As part of the ETV program, NSF developed a test/QA plan for evaluating POU reverse osmosis (RO) drinking water treatment systems for removal of chemical contaminants. To assist in this endeavor, NSF

assembled an expert technical panel, which gave suggestions on a protocol design prior to development of the test/QA plan.

The product-specific test/QA plan for evaluating the WP-4V was entitled *Test/QA Plan for Verification Testing of the Watts Premier WP-4V Point-of-Use Drinking Water Treatment System for Removal of Chemical Contamination Agents*.

By participating in this ETV evaluation, the vendor obtains USEPA and NSF verified independent test data indicating potential user protection against intentional or non-intentional chemical contamination of drinking water. Verifications following an approved test/QA plan serve to notify the public of the possible level of protection against chemical contamination agents afforded to them by the use of a verified system.

1.4 Challenge Chemicals

The challenge chemicals for this verification are listed in Table 1-1.

Organic Chemicals	Inorganic Chemicals
Aldicarb	Cadmium Chloride
Benzene	Cesium Chloride (nonradioactive isotope)
Carbofuran	Mercuric Chloride
Chloroform	Strontium Chloride (nonradioactive isotope)
Dicrotophos	
Dichlorvos	
Fenamiphos	
Mevinphos	
Oxamyl	
Strychnine	

1.5 Testing Participants and Responsibilities

The ETV testing of the WP-4V was a cooperative effort between the following participants:

NSF
Watts Premier Inc.
USEPA

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

1.5.1 NSF International

NSF is a not-for-profit organization dedicated to public health and safety, and to 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. The USEPA partnered with NSF to verify the performance of drinking water treatment systems through the USEPA's ETV Program.

NSF performed all verification testing activities at its Ann Arbor location. NSF prepared the test/QA plan, performed all testing, managed, evaluated, interpreted, and reported on the data generated by the testing, and reported on the performance of the technology.

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1.5.2 Watts Premier Inc.

The verified system is manufactured by Watts Premier, a division of Watts Water Technologies. Watts Premier manufactures industrial, food service, point-of-entry, and point-of-use water treatment systems

The manufacturer was responsible for supplying the test units, and for providing logistical and technical support as needed.

Contact Information:

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1.5.3 U.S. Environmental Protection Agency

The USEPA, 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 the USEPA, and recommended for public release.

Chapter 2 Equipment Description

2.1 Principals of Operation

2.1.1 Activated Carbon

Activated carbon removes organic chemicals from water through the process of adsorption. The chemicals are attracted to and attach to the surface of the carbon through electrostatic interactions. The adsorbent properties of activated carbon are a function of the raw material used and the activation process. Once the carbon is saturated with adsorbed molecules, it must be replaced.

2.1.2 RO Membrane

Membrane technologies are among the most versatile water treatment processes because of their ability to effectively remove a wide variety of contaminants. RO membranes operate by the principal of cross-flow filtration. In this process, the influent water flows over and parallel to the filter medium and exits the system as reject water. Under pressure, a portion of the water diffuses through the membrane becoming “permeate”. The membrane allows water molecules to pass through its pores, but not most dissolved inorganic chemical molecules and larger molecular weight organic chemical molecules. These molecules are concentrated in and washed away with the reject water stream.

Unlike activated carbon, which reaches an exhaustion point and needs to be replaced, the reduction capabilities of RO membranes remain in effect until the membrane is compromised. Monitoring of membrane performance can be conducted by measuring the TDS of the permeate water with a TDS monitor.

2.2 Equipment Capabilities

The WP-4V is certified by NSF to NSF/ANSI Standard 58 – *Reverse Osmosis Drinking Water Treatment Systems*. The post-membrane carbon filter in the system is certified to NSF/ANSI Standard 53 – *Drinking Water Treatment Units – Health Effects*. The WP-4V has a certified production rate of 9.06 gallons per day. This measurement is based on system operation at 50 pounds per square inch, gauge (psig) inlet pressure, a water temperature of 25 °C, and a total dissolved solids (TDS) level of 750 ± 40 mg/L. The amount and quality of treated water produced varies depending on the inlet pressure, water temperature, and level of TDS. These measurements were not subject to verification during this study.

2.3 System Components

The WP-4V is a four-stage treatment system. Incoming water first passes through a sediment filter to remove particulate matter, such as rust and silt, and then through a carbon filter to remove chlorine or other contaminants. The third stage of treatment is the reverse osmosis

membrane, which removes a wide variety of inorganic and larger molecular weight organic contaminants, and also protozoan cysts such as cryptosporidium and Giardia. The permeate water is sent to a 3-gallon maximum capacity storage tank. Upon leaving the storage tank, the water passes through a second carbon filter to remove organic chemicals and other taste and odor causing substances before dispensing through the faucet. A photograph of the system is shown in Figure 2.1, and a schematic diagram shown in Figure 2.2. Please note that this description, and the system operation description in Section 2.4 are given for informational purposes only. This information was not subject to verification.

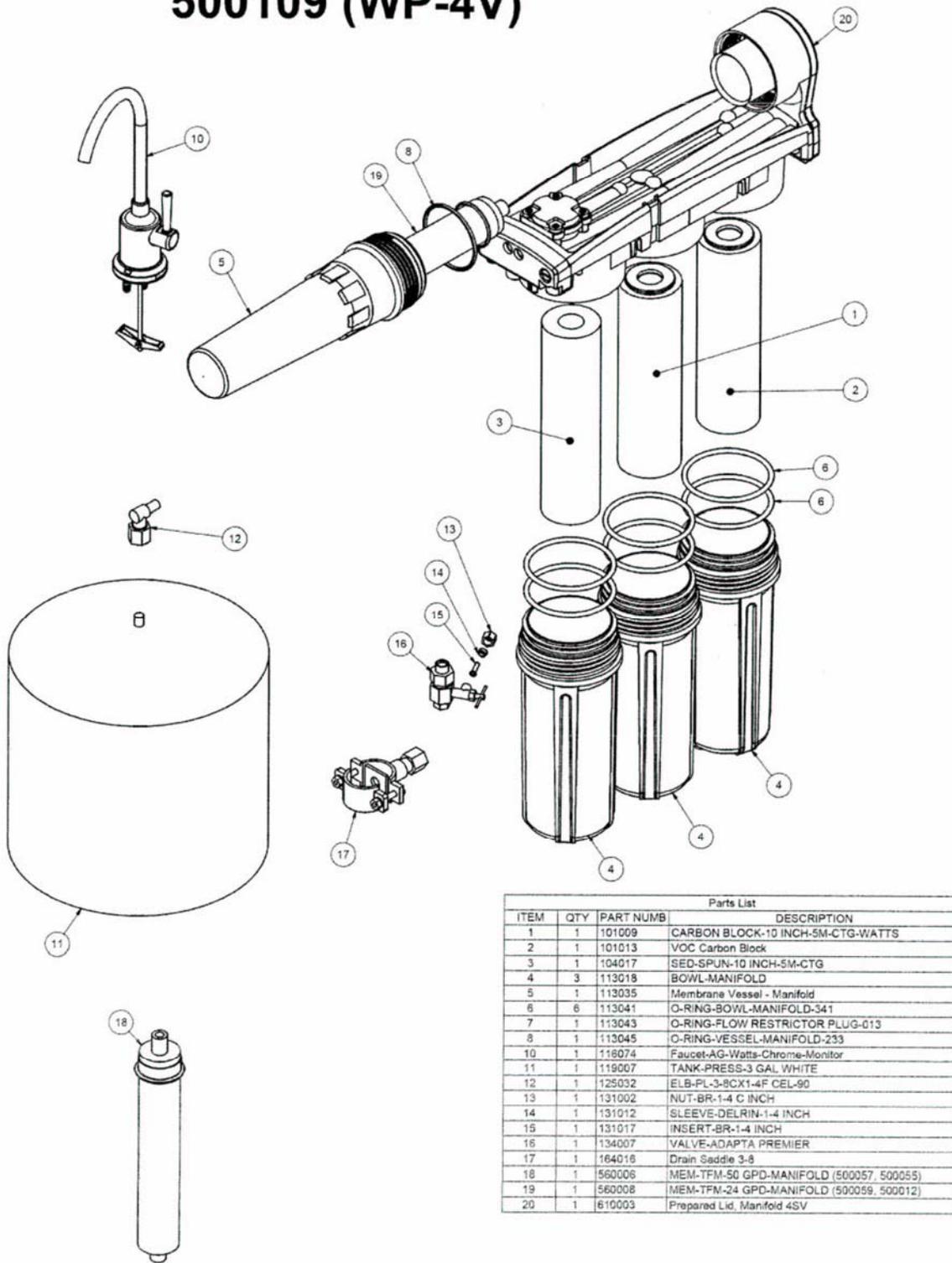


Figure 2-1. Photograph of the WP-4V

2.4 System Operation

When the flow of water into the system is started, treated water will be continually produced until the storage tank is nearly full. At that time, the water pressure in the tank causes an automatic shut-off valve to stop the flow of water through the system. After a portion of the water is dispensed from the tank, the shut-off valve deactivates, allowing water to once again flow through the RO membrane into the storage tank.

500109 (WP-4V)



Parts List			
ITEM	QTY	PART NUMB	DESCRIPTION
1	1	101009	CARBON BLOCK-10 INCH-5M-CTG-WATTS
2	1	101013	VOC Carbon Block
3	1	104017	SED-SPUN-10 INCH-5M-CTG
4	3	113018	BOWL-MANIFOLD
5	1	113035	Membrane Vessel - Manifold
6	6	113041	O-RING-BOWL-MANIFOLD-341
7	1	113043	O-RING-FLOW RESTRICTOR PLUG-013
8	1	113045	O-RING-VESSEL-MANIFOLD-233
10	1	118074	Faucet-AG-Watts-Chrome-Monitor
11	1	119007	TANK-PRESS-3 GAL. WHITE
12	1	125032	ELB-PL-3-8CX1-4F CEL-90
13	1	131002	NUT-BR-1-4 C INCH
14	1	131012	SLEEVE-DELRIIN-1-4 INCH
15	1	131017	INSERT-BR-1-4 INCH
16	1	134007	VALVE-ADAPTA PREMIER
17	1	164016	Drain Saddle 3-8
18	1	560006	MEM-TFM-50 GPD-MANIFOLD (500057, 500055)
19	1	560008	MEM-TFM-24 GPD-MANIFOLD (500059, 500012)
20	1	610003	Prepared Lid, Manifold 4SV

Figure 2-2. Schematic Diagram of the WP-4V

The operational storage tank capacity will vary slightly from system to system, and may also be affected by the inlet water pressure. The storage tank capacity was measured to be 2.64 gallons when the system was tested for NSF/ANSI Standard 58 certification.

