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Environmental Technology Verification Report

Removal of Chemical Contaminants in Drinking Water

EcoWater Systems Incorporated ERO-R450E Drinking Water Treatment System

Prepared by

NSF International

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

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**POINT-OF-USE DRINKING WATER TREATMENT SYSTEM**
APPLICATION:	**REMOVAL OF CHEMICAL CONTAMINANTS IN DRINKING WATER**
PRODUCT NAME:	**ECOWATER SYSTEMS ERO-R450E**
COMPANY:	**ECOWATER SYSTEMS, INC.**
ADDRESS:	**1890 WOODLANE DRIVE**
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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 EcoWater Systems ERO-R450E 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 permitters), and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

ABSTRACT

The EcoWater Systems ERO-R450E POU drinking water treatment system was tested for removal of aldicarb, benzene, cadmium, carbofuran, cesium, chloroform, dichlorvos, dicrotophos, fenamiphos, mercury, mevinphos, oxamyl, strontium, and strychnine. The ERO-R450E employs a reverse osmosis (RO) membrane and activated carbon filters to treat drinking water. Treated water is stored in a 3.1-gallon capacity storage tank. 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 organic chemical the RO membrane did not remove to below 30 μg/L. The carbon filter was also challenged with cesium and mercury because the membranes did not remove these two substances as well as total dissolved solids (TDS) in general. 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. Each pair of membranes was tested with only one of the ten organic chemicals because of concern that a chemical could compromise the integrity of the membrane or membrane seals. One pair of RO membrane components was also challenged with the inorganic chemicals. 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 ERO-R450E as a whole, considering both the RO membrane challenge and post-membrane carbon filter challenge results combined, reduced all of the challenge chemicals but cesium by 94% or more.

TECHNOLOGY DESCRIPTION

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

The ERO-R450E is a three-stage POU drinking water treatment system, employing an RO membrane, and activated carbon filters both upstream and downstream of the membrane. The system includes a 3.1-gallon maximum capacity pressurized bladder tank for storing the treated water, and a faucet to mount on the kitchen sink. The influent water first passes through a carbon filter designed to remove chlorine and particulate matter, such as rust and silt. The second stage of treatment is the reverse osmosis membrane, which reduces a wide variety of contaminants. The permeate water is sent to the storage tank. When the user opens the faucet, the partially treated water leaves the storage tank, passes through a second carbon filter to remove organic chemicals and any taste and odor chemicals, and then exits the faucet.

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 activates an automatic shut-off device, stopping the flow of water through the system. After a portion of the water is dispensed from the storage tank, the shut-off device deactivates, allowing water to again flow into the system until the storage tank is nearly full.

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 EcoWater Systems ERO-R450E 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. The complete ERO-R450E system, including the storage tank, was used for the RO membrane challenges, but the carbon filters were removed, leaving empty housings. 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. Each pair was tested with only one of the ten organic chemicals because of concern that a chemical, especially benzene or chloroform, could compromise the integrity of the membrane or membrane seals. One pair of RO membrane components was also challenged with the inorganic chemicals. The inorganic chemical challenges were conducted prior to the organic chemical challenges to eliminate the possibility of damage to the membranes that could bias the inorganic chemical test results. 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	

Prior to challenge testing, the RO membrane components were service-conditioned for seven days by feeding the systems the test water without any chemical spikes. After completion of the conditioning period, the membranes were subjected to a TDS reduction test using sodium chloride to verify that they were operating properly.

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 the 5th tank fill, and the next morning after the membranes rested under pressure overnight.

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 carbon filter was also challenged with cesium and mercury because the membranes did not remove these two substances as well as total dissolved solids (TDS) in general. The filters were attached to a separate manifold that was of the same design as the manifold in the full RO system. The pre-membrane carbon filter was not tested because it is only designed to remove chlorine to protect the RO membrane. 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 target chloroform concentration was 300 ± 90 μg/L, which is the influent challenge concentration for the VOC reduction test in NSF/ANSI Standard 53 (chloroform is the surrogate challenge chemical for the test). The filters were operated at a flow rate of 0.5 gallons per minute (gpm) for 375 gallons (EcoWater System's design capacity for the filter is 750 gallons).

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 on an "on/off" operation cycle where the "on" portion was the time required to empty the system storage tank when full, and the "off" portion was 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 94% or more of all challenge chemicals except cesium and mercury. The membrane removed 82% of cesium, and only 9% of the mercury challenge.

Table 2. RO Membrane Challenge Data

Chemical	Mean Influent (μg/L)	Mean Effluent (μg/L)	Percent Reduction (%)
Cadmium	960	33	97
Cesium	930	170	82
Mercury	1100	1000	9
Strontium	960	33	97
Aldicarb	1000	20	98
Benzene	980	7.1	> 99
Carbofuran	1100	19	98
Chloroform	1100	61	94
Dichlorvos	1300	69	95
Dicrotophos	1100	57	95
Fenamiphos	930	4	> 99
Mevinphos	1200	46	96
Oxamyl	980	10	99
Strychnine	1100	10	> 99

The TDS reduction by each membrane component for all challenge tests was 87% or higher. The effluent TDS levels for some of the chemical challenges rose from one sample point to the next over the challenge period, but no TDS levels were significantly higher than the maximum TDS levels measured during TDS reduction tests conducted on each unit after conditioning. Thus, the rising TDS levels likely do not indicate that the membrane components were becoming significantly compromised due to exposure to the chemicals. The increase may have been due to the challenge protocol design. The challenges began with empty storage tanks, so there was no back-pressure on the membranes when the start-up samples, which all had the lowest observed TDS levels, were collected. Most of the challenge chemical levels were also lowest in the start-up samples. The rest of the samples were collected after the membranes had been operating facing back-pressure from the storage tanks. RO membranes perform better without back-pressure, so the higher TDS levels are likely more indicative of the performance of the RO system under normal operating conditions.

The post-membrane carbon filter components were challenged with chloroform, dichlorvos, dicrotophos, and mevinphos based on the criteria that the RO membrane challenge effluents were above 30 μg/L. The carbon filters were also challenged with cesium and mercury. The target challenge levels were the maximum effluent levels measured during the RO membrane challenges. The carbon filters were operated at 1.15 gpm on an operating cycle where the "on" portion was five minutes and eleven seconds, and the "off" portion was one hour and ten minutes.

The carbon challenge results are shown below in Table 3. Note that the percent reduction of dicrotophos was limited by the detection limit for the chemical. The carbon filter removed 89% or more of all of the challenge chemicals but cesium, which was effectively not removed at all by the carbon.

Table 3. Post-Membrane Carbon Filter Challenge Data

Chemical	Mean Influent (μg/L)	Mean Effluent (μg/L)	Percent Reduction (%)
Cesium	230	220	4.3
Mercury	760	35	95
Chloroform	100	0.7	> 99
Dichlorvos	100	3.9	96
Dicrotophos	90	ND (10)	89
Mevinphos	40	2.1	95

The RO membrane and carbon challenge data combined shows that the two treatment technologies working in concert within the ERO-R450E system removed 97% or more of all challenge chemicals but cesium.

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

QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

NSF ETV and QA staff monitored the testing activities to ensure that the testing was in compliance with the test plan. NSF also conducted a data quality audit of 100% of the data. Please see the verification report referenced below for more QA/QC information.

Original signed by Andrew Avel, 10/25/05	*Original signed by Robert Ferguson, 11/07/05*
Andrew P. Avel Date	Robert Ferguson Date
Acting Director	Vice President
National Homeland Security Research Center	Water Systems
United States Environmental Protection Agency	NSF International

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

Availability of Supporting Documents
Copies of the test protocol, the verification statement, and the verification report (NSF report # NSF 04/14b/EPADWCTR) are available from the following sources:
(NOTE: Not all of the appendices are included in the verification report. The appendices are available from NSF upon request.)

1. ETV Drinking Water Systems Center Manager (order hard copy)
   NSF International
   P.O. Box 130140
   Ann Arbor, Michigan 48113-0140
2. NSF web site: http://www.nsf.org/etv/dws/dws_reports.html, and from http://www.nsf.org/etv/dws/dws_project_documents.html (electronic copy)
   EPA web site: http://www.epa.gov/etv (electronic copy)

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ERO-R450E Drinking Water Treatment System

Prepared by:

NSF International
Ann Arbor, Michigan 48105

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

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

Notice

The U.S. Environmental Protection Agency (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

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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:

EcoWater Systems Incorporated
1890 Woodlane Drive
Woodbury, MN 55125

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 permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, 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 ERO-R450E was entitled *Test/QA Plan for Verification Testing of the EcoWater Systems ERO-R450E 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.

