March 2002
NSF 02/18/EPADW395

Environmental Technology Verification Report

Physical Removal of *Cryptosporidium* oocysts, *E. coli*, and *Bacillus* spores in Drinking Water

Pall Corporation
Microza™ Microfiltration 3-inch Unit, Model 4UFD40004-45
Manchester, New Hampshire

Prepared by

NSF International

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

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**MICROFILTRATION USED IN PACKAGED DRINKING WATER TREATMENT SYSTEMS**		
APPLICATION:	**REMOVAL OF *CRYPTOSPORIDIUM* OOCYSTS, *E. COLI,* AND *BACILLUS* SPORES IN MANCHESTER, NEW HAMPSHIRE**		
TECHNOLOGY NAME:	**MICROFILTRATION USING MICROZA ã 3-INCH UNIT MODEL 4UFD40004-45**		
COMPANY:	**PALL CORPORATION**		
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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 ETV Drinking Water Systems (DWS) Pilot, one of 12 technology areas under ETV. The DWS Pilot recently evaluated the performance of the Pall Corporation Microza™ Microfiltration (MF) System Module used in package drinking water treatment system applications. This verification statement provides a summary of the test results for the Microza™ MF Unit. University of New Hampshire (UNH) Water Treatment Technology Center, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the Pall Corporation Microza™ MF System equipped with a 3-inch filter module, took place between April 30 and August 9, 2000 in Manchester, New Hampshire. The source water was drawn from a canal connected to Lake Massabesic, the public reservoir that serves the Town of Manchester. The source water contained low alkalinity (3.5 mg/l), with turbidity levels that averaged 0.8 NTU and ranged between 0.07 and 3.8 NTU. The source water had a close to neutral pH at 6.4 (ranged from 5.5 to 7.2), and a TOC concentration in mg/l of between 4.68 and 5.09 with an average of 4.83. The average feed water temperature was 19 °C. Large blooms of algae, diatoms, and zooplankton occurred in the raw water during the testing. These blooms usually do not occur in such abundance at this time of year. Use of a source water with high concentrations of algae and/or iron bacteria in the feed water is not typical for MF technology and presented a worst case scenario feed water and a severe use condition for the Pall unit.

The test unit produced an average of 2.3 gpm of filtrate when operating at an average recovery rate of 90%. The average transmembrane pressure and specific flux during the verification study were 14.22 psi and 3.60 gfd/psi, respectively. Microbial seeding challenges involving *Cryptosporidium* oocysts, *E. coli*, and *Bacillus* spores were performed on May 3rd, June 21st and August 9th, 2000. The first test on May 3rd was performed at the beginning of a filter run to assess the performance on a clean membrane. The other two challenge tests were performed when the transmembrane pressure (TMP) approached its 30 psi limit to assess the performance of the membrane under stress from maximum allowed differential pressure. As a result of the three *Cryptosporidium* oocyst seeding studies, the membrane demonstrated 6.6, 4.1, and 5.6 $\log_{10}$ removals of *Cryptosporidium* oocysts, respectively. *Cryptosporidium* oocysts were not detected in the filtrate. As a result of three *E. coli* challenges, the membrane demonstrated 6.7, 3.9, 6.5 $\log_{10}$ removal of *E. coli*, respectively. *E. coli* was detected in the filtrate in two of the *E. coli* challenge events. The results of two of the *Bacillus* spore challenges (the results of the *Bacillus* spore seeding on June 21st were inconclusive) indicate a 4.0 and 7.1 $\log_{10}$ removal of *Bacillus* spores, respectively. *Bacillus* spores were not detected in the filtrate during two of the challenges. Turbidity levels were reduced 96% on average. The algae in the source water reduced run times by at least 75% as estimated by the manufacturer, who anticipated run times on the order of 30 days between cleanings. The frequency of membrane fouling indicates that some sort of pre-filter would be necessary in order to achieve longer run times at this location. For additional information on operation and maintenance of the system on a cleaner water source, refer to a previous ETV Report (#00/09/EPADW395) for testing of this system at a site in Pittsburgh, Pennsylvania.

TECHNOLOGY DESCRIPTION

The unit is identified as the 3-inch Microza™ Test Skid, model number 4UFD40004-45, LGV3L, serial number 2114562. The unit has a 3-inch diameter membrane filter module with 75 square feet of membrane contact area, and is designed to filter up to 4 gpm. The manufacturer reports that the maximum membrane pore size as determined by the use of ASTM Method F316-86 is less than 0.3 microns (µm) diameter. Power requirements for the unit are 240 volts, at 20 amps under full load.

This model is specifically targeted for applications requiring a relatively low flow rate, such as would be required for a package plant, or for a small commercial operation, school, campground, or swimming pool. It would also be appropriate for a common water supply system for a small community. The Microza™ MF module consists of pressure-driven hollow fibers of polyvinylidene fluoride (PVDF). The maximum pressure differential across the membrane fibers is 30 psi. The unit is portable, light weight, and mounted on a steel skid with casters. The operation of the system and the monitoring of operational parameters are controlled by a Supervisory Control and Data Acquisition (SCADA) system, mounted on the filter unit. The unit, therefore, should be operated in an enclosure.

VERIFICATION TESTING DESCRIPTION

Test Site

A canal connected to Lake Massabesic, the water source for Manchester, New Hampshire was chosen as the site to challenge the MF filter unit. Lake Massabesic is a natural lake and is located roughly 3.5 miles east of the downtown Manchester business area. The lake has a surface area of about 2,500 acres. The storage capacity of the lake is close to 15 billion gallons, and is the runoff repository for a 42-square mile (26,880 acres) watershed. During testing the canal became stagnant and subject to seasonal warming and subsequent algal growth. Large blooms of algae, diatoms, and zooplankton occurred in the raw water during the testing. Use of a source water with high concentrations of algae and/or iron bacteria in the feed water is not typical for MF technology and presented a worst case scenario feed water and a severe use condition for the Pall unit.

Methods and Procedures

Water quality data were collected on the source water and the filtrate produced by the Pall Microza™ MF System and analyzed using *Standard Methods for the Examination of Water and Wastewater, 20th Edition* (APHA, 1998) and/or EPA approved methods. Turbidity, temperature, pH, flow rate, particle counts, and pressure were measured and logged in the field. The analysis of TOC and UV absorbance were performed at the laboratory at UNH. Alkalinity, hardness, TSS, and TDS, were analyzed at either Research Laboratories Inc., or at Analytics Environmental Laboratory Inc., State certified testing laboratories in Portsmouth, NH. Analysis for detection of *Cryptosporidium* was performed at Analytical Services, Inc. in Williston, Vermont. Analysis of *E. coli*, and *Bacillus* spores were performed at the microbiology laboratory at UNH in conjunction with Analytical Services, Inc.

VERIFICATION OF PERFORMANCE

System Operation

The system was operated for thirteen (13) separate filter runs for a total of 436 hours between April 30, 2000, and July 26, 2000. Table VS-1 presents the system performance data for the thirteen (13) filter runs. The average filtrate flow rate was 2.3 gpm, with a maximum value of 6.3 gpm and a minimum value of 1.8 gpm. Transmembrane pressure averaged 14 psi, with a maximum value of 30 psi, and a minimum value of 2.9 psi. The specific flux averaged 3.6 gfd/psi, with a maximum value of 14 gfd/psi and a minimum value of 1.3 gfd/psi. A summary of the system performance data is in the table below.

Table VS-1. System Performance Data for 13 Filter Runs

	Feed Flow (gpm)	Feed Pressure (psi)	Feed Temperature (°C)	Feed Turbidity (NTU)	Filtrate Flow (gpm)	Filtrate Pressure (psi)	Filtrate Turbidity (NTU)	Retentate Pressure (psi)	Transmembrane Pressure (psi)	Specific Flux (gfd/psi)
Average	2.50	17.47	18.88	0.80	2.30	4.20	0.03	15.35	14.22	3.60
Minimum	1.80	0.04	11.44	0.07	1.80	0.00	0.00	0.00	2.87	1.27
Maximum	9.80	36.13	35.26	3.79	6.26	31.68	0.32	34.43	30.23	14.19
Std Dev	0.63	6.61	3.14	0.28	0.43	2.83	0.01	7.18	5.25	1.36
95% Conf. Interval	(2.49, 2.51)	(17.35, 17.59)	(18.82, 18.94)	(0.79, 0.81)	(2.29, 2.31)	(4.15, 4.25)	(0.03, 0.03)	(15.22, 15.48)	(14.12, 14.32)	(3.57, 3.63)

Note: Results corrected for AS and RF procedures.

Reverse filtration (RF) and air scrub (AS) operation were initially set to repeat every 30 and 60 minutes respectively for a set duration of 60 seconds. The effectiveness of this cleaning procedure varied with the

water quality. It was found that the intensity of the operation had a greater impact on performance than the frequency. In other words, adjustments in the duration of the AS and RF procedures produced improved operational results rather than increasing the frequency. A chemical cleaning took place every time the transmembrane pressure exceeded 30 psi, or if the system shut down due to fouling of the membrane. Four chemical cleaning events took place during the testing period. The chemical cleanings were performed using the manufacturer's recommended procedures and it took approximately three hours to accomplish each cleaning. The membrane passed the integrity test after each cleaning operation was performed.

Water Quality Results

The system effectively removed microbiological and particulate contaminants from the feed water during the verification study. Microbial seeding challenges involving *Cryptosporidium* oocysts, *E. coli*, and *Bacillus* spores were performed on May 3rd, June 21st and August 9th, 2000. The first test on May 3rd was performed at the beginning of a filter run on a new clean membrane, and the other two tests were performed when the TMP approached its 30 psi limit. The membrane demonstrated 6.6, 4.1, and 5.6 $\log_{10}$ removals of *Cryptosporidium* oocysts, respectively, during the challenge studies. *Cryptosporidium* oocysts were not detected in the filtrate samples. The samples collected during the May 3rd *Cryptosporidium* challenge were analyzed outside the method's specified hold time; however, the deviation is not expected to influence the sample results because the samples were analyzed for total cyst concentration and not viability (see Quality Control Section of report for discussion). The membrane demonstrated 6.7, 3.9, 6.5 $\log_{10}$ removal of *E. coli*, respectively, during the challenge studies. *E. coli* was detected in the filtrate in two of the *E. coli* challenge events. The results of two of the *Bacillus* spore challenges (the results of the *Bacillus* spore seeding on June 21st were inconclusive) indicated a 4.0 and 7.1 $\log_{10}$ removal of *Bacillus* spores. *Bacillus* spores were not detected in the filtrate during two of the challenges. The $\log_{10}$ removals for *E. coli* and *Bacillus* spores were calculated based on a 100 mL sample. The $\log_{10}$ removals of the microorganisms seeded were limited by the concentration which was present in the stock feed solution, the percentage of the filtrate sampled, and the percent recovery of the analytical methodology.

The raw water particle count concentration of *Cryptosporidium*-sized particles (2 to 5 micron) and cumulative particles (>2 micron) averaged 3,120 and 5,601 counts/ml, respectively. The filtrate particle count concentration averaged 1.7 and 3.1 counts/ml, respectively. Percent reduction for both *Cryptosporidium*-sized particles (2 to 5 micron) and cumulative particles (>2 micron) was 99.94%. Turbidity was reduced from an average of 0.80 NTU in the feed water to 0.03 NTU in the filtrate.

Operation and Maintenance Results

The system evaluated in this study was highly automated, making day-to-day operation simple and straightforward. Aside from the chemical cleaning, labor was spent after start-up to adjust feed flow and adjust the reverse filtration and air scrub run time and frequency to enhance performance. The adjustments were accomplished via computer programming with the exception of valve adjustments performed manually to regulate the retentate flow. The water quality and the environmental conditions at the site required that three mechanical changes be made in the system. The demand for compressed air required that a larger compressor be used instead of the original supplied with the system. The maximum temperature setting allowed within the enclosed SCADA system was increased from the original factory setting to allow for the high air temperatures at the site. A solenoid valve that controlled one of the pneumatic flow control valves also failed and was replaced with another that was supplied with the membrane system.

The system operation was terminated seven times because the TMP termination criteria (30 psi) was reached. The terminations were believed to be a direct result of high concentrations of algae and/or iron bacteria in the feed water. Use of a source water with high concentrations of algae and/or iron bacteria in

the feed water is not typical for MF technology and presented a worst case scenario feed water and a severe use condition for the Pall unit. For additional information on operation and maintenance of the system, refer to a previous ETV Report (#00/09/EPADW395), which documents operation and maintenance results on a cleaner water source.

The Operation and Maintenance manual is well written and easy to follow. Sections include: System Description, Module Installation and Rinse-Up, Safety Instruction, System Operation, System Control Interface, and Clean-In-Place Procedures. The only technical assistance required that was not covered in the manual was membrane fouling caused by algae in the source water, system shutdown caused by an undersized compressor and the adjustment of factory settings to compensate for the higher than anticipated temperatures within the SCADA system due to the abnormally high ambient temperatures at the site.

Original Signed by		*Original Signed by*	
E. Timothy Oppelt	*04/08/02*	*Gordon Bellen*	*04/11/02*
E. Timothy Oppelt	Date	Gordon Bellen	Date
Director		Vice President	
National Risk Management Research Laboratory		Federal Programs	
Office of Research and Development		NSF International	
United States Environmental Protection Agency			

Availability of Supporting Documents

Copies of the *EPA/NSF ETV Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants* dated May 1999, the Verification Statement, and the Verification Report (NSF Report #02/18/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)

March 2002

Environmental Technology Verification Report

Physical Removal of *Cryptosporidium* oocysts, *E. coli*, and *Bacillus* spores in Drinking Water

Pall Corporation
Microza ä Microfiltration 3-inch Unit,
Model 4UFD40004-45, LGV3L
Manchester, New Hampshire

Prepared for:

NSF International
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Prepared by:

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

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Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under Cooperative Agreement No. CR 824815. This verification effort was supported by Drinking Water Treatment Systems Pilot operating under the Environmental Technology Verification (ETV) Program. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release.

Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for NSF International (NSF) and the United States Environmental Protection Agency (EPA) by the University of New Hampshire (UNH) Water Treatment Technology Center , in cooperation with the Pall Corporation. The testing was conducted between April 30 and July 26, 2000 at the intake site for the water treatment facility in Manchester, New Hampshire.

