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Environmental Technology Verification Report

Physical Removal of Microbiological, Particulate and Organic Contaminants in Drinking Water

ZENON
Enhanced Coagulation ZeeWeed® ZW-500 Ultrafiltration Membrane System
Escondido, California

Prepared by

NSF International

Under a Cooperative Agreement with

U.S. Environmental Protection Agency

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**ENHANCED COAGULATION MEMBRANE FILTRATION USED IN PACKAGED DRINKING WATER TREATMENT**
APPLICATION:	**PHYSICAL REMOVAL OF MICROBIOLOGICAL, PARTICULATE AND ORGANIC CONTAMINANTS IN DRINKING WATER IN ESCONDIDO, CALIFORNIA**
TECHNOLOGY NAME:	**ENHANCED COAGULATION ZEEWEED® ZW-500 ULTRAFILTRATION SYSTEM**
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially 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; stakeholders groups which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF) in cooperation with the EPA operates the Package Drinking Water Treatment Systems (PDWTS) pilot, one of 12 technology areas under ETV. The PDWTS pilot recently evaluated the

the performance of an enhanced coagulation membrane filtration system used in package drinking water treatment system applications. This verification statement provides a summary of the test results for the ZENON Enhanced Coagulation ZeeWeed® ZW-500 Ultrafiltration (UF) System. Montgomery Watson, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the ZENON Enhanced Coagulation ZeeWeed® UF System was conducted over two test periods. The first test period, from March 22, 1999 to April 19, 1999 represented winter/spring conditions. The second test period, from September 22, 1999 to October 29, 1999 represented summer/fall conditions. The test system consists of an enhanced coagulation unit followed by a submerged ultrafiltration membrane unit. Verification testing was conducted at manufacturer specified operating conditions. Alum was added to the enhanced coagulation unit at a dose of 30 mg/L along with acid to produce a coagulation pH of 6.2. The membrane unit was operated at a constant flux of 37 gfd (62 L/hr-m^2), with air flow of 15 scfm (420 lpm) and an overall feedwater recovery of 95 percent. The combined enhanced coagulation and membrane unit achieved significant removal of organic material, in addition to microbial and particulate contaminants (presented later). Chemical cleaning of the treatment equipment was conducted as part of the verification testing.

TECHNOLOGY DESCRIPTION

The ZENON Enhanced Coagulation ZeeWeed® UF System combines enhanced coagulation, for removal of organic material, with ultrafiltration, for removal of microbial and particulate contaminants. Enhanced coagulation relies on addition of coagulant and acid to natural waters along with mixing to promote destabilization, charge neutralization and agglomeration of particles and organic colloidal material. This results in the adsorption of organic material to floc particles. These particles are then removed by membrane filtration. The ability of the ZeeWeed® OCP UF membrane to operate in a high-solids environment further enhances the removal of organic material by combining the effects of coagulation, coprecipitation and adsorption. The ZeeWeed® UF membrane removes particles by physical sieving. Particulate material larger than the pore size of the membrane (0.03 um nominal, 0.1 um absolute) are removed.

The ZENON Enhanced Coagulation unit consists of chemical feed systems for coagulant and acid, a static mixer, and a serpentine flocculation tank using air diffusers to provide mixing energy. The effluent from the enhanced coagulation unit serves as the feed water to the membrane unit. The ZeeWeed® OCP UF membrane is a submerged hollow-fiber membrane that utilizes a vacuum of 1 to 12 psi (0.07 to 0.83 bar) to draw product water through the membrane. The approximately 4,700 fibers have a combined surface area of 463 ft^2 (43 m^2). The 5.4 ft (2.7 m) long fibers are connected to top and bottom headers and submerged in a 200 gallon process tank. The top and bottom headers are connected to the filtrate vacuum pump. A blower supplies air to a diffuser at the base of the process tank to continuously agitate the fibers and remove accumulated solids. A bleed pump continuously wastes process tank contents to drain, limiting the buildup of solids in the process tank. The bleed flow rate and net permeate flow rate determine overall system feedwater recovery. The system includes a clean-in-place (CIP) tank where filtrate is stored for backpulsing the membrane. During backpulsing, at regular intervals of from 10 to 20 minutes, the flow through the membrane is reversed for 10 to 15 seconds to remove solids accumulated on the membrane surface. The system included a diaphragm pump for adding chlorine, in the form of sodium hypochlorite, to the backpulse water. Both the enhanced coagulation and membrane units are skid mounted and can be moved by forklift and transported by truck.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification test site was the City of San Diego's Aqua 2000 Research Center at 14103 Highland Valley Road in Escondido, California. The Research Center includes office and lab trailers, a covered concrete test pad and a dedicated operations staff with substantial membrane experience. The source water for testing was Lake Skinner water via the San Diego Aqueduct. Lake Skinner water consists of Colorado River water and State Project water, which are two of the major raw drinking water supplies in Southern California.

Methods and Procedures

Turbidity, pH, chlorine and temperature analyses were conducted onsite daily using desk top units. All other water quality samples were sent to the City of San Diego Laboratory for analysis. These included alkalinity, total and calcium hardness, total dissolved solids (TDS), total suspended solids (TSS), total organic carbon (TOC), dissolved organic carbon (DOC), ultraviolet absorbance at 254 nanometers (UV254), aluminum, color, total coliform and heterotrophic plate count (HPC). All samples were analyzed according to the Standard Methods for the Examination of Water and Wastewater, 18th Ed. (APHA, et. al., 1992) and/or Methods for Chemical Analysis of Water and Wastes (EPA, 1979). Online Hach 1900 WPC particle counters and 1720D turbidimeters continuously monitored these parameters in both the raw water and membrane system filtrate. The particle counters were set up to enumerate particle counts in the following size ranges: 2-3 um, 3-5 um, 5-15 um, and > 15 um. SDS DBP formation tests were conducted during each test period. For this testing, the uniform formation conditions of the EPA Information Collection Rule were followed. DBP analyses were conducted according to EPA Method 502.2 for trihalomethanes and EPA Method 552.2 for haloacetic acids.

Virus seedings, using MS2 virus, were conducted after membrane cleaning, at system startup with enhanced coagulation. The first seeding was conducted approximately three hours after system startup and the second was conducted less than one hour after system startup. During each seeding, approximately 2 x 10^{13} virus were added directly to the process tank after the completion of a backpulse. The system was then allowed to operate for one 10-minute filtration cycle to allow for mixing and equilibration. Sampling was initiated after completion of the next backpulse, with three process tank and three filtrate samples being collected in each of the next two filtration cycles. Samples were analyzed within 24 hours according to EPA ICR Method for Coliphage Assay (Sobsey, et al. 1990).

VERIFICATION OF PERFORMANCE

System Operation

The flow rate of raw water to the enhanced coagulation unit was controlled manually using a valve and rotameter. Coagulant feed to the system was manually set using a diaphragm pump. The coagulation pH was automatically maintained with a Prominent pH controller. A stand-pipe within the flocculation tank maintained water level in the tank. The flow to the flocculation tank was automatically switched on and off by process tank level control signals received from the membrane unit to maintain adequate water levels in the process tank. Feed-on and feed-off signals generated by the control logic of the process tank level controlled the influent valve to the enhanced coagulation unit. Water entering the flocculation tank flowed through four serpentine chambers, then overflowed the standpipe in the last chamber and flowed under gravity into the top of the process tank. Air from the membrane unit blower was diverted to diffusers in the base of each of the four serpentine chambers to accomplish mixing. The air flow rate to each chamber was individually adjustable using a valve and rotameter.

The enhanced coagulation unit was operated with a raw water flow of 14 gpm (52 lpm) in the first test period and 16 gpm (61 lpm) in the second. The coagulant, coagulant dose and coagulation pH were established by the manufacturer. Alum was used as a coagulant at 30 mg/L with acid added to produce a coagulation pH of 6.2. Enhanced coagulation chemical tanks had to be refilled approximately every two days.

The ZeeWeed® UF membrane system required manual adjustments to the filtrate flow control valve to maintain a constant flux as the membrane fouled. The bleed waste pump required manual adjustment to maintain a constant bleed waste flow from the process tank. In addition, the chlorine dosing pump required initial manual adjustment to achieve the proper backpulse chlorine dose. Beyond this, the system was automated. Programmable logic controllers automatically opened the appropriate valves to initiate filtration and backpulse based on the settings of two timers mounted on the front panel of the membrane unit. Control signals were automatically sent to a feed valve to maintain the proper water level in the process tank. The manufacturer established membrane system operating conditions. The unit was operated at a constant flux of 37 gfd (62 l/hr-m^2) with a bleed waste flow of 0.62 gpm (2.4 lpm). A backpulse volume of 4.2 gallon (16 liter), backpulse duration of 15 seconds and backpulse frequency of every 10 minutes, resulted in overall system recovery of 95 percent. Air flow to the process tank was maintained at 15 scfm (420 lpm). Flows, pressures and temperatures were recorded twice daily.

At the above operating conditions, the enhanced coagulation UF system was able to operate for approximately 25 days during Test Period 1 before chemical cleaning was required. During Test Period 2, however, shorter filtration cycles of 9 to 12 days were observed. A total of four chemical cleanings were conducted over the course of ETV testing. To determine the effectiveness of the chemical cleanings in restoring membrane productivity, recovery of specific flux and loss of original specific flux were calculated for each cleaning. Recovery of specific flux ranged from 54 to 69 percent, while loss of original specific flux ranged from 11 to 17 percent.

Air pressure-hold tests were conducted by pressurizing the permeate side of the membrane and observing pressure decay over a 10 minute period. These tests were conducted at the beginning and end of each test period. The results showed minimal pressure decay (<0.5 psi every 5 minutes), indicating no loss of membrane integrity during the course of testing.

Particle Removal Results

Filtrate turbidity of the enhanced coagulation UF system was 0.05 NTU or less 95 percent of the time during both test periods. The test system removed greater than 3 logs of both *Cryptospordium*-sized (3-5 um) particles and *Giardia*-sized (5-15 um) particles, 95 percent of the time. Four hour average raw water and filtrate particle levels and daily average particle removal in these size ranges for Test Periods 1 and 2 are presented in the following table:

ZENON Enhanced Coagulation ZeeWeed® UF System Particle Concentrations and Particle Removals for Test Periods 1/2

	3-5 um Particles			5-15 um Particles		
	Raw Water (#/mL)	Filtrate (#/mL)	Log Removal	Raw Water (#/mL)	Filtrate (#/mL)	Log Removal
Average	2400/2400	0.16/0.28	4.3/4.0	1500/1300	0.13/0.29	4.2/4.0
Standard Deviation	750/540	0.25/0.48	0.31/0.43	730/370	0.13/0.29	0.30/0.41
95% Confidence Interval	2300-2500/ 2300-2500	0.12-0.20/ 0.20-0.36	4.2-4.2/ 3.9-4.1	1400-1600/ 1200/1400	0.80-0.12/ 0.13-0.23	4.1-4.3/ 3.9-4.1
Minimum	640/450	0.049/0.06	3.6/3.2	290/390	0.05/0.05	3.5/3.1
Maximum	5200/3800	2.1/4.9	4.7/4.6	3900/2400	1.1/3.0	4.6/4.6

Microbial Removal Results

Total Coliforms were analyzed on a weekly basis during both ETV test periods. Raw water total coliforms averaged 15 and 5 MPN/100mL during Test Periods 1 and 2, respectively. No total coliform were detected in the filtrate of the UF system during both Test Periods. HPC averaged 120 and 600 cfu/mL in the raw water for Test Periods 1 and 2. Filtrate levels of HPC averaged 1 and 4 cfu/mL. Two microbial seedings with MS2 virus were conducted on the ZENON Enhanced Coagulation ZeeWeed® UF system. Both seedings were conducted after a membrane cleaning and shortly after system startup with enhanced coagulation. The first seeding was conducted three hours after system startup. Feed concentrations of MS2 ranged from $3.5x10^8$ to $5.9x10^8$ pfu/mL, filtrate concentrations ranged from $<1x10^3$ to $1x10^3$ pfu/mL. Log removals of MS2 virus for the first seeding ranged from >5.5 to 5.8. The second seeding with MS2 virus was conducted less than one hour after system startup with enhanced coagulation. For this seeding, feed concentrations ranged from $2.4x10^8$ to $4.6x10^8$ pfu/mL, filtrate concentrations ranged from $3.1x10^6$ to $4.7x10^6$ pfu/mL. Log removals of MS2 virus for the second seeding ranged from 1.7 to 2.1.

Organics Removal Results

The enhanced coagulation membrane system achieved significant removal of naturally occurring organics. Dissolved organic carbon was reduced on average during Test Periods 1 and 2 from 2.2 and 2.7 mg/L in the raw water to 1.7 and 2.2 mg/L in the filtrate, respectively. This represents a 23 percent DOC reduction in each test period. UV254 was reduced on average during Test Periods 1 and 2 from 0.070 and 0.078 /cm in the raw water to 0.048 and 0.043 /cm in the filtrate, respectively. This represents reductions in UV254 of 31 and 44 percent in Test Periods 1 and 2, respectively. SDS DBP formation tests were conducted during each test period. Total trihalomethane concentration was reduced during Test Periods 1 and 2 from 73 and 69 ug/L in raw water to 43 and 46 ug/L in the filtrate, respectively. This represents a 41 and 34 percent TTHM reduction in Test Periods 1 and 2, respectively. HAA5 concentration was reduced during Test Periods 1 and 2 from 23 and 26 ug/L in raw water to 10 and 14 ug/L in the filtrate. This represents a 56 and 48 percent HAA5 reduction in Test Periods 1 and 2, respectively. The system also removed 76 percent of color from the source water during Test Period 2.

Operation and Maintenance Results

After system startup, routine operation of the system involved occasional adjustment of filtrate flow rate to maintain constant flux, and daily verification and adjustment of bleed waste flow and chemical feed flows. The system experienced one failure of the pH controller, which caused it to run without acid addition for three days during Test Period 1. The system experienced three high level alarms in the process tank during the first period which caused the system to shut down overnight. During the first test period, the membrane unit spent approximately 10 percent of filtration time in permeate-recycle mode because of problems with the process tank level-control logic. This was resolved in Test Period 2 by reprogramming the level control logic. Operation of the membrane unit consumed 0.05 gal (0.20 L) of 10% sodium hypochlorite per day to chlorinate backpulse water. Operation of the enhanced coagulation unit consumed 0.89 gal (3.4 L) of 48% alum stock per day on average and 0.6 gal (2.4 L) of 40% Sulfuric Acid. During the average cleaning, 2 gal (7.8 L) of household bleach (5.25% NaOCl) were used and 8.8 lb (4.0 kg) of citric acid. The manufacturer included an Operations and Maintenance manual with their system. The manual would be improved with better organization and better use of tables and graphics.

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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 a NSF Certification of the specific product mentioned herein.

Availability of Supporting Documents

Copies of the *ETV Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants,* dated April 20, 1998 and revised May 14, 1999, the Verification Statement, and the Verification Report (NSF Report #00/02/EPADW395) are available from the following sources:
(NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.)

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

August 2000

Environmental Technology Verification Report

Physical Removal of Microbiological and Particulate Contaminants in Drinking Water

ZENON (ZeeWeed^{Ò}) Enhanced Coagulation Membrane Escondido, California

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Notice

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Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for the NSF International (NSF) and the United States Environmental Protection Agency (EPA) by Montgomery Watson, in cooperation with ZENON Membrane Systems. The test was conducted in 1999 at the Aqua 2000 Research Center in San Diego, California.

Throughout its history, the EPA has evaluated the effectiveness of innovative technologies to protect human health and the environment. The ETV Program has been instituted to verify the performance of innovative technical solutions to environmental pollution or human health threats. ETV was created to substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. Verifiable, high quality data on the performance of new technologies are made available to regulators, developers, consulting engineers, and those in the public health and environmental protection industries. This encourages more rapid availability of approaches to better protect the environment.

The EPA has partnered with NSF, an independent, not-for-profit testing and certification organization dedicated to public health, safety and protection of the environment, to verify performance of small package drinking water systems that serve small communities under the Package Drinking Water Treatment Systems (PDWTS) ETV Pilot Project. A goal of verification testing is to enhance and facilitate the acceptance of small package drinking water treatment equipment by state drinking water regulatory officials and consulting engineers while reducing the need for testing of equipment at each location where the equipment's use is contemplated. NSF will meet this goal by working with manufacturers and NSF-qualified Field Testing Organizations (FTO) to conduct verification testing under the approved protocols.

The ETV PDWTS is being conducted by NSF with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division, Cincinnati, Ohio. It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the FTO.

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Appendices

Appendix A – Additional Documents and Data Analyses
Appendix B – Raw Data Sheets
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Abbreviations and Acronyms

°C	Celsius degrees
cfu	Colony forming unit(s)
CIP	Clean in place
C_f	Feed concentration
C_p	Permeate concentration
cm	Centimeter
CRW	Colorado River water
d	Day(s)
DBP	Disinfection by-product
DOC	Dissolved organic carbon
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
FOD	Field Operations Document
ft^2	Square foot (feet)
FTO	Field Testing Organization
gfd	Gallon(s) per day per square foot of membrane area
gpm	Gallon(s) per minute
HAA5	Sum of five measured haloacetic acids
HPC	Heterotrophic plate count
hr	Hour(s)
ICR	Information Collection Rule
in Hg	Inch(es) of Mercury
J_{s_i}	Initial specifictransmembrane flux
J_{s_f}	Final specific transmembrane flux
J_S	Specific flux
$J_{s_{i0}}$	Initial specific transmembrane flux at t=0 of membrane operation
J_t	Filtrate flux
J_{tm}	Transmembrane flux
kg	Kilogram(s)
L	Liter(s)
m^2	Square meter(s)
m^3/d	Cubic meter(s) per day
mgd	Million gallons per day
mg/L	Milligram(s) per liter
min	Minute(s)
mL	Milliliter(s)
MPN	Most probable number
NIST	National Institute of Standards and Technology
NSF	NSF International (formerly known as the National Sanitation Foundation)
NTU	Nephelometric turbidity unit(s)
O&M	Operations and Maintenance
P_i	Pressure at inlet of membrane module
P_o	Pressure at outlet of membrane module
P_p	Filtrate pressure
P_{tm}	Transmembrane pressure
PC	Personal computer
PDWTS	Package Drinking Water Treatment System
PLC	Programmable Logic Controller
ppm	Parts per million
psi	Pound(s) per square inch
PVC	Polyvinyl chloride
Q_f	Feed flow
Q_p	Process flow
Q_r	Recycle flow
QA	Quality assurance
QC	Quality control
S	Membrane surface area
SDS	Simulated distribution system
scfm	Standard cubic feet per minute
sec	Second(s)
SPW	State Project water
T	Temperature
TC	Total coliform
TOC	Total organic carbon
TDS	Total dissolved solids
TSS	Total suspended solids
TTHM	Total trihalomethanes
um	Micron(s)
UF	Ultrafiltration
UFC	Uniform formation conditions
UV254	Ultraviolet light absorbance at 254 nanometer

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Chapter 1
Introduction

1.1 Environmental Technology Verification (ETV) Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) 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 substantially 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; stakeholders groups which consist 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 testing (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF) in cooperation with the EPA operates the Package Drinking Water Treatment Systems (PDWTS) program, one of 12 technology areas under ETV. This PDWTS program evaluated the performance the ZENON ZeeWeed® Enhanced Coagulation System, ultrafiltration (UF) system used in package drinking water treatment system applications.

This report provides the ETV results for the ZENON ZeeWeed® Enhanced Coagulation System.

1.2 Project Participants

Figure 1-1 is an organization chart showing the project participants and the lines of communication established for the ETV. The Field Testing Organization (FTO) was Montgomery Watson, an NSF-qualified FTO, which provided the overall management of the ETV through the project manager and project engineer. The ultrafiltration membrane manufacturer for the ETV was ZENON Membrane Systems. The operations management and staff were from the test site at the City of San Diego Metropolitan Wastewater Department, Aqua 2000 Research Center in Escondido, California. Water quality analyses were provided by the City of San Diego laboratory, a State-certified laboratory. Data management and final report preparation were performed by the FTO, Montgomery Watson.

1.3 Definition of Roles and Responsibilities of Project Participants

1.3.1 Field Testing Organization Responsibilities

The specific responsibilities of the FTO, Montgomery Watson, were to:

- Provide the overall management of the ETV through the project manager and the project engineers.
- Provide all needed logistical support, the project communication network, and all scheduling and coordination of the activities of all participants.
- Manage, evaluate, interpret and report on data generated in the ETV.
- Evaluate the performance of the ultrafiltration enhanced coagulation membrane technology according to the Field Operating Document (FOD) and the testing, operations, quality assurance/quality control (QA/QC), data management and safety protocols contained therein.
- Provide all quality control (QC) information in the ETV report.
- Provide all data generated during the ETV in hard copy and electronic form in a common spreadsheet or database format.

1.3.2 Manufacturer Responsibilities

The specific responsibilities of the ultrafiltration membrane manufacturer, ZENON Membrane Systems, were to:

- Provide complete, field-ready equipment for the ETV at the testing site.
- Provide logistical and technical support as required throughout the ETV.
- Provide partial funding for the project.
- Attend project meetings as necessary.

1.3.3 Operator and Test Site Staff Responsibilities

The specific responsibilities of the operations and test site staff from the City of San Diego Metropolitan Wastewater Department were to:

- Provide set-up, shake-down, operations, maintenance and on-site analytical services according to the FOD and the testing, operations, QA/QC, data management and safety protocols.
- Provide the necessary and appropriate space for the equipment to be tested in the ETV.
- Provide all necessary electrical power, feedwater and other utilities as required for the ETV.
- Provide all necessary drains to the test site.

1.3.4 Water Quality Analyst Responsibilities

The specific responsibilities of the water quality analytical staff from the City of San Diego Laboratory were to:

- Provide all off-site water quality analyses prescribed in the FOD according to the QA/QC protocols contained therein.
- Provide reports with the analytical results to the data manager.
- Provide detailed information on the analytical procedures implemented.

1.3.5 NSF Responsibilities

NSF was responsible for administration of the testing program. Specific responsibilities of the NSF were to:

- Develop test protocols and qualify FTOs.
- Review and approve FODs.
- Conduct inspections and make recommendations based on inspections.
- Conduct financial administration of the project.
- Review all project reports and deliverables.

1.3.6 EPA Responsibilities

The specific responsibilities of EPA were to:

- Initiate the ETV program.
- Provide significant project funding.
- Review final reports.

Chapter 2
Equipment Description and Operating Processes

The equipment tested in this ETV is the ZENON Enhanced Coagulation ZeeWeed® UF package system. This system consists of two main components: an enhanced coagulation unit, where raw water is dosed with coagulant and acid, and a ZeeWeed® package membrane unit. The enhanced coagulation unit includes feed pumps for dosing acid and coagulant, followed by static mixers, and a serpentine flocculation tank. The effluent from the enhanced coagulation unit serves as the feedwater to the process tank of the ZeeWeed® package membrane unit. The ZeeWeed® package membrane unit consists of one ZeeWeed® ZW-500 UF module immersed in a process tank, along with associated pumps and blowers. OCP is the manufacturer's designation for their drinking water membrane. For the remainder of this report, the 500 square foot OCP ultrafiltration drinking water module will be referred to as the ZeeWeed® UF module. These ultrafilters typically remove particulate material, including protozoa and bacteria.

The ZENON Enhanced Coagulation ZeeWeed® UF system including enhanced coagulation and flocculation process for removal of organics and color was employed throughout the ETV testing presented in this report.

Table 2-1 provides the specification of the ZENON Enhanced Coagulation ZeeWeed® UF membranes. The information in Table 2-1 is taken from a letter supplied by the manufacturer (see Appendix A). The ZENON Enhanced Coagulation ZeeWeed® UF membranes are outside/in hollow fibers. The immersion of the membrane allows for operation of the ZENON Enhanced Coagulation system under a slight vacuum, instead of under pressure. The vacuum pressure is on the order of 1 to 12 psi (0.07 to 0.83 bar). The membrane surface chemistry is neutral and hydrophilic.