Table 1-1. 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	

1.5 Testing Participants and Responsibilities

The ETV testing of the ERO-R450E was a cooperative effort between the following participants:

NSF
EcoWater Systems 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.

Contact Information:

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

1.5.2 EcoWater Systems Inc.

The ERO-R450E is manufactured by EcoWater Systems Inc., a manufacturer of residential and commercial water treatment products.

The manufacturer was responsible for supplying the RO systems in accordance with Section 3.1.1, and for providing logistical and technical support as needed.

Contact Information:

EcoWater Systems Inc.
1890 Woodland Drive
Woodbury, MN 55125
Phone: 1-800-808-9899
Contact Person: Ms. Ann Baumann

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 and 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 ERO-R450E is certified by NSF to NSF/ANSI Standard 58 – *Reverse Osmosis Drinking Water Treatment Systems*. The system has a certified production rate of 22.2 gallons per day. This measurement is based on system operation at 50 pounds per square inch (psi) inlet pressure, a water temperature of 77 °F, 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 ERO-R450E is a three-stage POU treatment system, employing an RO membrane, and activated carbon filtration both upstream and downstream of the membrane. The system includes a 3.1-gallon maximum capacity pressurized bladder tank for storing the treated water, and a faucet to mount on the kitchen sink. A photograph of the system is shown in Figure 2-1. Please note that the information given in this section, and Section 2.4 is for informational purposes only, and is not subject to verification.

Figure 2-1. Photograph of the ERO-R450E

2.4 System Operation

Incoming water first passes through a carbon filter designed to remove chlorine and particulate matter, such as rust and silt. The second stage of treatment is the reverse osmosis membrane, which reduces 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 the storage tank. When the user opens the faucet, the partially treated water leaves the storage tank, passes through a second carbon filter to remove organic chemicals, mercury, and any taste and odor chemicals, and then exits the faucet. Figure 2-2 shows a schematic diagram of the ERO-R450E, with the path of water through the system illustrated.

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 device to activate, stopping the flow of water through the system. After a portion of the water is dispensed from the storage tank, the shut-off device deactivates, allowing water to again flow into the system until the storage tank is nearly full. The operational storage tank capacity will vary slightly from system to system, and may also be affected by the inlet water pressure. The capacity was measured to be approximately 2.5 gallons when the system was tested for NSF/ANSI Standard 58 certification.

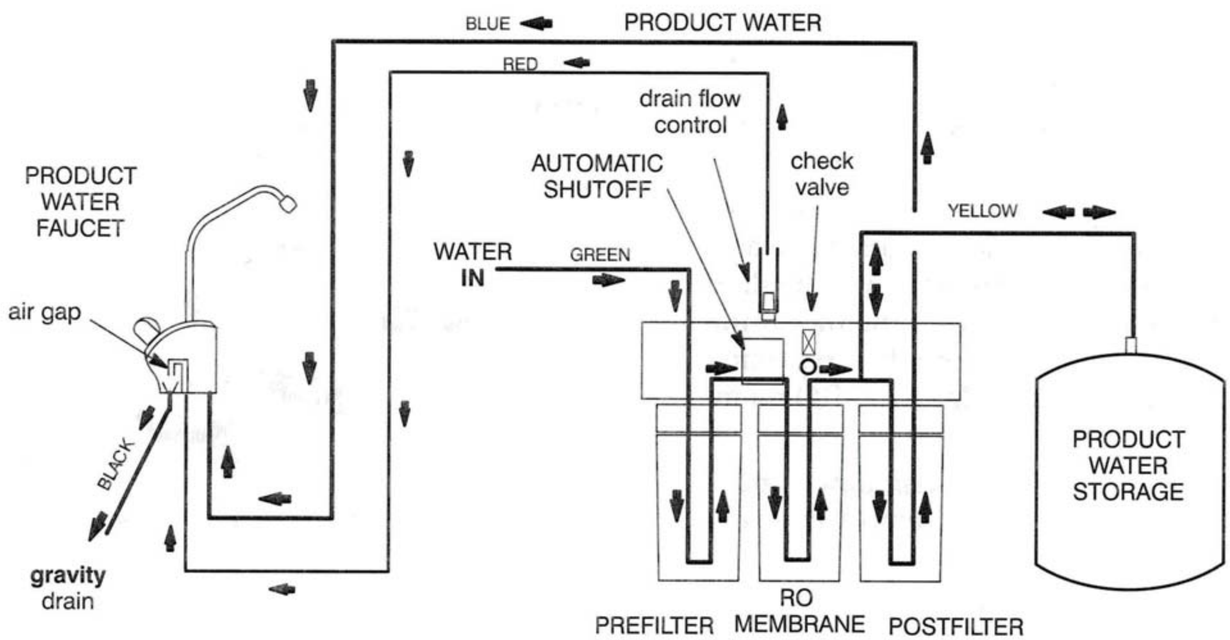

Figure 2-2. Schematic Diagram of the ERO-R450E

The ERO-R450E has a volume meter and TDS level meters that measure the volume of treated water produced, and the level of TDS in the influent and effluent water. The faucet has a three colored indicator light to tell the user when to replace the carbon filters and RO membrane. Under normal operation, the indicator light is green. After six months have passed, or 750 gallons of treated water have been produced, the light changes to amber, indicating that the carbon filters need to be replaced. The light turns red when the RO membrane's TDS rejection falls below 75%, as measured by comparing the influent and effluent TDS levels. When the red light comes on, the RO membrane should be replaced. The user must reset the meters each time any treatment elements are replaced.

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 ERO-R450E is 9.7%, which means the system produces approximately nine 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

EcoWater Systems gives the following operation limitations:

- feed water temperature of 40-100°F;
- feed water pressure of 40-100 psi;
- feed water pH 4-10;
- non-detectable iron, manganese, or hydrogen sulfide in the feed water supply;
- maximum inlet water TDS level of 2,000 mg/L;
- inlet water hardness of less than 10 grains per gallon (1 grain per gallon equals 17.1 mg/L, expressed as calcium carbonate equivalent); and
- maximum inlet water chlorine level of 2 mg/L.

2.7 Operation and Maintenance Requirements

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

- Replacement of the carbon filters when indicated by the meter (every six months or 750 gallons);
- Replacement of the RO membrane cartridge when indicated by the meter; and
- Sanitization of the system when the carbon filters or RO membrane are replaced (instructions included in the owner's manual.)

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 EcoWater Systems ERO-R450E Point-of-Use Drinking Water Treatment System for Removal of Chemical Contamination Agents*.

As described in Section 2.3, the ERO-R450E employs an RO membrane 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 test water that presented more of a worse-case scenario for that component. The pre-membrane carbon filter was not tested, because it is 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 mercury challenge were conducted individually, but cadmium, cesium, and strontium were combined into one challenge. Each membrane was only tested with 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. This approach eliminated the possibility that membrane performance against subsequent chemicals was negatively biased. 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 systems tested for the inorganic chemical challenges were used again for an organic chemical challenge. As discussed in Section 1.2, each challenge period was only one day. The systems were operated for six tank-fill periods, and then were allowed to rest overnight. Influent and effluent samples were collected during the operation period, and also the next morning after the rest period. In addition to influent and effluent samples, reject water samples were also collected and analyzed 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.

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	

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 Testing 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 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 challenge;
- 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 inorganic chemicals 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 ranged from 2.1 to 2.8 mg/L during testing. However, 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 membranes were installed on the test rigs by an NSF DWTS Laboratory technician according to the instructions in the ERO-R450E owner's manual. The recommended conditioning procedure of operation for six 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 μg/L of chloroform until 375 gallons passed through each filter. This is the volume equal to one-half of EcoWater System's stated capacity of 750 gallons for the filter. The filters were operated at an inlet water pressure of 60 ± 3 psi and a maximum flow rate of 0.5 gallons per minute (gpm), on a ten minutes on, ten minutes off cycle. Chloroform at 300 μg/L is the influent challenge concentration for the VOC (volatile organic chemical) reduction test in NSF/ANSI Standard 53 (chloroform is the surrogate test 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 psi 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.