Throughout its history, the EPA has evaluated the effectiveness of innovative technologies to protect human health and the environment. A new EPA program, the Environmental Technology Verification Program (ETV) 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 is made available to regulators, developers, consulting engineers, and those in the public health and environmental protection industries. This encourages more rapid availability of technology 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 Drinking Water Treatment Systems (DWTS) ETV Pilot. 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 DWTS 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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Abbreviations and Acronyms

A/D	Analog-to-Digital
AS	Air Scrub
ASI	Analytical Services, Inc.
C	Degrees Celsius
CIP	Clean in place
CLP	Contract Laboratory Program
Cl2	Chlorine
D.O.	Dissolved Oxygen
DE	Diatomaceous Earth
DI	Deionized (water)
DOC	Dissolved Organic Carbon
DQO	Data Quality Objectives
DWTS	Drinking Water Treatment System
EPA	United States Environmental Protection Agency
ESWTR	Enhanced Surface Water Treatment Rule
ETV	Environmental Technology Verification
FOD	Field Operations Document
FTO	Field Testing Organization
g/L	Grams per liter
GAC	Granulated Activated Carbon
GFD	Gallon per square foot per day
GPM	Gallons per Minute
HP	Horse Power
L	Liters
MF	Microfiltration
mg/L	milligram per liter
MSDS	Material Safety Data Sheets
NF	Nanofiltration
NHDES	New Hampshire Department of Environmental Services
NPT	National Pipe Thread
NSF	NSF International
NTIS	National Technical Information Service
NTU	Nephelometric Turbidity Units
PARCC	Precision, Accuracy, Representativeness, Completeness, and Comparability
PFW	Particle Free Water
PM	Preventative Maintenance
ppm	Parts per million
PQL	Practical Quantitation Limits
psi	Pounds per square inch
PVC	Polyvinyl Chloride
PVDF	Polyvinylidene Fluoride
QA	Quality Assurance
QC	Quality Control
RF	Reverse Filtration

RO	Reverse Osmosis
RPD	Relative Percent Difference
RSD	Relative Standard Deviation
SCADA	Supervisory Control and Data Acquisition
SCFM	Standard cubic feet per minute
SDWA	Safe Drinking Water Act
SWTR	Surface Water Treatment Rule
THMFP	Trihalomethane Formation Potential
TMP	Transmembrane pressure
TOC	Total Organic Carbon
UF	Ultrafiltration
UNH	University of New Hampshire
WTTC	Water Treatment Technology Center

ACKNOWLEDGMENTS

The Field Testing Organization, University of New Hampshire Water Treatment Technology Center, was responsible for all elements in the testing sequence, including collection of samples, calibration and verification of instruments, data collection and analysis, data management, data interpretation and the preparation of this report.

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In addition to the UNH laboratory, the laboratory selected for microbiological analysis analytical work of this study was:
Analytical Services, Inc.
Mr. Paul Warden, Vice President
50 Allen Brook Lane
P.O. Box 515
Williston, VT 05495
Phone: (802) 878-5138
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Other analytical services were provided by the following two laboratories:
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The Manufacturer of the Equipment was:
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University of New Hampshire Water Treatment Technology Center wishes to thank Mr. David Paris Director of the Manchester Water Treatment Plant and his associates for their extraordinary support and accommodation during this ETV project.

Chapter 1
Introduction

1.1 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by 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, collecting and analyzing data, and preparing peer reviewed reports. Evaluations are conducted in accordance with rigorous quality assurance protocols to verify that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF) in cooperation with the EPA operates the Drinking Water Treatment Systems (DWTS) Pilot, one of 12 technology areas under ETV. The DWTS Pilot evaluated the performance the Pall Corporation Microza™ Microfiltration System, which is a hollow fiber membrane microfiltration (MF) system used in package drinking water treatment system applications. The field testing evaluated the system's capability of reducing turbidity and also included microbial challenges to evaluate the system's ability to physically remove *Cryptosporidium*, *E. coli*, and *Bacillus* spores. This document provides the verification test results for the Pall Corporation Microza™ Microfiltration System.

1.2 Testing Participants and Responsibilities

The ETV testing of the Pall Microza™ Microfiltration System was a cooperative effort between the following participants:

NSF International
U.S. Environmental Protection Agency
The University of New Hampshire Water Treatment Technology Center
Pall Corporation
Manchester New Hampshire Water Treatment Plant at Lake Massabesic, Manchester, New Hampshire

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

1.2.1 NSF International

NSF is a not-for-profit standards and certification organization dedicated to public health safety and the protection of the environment. Founded in 1946 and located in Ann Arbor, Michigan, NSF has been instrumental in the development of consensus standards for the protection of public health and the environment. NSF also provides testing and certification services to ensure that products bearing the NSF Name, Logo and/or Mark meet those standards. The EPA partnered with the NSF to verify the performance of drinking water treatment systems through the EPA's ETV Program.

NSF provided technical and primarily quality oversight of the verification testing. An audit of the field analytical and data gathering and recording procedures was conducted. NSF also provided review of the Field Operations Document (FOD) to assure its conformance with pertinent ETV generic protocol and test plans. NSF also conducted a review of this report and coordinated the EPA and technical reviews of this report.

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1.2.2 Field Testing Organization

The University of New Hampshire (UNH) Water Treatment Technology Center, conducted the verification testing of the Pall Corporation Microza™ Microfiltration System. The UNH Water Treatment Technology Center is a NSF-qualified Field Testing Organization (FTO) for the DWTS ETV Pilot.

The FTO was responsible for conducting the verification testing. The FTO provided logistical support, established a communications network, and scheduled and coordinated activities of the participants. The FTO was responsible for selecting the testing location and feed water conditions such that the verification testing could meet its stated objectives. FTO employees performed the onsite analyses and recorded data during the testing. The FTO also prepared the FOD, oversaw the testing, managed, evaluated, interpreted and reported on the data generated by the testing, as well as evaluated and reported on the performance of the package system.

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1.2.3 Manufacturer

The treatment system is manufactured by the Pall Corporation. The manufacturer was responsible for supplying a field-ready Microza™ MF System equipped with the necessary components including treatment equipment, instrumentation and controls and an operations and maintenance manual. The manufacturer was responsible for providing logistical and technical support as needed as well as providing technical assistance to the FTO during operation and monitoring of the equipment undergoing field verification testing.

Contact Information:

Pall Corporation
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Phone: (516) 484-3600 ext. 6844
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1.2.4 Analytical Laboratory

Analytical Services, Inc. (ASI) was responsible for the analyses and laboratory QA/QC procedures for the microbiological samples, including bacterial samples, algae, and *Cryptosporidium*. *E. coli* and *Bacillus* spore analyses were performed by UNH in conjunction with ASI.

Contact Information:

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Fax: (802) 878-6765
Contact Person: Mr. Paul Warden, Vice President
e-mail: pwarden@asimicro.com

All other analytical services were performed by the following two laboratories:

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Analytics Environmental Lab Inc.
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Contact Person: Stephen Knollmeyer

1.2.5 U.S. Environmental Protection Agency

The EPA through its Office of Research and Development has financially supported and collaborated with NSF under Cooperative Agreement No. CR 824815. This verification effort was supported by DWTS Pilot operating under the ETV Program. This document has been peer reviewed, reviewed by NSF and EPA, and recommended for public release.

1.3 Verification Testing Site

The verification testing occurred at the Low Service Pumping Station of the Manchester Water Works located at 567 Cohas Avenue in Manchester, NH. The 3-inch Test Skid filter unit was housed at the electric power generation site at the facility. The facility had adequate power and direct access to the water supply source, which is located less than 50 m away from the proposed demonstration/study site. The facility was secured, especially in the evenings and is conveniently located with respect to the environmental engineering laboratories at the UNH WTTC. The location had laboratory facilities that were conducive for measuring on-site water quality and operational parameters including pH, D.O., temperature, flow rates, and head loss. Storage facilities were also available for storing sample bottles until they were used. There was ample staging area available for the preparation and packaging of sample bottles for transport to the FTO labs.

1.3.1 Source Water

The testing was arranged to take place at the Manchester Water Treatment Facility using water from their intake from Lake Massabesic. Estimated water quality parameters for the Treatment Facility's intake are presented in the following table.

Table 1-1. Estimated Water Quality Data for Manchester Water Treatment Facility

Parameter	Range of Estimated Results
Turbidity (NTU)	0.8-4.0
Total Coliform (#/100 ml)	1-150
pH	6-7
TOC/DOC (mg/l)	2-4
Trihalomethane Formation Potential (ug/l)	80-160

Note: This data is provided as an estimate of the water quality and was not verified by the verification organization.

The testing site was relocated to another water intake on the Treatment Facility's property due to concerns by the Manchester Water Treatment Facility of the seeding with microorganisms. The intake source water used during the verification testing of the Pall unit was water from a canal that receives its water from Lake Massabesic. The Manchester Water Treatment Facility indicated that this other intake had water quality similar to their intake for the Treatment Facility.

Unfortunately the water in the canal became stagnant during the testing due to lack of use of the canal water by a local power facility. The water during verification testing contained high amounts of algae as a result. Use of a source water with high concentrations of algae and/or iron bacteria in the feed water is not typical for MF technology and presented a worst case scenario feed water and a severe use condition for the Pall unit.

The source water for the verification testing was from a canal connected to Lake Massabesic. Lake Massabesic is located roughly 3.5 miles east of the downtown Manchester business area, and has a surface area of about 2,500 acres. The storage capacity of the lake is close to 15 billion gallons, and is the runoff repository for a 42-square mile watershed.

A summary of the feed water quality data during the verification test period is presented in Table 1-1 and Table 1-2. In addition to the information listed below, a quantitative analysis of the algae analyses are included in Chapter 4.

Table 1-2. Feed Water Quality

Date	TOC (mg/L)	UV Absorbance (1/cm)	Total Iron (mg/L)	Total Manganese (mg/L)	Alkalinity (mg/L)	Hardness (mg CaCo3/L)	TDS (mg/L)	TSS (mg/L)
5/11/00	4.77	0.136	---	---	---	---	---	---
5/12/00	4.69	0.133	---	---	---	---	---	---
6/9/00	4.76	0.125	0.073	0.015	---	---	---	---
6/14/00	---	---	0.16	0.013	---	---	---	---
6/21/00	5.09	0.119	---	---	3.5	11.2	79	<4
6/27/00	---	---	0.18	0.014	---	---	---	---
Average:	4.83	0.128	0.14	0.014	NA	NA	NA	NA
Maximum Value:	5.09	0.136	0.18	0.015	NA	NA	NA	NA
Minimum Value:	4.69	0.119	0.073	0.013	NA	NA	NA	NA

--- = Sample not collected on this date.

NA=Statistical calculations not performed because sample size =1.

Table 1-3. Feed Water On-line Turbidity and Particle Counts

Date	Turbidity (NTU)	Cumulative Particle Counts (2->15um) (particles/mL)
Average:	0.80	5601
Minimum value:	0.07	877
Maximum value:	3.79	17891
95% Confidence Interval:	(0.79, 0.81)	(5533, 5670)

1.3.2 Effluent Discharge

The effluent of the treatment unit was clear and odorless. After samples were collected, the effluent and source water were stored in 60 gallon juice drums. The drums were discharged to an approved outfall site that emptied into the Merrimack River watershed. Discharge permits were not required.

The caustic/chlorine cleaning solutions, the citric acid cleaning solutions, and the rinse solutions were kept separate in plastic storage barrels. After the project was completed they were transported to UNH and were subsequently disposed of by the Hazardous Waste Management Department at UNH.

Chapter 2
Equipment Description and Operating Processes

2.1 Equipment Description

The equipment tested was a package sized, portable microfiltration plant manufactured by Pall Corporation. The unit is identified as the 3-inch Microza™ Unit, model number 4UFD40004-45, LGV3L, serial number 2114562. The unit has a 3-inch diameter membrane filter module with 75 square feet (ft^2) of membrane contact area, and is designed to filter up to 4 gpm. Power requirements are 120 volts, at 20 amps under full load.

This model is specifically targeted for applications requiring a relatively low flow rate, such as would be required for a package plant, or for a small commercial operation, school, campground, or swimming pool. It would also be appropriate for a common water supply system for a small community. The Microza™ Microfiltration module consists of pressure-driven hollow fibers of PVDF. The maximum pressure differential across the membrane fibers is 30 psi. The unit is portable, light-weight, mounted on a steel skid with casters. The operation of the system and the monitoring of operational parameters are controlled by a SCADA system, mounted on the filter unit. The unit, therefore, should be operated in an enclosure.

2.1.1 Background Engineering Concepts

Microfiltration is a mechanical, pressure driven filtering process whereby a porous membrane provides a mechanical barrier to the particulates in the source feed water. Typical membranes used are categorized as spiral wound, hollow-fiber (HF), tubular, cassette, cartridge, or flat sheet. The membrane used in this particular unit are of the hollow-fiber category, with nominal pore size of 0.1 µm.

The microfiltration modules resemble vertical liquid-liquid heat exchangers. Two plates are vertically separated by several feet. Each plate consists of solidified seating material, which resembles a one inch thick disk of ice holding a circular bunch of hollow cattail reeds. The module has an outer cylinder case which seals against the circumference of the plates. Forcing water inside the case presses it around reed-like membrane fibers. These are permeable and much of the water sieves through the membrane where it flows away in the hollow membrane interior. Particles greater than the effective porosity of the fibers do not pass through the membrane, and are carried away in a recirculating flow.

The modules are composed of an outer shell of PVC, nominally 3" in diameter, and 42" in length (actual dimensions are 140 x 2227 mm). Empty weight is about 45 pounds. Inside the module are hundreds of fine (1.4 mm outside, 0.8 mm inside diameter) fibers fabricated from PVDF for the MF modules. The total surface area of each module, based on outside fiber diameter, is approximately 75 square feet. The fibers contain thousands of micro-pores in the range of 0.004 to 0.1 µm in diameter. These pores sieve particulate matter passing through the membrane surface. The method used to fabricate the fibers results in a tough skin on the inner and outer surfaces, making the fibers robust and long-lived. This double skin is unique to the Microza™ membrane, and also allows equal flow in either direction, as required.