A photograph of the ETV test unit is included as Figure 2-1. The photograph shows the ZeeWeed® UF test unit (on the left) along with a second unit, which is the flocculation tank. The ZENON ZeeWeed® UF unit is skid-mounted with dimensions 66 inches (168 cm) long by 36 inches (92 cm) wide by 87 inches (221 cm) high (Figure 2-2). The flocculation tank is used for enhanced coagulation applications, as described below. The flocculation tank is 48 inches (122 cm) long by 32 inches (80 cm) wide. The spatial requirements of the ZENON Enhanced Coagulation ZeeWeed® UF unit are presented graphically in Figure 2-2.

A schematic diagram of the ZeeWeed® process is shown in Figure 2-3. The membrane module is immersed in the process tank. The ZeeWeed® system is represented by the half black and half white rectangle in the process tank, denoting the feedwater side and the filtrate side of the membrane. The pretreated water from the flocculation basin enters the tank and is pulled by the vacuum pump through the membrane. A blower provides a constant supply of air for agitating the water and solids at the membrane surface. The resulting scouring action mitigates the build-up of solids on the membrane surface. Waste sludge is continuously bled at a low flow rate from the process tank for disposal.

Ultrafiltration enhanced coagulation is achieved by allowing a solids slurry to develop in the process tank. By coagulating the organic molecules in a high solids environment, benefits can be achieved from the mechanisms of coagulation, co-precipitation, adsorption and nucleation resulting in the effective removal of organic materials using relatively low coagulant doses, since the coagulated floc only needs to exceed the membrane pore size (0.030 microns). Alum at a dose of 30 mg/L was the coagulant used during the ETV testing. The coagulation pH was adjusted to 6.2 by addition of sulfuric acid.

2.1 Description of the Treatment Train and Unit Processes

The ZENON Enhanced Coagulation ZeeWeed® UF system tested included the following components:

- Pre-treatment chemical feed systems (acid and coagulant)
- Static mixer
- Serpentine flocculation chamber with air diffusers for mixing
- ZeeWeed® UF module (in a process tank)
- Air blower
- "CIP" (clean-in-place) tank
- Permeate pump
- Sodium hypochlorite dosing system
- Bleed waste pump and disposal line

The enhanced coagulation system consists of the pre-treatment chemical feed tanks and dosing pumps, the static mixer and the flocculation tank. Enhanced coagulation relies on addition of coagulant and acid to natural waters along with mixing to promote destabilization, charge neutralization and agglomeration of particles and organic colloidal material. This results in the adsorption of organic material to floc particles. These particles are then removed by filtration. The system uses the capability of the ZeeWeed® membrane to operate in a high-solids environment. A high solids concentration is developed in the process tank for adsorption and removal of organic carbon.

The ZeeWeed® membrane module was described above. The air blower provides a constant supply of air to promote scouring of solid material from the outside surface of the membrane. The scouring action alleviates solids accumulation on the membrane by moving the solids back into the bulk water of the process tank. During the ETV testing, the ZENON Enhanced Coagulation ZeeWeed® UF system was operated at a constant flux, with monitoring of the transmembrane vacuum pressure increase necessary to maintain the target flux over time.

The CIP tank is used for backpulsing of the membranes. In the backpulse mode, the direction of flow through the membranes is reversed. Filtrate water from the CIP tank is pumped from the clean water side of the membrane back to the feedwater side in order to clean away material accumulated on the membrane surface. The backpulse process is controlled by a programmable logic controller (PLC), which closes and opens appropriate valves to reverse the direction of flow through the membrane. A typical operating scenario for the backpulse system might involve backpulsing for 15 seconds every 10 minutes. When the backpulse is complete, the CIP tank is first refilled with filtrate before the membrane

system starts producing filtrate through the product water line, thus ensuring a sufficient supply of filtrate water for the next backpulsing cycle.

During backpulsing, solids removed from the membrane surface are washed back into the bulk water of the process tank. Sludge is bled continuously from the process tank at a constant rate, which controls the overall system water recovery.

2.2 Description of Physical Construction/Components of the Equipment

The enhanced coagulation ZeeWeed® unit was constructed to allow for quick equipment modifications, depending on the site specifications and also allows the addition of ancillary equipment. The unit is constructed of corrosion-resistant materials, including PVC, polyethylene, polypropylene and stainless steel. The main components of the system are:

- 200 gallon (757 L) polypropylene ZeeWeed® process tank
- 20 gallon (76 L) polypropylene clean-in-place tank
- Becker DT 3.4, 1.7 Hp, carbon vane blower
- Service Filtration, GNOK Series self-priming pump
- Goulds NPE, 1 Hp, centrifugal pump

The ancillary equipment includes:

- Prominent g/4a 1601 NP1 metering pumps
- Masterflex peristaltic bleed pump

The test system has a total weight in the range of 1,500 to 2,000 pounds (682 to 909 kg). For shipping purposes, the system is crated and can be moved with a forklift.

Chapter 3
Materials and Methods

3.1 Testing Site Name and Location

The test site selected for the ETV program is the City of San Diego's Aqua 2000 Research Center at 14103 Highland Valley Road in Escondido, California.

3.1.1 Site Background Information

The Aqua 2000 Research Center was established in 1995 to conduct most of the research work related to the water repurification project of the City of San Diego. The Center has dedicated full time operators with substantial experience in operating membrane systems. This site is also connected to San Diego County Water Authority's Aqueduct System. Sufficient influent water supply, electrical power, and proper drainage lines were provided to the ETV test system treatment train.

3.1.2 Test Site Description

Figure 3-1 is a schematic diagram of the test site and the location of the membrane pilot unit. Below is a list of the facilities and equipment that were available at the test site.

Structural

- 5,000 square foot concrete pad.
- Semi-permanent shading to protect from sunlight.
- Potable water connections.
- San Diego County Water Authority's Aqueduct System connections.
- Drainage system connected to a wastewater plant.
- Chemical containment area.
- Sufficient lighting for 24-hour operation.
- Full electrical supply.
- Chemical safety shower and eyewash.
- An operations trailer with conference room, offices, and computers.
- A laboratory trailer for on-site water quality analyses.

Instrumentation/Equipment

On-Site Laboratory

- DR 4000 Spectrophotometer by Hach.
- Ratio/non-ratio 2100N Turbidimeter by Hach.
- pH/Temperature meter by Fisher (No. 13-635-BAA).
- Portable conductivity meter by Fisher (No. 09-327-1).
- Two TOC Analyzers (Sievers Model No. 800).

Concrete Pad

- Feed, permeate, backwash, and waste storage tanks.
- Chemical Cleaning Skid with hot water supply.
- Chemical Feed Systems.
- Micro 2000 On-line Chlorine Analyzer.
- Five 1720C On-line Hach Turbidimeters.

Raw Water Intake

The raw water was delivered to the test site through schedule 80 PVC pipe. The San Diego Aqueduct connection was approximately one mile away from the test site. The available water flow rate was 150 gpm.

Collection of Raw Water

The raw water was directed to a covered tank with an overflow system. The feedwater pipe of the test unit was connected to the covered raw water tank.

Handling of Treated Water and Residuals

The Aqua 2000 research center has a drainage system that connects to a wastewater treatment plant. All of the treated water, backwash water, and any chemicals used were directed to waste.

3.2 Source/Feed Water Quality

The source of feedwater for the ETV testing is San Diego Aqueduct Water. The aqueduct is supplied primarily from Lake Skinner which receives Colorado River Water (CRW) from the West Portal of the San Jacinto Tunnel, and State Project Water (SPW) from Lake Silverwood. A typical blending ratio of these two waters in Lake Skinner is 70 percent CRW and 30 percent SPW. The lower total dissolved solids (TDS) SPW is added to maintain the TDS of Lake Skinner at approximately 500 mg/L or less (depending on availability of SPW). The aqueduct water is characterized by relatively high levels of total dissolved solids, hardness and alkalinity, with moderate levels of organic material and relatively low turbidity.

Figure 3-2 illustrates Lake Skinner water quality for the period of November 1997 through November 1998, which is typical for this source water. The stable quality of the water is apparent in all parameters illustrated in the figure. Hardness ranged from 200 through 298 mg/L as $CaCO_3$, alkalinity ranged from 108 to 130 mg/L as $CaCO_3$ and calcium ranged from 47 to 75 mg/L. The hardness levels are quite high, with relatively high alkalinity as well. TDS ranged from 429 to 610 mg/L, indicating the relatively high level of salinity in this source water. pH ranged from 8.26 to 8.45 during the year.

Figure 3-3 illustrates turbidity, temperature and total organic carbon (TOC) for Lake Skinner water. Turbidity was relatively low with a range of 1.10 to 3.50 NTU. Lake Skinner exhibits relatively warm temperatures throughout the year, typical of many water supplies in the southwestern and southeastern United States. The temperature range was 13 to 27°C. Annual low temperatures on the order of

10°C are typical of this supply. The levels of organic material, as quantified by TOC, are moderate in this supply. The TOC range was 2.33 to 2.94 mg/L.

3.3 Environmental Technology Verification Testing Plan

This section describes the tasks completed for the ETV. The test equipment was operated 24 hours a day, seven days a week, with operations staff on-site Monday through Friday for one 8-hour shift each day. Tasks that were performed by the operations and engineering staff are listed below:

Task 1: Characterization of Membrane Flux and Recovery
Task 2: Evaluation of Cleaning Efficiency
Task 3: Evaluation of Finished Water Quality
Task 4: Reporting of Membrane Pore Size
Task 5: Membrane Integrity Testing
Task 6: Data Management
Task 7: Quality Assurance/Quality Control
Task 8: Microbial Removal (optional)
Task 9: Ultrafiltration Enhanced Coagulation

An overview of each task is provided below.

3.3.1 Task 1: Characterization of Membrane Flux and Recovery

The objective of this task is to evaluate the membrane operational performance. Membrane productivity was evaluated relative to feedwater and pretreated water quality. The rates of transmembrane pressure increase and/or specific flux decline were used, in part, to evaluate operation of the membrane equipment under the operating conditions being verified and under the raw and pretreated water quality conditions present during the testing period.

Work Plan
After set-up and shakedown of the membrane equipment, membrane operation was established at the flux condition being verified in this ETV. Testing took place over two 30-day test periods. When substantial specific flux decline occurred before the end of the 30-day test period, chemical cleaning was performed and (if necessary) adjustments to the operational strategy were made. Measurement of the membrane feedwater (i.e., pretreated water from the flocculation tank) flow, filtrate flow, and system pressures and temperatures were collected at a minimum of twice a day.

3.3.2 Task 2: Evaluation of Cleaning Efficiency

An important aspect of membrane operation is the restoration of membrane productivity after specific flux decline has occurred. The objective of this task is to evaluate the effectiveness of chemical cleaning for restoring finished water productivity to the membrane system. The recovery of specific flux and the fraction of original specific flux lost were determined after each chemical cleaning.

Work Plan

The membrane was operated at the flux condition being verified in this ETV until such time as the termination criteria were reached. The two criteria for cleaning of the membrane were: 1) reaching the maximum transmembrane vacuum pressure operational limit of the membrane, or, 2) completing the 30-day test period. The membrane was chemically cleaned when either of these termination criteria were reached. Chemical cleaning was performed in accordance to the manufacturer procedure (see Appendix A). For the feedwater utilized in this ETV, the manufacturer recommended their typical chemical cleaning procedure which requires soaking the membrane modules for 4 – 6 hours in sequence using the following two solutions:

1. Approximately 300-500 mg/L sodium hypochlorite solution
2. 5-10 g/L of ZENON's MC-1 cleaner (a citric acid based cleaner)

A flux-vacuum profile was developed at each stage of the chemical cleaning procedure (i.e, before cleaning, after first chemical solution, after second chemical solution). The slope of the flux-vacuum profile represents the specific flux of the membrane at each cleaning stage and was used to calculate the cleaning efficiency indicators. Two primary indicators of cleaning efficiency and restoration of membrane productivity were examined in this ETV:

1. The immediate recovery of membrane productivity, as expressed by the ratio between the final specific flux value of the current filtration run (Js_f) and the initial specific flux (Js_i) measured for the subsequent filtration run:

$$\text{Recovery of Specific Flux} = 100 \times [1 - (Js_f \div Js_i)]$$

where: Js_f = specific flux (gfd/psi, L/(hr-m^2)/bar) at end of current run (final)

Js_i = specific flux (gfd/psi, L/(hr-m^2)/bar) at beginning of subsequent run (initial)

2. The loss of specific flux capabilities is expressed by the ratio between the initial specific flux for any given filtration run (Js_i) and the specific flux (Js_{io}) at time zero, as measured at the initiation of the first filtration run in a series:

$$\text{Loss of Original Specific Flux} = 100 \times [1 - (Js_f \div Js_{io})]$$

where: Js_{io}= specific flux (gfd/psi, L/(hr-m^2)/bar) at time t = 0 of membrane testing

3.3.3 Task 3: Evaluation of Finished Water Quality

The objective of this task is to evaluate the quality of water produced by the UF enhanced coagulation membrane system. Many of the water quality parameters described in this task were measured on-site.

Analysis of the remaining water quality parameters was performed by the City of San Diego Laboratory, a State-certified analytical laboratory.

Work Plan

The parameters monitored during this ETV and the methods used for their measurement are listed in Table 3-1. Finished water quality was evaluated relative to feedwater and pretreated water quality and operational conditions, using the ZENON Enhanced Coagulation ZeeWeed® UF test unit as a UF-enhanced coagulation process.

Simulated Distribution System (SDS) Test Protocol

The SDS DBP test simulates full-scale disinfection by spiking a water sample with a disinfectant and holding the spiked sample in the dark at a designated temperature and contact time. For this testing, the uniform formation conditions (UFC) specified by the Information Collection Rule (ICR) were used, as follows:

- Incubation period: 24 ± 1 hours
- Incubation temperature: 20 ± 1°C
- Buffered pH of 8.0 ± 0.2
- 24-hour free chlorine residual: 1.0 ± 0.4 mg/L

For each SDS sample, three incubation bottles were set up. At the end of the incubation period, each sample was analyzed for the final disinfectant residual and the sample with the residual closest to the 1.0 ± 0.4 mg/L range was used for the specified DBP analyses, total trihalomethanes (TTHMs) and the sum of 5 measured haloacetic acids (HAA5). The four trihalomethanes comprising TTHM are chloroform, bromoform, dibromochloromethane and bromodichloromethane. The five haloacetic acids included in HAA5 are monobromoacetic acid, dibromoacetic acid, monochloroacetic acid, dichloroacetic acid and trichloroacetic acid. A sixth haloacetic acid, bromochloroacetic acid, was also reported, but this DBP is not included in the calculation of the regulated parameter HAA5.

One liter, amber glass bottles with Teflon lined caps were used to store the SDS samples during incubation. These bottles were stored in a temperature-controlled incubator at the specified temperature. All glassware used for preparation of the SDS samples and reagents were chlorine demand free.

3.3.4 Task 4: Reporting of Membrane Pore Size

Membranes for particle and microbial removal do not have a single pore size, but rather have a distribution of pore sizes. Membrane rejection capabilities are limited by the maximum membrane pore size.

Work Plan
The manufacturer was asked to supply the 90 percent and the maximum pore size of the membranes being tested in the ETV. The manufacturer was also asked to identify the general method used in determining the pore size values.

3.3.5 Task 5: Membrane Integrity Testing

A critical aspect of any membrane process is the ability to verify that the process is producing a specified water quality on a continual basis. For example, it is important to know whether the membrane is providing a constant barrier to microbial contaminants. The objective of this task is to evaluate one or more integrity monitoring methods for the membrane system.

Work Plan
The selected methods for monitoring of membrane integrity of the Manufacturer's UF system during this study are described below:

Air Pressure-Hold Test
The air pressure-hold test is one of the direct methods for evaluation of membrane integrity. This test can be conducted on several membrane modules simultaneously; thus, it can test the integrity of a full rack of membrane modules used for full-scale systems. The test is conducted by pressurizing the permeate side of the membrane lumen after which the pressure is held and the decay rate is monitored over time. Minimal loss of the held pressure (generally less than 1 psi every 5 minutes) at the filtrate side indicates a passed test, while a significant decrease of the held pressure indicates a failed test.

Particle Counting
On-line particle counting in the size ranges of 2-3 um, 3- 5 um, 5-15 um, >15 um was used in this ETV as an indirect method of monitoring membrane integrity.

Turbidity Monitoring
On-line turbidity monitoring was also used in this ETV as an indirect method of monitoring membrane integrity.

3.3.6 Task 6: Data Management

The objective of this task is to establish the protocol for management of all data produced in the ETV and for data transmission between the FTO and the NSF.

Work Plan
According to EPA/NSF ETV protocols, a data acquisition system was used for automatic entry of on-line testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters were then downloaded for importation into Excel as a comma delimited file. These specific database parcels were identified based on discrete time spans and monitoring parameters. In spreadsheet form, data were manipulated into a convenient framework to allow analysis

of membrane equipment operation. For those parameters not recorded by the data acquisition system, field-testing operators recorded data and calculations by hand in laboratory notebooks. Daily measurements were recorded on specially-prepared data log sheets as appropriate.

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

Data from the outside laboratory were received and reviewed by the field testing operator. Data from the onsite lab and City of San Diego Microbiology lab were entered into the data spreadsheets, corrected, and verified in the same manner as the field data. Data from the City of San Diego Water Quality lab were received both electronically and in hardcopy printouts generated from the electronic data.

3.3.7 Task 7: Quality Assurance/Quality Control

An important aspect of verification testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure the high quality of all measurements of operational and water quality parameters during the ETV.

Work Plan

Equipment flow rates and associated signals were documented and recorded on a routine basis. A routine daily walk-through during testing was performed to verify that each piece of equipment or instrumentation is operating properly. On-line monitoring equipment, such as flow meters, were checked to confirm that the read-out matches the actual measurement (i.e., flow rate) and that the signal being recorded is correct. Below is a list of the verifications conducted:

Monitoring Equipment

System Pressure Gauges

Pressure and vacuum gauges supplied with the membrane systems tested were verified against grade 3A certified pressure and vacuum gauges purchased at the start of NSF testing. The certified pressure and vacuum gauges were manufactured by Ashcroft and have an accuracy of 0.25% over their range (0-30 psi pressure, 0-30 in Hg vacuum). Where possible, system gauges were removed and tested over the expected range of operating pressures against the verification gauge, using a portable hand pump. The vacuum gauge for the ZENON system had an error well less than 5 percent.

System Flow Rates

Membrane and enhanced coagulation system flow rates were verified volumetrically on a monthly basis near the beginning and end of each test period. System flows were diverted to a 55 gallon graduated tank for approximately 2 minutes. The measured flow rate was compared with flows indicated on rotameters. Measured and indicated flow rates agreed to within 5 percent for the ZENON permeate rotameter and enhanced coagulation feed rotameter. The ZENON feed totalizer read approximately 8 percent lower than actual measured volume. Calculations made using this parameter were corrected for this error.

Analytical Methods

pH

An Accumet Research Model AR15 laboratory pH meter was used to conduct routine pH readings at the test facility. Daily calibration of the pH meter using pH 4, 7 and 10 buffers was performed. The slope obtained after calibration was recorded. The temperature of the sample when reading sample pH was also recorded.

Temperature

Accuracy of the feed water inline thermometer was verified against an National Institute of Standards and Technology (NIST) certified thermometer on 4/14, 6/16 and 12/12/99. Comparisons were made at three temperatures covering the range of anticipated raw water temperatures. In all cases, the raw water thermometer compared to within 1 percent of the NIST certified thermometer.

Turbidity

On-line turbidimeters were used for measurement of turbidity in the raw and filtrate waters, and a bench-top turbidimeter was used for measurement of the feed (pretreated) water and backwash waste water.

On-line Turbidimeters: Hach 1720D online turbidimeters were used during testing to acquire raw and filtrate turbidities at 1-minute intervals. The following procedures were followed to ensure the integrity and accuracy of these data:

- a primary calibration of the on-line turbidimeters was performed near the beginning of the test periods.
- Aquaview + data acquisition software was used to acquire and store turbidity data. Data were stored to the computer database each minute. After initial primary calibration of the turbidimeters, zero, mid-level and full-strength signals (4, 12 and 20 mA) were output from each turbidimeter to the data acquisition software. The signals received by the data acquisition software from all 4 on-line turbidimeters had less than one percent error over their range of output (0, 1 and 2 NTU for permeate, and 0, 10 and 20 NTU for feed) as stored in the Aquaview database.
- the manufacturer's specified acceptable flow range for these turbidimeters is 250 to 750 mL/min. The flow range initially targeted during testing was 500 mL/min +/- 100 mL/min. On-line turbidimeter flows were verified manually with a graduated cylinder and stopwatch daily.

- turbidimeter bodies were drained and sensor optics cleaned approximately every week on an as needed basis.
- on-line turbidities were compared to desktop turbidities when turbidity samples were collected. Comparative calibrations of the raw water on-line turbidimeter against the Hach 2100N desktop turbidimeter were conducted on as needed basis during the course of the testing when the difference between online and desktop turbidity readings were greater than 10 percent.
- Approximately 50 ppm free chlorine solution was pumped through turbidity sample lines as needed to clean potential buildup from these lines.

Bench-top Turbidimeters: A Hach 2100N desktop turbidimeter was used to perform onsite turbidity analyses of raw water, backwash and permeate samples. Readings were recorded in non-ratio operating mode. The following quality assurance and quality control procedures were followed to ensure the integrity and accuracy of onsite laboratory turbidity data:

Primary calibration of turbidimeter according to manufacturer's specification was conducted on a weekly basis. Secondary standard calibration verification was performed on a daily basis. Three secondary standards (approx. 0.8 NTU, 1.8 NTU and 20 NTU) were recorded after primary calibration and on a daily basis for the remaining 6 days until the next primary calibration. Proficiency samples with a known turbidity of 0.8 NTU were purchased from a commercial supplier. Turbidity proficiency samples were prepared and analyzed every two weeks.

Particle Counting

Hach 1900 WPC light blocking particle counters were used to monitor particles in raw and filtrate waters. These counters enumerate particles in the range 2 to 800 microns.

The particle counters were factory calibrated. Factory calibrations took place from late September, 1998 to October, 1998. The manufacturer recommends factory calibration on a yearly basis. The following procedures were followed to ensure the integrity and accuracy of the on-line particle data collected:

- the Aquaview software was configured to store particle counts in the following size ranges: 2-3 um, 3-5 um, 5-15 um and >15 um.
- To demonstrate the comparative response of the particle counters, NIST traceable monospheres were purchased from Duke Scientific in the following sizes: 2 um, 4 um, 10 um and 20 um. Duke monospheres were added to constantly stirred DI water and pumped to one of the constant head flow controllers using a peristaltic pump. The flow from this controller was then directed to each of the particle counters for approximately 10 minutes. The same solution was used for each particle counter (raw water and ZENON filtrate).

The precise concentration of each monosphere was not known, but based on Duke Scientific estimates the following concentration range of each monosphere was targeted in the test solution:

- 2 um 1,000 - 10,000/mL

- 4 um 100 - 1,000/mL
- 10 um 10 - 100/mL
- 20 um 1 - 10/mL

A typical response of the particle counters to this monosphere solution near both test periods is presented in Figure 3-4. The particle counter response of the raw and ZENON filtrate particle counters were within 35 percent in all size ranges. The figures show a good comparative response of the particle counters to the same monosphere solution.

- flows through the particle counters were maintained at 200+/- 10 mL/min with constant head devices. Flows were verified on a daily basis with a graduated cylinder and stop watch. Flows were observed to be extremely consistent (typically within 2 mL/min of the target flow rate).
- 50 ppm free chlorine was run through particle counters for on an as needed basis to remove potential buildup.