The challenge tests were conducted as follows:

1. At the start of each challenge period, the test system storage tanks were emptied.

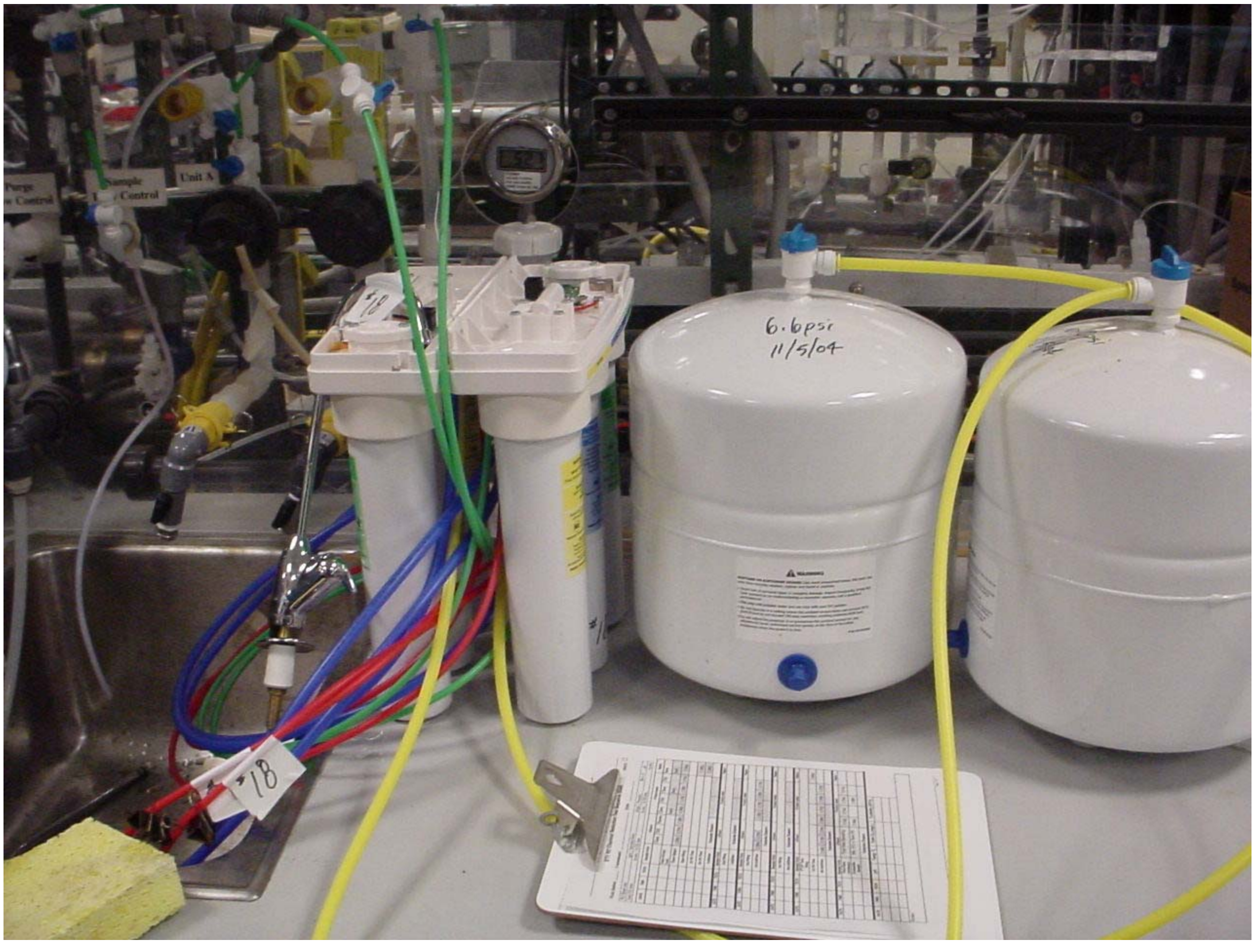

Figure 3-1. RO Membrane Systems Installed at Test Station

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. The effluent samples were collected from the faucet that comes with the system. All influent and effluent samples for challenge chemical analysis were collected and analyzed in triplicate, except where indicated. 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. While under operation for the first storage tank fill period, 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 units 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. 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, duplicate reject water samples were 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, 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.

3.2.5.3 Post-Membrane Carbon Filter Challenge Testing

The post-membrane carbon filter in the ERO-R450E 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.

Table 3-2. Summary of 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	

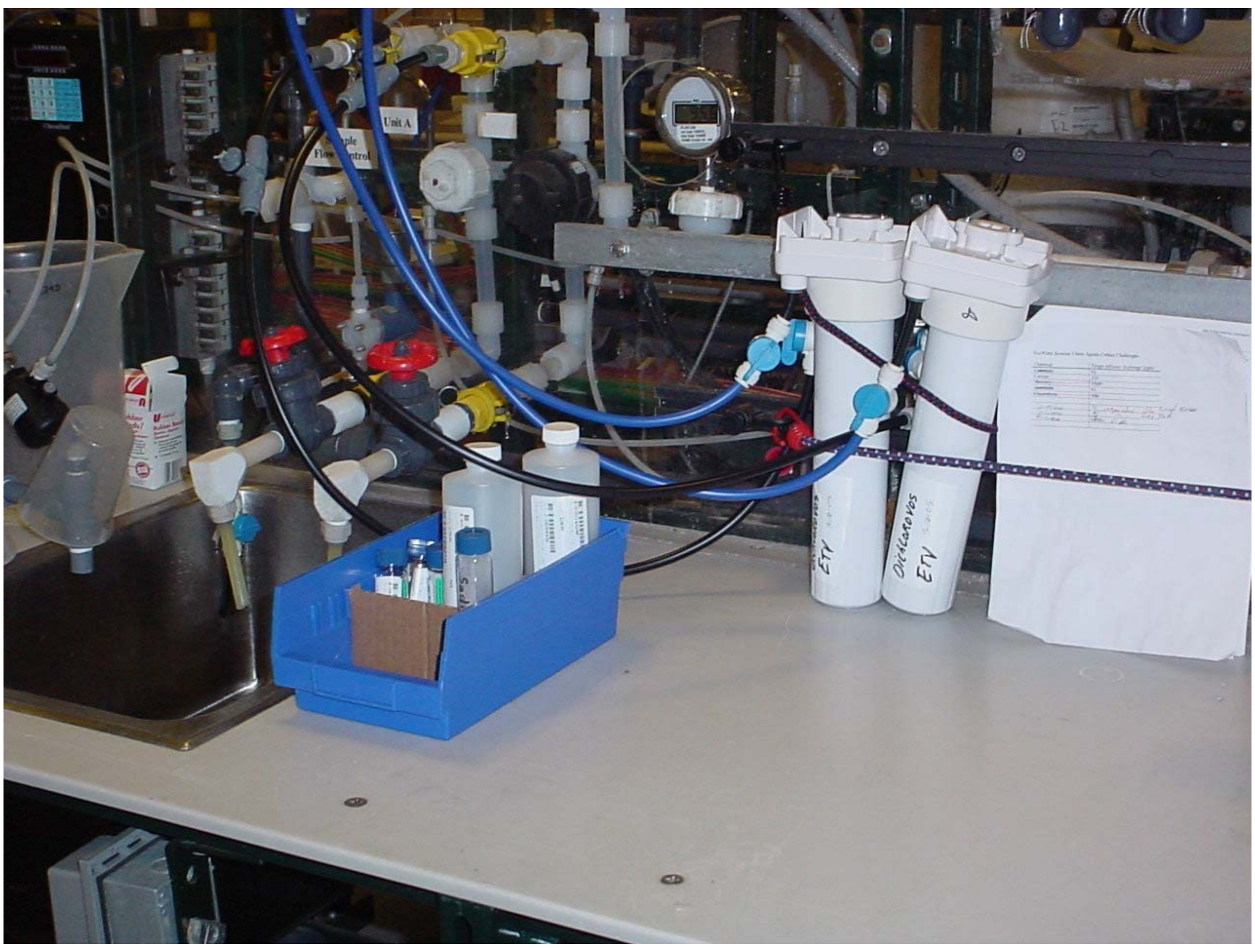

Figure 3-2. Post-Membrane Carbon Filters Installed at Test Station

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.