The fibers are potted in epoxy, and arranged so that the feed flow enters the bottom of the module and flows on the outside of the fibers. Water passes into the fiber interior core via the pores. Contaminates which cannot pass through the pores remain exterior to the filter module. Water that enters the fiber cores is channeled to the filtrate plenum. This "outside- in" flow path provides for a larger effective membrane area, and allows higher flux rates than most other membrane modules.

2.1.2 Physical Characteristics

The Microza™ MF system module, pumps, tanks, and SCADA unit are mounted on a mobile steel skid, equipped with industrial-grade casters. The overall footprint of the filter unit is 34 inches wide by 90 inches long. The unit height overall is approximately 78 inches. It is designed to pass through most doorways. A photograph of the system is shown in Figure 2-1. A schematic of the three-inch diameter module filter system is shown in Figure 2-2.

Figure 2-1. Photograph of the Pall Microza™ System

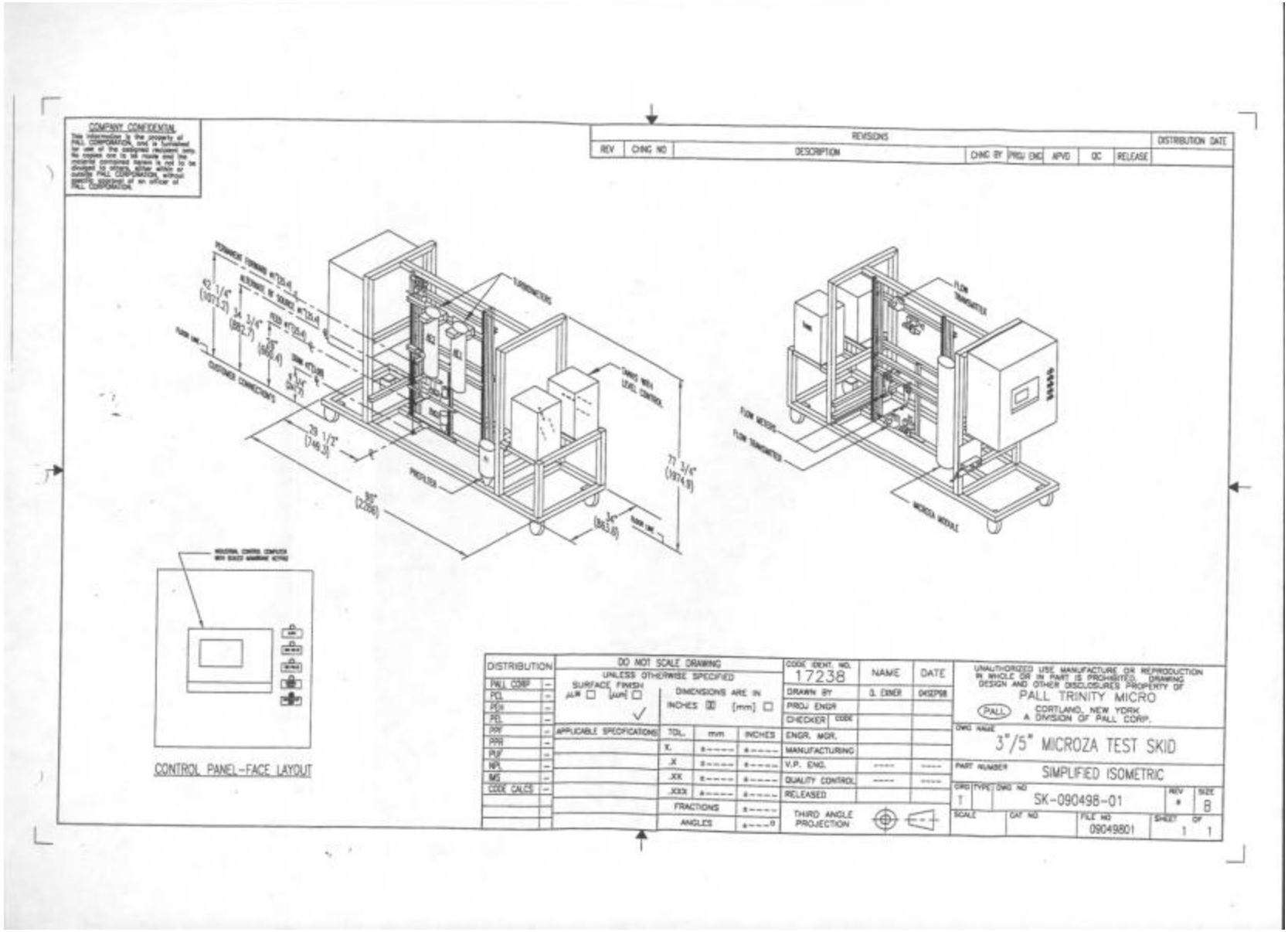

Figure 2-2. Schematic of the Pall MicrozaÔ System

The system is designed to intercept the flow from the customer's feed connection, and deliver treated filtrate to the downstream distribution system. Feed water connection to the source is by a 1-inch line leading to the filter feed water tank.

A prefilter is connected in the feed line upstream of the filter module to capture particles larger than typically one-tenth the diameter of the hollow-tube fiber. The prefilter is manufactured by Filter Specialists, Inc. (FSI). The prefilter used on the Pall filter unit is a model number BPEM400P 3P prefilter. It consists of a disposable bag filter made of polyester nylon mesh with a pore size of 400 um. The bag is attached to a polypropylene ring.

Two 24-gallon tanks are mounted on one end of the filter skid. Both tanks are regulated with float valves, consisting of float balls connected to a needle metering valve by a float rod. The first of these tanks is the feed water tank. Water enters this tank from two sources. The primary source is the raw feed water. Source water is brought to the tank via an 1-inch line. The secondary inflow source is the excess recirculation (XR) flow. A variable speed pump delivers the feed water from the tank to the bottom of the module. Approximately 90% of feed water flows through the hollow-tube fibers, and flows out the top of the filter module as filtrate. The remaining 10% of the feed water flows by the outside of the filter fibers, collecting particles in the near vicinity of the fibers and transporting them away from the fiber surfaces. This flow is the excess recirculation, which recycles back into the feed tank.

The second tank, for Reverse Filtration (RF), is fed by the filtrate from the filter module. The filtrate discharge from the filter module is run to a tee fitting. One branch of the tee is connected to a float valve in the RF tank. This branch siphons off a small percentage of the filtrate flow for the Reverse Filtration membrane cleaning process. The RF cleaning is performed regularly, at 15-30 minute intervals. The filtrate water in the RF tank is pumped back through the filter module in the reverse direction, at a rate 1.5 times the filter rate (6 gpm) for typically less than one minute, to dislodge the particles from the outside of the hollow-tube fibers. The discharge from the RF filtration is through the XR port at the top of the module, and is run back into the feed water tank.

The filtrate from the forward filter flow flows from the second branch of the tee in the discharge line through a 1-inch diameter pipe. This discharge is not at high pressures, rather the discharge is designed to collect in a holding tank that stores the treated water at atmospheric pressure. The system is not designed to deliver water flow under significant pressure. Two in-line electronic flow meters provide continuous monitoring and back-up monitoring of the flow rate.

There is also a 1-inch alternate source clean water line provided to supplement the water from the RF tank. This source is used in the event that the RF tank is exhausted, and during clean-in-place (CIP) procedures. A variable speed centrifugal pump controls the flow out of each tank. Pressure transducers are installed in the feed water and filtrate lines to measure the pressure differential across the filter module. Flow is controlled by solenoid valves on the various water lines, which in turn are controlled by the SCADA system. In addition, a compressed air line is connected to the filter module at the feed water end for the air scrubbing cleaning procedure. This is also regulated by an electrically actuated valve and the SCADA system. The air flow is monitored by a flow meter on the air line, which also is connected to the SCADA system. The

SCADA system monitors flow rates and cumulative volumes of filtrate and waste, tank levels, in-line temperature, turbidity, and particle counts.

The SCADA computer controls are mounted on the unit in a panel opposite the feed and retentate tanks. The control panel provides real-time monitoring of flow rate, pressures across the filter module, and turbidity of filtrate waters. The pumps are variable speed pumps, which are controlled remotely at the control panel. The system may operate in two modes, manual or automatic. In automatic mode, the computer controls the valves, and pump speeds for regular filter operation and periodic RF, and air scrubbing cleaning. CIP procedures are performed in manual mode. Chemicals are added to the feed tank during this procedure.

2.2 Operating Process

2.2.1 Forward Flow

During normal flow, the module receives inlet flow. This flow enters the bottom of the module, and flows up the module on the outside of the hundreds of hollow fibers that run the length of the module. Of this, 95% 'permeates' through the fiber surface, travels up the inside of the hollow fiber, and flows into the Reverse Filtration Tank before leaving the system as clean water. The remaining 5% is recycled back to the Feed Tank as Excess Recirculation (XR). This XR flow prevents the accumulation of air that may come out of solution in the module, and helps to ensure even flow distribution throughout the module.

2.2.2 Reverse Filtration

As water is filtered through the membrane surface, a cake of rejected particulates accumulates on the surface of the fibers. With greater accumulation, this deposition gradually impedes the filtrate flow. To maintain stable flow over the short term, a periodic cleaning cycle, called a Reverse Filtration (RF) Cycle, is performed. RF typically takes place every 15-30 minutes. During the RF cleaning mode, the feed flow is stopped, and filtrate is pumped backwards through the module from the inside of the fibers out through the pores. Typically, the RF rate of flow is fixed at around 1.5 - 2 times the forward flow rate, washing away the accumulated particulates. The reverse flow is short lived - a typical RF duration could be 20 seconds of every 24 minutes. This RF water exits the XR port near the top of the module, and is returned to the Feed Tank. In permanent installations, RF is generally diverted to a drain to prevent the concentrated particulates from reentering the flow path. Drainage of RF constitutes the majority of the lost feed flow (approximately 5%).

To aid in cleaning the module, and particularly in removing biogrowth on the membrane surfaces, chlorine, in the form of 12.5% sodium hypochlorite, is injected into the RF flow stream at a concentration of approximately 20 mg/L. Valves direct all chlorine-laden RF clean flow into a drain, consequently, no chlorine residual is sent in the MF filtrate to sensitive downstream processes such as Reverse Osmosis.

2.2.3 Air Scrub

Occasionally, RF is not totally effective in cleaning the membrane fibers and a more vigorous cleaning is required. Pall Corporation calls the more vigorous cleaning method used Air Scrubbing (AS), which is a two step process. The first step consists of bubbling about 3 SCFM of compressed air through each module with no water flow. The air is introduced into the feed connection of the module. Gaseous air will not pass through the fibers, and will stay on the feed side of the membrane. The air bubbles shake the fibers intensely, sloughing off material that resists the RF cycle.

The second part of the AS cycle serves as a rinse and flush. Air is still bubbled up through the module, but water is also circulated through the feed side of the module, which is even more effective in cleaning the module surface. Air Scrubbing is an energetic process, and increases the wear on the hollow fibers. For this reason, the AS frequency and duration must be kept to the minimum required to keep the modules clean.

2.2.4 Clean-In-Place

The RF and AS membrane regeneration procedures need to be supplemented with periodic chemical cleaning to remove gradually accumulated foulants that are resistant to daily RF/AS procedures. The Clean-in-Place (CIP) process requires scheduled down-time. The entire system is taken off-line for several hours. In new systems, the CIP cycle is initially scheduled every two to three months. As flow or incoming particulate levels increase, it is likely that the CIP frequency will increase, accordingly.

The CIP process is performed manually on this particular filter unit. (CIP is generally automated for larger, permanent systems). The system is drained, and then refilled with filtrate. Sodium hydroxide and sodium hypochlorite are added to the filtrate, which is then circulated through the system in normal forward flow for 45 minutes. The same procedure then occurs with citric acid. If metals were suspected to be the primary foulant, a citric acid cleaning would be performed in the same manner before the caustic/chlorine cleaning. The solution is drained to waste, and fresh filtrate (or other clean water) is circulated to rinse the system. Once the pH of the rinse is acceptable (matches the normal pH of the fresh filtrate water used for the rinse), the rinse is drained and the MF system is ready to resume operation.

2.2.4.1 Chemical and Raw Material Usage

Clean-in-Place procedures are typically performed once every two to three months when the module is new depending on feed water quality. For each chemical cleaning the following materials are required:

- 60 gallons (240 L) of DI, RO, NF, softened, or distilled water, preferably heated to about 100 °F (40 °C). High purity water is preferred to avoid unintentional reactions. Cleanings during the verification testing were performed with tap water because this was deemed appropriate for this application.
- 100 ml of 12.5% Sodium Hypochlorite.
- 340 ml of 50% Sodium Hydroxide.

- 2.5 LB (1.1 Kg) of dry citric acid.

No other chemicals or raw materials are used for the filter unit.

2.2.5 Operation Limitations

Microfiltration has excellent performance records for the mechanical removal of particulates and turbidity. The primary limitation of the technique is its inability to remove or treat dissolved species. Microfiltration, due to the average pore size of the membranes, is not effective at removing dissolved trihalomethane precursors. It is capable of treating water with relatively high turbidity levels, however high turbidity levels shorten the run times between cleaning, with corresponding higher operating costs. Microfiltration is not regarded as a highly effective removal mechanism for viruses. The viruses are removed by filtering through smaller pores of the membrane, and those pores over which particle cake has formed.

In a MF system, the life of the filter may be limited by fracturing of the membrane fibers. When the fibers break, short-circuiting of flow occurs, and the filter module exhibits a particulate break-through. A significant, abrupt change in the particles observed in the filtrate line might be an indication that there is a fiber break. The air integrity test that is performed on start-up of a membrane system is designed to verify initial membrane integrity. The life of the hollow-tube fibers is dependent on the feed water quality. High levels of turbidity and particulates will require more frequent cleaning. The more frequent use of the air scrubbing technique reduces the expected life of the fibers.

2.2.6 Performance Range

The unit tested is rated for 4 gpm, or a flux rate of 120 GFD. The maximum operating pressure differential is 30 psi. In a previous ETV study, this particular unit was tested in February and March 1999 as a package plant to treat water from the Pittsburgh, Pennsylvania Highland Reservoir No. 1. The testing was performed according to ETV protocols. Treatment performance during this testing included influent water with 0.1 NTU and results of the study indicated a 6 $\log_{10}$ reduction in *Cryptosporidium* oocysts. The feed water for the Pittsburgh study was very clean, with source water turbidity in the range of 0.1-0.14 NTU, no coliform bacteria, TDS of 200 ppm, and TOC at 2-2.5 ppm.