Chemical and Microbial Water Quality Parameters

The analytical work for the study was performed by the City of San Diego Laboratory, which is a State of California certified water laboratory. All water samples were collected in appropriate containers (containing preservatives as applicable) prepared by the City of San Diego laboratory. Samples for analysis of Total Coliforms (TC) and Heterotrophic Plate Count (HPC) analysis were collected in bottles supplied by the City of San Diego laboratory and transported with an internal cooler temperature of approximately 2 to 8°C to the analytical laboratory. All samples were preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times. All reported results had acceptable QA and met USEPA QC guidelines, which was confirmed by letters from the City of San Diego Laboratory (Appendix A).

3.3.8 Task 8: Microbial Removal (Optional)

The objective of this task is to evaluate microbial removal capabilities by seeding the membrane system with selected virus. Removal capabilities were evaluated under the worst case scenario for the membrane system operation (in this case, directly after chemical cleaning of the membrane modules).

Work Plan

The seeding experiments were performed at the test site and the samples collected during the seeding experiments were submitted to the City of San Diego Marine Microbiology Lab, a State-certified laboratory, for analysis of the seeded microorganisms.

Organisms for Seeding Experiments

The organism selected for seeding experiments is MS2 bacterial virus. MS2 virus is not a human pathogen; however, this organism is similar in size (0.025 microns), shape (icosahedron) and nucleic acid (RNA) to polio virus and hepatitis. Since MS2 is not a human pathogen, live MS2 virus was used in the seeding experiments. Organism stocks received from the suppliers were stored refrigerated at 4°C in the dark until use in the seeding experiments.

Microbial Seeding Protocols

MS2 virus was added directly to the process tank at the completion of a backpulse. The membrane system was operated for one service cycle to stabilize the organism concentration in the membrane system, after which sampling was initiated. The microorganism concentration in the process tank was sufficient to demonstrate a minimum of 4 logs of removal of the seeded organism.

During the MS2 seeding experiment, three samples from the bleed waste (process tank waste) and three samples from the filtrate water were collected during the second and third service cycles after the initiation of seeding. The first filtrate sample during each filtration cycle was collected within the first minute of filtration after completion of backpulse. The last filtrate sample during each filtration cycle was collected within 3 minutes of the end of the cycle. Each sample was collected in sterile 250-mL bottles, was stored at 1°C and processed within 24 hours.

The MS2 seeding experiments were conducted during the second period of NSF testing. The experiments were conducted under the operating conditions in which the microorganisms would most likely penetrate the membrane; when the membrane is clean, and at a high flux rate (Jacangelo et al. 1995, Montgomery Watson, 1997 and 1999). Therefore, the membrane was cleaned immediately prior to MS2 seeding.

3.3.9 Task 9: Ultrafiltration Enhanced Coagulation

The ZENON membrane tested in this ETV has an enhanced coagulation system upstream of the membrane module. While not a necessary part of the membrane system for removal of particulate material and microbial contaminants, the enhanced coagulation system can provide removal of organic material not otherwise achievable with UF, allowing effective treatment of a wider range of source waters, including organic-laden surface waters. The objective of this task is to evaluate the efficiency of UF enhanced coagulation for removal of organic material.

Work Plan

Operating conditions for the chemical pretreatment system were determined based on existing full-scale water treatment facilities treating the same source water, as well as the Manufacturer's experience in optimum pretreatment conditions for the ZeeWeed® system. Pretreatment system operating conditions determined included coagulant chemical and dose, coagulation pH and flocculation mixing energy.

Membrane operating conditions to be used in conjunction with the pretreated water were also determined based on the Manufacturer's experience in optimum operation of the ZeeWeed® system. Membrane system operating conditions determined in conjunction with pretreatment included membrane flux, backpulse frequency, backpulse duration, backpulse pressure, bleed waste flow rate and air flow rate.

Evaluation criteria for Task 9 are the removal of organic material as characterized by UV254, TOC, DOC, color and SDS DBPs, as well as the impact of chemical pretreatment on other water quality

parameters such as filtrate pH, alkalinity and aluminum or iron concentrations. The DBPs of concern are TTHMs and HAA5.

3.4 Calculation of Membrane Operating Parameters

3.4.1 Filtrate Flux

The average filtrate flux is the flow of product water divided by the surface area of the membrane. Filtrate flux is calculated according to the following formula:

$J_t = Q_p \div S$

where J_t = filtrate flux at time t (gfd, L/(hr-m^2))
Q_p = filtrate flow (gpd, L/h)
S = membrane surface area (ft^2, m^2)

Flux is expressed only as gfd and L/(hr-m^2) in accordance with EPA/NSF ETV protocol.

3.4.2 Specific Flux

The term specific flux is used to refer to filtrate flux that has been normalized for the transmembrane pressure. The equation used for calculation of specific flux is:

$J_{tm} = J_t \div P_{tm}$

where J_{tm} = specific flux at time t (gfd/psi, L/(hr-m^2)/bar)
J_t = filtrate flux at time t (gfd, L/(hr-m^2))
P_{tm} = transmembrane pressure (psi, bar)

3.4.3 Transmembrane Pressure

The average transmembrane pressure is calculated as follows:

$P_{tm} = [(P_i + P_o) \div 2] - P_p$

where P_{tm} = transmembrane pressure (psi, bar)
P_i = pressure at the inlet of the membrane module (psi, bar)
P_o = pressure at the outlet of the membrane module (psi, bar)
P_p = filtrate pressure (psi, bar)

3.4.4 Temperature Adjustment for Flux Calculation

Temperature corrections to 20°C for transmembrane flux were made to account for the variation of water viscosity with temperature. The following equation was employed:

$$J_{tm} \text{ (at } 20°C) = [Q_p \times e^{(-0.0239 \times (T - 20))}] \div S$$

where J_{tm} = instantaneous flux (gfd, L/(hr-m^2))
Q_p = filtrate flow (gpd, L/hr)
T = temperature, (°F, °C)
S = membrane surface area (ft^2, m^2)

3.4.5 Feedwater System Recovery

The recovery of filtrate from feedwater is the ratio of filtrate flow to feedwater flow:

$$\% \text{ System Recovery} = 100 \times (Q_p/Q_f)$$

where Q_p = filtrate flow (gpd, L/hr)
Q_f = feed flow to the membrane (gpd, L/hr)

3.4.6 Rejection

The rejection of contaminants by membrane process was calculated as follows:

$$R = (1 - C_P/C_F) \times 100$$

where: R = Rejection, %
C_p = Permeate water concentration, (mg/L)
C_F = Feed water concentration, (mg/L)

3.5 Calculation of Data Quality Indicators

3.5.1 Precision

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

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

where: $\overline{X}$ = sample mean
$\overline{X}_i$ = *i* th data point in the data set
n = number of data points in the data set

3.5.2 Relative Percent Deviation

For this ETV, duplicate samples were analyzed to determine the overall precision of an analysis using relative percent deviation. An example of duplicate sampling in this ETV is the daily duplicate analysis of turbidity samples using the bench-top turbidimeter.

Relative Percent Deviation = $100 \times [(x_1 - x_2) \div \overline{X}]$

where $\overline{X}$ = sample mean
x_1 = first data point of the set of two duplicate data points
x_2 = second data point of the set of two duplicate data points

3.5.3 Accuracy

Accuracy is quantified as the percent recovery of a parameter in a sample to which a known quantity of that parameter was added. An example of an accuracy determination in this ETV is the analysis of a turbidity proficiency sample and comparison of the measured turbidity to the known level of turbidity in the sample.

Accuracy = Percent Recovery = $100 \times [X_{measured} \div X_{known}]$

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

3.5.4 Statistical Uncertainty

For the water quality parameters monitored, 95 percent confidence intervals were calculated. The following equation was used for confidence interval calculation:

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

where: $\bar{}$ = sample mean
S = sample standard deviation
n = number of independent measurements included in the data set
t = Student's t distribution value with n-1

degrees of freedom

α = significance level, defined for 95 percent confidence as: 1 - 0.95 = 0.05

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

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

3.6 Testing Schedule

The ETV schedule is illustrated in Figure 3-5. The testing program took place starting in November 1998, and finishing by the end of October 1999. Test Period 1 represented the winter/spring seasons and Test Period 2 represented the summer/autumn seasons.

Chapter 4
Results and Discussion

This chapter presents the data obtained under each task of the ETV program of the ZENON Enhanced Coagulation ZeeWeed® UF system.

4.1 Task 1: Characterization of Membrane Flux and Recovery

The operating conditions for the ZENON Enhanced Coagulation ZeeWeed® UF membrane system and the enhanced coagulation unit are provided in Tables 4-1 and 4-2, respectively. The manufacturer established ETV test operating conditions. The operating conditions verified in both testing periods were primarily the same. In summary, the enhanced coagulation membrane system ran at a target flux of 37 gfd (62 L/hr-m^2), a back pulse frequency of every 10 minutes, a back pulse duration of 15 sec, air flow of 15 scfm (420 lpm) and an overall water recovery of 95 percent. The enhanced coagulation conditions included alum as a coagulant at a dose of 30 mg/L, and a target coagulation pH of 6.2 via acid addition.

Figure 4-1 (A and B) provides the membrane vacuum pressure and temperature profiles for Test Periods 1 and 2. For Test Period 1, the clean membrane vacuum pressure began at approximately 2.5 psi and increased to 9 psi (maximum limit) over 24 days. The membrane was then chemically cleaned to a vacuum pressure of 2.5 psi. There was a two-day period starting March 29, 1999 when the pH control system was off due to a control signal failure. The system fouled more rapidly over this period and initially, after the pH control was repaired. The system was allowed to run and eventually recovered on April 4, 1999. For Test Period 2, the filtration runs were relatively shorter, where the clean membrane vacuum pressure began also at approximately 2.5 psi but more rapidly increased to 9 psi over 9 to 12 days operational period. The higher suspended solids in the process tank (see Task 3) may be a factor in the shorter runs observed during Test Period 2. In addition, during Test Period 1 the membranes were new which may also have resulted in better performance (i.e. longer operational runs) as compared to Test Period 2 where the membranes were fouled and subjected to chemical cleaning episode(s).

Figure 4-2 (A and B) provides the membrane flux and specific flux data profiles for Test Periods 1 and 2. The target flux for both testing periods was 37 gfd. For Test Period 1 (winter/spring), the average temperature adjusted membrane flux was approximately 40 gfd at 20°C. Due to the relatively higher water temperatures during Test Period 2 (summer/autumn), a lower average temperature adjusted membrane flux of 32 gfd at 20°C was calculated. The temperature adjusted specific flux decreased from 13.5 gfd/psi at 20°C to 4 gfd/psi at 20°C over 25 days during Test Period 1. A similar decrease in the temperature adjusted specific flux was observed in Test Period 2 but over a shorter period (9-12 days).

The same data in Figures 4-1 and 4-2 are also provided in Appendix A of this report, but with metric units.

4.2 Task 2: Evaluation of Cleaning Efficiency

Chemical cleanings were performed when the membrane fouled (vacuum pressure > 9 psi) or the end of a test period had been reached. The manufacturer's cleaning procedure was a two step process. Initially the process tank was drained and refilled with tap water. A flux-vacuum profile was performed on the membrane before cleaning. After this, sodium hypochlorite was added to the process tank and CIP tank to produce a free chlorine residual of approximately 300-500 mg/L. The contents of the CIP tank were manually backpulsed through the membrane and then the system was run in permeate recycle mode (permeate flow redirected back to the process tank) for a period of 30 minutes with a permeate flow of 10 gpm and the blower on. After this the unit was shut down and allowed to soak in the cleaning solution for a period of several hours. This solution was then drained from the process tank, the tank was refilled with tap water and a flux-vacuum profile after the first cleaning step was conducted. The same procedure was repeated with a 5-10 g/L citric acid solution. After this, the process tank was drained of the cleaning solution, refilled with tap water, and a final, clean-membrane, flux-vacuum profile was performed.

The flux-vacuum profiles of the membrane system at different stages of the chemical cleaning procedure for Test Periods 1 and 2 are shown in Figures 4-3 and 4-4, respectively. The slope of the flux-vacuum profile represents the specific flux of the membrane at each cleaning stage and was used to calculate the cleaning efficiency indicators. These are listed in Table 4-3. The recovery of specific flux for each cleaning was in the range of 55 to 70 percent. The higher recovery numbers were a result of the lower specific flux values before cleaning. Overall, the specific flux recovery values were similar, indicating reproducible and efficient chemical cleaning events.

New membranes are generally expected to have a noticeable loss of the original specific flux values after the first operation cycle. After that, a much lower irreversible fouling rate is usually observed (if any) as the membrane gets conditioned to the water chemistry. This was evident in the data presented in Table 4-3, where the maximum loss of original specific flux was observed after the first chemical cleaning after which no loss was observed. In fact, some of the original specific flux lost in Test Period 1 (winter/spring) was also recovered in Test Period 2 (summer/autumn), possibly due to the higher temperatures of the solution used for chemical cleaning. Since no consistent trend was observed for the loss of the original specific flux data, the usable membrane life can not be estimated. It should be noted, however, that ZENON Membrane Systems typically provide a 5-yr warrantee on their ZeeWeed® UF membrane modules.

The same data in Figures 4-3 and 4-4 are also provided in Appendix A of this report, but with metric units.

4.3 Task 3: Evaluation of Finished Water Quality

Several water quality parameters were monitored during the testing period. Below is a summary of the water quality data.

4.3.1 Turbidity, Particle Concentration and Particle Removal

Figures 4-5 and 4-6 present the on-line turbidity profile across the enhanced coagulation membrane system during Test Period 1 and 2, respectively. Turbidity was also monitored using an onsite desktop turbidimeter, also shown in Figures 4-5 and 4-6 and summarized in Table 4-4. For both testing periods, the raw water turbidity was in the range of 1-2 NTU, which increased after coagulant addition up to the 2-8 NTU range. The turbidity of the bleed stream, which represents the turbidity of the process tank where the membranes are immersed, reached up to 100 NTU, while the permeate turbidity was typically below 0.1 NTU.

Figures 4-7 and 4-8 present the particle count profile (2-3 um, 3-5 um, and 5-15 um, >15 um) collected during Test Period 1 and 2, respectively. The data presented represent 4-hour average values of data collected at one minute intervals. For both testing periods, the feed particle concentration of the *Cryptosporidium*-sized particles (3-5 um) and *Giardia*-sized particles (5-15 um) was in the range of 1,000 to 10,000 particle/mL, while the permeate concentration was typically in the range of 0.1 to 1 particle/mL. Gaps in the permeate particle data for Test Period 2 are due to chemical cleaning shutdown periods.

Figures 4-9 and 4-10 present the log removal of particles (2-3 um, 3-5 um, and 5-15 um, >15 um) based on raw and permeate particle count data collected during Test Period 1 and 2, respectively. Data presented on this plot represent 1-day average values of data collected at one minute intervals. Overall, 3.5 to 5.0 logs removal was consistently achieved for the *Cryptosporidium*-sized particles (3-5 um) and *Giardia*-sized particles (5-15 um). The online turbidity and particle count data are summarized in Table 4-5.

To assist in assessing test system performance, Figure 4-11 presents the probability plots of the membrane system permeate turbidity and particle removal data for the *Cryptosporidium*-sized particles (3-5 um) and *Giardia*-sized particles (5-15 um). The figure shows that the permeate turbidity was 0.05 NTU or less 95 percent of times and that removal of particles (3-5 um and 5-15 um) was greater than 3 logs 95 percent of times.

4.3.2 Indigenous Bacteria Removal

The removal of naturally occurring bacteria was also monitored during the ETV study (see Table 4-6). The influent total coliform bacteria ranged from <2 to 50 MPN/100 mL during Test Period 1 and from <2 to 8 MPN/100 mL during Test Period 2. Total coliform bacteria were not detected in the permeate of the enhanced coagulation membrane system during both testing periods. HPC bacteria were also reduced significantly by membrane filtration. However, very low levels (1 – 4 cfu/mL) were enumerated in the permeate during both testing periods. Previous studies (Jacangelo et al., 1995) have demonstrated that HPC bacteria can be introduced on the permeate side of the membrane rather than by penetration through it. The above data demonstrate the effectiveness of the ZENON Enhanced Coagulation ZeeWeed® UF system for removal of indigenous bacteria.

4.3.3 Other Water Quality Parameters

Table 4-7 presents the concentration of several other water quality parameters across the ZENON Enhanced Coagulation ZeeWeed® UF system for Test Periods 1 and 2. The alkalinity of the water was reduced in the permeate as a result of coagulant addition to the membrane system. As expected, no change was observed in the total dissolved solids, total hardness, and calcium hardness of the water across the membrane system. Aluminum concentration in the permeate was approximately doubled (up to 100 ug/L) due to alum addition, but it is still below the California maximum contaminant standard of primary contaminants of 1000 ug/L. The enhanced coagulation process resulted in a reduction in organic material in the permeate. In both test periods, permeate concentrations of total organic carbon, dissolved organic carbon and UV-254 were all significantly lower than raw water concentrations. The removal of these parameters by the enhanced coagulation test unit will be presented in the discussion of Task 9 - Ultrafiltration Enhanced Coagulation.

The total suspended solids (TSS) in the bleed waste reached as high as 330 mg/L (during Test Period 2), while the permeate TSS remained consistently below the detection limit (1 mg/L). As was noted earlier, the TSS of the pretreated water (membrane feed water) and bleed waste (process tank contents) during Test Period 2 was higher than in Test Period 1, possibly due to higher water temperatures resulting in more floc formation. This may have been a factor in the shorter filtration runs experienced in Test Period 2.

Table 4-8 presents the mass balance conducted on total suspended solids across the enhanced coagulation membrane system. Two of the calculated results in each test period showed a relatively good correlation between calculated and measured waste stream TSS.

4.4 Task 4: Reporting Membrane Pore Size

A request was submitted to the membrane Manufacturer to provide the 90 percent and maximum pore size of the membrane being verified. ZENON Membrane Systems responded that the ZeeWeed® UF membrane has 90 percent pore size of 0.03 um and an absolute pore size of 0.1 um.

ZENON determines the pore size distribution using flow porometry in accordance with ASTM-F316 “Standard Test Methods for Pore Size Characteristics of Membrane Filters by Bubble Point and Mean Flow Pore Test.”

The above information are taken from a letter supplied by the manufacturer which is included in Appendix A of this report. This is provided for informational purposes only and the results were not verified during the ETV testing.

4.5 Task 5: Membrane Integrity Testing

Figure 4-12 shows the results of the air pressure-hold tests conducted on the UF membrane at the beginning and end of both testing periods. If any of the membrane fibers were compromised, one

would expect significant loss of held pressure (>1 psi every 5 minutes) across the membrane element. Since no significant change in the held pressure (<0.5 psi every 5 minutes) was observed during both testing periods, it would be reasonable to assume that the membrane module was uncompromised during both testing periods. The above is also confirmed with the turbidity profiles shown in Figures 4-5 and 4-6 and the particle count profiles shown in Figures 4-7 and 4-8. The particle concentrations in the permeate would be expected to noticeably increase if the membrane module were compromised (Adham et. al., 1995, Montgomery Watson, 1999).

4.6 Task 6: Data Management

4.6.1 Data Recording

Data were recorded manually on operational and water quality data sheets prepared specifically for the study. In addition, other data and observations such as the system calibration results were recorded manually on laboratory and QC notebooks. Data from the particle counters and turbidimeters were also recorded via data acquisition systems. All of the raw data sheets are included in Appendix B of this report.

4.6.2 Data Entry, Validation, and Reduction

Data were first entered from raw data sheets into similarly designed data entry forms in a spreadsheet. Following data entry, the spreadsheet was printed and checked against handwritten datasheets. All corrections were noted on the electronic hard copies and then corrected on the screen. The hardcopy of the electronic data are included in Appendix C of this report.

4.7 Task 7: Quality Assurance/Quality Control (QA/QC)

The objective of this task is to assure the high quality and integrity of all measurements of operational and water quality parameters during the ETV program. Below is a summary of the analyses conducted to ensure the correctness of the data.

4.7.1 Data Correctness

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

- Representativeness
- Statistical Uncertainty
- Completeness
- Accuracy
- Precision

Calculation of the above data quality indicators were outlined in the Materials and Methods section. All water quality samples were collected according to the sampling procedures specified by the NSF protocols, which ensured the representativeness of the samples. Below is a summary of the calculated indicators.

4.7.2 Statistical Uncertainty

Ninety-five percent confidence intervals were calculated for the water quality parameters of the ZENON Enhanced Coagulation ZeeWeed® UF system. These include turbidity, particle concentrations, particle removal, and indigenous bacteria. Ninety-five percent confidence intervals were presented in summary tables in the discussion of Task 3 – Finished Water Quality.

4.7.3 Completeness

Data completeness refers to the amount of data collected during the ETV study as compared to the amount of data that were proposed in the FOD. Calculation of data completeness was made for onsite water quality measurements, laboratory water quality measurements, and operational data recording. These calculations are presented in Appendix A of this report. Nearly all parameters were 100 percent complete. Overall, the database of laboratory water quality data and operational readings was more than 85 percent complete, which met the objective of the ETV program.

4.7.4 Accuracy

Accuracy is quantified as the percent recovery of a parameter in a sample to which a known quantity of that parameter was added. An example of an accuracy determination in this ETV is the analysis of a turbidity proficiency sample and comparison of the measured turbidity to the known level of turbidity in the sample. Calculations of data accuracy were made to ensure the accuracy of the onsite desktop turbidimeter used in the study. All calculations were within 10 percent of the proficiency sample values. Comparative calibrations of online turbidimeters with the desktop turbidimeters were performed as corrective actions as needed. All accuracy calculations are presented in Appendix A.

4.7.5 Precision and Relative Percent Deviation

Duplicate water quality samples were analyzed to determine the consistency of sampling and analysis using relative percent deviation. Based on these calculations, five results from the City of San Diego Laboratory were excluded from the final dataset. The excluded results were three aluminum duplicate samples, one dissolved organic carbon duplicate sample, and one total suspended solids duplicate sample. Relative percent deviation calculations were also performed on online and desktop turbidity measurements. Calculations of relative percent deviation are included in Appendix A of this report.

4.8 Task 8: Microbial Removal

To demonstrate microbial removal by the ZENON Enhanced Coagulation ZeeWeed® UF system, two seeding experiments with MS2 bacterial virus were conducted during Test Period 2. The two seeding experiments were conducted immediately after a membrane cleaning which simulate worst case conditions for virus removal (Jacangelo et al. 1995, Montgomery Watson, 1997 and 1999). The virus were added directly to the process tank immediately after completion of a backwash and with coagulant addition to the system. One seeding was conducted three hours after system initiation with coagulant addition after a chemical cleaning and the second seeding was conducted less than an hour subsequent to system initiation with coagulant addition after a chemical cleaning. Paired samples from the feed and filtrate were taken at the beginning, middle and end of the second and third filtration cycles after seeding the virus resulting in six samples per seeding experiment.

The feed and filtrate concentrations and log removal of virus during this seeding are presented in Table 4-9 and Figure 4-13. The membrane demonstrated approximately 2 log virus rejection within less than an hour of operation after chemical cleaning and more than 5 logs within 3 hours of operation after chemical cleaning. The higher virus log removal observed after three hours of operation may be due to the higher solids in the process tank where the membrane is immersed. This creates a dynamic cake layer on the membrane surface, enhancing virus rejection. In addition, the virus may absorb directly on the coagulation flocs, which are subsequently rejected by the membrane. The above data demonstrate the ZENON Enhanced Coagulation ZeeWeed® UF system is likely capable of achieving a 2 log removal of virus under worst-case scenario.

4.9 Task 9: Ultrafiltration Enhanced Coagulation

The impact of enhanced coagulation on organics removal by the membrane system is presented in Table 4-10. The removal of dissolved organic carbon (DOC) across the enhanced coagulation membrane system was 23 percent in both testing periods. This removal is mainly due to the addition of 30 mg/L alum to the membrane system since no DOC removal (0 percent) was achieved when the membrane system was operated without coagulant addition using the same source water (Montgomery Watson, 1999). Removal of color by the system was 76 percent.