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

Sample Point	Influent Water Chemistry Sample Numbers	Challenge Chemical Influent SampleNumbers	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.

- 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.

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

Parameter	Reporting Limit	Acceptable Precision (RPD or RSD)	Acceptable Accuracy (% recovery)	
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%	
			LFB	LFM
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

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. The first liter flow rates were calculated for each system from the first liter dispense times. The results are given below in Table 4-1. This data was used to determine the operation parameters for the carbon filter challenges.

Table 4-1. RO Membrane System Operation Data

Unit Number	Tank Fill Time (minutes)	1st Liter Time (seconds)	1st Liter Flow Rate (gpm)	Tank Dispense Time
4	73	14.4	1.10	4 min., 51 sec.
7	72	13.8	1.15	4 min., 26 sec.
9	71	16.1	0.98	5 min., 11 sec.

4.2 Post-Membrane Carbon Filter Conditioning

As described in Section 3.2.4.2, the post-membrane carbon filters were conditioned with water containing 300 ± 90 µg/L of chloroform until 375 gallons had passed through them. Eight filters were conditioned first, and then another seven were conditioned later. Influent and effluent samples were collected for analysis at start-up, approximately 188 gallons, and approximately 375 gallons. The influent and effluent chloroform data are given below in Table 4-2. All water chemistry parameters measured during carbon filter conditioning were within the limits specified in Section 3.2.3.2. The water chemistry data are presented in Table A-2 of Appendix A.

There appeared to be a quality problem with the post-membrane carbon filters submitted for the tests. The ERO-R450E is certified under NSF/ANSI Standard 58 for the VOC reduction claim, which uses chloroform as a surrogate challenge chemical, and is solely based on the performance of the post-membrane carbon filter. To obtain the VOC reduction claim, the filter must reduce a 300 ± 30 µg/L challenge down to less than 15 µg/L at each sample point up to 120% of the 750 gallon design capacity. Here, six of the fifteen carbon filters had effluents exceeding 15 µg/L at or prior to 50% of capacity. The influent and effluent chloroform data was not available to the lab technicians when they were picking which carbon filters to test for the chemical challenges, so four of the six filters with poor chloroform reduction performance were used. However, these four filters were able to reduce the chemical challenges by 90% or more. See Section 4.5 for the post-membrane carbon filter challenge data.

Table 4-2. Post-Membrane Carbon Filter Conditioning Chloroform Data

		Chloroform (µg/L)		
	Sample	Start-Up	25% of Capacity	50% of Capacity
Group 1	Influent	340	310	310
	Unit 1 Effluent	ND (0.5)	ND (0.5)	ND (0.5)
	Unit 2 Effluent	ND (0.5)	ND (0.5)	ND (0.5)
	Unit 3 Effluent	ND (0.5)	ND (0.5)	ND (0.5)
	Unit 4 Effluent	ND (0.5)	ND (0.5)	ND (0.5)
	Unit 5 Effluent	ND (0.5)	ND (0.5)	ND (0.5)
	Unit 6 Effluent	13	22	24
	Unit 7 Effluent	ND (0.5)	ND (0.5)	ND (0.5)
	Unit 8 Effluent	ND (0.5)	ND (0.5)	ND (0.5)
Group 2	Influent	310	270	360
	Unit 9 Effluent	2.6	9.1	36
	Unit 10 Effluent	12	23	29
	Unit 11 Effluent	ND (0.5)	30	ND (0.5)
	Unit 12 Effluent	9.0	21	30
	Unit 13 Effluent	ND (0.5)	ND (0.5)	ND (0.5)
	Unit 14 Effluent	9.0	21	36
	Unit 15 Effluent	34	68	73

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 100 mg/L, corresponding to a minimum 87% reduction of TDS. The average TDS reduction was 91%. EcoWater Systems' reported TDS reduction for the ERO-R450E is a minimum of 87%, and an average of 92.6%, so test systems were representative of expected membrane performance. The TDS reduction data for each RO membrane system can be found in Table A-3 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 tank-fill times were approximately 70 minutes, so the systems were in operation for approximately seven hours per challenge.

4.4.1 Inorganic Chemicals Challenges

The inorganic chemicals challenge data are shown in Table 4-3. 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 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.

Unit 1(unit 11) removed 99% of both cadmium and strontium, while unit 2 (unit 12) removed 95% of both metals. Cesium was removed by 80% and 84%. The RO membrane did not remove a significant portion of the mercury challenge, but this 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.

Table 4-3. 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	950	920	1000	950	730	750
Start-up Effluent, Unit 1	9.9	110	980(1)	9	60	64
Start-up Effluent, Unit 2	48	140	860	50	85	70
3rd Tank Influent	960	930	1100	960	750	750
3rd Tank Effluent, Unit 1	23	160	1100	27	91	84
3rd Tank Effluent, Unit 2	43	190	970	44	130	94
5th Tank Influent	960	920	1200	960	740	750
5th Tank Effluent, Unit 1	10	150	1100	10	92	93
5th Tank Effluent, Unit 2	55	210	1100	57	120	100
Post-Rest 1st Liter Draw, Unit 1	10	170	1000	10	98	94
Post-Rest 1st Liter Draw, Unit 2	61	200	930	55	120	100
Post-Rest 2nd Sample, Unit 1	11	160	990	10		
Post-Rest 2nd Sample, Unit 2	56	210	990	57		
Mean Influent	**960**	**930**	**1100**	**960**	**740**	**750**
Mean Effluent, Unit 1	**13**	**150**	**1000**	**13**	**81**	**80**
Mean Effluent, Unit 2	**53**	**190**	**970**	**53**	**110**	**88**
Percent Reduction, Unit 1	**99**	**84**	**9**	**99**	**89**	**89**
Percent Reduction, Unit 2	**95**	**80**	**12**	**95**	**85**	**88**
Overall Percent Reduction	**97**	**82**	**9**	**97**	**—**	**—**
Units Tested (Unit #'s)	11, 12	11, 12	11, 12	11, 12	—	—

(1) Number only the average of two of the triplicate analysis numbers, analytical error with the third.

The reject water sample data are given in Table 4-4. The values presented are the arithmetic means of the duplicate sample analyses, except where indicated. The individual sample results are presented in Table A-7 of Appendix A. The reject water levels are as expected, given that the ERO-R450E has an efficiency rating of 9.7% (see Section 2.5 for further discussion). This efficiency means the reject water should have approximately 10% more of the challenge chemical than the influent water, assuming almost 100% rejection by the membrane.

Table 4-4. Inorganic Chemicals Challenge Reject Water Data

Sample	Cadmium (μg/L)	Cesium (μg/L)	Mercury (μg/L)	Strontium (μg/L)
Start-up	1200	1100	880	1200
1/2 through 1st Tank	1200	1100	1200	1200
3/4 through 1st tank	1100	1000	1000	1100
1/2 through 5th Tank	1100	1000	1200	1100
Unit Sampled	11	11	11	11

4.4.2 Organic Chemical Challenges

The organic chemical challenge data are shown below in Table 4-5. 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 water chemistry data for these challenges are presented in Table A-6 in Appendix A.