2.5 Rate of Waste Production

The rate of reject water production was measured during the certification process for NSF/ANSI Standard 58 certification. The efficiency rating, as defined by Standard 58 is the percentage measure of the amount of influent water delivered as permeate under a closed permeate discharge set of actual use conditions. The efficiency rating of the WP-4V is 8.4%, which means the system produces approximately 11 gallons of reject water for each gallon of product water produced. The efficiency rating was not verified as part of this evaluation.

2.6 Equipment Operation Limitations

Watts Premier gives the following limitations for the drinking water to be treated by the system:

- temperature of 40 – 100 °F;
- pressure of 40 – 100 psi;
- pH of 3 – 11;
- maximum TDS level of 1,800 mg/L;
- maximum water hardness of 10 grains per gallon (1 grain per gallon equals 17.1 mg/L of hardness, expressed as calcium carbonate equivalent); elevated hardness levels may reduce membrane life; and
- maximum iron level of 0.2 ppm.

2.7 Operation and Maintenance Requirements

The following are the operation and maintenance requirements specified in the product owner's manual:

- Replacement of the pre-membrane sediment and pre-membrane carbon filter every 12 months;
- Replacement of the RO membrane every 2 to 5 years (Watts Premier offers free treated water TDS analysis for monitoring membrane operation, or the user can purchase a TDS monitor);
- Replacement of the post-membrane carbon filter every 12 months or 600 gallons treated;
- Annual sanitization of the system with hydrogen peroxide or bleach is recommended; and
- The flow restrictor plug must be cleaned each time the RO membrane is replaced.

The WP-4V system relies on the user to determine when the filters and RO membrane need to be replaced. There are no on-line monitors or indicators built into the system to track the volume of water treated. However, to compensate for this, for NSF/ANSI Standard 58 certification the post-membrane carbon filter was tested out to 200% of the claimed capacity, as opposed to 120% of capacity for systems with volume-based monitors.

Chapter 3 Methods and Procedures

3.1 Introduction

The challenge tests followed the procedures described in the *Test/QA Plan for Verification Testing of the Watts Premier WP-4V Point-of-Use Drinking Water Treatment System for Removal of Chemical Contamination Agents*.

As described in Section 2.3, the WP-4V employs an RO membrane, a sediment filter, and carbon filters to treat drinking water. The system was first tested with only the RO membrane component in place. After the RO membrane challenges were complete, the post-membrane carbon filter was challenged alone. This approach allowed an evaluation of the individual performance of each component, and also served to simulate a worst-case scenario where the carbon filters are at or past the end of their useful life. This approach also allowed each treatment component to be challenged using a challenge water that presented more of a worst-case scenario for that component. The pre-membrane carbon and sediment filters were not tested, because they are only designed to remove chlorine and particulate matter to protect the RO membrane.

3.1.1 RO Membrane Challenges

The RO membranes were challenged with each chemical in Table 3-1. The target challenge concentration for each chemical was 1 mg/L, which is much higher than most challenge levels in the NSF/ANSI Standards for POU devices. Of the chemicals in Table 3-1 included in the POU device standards, the highest challenge is chloroform at 450 µg/L for the total trihalomethanes reduction test.

Only two membranes were challenged with each chemical. The organic chemical challenges and the mercury challenge were conducted individually, but cadmium, cesium, and strontium were combined into one challenge. The test/QA plan called for each membrane to be tested with only one of the ten organic chemicals, because of concern that some of them, especially benzene and chloroform, could damage the membranes or membrane seals at the high challenge levels. However, two units had to be tested with three of the organic chemicals. See Sections 4.4.2 and 5.7.4.1 for further discussion.

TDS reduction was also measured during the challenges, to serve as a membrane performance benchmark, and also to evaluate whether any organic chemicals damaged the membrane or integrity of the membrane seals.

A total of twenty RO membranes were tested, divided into ten pairs. The inorganic chemical challenges were conducted first. The two systems used for with the inorganic chemicals were used again for an organic chemical challenge. As discussed in Section 1.2, each challenge period was only one day. The membranes were operated for five tank-fill periods or fifteen hours,

Table 3-1. Challenge Chemicals

Organic Chemicals	Inorganic Chemicals
Aldicarb	Cadmium Chloride
Benzene	Cesium Chloride (nonradioactive isotope)
Carbofuran	Mercuric Chloride
Chloroform	Strontium Chloride (nonradioactive isotope)
Dicrotophos	
Dichlorvos	
Fenamiphos	
Mevinphos	
Oxamyl	
Strychnine	

whichever came first. Influent and effluent samples were collected during the operation period at start-up, after the third tank-fill, and after the fifth tank-fill, or end of fifteen hours of operation. After the last samples were collected, the systems were operated again for a sixth tank fill, then rested overnight. Post-rest effluent samples were collected from the storage tank the next morning. In addition to influent and effluent samples, reject water samples were also collected during the organic chemical challenges in an attempt to determine whether any of the chemicals adsorbed onto or absorbed into the membrane material in significant amounts. See Section 3.2.5.2 for RO membrane challenge protocol details.

3.1.2 Post-Membrane Carbon Filter Challenges

The post-membrane carbon filter was tested alone for reduction of some of the chemicals. The carbon filter was challenged with the organic chemicals the RO membrane did not remove to a level of 30 µg/L or less. The inorganic chemicals were considered on a case-by-case basis, since USEPA does not consider carbon to be the best available technology for removing cadmium, cesium, or strontium. As with the membranes, the carbon filters were challenged in pairs, and each pair was only tested once. Each challenge was 15 hours. The target challenge concentrations for the carbon filter tests were the maximum effluent levels measured during the RO tests. See Section 3.2.5.3 for the post-membrane carbon filter test protocol details.

3.1.3 System Operation Scenarios

The challenge protocol was designed to evaluate system performance under two different operation scenarios. The first is operation with the product water storage tank over half full, giving high back-pressure. This is how the system is likely to operate in the home, as the user will usually dispense small volumes of water until the shut-off valve deactivates, allowing the storage tank to fill again. RO membrane performance is affected by the net driving pressure on the membrane. The net driving pressure is the feed water pressure minus the osmotic pressure minus the back-pressure from the storage tank. As the storage tank fills up and the tank bladder expands, the back-pressure increases, reducing the net driving pressure. As the net driving pressure drops, the ion rejection performance of the membrane can also drop (Slovak, 2000).

This test protocol was designed so that the membranes operate for multiple tank fills under conditions where the net driving pressure was as low as possible. After the first tank fill, the lab technician dispensed the product water to the drain until the shut-off valve deactivated, allowing the RO membrane to again produce treated water. This cycle was repeated for a total of five storage tank fill periods.

The second operation scenario is continued contaminant rejection while the system is at rest. The NSF/ANSI Standard 58 testing protocols call for a two-day stagnation period to check whether the membrane can maintain rejection of the contaminants. NSF has observed that RO systems can give higher contaminant concentrations after the rest period than before. This phenomenon is due to the membrane's difficulty maintaining the osmotic differential across the membrane, and perhaps also imperfections in the membrane material. At the end of each challenge, the membranes were allowed to rest under pressure overnight, and product water samples were collected for analysis the next morning.

3.2 Verification Test Procedure

3.2.1 Challenge Protocol Tasks

The following are the tasks in the challenge protocol, and the order in which they were conducted:

1. Installation of the RO membrane devices on the test rig, and seven days of conditioning (Section 3.2.4.1);
2. One-day TDS challenge test to evaluate system integrity (Section 3.2.5.1);
3. Conditioning of the post-membrane carbon filters while the RO membrane tests are being conducted (Section 3.2.4.2); and
4. Chemical challenge tests
 - a. RO inorganic chemical challenges (Section 3.2.5.2)
 - b. RO organic chemical challenges (Section 3.2.5.2)
 - c. Post-membrane carbon filter challenges (Section 3.2.5.3).

3.2.2 Test Rig

All test units were plumbed to "injection rig" test stations in the NSF Drinking Water Treatment Systems (DWTS) Laboratory. The injection rigs have a common 90-gallon tank to hold the test water without the challenge chemicals. Fresh water is periodically added to the tank as it is being used. Online monitors and a computer system automatically control the water level and water chemistry. Downstream of the feedwater tank, a precisely controlled pump is used to inject the challenge chemical(s) at the proper concentrations. Immediately downstream of the pump lies a motionless in-line mixer to assure complete mixing of the challenge water. An influent sample port is downstream of the in-line mixer. No schematic diagram of the injection rig is available, due to the proprietary nature of the design.

3.2.3 Test Water

3.2.3.1 RO Membrane Conditioning and Challenge Test Water

The test water for the RO membrane conditioning and challenges was a synthetic water constructed from deionized municipal drinking water. The municipal water was first filtered through activated carbon to remove chlorine, then it was deionized and treated with reverse osmosis. Sodium chloride was added for TDS, and the pH was adjusted with hydrochloric acid (HCl) or sodium hydroxide (NaOH), if necessary, to achieve the following characteristics prior to addition of the challenge chemical(s):

- pH – 7.5 ± 0.5 for the TDS reduction test, conditioning, and organic chemical challenges, 6.0-6.5 for the inorganic chemicals challenges;
- total chlorine – ≤ 0.05 mg/L;
- temperature – 25 ± 1 °C;
- TDS – 750 ± 75 mg/L; and
- turbidity – ≤ 1 Nephelometric Turbidity Unit (NTU).

TDS, pH, temperature, and turbidity were maintained within the appropriate range by a computer system with on-line monitors. In addition, grab samples were collected and analyzed for all parameters according to the sampling plans described in Sections 3.2.4.1, 3.2.5.1, and 3.2.5.2. Note that the pH specification for the inorganic chemicals challenges was 6.0 to 6.5, to ensure that the metals were present as dissolved free ions in the challenge water. This ensured that the metals challenges were testing the ability of the RO membrane to reject the ions instead of physically removing suspended particles of the metals.

3.2.3.2 Post-Membrane Carbon Filter Conditioning and Test Water

The test water for post-membrane carbon filter conditioning and testing was the “general test water” specified in *NSF/ANSI Standard 53, Drinking water treatment units – health effects* (NSF International, 2002). This water is the Ann Arbor municipal drinking water that is adjusted, if necessary, to have the following characteristics prior to addition of the challenge chemical:

- pH – 7.5 ± 0.5 ;
- TDS – 200-500 mg/L
- temperature – 20 ± 2.5 °C;
- total organic carbon (TOC) – > 1.0 mg/L; and
- turbidity – ≤ 1 NTU.