The removal of the SDS disinfection by products (DBPs) was also evaluated during the study. Overall, 34 - 41 percent removal of Total THMs and 48 - 56 percent removal of HAA5 were observed across the enhanced coagulation membrane system. This level of removal is significant as it may help in meeting Stages I and II of the EPA DBP Rule.

4.10 Additional ETV Program Requirements

4.10.1 Operation and Maintenance (O&M) Manual

The O&M manual for the ZENON Enhanced Coagulation ZeeWeed® UF system supplied by the manufacturer was reviewed during the ETV testing program. The review comments for the O&M

manual are presented in Table 4-11. Overall, the review found the O&M manual includes most of the critical information for process operation. The manual is short and straightforward. The manual would be improved with the addition of more tables, charts, and schematics of the process components and better organization. Also, a separate O&M manual for the enhanced coagulation system should be provided. Finally, the O&M manual includes a useful "calculation section" which provides examples of calculating common process evaluation parameters.

4.10.2 System Efficiency and Chemical Consumption

The efficiency of the small-scale ZENON Enhanced Coagulation ZeeWeed® UF system was calculated based on the electrical usage and water production of the system. The data are presented in Table 4-12. Overall, an efficiency of only 1.1 percent was calculated for the system which is typical of many small-scale low pressure membrane systems.

The chemical consumption of the system was also estimated based on the operating criteria used during the ETV program. Table 4-13 provides a summary of the chemical consumption of the small-scale ZENON Enhanced Coagulation ZeeWeed® UF system.

4.10.3 Equipment Deficiencies Experienced During the ETV Program

Test Period 1

Enhanced Coagulation System

A failure occurred in the electrical control line from the enhanced coagulation system pH probe to the pH control acid dosing pump during Test Period 1. There was an approximate two-day period when the system was running without pH adjustment. When the electrical control line failed, the pH control logic read a high pH value. This put the acid dosing pump into continuous output and produced pH in the process tank as low as 2 before the acid dosing pump was manually stopped. After installing a new cable, the transmembrane pressure of the system increased to fouled levels. The system was allowed to run to determine if it would recover. Within 4 days the transmembrane pressure had recovered significantly and the test unit continued to run for 10 days before fouling. There was no membrane damage or loss of integrity from the exposure of the membrane to low pH caused by the acid controller failure.

ZENON Enhanced Coagulation ZeeWeed® UF Membrane System

At the beginning of the first testing period, the unit shut down two to three times due to the high level of water in the process tank when the system went into backpulse. The water volume added during backpulse was sufficient to put the system into high level alarm. After shutdown, the suction through the permeate tubing was sufficient to drain the process tank to a level below the top of the membrane, exposing them to air and putting the system into low level alarm. Since this occurred overnight, when temperatures were low, no damage was sustained by the membrane due to exposure to air. This problem was solved by decreasing the backpulse volume. After that, the system ran reliably without going into high level alarm of the process tank.

Another problem identified with the ETV test units had to do with controlling the water level in the process tank. The membrane system sensitivity to feed level was due to the fact that when the system signaled the feed valve to open after the water level in the process tank was getting low, the feed valve to the enhanced coagulation system was opened. There was an approximate delay of three to four seconds before the flow from the enhanced coagulation tank reached the membrane system process tank. Likewise, when the system signaled the feed valve to close because process tank water level had reached an adequate level, the flow from the enhanced coagulation system to the process tank did not stop completely for three to four seconds.

A consequence of the delayed response to feed flow signals was the fact that the system spent approximately 10 to 15 percent of each filtration cycle in permeate recycle. Permeate recycle occurred when the system sensed a low process tank level and signaled feed flow to the process tank. Since this feed demand was not met soon enough, the system would close the permeate to waste valve and open the permeate recycle valve, directing permeate back to the process tank. Based on flow totalizer and hour meter readings, it was determined the system was in permeate recycle approximately 10 percent of the time.

This deficiency was resolved before the start of Test Period 2 by reprogramming the level control chip. The chip was reprogrammed so feed-on was signaled at a higher tank level and feed-off was signaled at a lower tank level. During Test Period 2 the system was not observed to switch to permeate recycle mode during normal operation.

Finally, on March 31, 1999, the chemical used to chlorinate backwash water in the clean-in-place tank was changed from calcium hypochlorite to sodium hypochlorite. This was done because of concerns over possible fouling due to calcium in the backwash water, and to more accurately control the backwash chlorine dose with liquid hypochlorite and a positive-displacement dosing pump.

Online Turbidimeters

At the start of Test Period 1, the flow rate to the Hach 1720D online turbidimeters was maintained at 500 mL per minute as per the manufacturers recommendation. During the course of testing, on approximately 4 readings from March 22 to 25, 1999, the online-filtrate turbidity values were up to 50 percent higher than samples of filtrate analyzed on the desktop turbidimeter. Representatives from Hach were contacted. Cleanings and calibration checks were performed on all turbidimeters, but the online units still read significantly higher. The flowrate to the online turbidimeter was decreased in a stepwise fashion. When the flow was reduced to approximately 225 mL/min, the turbidity readings on the online filtrate turbidimeter stabilized at the expected levels. The Hach representative speculated that the problem was due to inadequate degassing in the 1720D online turbidimeter. The degassing capability was improved by reducing the flow rate through the instrument. Based on the Hach representative's recommendation, flow rates were decreased to approximately 200 mL/min on all online turbidimeters after March 26, 1999. It is possible that as the weather warms, this degassing problem also may affect the performance of online particle counters.

Test Period 2

ZENON Enhanced Coagulation ZeeWeedÒ UF Membrane System

During Test Period 2, at fouled membrane conditions, it was observed that the CIP tank would not refill after backpulse. After a number of backpulses the remaining filtrate in the CIP tank would be consumed, and the system was then unable to perform effective backpulses. This condition occurred at operating vacuum pressure levels between 8 and 10 psi (0.55 to 0.69 bar), when the membrane was fouled. Another important factor was water temperature. This condition had not developed during colder weather testing of Test Period 1, but was encountered during the warm water conditions of Test Period 2. Also, because of the relatively high water temperatures and high operating vacuums, significant amounts of air were noted in the filtrate water passing through the filtrate rotameter.

This condition was observed twice during Test Period 2. The first instance occurred on October 4, 1999 and the second on October 18, 1999. In both cases, the problem was resolved by chemically cleaning the membrane module.

A chronological listing of all problems experienced with the ZENON Enhanced Coagulation ZeeWeed® UF system during the ETV Program and their associated corrective actions is provided in Appendix A of this report.

4.10.4 Audit Reports

NSF International performed a virus seeding inspection of the Montgomery Watson ETV program at Aqua 2000 Research Center. Tina Beaugrand of NSF performed the virus seeding inspection on September 22, 1999. No deficiencies in the virus seeding were noted during the inspection. A copy of the audit report is included in Appendix A of this report.

Chapter 5
References

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Tables and Figures

Table 2-1. Characteristics of the ZENON Enhanced Coagulation ZeeWeed® UF membrane.

	Units	Value
Commercial designation		ZeeWeed®-500 OCP UF
Approximate size of element (L x W x H)	ft, (m)	6.6 x 2.5 x 0.65, (2.0 x 0.75 x 0.30)
Active membrane area (outside)	ft^2, (m^2)	463 (43)
Number of fibers		~4700
Inside diameter of fiber	mm	0.75
Outside diameter of fiber	mm	1.95
Approximate length of fiber	ft, (m)	5.4, (1.7)
Flow direction		Outside-In
Nominal molecular weight cutoff	Daltons	~100,000
Absolute molecular weight cutoff	Daltons	~120,000
Nominal membrane pore size	um	0.035
Absolute membrane pore size	um	0.10
Membrane material/construction		Proprietary Polymer
Membrane surface characteristics		Hydrophilic
Membrane charge		Neutral
Design operating pressure	psi, (bar)	-1.0 to -12.0, (-0.07 to -0.83)
Design flux at design pressure	gfd, (L/(h-m^2))	30 to 100, (51 to 170)
Standard testing pH		7.0
Standard testing temperature	^oF, (°C)	77, (25)
Acceptable range of operating pH values		5.0-9.0 (cleaning range 2.0-10.5)
Maximum permissable turbidity	NTU	>1000
Chlorine/oxidant tolerance	mg/L	>1000

Table 3-1. Water quality analytical methods.

Parameter	Facility	Standard Method
General Water Quality		
pH	On-Site	4500H+
Alkalinity	Laboratory	2320 B
Total Hardness	Laboratory	2340 C
Calcium Hardness	Laboratory	3500Ca D
Temperature	On-Site	2550 B
Total Suspended Solids	Laboratory	2540 D
Total Dissolved Solids	Laboratory	2540 C
Aluminum or Iron	Laboratory	EPA200.8 or 3500-FeC
Particle Characterization		
Turbidity (Bench-Top)	On-Site	2130 B
Turbidity (On-Line)	On-Site	Manufacturer
Particle Counts (On-Line)	On-Site	Manufacturer
Organic Material Characterization		
TOC and DOC	Laboratory	5310 B
UV Absorbance at 254 nm	Laboratory	5910 B
Color	Laboratory	2120 C
Total Trihalomethanes	Laboratory	EPA Method 502.2
Haloacetic Acids	Laboratory	EPA Method 552.2
Microbiological Analyses		
Total Coliform	Laboratory	9221 B
HPC Bacteria	Laboratory	9215 B
MS2 Virus	Laboratory	EPA ICR Method for Coliphage Assay

Table 4-1. ZENON Enhanced Coagulation ZeeWeed® UF membrane system operating conditions.

Parameter	Unit					
Test Period		1	1	2	2	2
Run		1-1	1-2	2-1	2-2	2-3
Start Date & Time		3/22/99 11:00	4/16/99 15:18	9/22/99 10:30	10/6/99 13:50	10/20/99 14:55
End Date & Time		4/15/99 7:10	4/19/99 10:25	10/4/99 12:50	10/18/99 10:47	10/29/99 13:05
Run Length	days-hrs	23 days 20 hrs	2 days 19 hrs	12 days 2 hrs	11 days 21 hrs	8 days 22 hrs
Run Terminating Condition		Fouled	Time	Fouled	Fouled	Fouled
Filtrate Flow	gpm (lpm)	14 (51)	14 (51)	14 (51)	14 (51)	14 (51)
Flux	gfd (L/hm^2)	37 (62)	37 (62)	37 (62)	37 (62)	37 (62)
Air Flow	scfm (lpm)	15 (420)	15 (420)	15 (420)	15 (420)	15 (420)
Backpulse Frequency	min	10	10	10	10	10
Backpulse Duration	sec	15	15	15	15	15
Backpulse Volume	gal (liter)	4.2 (16)	4.2 (16)	4.2 (16)	4.2 (16)	4.2 (16)
Backpulse Chlorine	mg/L	8.0 avg	8.5 avg	8.5 avg	8.5 avg	8.5 avg
Bleed Waste Flow	gpm (lpm)	0.62 (2.4)	0.62 (2.4)	0.67 (2.6)	0.67 (2.6)	0.67 (2.6)
Volume Reduction	%	95%	95%	95%	95%	95%

Table 4-2. ZENON enhanced coagulation operating conditions during ETV testing.

Parameter	Unit		
Test Period		1	2
Start Date		3/22/99 11:00	9/22/99 10:30
End Date		4/19/99 10:25	10/29/99 13:05
Coagulant		Alum	Alum
Coagulant Dose	mg/L	30	30
Acid		40% H2SO4	40%-50% H2SO4
Target pH		6.2	6.2
Process Water Flow	gpm (lpm)	14 (52)	16 (61)
Baffle 1 Air Flow	scfh (lph)	2.0 (57)	2.0 (57)
Baffle 2 Air Flow	scfh (lph)	2.0 (57)	4.0 (110) [1]
Baffle 3 Air Flow	scfh (lph)	3.0 (85)	3.0 (85)
Baffle 4 Air Flow	scfh (lph)	3.0 (85)	3.0 (85)

[1] Air flow to baffle 2 increased during Test Period 2 to compensate for leak at baffle end.

Table 4-3. Evaluation of cleaning efficiency for ZENON Enhanced Coagulation ZeeWeed® UF membrane.

Clean Number	Clean Date	Specific Flux @20°C Before Clean Jsf gfd/psi (l/hr-m^2-bar)	Specific Flux @20°C After Clean Jsi gfd/psi (l/hr-m^2-bar)	Recovery of Specific Flux 100(1 - Jsf / Jsi) %	Loss of Original Specific Flux 100(1-(Jsi / Jsio)) %
Start	3/22/99	---	**13 (330)**	---	---
1-1	4/15/99	5.1 (130)	11 (270)	54	17
2-1	10/5/99	4.0 (98)	11 (270)	64	16
2-2	10/19/99	3.4 (85)	11 (280)	69	15
2-3	11/1/99	5.0 (120)	12 (290)	58	11

Table 4-4. Onsite lab water quality analyses for ZENON Enhanced Coagulation ZeeWeed® UF membrane system.

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	95 Percent Confidence Interval
TEST PERIOD 1							
Raw Water							
pH		28	8.3	8.1 - 8.7	8.3	0.17	8.2 - 8.4
Desktop Turbidity	NTU	52	1.2	0.8 - 1.7	1.2	0.24	1.1 - 1.3
Temperature	degC	52	16	11 - 28	17	3.7	16 - 18
Pretreated Water							
pH		49	6.3	5.0 - 7.5	6.4	0.39	6.3 - 6.5
Desktop Turbidity	NTU	49	3.6	1.1 - 7.8	3.7	1.5	3.3 - 4.1
Permeate							
Desktop Turbidity	NTU	26	0.050	0.050 - 0.10	0.050	0.0098	0.050 - 0.050
Bleed Waste							
Desktop Turbidity	NTU	49	69	7.9 - 130	68	28	60 - 76
TEST PERIOD 2							
Raw Water							
pH		23	8.1	8.0 - 8.3	8.1	0.077	8.1 - 8.1
Desktop Turbidity	NTU	46	1.8	1.3 - 2.5	1.7	0.34	1.6 - 1.8
Temperature	degC	46	25	18 - 39	27	5.3	25 - 29
Pretreated Water							
pH		46	6.2	4.9 - 6.5	6.1	0.27	6.0 - 6.2
Desktop Turbidity	NTU	26	4.0	2.6 - 5.5	3.9	0.78	3.6 - 4.2
Permeate							
Desktop Turbidity	NTU	22	0.050	0.050 - 0.10	0.050	0.011	0.050 - 0.050
Bleed Waste							
Desktop Turbidity	NTU	45	72	14 - 120	71	22	65 - 77

Table 4-5. Summary of online turbidity and particle count data for the ZENON Enhanced Coagulation ZeeWeed® UF membrane system.

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	95 Percent Confidence Interval
TEST PERIOD 1							
Raw Water							
Turbidity	NTU	170	1.2	0.85 - 5.8	1.4	0.51	1.3 - 1.5
> 2 um Particles	#/mL	167	7500	2200 - 16000	7500	2300	7200 - 7800
2-3 um Particles	#/mL	167	3700	1200 - 6500	3600	860	3500 - 3700
3-5 um Particles	#/mL	167	2400	640 - 5200	2400	750	2300 - 2500
5-15 um Particles	#/mL	167	1400	290 - 3900	1500	730	1400 - 1600
>15 um Particles	#/mL	167	63	11 - 210	71	47	64 - 78
Permeate							
Turbidity	NTU	161	0.050	0.010 - 0.15	0.05	0.022	0.050 - 0.050
> 2 um Particles	#/mL	161	0.32	0.048 - 6.7	0.53	0.87	0.40 - 0.66
2-3 um Particles	#/mL	161	0.17	0.048 - 3.4	0.31	0.49	0.23 - 0.39
3-5 um Particles	#/mL	161	0.11	0.048 - 2.1	0.16	0.25	0.12 - 0.20
5-15 um Particles	#/mL	161	0.072	0.048 - 1.1	0.100	0.13	0.080 - 0.12
>15 um Particles	#/mL	161	0.048	0.048 - 0.13	0.050	0.0088	0.049 - 0.051
Log Removal 2-3 um Particles		29	4.2	3.5 - 4.9	4.2	0.39	4.1 - 4.3
Log Removal 3-5 um Particles		29	4.2	3.6 - 4.7	4.3	0.31	4.2 - 4.4
Log Removal 5-15 um Particles		29	4.3	3.5 - 4.6	4.2	0.30	4.1 - 4.3
Log Removal >15 um Particles		29	3.1	2.6 - 3.5	3.1	0.29	3.0 - 3.2
TEST PERIOD 2							
Raw Water							
Turbidity	NTU	230	1.7	1.2 - 3.1	1.8	0.33	1.8 - 1.8
> 2 um Particles	#/mL	192	7700	2000 - 12000	7800	1500	7600 - 8000
2-3 um Particles	#/mL	192	4000	740 - 5700	4100	710	4000 - 4200
3-5 um Particles	#/mL	192	2400	450 - 3800	2400	540	2300 - 2500
5-15 um Particles	#/mL	192	1200	390 - 2400	1300	370	1200 - 1400
>15 um Particles	#/mL	192	41	4.9 - 200	45	21	42 - 48
Permeate							
Turbidity	NTU	217	0.050	0.050 - 0.050	0.050	0.00	undefined
> 2 um Particles	#/mL	150	0.58	0.17 - 16	1.00	1.6	0.74 - 1.3
2-3 um Particles	#/mL	150	0.27	0.11 - 8.3	0.51	0.80	0.38 - 0.64
3-5 um Particles	#/mL	150	0.14	0.059 - 4.9	0.28	0.48	0.20 - 0.36
5-15 um Particles	#/mL	150	0.091	0.046 - 3.0	0.18	0.29	0.13 - 0.23
>15 um Particles	#/mL	150	0.042	0.041 - 0.41	0.078	0.079	0.065 - 0.091
Log Removal 2-3 um Particles		33	4.1	2.3 - 4.9	3.8	0.55	3.6 - 4.0
Log Removal 3-5 um Particles		33	4.2	3.2 - 4.6	4.0	0.43	3.9 - 4.1
Log Removal 5-15 um Particles		33	4.1	3.1 - 4.6	4.0	0.41	3.9 - 4.1
Log Removal >15 um Particles		33	2.9	2.2 - 3.3	2.9	0.28	2.8 - 3.0

Table 4-6. Summary of the microbial water quality analyses for the ZENON Enhanced Coagulation ZeeWeed® UF membrane system.

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	Confidence Interval
TEST PERIOD 1							
Raw Water							
Total Coliforms	MPN/100mL	4	4.5	<2 - 50	15	23	0 - 38
HPC	cfu/mL	4	120	14 - 240	120	93	29 - 210
Permeate							
Total Coliforms	MPN/100mL	4	<2	<2 - <2	<2	0.00	undefined
HPC	cfu/mL	4	1	<1 - 1	<1	0.00	undefined
Bleed Waste							
Total Coliforms	MPN/100mL	4	3	<2 - 170	120	93	29 - 210
TEST PERIOD 2							
Raw Water							
Total Coliforms	MPN/100mL	4	4	<2 - 8	5	2.5	2.6 - 7.4
HPC	cfu/mL	4	230	26 - 2100	600	980	0 - 1600
Permeate							
Total Coliforms	MPN/100mL	4	<2	<2 - <2	<2	0.00	undefined
HPC	cfu/mL	4	2.5	<1 - 4	3	1.3	1.7 - 4.3
Bleed Waste							
Total Coliforms	MPN/100mL	4	111	<2 - 240	100	130	0 - 230

Table 4-7. Summary of general water quality analyses for the ZENON Enhanced Coagulation ZeeWeed® UF membrane system.

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	95 Percent Confidence Interval
TEST PERIOD 1							
Raw Water							
Alkalinity	mg/L	4	120	100 - 130	120	12	110 - 130
Total Hardness	mg/L	3	240	200 - 280	240	42	190 - 290
Calcium Hardness	mg/L	3	150	120 - 220	160	48	110 - 210
Total Suspended Solids	mg/L	4	5.0	1.9 - 9.5	5.4	3.6	1.9 - 8.9
Total Dissolved Solids	mg/L	4	490	410 - 600	500	75	430 - 570
Total Organic Carbon	mg/L	4	2.5	2.3 - 2.9	2.5	0.30	2.2 - 2.8
Dissolved Organic Carbon	mg/L	3	2.1	2.1 - 2.5	2.2	0.26	1.9 - 2.5
UV-254	/cm	8	0.070	0.057 - 0.089	0.073	0.011	0.065 - 0.081
Aluminum	ug/L	4	28	22 - 52	32	14	18 - 46
Iron	ug/L	4	55	50 - 58	54	3.9	50 - 58
Pretreated Water							
Total Suspended Solids	mg/L	4	9.3	4.6 - 11	8.6	2.8	5.9 - 11
Aluminum	ug/L	3	2100	390 - 2200	1600	1000	470 - 2700
Iron	ug/L	3	60	50 - 73	61	12	47 - 75
Color	PCCU	4	9.5	8.0 - 13	10	2.2	7.8 - 12
Permeate							
Alkalinity	mg/L	4	38	34 - 46	39	5.7	33 - 45
Total Hardness	mg/L	3	240	200 - 280	240	40	190 - 290
Calcium Hardness	mg/L	3	150	120 - 200	150	43	100 - 200
Total Suspended Solids	mg/L	4	<1.0	<1.0 - <1.0	<1.0	0.00	undefined
Total Dissolved Solids	mg/L	4	510	440 - 630	520	81	440 - 600
Total Organic Carbon	mg/L	4	1.9	1.7 - 2.2	2.0	0.21	1.8 - 2.2
Dissolved Organic Carbon	mg/L	3	1.6	1.5 - 2.0	1.7	0.29	1.4 - 2.0
UV-254	/cm	7	0.048	0.043 - 0.077	0.052	0.012	0.043 - 0.061
Bleed Waste							
Total Suspended Solids	mg/L	4	120	49 - 190	120	79	43 - 200

Table 4-7. Continued.

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	95 Percent Confidence Interval
TEST PERIOD 2							
Raw Water							
Alkalinity	mg/L	4	110	110 - 110	110	1.7	110 - 110
Total Hardness	mg/L	2	230	220 - 230	230	2.8	230 - 230
Calcium Hardness	mg/L	2	140	140 - 140	140	1.4	140 - 140
Total Suspended Solids	mg/L	5	5.0	1.9 - 50	21	24	-0.037 - 42
Total Dissolved Solids	mg/L	5	460	450 - 490	460	17	450 - 470
Total Organic Carbon	mg/L	5	2.6	2.3 - 3.2	2.7	0.34	2.4 - 3.0
Dissolved Organic Carbon	mg/L	4	2.7	2.5 - 3.0	2.7	0.25	2.5 - 2.9
UV-254	/cm	7	0.078	0.070 - 0.097	0.081	0.011	0.073 - 0.089
Aluminum	ug/L	3	38	18 - 53	36	18	16 - 56
Pretreated Water							
Total Suspended Solids	mg/L	5	16	14 - 25	17	4.5	13 - 21
Aluminum	ug/L	5	3500	2000 - 6800	4100	1900	2400 - 5800
Color	PCCU	5	16	4.0 - 19	13	6.9	7.0 - 19
Permeate							
Alkalinity	mg/L	4	33	27 - 35	32	3.2	29 - 35
Total Hardness	mg/L	2	230	220 - 240	230	11	210 - 250
Calcium Hardness	mg/L	2	170	150 - 180	170	21	140 - 200
Total Suspended Solids	mg/L	4	<1.0	<1.0 - <1.0	<1.0	0.00	undefined
Total Dissolved Solids	mg/L	5	480	480 - 510	490	14	480 - 500
Total Organic Carbon	mg/L	5	2.5	1.8 - 2.8	2.4	0.36	2.1 - 2.7
Dissolved Organic Carbon	mg/L	5	2.1	1.7 - 3.0	2.2	0.55	1.7 - 2.7
UV-254	/cm	8	0.043	0.038 - 0.049	0.043	0.0044	0.040 - 0.046
Aluminum	ug/L	3	100	67 - 110	92	21	68 - 120
Bleed Waste							
Total Suspended Solids	mg/L	5	240	150 - 330	240	67	180 - 300

Table 4-8. Comparison of calculated and measured total suspended solids for ZENON Enhanced Coagulation ZeeWeed® UF membrane system.