Table 4-5. 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	1100	980	1100	1100	1400	1100	910	1200	950	1100
Start-up Effluent, Unit 1	11	ND (0.5)	17	2.5	34	30	ND (4)	31	10	ND (5)
Start-up Effluent, Unit 2	21	ND (0.5)	15	2.4	34	50	ND (4)	41	6	7
3rd Tank Influent	980	1100	1100	1100	1300	1100	950	1200	1000	1100
3rd Tank Effluent, Unit 1	25	7.7	20	45	65	40	ND (4)	42	11	8
3rd Tank Effluent, Unit 2	14	3.1	18	59	72	70	ND (4)	53	8	11
5th Tank Influent	1000	930	1100	1100	1300	1000	930	1200	970	1100
5th Tank Effluent, Unit 1	16	15	20	65	81	50	ND (4)	45	11	13
5th Tank Effluent, Unit 2	27	7.0	18	87	86	80	ND (4)	53	9	8
Post-Rest 1st Draw, Unit 1	16	9.7	21	74	#	50	5	46	11	8
Post-Rest 1st Draw, Unit 2	27	7.1	19	100	87	80	5	54	9	13
Post-Rest 2nd Sample, Unit 1	16[1]	13	20	80	74	50	5	43	11	10
Post-Rest 2nd Sample, Unit 2	26	7.0	19	100	87	80	4	56	9	14
Mean Influent	**1000**	**980**	**1100**	**1100**	**1300**	**1100**	**930**	**1200**	**980**	**1100**
Mean Effluent, Unit 1	**17**	**9**	**20**	**53**	**66**	**40**	**4**	**41**	**11**	**9**
Mean Effluent, Unit 2	**24**	**5**	**18**	**70**	**73**	**70**	**4**	**51**	**8**	**11**
Percent Reduction, Unit 1	**98**	**> 99**	**98**	**95**	**95**	**96**	**> 99**	**97**	**99**	**> 99**
Percent Reduction, Unit 2	**98**	**> 99**	**98**	**94**	**94**	**94**	**> 99**	**96**	**> 99**	**99**
Overall Percent Reduction	**98**	**> 99**	**98**	**94**	**95**	**95**	**> 99**	**96**	**99**	**> 99**
Units Tested (Unit #'s)	11, 12	21, 22	13, 14	9, 10	1, 2	3, 4	7, 8	15, 16	5, 6	19, 20

Note: The detection limit values were used for calculating the mean effluents and percent reductions.
(1) Number only the average of two of the triplicate analyses, analytical error with the third.
Data point not reported due to analytical error.

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 4-6.

The reject water data are shown in Table 4-7. The values presented are the arithmetic means of the duplicate sample analyses. The individual sample results are presented in Table A-8 of Appendix A.

Table 4-6. 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	740	760	750	760	730	720	760	760	760	750
Start-up Effluent, Unit 1	36	42	38	41	39	46	35	41	42	37
Start-up Effluent, Unit 2	43	42	36	44	43	69	39	47	40	36
3rd Tank Influent	740	750	730	730	730	730	760	760	760	752
3rd Tank Effluent, Unit 1	59	65	55	59	60	68	52	57	60	59
3rd Tank Effluent, Unit 2	50	62	55	67	59	91	63	63	59	52
5th Tank Influent	740	750	730	750	730	730	760	760	760	750
5th Tank Effluent, Unit 1	55	68	59	63	68	78	58	61	66	62
5th Tank Effluent, Unit 2	65	67	57	68	67	100	69	68	60	58
Post-Rest 1st Draw, Unit 1	55	67	61	65	74	84	66	67	68	64
Post-Rest 1st Draw, Unit 2	65	68	59	72	87	110	72	73	60	59
Mean Influent	**740**	**750**	**730**	**750**	**730**	**730**	**760**	**760**	**760**	**750**
Mean Effluent, Unit 1	**51**	**61**	**53**	**57**	**60**	**69**	**53**	**57**	**59**	**56**
Mean Effluent, Unit 2	**56**	**60**	**52**	**63**	**64**	**93**	**61**	**63**	**55**	**51**
Percent Reduction, Unit 1	**93**	**92**	**93**	**92**	**92**	**91**	**93**	**93**	**92**	**93**
Percent Reduction, Unit 2	**92**	**92**	**93**	**92**	**91**	**87**	**92**	**92**	**93**	**93**

Table 4-7. 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	1200	890	1500	900	1600	1400	1300	1600	1100	1400
1/2 through 1st Tank	1200	910	1400	950	1500	1300	1100	1400	1200	1400
3/4 through 1st tank	1100	980	1400	990	1500	1400	1200	1500	1300	1400
1/2 through 5th Tank	1100	1200	1300	1200	1500	1200	950	1400	1100	1200
Unit Sampled	11	21	13	9	1	3	7	15	5	11

The RO membrane removed all chemicals by 94% or more. The effluent levels of many chemicals increased from the start-up to the 3rd tank samples. This trend is also evident in the TDS reduction data for all chemicals. The effluent levels of most chemicals then leveled off and did not increase significantly through the end of the challenges. Benzene, chloroform, dicrotophos, and dichlorvos did continue to increase from the 3rd tank to 5th tank samples, and chloroform also increased in concentration from the 5th tank sample to the post-rest samples. The effluent TDS levels associated with the dichlorvos, dicrotophos, fenamiphos, and mevinphos challenges also increased from each sample point to the next through the entire challenge periods. Note however, that the effluent TDS levels did not increase to above those measured during the TDS system check tests. Thus, the rising TDS levels likely do not indicate that the membranes were becoming significantly compromised due to exposure to the chemicals. More research would be needed to evaluate whether the membranes were actually adversely affected by chemical exposure.

The increases may be an artifact of the challenge protocol. The challenges began with empty storage tanks, so there was no back-pressure on the membranes when the water collected for the start-up samples passed through the membranes. The rest of the samples were collected when the storage tanks were full, so the membranes had been operating with back-pressure. RO membranes perform better without back pressure, so the 3rd tank, 5th tank, and post-rest samples are likely more indicative of the true performance of the system as used by the consumer.

The rise in effluent chloroform levels could also be due to the substance adsorbing onto and diffusing through the membrane. The small size of the chloroform molecule may have also played a role in its passage, since RO membranes remove organic chemicals by size exclusion.

The adsorption theory is lent some weight by an examination of the reject water data in Table 4-7. The average concentration of chloroform is lower than for the other chemicals, as is that of benzene. The reject water concentrations for all other chemicals are above the influent challenge levels, indicating that they did not adsorb onto the membrane or internal surfaces in contact with the water.

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 cesium, mercury, chloroform, dichlorvos, dicrotophos, and mevinphos. The target challenge levels were the maximum effluent levels measured during the RO membrane challenges. Based on the data in Table 4-2, the carbon filters were operated at 1.15 gpm on an operation cycle where the "on" portion was five minutes and eleven seconds, and the "off" portion was one hour and ten minutes.

The carbon challenge results are shown below in Table 4-8. 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-9 in Appendix A. The water chemistry data for these challenges can be found in Table A-10 of Appendix A.

Table 4-8. Post-Membrane Carbon Filter Challenge Data

Sample	Cesium (µg/L)	Mercury (µg/L)	Chloroform (µg/L)	Dichlorvos (µg/L)	Dicrotophos (µg/L)	Mevinphos (µg/L)
Target Influent Level	220	1000	100	95	90	61
Start-up Influent	230	910	99	100	80	24
Start-up Effluent, Unit 1	210	43	ND (0.5)	ND (0.2)	ND (10)	ND (0.2)
Start-up Effluent, Unit 2	200	21	ND (0.5)	8.5	ND (10)	2.7
7.5 Hours Influent	230	710	100	100	90	49
7.5 Hours Effluent, Unit 1	220	47	ND (0.5)	0.3	ND (10)	ND (0.2)
7.5 Hours Effluent, Unit 2	230	26	ND (0.5)	7.3	ND (10)	4.3
15 Hours Influent	230	650	100	100	90	46
15 Hours Effluent, Unit 1	230	46	1.6	0.2	ND (10)	0.3
15 Hours Effluent, Unit 2	230	27	ND (0.5)	7.2	ND (10)	5.1
Mean Influent	**230**	**760**	**100**	**100**	**90**	**40**
Mean Effluent, Unit 1	**220**	**45**	**0.9**	**0.2**	**ND (10)**	**0.2**
Mean Effluent, Unit 2	**220**	**24**	**0.5**	**7.9**	**ND (10)**	**3.9**
Percent Reduction, Unit 1	**4.3**	**94**	**> 99**	**> 99**	**89(1)**	**> 99**
Percent Reduction, Unit 2	**4.3**	**97**	**> 99**	**92**	**89(1)**	**90**
Overall Percent Reduction	**4.3**	**95**	**> 99**	**96**	**89(1)**	**95**
Units Tested (Unit #'s)	1, 2	9, 10	7, 8	11, 12	3, 4	13, 14

Note: The detection limit values were used for calculating the mean effluents and percent reductions.
(1) Percent reductions limited by the chemical detection limit.