Please note that the TOC parameter only has a minimum level specified, since it is the natural TOC in the municipal water supply. The natural TOC in the water supply usually ranges from approximately 2 to 3 mg/L. The TOC levels in the organic chemical challenge waters were much higher due to the methanol used as the carrier solution for the chemicals.

TDS, pH, and temperature were maintained within the appropriate range by a computer system with on-line monitors. The pH of the Ann Arbor drinking water was above 7.5 during the test period, so the pH was adjusted with HCl. The TDS level was within the allowable range, so no adjustments were needed. The water was not dechlorinated prior to use.

Grab samples were collected and analyzed for all parameters according to the sampling plans described in Sections 3.2.4.2 and 3.2.5.3. Total chlorine was also measured, although there is no specification given for it as there is in Section 3.2.3.1 for the RO membrane test water.

3.2.3.3 Chemical Challenges

The appropriate chemical(s) were added to the base test waters given in Sections 3.2.3.1 and 3.2.3.2 to make the challenge waters. The RO membrane challenge target concentration for each chemical was 1 ± 0.5 mg/L. The target challenge concentrations for the carbon filter tests were the maximum effluent levels measured during the RO tests. For each challenge, a concentrated solution of the chemical(s) was made, and this mixture injected into the influent water stream at an appropriate rate. Due to analytical procedure lengths, the amount of chemical to add to the test water to achieve the proper challenge concentration was calculated based on the known concentration in the feed solution. The tests were conducted without waiting for confirmation of the influent level from the chemistry laboratory.

3.2.4 Test System Installation and Conditioning

3.2.4.1 RO Membrane Test Units

The RO membrane test units were installed on the test rigs by an NSF DWTS Laboratory technician according to the instructions in the WP-4V owner's manual. Watts Premier's recommended conditioning procedure of operation for three tank-fill periods was not conducted, instead the membranes underwent a seven-day, seven tank-fills conditioning period. Previous POU RO system ETV tests for microbial agents indicated that perhaps membrane performance does not stabilize until after four or five days (four or five tank fills) of conditioning. A seven-day conditioning period ensured that the membranes were performing optimally prior to the chemical challenges.

For the first six days, the membranes were operated at 60 ± 3 psi inlet pressure for one storage tank fill period per day using the water described in Section 3.2.3.1. Influent water samples were collected each day at the beginning of the operation period for analysis of pH, TDS, temperature, total chlorine, and turbidity. The membranes rested under pressure overnight, and the storage tanks were emptied the next morning prior to beginning that day's operation period.

On the seventh day, the membranes were instead operated at 80 ± 3 psi inlet pressure. Influent water samples were collected at the beginning of the operation period for analysis of pH, TDS, temperature, total chlorine, and turbidity. The times required to fill the storage tanks were measured and recorded for the three test units whose tanks filled the fastest. On the morning of the eighth day, the times to dispense the first liter of water and to empty the storage tanks with the faucet fully open were measured and recorded for the three test units whose operation times were recorded the previous day. The tank fill times, times to empty the storage tank, and first liter flow rates were used to determine the operating parameters for the post-membrane carbon filters during the carbon filter challenge tests. The longest time to empty the storage tank was used for the "on" time portion of the operating cycle. The shortest tank fill time was used for the "off" portion of the cycle. The flow rates during the carbon filter challenges were set at the fastest first liter flow rate. Operation at 80 psi instead of 60 psi caused the tank fill time to be

shorter, which gave a worse case testing scenario for the carbon filters. See Section 3.2.5.3 for further discussion about the post-membrane carbon filter challenge tests.

3.2.4.2 Post-Membrane Carbon Filter Test Units

The carbon filters were plumbed to a test station and operated using the water described in Section 3.2.3.2 amended with 300 ± 90 $\mu\text{g/L}$ of chloroform until 300 gallons passed through each filter. This is the volume equal to one-half of Watts Premier's stated capacity of 600 gallons for the filter. The filters were operated at an inlet water pressure of 60 ± 3 psi and a maximum flow rate of approximately 0.4 gallons per minute (gpm), on a ten minutes on, ten minutes off cycle. Chloroform at 300 $\mu\text{g/L}$ is the influent challenge concentration for the VOC (volatile organic chemical) reduction test in NSF/ANSI Standard 53 (chloroform is the surrogate challenge chemical). The chloroform served to load the carbon filters to a degree that simulated contaminant loading in the middle of their effective lifespan. Influent samples were collected for analysis of chloroform, pH, temperature, TOC, and turbidity at start-up, approximately 25% of capacity, and approximately 50% of capacity. Effluent samples were collected at the same three points for chloroform analysis.

If the filters were not immediately used for a challenge test, they were stored with the conditioning water still in them. The manifold inlets and outlets were closed off by valves to ensure that the chloroform remained on the carbon.

3.2.5 Challenge Protocols and Sampling Plans

3.2.5.1 TDS Reduction System Performance Check

After the RO membrane conditioning period was complete, they underwent a short-term TDS reduction test to verify that they were operating properly. The challenge was conducted as follows:

1. The product water storage tanks were drained, and membrane operation was started at 50 ± 3 psig inlet pressure using the water described in Section 3.2.3.1 without any challenge chemicals added.
2. Immediately after the membranes began operation, influent samples were collected for analysis of pH, temperature, total chlorine, turbidity, and TDS.
3. The systems were allowed to operate until the automatic shut-off mechanisms activated.
4. The entire contents of the storage tanks were emptied into separate containers, and three 250 mL samples were collected from each container for TDS analysis.

Removal of 75% or more of the TDS was required for the use of each membrane for the chemical challenges.

3.2.5.2 RO Membrane Challenge Testing

As discussed in Section 3.1.1, the RO membrane test units were divided into ten pairs. The inorganic chemical challenges were conducted first, followed by the organic chemicals. Figure 3-1 shows a pair of test devices plumbed to the test rig.

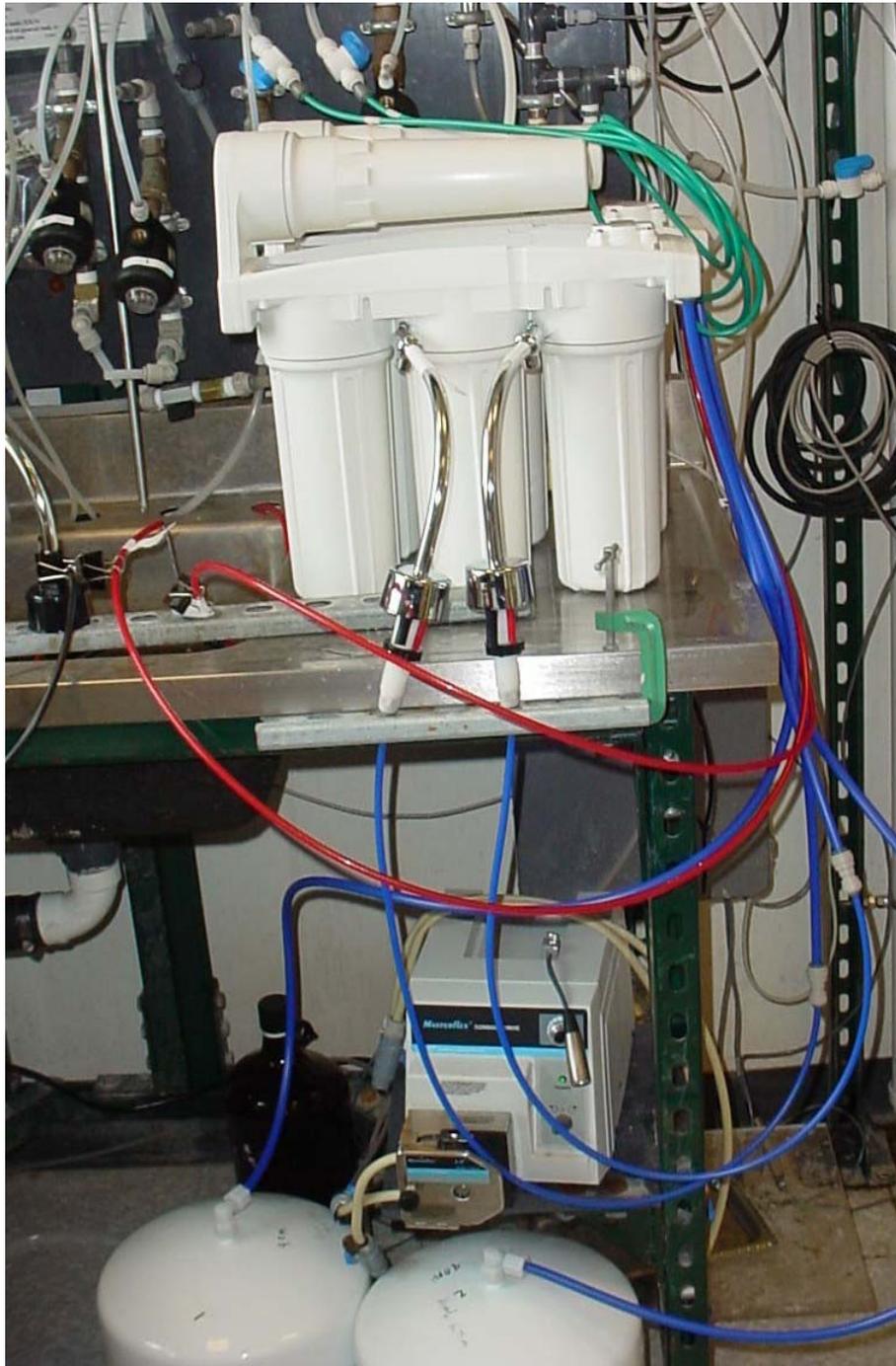


Figure 3-1. RO Membrane Test Units Installed at Test Station

The challenge tests were conducted as follows:

1. At the start of each challenge period, the test system storage tanks were emptied.
2. The initial dynamic inlet water pressure was set at 50 ± 3 psi, and test system operation was started using the test water described in Section 3.2.3.1 with the proper challenge chemical(s) added.
3. Influent and effluent water samples were collected for analysis of the challenge chemical(s) and TDS immediately after the units began operation. Influent samples were also collected for analysis of pH, temperature, total chlorine, and turbidity. All influent and effluent samples for challenge chemical analysis were collected and analyzed in triplicate, except where indicated below. To collect the triplicate samples, the volumes necessary to obtain the triplicate samples were first collected into a polyethylene container, and then the triplicate samples were collected from that volume. Due to the volatility of benzene and chloroform, true triplicate samples were not collected for these chemicals. Instead, three consecutive replicate samples were collected directly into the sample bottles that were delivered to the NSF Chemistry Laboratory. TDS samples were collected as single samples.
4. During first tank-fill period of the organic chemical challenges, duplicate samples were collected from the reject water line of one of the systems for challenge chemical(s) analysis. Samples were collected at start-up, approximately halfway through, and approximately three-fourths of the way through the period.
5. The systems were operated continuously until the shut-off valves activated. The faucets were then fully opened, and a minimum of one liter, the volume required for sample analysis, or the amount needed to fully deactivate the shut-off valve, was dispensed to drain from each system. Full deactivation was estimated by monitoring resumption of the flow of reject water as the product water is dispensed. The shut-off valve was considered fully deactivated when the flow of reject water appeared to have fully resumed.
6. Step 5 was repeated until five storage tank fill periods were complete, or 15 hours of operation had passed. After the third storage tank fill period ended, influent and effluent samples were collected for analysis of the challenge chemical(s) and TDS.
7. Approximately halfway through the last tank fill period for the organic chemical challenges, duplicate reject water samples were again collected for challenge chemical(s) analysis. The samples were collected from the same system from which the reject water samples were collected in step 4. This sample served to check whether any chemical adsorption/absorption observed during the first storage tank fill period was still occurring, or the membrane became saturated with the chemical.
8. After the fifth storage tank fill, or after 15 hours of operation, effluent samples were collected from each system for challenge chemical(s) and TDS analysis. Influent samples were collected for analysis of the challenge chemical(s), TDS, pH, temperature, total chlorine, and turbidity. If a system did not resume operation after sample collection, the additional volume necessary to resume operation was dispensed from each system.
9. The units were then allowed to operate until the shut-off valves activated, and then rest under pressure for at least eight hours. After the rest period, the faucets were fully opened, and the first draw out of each faucet was collected for single challenge chemical and TDS analysis. After collection of the first draw water, the rest of the contents of each storage tank were

collected into suitable containers, and three samples were collected from each volume for triplicate challenge chemical analysis. Table 3-2 gives a summary of the sampling plan.

Table 3-2. Summary of the Sampling Plan for RO Membrane Challenges

Sample Point	Influent Sample Numbers			Effluent Sample Numbers (per system)	
	Water Chemistry Parameters	Challenge Chemical	TDS	Challenge Chemical	TDS
Start Up	1 sample for each parameter	3	1	3	1
1st Tank Reject Water Samples					
Start Up				2 (from one system)	
Half Tank				2 (from one system)	
Three-fourths Tank				2 (from one system)	
3rd Tank Fill		3	1	3	1
5th Tank Fill	1 sample for each parameter	3	1	3	1
Reject Water – Halfway Through 5th Tank Fill				2 (from one system)	
Post-Rest – First Draw				1	1
Post-Rest – Rest of Tank				3	

3.2.5.3 Post-Membrane Carbon Filter Challenge Testing

The post-membrane carbon filter in the WP-4V is downstream from the storage tank, so it was tested at the flow rate measured at the faucet outlet during the RO membrane conditioning step. Each challenge was 15 hours. The filters were operated on an “on/off” operation cycle where the “on” portion was the time required to empty the storage tank when full, and the “off” portion of the cycle was the time required to fill the storage tank at 80 psi inlet pressure, as measured during the RO membrane conditioning period. Figure 3-2 shows a pair of carbon filters being tested for dichlorvos removal.

The challenge tests were conducted as follows:

1. The proper “on/off” cycle parameters were entered into the test station computer.
2. The initial dynamic inlet water pressure was set at 60 ± 3 psi, and filter operation was started using the water described in Section 3.2.3.2 with the proper challenge chemical added. The flow rate was adjusted as necessary using a valve downstream of each filter on the effluent line.
3. Influent and effluent samples were collected for challenge chemical analysis immediately after operation began. All effluent samples were collected during the last half of the “on” portion of the operation cycle, so that the dwell water was flushed out prior to sample collection. All challenge chemical samples were collected and analyzed in triplicate. The sample volumes were those required to obtain the triplicate samples.
4. Single influent samples were also collected for analysis of pH, TDS, temperature, TOC, total chlorine, and turbidity whenever challenge chemical samples were collected.

5. After 7.5 and 15 hours of operation, second and third sets of influent and effluent samples were collected for challenge chemical analysis. The flow of challenge water through the filters was started manually if they were not in the “on” portion of the operation cycle. Table 3-3 gives a summary of the sampling schedule.



Figure 3-2. Post-Membrane Carbon Filters Installed at Test Station

Table 3-3. Summary of the Sampling Plan for Post-Membrane Carbon Filter Challenges

Sample Point	Influent Water Chemistry Sample Numbers	Challenge Chemical Influent Sample Numbers	Challenge Chemical Effluent Sample Numbers
Start Up	1 for each parameter	3	3
7.5 Hours	1 for each parameter	3	3
15 Hours	1 for each parameter	3	3

3.3 Analytical Methods

3.3.1 Water Quality Analytical Methods

The following are the analytical methods used during verification testing. All analyses followed procedures detailed in NSF’s Standard Operating Procedures (SOPs). The reporting limits, and the acceptable precision and accuracy for each parameter are shown in Table 3-4.

Table 3-4. QC Limits and Method Reporting Limits for Analyses

Parameter	Reporting Limit	Acceptable Precision (RPD or RSD)	Acceptable Accuracy (% recovery)	
			LFB	LFM
pH	NA	RPD < 10%	90-110%	
TDS (conductivity)	2 mg/L	RPD < 10%	80-120%	
TDS (gravimetric)	5 mg/L	RPD < 10%	90-110%	
TOC	0.1 mg/L	RPD < 10%	80-120%	
Total Chlorine	0.05 mg/L	RPD < 10%	90-110%	
Turbidity	0.1 NTU	RPD < 10%	95-105%	
Aldicarb	1.0 µg/L	RSD < 20%	80-120%	65-135%
Benzene	0.5 µg/L	RSD < 20%	80-120%	NA
Cadmium	0.3 µg/L	RSD < 20%	85-115%	70-130%
Carbofuran	1 µg/L	RSD < 20%	80-120%	65-135%
Cesium	1 µg/L	RSD < 20%	85-115%	70-130%
Chloroform	0.5 µg/L	RSD < 20%	80-120%	NA
Dicrotophos	10 µg/L	RSD < 30%	70-130%	70-130%
Dichlorvos	0.2 µg/L	RSD < 30%	70-130%	70-130%
Fenamiphos	4 µg/L	RSD < 30%	70-130%	70-130%
Mercury	0.2 µg/L	RSD < 20%	85-115%	70-130%
Mevinphos	0.2 µg/L	RSD < 30%	70-130%	70-130%
Oxamyl	1.0 µg/L	RSD < 20%	80-120%	65-135%
Strontium	2 µg/L	RSD < 20%	85-115%	70-130%
Strychnine	5 µg/L	RSD < 20%		70-130%

LFB = Laboratory Fortified Blank
 LFM = Laboratory Fortified Matrix
 RPD = Relative Percent Deviation
 RSD = Relative Standard Deviation

- pH – All pH measurements were made with an Orion Model SA 720 meter. The meter was operated according to the manufacturer’s instructions, which are based on Standard Method 4500-H⁺.
- Temperature – Water temperature was measured using an Omega model HH11 digital thermometer.
- TDS (by conductivity) – TDS for the TDS reduction system check test was measured through conductivity according to Standard Method 2510 using a Fisher Scientific Traceable™ Conductivity Meter. This method has been validated for use with the test water; NSF uses this method for analysis of samples from TDS reduction tests under Standard 58.

- TDS (gravimetrically) – The TDS in the carbon filter conditioning and challenge water was measured gravimetrically. The method used was an adaptation of USEPA Methods 160.3 and 160.4. An appropriate amount of sample was placed in a pre-weighed evaporating dish. The sample was evaporated and dried at 103-105 °C to a constant weight. The dish was then weighed again to determine the total solids weight.
- Total Chlorine – Total chlorine was measured according to Standard Method 4500-Cl G with a Hach Model DR/2010 spectrophotometer using AccuVac vials.

3.3.2 Challenge Chemical Analytical Methods

The following are the analytical methods used during verification testing. All analyses followed procedures detailed in NSF SOPs. The reporting limits, and the acceptable precision and accuracy for each parameter are shown in Table 3-4.

- Aldicarb, Carbofuran, and Oxamyl were measured by high pressure liquid chromatography (HPLC) according to USEPA Method 531.1 or 531.2.
- Dichlorvos, Dicrotophos, Fenamiphos, and Mevinphos were measured by gas chromatography/mass spectrometry (GC/MS) according to USEPA Method 525.2.
- Cadmium, Chromium, Mercury, and Strontium were measured by Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) according to USEPA Method 200.8.
- Benzene and Chloroform were measured by purge and trap capillary gas chromatography according to USEPA Method 502.2.
- There is no standard analytical method for strychnine. NSF developed a method to measure it using reverse phase HPLC with ultraviolet lamp detection.

Chapter 4 Results and Discussion

4.1 RO membrane Conditioning

As discussed in Section 3.2.4.1, the RO membranes were conditioned for seven days prior to the chemical challenges. All of the influent water quality parameters in Section 3.2.3.1 were maintained within the allowable ranges. The individual data values for these parameters can be found in Table A-1 of Appendix A

4.1.1 RO Membrane System Operation Data

As described in Section 3.2.4.1, the storage tank fill times, first liter dispense times, and times to dispense the entire tanks were measured and recorded for the three systems whose tanks filled the fastest. These parameters were to be used for the post-membrane carbon filter challenges. The shortest tank fill time measured was 3 hours, 45 minutes, and the fastest first liter flow rate was 1.22 gpm. However, the flow rates were measured without the post-membrane carbon filter in place. When the carbon filters were plumbed to the test rigs, 1.22 gpm could not be achieved. Watts Premier informed NSF that the filter has an integral flow controller that limits the flow rate through the carbon to approximately 0.3 gpm. A carbon filter was installed into an RO unit to confirm this. NSF measured a first liter flow rate of 0.29 gpm and a storage tank dispense time of 19 minutes, 4 seconds. These parameters, along with the tank-fill time of 3 hours, 45 minutes, were used for the carbon filter challenges.