Date	Net Pretreated Flow (gpm)	Bleed Flow (mL/min)	Volume Reduction (%)	Measured Pretreated TSS (mg/L)	Measured Bleed TSS (mg/L)	Calculated Bleed TSS (mg/L)
TEST PERIOD 1						
3/23/99	12	2300	0.95	4.6	58	90
4/1/99	12	2200	0.95	11	190	230
4/6/99	12	2300	0.95	9.2	49	180
4/15/99	12	2300	0.95	9.5	190	190
TEST PERIOD 2						
9/27/99	13	2600	0.95	14	150	270
10/11/99	13	2600	0.95	15	250	280
10/18/99	13	2500	0.95	16	230	310
10/25/99	13	2600	0.95	25	330	480
10/27/99	13	2600	0.95	16	240	300

Note: Pretreated flow based on corrected feed flow totalizer readings and hour meter readings for Test Period 1. Pretreated Flow based on net permeate flow plus bleed flow for Test Period 2.

Table 4-9. Feed and permeate concentrations of MS2 virus for the ZENON Enhanced Coagulation ZeeWeed® UF membrane system.

Seeding #1
Seeding date: 9/22/99
Specific flux at 20°C = 13.0 gfd/psi (259 L/hr-m^2-bar)
Time from system startup = 3 hr

Feed concentration (pfu/100mL)	Permeate concentration (pfu/100mL)	Log removal
3.7E+8	< 1.0E+3	> 5.6
5.9E+8	1.0E+3	5.8
4.2E+8	< 1.0E+3	> 5.6
4.7E+8	< 1.0E+3	> 5.7
4.5E+8	< 1.0E+3	> 5.7
3.5E+8	< 1.0E+3	> 5.5

Seeding #2
Seeding date: 10/20/99
Specific flux at 20°C = 13.7 gfd/psi (271 L/hr-m^2-bar)
Time from system startup < 1 hr

Feed concentration (pfu/100mL)	Permeate concentration (pfu/100mL)	Log removal
4.1E+8	3.7E+6	2.0
2.9E+8	4.7E+6	1.8
4.6E+8	4.0E+6	2.1
4.0E+8	3.8E+6	2.0
2.4E+8	4.3E+6	1.7
2.4E+8	3.1E+6	1.9

Table 4-10. Effect of enhanced coagulation on organics removal.

Parameter	Unit	Raw Water	Permeate	Percent Reduction
TEST PERIOD 1				
Organic Material				
TOC [1]	mg/L	2.5	1.9	23
DOC[1]	mg/L	2.1	1.6	23
UV254[1]	/cm	0.07	0.05	31
Color[1]	PCCU	7.0		
SDS DBP				
Bromoform	ug/L	0.7	1.81	
Dibromochloromethane	ug/L	28.1	16.2	
Bromodichloromethane	ug/L	12	11.8	
Chloroform	ug/L	32.6	13.3	
Total THMs	**ug/L**	**73.4**	**43.1**	**41**
Monobromoacetic Acid	ug/L	< 0.1	< 0.1	
Dibromoacetic Acid	ug/L	2.82	2.83	
Monochloroacetic Acid	ug/L	< 0.3	< 0.3	
Dichloroacetic Acid	ug/L	11.5	5.05	
Trichloroacetic Acid	ug/L	8.92	2.26	
Bromochloroacetic Acid	ug/L	7.47	4.5	
HAA5 [2]	**ug/L**	**23.2**	**10.1**	**56**
TEST PERIOD 2				
pH[1]		8.1	6.2	23
Alkalinity[1]	mg/L	110	33	70
Aluminum[1]	ug/L	44	100	-130
Organic Material				
TOC[1]	mg/L	2.6	2.5	4.9
DOC[1]	mg/L	2.7	2.1	23
UV254[1]	/cm	0.08	0.04	44
Color[1]	PCCU	8.5	2.0	76
SDS DBP				
Bromoform	ug/L	1.18	2.49	
Dibromochloromethane	ug/L	22	15.3	
Bromodichloromethane	ug/L	13.1	12.6	
Chloroform	ug/L	32.3	15.1	
Total THMs	**ug/L**	**68.6**	**45.5**	**34**
Monobromoacetic Acid	ug/L	< 0.5	< 0.5	
Dibromoacetic Acid	ug/L	3.25	3.68	
Monochloroacetic Acid	ug/L	< 1.0	< 1.0	
Dichloroacetic Acid	ug/L	12.6	6.26	
Trichloroacetic Acid	ug/L	10.5	3.74	
Bromochloroacetic Acid	ug/L	7.99	5.96	
HAA5 [2]	**ug/L**	**26.4**	**13.7**	**48**

[1] median value

[2] Bromochloroacetic Acid not included in calculation of HAA5.

Table 4-11. Review of manufacturer's operations and maintenance manual for the ZENON Enhanced Coagulation ZeeWeed® UF membrane system.

O & M Manual Section	Grade*	Comment
ENHANCED COAGULATION UNIT	-	• Flocculation tank volume included in introductory description of main components, but operation and maintenance for enhanced coagulation system not included in manual beyond this
ZEEWEED ULTRAFILTRATION MEMBRANE SYSTEM		
General Description - Introduction	+	• Includes a good description of operating modes, a list of major components and ancillary equipment, power and water requirements
Equipment List	-	• Included in Introduction, but should be organized into a table
Power and Water Requirements	+	• Included in Introduction, but should be organized into a table
Operations		
Startup	+	• Good discussion, includes sections on installation, initial bubble test and initial operation
Filtration	+	• Different filtration modes discussed early in document and then a more detailed discussion in the "Control Narrative Operations" section
Backpulse (backwash)	+	• A good discussion included in an introductory narrative at beginning of the operations section. Also included in discussion of cleaning operation and membrane conditioning
Cleaning	+	• A good discussion of cleaning steps and methods • The cleaning procedure described is not exactly the one used during NSF testing
Integrity Testing	-	• Bubble test description included in Equipment Startup section, but this information along with a discussion of air pressure-hold test and particle counting should be included in a separate section on integrity testing

* Grade of "+" indicates acceptable level of detail and presentation, grade of "-" indicates the manual would benefit from improvement in this area.

Table 4-11. Continued

O & M Manual Section	Grade*	Comment
Shutdown and Storage	-	• Includes a description of long term membrane storage and preservation with a glycerine and water solution, but does not include short term storage and shutdown recommended procedures
Operational Limits	-	• Operational limits for backwash pressure and water temperature included in text, but this information should be summarized in a table for all significant limitations • Should include a discussion of permeate recycle mode. Methods for quantifying the effect on volume reduction, including short-term and long-term adjustments required to compensate for this condition or correct it
Maintenance	+	• Includes maintenance requirements for membrane, permeate pump and blower
Alarms	+	• Includes a description of alarm conditions and what they are designed to protect • Includes alarm control table which shows effect of various alarms on system pumps and valves
Troubleshooting	+	• Manual includes a table of common problems, possible causes and solutions
Ancillary Equipment Information	+	• Included as an appendix. The appendix states ancillary equipment manufacturers information sheets are available by request. Phone number included
Drawings and Schematics	-	• Includes valve chart which shows settings of all valves in each operating mode • P&ID schematic included but at 8.5 x 11 inch is too small to be readable • Manual should use schematics to more clearly present settings for manual valves, etc. during the various operation modes
Use of Tables	-	• Manual should include more tables to more clearly organize and present information

* Grade of "+" indicates acceptable level of detail and presentation, grade of "-" indicates the manual would benefit from improvement in this area.

Table 4-11. Continued

O & M Manual Section	Grade*	Comment
OVERALL COMMENT	+	• All the most important information is included in the manual. The manual is short and to the point. • The manual could be improved with better organization and more extensive use of tables and schematics. • A separate O&M manual for the enhanced coagulation system should be included • Manual includes a useful "Calculation Section" which describes and gives examples of calculating common parameters such as net permeate rate and volume reduction

* Grade of "+" indicates acceptable level of detail and presentation, grade of "-" indicates the manual would benefit from improvement in this area.

Table 4-12. Efficiency of the ZENON Enhanced Coagulation ZeeWeed® UF membrane system.

Parameter	Unit	Value
ELECTRICAL USE		
Voltage	Volt - single phase	240
Permeate Pump Current	Amp	2.8
Blower Current	Amp	10
Permeate Pump Power	Watt	670
Blower Power	Watt	2400
Total Electrical Power Consumption	Watt	3100
WATER PRODUCTION		
Vacuum	in Hg. Pa	12 3.9E+04
Flow Rate	gpm m3/s	14 8.5E-04
Power	Watt	33
EFFICIENCY	%	**1.1%**

Table 4-13. Chemical consumption for the ZENON Enhanced Coagulation ZeeWeed® UF membrane system.

	Unit	Value
Backwash Chlorine*		
Average Chlorine Dose	mg/L	8.5
Stock Chlorine Concentration	%	10
Average Backpulse Volume	L	16
Stock Volume per Backpulse	mL	1.4
Backpulse Per Day	#	140
Stock Chlorine Use Per Day	Gal (L)	0.05 (0.20)
Enhanced Coagulation Alum †		
Alum Stock Used	Gal (L)	8.1 (31)
Alum Stock Concentration	mg/mL	640
Feedwater Treated	Gal	170,000
Days of Operation		9.1
Calculated Alum Dose	mg/L	30
Alum Stock Use Per Day	Gal (L)	0.89 (3.4)
Enhanced Coagulation Acid ‡		
Undiluted 40% H_2SO_4 Used	Gal (L)	5.6 (22)
Feedwater Treated	Gal (L)	170,000 (644,000)
Days of Operation		9.1
Average Enh. Coagulation pH		6.2
Acid Stock Use Per Day	Gal (L)	0.63 (2.4)
Cleaning Chemicals		
Household Bleach (NaOCl 5.25%) Use Per Cleaning	Gal (L)	2.0 (7.8)
Citric Acid Use Per Cleaning	lb (kg)	8.8 (4.0)

* Based on average chlorine dose per backpulse

† Based on Test Period 2 alum feed tank use and feed totalizer readings, 9/22 to 10/1/99

‡ Based on Test Period acid feed tank use and feed totalizer readings, 9/22 to 10/1/99

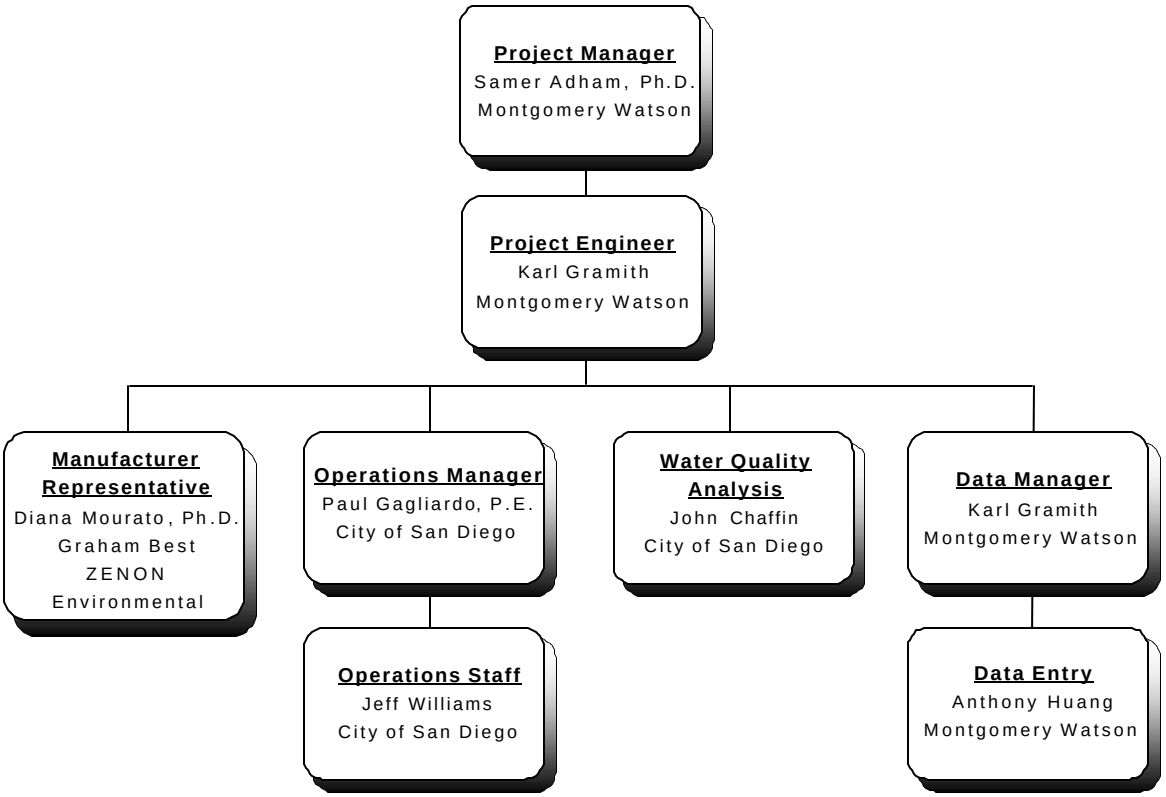
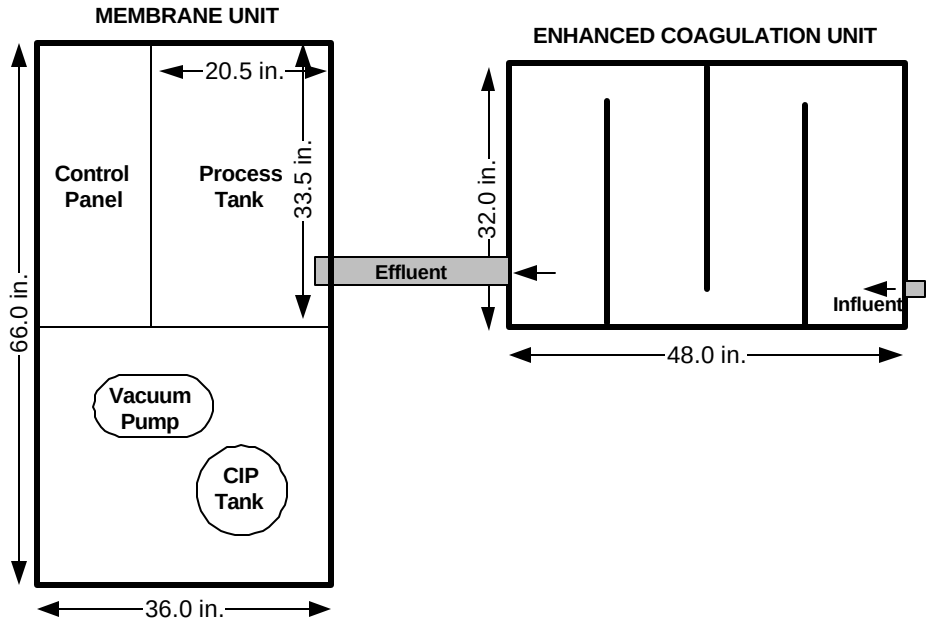


Figure 1-1. Organizational chart showing lines of communication.

Figure 2-1. Photograph of the ETV test unit.

PLAN VIEW



SIDE VIEW

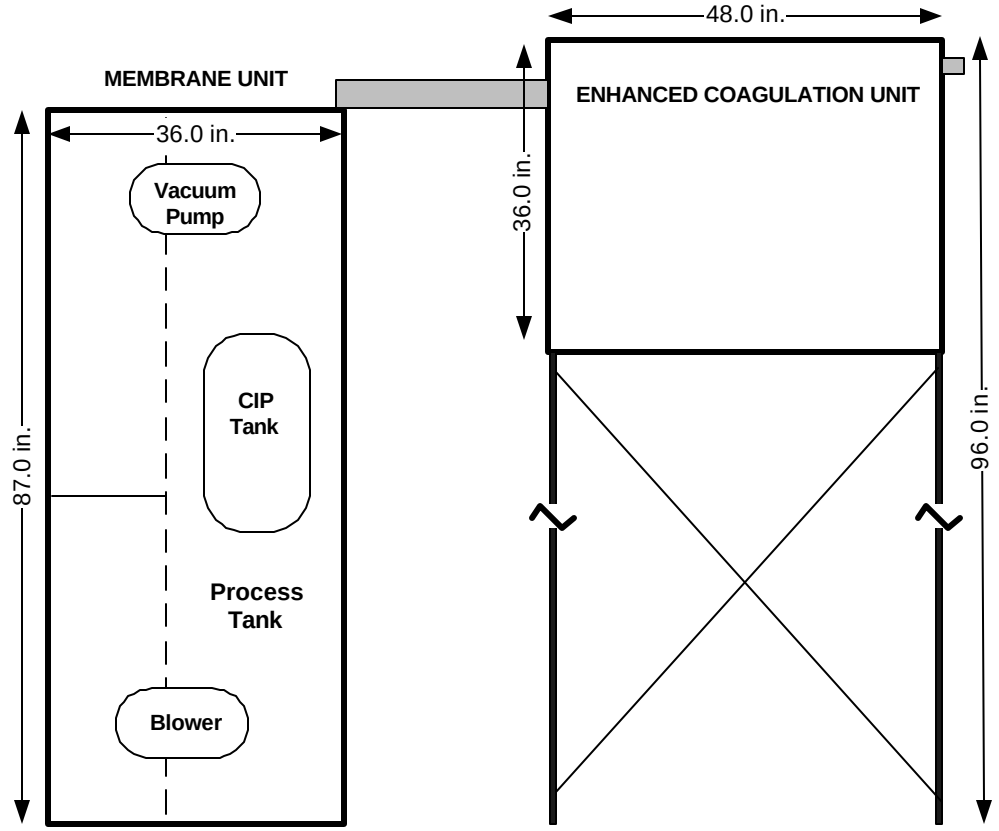


Figure 2-2. Spatial requirements for the ZENON Enhanced Coagulation ZeeWeed® UF unit.

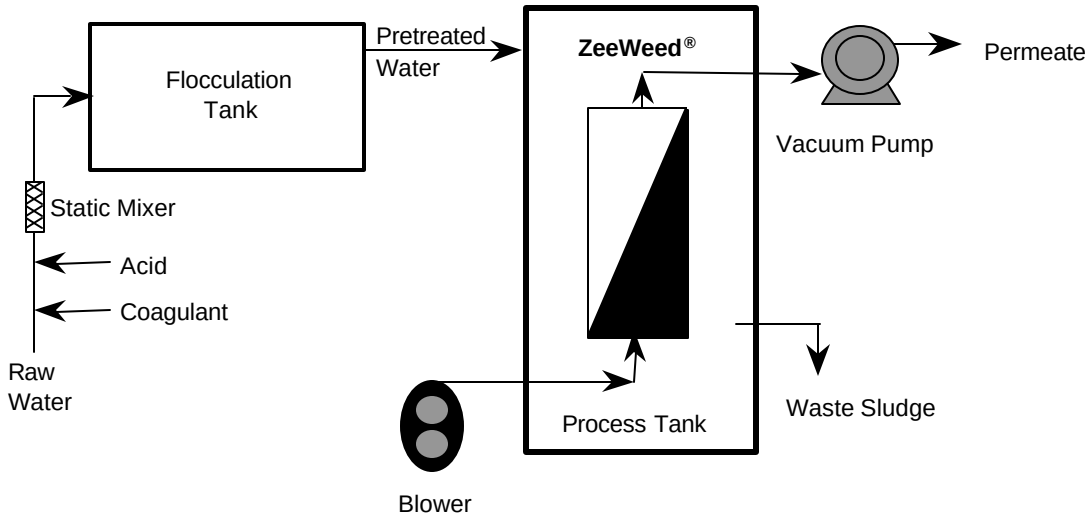


Figure 2-3. Schematic diagram of the ZENON Enhanced Coagulation ZeeWeed® UF membrane process.