The post-membrane carbon filter performed well against mercury and the organic chemicals, as expected, but not against cesium. As discussed in Section 4.2, units 12 and 14 both demonstrated chloroform breakthrough during conditioning. For the carbon filter challenges, both units were paired with units that did not show breakthrough, and both gave higher effluent levels of the challenge chemicals than did the other unit of the pair. However, units 12 and 14 still removed 92% and 90%, respectively, of the challenge chemicals.
Units 9 and 10, used for the mercury challenge, also both demonstrated chloroform breakthrough during conditioning. These units gave average effluent mercury concentrations (45 and 24 μg/L) in the same range as the maximum effluent chloroform concentrations during conditioning (36 and 29 μg/L). However, the mercury percent reductions are much higher, at 94% and 97%, because the mercury challenge concentration was much higher.

4.6 Conclusions

Table 4-9 gives an estimate of the combined performance of both the RO membrane and post-membrane carbon filter, using the data from Tables 4-3, 4-5, and 4-8. An examination of the data in Table 4-9, along with the data in Tables 4-3 and 4-5, shows that the full ERO-R450E system with the RO membrane and post-membrane carbon filter working in concert removed all of the challenge chemicals but cesium by 96% or more.

Table 4-9. Combined Performance of RO Membrane and Post-Membrane Carbon Filter

Sample	Cesium (μg/L)	Mercury (μg/L)	Chloroform (μg/L)	Dichlorvos (μg/L)	Dicrotophos (μg/L)	Mevinphos (μg/L)
Mean Influent	930	1100	1100	1300	1100	1200
Mean Effluent, Unit 1	150	45	0.9	0.2	ND (10)	0.2
Mean Effluent, Unit 2	190	24	0.5	7.9	ND (10)	3.9
Percent Reduction, Unit 1	84	96	> 99	> 99	> 99	> 99
Percent Reduction, Unit 2	80	98	> 99	> 99	> 99	> 99
Overall Percent Reduction	82	97	> 99	> 99	> 99	> 99

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. All chemical challenge levels for the RO membranes were within the allowable range of 1.0 ± 0.5 mg/L. There were no allowable challenge level ranges specified for the carbon filter challenges, but the measured challenge levels for the mercury and mevinphos challenges were significantly low. The initial mercury challenge level was 910 μg/L, fairly close to the target challenge level of 1000 μg/L. However, the 7.5-hour influent was down to 710 μg/L, and the 15-hour influent was even lower, at 650 μg/L. This phenomenon was not observed during the RO membrane challenge, indicating that plating of the mercury on the internal surfaces of the test rig plumbing was not the cause of the drop in the challenge level.

The mevinphos challenge target was 61 μg/L. The average influent at start-up was only 24 μg/L, with a 95% confidence interval of 6 μg/L. The results from the 7.5-hour and 15-hour influent samples were higher – 49 μg/L and 46 μg/L, respectively.

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:

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

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:

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

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;

X = the arithmetic mean of then 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, giving a completeness measurement of 100% for this category.

5.7.4.2 Water Chemistry Measurements

All of the planned samples were collected and reported for every parameter but total chlorine. The technician did not collect total chlorine samples for any of the post-membrane carbon filter challenges except mevinphos. However, during the timeframe of the carbon filter challenges, free chlorine in the test water described in Section 3.2.3.2 was measured for other tests. The DWTS Laboratory provided three measurements: 1.8 mg/L, 2.1 mg/L, and 2.1 mg/L. These measurements were taken on the same days as the mercury, chloroform, and cesium carbon filter challenges, respectively. No data was provided for the days of the dichlorvos, dicrotophos, or mevinphos challenges. While any spikes in the chlorine level much above 2.1 mg/L were unlikely, the lack of chlorine data does not allow an evaluation of whether the chlorine in the test water may have impacted the carbon's ability to adsorb the challenge chemicals. A total of 15 samples were not collected out of 50 planned samples. This gives a completeness percentage of 70% for total chlorine.

5.7.4.3 Challenge Chemicals

All planned samples were collected, but results for a few were not reported due to analytical errors.

- RO membrane mercury challenge: Triplicate sample 1 for the unit 1 start-up effluent was an outlier, and was not reported. Thirty-four of thirty-five samples were reported, for a completeness percentage of 97%.
- RO membrane aldicarb challenge: Triplicate sample 3 for the unit 1 post-rest 2nd sample result was not reported due to an analytical error. Thirty-four of thirty-five samples were reported, for a completeness percentage of 97%.
- RO membrane dichlorvos challenge: The post-rest first draw sample result for unit 1 was not reported due to an analytical error. Thirty-four of thirty-five samples were reported, for a completeness percentage of 97%.

Chapter 6
References

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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
pH	7.7	7.0	7.1	7.1	7.0	7.2	7.1
Temperature (°C)	25	25	25	25	25	26	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)
TDS (mg/L)	750	750	750	750	750	750	750
Turbidity (NTU)	0.1	ND (0.1)	0.1	0.2	0.3	0.1	ND (0.1)

Table A-2. Post-Membrane Carbon Filter Conditioning Influent Water Chemistry

Sample Point		Chloroform (µg/L)	pH	Temperature (°C)	Total Organic Carbon (mg/L)[(1)]	Turbidity (NTU)
Group 1, Start-Up	Influent	340	7.2	21	38	0.1
	Unit 1	ND (0.5)				
	Unit 2	ND (0.5)				
	Unit 3	ND (0.5)				
	Unit 4	ND (0.5)				
	Unit 5	ND (0.5)				
	Unit 6	13				
	Unit 7	ND (0.5)				
	Unit 8	ND (0.5)				
Group 1, 25% of Capacity	Influent	310	7.2	20	38	0.1
	Unit 1	ND (0.5)				
	Unit 2	ND (0.5)				
	Unit 3	ND (0.5)				
	Unit 4	ND (0.5)				
	Unit 5	ND (0.5)				
	Unit 6	22				
	Unit 7	ND (0.5)				
	Unit 8	ND (0.5)				
Group 1, 50% of Capacity	Influent	310	7.3	20	38	ND (0.1)
	Unit 1	ND (0.5)				
	Unit 2	ND (0.5)				
	Unit 3	ND (0.5)				
	Unit 4	ND (0.5)				
	Unit 5	ND (0.5)				
	Unit 6	24				
	Unit 7	ND (0.5)				
	Unit 8	ND (0.5)				
Group 2, Start-Up	Influent	310	7.3	20	38	0.1
	Unit 9	2.6				
	Unit 10	12				
	Unit 11	ND (0.5)				
	Unit 12	9.0				
	Unit 13	ND (0.5)				
	Unit 14	9.0				
	Unit 15	34				
Group 2, 25% of Capacity	Influent	270	7.2	20	37	ND (0.1)
	Unit 9	9.1				
	Unit 10	23				
	Unit 11	30				
	Unit 12	21				
	Unit 13	ND (0.5)				
	Unit 14	21				
	Unit 15	68				
Group 2, 50% of Capacity	Influent	360	7.4	21	42	0.2
	Unit 9	36				
	Unit 10	29				
	Unit 11	ND (0.5)				
	Unit 12	30				
	Unit 13	ND (0.5)				
	Unit 14	36				
	Unit 15	73				

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

Table A-3. RO Membrane TDS Reduction System Check Data

Sample	pH	Temperature (°C)	Total Chlorine (mg/L)	Turbidity (NTU)	Influent TDS (mg/L)	TDS Effluent Sample 1 (mg/L)	TDS Effluent Sample 2 (mg/L)	TDS Effluent Sample 3 (mg/L)	**Percent Reduction**
Influent	7.2	25	ND (0.05)	ND (0.1)	750				
Unit 1						68	70	70	**91**
Unit 2						68	68	69	**91**
Unit 3						79	81	81	**89**
Unit 4						100	100	100	**87**
Unit 5						76	77	77	**90**
Unit 6						58	60	59	**92**
Unit 7						68	68	68	**91**
Unit 8						70	70	71	**91**
Unit 9						64	65	65	**91**
Unit 10						67	68	68	**91**
Unit 11						59	60	60	**92**
Unit 12						99	100	100	**87**
Unit 13						69	70	70	**91**
Unit 14						66	67	67	**91**
Unit 15						68	69	69	**91**
Unit 16						74	76	76	**90**
Unit 17						62	62	62	**92**
Unit 18						67	67	67	**91**
Unit 19						67	68	68	**91**
Unit 20						65	66	67	**91**
Unit 21						66	67	67	**91**
Unit 22						66	67	67	**91**