4.2 Post-Membrane Carbon Filter Conditioning

As described in Section 3.2.4.2, the post-membrane carbon filters were to be conditioned with water containing $300 \pm 90 \mu\text{g/L}$ of chloroform until 300 gallons had passed through them. However, the measured influent chloroform levels were higher, ranging from 430 to 520 $\mu\text{g/L}$. This loaded the carbon filters with more chloroform than was planned, but the carbon filter challenge data in Table 4-8 does not indicate that the excess chloroform loading adversely affected the performance of the carbon.

The carbon filter conditioning effluent samples were all below the detection limit of 0.5 $\mu\text{g/L}$, except for the unit 6 25% effluent sample, which was 160 $\mu\text{g/L}$. The 160 $\mu\text{g/L}$ is likely due to a sampling or analytical error, since the start-up and 50% effluent samples for unit 6 were non-detects. The chloroform and water chemistry data are presented in Table A-3 of Appendix A.

4.3 TDS Reduction System Performance Check

After the RO membranes were conditioned, all underwent the TDS reduction test described in Section 3.2.5.1. The maximum effluent TDS level measured was 23 mg/L, corresponding to a minimum 97% reduction of TDS. The average TDS reduction was 98%. Watts Premier's reported TDS reduction is 97%, so the tested systems were representative of expected membrane

performance. The TDS reduction data for each RO membrane system can be found in Table A-2 of Appendix A.

4.4 RO Membrane Chemical Challenges

The RO membrane challenges were conducted according to the procedure in Section 3.2.5.2. The systems operated too slowly in all challenges but that for mercury to complete five tank-fills within the 15-hour operation period. Note that the challenge period likely ended while the systems were in operation, so the 15-hour samples may have been collected from partially filled tanks. The numbers of tank-fills completed are given in the challenge data tables that follow.

4.4.1 Inorganic Chemicals Challenges

The inorganic chemicals challenge data are shown in Table 4-1. Each challenge chemical data point is the arithmetic mean of the triplicate sample analyses, except for the post-rest first liter draws, which were only single samples. All individual challenge chemical sample values constituting the triplicate analyses are presented in Table A-4 of Appendix A. The challenge water chemistry data are presented in Table A-6 of Appendix A.

Table 4-1. RO Membrane Inorganic Chemicals Reduction Data

Sample	Cadmium (µg/L)	Cesium (µg/L)	Mercury (µg/L)	Strontium (µg/L)	Cd, Cs, Sr Challenge TDS (mg/L)	Mercury Challenge TDS (mg/L)
Start-up Influent	1000	640	1200	940	740	660
Start-up Effluent, Unit 1	ND (0.3)	8	470	1	19	16
Start-up Effluent, Unit 2	0.3	7	520	ND (1)	16	12
3 rd Tank Influent	890	700	1300	950	750	650
3 rd Tank Effluent, Unit 1	0.4	12	670	ND (1)	14	15
3 rd Tank Effluent, Unit 2	0.3	10	670	ND (1)	12	14
5 th Tank/15 Hr. Influent	830	650	1200	860	750	420
5 th Tank/15 Hr. Effluent, Unit 1	0.5	13	710	ND (1)	15	14
5 th Tank/15 Hr. Effluent, Unit 2	ND (0.3)	11	720	ND (1)	13	11
Post-Rest 1 st Liter Draw, Unit 1	0.6	13	720	ND (1)	15	11
Post-Rest 1 st Liter Draw, Unit 2	ND (0.3)	11	740	ND (1)	14	12
Post-Rest 2 nd Sample, Unit 1	0.6	13	710	ND (1)	NA	NA
Post-Rest 2 nd Sample, Unit 2	ND (0.3)	11	740	ND (1)	NA	NA
Mean Influent	910	660	1200	920	750	580
Mean Effluent, Unit 1	0.5	12	650	1	16	14
Mean Effluent, Unit 2	0.3	10	680	ND (1)	14	12
Percent Reduction, Unit 1	> 99	99	46	> 99	98	98
Percent Reduction, Unit 2	> 99	99	44	> 99	98	98
Overall Mean Effluent	0.4	11	670	1	—	—
Overall Percent Reduction	> 99	99	44	> 99	—	—
Units Tested (Unit #'s)	5, 6	5, 6	1, 2	5, 6	—	—
Number of Tank-Fills Completed	4	4	5	4	—	—

The RO membrane removed 99% or more of the cadmium, cesium, and strontium. The membrane removed less than 50% of the mercury challenge, but this was not a surprising result. There are no POU RO systems certified by NSF for mercury reduction because mercury is not well removed by RO membranes using the test water specified in NSF/ANSI Standard 58.

4.4.2 Organic Chemical Challenges

The organic chemical challenge data are shown below in Table 4-2. Each data point is the arithmetic mean of the triplicate sample analyses, except where indicated, and for the post-rest first draw samples, which were only single samples. All individual sample values constituting the triplicate analyses are presented in Table A-5 in Appendix A. The challenge water chemistry data are presented in Table A-6 of Appendix A.

As discussed in Section 3.1.1, the challenge water also contained TDS to serve as a membrane integrity check. The TDS reduction data are presented in Table 4-3.

The reject water data are shown in Table 4-4. The values presented are the arithmetic means of the duplicate sample analyses. The individual sample results are presented in Table A-7 of Appendix A.

Table 4-2. RO Membrane Organic Chemical Challenge Data

Sample	Aldicarb (µg/L)	Benzene (µg/L)	Carbofuran (µg/L)	Chloroform (µg/L)	Dichlorvos (µg/L)	Dicrotophos (µg/L)	Fenamiphos (µg/L)	Mevinphos (µg/L)	Oxamyl (µg/L)	Strychnine (µg/L)
Start-up Influent	1100	900	1000	1100	560	900	1300	1200	1200	1000
Start-up Effluent, Unit 1	10	ND (0.5)	3	0.8	7.0	10	7	12	2	ND (5)
Start-up Effluent, Unit 2	4	0.5	3	0.8	12	20	ND (4)	10	1	ND (5)
3rd Tank Influent	1100	1100	1100	X	X	800	X	1200	1200	1000
3rd Tank Effluent, Unit 1	12	140	4	X	X	ND (10)	X	17	6	ND (5)
3rd Tank Effluent, Unit 2	7	99	5	X	X	20	X	22	5	5
15 hr. Influent	1200	1200	1100	1200	ND (8) ⁽¹⁾	860	990	1100	1000	1000
15 hr. Effluent, Unit 1	12	220	4	120	16	ND (10)	16	18	6	5
15 hr. Effluent, Unit 2	8	150	5	160	23	10	4	18	5	6
Post-Rest 1st Draw, Unit 1	12	270	4	290	15	ND (10)	22	19	4	6
Post-Rest 1st Draw, Unit 2	8	190	5	270	24	10	7	12	3	6
Post-Rest 2nd Sample, Unit 1	12	290	4	300	15	10	22	18	4	5
Post-Rest 2nd Sample, Unit 2	8	190	5	280	23	10	6	15	3	7
Mean Influent	1100	1100	1100	1100	560⁽²⁾	840	1200	1200	1100	1000
Mean Effluent, Unit 1	12	190	4	180	7.0⁽²⁾	10	17	17	4	5
Mean Effluent, Unit 2	7	120	5	180	12⁽²⁾	10	5	15	3	6
Percent Reduction, Unit 1	99	83	> 99	84	99	99	99	99	> 99	> 99
Percent Reduction, Unit 2	> 99	88	> 99	84	98	98	> 99	99	> 99	> 99
Overall Mean Effluent	10	160	5	180	10	10	11	16	4	6
Overall Percent Reduction	> 99	85	> 99	84	98	99	> 99	99	> 99	> 99
Units Tested (Unit #'s)	7, 8	3, 4	11, 12	1, 2	4, 5	13, 14	4, 5	17, 18	5, 6	19, 20
Number of Tank-Fills Completed	4	4	4	3	3	4	3	4	4	4

Note: The detection limit values were used for calculating the mean effluents and percent reductions.

X – Samples not collected

- (1) Influent sample was non-detect for the challenge chemical, likely due to sampling error (sampling from the wrong tap).
- (2) The mean influent and effluents are only the start-up sample means. The other influent and effluent data were not included because of the lack of 3rd tank and 15-hour influent data.

Table 4-3. TDS Reduction Data for Organic Chemical Challenges

Sample	Aldicarb TDS (mg/L)	Benzene TDS (mg/L)	Carbofuran TDS (mg/L)	Chloroform TDS (mg/L)	Dichlorvos TDS (mg/L)	Dicrotophos TDS (mg/L)	Fenamiphos TDS (mg/L)	Mevinphos TDS (mg/L)	Oxamyl TDS (mg/L)	Strychnine TDS (mg/L)
Start-up Influent	750	830	740	860	830	730	1200	450	750	780
Start-up Effluent, Unit 1	30	18	34	20	39	12	74	15	17	18
Start-up Effluent, Unit 2	24	19	46	22	37	13	55	16	20	24
3rd Tank Influent	740	790	740	X	X	630	X	620	750	770
3rd Tank Effluent, Unit 1	14	19	14	X	X	11	X	13	13	12
3rd Tank Effluent, Unit 2	12	14	14	X	X	13	X	12	12	12
15 hr. Influent	740	790	750	840	840	640	1100	590	740	760
15 hr. Effluent, Unit 1	15	19	12	24	27	14	59	13	13	12
15 hr. Effluent, Unit 2	12	14	12	24	45	11	44	13	12	12
Post-Rest 1 st Draw, Unit 1	15	19	12	25	28	11	56	13	13	13
Post-Rest 1 st Draw, Unit 2	12	14	13	25	43	13	39	12	12	13
Mean Influent	740	800	740	850	840	670	1200	550	750	770
Mean Effluent, Unit 1	19	19	18	23	31	12	63	14	14	14
Mean Effluent, Unit 2	15	15	21	24	42	13	46	13	14	15
Percent Reduction, Unit 1	98	98	98	97	96	98	95	98	98	98
Percent Reduction, Unit 2	98	98	97	97	95	98	96	98	98	98

Table 4-4. Organic Chemical Challenge Reject Water Data

Sample	Aldicarb (µg/L)	Benzene (µg/L)	Carbofuran (µg/L)	Chloroform (µg/L)	Dichlorvos (µg/L)	Dicrotophos (µg/L)	Fenamiphos (µg/L)	Mevinphos (µg/L)	Oxamyl (µg/L)	Strychnine (µg/L)
Start-up	2900	890	1100	940	300*	1000	680	810	1100	260
1/2 through 1 st Tank	1300	990	1300	1100	580	1200	1600	1300	1400	1200
3/4 through 1 st tank	1300	1000	1300	1100	570	1000	1600	1300	1300	1100
1/2 through Last Tank	1300	1300	1100	1200	510	1000	980	1200	1300	1100
Unit Sampled	7	3	11	1	4	13	4	17	5	19

*Reported number is one of the duplicate analyses, there was an analytical error with the second sample, so average not calculated

The RO membrane removed all chemicals but benzene and chloroform by 98% or more. However, please note that the dichlorvos mean influent, effluents and percent reductions are only from the start-up samples. Third tank samples were not collected, because the two systems tested had not yet completed their third tank-fills at the 15-hour point. The 15-hour and post-rest sample data was not used because the challenge chemical was not detected in the 15-hour influent samples. It is likely that the influent samples were collected from the wrong sample port, and the proper challenge water was being fed into the test units since the 15-hour effluent and post-rest effluent samples all had detectible levels of dichlorvos.