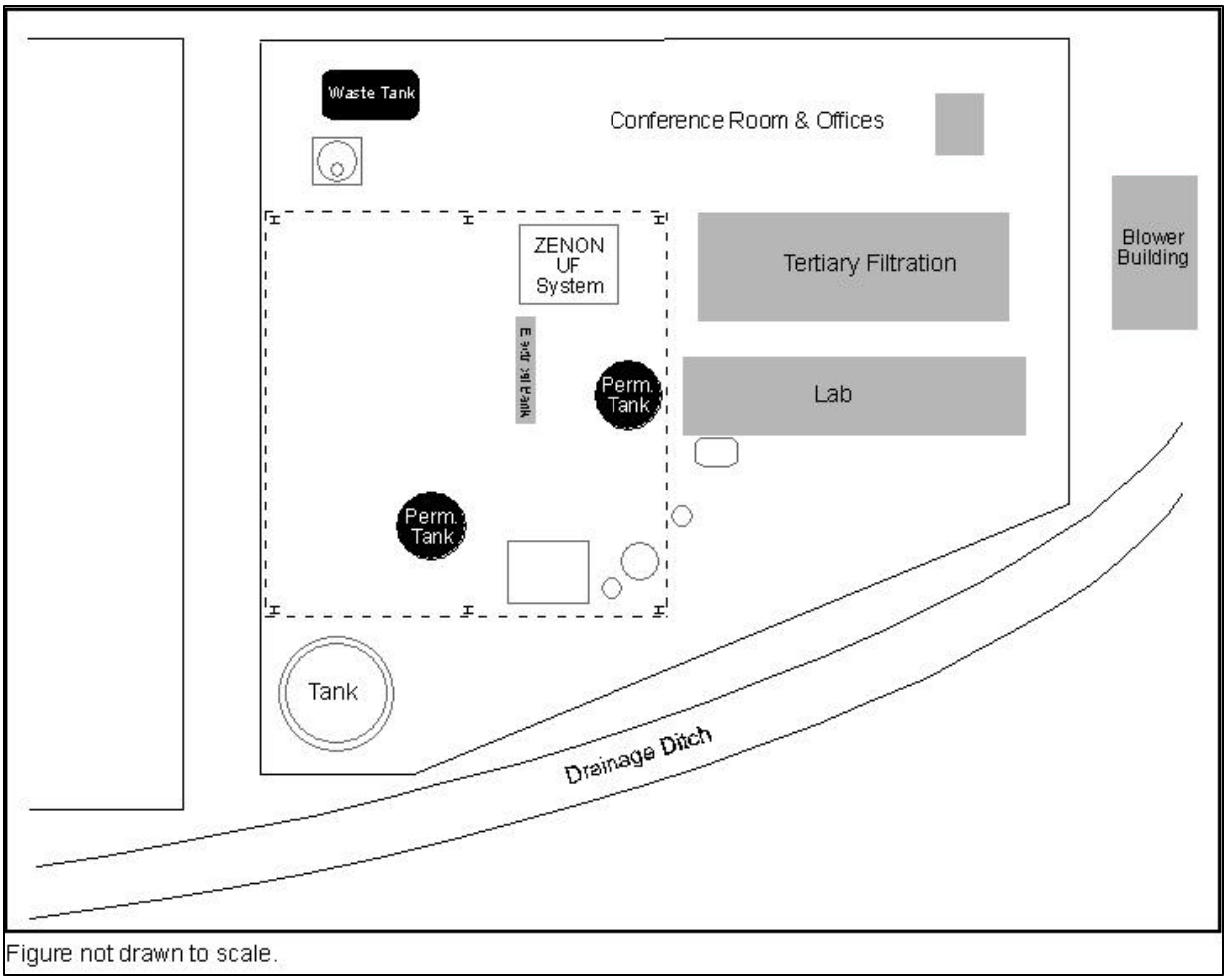
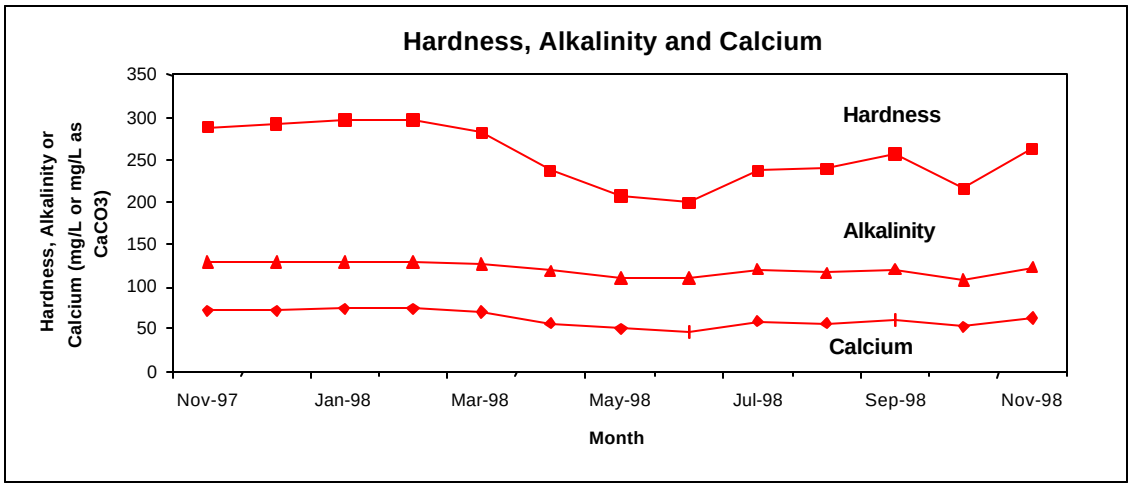
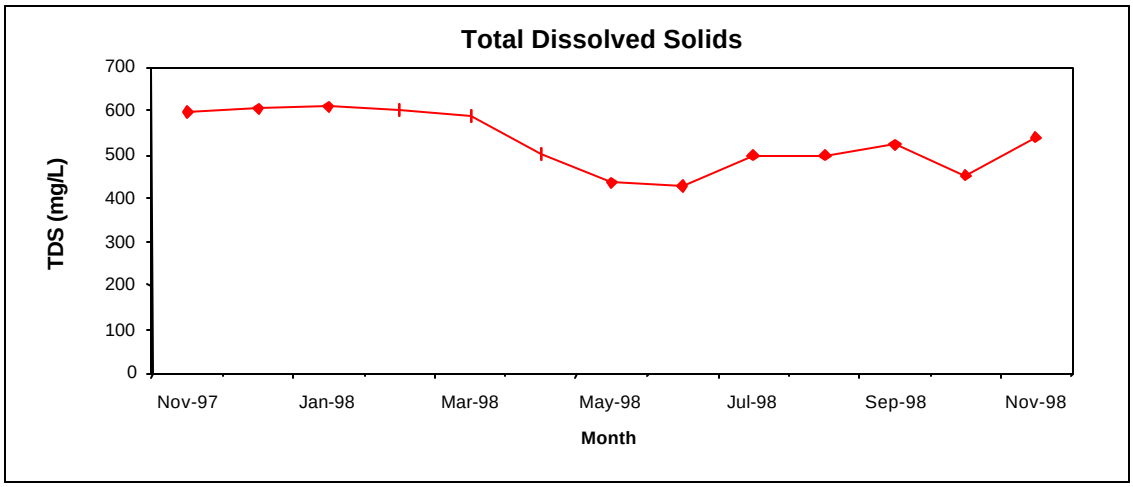


Figure 3-1. Schematic of Aqua 2000 Research Center test site.





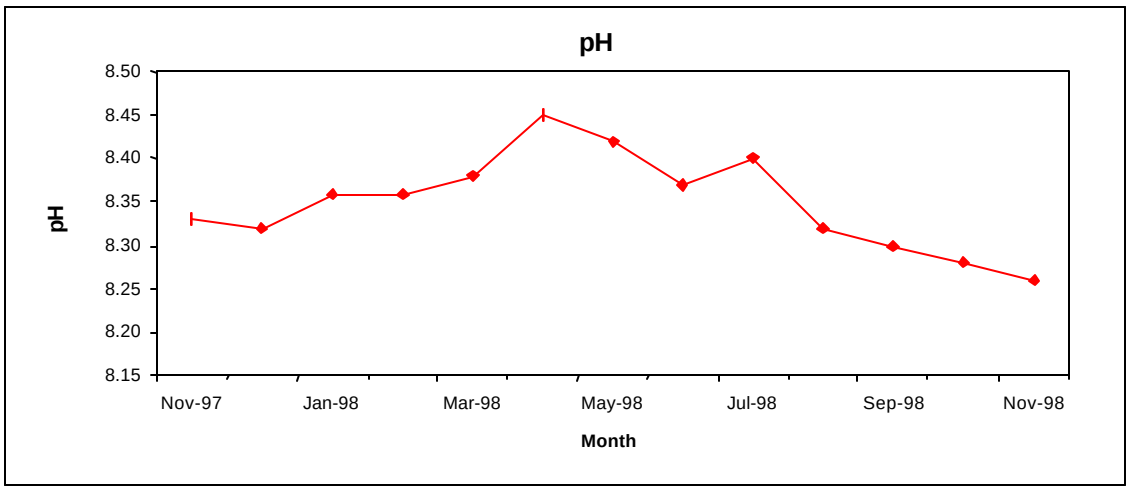


Figure 3-2. Lake Skinner raw water quality.

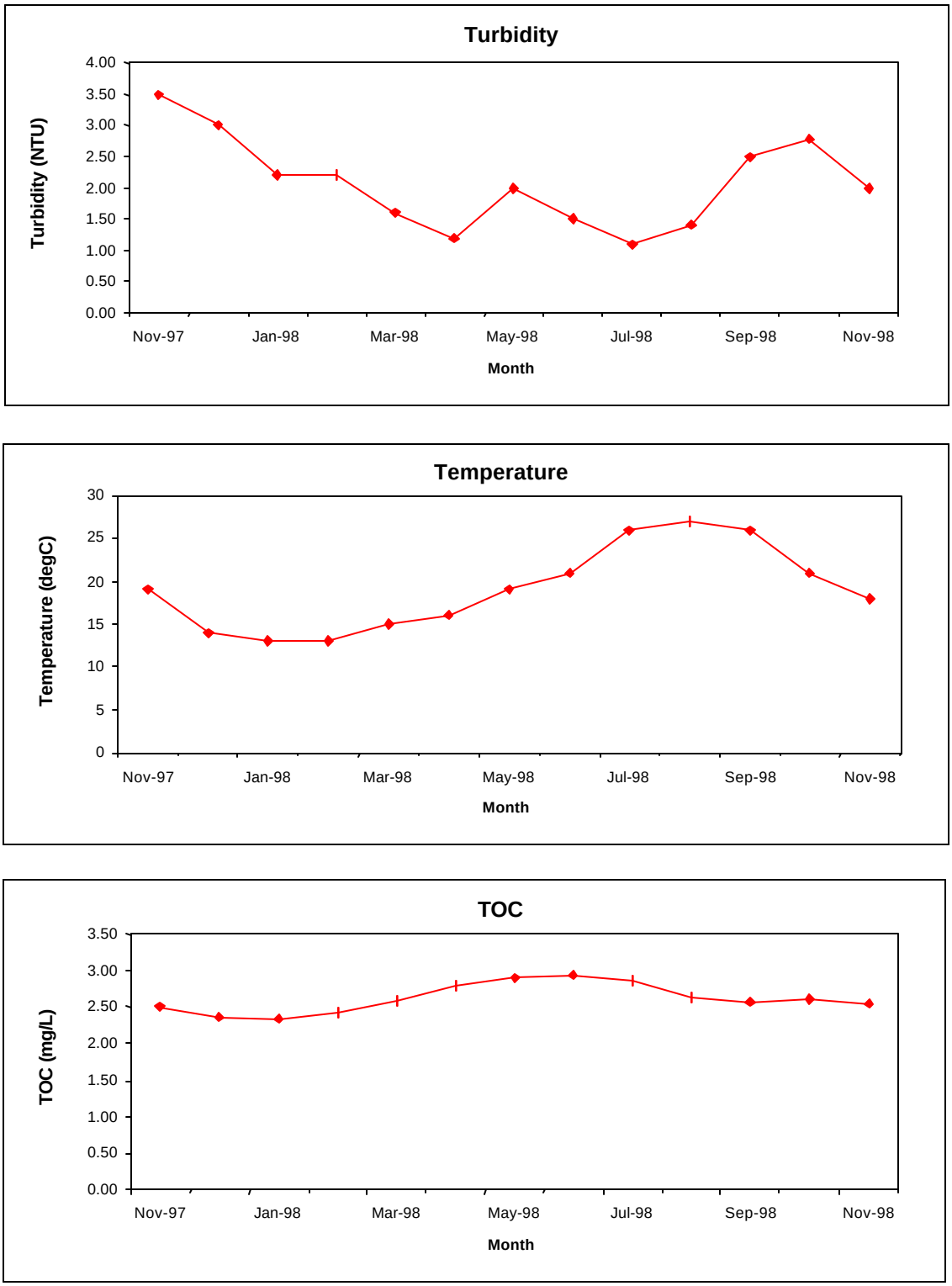


Figure 3-3. Lake Skinner raw water quality.

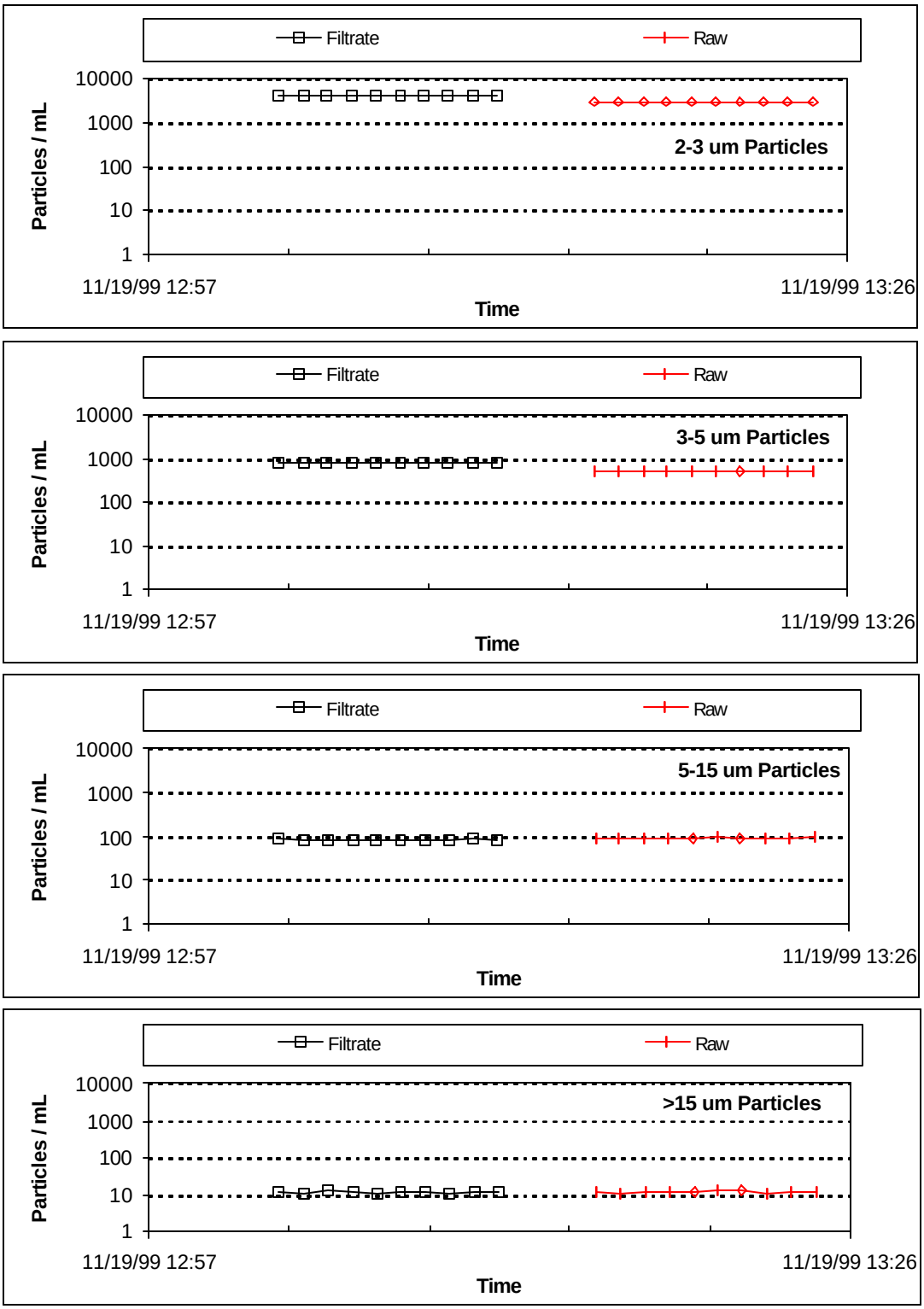


Figure 3-4. Response of online particle counters to Duke Monosphere Solution.

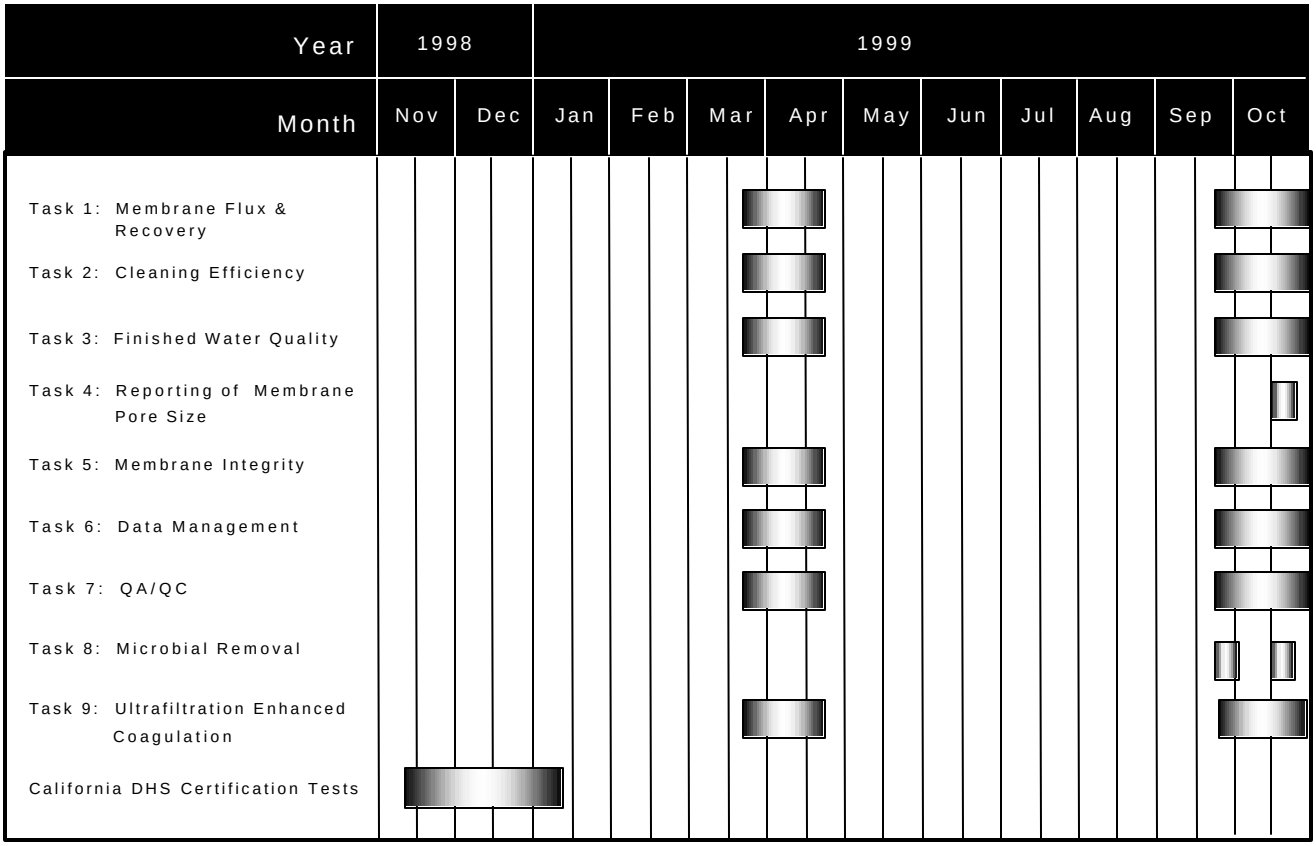
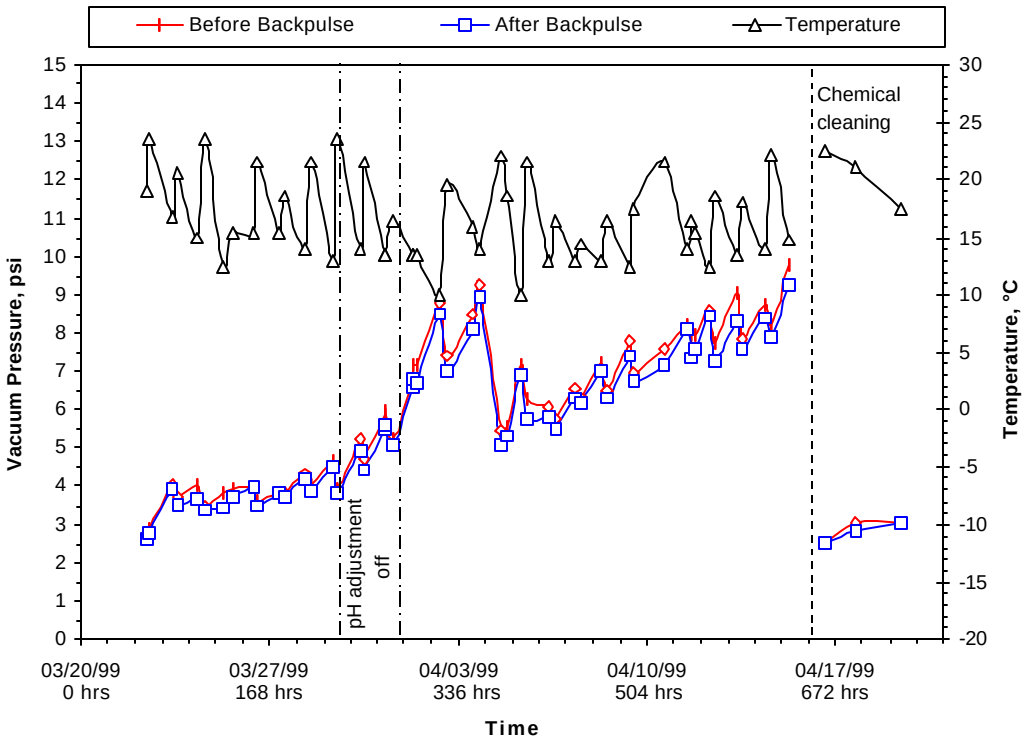
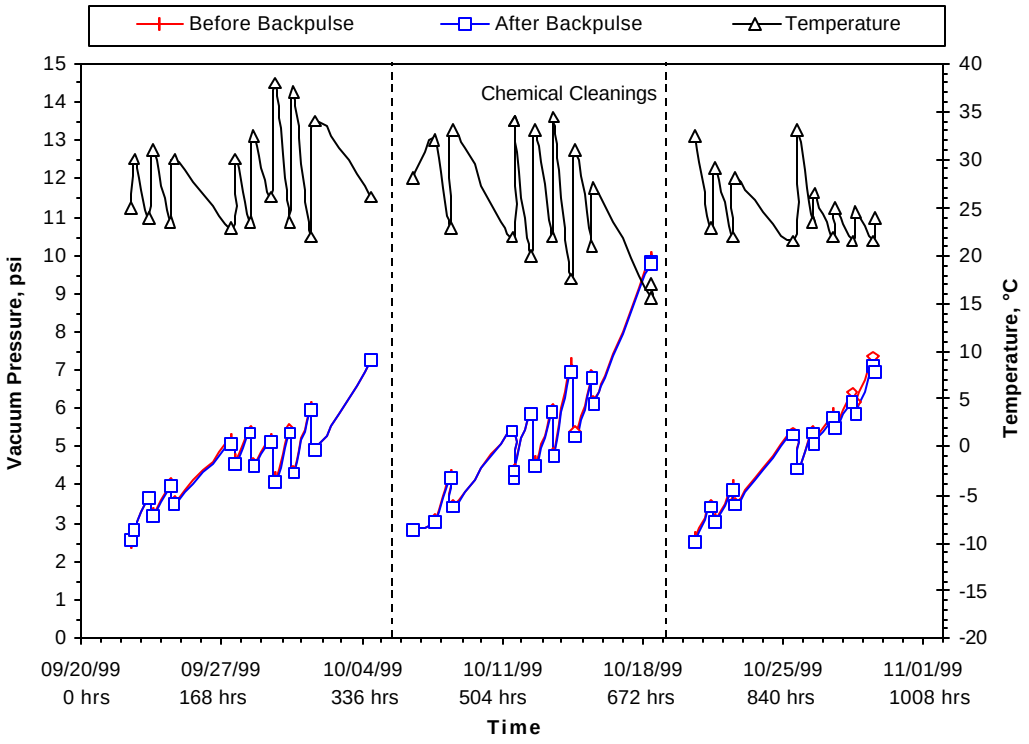


Figure 3-5. Membrane verification testing schedule.

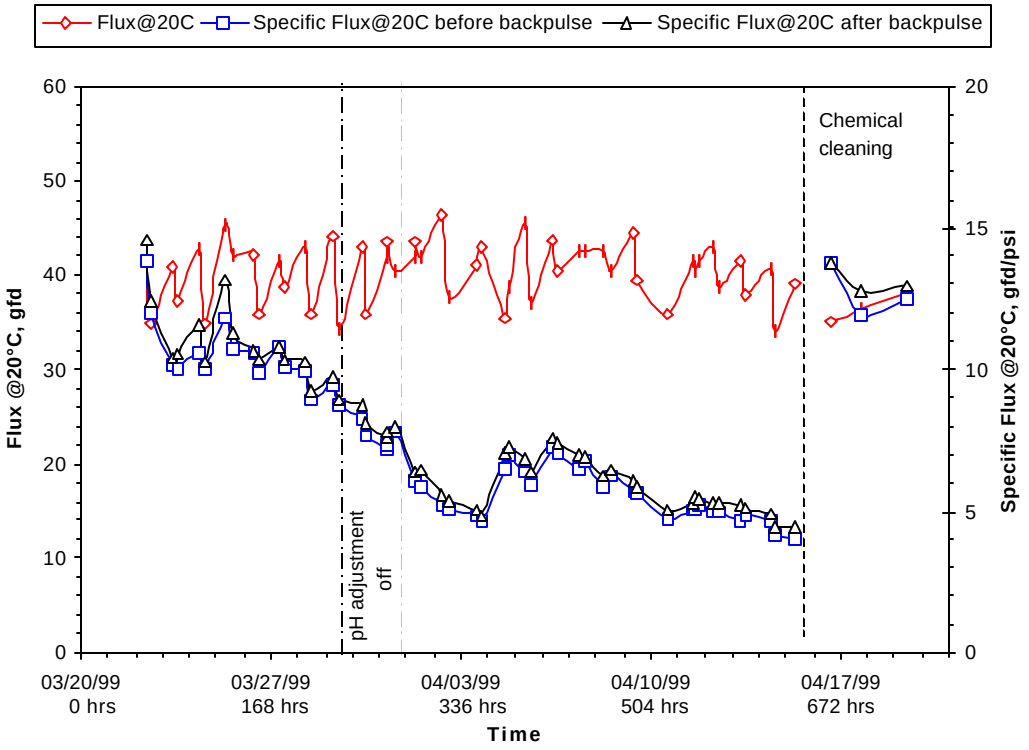


A – Test Period 1.