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	950	920	1000	960
Triplicate Sample 2	950	920	1000	950
Triplicate Sample 3	940	910	1100	950
Mean	**950**	**920**	**1000**	**950**
Start-up Effluent, Unit 1				
Triplicate Sample 1	9.9	110	2000(1)	9
Triplicate Sample 2	10	110	980	9
Triplicate Sample 3	9.7	110	970	9
Mean	**9.9**	**110**	**980**	**9**
Start-up Effluent, Unit 2				
Triplicate Sample 1	43	130	890	53
Triplicate Sample 2	51	150	980	48
Triplicate Sample 3	51	150	710	48
Mean	**48**	**140**	**860**	**50**
3rd Tank Influent				
Triplicate Sample 1	950	930	1100	950
Triplicate Sample 2	930	910	1000	930
Triplicate Sample 3	1000	960	1100	1000
Mean	**960**	**930**	**1100**	**960**
3rd Tank Effluent, Unit 1				
Triplicate Sample 1	48	180	1000	59
Triplicate Sample 2	9.5	150	960	10
Triplicate Sample 3	11	150	1400	11
Mean	**23**	**160**	**1100**	**27**
3rd Tank Effluent, Unit 2				
Triplicate Sample 1	57	220	1000	59
Triplicate Sample 2	59	210	910	63
Triplicate Sample 3	12	150	1000	10
Mean	**43**	**190**	**970**	**44**
5th Tank Influent				
Triplicate Sample 1	960	930	1300	960
Triplicate Sample 2	980	920	1200	970
Triplicate Sample 3	950	920	1200	950
Mean	**960**	**920**	**1200**	**960**
5th Tank Effluent, Unit 1				
Triplicate Sample 1	10	160	1100	10
Triplicate Sample 2	9.6	140	1000	10
Triplicate Sample 3	11	160	1100	10
Mean	**10**	**150**	**1100**	**10**
5th Tank Effluent, Unit 2				
Triplicate Sample 1	56	220	1100	57
Triplicate Sample 2	55	200	1000	57
Triplicate Sample 3	54	220	1200	57
Mean	**55**	**210**	**1100**	**57**
Post-Rest 1st Draw, Unit 1	10	170	1000	10
Post-Rest 1st Draw, Unit 2	61	200	930	55
Post-Rest 2nd Sample, Unit 1				
Triplicate Sample 1	11	160	980	10
Triplicate Sample 2	12	160	1000	10
Triplicate Sample 3	11	160	1000	10
Mean	**11**	**160**	**990**	**10**
Post-Rest 2nd Sample, Unit 2				
Triplicate Sample 1	52	200	1000	59
Triplicate Sample 2	62	210	970	5
Triplicate Sample 3	55	210	1000	57
Mean	**56**	**210**	**990**	**57**

(1) Sample result not included in mean calculation due to analytical error.

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	920	1100	1100	1500	1100	860	1300	960	1100
Triplicate Sample 2	1100	1100	1100	1100	1300	1100	920	1200	960	1100
Triplicate Sample 3	1000	930	1100	1100	1300	1100	950	1200	940	1100
Mean	**1100**	**980**	**1100**	**1100**	**1400**	**1100**	**910**	**1200**	**950**	**1100**
Start-up Effluent, Unit 1										
Triplicate Sample 1	11	ND (0.5)	17	1.7	43	20	ND (4)	29	10	ND (5)
Triplicate Sample 2	11	ND (0.5)	17	2.0	39	30	ND (4)	32	9	ND (5)
Triplicate Sample 3	11	ND (0.5)	17	1.9	19	30	ND (4)	33	10	ND (5)
Mean	**11**	**ND (0.5)**	**17**	**2.5**	**34**	**30**	**ND (4)**	**31**	**10**	**ND (5)**
Start-up Effluent, Unit 2										
Triplicate Sample 1	21	ND (0.5)	15	2.5	42	30	ND (4)	40	6	10
Triplicate Sample 2	21	ND (0.5)	15	2.6	35	60	ND (4)	42	6	ND (5)
Triplicate Sample 3	21	ND (0.5)	16	2.2	24	60	ND (4)	40	6	ND (5)
Mean	**21**	**ND (0.5)**	**15**	**2.4**	**34**	**50**	**ND (4)**	**41**	**6**	**7**
3rd Tank Influent										
Triplicate Sample 1	980	1100	1100	1100	1300	1200	1000	1300	1100	1100
Triplicate Sample 2	1000	990	1100	1100	1300	1100	930	1200	1000	1100
Triplicate Sample 3	950	1200	1100	1100	1300	1100	920	1200	980	1100
Mean	**980**	**1100**	**1100**	**1100**	**1300**	**1100**	**950**	**1200**	**1000**	**1100**
3rd Tank Effluent, Unit 1										
Triplicate Sample 1	25	7.3	20	43	66	30	ND (4)	43	11	8
Triplicate Sample 2	25	8.4	20	47	64	40	ND (4)	42	11	7
Triplicate Sample 3	24	7.4	19	45	65	40	ND (4)	41	11	8
Mean	**25**	**7.7**	**20**	**45**	**65**	**38**	**ND (4)**	**42**	**11**	**8**
3rd Tank Effluent, Unit 2										
Triplicate Sample 1	14	3.0	18	59	71	70	ND (4)	54	8	11
Triplicate Sample 2	14	2.7	18	58	72	70	ND (4)	53	8	11
Triplicate Sample 3	14	3.5	18	60	72	80	ND (4)	52	8	11
Mean	**14**	**3.1**	**18**	**59**	**72**	**70**	**ND (4)**	**53**	**8**	**11**
5th Tank Influent										
Triplicate Sample 1	1000	930	1100	1100	1300	1000	860	1200	950	1100
Triplicate Sample 2	1000	860	1100	1100	1300	1000	1000	1200	980	1100
Triplicate Sample 3	1000	990	1100	1100	1400	1000	930	1300	990	1100
Mean	**1000**	**930**	**1100**	**1100**	**1300**	**1000**	**930**	**1200**	**970**	**1100**
5th Tank Effluent, Unit 1										
Triplicate Sample 1	16	15	20	67	83	50	ND (4)	50	12	14
Triplicate Sample 2	16	13	20	68	76	40	ND (4)	46	11	13
Triplicate Sample 3	17	18	20	61	85	50	ND (4)	40	11	13
Mean	**16**	**15**	**20**	**65**	**81**	**50**	**ND (4)**	**45**	**11**	**13**
5th Tank Effluent, Unit 2										
Triplicate Sample 1	27	8.3	18	85	93	80	ND (4)	53	9	8
Triplicate Sample 2	27	7.0	18	89	76	70	ND (4)	56	9	8
Triplicate Sample 3	27	5.6	19	86	88	90	ND (4)	51	9	9
Mean	**27**	**7.0**	**18**	**87**	**86**	**80**	**ND (4)**	**53**	**9**	**8**
Post-Rest 1st Draw, Unit 1	16	9.7	21	74	#	50	5	46	11	8
Post-Rest 1st Draw, Unit 2	27	7.1	19	100	87	80	5	54	9	13
Post-Rest 2nd Sample, Unit 1										
Triplicate Sample 1	16	17	20	82	71	50	5	47	11	9
Triplicate Sample 2	16	10	21	81	80	50	5	42	11	12
Triplicate Sample 3	1600(1)	11	20	77	70	40	5	39	11	9
Mean	**16**	**13**	**20**	**80**	**74**	**50**	**5**	**43**	**11**	**10**
Post-Rest 2nd Sample, Unit 2										
Triplicate Sample 1	26	8.2	19	100	86	80	4	55	9	15
Triplicate Sample 2	27	5.5	19	100	81	70	4	51	9	14
Triplicate Sample 3	26	7.3	20	100	94	80	ND (4)	61	9	13
Mean	**26**	**7.0**	**19**	**100**	**87**	**80**	**4**	**56**	**9**	**14**

(1) Sample result not included in mean calculation due to analytical error.