The testing of this unit for this ETV project was performed in New Hampshire, with different water quality parameters, as discussed in Section 1.3.1. The manufacturer reports Pall Microza™ systems have successfully treated waters with 40-50 NTU turbidity levels. However, turbidity levels this high did not occur during the verification test and therefore, could not be verified.

Typical MF filtration performance compiled from P.L. Dwyer (1996) for microbiological challenges on various hollow-fiber MF filter units using distilled water is described in Table 2-1.

Table 2-1. Typical MF filter performance

Parameter Removals	
Cryptosporidium	>4.9 $\log_{10}$
E. coli	>7.8 $\log_{10}$
Turbidity to less than 0.1 NTU	

2.2.7 Operator Skill/Licensing Requirements

The system requires a degree of specialized training, which is typically provided by the manufacturer prior to signing over a new filter unit. Technical support is also available from the manufacturer. Operators are also trained in the special handling requirements for safe use of the chemicals required for cleaning. The manufacturer has complied specific safety guidelines for the operation of this unit. Special licensing is not required to operate this piece of equipment.

2.2.8 Application of Equipment

This MF filter unit is portable, and operates at a relatively low flow rate. As such, when combined with storage, it is well suited for applications of low demand, such as a campground, school, small community, industrial processes, or small commercial operations. It is also used as a package unit for larger industrial and municipal applications. The results from testing this MF filter unit are expected to be applicable to larger MF filter units with multiple modules.

Chapter 3
Methods and Procedures

The objectives of the verification testing were met through nine-tasks involving the evaluation of membrane flux and recovery, the cleaning efficiency of the membranes, the water quality of the filtrate, the membrane pore size distribution reporting by the manufacturer, and the membrane module integrity. Data management and QA/QC are included in the list of tasks. The eighth task was the microbiological challenges. The final task involved the evaluation of the Pall Corporation O&M manual for this unit. The nine tasks were developed to be performed during test runs lasting one complete cleaning cycle, or a minimum of 30 days for each verification test period.

3.1 Start-up Testing

Initial testing included set-up and trial runs to establish the optimal settings for the filter unit, including RF and AS cleaning cycle frequency, duration, and flow rate. The initial testing was also the period used to make final adjustments in the field set-up and operational procedures.

Water quality parameters were monitored during the initial testing phase. The parameters monitored included pH, temperature, particle counts, and turbidity. Temperature, turbidity and particle counts were measured on a continuous basis using in-line sensors and/or flow cells for sensor probes. The data were collected using the SCADA system, or an external laptop computer to log the data. The computer also provided real-time monitoring of the following filter operational parameters: flows and pressures. Where appropriate, periodic samples were collected of both feed water and filtrate, and were analyzed for microbiological contaminants, including *E. coli* and *Bacillus* spores.

3.2 Verification Testing

The verification testing task marks the second phase of testing in which filter runs were performed and monitored on feed water sources designed to demonstrate the capability of the filter unit according to the manufacturer's guidelines. The verification testing was designed for continuous monitoring and testing of the filter equipment under routine operating conditions for a complete cleaning cycle or of 30 continuous days of operation.

3.3 Verification Testing Schedule

The verification testing period occurred from April 30, 2000 to July 26, 2000. An additional microbial seeding challenge occurred on August 9, 2000.

3.4 Verification Testing Tasks

The following is a description of each of the nine verification tasks.

3.4.1 Task 1: Membrane Flux and Operation

The purpose of Task 1 was to quantify operational characteristics of the MF equipment under the particular feed water quality at the field test site. The specific operational characteristics evaluated under this task include the membrane flux rates, the rate of decline of the flux rate, and the product water recoveries. The rate of flux decline provided an indication of the run duration before cleaning is required. Data was collected on the flow and pressure differential across the filter module over the period of flux decline.

The following were the experimental objectives of this task:

1. Establish the appropriate operational conditions for the membrane equipment for the field site feed water quality,
2. Establish the product water recovery for the MF unit,
3. Establish the rate of flux decline over a period of extended operation.

The feed water quality was also established, and monitored throughout the filter run.

The 3-inch Test Skid MF unit was operated according the manufacturer's membrane system operation manual until a complete cleaning cycle was required. A copy of the specific operating instructions from the operation manual is presented in Appendix A. The filter was operated with the frequency of RF and AS cleaning determined during the first phase initial testing. The criteria for terminating a filter run and performing a CIP cleaning procedure was when the other methods, RF and AS, could not adequately restore the system to the normal transmembrane pressure and the transmembrane pressure reaches approximately 30 psi.

Operational data was monitored on a continuous basis during the test run. The parameters monitored included the filtrate flow rate, RF flow rate, product water recovery, filtrate flux, transmembrane pressure, feed water temperature, and power consumption. The majority of these parameters were monitored electronically by the system control interface (SCADA system). Operational parameters that were not monitored by the SCADA system were monitored by using laptop computers. Data was downloaded every 2 minutes or every 10 minutes during the test period.

The data collected for each of the monitored parameters was incorporated into a spreadsheet. Time record histories are presented graphically for the transmembrane pressure, feed water temperature, filtrate flux, and power consumption.

The filtrate flux was computed according to:

(1) $$J_t = \frac{Q_p}{S}$$

where: J_t = filtrate flux at time t (gfd, L/(h-m2))
Q_p = filtrate flow (gpd, L/H)
S = membrane surface area

Filtrate flux results are reported with indication of the time interval after initiation of the experimental test run. The filtrate flux is corrected for the feed water temperature by the following:

(2) $$J_t(@\,20°C) = \frac{Q_p \times e^{-0.0239(T-20°C)}}{S}$$

where: Jt = instantaneous flux (gfd, L/(h-m2))
QP = filtrate flow (gpd, L/h)
T = temperature, (°C)
S = membrane surface area (ft2, m2)

The transmembrane pressure is calculated by the following:

(3) $$P_{TM} = \frac{P_I \times P_o}{2} - P_p$$

P_I = Pressure Inside Membrane
P_o = Pressure Outside Membrane
P_p = Filtrate Pressure

Data pertaining to the cleaning process, frequency, amount used of each chemical as well as clean water usage, is presented in tabular format. In addition, data is graphically presented for the temperature corrected specific flux rate, transmembrane pressure, and feed water temperature.

The term specific flux is used to refer to filtrate flux that has been normalized for the transmembrane pressure. The specific flux is calculated by the following:

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

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)

The recovery of filtrate from feedwater is given as the ratio of filtrate flow to feedwater flow as in the following equation:

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

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

3.4.2 Task 2: Cleaning Efficiency

The objective of this task is to evaluate the effectiveness of the manufacturer's specific chemical cleaning procedures in restoring the finished water productivity to the membrane system. Chemical cleaning is an integral element of the operation and maintenance of a MF membrane system. The Pall Corporation 3-inch Microza™ filter system was run until the transmembrane pressure reached 30 psi. This occurred at intervals of between 8 hours and 3 days. The membrane was unable to reach the 30-day cleaning cycle due to the presence of algae in the feed water and was cleaned four times during testing. Please refer to Phytoplankton Analysis data in section 4.4.3.

Since the cleaning solutions selected can be water quality specific, the feed water quality was measured at the time of cleaning. The initial testing evaluated the effectiveness of several cleaning solutions prior to the verification test run. The following procedure was used to perform a chemical CIP procedure on the test filter unit.

CIP materials and procedural guidelines are as follows:

Materials required:

- 60 gallons (240 L) of DI, RO, NF, softened, or distilled water, preferably heated to about 100 °F (40 °C). High purity water is preferred to avoid unintentional reactions. Cleanings during the verification testing were performed with tap water because this was deemed appropriate for this application.
- 100 ml of 12.5% Sodium Hypochlorite.
- 340 ml of 50% Sodium Hydroxide.
- 2.5 LB (1.1 Kg) of dry citric acid.

Note that the sequence of chemicals can be reversed depending on the water chemistry. For instance, if metals are present in the water in large quantities, the acid step is usually performed first.

Recommended Procedure:
Although a form of this procedure is contained in the O&M manual, this procedure is specific to the unit.

1. The feed connection can be disconnected to isolate the system, if required. If the normal drainage system cannot accept small amounts of high and low pH water, as well as free chlorine content of up to 200 ppm, alternate provisions for gravity drainage of this liquid must be made.
2. Put the system in Manual Mode, and drain completely. Close all valves.
3. Add 15 gallons (60 L) of water to the feed tank.
4. Open HV14 (Filtrate Recycle). Start the Feed Pump and adjust speed until flow through FT1 (Flow Transmitter 1, Feed) is about 50% of normal forward flow. Adjust HV5 (Excess Recirculation adjustment valve) so that the filtrate flow through FT2 (Flow Transmitter 2, Filtrate) is about two thirds of the flow through FT1.
5. Add first step chemicals. The caustic/chlorine step is usually first. If so, add the sodium hydroxide and sodium hypochlorite to the feed tank. The amounts listed above should give a 0.2N solution of sodium hydroxide, and 200 ppm of chlorine.

6. After 5 minutes, check the pH and free chlorine content of the water, if possible. pH should be 11.5 - 12.5. Free chlorine should be at least 50 ppm. If the measured values are too low, adjust as required.
7. Circulate for 30 minutes, then drain the system.
8. Fill the feed tank with 15 gallons (60 L) of water, and circulate for 5 minutes. Drain.
9. Fill the feed tank with 15 gallons (60 L) of water, and add the second chemical, typically the citric acid (to give a 2% w/w solution). Circulate for 30 minutes. Drain.
10. Fill the feed tank with 15 gallons (60 L) of water, and circulate for 5 minutes. Check pH, then drain.
11. If pH in Step 10 is acceptable, the system can be put back in operation. Otherwise, repeat rinse with feed water as required.

During the cleaning process the following parameters were documented in a water resistant logbook:

- cleaning chemicals used and their respective order of usage;
- quantities of cleaning chemicals used;
- hydraulic conditions of cleaning;
- duration of each cleaning step;
- initial and final temperatures of chemical cleaning solution; and
- quantity and pH of residual waste volume to be disposed.

Once the system was cleaned, it was put back on line, and the operational characteristics following the cleaning process were monitored. The operational characteristics monitored included the filtrate flux, transmembrane pressure, and the rejection capabilities of the filter unit. In addition to the operational parameters, selected water quality parameters were monitored before, during, and after cleaning. The pH, turbidity and TDS of each cleaning solution were measured by the SCADA system and by sampling from the effluent periodically during the cleaning process according to the schedule presented in Table 3-1. In addition, the concentration of chlorine was measured in the filtrate water prior to cleaning, and again immediately following the cleaning procedure. Physical observations of the water effluent, such as color, or visible turbidity were noted in the logbook at the time of observation.

Table 3-1. Analytical and Operational Data Collection Schedule

Parameter	Frequency
pH of cleaning solution initial	1/episode
pH of cleaning solution during process	1/episode
pH of cleaning solution final	1/episode
TDS of cleaning solution initial	1/episode
TDS of cleaning solution during process	1/episode
TDS of cleaning solution final	1/episode
Turbidity of cleaning solution initial	1/episode
Turbidity of cleaning solution during process	1/episode
Turbidity of cleaning solution final	1/episode
Oxidant residual initial (if used)	1/episode
Oxidant residual final (if used)	1/episode
Visual observation of backwash waste initial	1/episode
Visual observation of backwash waste final	1/episode
Flow of MF unit prior to cleaning	1/episode
Pressure of MF unit prior to cleaning	1/episode
Temperature of MF unit prior to cleaning	1/episode
Flow of MF unit after cleaning	1/episode
Pressure of MF unit after cleaning	1/episode
Temperature of MF unit after cleaning	1/episode

The information gathered during the Task 2 activities was entered into a spreadsheet. The efficacy of chemical cleaning was evaluated by the recovery of specific flux after chemical cleaning, calculated according to the following equation:

(3) $$\text{recovery of specific flux} = 100 \text{ x} \left[1 - \frac{J_{sf}}{J_{si}} \right]$$

where: Jsf = Specific flux (gfd/psi, L/(h-m2)/bar) at end of current run (final)
Jsi = Specific flux (gfd/psi, L/(h-m2)/bar) at beginning of subsequent run (initial).

Comparisons were made of the recovery of specific flux and the initial specific flux (Jsi) measured for the subsequent filtration run with the recoveries and initial specific flux from previous or historic cleaning for the same filter unit, to evaluate the potential for irreversible loss of specific flux and projections for usable membrane life.

In addition to the specific flux recovery, the loss of specific flux from the beginning of testing was computed by the following equation:

(4) $$\text{Loss} = 100 \text{ x} \left[1 - \frac{J_{si}}{J_{si0}} \right]$$

where: Jsi0 = Specific flux (gfd/psi, L/(h-m2)/bar) at the time zero point of membrane testing

3.4.3 Task 3: Finished Water Quality

Water quality data was collected for the feed water and membrane filtrate water, as shown in the sampling schedule below, during the membrane test runs of Task 1. The filter unit was operated until the transmembrane pressure reached 30 psi. At this point the filter unit was shut down and the membrane was chemically cleaned. The terminal conditions were defined by the manufacturer in the operation manual.

Water quality parameters were monitored during the filter run. Both the feed water and the filtered water was tested for the following parameters:

- total alkalinity, once per month
- hardness, once per month
- total organic carbon (TOC), weekly
- dissolved organic carbon (DOC), weekly
- total dissolved solids (TDS), every two weeks
- total suspended solids (TSS), every two weeks
- iron, every two weeks
- manganese, every two weeks
- color, weekly
- total coliform bacteria, weekly
- *Bacillus* spores, twice during test period
- algae, weekly
- UV254 absorbance, weekly
- dissolved oxygen, daily
- temperature, continuous basis
- pH, twice per week
- turbidity, continuous basis
- particle counts, continuous basis.

Task 3 evaluated the rejection effectiveness of the filter and addressed the primary objective set out for the verification testing. The goal of this portion of the ETV was to demonstrate the unit's ability to produce water that would comply with current regulations in the Surface Water Treatment Rule (SWTR) and Enhanced Surface Water Treatment Rule (ESWTR).