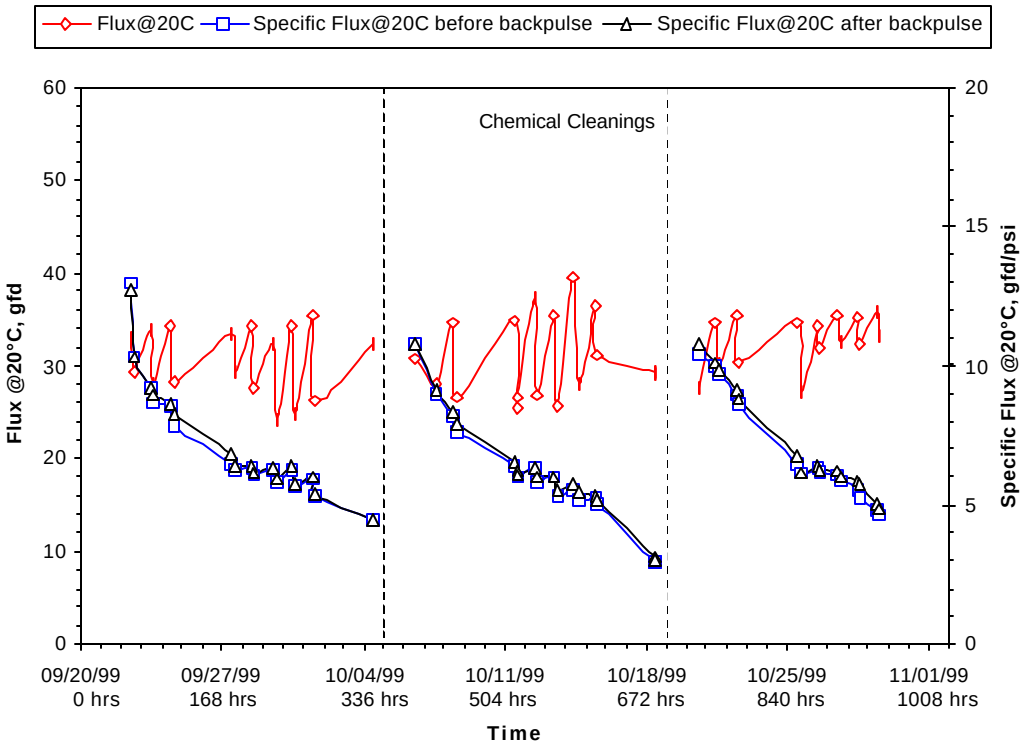


B – Test Period 2.

Figure 4-1. Transmembrane pressure and temperature profiles for the ZENON Enhanced Coagulation ZeeWeed® UF membrane system.

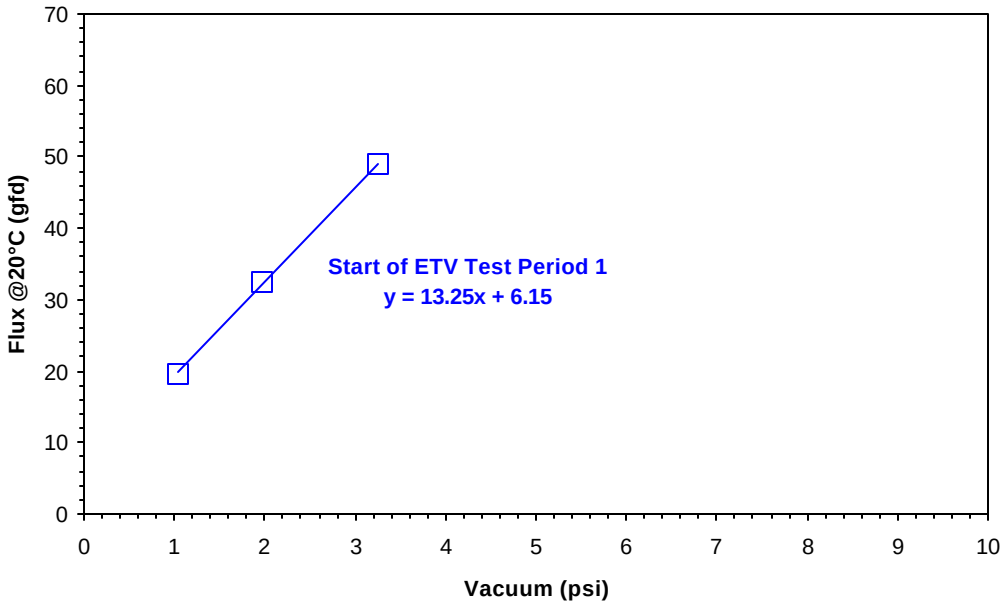


A – Test Period 1.

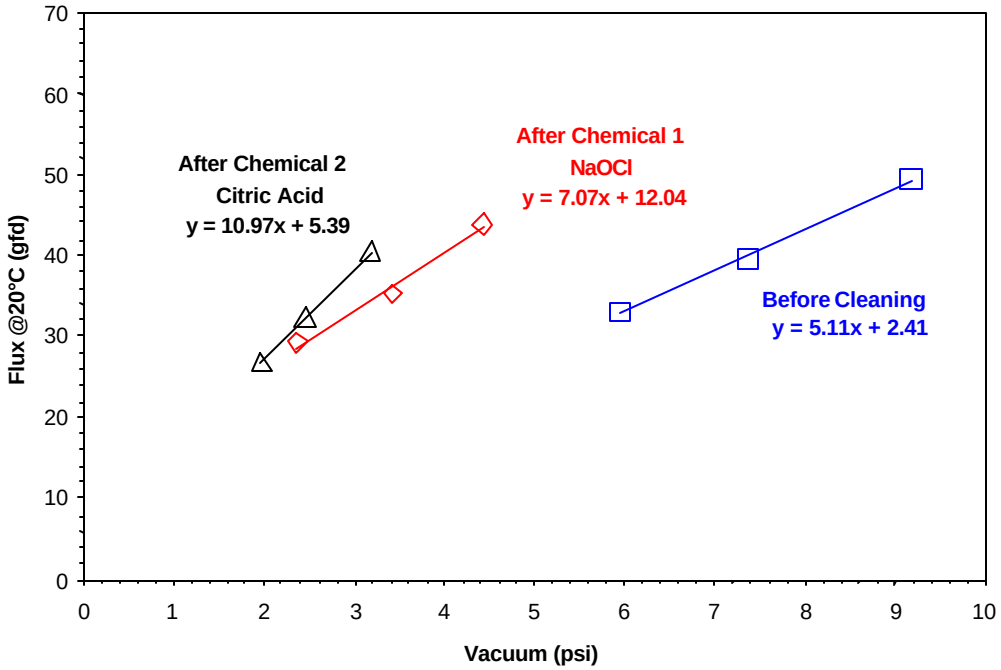


B – Test Period 2.

Figure 4-2. Operational flux and specific membrane flux profiles for the ZENON Enhanced Coagulation ZeeWeed® UF membrane system.

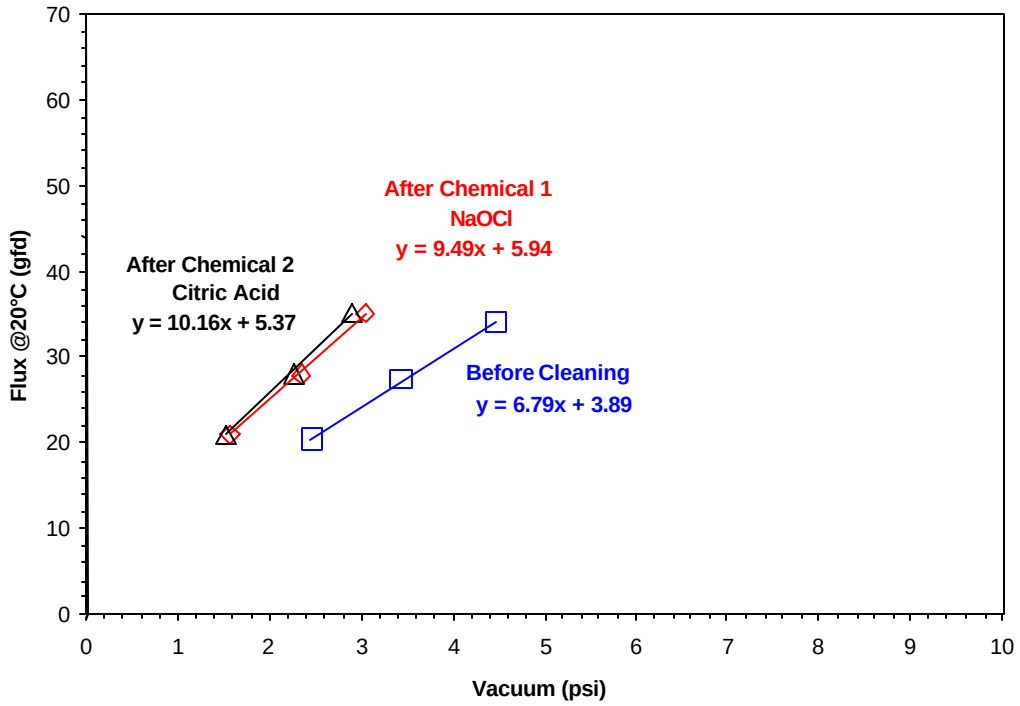


A – Clean membrane: start of Test Period 1.

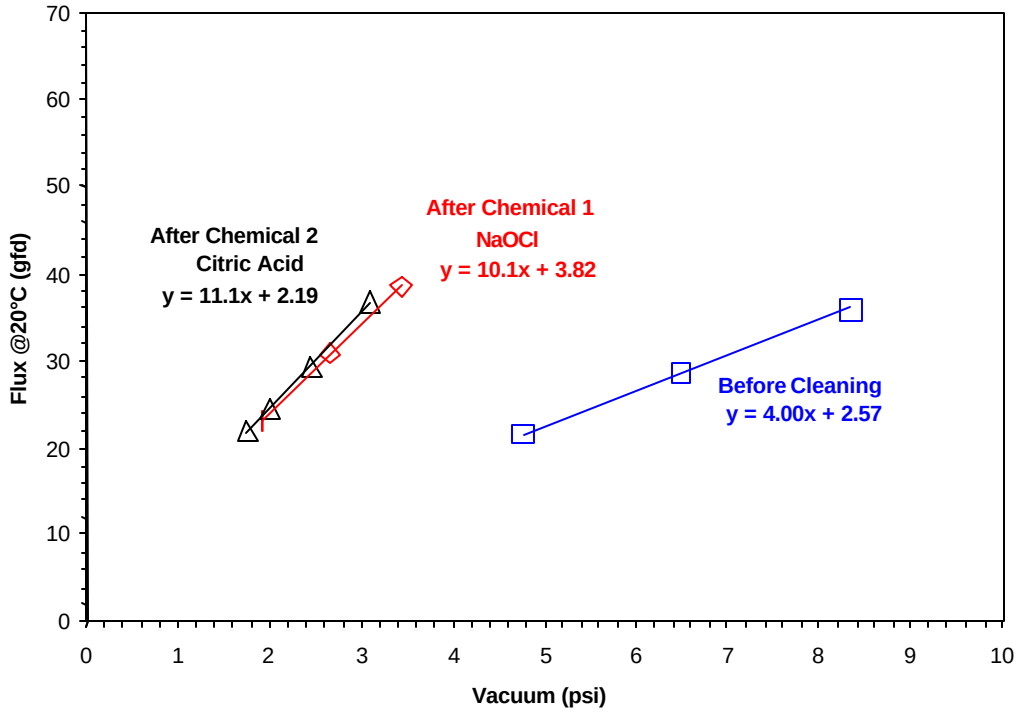


B – Test Period 1: cleaning 1-1 (4/16/99).

Figure 4-3. Clean water flux profile during membrane chemical cleanings - Test Period 1.

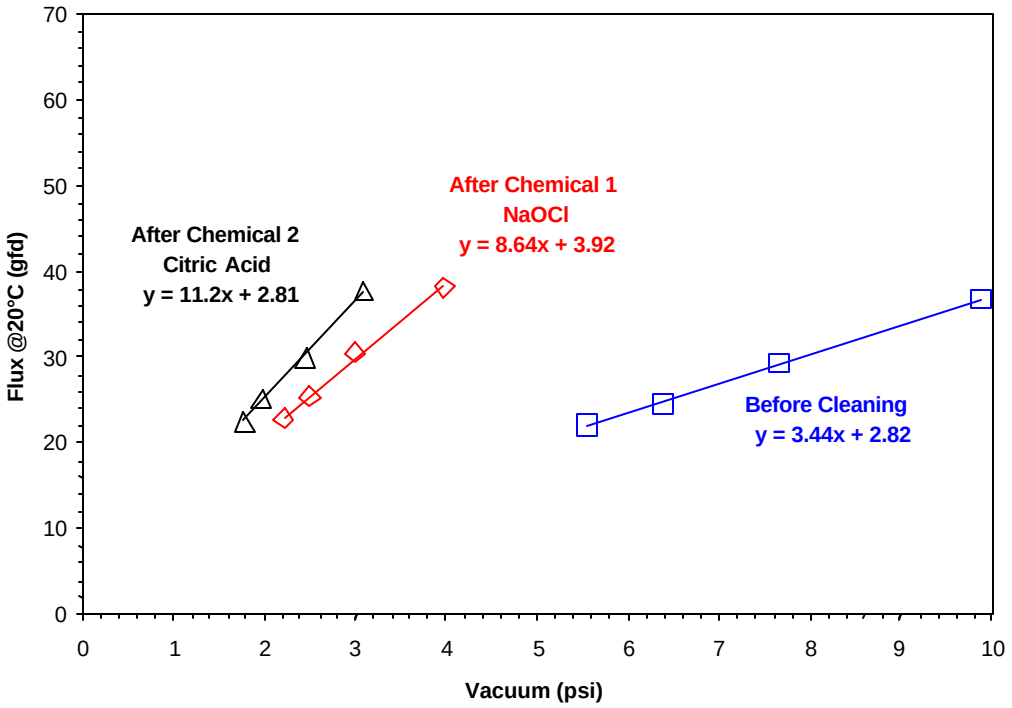


A – Clean membrane: start of Test Period 2.

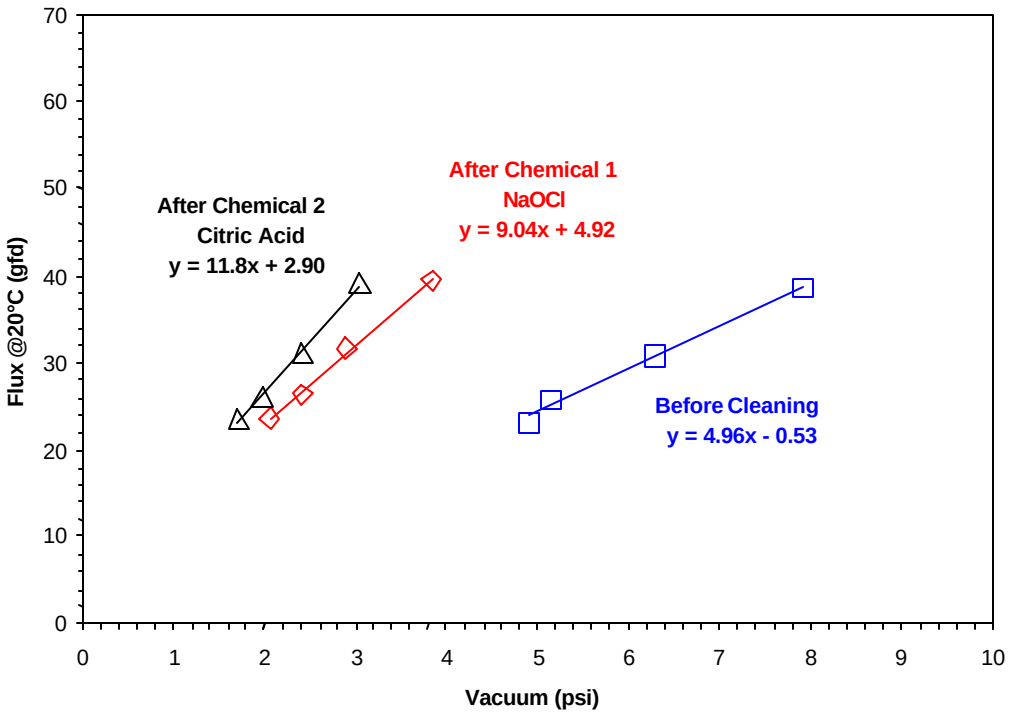


B – Test Period 2: cleaning 2-1 (10/05/99).

Figure 4-4. Clean water flux profile during membrane chemical cleanings - Test Period 2.



C – Test Period 2: Cleaning 2-2 (10/19/99)



D – Test Period 2: Cleaning 2-3 (11/01/99)

Figure 4-4. Continued

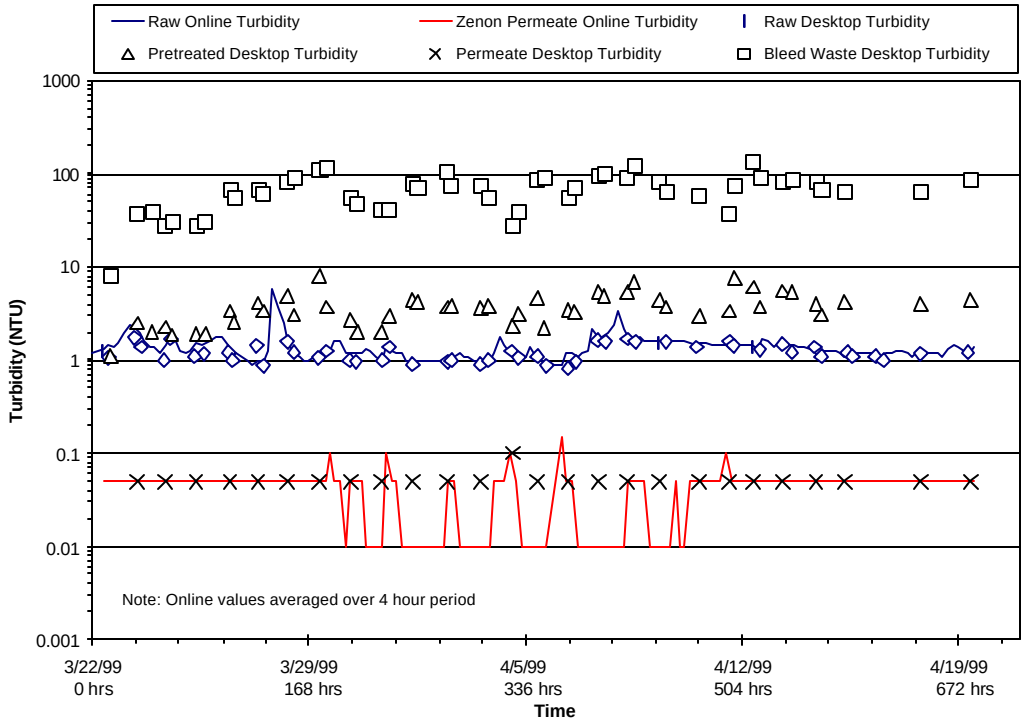


Figure 4-5. Turbidity profile for raw water and ZENON Enhanced Coagulation ZeeWeed® UF membrane system permeate - Test Period 1.