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	6.3	6.5	7.5	7.6	7.6	7.1	7.4	7.7	7.3	7.3	7.3	7.2
Temperature (°C)	24	25	25	25	24	26	25	25	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)	0.1	ND (0.1)	0.1	0.1	ND (0.1)	ND (0.1)	ND (0.1)	ND (0.1)	0.1	0.2	ND (0.1)	0.4
5th Tank Influent												
pH	6.2	6.4	7.5	7.2	7.5	7.2	7.4	7.2	7.1	7.3	7.2	7.1
Temperature (°C)	25	24	24	25	25	25	25	25	25	25	25	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)	0.2	ND (0.1)	ND (0.1)	0.1	0.2	ND (0.1)	ND (0.1)	0.1	0.3	0.2	ND (0.1)

Table A-7. RO Membrane Inorganic Chemicals Challenge Reject Water Data

Sample	Cadmium (μg/L)	Cesium (μg/L)	Mercury (μg/L)	Strontium (μg/L)
Start-up				
Duplicate Sample 1	1200	1100	970	1200
Duplicate Sample 2	1200	1100	780	1200
Mean	**1200**	**1100**	**880**	**1200**
1/2 Through First Tank				
Duplicate Sample 1	1100	1000	1400	1100
Duplicate Sample 2	1200	1100	1000	1200
Mean	**1200**	**1100**	**1200**	**1200**
3/4 Through First Tank				
Duplicate Sample 1	1100	1000	990	1100
Duplicate Sample 2	1100	1000	1000	1100
Mean	**1100**	**1000**	**1000**	**1100**
1/2 Through 5th Tank				
Duplicate Sample 1	1100	1000	1200	1100
Duplicate Sample 2	1100	1000	1200	1100
Mean	**1100**	**1000**	**1200**	**1100**

Table A-8. 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	1200	790	1400	830	1600	1300	1100	1600	1100	1400
Duplicate Sample 2	1200	990	1500	970	1500	1400	1400	1600	1100	1400
Mean	**1200**	**890**	**1500**	**900**	**1600**	**1400**	**1300**	**1600**	**1100**	**1400**
1/2 Through First Tank										
Duplicate Sample 1	1200	840	1400	940	1500	1300	1200	1400	1200	1400
Duplicate Sample 2	1200	970	1400	960	1500	1200	1000	1400	1200	1400
Mean	**1200**	**910**	**1400**	**950**	**1500**	**1300**	**1100**	**1400**	**1200**	**1400**
3/4 Through First Tank										
Duplicate Sample 1	1100	1100	1400	970	1400	1300	1100	1500	1300	1300
Duplicate Sample 2	1100	860	1400	1000	1500	1400	1300	1500	1200	1400
Mean	**1100**	**980**	**1400**	**990**	**1500**	**1400**	**1200**	**1500**	**1300**	**1400**
1/2 Through 5th Tank										
Duplicate Sample 1	1100	1200	1300	1000	1600	1300	1000	1300	1100	1200
Duplicate Sample 2	1100	1200	1300	1400	1400	1100	890	1400	1100	1200
Mean	**1100**	**1200**	**1300**	**1200**	**1500**	**1200**	**950**	**1400**	**1100**	**1200**

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

Sample	Cesium (µg/L)	Mercury (µg/L)	Chloroform (µg/L)	Dichlorvos (µg/L)	Dicrotophos (µg/L)	Mevinphos (µg/L)
Target Influent Level	220	1000	100	95	90	61
Start-up Influent						
Triplicate Sample 1	230	890	100	96	80	28
Triplicate Sample 2	230	910	97	110	80	26
Triplicate Sample 3	230	940	100	100	90	18
Mean	**230**	**910**	**99**	**100**	**80**	**24**
Start-up Effluent, Unit 1						
Triplicate Sample 1	210	41	ND (0.5)	ND (0.2)	ND (10)	ND (0.2)
Triplicate Sample 2	220	43	ND (0.5)	ND (0.2)	ND (10)	ND (0.2)
Triplicate Sample 3	210	44	ND (0.5)	ND (0.2)	ND (10)	ND (0.2)
Mean	**210**	**43**	**ND (0.5)**	**ND (0.2)**	**ND (10)**	**ND (0.2)**
Start-up Effluent, Unit 2						
Triplicate Sample 1	200	18	ND (0.5)	5.1	ND (10)	2.2
Triplicate Sample 2	200	24	ND (0.5)	5.5	ND (10)	3.1
Triplicate Sample 3	200	22	ND (0.5)	15	ND (10)	2.7
Mean	**200**	**21**	**ND (0.5)**	**8.5**	**ND (10)**	**2.7**
7.5 Hours Influent						
Triplicate Sample 1	220	750	100	110	100	51
Triplicate Sample 2	230	680	100	100	100	46
Triplicate Sample 3	230	690	110	100	80	50
Mean	**230**	**710**	**100**	**100**	**90**	**49**
7.5 Hours Effluent, Unit 1						
Triplicate Sample 1	220	46	ND (0.5)	ND (0.2)	ND (20)(1)	ND (0.2)
Triplicate Sample 2	220	47	ND (0.5)	ND (0.2)	ND (10)	ND (0.2)
Triplicate Sample 3	210	47	ND (0.5)	0.5	ND (10)	ND (0.2)
Mean	**220**	**47**	**ND (0.5)**	**0.3**	**10**	**ND (0.2)**
7.5 Hours Effluent, Unit 2						
Triplicate Sample 1	240	26	ND (0.5)	7.8	ND (10)	4.6
Triplicate Sample 2	230	26	ND (0.5)	7.3	ND (10)	4.2
Triplicate Sample 3	230	26	ND (0.5)	6.7	ND (10)	4.1
Mean	**230**	**26**	**ND (0.5)**	**7.3**	**ND (10)**	**4.3**
15 Hours Influent						
Triplicate Sample 1	230	660	100	100	90	43
Triplicate Sample 2	230	620	100	100	80	47
Triplicate Sample 3	220	670	100	100	90	47
Mean	**230**	**650**	**100**	**100**	**90**	**46**
15 Hours Effluent, Unit 1						
Triplicate Sample 1	230	48	1.7	0.2	ND (10)	ND (0.2)
Triplicate Sample 2	230	43	1.6	ND (0.2)	ND (10)	0.5
Triplicate Sample 3	230	47	1.6	ND (0.2)	ND (10)	ND (0.2)
Mean	**230**	**46**	**1.6**	**0.2**	**ND (10)**	**0.3**
15 Hours Effluent, Unit 2						
Triplicate Sample 1	220	28	ND (0.5)	6.7	ND (10)	5.1
Triplicate Sample 2	230	27	ND (0.5)	7.3	ND (10)	5.1
Triplicate Sample 3	230	25	ND (0.5)	7.7	ND (10)	5.2
Mean	**230**	**27**	**ND (0.5)**	**7.2**	**ND (10)**	**5.1**

(1) Detection limit higher due to dilution of the sample prior to analysis.

Table A-10. Post-Membrane Carbon Filter Challenges Water Chemistry Data

Sample	Cesium Challenge	Mercury Challenge	Chloroform Challenge	Dichlorvos Challenge	Dicrotophos Challenge	Mevinphos Challenge
Start-up Influent						
pH	7.3	7.5	7.5	7.3	7.3	7.3
Temperature (°C)	21	20	20	20	20	20
Total Chlorine (mg/L)	#	#	#	#	#	1.6
TOC (mg/L)	2.9	2.5	2.6	2.7	2.2	2.3
TDS (mg/L)	450	310	340	390	310	320
Turbidity (NTU)	0.2	0.1	ND (0.1)	0.1	0.1	0.1
7.5 Hour Influent						
pH	7.3	7.3	7.3	7.3	7.3	7.2
Temperature (°C)	20	22	21	20	21	21
Total Chlorine (mg/L)	#	#	#	#	#	1.6
TOC (mg/L)	2.3	2.6	29(1)	2.2	2.3	2.3
TDS (mg/L)	370	320	320	320	300	310
Turbidity (NTU)	0.2	0.1	0.3	0.3	0.1	0.1
15 Hour Influent						
pH	7.3	7.3	7.4	7.3	7.3	7.3
Temperature (°C)	21	21	21	20	22	21
Total Chlorine (mg/L)	#	#	#	#	#	2.4
TOC (mg/L)	2.1	2.8	2.7	2.5	2.3	2.3
TDS (mg/L)	360	360	340	330	310	320
Turbidity (NTU)	0.3	0.1	0.2	0.1	0.1	0.1

Technician missed sample collection

(1) TOC measured after addition of chloroform, which was in a methanol solution. High TOC reading was due to the methanol.