At start-up, the membranes removed greater than 99% of both benzene and chloroform, but the effluent levels rose after that from sample point to sample point. The maximum effluents were 290 µg/L for benzene, and 300 µg/L for chloroform. These effluents correspond to percent reductions of 74% and 73%, respectively, using the overall mean influents for the percent reduction calculations. Both of these substances are volatile, so perhaps volatility played a role in their passage through the membrane. They may have absorbed into and diffused through the membrane material. It is not apparent that benzene or chloroform began to degrade the integrity of the RO membrane, because the membranes maintained rejection of TDS as detailed in Table 4-3. There is also no evidence in Table 4-3 that any other chemicals adversely affected membrane TDS rejection.

Another possible factor in the lower rejection of benzene and chloroform is the low molecular weight of the compounds (78.1 and 119.4, respectively). RO membranes are known to be most effective at removing by size exclusion organic compounds with molecular weights over 200. However, this does not explain the greater than 99% removal at start-up.

The test plan called for each RO membrane to be challenged with only one of the organic chemicals. However, units 4 and 5 were used for both the dichlorvos and fenamiphos challenges after they were already used in other challenges. Unit 4 was first challenged with benzene, and unit 5 was first challenged with oxamyl. The dichlorvos and fenamiphos challenge data presented in Table 4-2 are from retests. The influent challenge levels from the first tests were below the allowable minimum level of 0.5 mg/L. By the time the influent samples had been analyzed, and then reanalyzed to confirm the low numbers, the test units had been discarded. Therefore, the retests had to be conducted with units already used for another challenge. The dichlorvos and fenamiphos data in Table 4-2 does not indicate that the membranes were compromised at all by exposure to benzene or oxamyl during the first challenges.

4.5 Post-Membrane Carbon Filter Challenges

Based on the RO membrane challenge results, and the criteria discussed in Section 3.1.2, the post-membrane carbon filter was challenged with benzene, chloroform, and mercury. The target challenge levels were the maximum effluent levels measured during the RO membrane challenges. Using the data from Section 4.1.1, the filters were operated at 0.3 gpm on an operation cycle where the “on” portion was 19 minutes, and the “off” portion was 3 hours and 45 minutes.

The carbon challenge results are shown below in Table 4-5. Each data point is the arithmetic mean of the triplicate sample analyses. All individual sample values constituting the triplicate analyses are presented in Table A-8 in Appendix A. The water chemistry data for these challenges can be found in Table A-9 of Appendix A.

The post-membrane carbon filters removed 98% of the mercury challenge, and greater than 99% of the benzene and chloroform challenges.

An examination of the data in Tables 4-1, 4-2 and 4-5 shows that the full WP-4V system with the RO membrane and post-membrane carbon filter working in concert removed all of the challenge chemicals by 98% or more.

Table 4-5. Post-Membrane Carbon Filter Challenge Data

Sample	Benzene (µg/L)	Chloroform (µg/L)	Mercury (µg/L)
Target Influent Level	290	300	740
Start-up Influent	280	300	820
Start-up Effluent, Unit 1	ND (0.5)	ND (0.5)	22
Start-up Effluent, Unit 2	ND (0.5)	ND (0.5)	28
7.5 Hours Influent	330	310	1000
7.5 Hours Effluent, Unit 1	ND (0.5)	ND (0.5)	1.3
7.5 Hours Effluent, Unit 2	ND (0.5)	ND (0.5)	1.3
15 Hours Influent	290	300	570
15 Hours Effluent, Unit 1	0.5	ND (0.5)	5.4
15 Hours Effluent, Unit 2	ND (0.5)	ND (0.5)	1.3
Mean Influent	300	300	800
Mean Effluent, Unit 1	0.5	ND (0.5)	9.6
Mean Effluent, Unit 2	ND (0.5)	ND (0.5)	10
Percent Reduction, Unit 1	> 99	> 99	99
Percent Reduction, Unit 2	> 99	> 99	99
Overall Mean Effluent	0.5	ND (0.5)	9.8
Overall Percent Reduction	> 99	> 99	99
Units Tested (Unit #'s)	3, 4	5, 6	7, 8

Note: The detection limit values were used for calculating the mean effluents and percent reductions.

Chapter 5 QA/QC

5.1 Introduction

An important aspect of verification testing is the QA/QC procedures and requirements. Careful adherence to the procedures ensured that the data presented in this report was of sound quality, defensible, and representative of the equipment performance. The primary areas of evaluation were representativeness, precision, accuracy, and completeness.

Because the ETV was conducted at the NSF testing lab, all laboratory activities were conducted in accordance with the provisions of the *NSF International Laboratories Quality Assurance Manual*.

5.2 Test Procedure QA/QC

NSF testing laboratory staff conducted the tests by following an NSF SOP created specifically for the tests. NSF QA Department Staff performed an informal audit during testing to ensure the proper procedures were followed.

All water chemistry measurements were within the specifications in Sections 3.2.3.1 and 3.2.3.2, except for the challenge water pH for the cadmium, cesium, and strontium challenge. The test/QA plan called for the pH to be between 6.0 and 6.5 to ensure that the metals remained dissolved. However, the lab technician responsible for the challenge instead adjusted the pH to 7.5 ± 0.5 , as was done for the organic chemical challenges. The substances' solubilities in water are all much higher than 1 mg/L, so it is unlikely that any significant amounts precipitated out of solution during the challenges, thus being mechanically filtered instead of being ionically rejected by the membrane.

All chemical challenge levels for the RO membranes were within the allowable range of 1.0 ± 0.5 mg/L, except for dichlorvos at the 15-hour sample point. As discussed in Section 4.4.2, the challenge chemical was not detected in the 15-hour influent samples. The samples were analyzed three times, each time no dichlorvos was detected. The laboratory fortified blanks and laboratory fortified blank duplicates showed acceptable recovery of the surrogates, internal standards, and dichlorvos. It is likely that the influent samples were collected from the wrong sample port, and the proper challenge water was being fed into the test units since the 15-hour effluent and post-rest effluent samples all had detectible levels of dichlorvos.

5.3 Sample Handling

All samples analyzed by the NSF Chemistry Laboratory were labeled with unique ID numbers. These ID numbers appear on the NSF laboratory reports for the tests. All samples were analyzed within allowable holding times.

5.4 Analytical Methods QA/QC

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

The NSF QA/QC requirements are all compliant with those given in the USEPA Method or Standard Method for the parameter. Also, every analytical instrument has an NSF SOP governing its use.

5.5 Documentation

All laboratory activities were documented using specially prepared laboratory bench sheets and NSF laboratory reports. Data from the bench sheets and laboratory reports were entered into Microsoft Excel spreadsheets. These spreadsheets were used to calculate average influents and effluents, and percent reductions for each challenge chemical. One hundred percent of the data entered into the spreadsheets was checked by a reviewer to confirm all data and calculations were correct.

5.6 Data Review

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

5.7 Data Quality Indicators

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

5.7.1 Representativeness

Representativeness refers to the degree to which the data accurately and precisely represent the conditions or characteristics of the parameter represented by the data, or the expected performance of the RO system under normal use conditions. Representativeness was ensured by consistent execution of the test protocol for each challenge chemical, including timing of sample collection, sampling procedures, and sample preservation. Representativeness was also ensured by using each analytical method at its optimum capability to provide results that represent the most accurate and precise measurement it is capable of achieving.

5.7.2 Accuracy

Accuracy was quantified as the percent recovery of the parameter in a sample of known quantity. Accuracy was measured through use of LFB and/or LFM samples of a known quantity, and certified standards during calibration of the instrument. The following equation was used to calculate percent recovery:

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

where: X_{known} = known concentration of the measured parameter
 X_{measured} = measured concentration of parameter

The accuracy of the benchtop chlorine, pH, TDS, and turbidity meters were checked daily during the calibration procedures using certified check standards. For samples analyzed in batches (gravimetric TDS, TOC, all challenge chemicals), certified QC standards, and LFB and/or LFM samples were run with each batch.

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

5.7.3 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. One sample per batch was analyzed in duplicate for the gravimetric TDS and TOC analyses. LFB and/or LFM samples were analyzed to measure precision for the challenge chemical analyses. Duplicate drinking water samples were analyzed as part of the daily calibration process for the benchtop chlorine, pH, TDS, and turbidity meters.

Precision of the duplicate analyses was measured by use of the following equation to calculate relative percent deviation (RPD):

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

where:

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

Precision of the LFB and LFM sample analyses was measured through calculation of the RSD as follows:

$$\%RSD = S(100) / X_{\text{average}}$$

where: S = standard deviation and
 X_{average} = the arithmetic mean of the recovery values.

Standard Deviation is calculated as follows:

$$\text{Standard Deviation} = \sqrt{\frac{\sum_{i=1}^n (X_i - X)^2}{n - 1}}$$

Where: X_i = the individual recovery values;
 \bar{X} = the arithmetic mean of the recovery values; and
 n = the number of determinations.

All RPDs were within NSF's established allowable limits for each parameter.

5.7.4 Completeness

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

Table 5-1. Completeness Requirements

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

Completeness is defined as follows for all measurements:

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

where:

$\%C$ = percent completeness;
 V = number of measurements judged valid; and
 T = total number of measurements.

5.7.4.1 Number of Systems Tested

Twenty systems were tested, as called for in the test/QA plan. However the reported results did not come from twenty systems. As discussed in Section 4.4.2, the results from the first dichlorvos and fenamiphos challenges were not reported, and the systems used for those tests were discarded before it was known that the tests would have to be conducted over again. Therefore, the reported results came from only 16 systems. This gives a completeness of 80% for the number of systems tested.

5.7.4.2 Water Chemistry Measurements

All of the planned samples were collected, and acceptable results were reported for all water chemistry measurements.