Temperature of the feed water was measured using in-line sensors and/or flow cells for sensor probes. Data for temperature, flow rate, turbidity, particle counts and transmembrane pressure were collected using either the SCADA system provided with the unit, or a separate laptop computer. Turbidity measurements were recorded with two in-line turbidimeters, one in the feed water line, and one to measure the filtered water. In-line turbidity measurements were checked with a bench top meter on a daily basis. Particle counts were made on a continuous basis for the feed water and filtered water using in-line particle counters. The dissolved oxygen was measured on a daily basis. The pH was measured at least twice per week.

Samples for total alkalinity and total hardness were collected once during the cleaning cycle or 30 day period, in the middle of the filter run. TDS and TSS were collected every two weeks during the filter run. The results of the TSS analyses constructed a mass balance of suspended

solids through the membrane system. Samples for the remaining parameters were collected on a weekly basis during the filter runs.

Total coliform sampling was performed on a weekly basis and samples for indigenous *Bacillus* spores were collected two times during the test. The bacteria samples were collected from a tap, on both sides of the filter unit, that was sterilized with Clorox bleach. The samples were then immediately preserved with 0.008% Na2S2O3 and by placing them in coolers with ice. The samples were delivered to the laboratory within 24 hours of sampling. The total coliform bacteria counts and *Bacillus* spore analyses were performed by the UNH Water Treatment Technology Center laboratories.

Samples for algae analysis were collected on a weekly basis (or daily if an algae bloom occurs), preserved with Lugol's solution according to *Standard Method* 10200B, and placed in a cooler at 4° C for transport to the laboratory within 24 hours. Parameters that have holding times greater than 24 hours were transported to the laboratory in coolers at 4°C within a 24-hr period as well. Total organic carbon and UV Absorbance at 254 nm were analyzed by the UNH Water Treatment Technology Center laboratories.

Operating conditions and operation resources were recorded on a regular or continuous basis throughout each filter test run. The operating conditions included the flow rate, transmembrane pressure, number of cleanings, flow rate through the filter, total gallons filtered, filtrate flux, power consumption, and operator hours. The terminal conditions used to halt a filter run were also recorded for chemical cleaning operations performed during the testing period. Operation parameters during cleaning were also recorded in a logbook.

Filter cleaning operations performed during the test runs were fully documented as to the operating conditions at the time of the decision to clean the filter, the times for cleaning, and the time that the filter unit was brought back on-line. This data was available from the filter unit SCADA system for the RF and AS cleaning. Similar records were recorded in the logbook for CIP chemical cleanings. Records were kept on the chemical and clean water usage and clean water. Records were kept in a field book, and transcribed to an Excel spreadsheet, where the data was analyzed and presented in tabular and graphical form. Logs were also kept of operator hours and activities, to evaluate the number of man-hours required to operate the system, as well as establish the level of skill required.

A daily log was maintained of hydrologic, and unusual, events within the feed water watershed during the verification testing filter runs. The criteria for recording events were if the event had a potential effect on the feed water quality during the test runs. Hydrologic events such as rainfall, snowmelt, temperature fluctuations, flood events, etc. were noted. Anthropogenic activities which changed the source water quality were recorded and placed in the files.

3.4.4 Task 4: Reporting of Maximum Membrane Pore Size

Manufacturers typically report an average pore size for their membrane systems. Membranes have a distribution of pore sizes, which is represented by the mean value. The maximum pore size in the distribution, however, has significance with respect to the maximum size particles that

are physically able to pass through the membrane. Quantifying the pore size distribution is necessary to assess the potential for the membrane to remove microorganisms of particular size.

The objective of this task was to report the maximum membrane pore size, and the 90% membrane pore size. The Manufacturer was contacted to provide pore size distribution test results.

3.4.5 Task 5: Membrane Integrity Testing

The objective of this task was to demonstrate that the membrane integrity was maintained throughout the test. The membrane was monitored to evaluate whether the integrity of the membrane had been compromised during the testing program. Compromises in the case of the Pall Corporation Microza™ hollow-tube membrane system are defined as broken membrane fibers. When the fibers break, water can enter the open end of the hollow tube, which has a much larger diameter than the maximum pore size of the filter, and consequently microorganisms would be able to pass through the filter module.

The membrane integrity was evaluated by both an indirect and a direct method. The indirect method was the continuous measurement of particle counts with an in-line particle counter in both the feed and filtered water line. An increase in the particle counts for the filtered water following a cleaning event may be indicative of broken membrane fibers.

The direct method of evaluating the membrane integrity was performed by the air pressure-hold test, where 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. Integrity testing was performed as per manufacturer's specification after each membrane chemical cleaning. The test involved fully wetting the membrane, draining the water from the membrane cartridge, opening the filtrate lines to the air and applying 20 psi of compressed air to the feed water side of the membrane. Less than a loss of 1 psi of air pressure over a 5-minute time period indicated a successful air integrity test. The time was measured with a stopwatch and the pressure gauge was monitored visually at one-minute intervals.

3.4.6 Task 6: Data Management and Reporting Protocols

Data collection of most of the operating parameters was performed using either the SCADA system of the filter unit, or a laptop computer in conjunction with an analog-to-digital converter. Data was collected and organized into text files using a custom Visual Basic program. The text files were formatted so that they are readily imported into Microsoft Excel spreadsheets or Microsoft Access data files.

The operational data collected in this manner included the transmembrane pressure; filter flow rate; specific flux, and time of operation. In addition, water quality data were also collected on a continuous basis. Temperature and turbidity were recorded at regular intervals throughout the test using flow through cells with appropriate probes and meters coupled to the data logger. Particle counts from the in-line particle counters were also monitored on a continual basis

throughout the tests. The data logging programs wrote data to external files on the hard drive, and a copy of the data files were made to a floppy disk for back-up.

Real-time operational measurements were recorded manually and logged in a dedicated logbook containing water resistant rag-content paper (Appendix B). Photocopies were made of each day's data entry in the logbook at the end of each day, signed, dated, and placed in the equipment testing files. The logbook remained at the test site in a secure location during the testing period. Data entry logs included the name of the technician, date and time of entries, and notations on hydrologic conditions for that day. Parameters that were recorded manually included power consumption rate, cumulative power consumed, chemical cleaning times, chemicals and consumption, clean water and consumption, duration of filter cleaning, operator's hours and tasks, and sampling data. Sampling data included the date and time of grab sample collection, samplers, number and size of sample containers filled, preservatives used, and analyses to be performed. Unusual events or problems that occurred during the sampling or operation of the filter were noted in the logbook.

The data collected in the logbook was entered into an Excel spreadsheet or an Assess Database file on a daily basis, thus providing for real-time analyses of the operational data. A hard copy of the data entry was generated following each day's data entry, and was checked against the originals for errors. Data errors were noted on the hard copy, and corrected in the database. Hard copies were then made of the corrected spreadsheet or database file, and rechecked.

Water quality samples collected during the testing period were recorded into the logbook, and also recorded onto a chain-of-custody form. This form subsequently accompanied the samples to their final destination, typically the laboratory. Possession changes were documented on the chain-of-custody form. Following the analysis of each sample, a copy of the chain-of-custody form was maintained in the project files. Each filter run was designated with an unique identification number, which was written on each sample container. The identification number was used in the laboratory to maintain continuity, and to keep track of the analyses results.

3.4.7 Task 7: QA/QC Plan

This Quality Assurance/Quality Control Plan describes the procedures that the UNH WTTC and ASI took to assure the quality of information collected for the verification test. Quality Assurance (QA) is a set of planned and systematic actions to ensure that data collected during the investigation were valid, sound, and retrievable. QA helps to avoid data omissions and oversights. These measures are essential in optimizing the usefulness of the data and ultimately in generating accurate conclusions from the data. When specific items of equipment or instruments were used, the objective of QA/QC procedures were to maintain the operation of the equipment or instruments with the ranges specified by the Manufacturer or by *Standard Methods*.

3.4.7.1 Overall Project Quality Objectives

Data Quality Objectives (DQO) were quantitative and qualitative statements specifying the quality of the environmental data required to achieve the objectives of the FOD. DQO define the

confidence level of the data that is acceptable for each specific activity during the investigation with regard to both sampling error and analytical error.

Ideally, a confidence level of 100% was the goal; however, the variables associated with the processes (field and laboratory) inherently contribute to reducing this confidence level. In order to achieve the DQO, specific data quality requirements such as criteria for accuracy and precision, sample representatives, data comparability and data completeness were specified.

The quality indicators used in this program are precision, accuracy, representativeness, completeness, and comparability (PARCC). The definitions are as follows:

> Precision - a measure of the reproducibility of measurements under a given set of conditions. This measurement is calculated by either Relative Percent Difference (RPD) or Relative Standard Deviation (RSD).
> Accuracy - a measure of how close the data come to the true value. Accuracy measures the amount of bias present in the measurement system.
> Representativeness - the degree to which data accurately and precisely represent selected characteristics of the media sampled.
> Completeness - the amount of valid data obtained compared to the amount that was expected under "normal" conditions.
> Comparability - an expression of confidence with which one data set can be compared with another.

3.4.7.2 Field Investigation Quality Objectives

The objectives with respect to the field investigation were to maximize the confidence in the data in terms of PARCC. Field duplicates and field blanks were collected to measure precision and accuracy. The data quality objective for field duplicates is to achieve precision consistent with the Laboratory Duplicate Precision required in EPA's Certification Laboratory Program (CLP). Precision was calculated as Relative Percent Difference (RPD) if there were only two (2) analytical points and Relative Standard Deviation (RSD) if there were more than two (2) analytical points.

Submission of field and method blanks checked accuracy. Submission of blanks monitored errors associated with the sampling process, field contamination, sample presentation, and sample handling. The data quality objective for field blanks met or exceed those criteria established in the EPA's CLP. In the event that the blanks were contaminated and/or poor precision is obtained the associated data was qualified. Through the submission of field QC samples the distinction was made between laboratory problems, sampling technique, and sample matrix variability.

The data quality objective for the completeness of data with respect to the sampling (field investigation) was that data be within an appropriate confidence level. Efforts were made to obtain valid data for sampling points, particularly those sampling points classified as critical points. Critical-point samples were selected as subsequent QC samples (duplicate and matrix spikes).

In order to establish a degree of comparability such that observations and conclusions could be directly compared with historical data, standardized methods of field analysis, sample collection, holding times, and sample preservation were used. In addition, field conditions were considered prior to sampling, in order to attain a high degree of data comparability.

3.4.7.3 Laboratory Quality Objectives

The laboratory demonstrated analytical precision and accuracy, through analysis of laboratory duplicates and matrix spike duplicates. Laboratory accuracy was demonstrated by the addition of surrogate and matrix spikes. Accuracy was measured by percent recovery. The percent recovery for the matrix spikes was calculated according to:

(5) $$\%\text{Recovery} = 100 \times \frac{(SSR - SR)}{SA}$$

where:

SSR = spiked sample results,
SR = sample result,
SA = spike amount added.

Laboratory blanks and controls were used to determine accuracy. The percent recovery for laboratory control samples were calculated by the following:

(6) $$\%\text{Recovery} = \frac{Measured\_Concentration}{True\_Concentration}$$

Precision was presented as RPD and RSD, whichever is applicable to the specific type of QC sample. The RSD was calculated by the following:

(7) $$\%\text{Relative Standard Deviation} = 100 \times \frac{S}{\overline{X}}$$

where:

S = standard deviation
$\overline{X}$ = arithmetic mean of the recovery values.

The standard deviation is given by:

(8) $$S = \sqrt{\frac{\left(X_i - \overline{X}\right)^2}{n-1}}$$

where: Xi = individual recovery values,
n= number of determinations.

3.4.7.4 Criteria

The laboratory was expected (as an ideal objective) to achieve EPA approved practical quantitation limits (PQL) for samples analyzed. However, it should be noted that actual detection limits are sample-specific and depend on variables such as dilution factors, sample matrices and the specific analyte. The handling of data reported at, or near, the PQL was done cautiously, since the stated data-quality objectives for accuracy and precision may not translate well in certain cases.

3.4.7.5 Control of Procedures

Procedures used in this investigation were assessed for correctness prior to their implementation. These procedures, including sampling techniques, analytical techniques, data compilation, data analysis, and data reporting, were in accordance with accepted professional standards and methods. The Project Director approved analytical procedures prior to their implementation. To verify the correct application of procedures, work described in the FOD was documented to provide a paper trail from data collection to the reporting stages of the project. Changes to the proposed procedures were approved by the Project Director. The Project Director insured that updated procedures were distributed to appropriate personnel.

3.4.7.6 Chain-of-Custody

The primary objective of the Chain-of-Custody procedure is to create an accurate written record that can be used to trace the possession and handling of samples collected. Chain-of-Custody started in the laboratory with the bottles the laboratory provided for sampling. It followed those containers through sample collection, analysis, and up to their final disposition. Sample custody during the sampling phase of this project was maintained by the samplers, who were responsible for documenting each sample transfer and maintaining custody of the samples until they were relinquished to the laboratory personnel. Chain-of-Custody forms from the testing are provided in the appropriate appendices.

3.4.7.7 Documentation

During the sampling process information was recorded on the Chain-of-Custody form, sampling data sheet, and in the field notebook.

> Chain-of-Custody - The Chain-of-Custody was used for tracking the sample through phases of handling.
>
> Field Logbook - The logbook was used to record operational, maintenance, and hydrologic data. Entries were recorded documenting each sampling event, the conditions at the time of sampling, and the personnel making the measurements. The logbook was also used to document necessary or appropriate deviations from standard sampling methodology.

3.4.7.8 QC Samples

To obtain a quantitative measure of the reproducibility of the sampling and analysis results, QC samples were collected or supplied. QC samples included trip blanks, field blanks, duplicates, triplicates, and matrix spikes. Table 3-2 presents the QA/QC criteria objectives.

Trip (Travel) Blank

A Trip Blank was provided by the laboratory and accompanied the sample containers throughout the collection activity. One trip blank accompanied each sample shipment or cooler of samples and was not opened until analysis.

Field Blank

A Field Blank consists of a sample of deionized water (supplied by the laboratory) that has been put through the decontaminated sample-collection equipment and into sample bottles. One Field Blank was collected for each day of sampling.