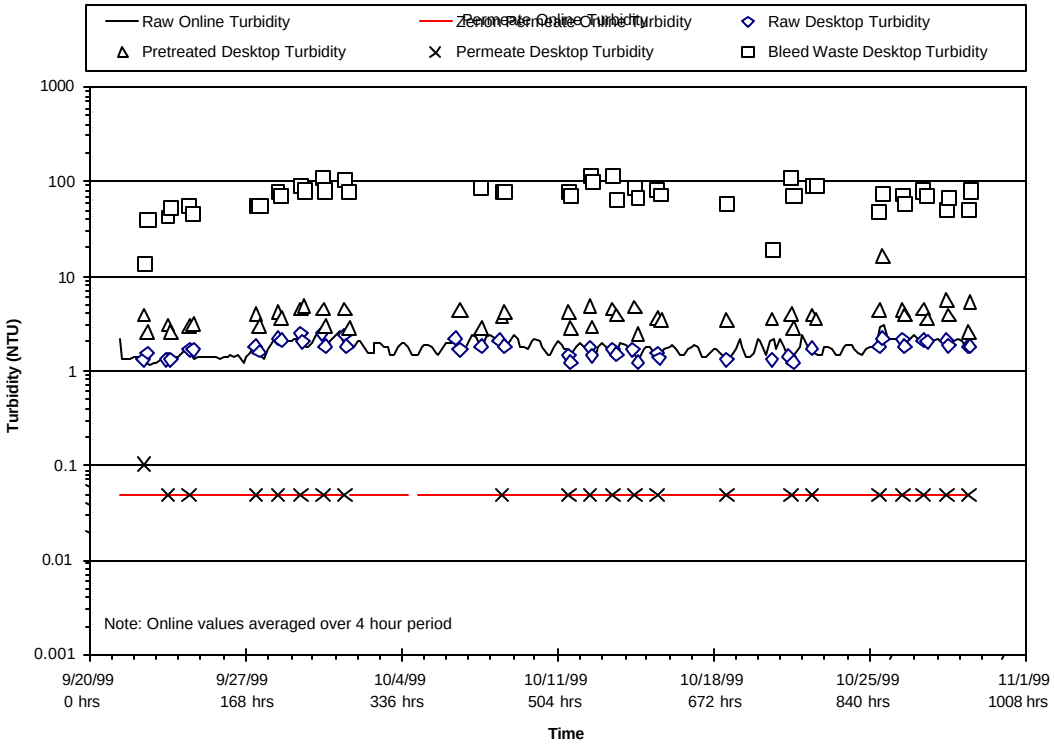
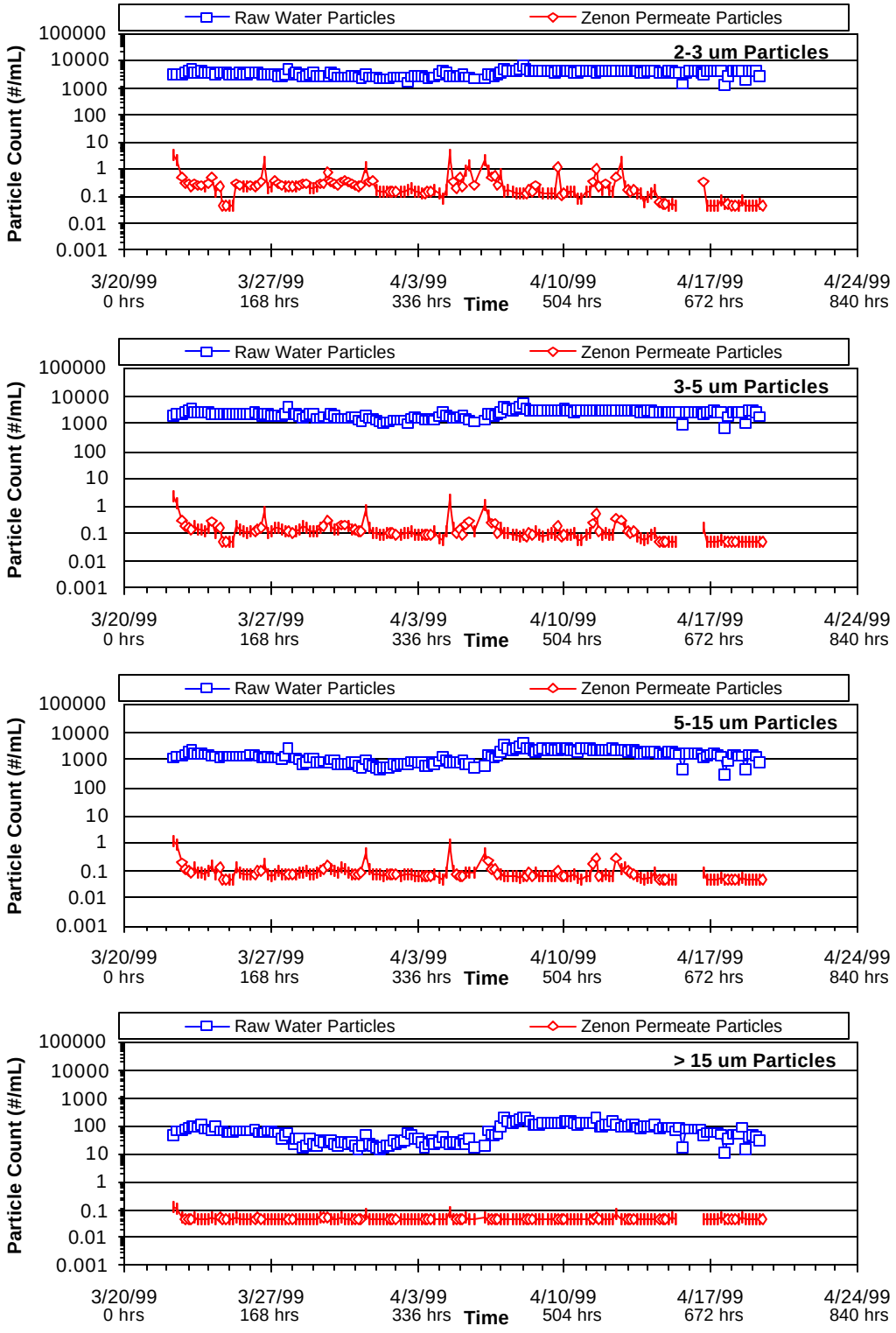
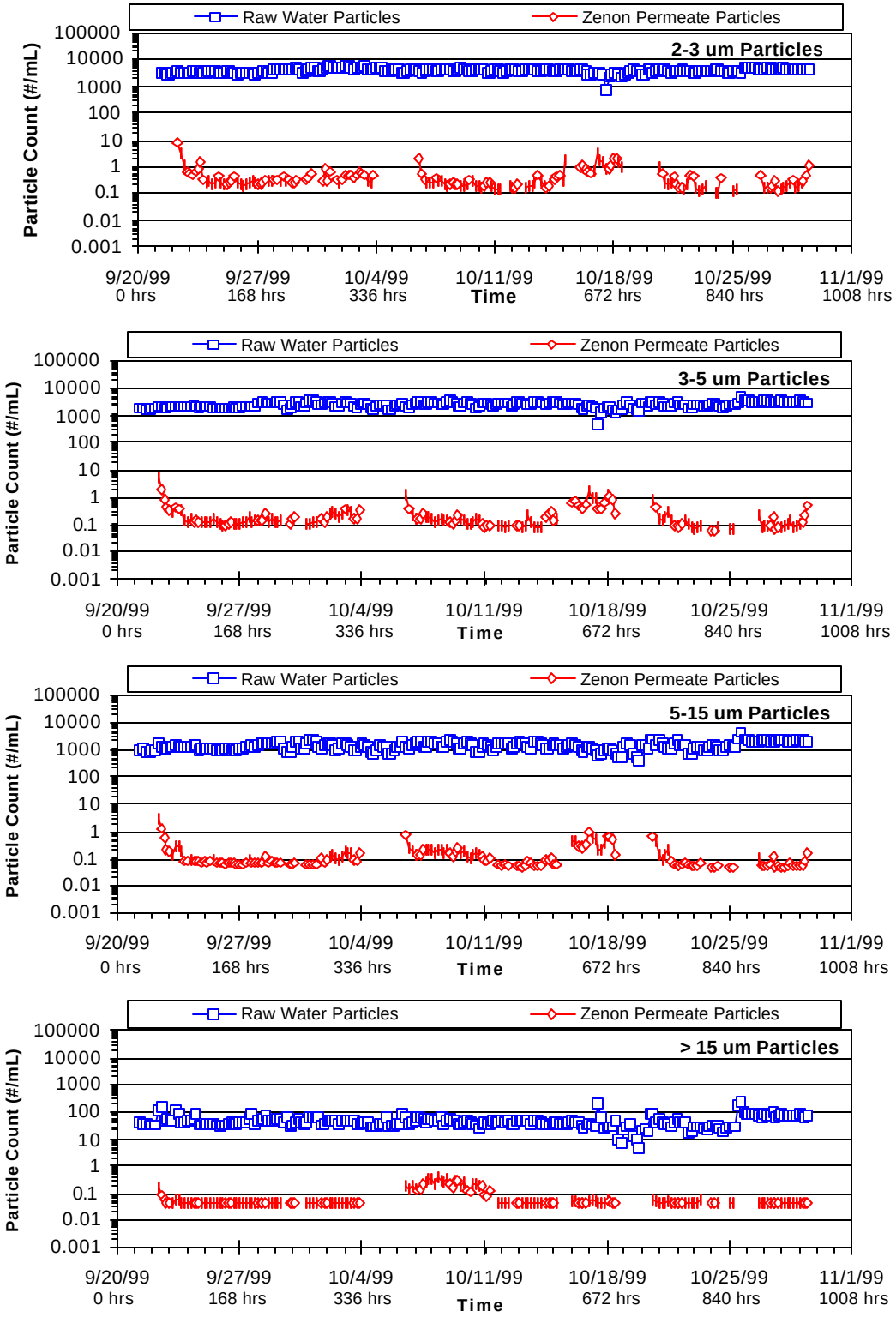


Figure 4-6. Turbidity profile for raw water and ZENON Enhanced Coagulation ZeeWeed® UF membrane system permeate - Test Period 2.



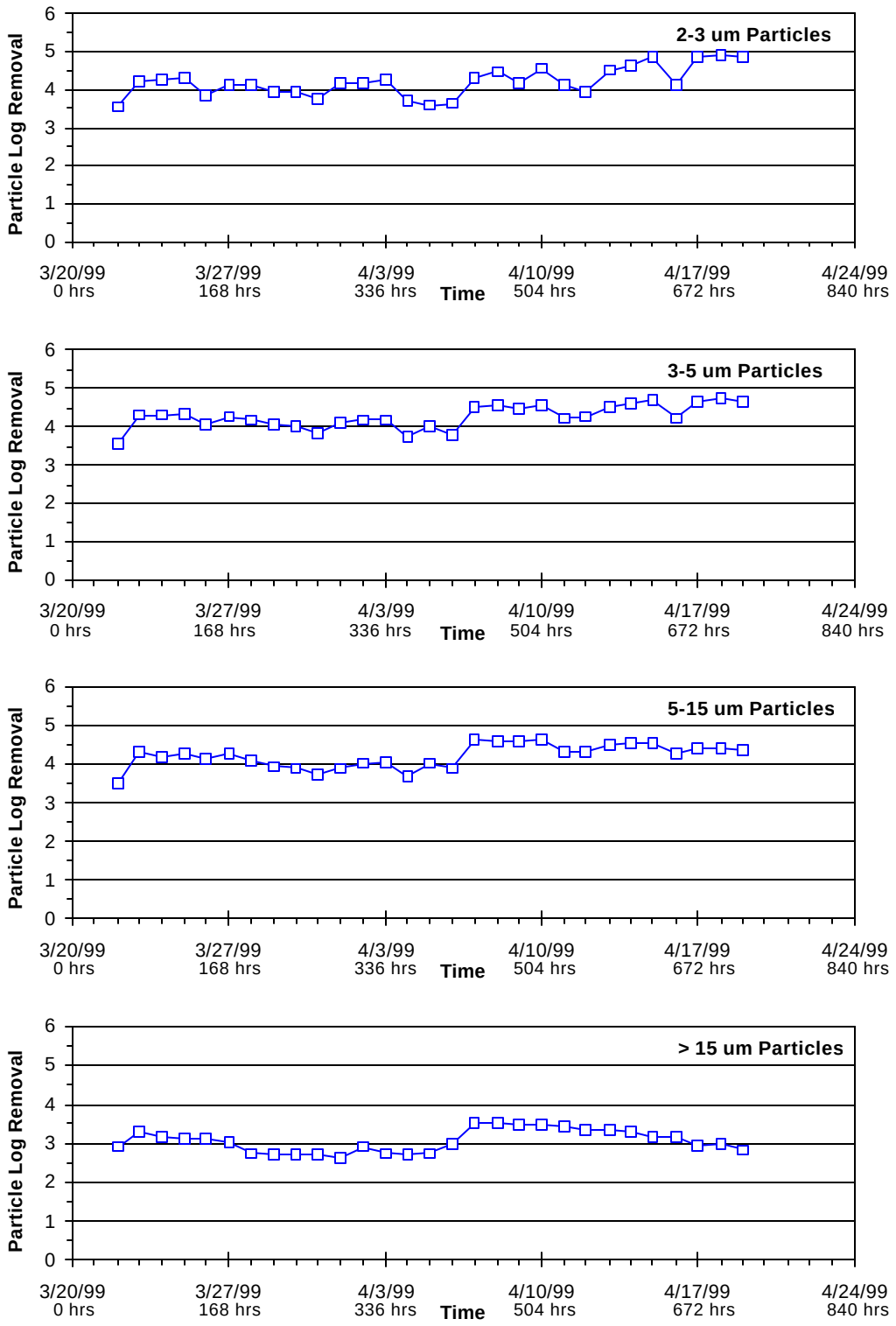
Note: Online values averaged over 4-hour period
Gaps in data due to chemical cleaning shutdown periods

Figure 4-7. Particle counts profile for raw water and ZENON Enhanced Coagulation permeate - Test Period 1.



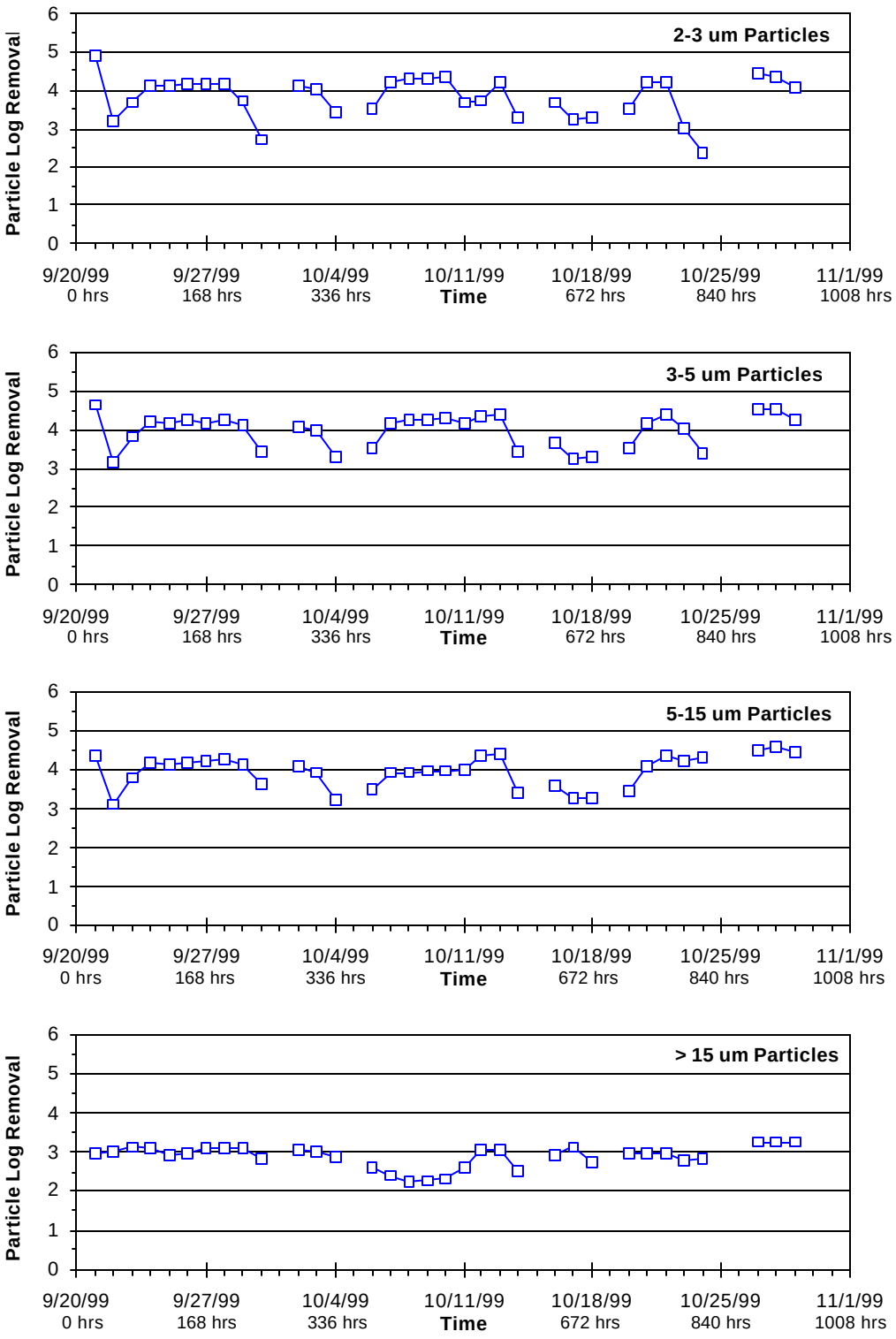
Note: Online values averaged over 4-hour period
Gaps in data due to chemical cleaning shutdown periods

Figure 4-8. Particle counts profile for raw water and ZENON Enhanced Coagulation permeate - Test Period 2.



Note: Online values averaged over 1-day period.

Figure 4-9. Particle removal for ZENON Enhanced Coagulation membrane permeate - Test Period 1.



Note: Online values averaged over 1-day period
Gaps in data due to cleaning shutdown periods

Figure 4-10. Particle removal for ZENON Enhanced Coagulation membrane permeate - Test Period 2.

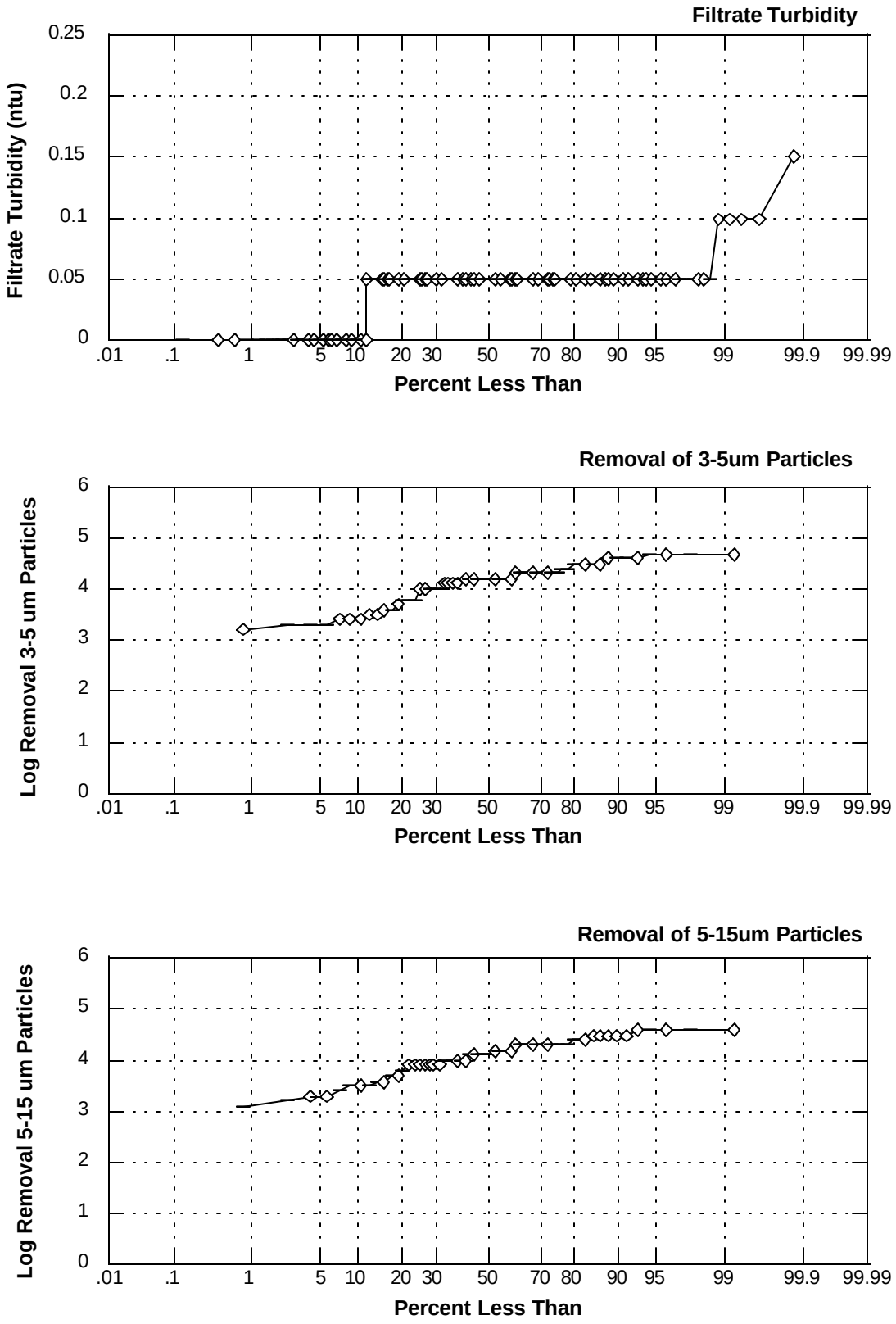


Figure 4-11. Probability plots of filtrate turbidity and log removal of particles for the ZENON Enhanced Coagulation ZeeWeed® UF membrane system.

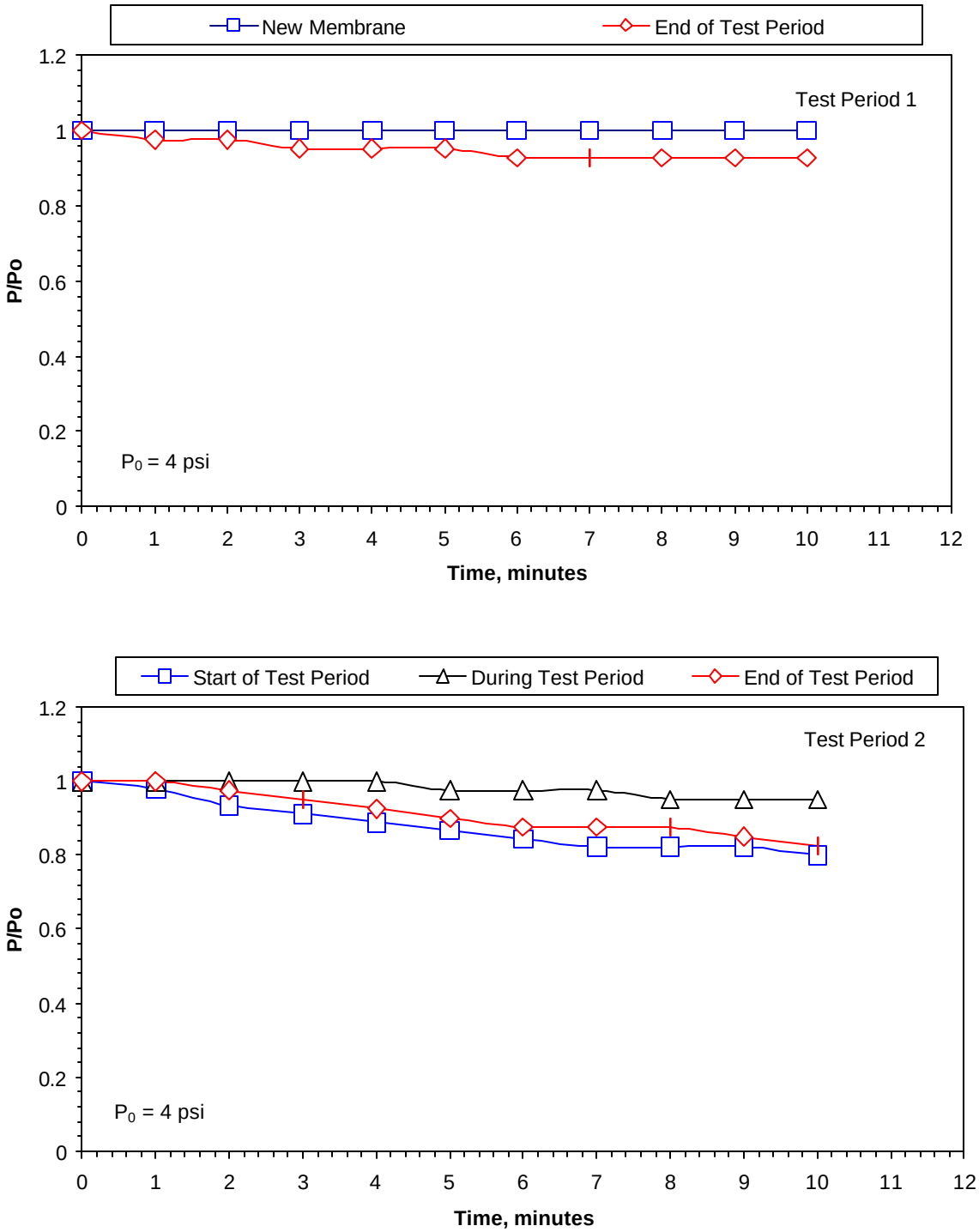


Figure 4-12. Air pressure hold test results for the ZENON Enhanced Coagulation ZeeWeed® UF membrane system.

Seeding 1
Seeding date: 9/22/99
Specific flux at 20°C = 13 gfd/psi (259 L/hr-m^2-bar)
Time from system startup = 3 hr

Seeding 2
Seeding date: 10/20/99
Specific flux at 20°C = 13.7 gfd/psi (271 L/hr-m^2-bar)
Time from system startup = < 1 hr

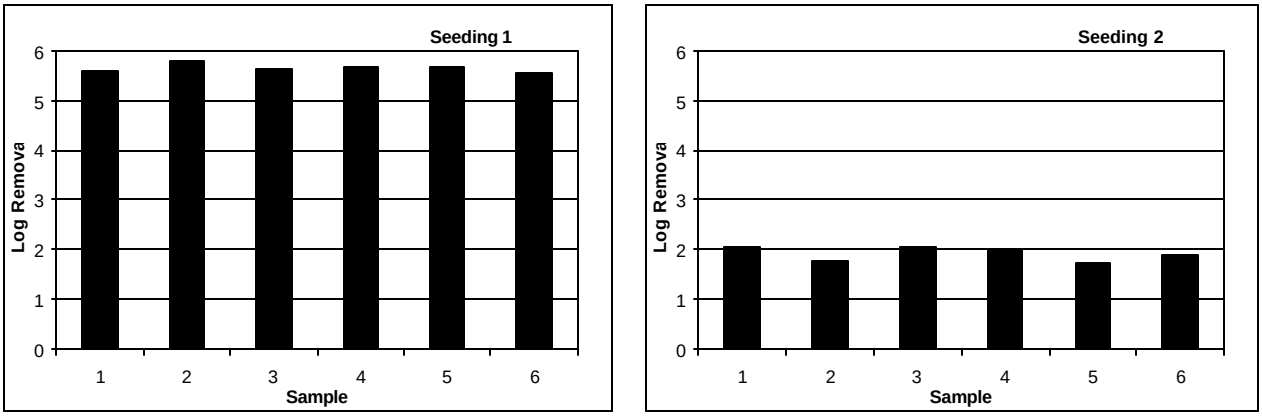


Figure 4-13. Log removal of seeded MS2 virus by ZENON Enhanced Coagulation ZeeWeed® UF membrane system.