5.7.4.3 Challenge Chemicals

All planned samples were collected, but results for four dichlorvos challenge samples were deemed unacceptable due to analytical or sampling error. The samples in question are the three 15-hour influent triplicate samples, and one of the start-up reject water duplicate samples. Discarding these sample results gives acceptable results from 30 of the 34 dichlorvos samples collected, for a completeness of 88%.

Chapter 6 References

- APHA, AWWA and WEF (1998). *Standard Methods for Examination of Water and Wastewater*. 20th ed. Washington, D.C. APHA.
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- Slovak, Robert (2000). *A Practical Application Manual for Residential, Point of Use Reverse Osmosis Systems*. Lisle, IL, Water Quality Association
- USEPA (2004). Water Security Research and Technical Support Action Plan. EPA/600/R-04/063.

Appendix A
Conditioning and Chemical Challenges Data Tables

Table A-1. RO Membrane Conditioning Water Chemistry Data

Sample	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Group A, Units 1-11							
pH	7.9	7.2	7.1	7.9	7.2	7.0	7.5
Temperature (°C)	26	26	26	26	26	24	26
Total Chlorine (mg/L)	ND (0.05)	0.06	ND (0.05)				
TDS (mg/L)	760	780	750	740	780	780	750
Turbidity (NTU)	ND (0.1)	ND (0.1)	ND (0.1)	0.1	ND (0.1)	ND (0.1)	0.2
Group B, Units 12-20							
pH	7.3	7.2	7.7	7.6	7.7	7.9	7.9
Temperature (°C)	26	25	26	25	26	26	24
Total Chlorine (mg/L)	ND (0.05)						
TDS (mg/L)	750	740	780	780	780	740	740
Turbidity (NTU)	ND (0.1)	ND (0.1)	0.1	ND (0.1)	0.1	ND (0.1)	0.1

Table A-2. RO Membrane TDS Reduction System Check Data

Sample	pH	Temperature (°C)	Total Chlorine (mg/L)	Turbidity (NTU)	Influent TDS (mg/L)	Effluent TDS (mg/L)	Percent Reduction
Group 1 Influent	7.4	26	ND (0.05)	ND (0.1)	780		
Unit 1						17	98
Unit 2						18	98
Unit 3						23	97
Unit 4						19	98
Unit 5						18	98
Unit 6						16	98
Unit 7						19	98
Unit 8						17	98
Unit 9						19	98
Unit 10						22	97
Unit 11						19	98
Group 2 Influent	7.4	25	ND (0.05)	0.1	750		
Unit 12						19	97
Unit 13						19	97
Unit 14						18	98
Unit 15						16	98
Unit 16						17	98
Unit 17						18	98
Unit 18						17	98
Unit 19						15	98
Unit 20						17	98

Table A-3. Carbon Filter Conditioning Influent Water Chemistry

Sample Point		Chloroform (µg/L)	pH	Temperature (°C)	Total Organic Carbon (mg/L)	Turbidity (NTU)
Unit 1, Start-Up	Influent	430	7.3	21	20*	0.2
	Effluent	ND (0.5)				
Unit 1, 25% of Capacity	Influent	460	7.4	22	2.9	0.1
	Effluent	ND (0.5)				
Unit 1, 50% of Capacity	Influent	480	7.4	21	2.9	ND (0.1)
	Effluent	ND (0.5)				
Unit 2, Start-Up	Influent	430	7.3	21	20*	0.2
	Effluent	ND (0.5)				
Unit 2, 25% of Capacity	Influent	470	7.4	22	2.9	0.1
	Effluent	ND (0.5)				
Unit 2, 50% of Capacity	Influent	500	7.4	21	2.9	ND (0.1)
	Effluent	ND (0.5)				
Unit 3, Start-Up	Influent	430	7.3	21	20*	0.2
	Effluent	ND (0.5)				
Unit 3, 25% of Capacity	Influent	490	7.4	21	2.9	ND (0.1)
	Effluent	ND (0.5)				
Unit 3, 50% of Capacity	Influent	470	7.4	21	2.9	0.8
	Effluent	ND (0.5)				
Unit 4, Start-Up	Influent	430	7.3	21	20*	0.2
	Effluent	ND (0.5)				
Unit 4, 25% of Capacity	Influent	490	7.4	21	2.9	ND (0.1)
	Effluent	ND (0.5)				
Unit 4, 50% of Capacity	Influent	520	7.4	21	3.0	0.8
	Effluent	ND (0.5)				
Unit 5, Start-Up	Influent	430	7.4	22	20*	ND (0.1)
	Effluent	ND (0.5)				
Unit 5, 25% of Capacity	Influent	490	7.4	22	2.9	0.1
	Effluent	ND (0.5)				
Unit 5, 50% of Capacity	Influent	470	7.3	22	2.9	ND (0.1)
	Effluent	ND (0.5)				
Unit 6, Start-Up	Influent	430	7.4	22	20*	ND (0.1)
	Effluent	ND (0.5)				
Unit 6, 25% of Capacity	Influent	470	7.4	22	2.9	0.1
	Effluent	160				
Unit 6, 50% of Capacity	Influent	480	7.3	22	2.9	ND (0.1)
	Effluent	ND (0.5)				
Unit 7, Start-Up	Influent	430	7.4	22	20*	ND (0.1)
	Effluent	ND (0.5)				
Unit 7, 25% of Capacity	Influent	470	7.4	21	2.9	ND (0.1)
	Effluent	ND (0.5)				
Unit 7, 50% of Capacity	Influent	480	7.3	21	2.9	ND (0.1)
	Effluent	ND (0.5)				
Unit 8, Start-Up	Influent	430	7.4	22	20*	ND (0.1)
	Effluent	ND (0.5)				
Unit 8, 25% of Capacity	Influent	470	7.4	21	2.9	ND (0.1)
	Effluent	ND (0.5)				
Unit 8, 50% of Capacity	Influent	500	7.3	21	2.9	ND (0.1)
	Effluent	ND (0.5)				

* TOC measured after addition of chloroform, which was in a methanol solution. High TOC readings were due to the methanol.

Table A-4. RO Membrane Inorganic Chemicals Challenge Data

Sample	Cadmium (µg/L)	Cesium (µg/L)	Mercury (µg/L)	Strontium (µg/L)
Start-up Influent				
Triplicate Sample 1	1000	640	1200	940
Triplicate Sample 2	1000	640	1200	950
Triplicate Sample 3	1000	640	1200	920
Mean	1000	640	1200	940
Start-up Effluent, Unit 1				
Triplicate Sample 1	ND (0.3)	8	430	ND (1)
Triplicate Sample 2	ND (0.3)	7	460	1
Triplicate Sample 3	ND (0.3)	8	510	ND (1)
Mean	ND (0.3)	8	470	1
Start-up Effluent, Unit 2				
Triplicate Sample 1	ND (0.3)	6	480	ND (1)
Triplicate Sample 2	ND (0.3)	7	550	ND (1)
Triplicate Sample 3	0.3	7	530	ND (1)
Mean	0.3	7	520	ND (1)
3rd Tank Influent				
Triplicate Sample 1	910	710	1300	960
Triplicate Sample 2	890	700	1200	960
Triplicate Sample 3	880	690	1300	930
Mean	890	700	1300	950
3rd Tank Effluent, Unit 1				
Triplicate Sample 1	0.5	12	670	ND (1)
Triplicate Sample 2	0.4	11	670	ND (1)
Triplicate Sample 3	0.4	12	660	ND (1)
Mean	0.4	12	670	ND (1)
3rd Tank Effluent, Unit 2				
Triplicate Sample 1	ND (0.3)	10	670	ND (1)
Triplicate Sample 2	ND (0.3)	10	660	ND (1)
Triplicate Sample 3	0.3	10	670	ND (1)
Mean	0.3	10	670	ND (1)
15-Hour Influent				
Triplicate Sample 1	840	650	1100	870
Triplicate Sample 2	810	630	1100	850
Triplicate Sample 3	830	660	1300	860
Mean	830	650	1200	860
15-Hour Effluent, Unit 1				
Triplicate Sample 1	0.6	13	710	ND (1)
Triplicate Sample 2	0.4	12	700	ND (1)
Triplicate Sample 3	0.5	13	710	ND (1)
Mean	0.5	13	710	ND (1)
15-Hour Effluent, Unit 2				
Triplicate Sample 1	ND (0.3)	11	730	ND (1)
Triplicate Sample 2	ND (0.3)	11	720	ND (1)
Triplicate Sample 3	ND (0.3)	11	720	ND (1)
Mean	ND (0.3)	11	720	ND (1)
Post-Rest 1st Draw, Unit 1				
Post-Rest 1st Draw, Unit 1	0.6	13	720	ND (1)
Post-Rest 1st Draw, Unit 2				
Post-Rest 1st Draw, Unit 2	ND (0.3)	11	740	ND (1)
Post-Rest 2nd Sample, Unit 1				
Triplicate Sample 1	0.6	13	710	ND (1)
Triplicate Sample 2	0.6	14	700	ND (1)
Triplicate Sample 3	0.6	13	720	ND (1)
Mean	0.6	13	710	ND (1)
Post-Rest 2nd Sample, Unit 2				
Triplicate Sample 1	ND (0.3)	11	740	ND (1)
Triplicate Sample 2	ND (0.3)	12	740	ND (1)
Triplicate Sample 3	ND (0.3)	11	740	ND (1)
Mean	ND (0.3)	11	740	ND (1)