Duplicate Sample

A Duplicate Sample was collected in a manner that produces two samples with a high degree of homogeneity. Samples were collected from the same collection container. If a large quantity of water was needed for a number of analyses then each collection was among a pair of sample bottles. Duplicate samples were collected during the verification testing. One set of duplicate samples was collected during each microbiological challenge. The duplicate sample was given a fictitious number so that the laboratory did not know it was a duplicate sample, and was sent to the laboratory as a "blind" duplicate.

Sample Spikes and Performance Evaluation Samples

Spikes for microbiological analyses were prepared by the laboratory, with a frequency of one per week, or one per every 10 samples analyzed. The spikes were used by the laboratory to evaluate the accuracy of the analytical instruments. A performance evaluation sample for turbidity was analyzed just prior to the start of each verification testing run, as part of an on-site QA evaluation of turbidity measurement techniques.

Triplicate Sample

For every 10 samples collected, one sample was collected in triplicate to be used for the laboratory's QC testing. Triplicates were collected in the same manner as the Duplicate Samples.

Method Blanks

Laboratory-grade Milli-Q water was used for method blanks, to evaluate the baseline of the analytical instrument. A method blank was collected for every ten samples analyzed. It provided the means to evaluate interference from the sample bottle and sample preparation methodology. If measurable quantities were reported in the method blank, all containers were cleaned again, or the laboratory methods modified until subsequent method blanks contain no significant concentrations.

Table 3-2. QA/QC Criteria Objectives

QA/QC Parameter	Sample Type	Objective for Aqueous Samples
Precision	Duplicates/Replicates (Blind or Labeled)	Less than 15% RPD
	Laboratory Duplicates (Unspiked)	Less than 15% RPD
	Laboratory Duplicate (Matrix Spike Duplicate)	Consistent with current EPA CLP
Accuracy	Field or Trip blanks	Less than the PQL
	Laboratory blanks	Consistent with current EPA CLP

3.4.7.9 Identification of Samples

An identification number was assigned to each sample as soon as it was obtained. The number was unique to each sample. The number was written on the sample label and recorded on the Chain-of-Custody form. If the sample was subdivided, each subsample was assigned its own identification number, which retains each subsample's association with the original sample. Additional information written on the label included time and date of sample, sampler's initials, preservatives used, test site identification, and parameters analyzed.

3.4.7.10 Handling

Samples were handled in a way that does not adversely affect their future use. Containers were free of foreign substances, particularly any substance which would have changed the sample or interfere with required analyses and tests. The laboratory provided containers of appropriate size and material for each type of analysis. The samples were fixed with the appropriate preservative. Samples analyzed were stored in a manner which prevented changes in temperature and which protected the sample from breakage. In the field, samples were kept in iced coolers with an internal temperature sufficient to maintain the integrity of the sample. Each sample container was placed in a plastic bag and sealed to prevent cross contamination with other samples.

Samples not sent to the laboratory on the day of collection were placed in a controlled refrigerated storage unit on the site, which provided protection against damage or loss until samples were sent to the laboratory. Samples placed in this storage overnight included samples for TOC, UV, iron, and manganese. Temperature of this storage unit was not monitored. It is possible that this storage unit may have adversely affected results of the TOC and UV samples, if the unit was not maintained at an appropriate temperature.

3.4.7.11 Sample Transport

Samples were packed to prevent breakage and ice packs were used to maintain an internal temperature sufficient to protect the integrity of the samples. The Chain-of-Custody accompanied the samples from the time of collection until they were received by the laboratory. Each party handling the samples were required to sign the Chain-of-Custody signifying receipt. A copy of the completed form was provided by the laboratory along with their report of results.

3.4.7.12 Calibration of Field Instruments

Field instruments were used to measure parameters of temperature, pH, dissolved oxygen, particle counts, and turbidity. Several of these parameters were measured on a continuous basis using flow-through cells and in-line probes. Separate probes were calibrated and used to spot check the in-line instrument calibration. For example, a bench-top turbidimeter was used to check the calibration of the in-line turbidimeters.

A log was kept of the calibration check activities by the field personnel. It included the date of the calibration check, concentration of the check standard, the reading obtained, whether it was reset, the reading after resetting, and the initials of the person doing the calibration check.

3.4.7.12.1 General Field Equipment Verification

Quality Assurance verifications were performed on the measurement devices on the filter unit itself, and also on the instrumentation used to characterize the feed water and filtered water. The equipment on the filter unit itself requiring calibration included the flow meter, tank level sensors, in-line turbidimeters, and temperature sensors.

The flow through the filter was monitored by in-line flow meters coupled to a data logger. The feed and filtered water flow meter flowrates were verified volumetrically at the beginning of testing using a bucket-and-stop-watch technique.

The pressure gages used to measure the pressure head differential were calibrated prior to the test. Pressure differential was measured on a continuous basis using pressure transducers. The calibration curve of the transducers was established prior to testing, and was rechecked before each verification testing run. Daily readings were made of pressure gages, recorded in the logbook, and compared to the data logger readout as a check on the performance of the transducers. If a significant discrepancy was noted, the manual reading frequency of the gages were increased, and the data validity of each evaluated by the end-of-run recalibrations.

All tubing and piping was inspected for both the filter unit and the flow-through cells used for continuous field parameter measurement. The tubing was inspected prior to the test for excess sediment build-up, and cracking. Leaks were fixed upon discovery.

3.4.7.12.2 Specific Equipment QA Verification

A routine daily walk-through during testing was established to verify that each piece of equipment or instrumentation was operating properly. Operational records were displayed on the SCADA system and checked for abnormalities. Daily readings of the in-line flow meter, and the pressure gages were taken, along with daily calibration checks of the in-line turbidimeters, and particle counters, and field parameter instruments. The individual calibration requirements for each instrument used in the testing are described below.

pH

Analyses for pH was performed according to *Standard Methods* 4500-H+. A 2 point calibration of the pH meter used in this study was performed once per day when the instrument was in use. Certified pH buffers in the expected range were used. The pH probe was stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. Measurement of pH was performed in a confined flow-through cell for a continuous record, which also minimized the effects of carbon dioxide loss to the atmosphere.

Temperature

Readings for temperature were conducted in accordance with *Standard Methods* 2550. Raw water temperatures were measured electronically on a continuous basis in a flow-through cell. The temperature meter had a precision of at least 0.1°C, and was calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST).

Dissolved Oxygen

Analysis for dissolved oxygen (D.O.) was performed according to *Standard Method* 4500-O using the membrane electrode method. The techniques described for sample collection was followed very carefully to avoid causing changes in dissolved oxygen during the sampling event. Samples taken for dissolved oxygen were analyzed immediately using the D.O. membrane-electrode probe.

Bench-top Turbidimeters

Turbidity analyses were performed according to *Standard Methods* 2130 with either a bench-top or in-line turbidimeter. In-line turbidimeters were used for measurement or turbidity in the filtrate water and feed water.

During each verification testing period, the bench-top turbidimeters remained on continuously. Once each turbidity measurement was completed, the bench-top unit was switched back to its lowest setting. Glassware for turbidity measurements were cleaned and handled using lint-free tissues to prevent scratching. Sample vials were stored inverted to prevent deposits from accumulating on the bottom surface of the cell.

Grab samples were collected daily for analysis using a bench-top turbidimeter. Readings from this instrument served as reference measurements throughout the study. The bench-top turbidimeter was calibrated within the expected range of sample measurements at the beginning of package plant operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards were obtained and checked against the primary standards. Secondary standards were used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range was used.

The method for collecting grab samples consisted of the following: running a slow, steady stream from the sample tap; triple-rinsing a dedicated sample beaker in this stream; allowing the sample to flow down the side of the beaker to minimize bubble entrainment; double-rinsing the sample vial with the sample; carefully pouring from the beaker down the side of the sample vial; wiping the sample vial clean; inserting the sample vial into the turbidimeter; and recording the measured turbidity. For the case of cold water samples that cause the vial to fog preventing accurate readings, the vial was allowed to warm up by partially submersing it into a warm water bath for approximately 30 seconds.

In-line Turbidimeters

In-line turbidimeters were used for feed water and filter water monitoring during verification testing and were calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It was necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis was not identical between the two instruments the readings were comparable. Should these readings suggest inaccurate readings then the in-line turbidimeters were recalibrated. In addition to calibration, periodic cleaning of the lens was conducted, using lint-free paper, to prevent particle or microbiological build-up that could produce inaccurate readings. Daily verification of the sample flow rate was performed using a volumetric measurement. The in-line turbidimeter flowrates were checked daily to verify that the flow was within the manufacturers recommended range of 250-750 mL/minute. Instrument bulbs were replaced on an as-needed basis. It was verified that the LED readout matched the data recorded on the data acquisition system.

In-line Particle Counters

In-line particle counters were employed for measurement of particle concentrations in both feed waters and filtrate waters. Laser light scattering or light blocking instruments were used in the verification testing.

The following particle size ranges (as recommended by the AWWARF Task Force) were monitored during the verification testing:

- 2-3 µm
- 3-5 µm
- 5-7 µm
- 7-10 µm
- 10-15 µm
- >15 µm

Problems experienced with the particle counting instrument were documented in the daily logbook. Modifications or remedial actions were also documented in the logbook. The flow through the particle counters was verified volumetrically on a daily basis and the flow was also checked so that the flow was within the manufacturer recommended limits of approximately 100 mL/minute ± 5%.

The use of particle counting to characterize feed water and filtered water quality was planned as one surrogate method for evaluation of microbiological contaminant removal, and was supported by analytical sampling results for *Cryptosporidium* (size range 2 to 5 micron). The particle sensor selected for this project was capable of measuring particles as small as 2 µm. Performance criteria included less than a ten percent coincidence error for any one measurement.

Calibration. Calibration of the particle counter was performed by the instrument manufacturer. The particle counters used during verification testing were Met One particles counters model # PCXCE155B. Both particle counters were manufactured in November 1999 and were factory calibrated by the manufacturer on November 17, 1999 according to the labels affixed to the particle counters. Field verification of the particle counter calibration was not performed according to the ETV Protocol; however the raw water particle counter measurements were compared to another Met One particle counter that was also simultaneously measuring the raw water particles. No significant deviation between the two particle counters was noted.

Maintenance. The need for routine cleaning of the sensor cell is typically indicated by: 1) illumination of the sensor's "cell" or "laser" lamps, 2) an increase in sampling time from measurement to measurement, or 3) an increase in particle counts from measurement to measurement. During the phase 1 initial testing, the sensor's "cell" and "laser" lamps and the sampling time were checked periodically.

3.4.7.13 Maintenance

Routine Preventive Maintenance (PM) was conducted on instruments used in the field. Maintenance was based on the recommendations of the instrument manufacturer and experience gained through use of the instrument in the field. A log of these activities was kept and detailed the PM performed, when it was performed, and the name of the person doing the work.

3.4.7.14 Laboratory QA/QC

The laboratory was responsible for timely analysis of the samples according to approved methods. The analysis report included the following:

- Method of analysis,
- Detection limits,
- Copy of the Chain-of-Custody,
- Analysis results of samples listed on the Chain-of-Custody,
- Analysis results of QA/QC samples,
- Documentation of analytical problems encountered and the corrective procedures taken to solve those problems.

3.4.7.15 Project Quality Assessment

3.4.7.15.1 Data Quality Assessment

Overall data quality was assessed by a thorough understanding of the Data Quality Objectives (DQOs) developed for the FOD.

3.4.7.15.1.1 Overall Project Assessment

The project data was closely monitored for accuracy, precision and completeness by:

1) Maintaining thorough documentation of all decisions made during each phase of sampling.

2) Field and Laboratory Audits

3) Thoroughly reviewing (validating) the analytical data as they were generated by the laboratory

4) Providing appropriate feedback as problems arose in the field or at the laboratory

3.4.7.15.1.2 Field Data Quality Assessment

To assure that field data were collected accurately and properly, the Project Director issued specific written instructions to personnel involved in field data acquisition. These instructions, in the form of a sampling and analysis plan, were written for each different type of sampling effort. The QA personnel performed field audit(s) during the investigation to document that the appropriate procedures were being followed with respect to sampling. These audits included a thorough review of the field books used by the project personnel to verify that tasks were performed as specified in the instructions. Evaluation of field blanks and other field QC samples provided indications of data quality. If a problem arose, corrective procedures were instituted for future field efforts.

3.4.7.15.1.3 Data Quality Assessment

A preliminary review was performed to verify necessary paperwork (Chain-of-Custody, analytical reports, laboratory personnel signatures) and deliverables. A detailed quality assurance review was performed by the QA personnel to verify the qualitative and quantitative reliability of the data as they were presented. This review included a detailed review and interpretation of data generated. The primary tools used included guidance documents, established (contractual) criteria, and professional judgment. Once the laboratory analytical data were validated, the data were assessed by comparison with analytical results obtained from previous samplings.

A quality assurance report was prepared for each testing event based upon the review of the analytical data. This report stated the qualitative and quantitative reliability of the analytical data. The report consisted of a general introduction section, followed by qualifying statements that were taken into consideration for the analytical results to best be utilized. During the course of the data review, a documentation package was prepared which provided the backup information, which accompanied qualifying statements presented in the quality assurance review.

Once the review had been completed, the QA personnel submitted the data to the Project Director. The approved data tables and quality assurance reviews were signed and dated by the QA personnel.

3.4.7.15.2 On-Site Audit

An on-site audit was conducted during field activities to review field-related quality-assurance activities. The audit was conducted by the QA personnel. This audit took the form of a checklist that assisted the QA personnel in checking the necessary quality-assurance details.

Specific elements of the on-site audit included the verification of the following:

- Completeness and accuracy of sample Chain-of-Custody forms, including documentation of times, dates, transaction descriptions, and signatures.
- Completeness and accuracy of sample identification labels, including notation of time, date, location, type of sample, person collecting sample, preservation method used, and type of testing required.
- Completeness and accuracy of field notebooks, including documentation of times, dates, sampling method used, sampling locations, number of samples taken, name of person collecting samples, types of samples, results of field measurements, and problems encountered during sampling.
- Adherence to sample collection, preparation, preservation, and storage procedures.

3.4.7.15.3 Corrective Procedures

Field quality assurance activities were reported to the Project Director. Problems encountered during the study affecting quality assurance were reported on a Corrective Procedures Form. The appropriate sampler was responsible for initiating the corrective procedures and for providing that action was taken in a timely manner, and that the desired results were produced. Corrective procedures that were implemented were reported to the Project Director.

3.4.7.16 Certification of UNH Laboratories

The UNH Environmental Engineering Laboratories are not State or EPA certified because of the nature of the educational mission of the University. However, the UNH FTO laboratories underwent internal and NSF QA audits as part of the testing protocol. Analytical procedures that were performed in the UNH Laboratories included TOC/DOC, UV254 absorbance, alkalinity,

and hardness. Microbiological analyses (*Cryptosporidium, E. coli,* and *Bacillus*) were performed by Analytical Services, Inc. (ASI) in Williston, VT. Analytical Services, Inc. are State certified and are teamed with UNH to perform *E. coli* and *Bacillus* spore analyses. Other parameters, e.g. turbidity, particle counts, temperature, pH, and D.O., were performed on site.

The results of the Quality Assurance/Quality Control Plan are included in the data attached in respective Appendices. Quantification of data precision and statistical uncertainty, the results of the field and control blanks, and other notes pertaining to this subject are provided in Appendix J. During the testing period, field blanks and control blanks showed expected results. Duplicate and triplicate samples that did not fall into statistical viability were discarded and the entire test was repeated.

3.4.8 Task 8: Microbial Removal Challenge

This task was designed to address the primary objective of the verification testing, to evaluate the removal of microorganisms *Cryptosporidium, E. coli, and Bacillus* spores. The Microza™ filter accomplishes this task through direct filtration through the hollow-tube membrane. Seeding of *Cryptosporidium* oocysts *E. coli* and *Bacillus* spores occurred on May 3, 2000, June 21, and August 9, 2000. The addition of seed microorganisms was performed immediately after chemical cleaning, and again at 85% of the terminal transmembrane pressure threshold of 30 psi.

Each challenge was performed as a batch-seeding test. Each microorganism used for challenge testing was seeded to a constant volume of feed water (between 200 and 275 gallons). Sufficient volume of stock suspension was created in the seeding tank to sustain membrane operation for a minimum of 30 minutes. For the protozoa seeding studies, the target final seeding concentration in the feed water tank was approximately 7 $\log_{10}$. For the *E. coli* and *Bacillus* spores seeding studies, the target final seeding concentration in the feed water tank was approximately high enough to demonstrate at least 3 $\log_{10}$ removal of *E. coli* and *Bacillus* spores.

The feed suspension of protozoa and bacteria was prepared in the seeding tank by adding the concentrated stock suspensions of organisms into an appropriate tank. This reservoir was connected to the feed water line of the filter. The water in the seed tank was completely mixed during preparation of the seeded feed water and throughout the filtration period. After the addition of protozoa and bacteria to the seeding tank and before the initiation of filtration, samples were collected to establish the initial concentration of the microorganisms. Once started, filtration continued as per normal operation, with transmembrane pressure, filtrate flux and recirculation rate (where appropriate) monitored by the SCADA system. Sample volumes of the feed water, filtrate water and backwash (RF) water were recorded. Filtrate water from the microbiological challenges was discharged to waste.

During the protozoa studies, a minimum of three replicates of the filtered water samples was prepared for analysis. Each sample was collected in sterile laboratory approved containers, stored in a refrigerated environment, and processed within 24 hours. *Cryptosporidium* samples were analyzed by ASI according to EPA Method 1622. *E. coli* and *Bacillus* spore samples were analyzed by UNH Laboratories according to Proposed Method 19 (ASTM 1994).

3.4.9 Task 9: Operation and Maintenance Manual Evaluation

The Operation and Maintenance (O&M) manual supplied by Pall Corporation for the Microza™ MF 3-inch filter unit was evaluated by UNH throughout the course of the initial testing and verification testing program. The 27 page document provided detailed information of the RF, AS and chemical cleaning procedures, as well as graphical guidance to the use of the SCADA system.

Chapter 4
Results and Discussion

4.1 Introduction

The testing of the Pall Corporation 3-inch Microza™ Microfiltration system was initiated on April 30, 2000 and ran intermittently due to stoppages for cleaning and other site related stoppages until July 26, 2000. Table 4-1 presents the filter run schedule. A total of thirteen filter runs were performed ranging from approximately 4 hours to 79 hours in length. The system module ran for a total of 436 hours during the test period. The longest period of consecutive run time occurred between June 11, 2000 and June 14, 2000. An additional microbial challenge employing *Cryptosporidium*, *E. coli*, and *Bacillus* spores was performed on August 9, 2000, and the operating conditions and results are discussed in Section 4.9.

Data was collected during the various phases of the testing procedure according to the methods and procedures outlined in Chapter 3. The data logbook is provided as Appendix B. The results of the verification test summarized in this chapter are presented according to the following tasks:

- Membrane Flux and Operation
- Cleaning Efficiency
- Finished Water Quality
- Reporting of Maximum Membrane Pore Size
- Membrane Integrity Testing
- Data Management
- Quality Assurance / Quality Control
- Microbiological Challenges
- Evaluation of O&M Manual

The verification testing process was initiated after a 5-day startup period where the flow rate, operating pressures, and cleaning regimen was established. During this startup period, it was determined that the target feed flow rate was 4 gpm with a 90% feed water recovery, and the Reverse Filtration and Air Scrub would cycle every 30 and 60 minutes, respectively.

4.2 Task 1: Membrane Flux and Operation

4.2.1 Operation

The system was a self contained unit that monitored feed temperature, feed and filtrate flow rates, feed and filtrate turbidity, and feed, filtrate and retentate pressures. Adjustments were made either by computer touch screen, or by manually turning valves to stabilize flow within the system. One full day with a system instructor was sufficient to initiate testing.

Table 4-1. Filter Run Schedule

Filter Run	Start	End	Length of Run (hours, minutes)	Cumulative Run Time (hours, minutes)	Reason for Run Termination
#1	4/30/00 12:50 pm	5/2/00 11:22 am	55 hours, 17 minutes	55 hours, 17 minutes	Compressor Failure
#2	5/3/00 2:40 pm	5/4/00 12:42 pm	22 hours, 2 minutes	77 hours, 19 minutes	Water shut off at plant
#3	5/9/00 5:22 pm	5/12/00 2:41 pm	68 hours, 57 minutes	146 hours, 16 minutes	Water shut off at plant
#4	5/18/00 2:27 pm	5/19/00 8:37 pm	30 hours, 10 minutes	176 hours, 26 minutes	Water shut off at plant
#5	6/2/00 4:28 pm	6/3/00 7:47 am	15 hours, 19 minutes	191 hours, 45 minutes	TMP limit reached due to rust flakes in feed water when system was put back on line
#6	6/6/00 5:13 pm	6/6/00 9:13 pm	4 hours	195 hours, 45 minutes	Solenoid valve failed
#7	6/7/00 12:11 pm	6/10/00 12:46 pm	70 hours, 35 minutes	266 hours, 20 minutes	Water shut off at plant
#8	6/11/00 12:05 am	6/14/00 7:51 pm	79 hours, 46 minutes	346 hours, 6 minutes	TMP limit reached due to algae and iron bacteria
#9	6/20/00 11:22 am	6/23/00 10:28 am	70 hours, 52 minutes	416 hours, 58 minutes	Same as above
#10	7/5/00 11:19 am	7/5/00 12:03 am	43 minutes	417 hours, 41 minutes	Same as above
#11	7/10/00 9:50 am	7/10/00 4:28 pm	6 hours, 38 minutes	424 hours, 19 minutes	Same as above
#12	7/12/00 11:09 am	7/12/00 4:40 pm	5 hours, 51 minutes	430 hours, 10 minutes	Same as above
#13	7/26/00 12:55 pm	7/26/00 6:51 pm	5 hours, 56 minutes	436 hours, 6 minutes	Same as above

The membrane system performed well mechanically during the testing period. The only difficulties encountered were associated with the air compressor and the pneumatic solenoid valves, which controlled the automatic flow valves and cooling system for the SCADA unit. The original compressor supplied with the membrane system was not large enough to handle the periods of peak demand for air caused by the conditions at the site (hot and humid). The problem was solved with the installation of a larger compressor on June 6, 2000. The maximum temperature setting within the SCADA system also was elevated to a slightly higher level to accommodate the conditions at the site. Solenoid valves were re-taped with teflon tape to stop air leaks, and one solenoid valve was replaced with a spare solenoid valve. The air compressor was drained periodically to minimize the build up of water in the pressure tank and to prevent moisture from entering the air delivery system. The desiccant that protects the compressed air system was dried once during the testing period.

4.2.2 Flowrate

The target flowrate for the membrane system was 4 gpm. During the course of testing the filtrate flowrate averaged 2.3 gpm for the cumulative run times and ranged from 1.8 to 6.3 gpm. The variability in flow was due to the high fouling associated with the large amount of algae and diatoms in the feed water. During the microbial challenges, the concern was to stress the system under high and low transmembrane pressures. To accommodate this, the flowrate was adjusted to create a stable testing condition throughout the challenge period. The retentate flow rate was targeted at 10% of the feed flowrate. When the system was operating in automatic mode, the pump varied its output according to the set filtrate flowrate. The power ramped up to provide the necessary filtrate flow until a manually set parameter was reached. During the test period, the pump operated between 40 and 60% of its total power capacity.

The variation in flowrate was primarily due to the seasonal algal blooms experienced during the test period. High levels of either turbidity or particle counts were not detected. Samples of the background water were collected and analyzed for Fats, Oils, and Greases (FOG), on May 8, 2000 (during a time when eels clogged the intake structure), but found no significant levels of any FOG material (Appendix C). The only major variation found between the background water conditions during the test period and the background water conditions anticipated was the high levels of algae, diatoms, and zooplankton. Feed water analysis of these parameters occurred on May 12, May 18, June 9, and June 21, 2000. According to local Limnologists and plant biologists, these species would be common to this particular reservoir system in the Northeast during spring conditions, however, the length and severity of the episode was considered unusual. Filtrate samples were not collected for phytoplankton analyses. Algae was analyzed in the raw water to assess if algae were fouling the membrane. The presence of algae in the feed water was assessed to be a membrane foulant and appears to have shortened filter runs. The algae shortened reduced run times by at least 75% as estimated by the manufacturer, who had anticipated run times on the order of 30 days between cleanings. A discussion of the results of the feed water algae testing can be found in Section 4.4.3 and the analytical reports can be found in Appendix D.

4.2.3 Pressure

The system operated with TMP ranging from 2.9 to 30 psi with an average TMP of 14 psi. The uppermost value that signaled an automatic air scrub and reverse filtration was set to 30 psi. The inlet pressure to the pump averaged 8 psi. Figure 4-1 illustrates the TMP over the thirteen filter runs.

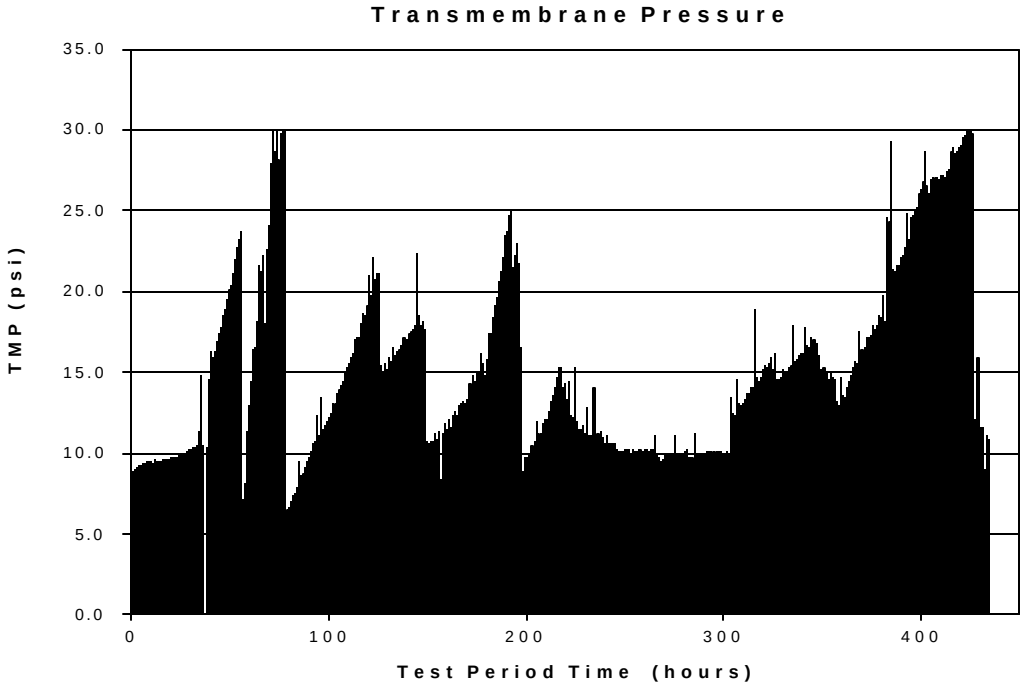

Figure 4-1. Transmembrane Pressure

4.2.4 Temperature

The feed temperature ranged between 11.4and 35.3 °C, and averaged 19°C throughout the test period. The filtrate temperature was checked in the field daily and did not vary from the feed water temperature. During periods when the system was in recirculation mode for cleaning purposes, the temperature of the filtrate increased but did not exceed 25°C.

4.2.5 Membrane Flux

The specific flux of the system averaged 3.60 gfd/psi and ranged from 1.27 to 14 gfd/psi. The values of specific flux were normalized to 20°C. The statistical values of the specific flux were calculated with operational data excluding AS and RF cycles. A summary of the filter performance is presented in Table 4-2. The graph of the specific flux during the filter runs appears in Figure 4-2. During the test verification period, the data for two filter runs#2 and

#4was downloaded every 10 minutes with the SCADA system. All other filter run data was collected at 2 minute time intervals. A printout of the SCADA information is provided in Appendix E.