Table A-5. RO Membrane Organic Chemical Challenge Data

Sample	Aldicarb (µg/L)	Benzene (µg/L)	Carbofuran (µg/L)	Chloroform (µg/L)	Dichlorvos (µg/L)	Dicrotophos (µg/L)	Fenamiphos (µg/L)	Mevinphos (µg/L)	Oxamyl (µg/L)	Strychnine (µg/L)
Start-up Influent										
Triplicate Sample 1	1100	910	1000	1100	590	800	1400	1200	1200	1000
Triplicate Sample 2	1100	900	1000	1000	550	1000	1400	1200	1200	1000
Triplicate Sample 3	1100	880	1000	1100	540	900	1200	1100	1200	1000
Mean	1100	900	1000	1100	560	900	1300	1200	1200	1000
Start-up Effluent, Unit 1										
Triplicate Sample 1	3	ND (0.5)	3	0.6	1.7	10	ND (4)	7.1	ND (1)	ND (5)
Triplicate Sample 2	10	ND (0.5)	3	0.6	8.4	ND (10)	8	14	1	ND (5)
Triplicate Sample 3	16	ND (0.5)	3	1.3	11	10	10	15	3	ND (5)
Mean	10	ND (0.5)	3	0.8	7.0	10	7	12	2	ND (5)
Start-up Effluent, Unit 2										
Triplicate Sample 1	ND (1)	ND (0.5)	3	0.7	3.9	10	ND (4)	6.2	ND (1)	ND (5)
Triplicate Sample 2	4	0.5	3	0.8	15	20	ND (4)	12	2	ND (5)
Triplicate Sample 3	8	ND (0.5)	3	1.0	18	20	ND (4)	13	1	ND (5)
Mean	4	0.5	3	0.8	12	20	ND (4)	10	1	ND (5)
3rd Tank Influent										
Triplicate Sample 1	1100	1000	1100	X	X	800	X	1400	1200	1000
Triplicate Sample 2	1100	1300	1100	X	X	700	X	1200	1200	1000
Triplicate Sample 3	1100	1000	1100	X	X	800	X	1000	1200	1000
Mean	1100	1100	1100			770		1200	1200	1000
3rd Tank Effluent, Unit 1										
Triplicate Sample 1	12	120	4	X	X	ND (10)	X	16	6	ND (5)
Triplicate Sample 2	12	160	4	X	X	ND (10)	X	17	6	ND (5)
Triplicate Sample 3	12	140	4	X	X	ND (10)	X	17	6	ND (5)
Mean	12	140	4			ND (10)		17	6	ND (5)
3rd Tank Effluent, Unit 2										
Triplicate Sample 1	7	96	5	X	X	20	X	27	4	5
Triplicate Sample 2	8	100	5	X	X	20	X	18	5	5
Triplicate Sample 3	7	100	5	X	X	10	X	20	5	5
Mean	7	99	5			20		22	5	5
15-Hour Influent										
Triplicate Sample 1	1200	1300	1100	1200	ND (8.0)	1000	1000	1200	1000	1000
Triplicate Sample 2	1200	1100	1100	1200	ND (8.0)	870	990	1100	1100	1000
Triplicate Sample 3	1100	1300	1100	1200	ND (8.0)	700	980	1100	1000	1000
Mean	1200	1200	1100	1200	ND (8.0)	860	990	1100	1000	1000
15-Hour Effluent, Unit 1										
Triplicate Sample 1	12	230	4	110	15	ND (10)	18	17	6	ND (5)
Triplicate Sample 2	12	220	4	140	16	ND (10)	14	19	6	5
Triplicate Sample 3	12	220	4	120	16	ND (10)	15	18	6	5
Mean	12	220	4	120	16	ND (10)	16	18	6	5
15-Hour Effluent, Unit 2										
Triplicate Sample 1	8	140	5	150	24	10	4	18	5	6
Triplicate Sample 2	8	160	5	170	23	20	4	17	5	6
Triplicate Sample 3	8	140	5	170	23	10	4	18	5	6
Mean	8	150	5	160	23	10	4	18	5	6
Post-Rest 1st Draw, Unit 1										
Post-Rest 1st Draw, Unit 1	12	270	4	290	15	ND (10)	22	19	4	6
Post-Rest 1st Draw, Unit 2										
Post-Rest 1st Draw, Unit 2	8	190	5	270	24	10	7	12	3	6
Post-Rest 2nd Sample, Unit 1										
Triplicate Sample 1	12	290	4	300	15	ND (10)	23	18	4	5
Triplicate Sample 2	12	280	4	290	15	10	19	18	4	5
Triplicate Sample 3	12	310	4	310	15	ND (10)	23	17	4	5
Mean	12	290	4	300	15	10	22	18	4	5
Post-Rest 2nd Sample, Unit 2										
Triplicate Sample 1	8	190	5	280	23	ND (10)	7	13	3	7
Triplicate Sample 2	8	180	5	280	23	10	6	16	3	7
Triplicate Sample 3	8	190	5	280	23	10	6	16	3	7
Mean	8	190	5	280	23	10	6	15	3	7

Table A-6. RO Membrane Challenges Water Chemistry Data

Sample	Cd, Cs, Sr Challenge	Mercury Challenge	Aldicarb Challenge	Benzene Challenge	Carbofuran Challenge	Chloroform Challenge	Dichlorvos Challenge	Dicrotophos Challenge	Fenamiphos Challenge	Mevinphos Challenge	Oxamyl Challenge	Strychnine Challenge
Start-up Influent												
pH	7.6	6.5	7.4	7.3	7.5	7.5	7.7	7.4	7.4	7.4	7.4	7.6
Temperature (°C)	24	25	24	24	24	24	25	26	25	25	24	25
Total Chlorine (mg/L)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)
Turbidity (NTU)	0.3	0.1	ND (0.1)	0.2	ND (0.1)	0.1	ND (0.1)	ND (0.1)	ND (0.1)	0.1	ND (0.1)	ND (0.1)
15-Hour Influent												
pH	7.3	6.1	7.3	7.2	7.3	7.1	7.3	7.4	7.3	7.5	7.3	7.3
Temperature (°C)	24	24	24	24	24	24	22	26	25	25	24	24
Total Chlorine (mg/L)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)
Turbidity (NTU)	ND (0.1)	ND (0.1)	ND (0.1)	ND (0.1)	ND (0.1)	0.5	ND (0.1)	0.5	0.2	ND (0.1)	ND (0.1)	ND (0.1)

Table A-7. RO Membrane Organic Chemical Challenges Reject Water Data

Sample	Aldicarb (µg/L)	Benzene (µg/L)	Carbofuran (µg/L)	Chloroform (µg/L)	Dichlorvos (µg/L)	Dicrotophos (µg/L)	Fenamiphos (µg/L)	Mevinphos (µg/L)	Oxamyl (µg/L)	Strychnine (µg/L)
Start-up										
Duplicate Sample 1	2900	860	1100	930	30 ⁽¹⁾	1000	810	680	1100	180
Duplicate Sample 2	2900	910	1100	940	300	900	540	940	1100	330
Mean	2900	890	1100	940	300	950	680	810	1100	260
1/2 Through First Tank										
Duplicate Sample 1	1300	1000	1300	1100	590	1100	1500	1300	1400	1200
Duplicate Sample 2	1300	980	1300	1100	570	1200	1600	1200	1400	1200
Mean	1300	990	1300	1100	580	1200	1600	1300	1400	1200
3/4 Through First Tank										
Duplicate Sample 1	1200	920	1300	1100	570	900	1500	1200	1300	1100
Duplicate Sample 2	1300	1100	1200	1100	570	1000	1600	1300	1300	1100
Mean	1300	1000	1300	1100	570	970	1600	1300	1300	1100
1/2 Through Last Tank										
Duplicate Sample 1	1200	1300	1100	1200	500	900	950	1200	1200	1100
Duplicate Sample 2	1300	1300	1100	1200	520	1000	1000	1200	1300	1100
Mean	1300	1300	1100	1200	510	970	980	1200	1300	1100

(1) Result not used for mean calculation, due to a likely dilution error.

Table A-8. Post-Membrane Carbon Filter Challenges Data

Sample	Mercury (µg/L)	Benzene (µg/L)	Chloroform (µg/L)
Target Influent Level	740	290	300
Start-up Influent			
Triplicate Sample 1	810	280	300
Triplicate Sample 2	810	280	300
Triplicate Sample 3	840	280	300
Mean	820	280	300
Start-up Effluent, Unit 1			
Triplicate Sample 1	8.9	ND (0.5)	ND (0.5)
Triplicate Sample 2	17	ND (0.5)	ND (0.5)
Triplicate Sample 3	39	ND (0.5)	ND (0.5)
Mean	22	ND (0.5)	ND (0.5)
Start-up Effluent, Unit 2			
Triplicate Sample 1	40	ND (0.5)	ND (0.5)
Triplicate Sample 2	37	ND (0.5)	ND (0.5)
Triplicate Sample 3	7.4	ND (0.5)	ND (0.5)
Mean	28	ND (0.5)	ND (0.5)
7.5 Hours Influent			
Triplicate Sample 1	1000	300	310
Triplicate Sample 2	1000	340	310
Triplicate Sample 3	1000	350	310
Mean	1000	330	310
7.5 Hours Effluent, Unit 1			
Triplicate Sample 1	1.3	ND (0.5)	ND (0.5)
Triplicate Sample 2	1.3	ND (0.5)	ND (0.5)
Triplicate Sample 3	1.4	ND (0.5)	ND (0.5)
Mean	1.3	ND (0.5)	ND (0.5)
7.5 Hours Effluent, Unit 2			
Triplicate Sample 1	1.3	ND (0.5)	ND (0.5)
Triplicate Sample 2	1.2	ND (0.5)	ND (0.5)
Triplicate Sample 3	1.4	ND (0.5)	ND (0.5)
Mean	1.3	ND (0.5)	ND (0.5)
15 Hours Influent			
Triplicate Sample 1	590	290	300
Triplicate Sample 2	570	290	300
Triplicate Sample 3	550	290	300
Mean	570	290	300
15 Hours Effluent, Unit 1			
Triplicate Sample 1	5.6	0.5	ND (0.5)
Triplicate Sample 2	5.3	0.5	ND (0.5)
Triplicate Sample 3	5.3	0.5	ND (0.5)
Mean	5.4	0.5	ND (0.5)
15 Hours Effluent, Unit 2			
Triplicate Sample 1	1.5	ND (0.5)	ND (0.5)
Triplicate Sample 2	1.0	ND (0.5)	ND (0.5)
Triplicate Sample 3	1.3	ND (0.5)	ND (0.5)
Mean	1.3	ND (0.5)	ND (0.5)

Table A-9. Post-Membrane Carbon Filter Challenges Water Chemistry Data

Sample	Mercury Challenge	Benzene Challenge	Chloroform Challenge
Start-up Influent			
pH	7.3	7.3	7.3
Temperature (°C)	22	21	22
Total Chlorine (mg/L)	0.83	0.57	0.79
TOC (mg/L)	3.0	57	50
TDS (mg/L)	300	330	350
Turbidity (NTU)	0.2	ND (0.1)	ND (0.1)
7.5 Hour Influent			
pH	7.2	7.3	7.4
Temperature (°C)	22	22	22
Total Chlorine (mg/L)	0.96	1.5	1.5
TOC (mg/L)	2.8	53	50
TDS (mg/L)	330	320	340
Turbidity (NTU)	0.2	0.1	0.1
15 Hour Influent			
pH	7.2	7.1	7.3
Temperature (°C)	20	22	22
Total Chlorine (mg/L)	1.2	0.68	1.8
TOC (mg/L)	3.2	53	50
TDS (mg/L)	320	320	350
Turbidity (NTU)	0.5	0.2	ND (0.1)