Table 4-2. Summary of Filter Performance

	Feed Flow (gpm)	Feed Pressure (psi)	Feed Temperature (°C)	Filtrate Flow (gpm)	Filtrate Pressure (psi)	Retentate Pressure (psi)	Transmembrane Pressure (psi)	Specific Flux (gfd/psi)
Average	2.50	17.47	18.88	2.30	4.20	15.35	14.22	3.60
Minimum	1.80	0.04	11.44	1.80	0.00	0.00	2.87	1.27
Maximum	9.80	36.13	35.26	6.26	31.68	34.43	30.23	14.19
Std Deviation	0.63	6.61	3.14	0.43	2.83	7.18	5.25	1.36
95% Conf. Int.	(2.49, 2.51)	(17.35, 17.59)	(18.82, 18.94)	(2.29, 2.31)	(4.15, 4.25)	(15.22, 15.48)	(14.12, 14.32)	(3.57, 3.63)

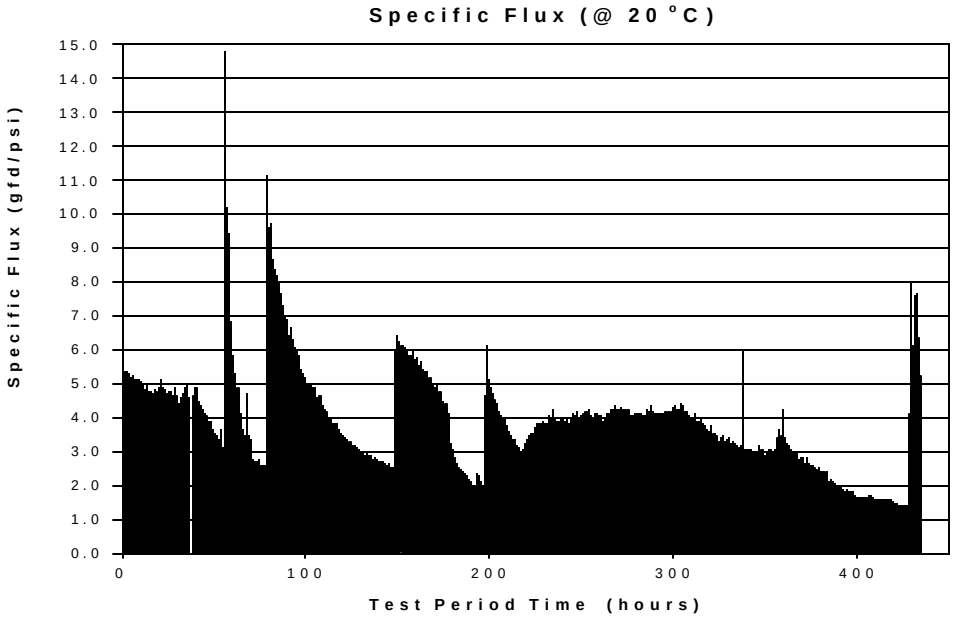

Figure 4-2. Specific Flux at 20°C

4.3 Task 2: Cleaning Efficiency

The AS and RF cycles were initially set at 60 and 30 minutes, respectively. During the course of testing the frequency of cleaning cycles was tested to optimize performance. To reduce the rate of increase of the TMP, the frequency of the cleaning cycles was increased to every 40 and 20 minutes for the AS and the RF, respectively. This change did not dramatically alter the rate of the increase of the TMP and the frequencies were reset to every 60 and 30 minutes. After a chemical cleaning of the membrane on June 7, 2000, the duration of the RF was increased from 30 seconds to 60 seconds and the frequency of the AS was increased from every 60 minutes to every 30 minutes. Prior to the adjustment the TMP had been rapidly increasing. The new

cleaning regimen lowered TMP from 15 psi to a steady 10 psi. When the filtrate flow rate was increased from 2.1 to 2.5 gpm, the TMP resumed its increase. The more rigorous cleaning was not sufficient to offset the impact of the higher filtrate flow rate. The results of this portion of the study could be attributed to the type of biological fouling caused by algae, which were present in the feed water. The air scrub appeared to be the more effective than the reverse filtration cleaning method for these feed water conditions.

Typical product water recovery during the operation of the unit was 93.3%, which equates to 93.3% of the filtrate flow was available for consumption and 6.7% was used for cleaning the membrane (backwashing).

Four chemical cleanings took place during the testing. The chemical cleaning was effective in consistently returning the TMP to starting levels of 11 psi on average. The first cleaning showed a complete recovery of specific flux. The second, third and fourth cleanings showed improved recovery of the original flux but not a complete recovery. The manufacturer indicated that the algae or other aquatic organisms may have irreversibly fouled the membrane. It may be that the cleaning times should have been longer or the cleaning solution warmer than was available at the site. Table 4-3 summarizes the cleaning efficiency evaluation. Further details of the cleaning events are in Appendix F.

Table 4-3. Evaluation of Cleaning Efficiency

Clean Number	Clean Date	Specific Flux at 20oC Before Clean, Jsf (gfd/psi)	Specific Flux at 20oC After Clean, Jsi (gfd/psi)	Recovery of Specific Flux 100(1-Jsf/Jsi) %	Loss of Original Specific Flux 100(1-(Jsi/Jsio)) %
Start (Jsio)	4/30/00	**11.4**	---	---	---
Cleaning 1	5/9/00	6.4	11.9	46	-4
Cleaning 2	5/18/00	3.7	5.7	35	50
Cleaning 3	6/7/00	2.5	6.2	60	46
Cleaning 4	7/10/00	3.0	7.8	62	32

Before a run was initiated and after a chemical cleaning was performed, an integrity test (air pressure hold test) was performed. The membrane held pressure for 5 minutes during each integrity test.

4.4 Task 3: Finished Water Quality

4.4.1 Particle Counts

The raw water particle count concentration of *Cryptosporidium*-sized particles (2-5 micron) and cumulative particles (2->15 micron) averaged 3,120 and 5,601 counts/ml, respectively. The filtrate particle count concentration averaged 1.7 and 3.1 counts/ml, respectively. Percent reduction for both *Cryptosporidium*-sized particles (2-5 micron) and cumulative particles (2->15 micron) was 99.94%. Tables 4-4 and 4-5 present the raw water and filtrate water particle counts during testing. Table 4-6 presents the percent removal of particles. Results were computed using

filter run data from the following time periods when the particle counters were on-line during the verification test period.

- Filter Run #2 - 14:40 May 3, 2000 to 12:42 May 4, 2000
- Filter Run #3 - 17:17 May 9, 2000 to 14:45 May 12, 2000
- Filter Run #4 - 14:27 May 18, 2000 to 20:37 May 19, 2000
- Filter Run #5 - 16:40 June 2, 2000 to 7:56 June 3, 2000
- Filter Run #9 - 11:14 June 20, 2000 to 10:31 June 23, 2000

Total data collection time for particle counts was approximately 209 hours. Problems were experienced in retrieving the data during some portions of the verification period, therefore particle count data is not presented from all thirteen filter runs. This problem was attributed to a data transmission connection between the computer and the particle counters.

Table 4-4. Raw Water Particle Counts (counts/mL)

	Raw Water Particle Count Size (μm)							
	2 – 3	3 - 5	2-5	5 - 7	7 - 10	10 - 15	> 15	Cumulative
Average	1366	1755	3120	504	357	925	695	5601
Minimum	5	5	10	3	2	1	1	877
Maximum	4180	8662	12672	4593	2961	4140	2948	17891
95% Conf Interval	(1344, 1387)	(1717, 1792)	(3064, 3177)	(484, 523)	(345, 369)	(897, 953)	(673, 718)	(5533, 5670)
No. of Samples	6266	6266	6266	6266	6266	6266	6266	6266

Table 4-5. Filtrate Particle Counts (counts/mL)

	Filtrate Particle Count Bin Size (μm)							
	2 - 3	3 - 5	2-5	5 - 7	7 - 10	10 - 15	> 15	Cumulative
Average	0.83	0.88	1.72	0.18	0.16	0.58	0.43	3.1
Minimum	0	0	0	0	0	0	0	0
Maximum	606	603	1209	92	69	205	116	1400
95% Conf Interval	(0.60, 1.07)	(0.64, 1.12)	(1.25, 2.19)	(0.14, 0.22)	(0.12, 0.19)	(0.46, 0.70)	(0.35, 0.52)	(2.5, 3.7)
No. of Samples	6266	6266	6266	6266	6266	6266	6266	6266

Table 4-6. Average Particle Count Removal Percentage

	Particle Count Size (μm)							
	2 - 3	3 - 5	2-5	5 - 7	7 - 10	10 - 15	> 15	Cumulative
Removal %	99.94	99.95	99.94	99.96	99.96	99.94	99.94	99.94

Figures 4-3 through 4-7 present the raw water and filtrate water particle counts for Filter Runs #2, #3, #4, #5, and #9 in log scale. The data presented represents values collected at two-minute intervals.

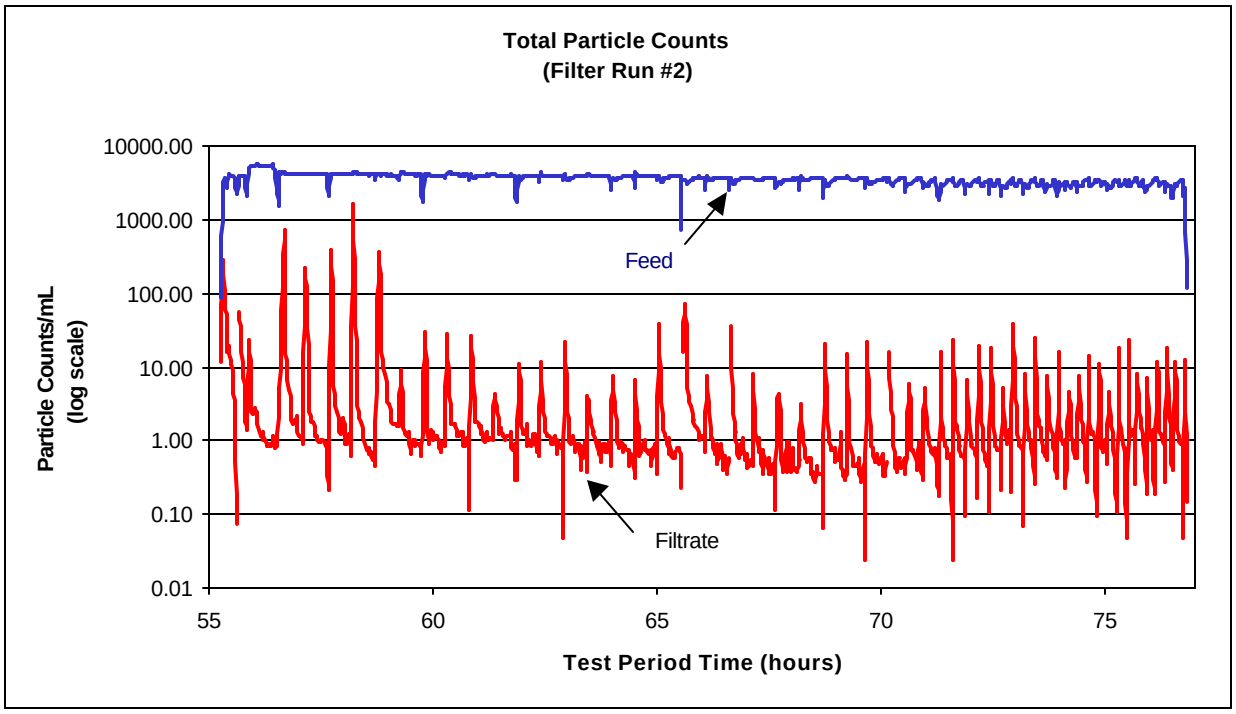

Figure 4-3. Cumulative Particle Counts for Test Period 2 on Log_{10} Scale.

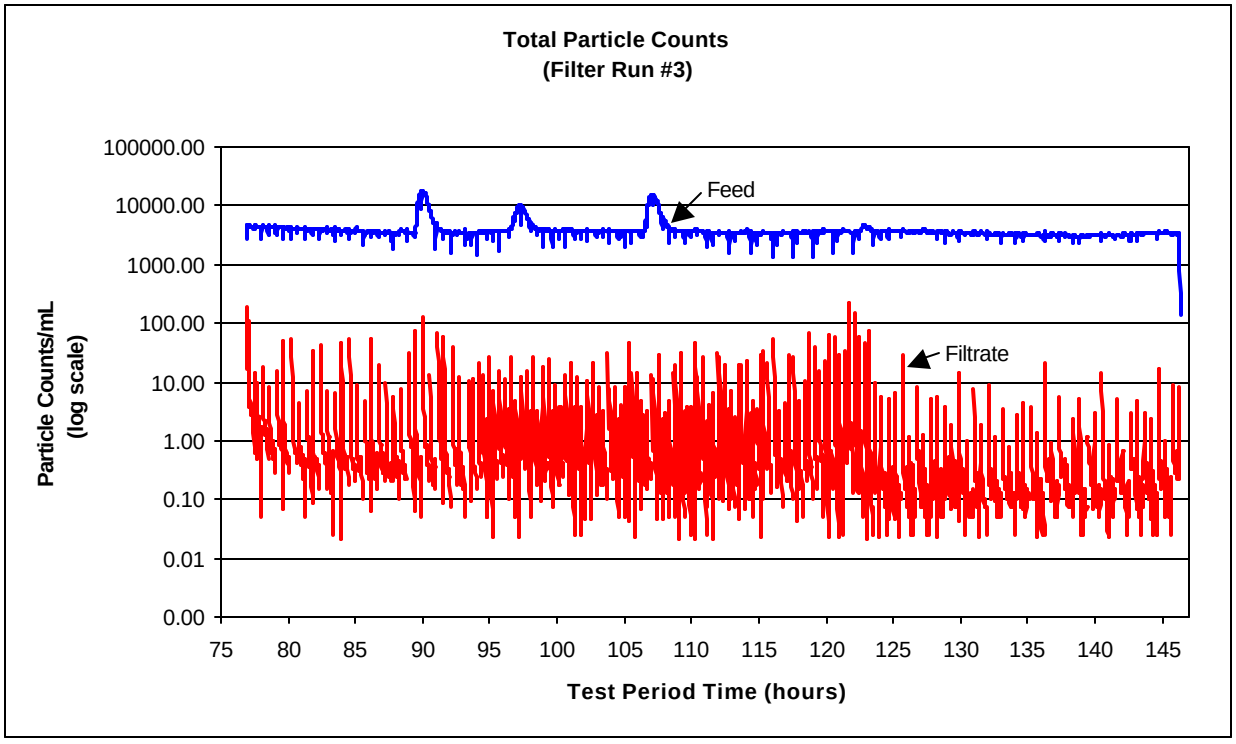

Figure 4-4. Cumulative Particle Counts for Test Period 3 on Log_{10} Scale

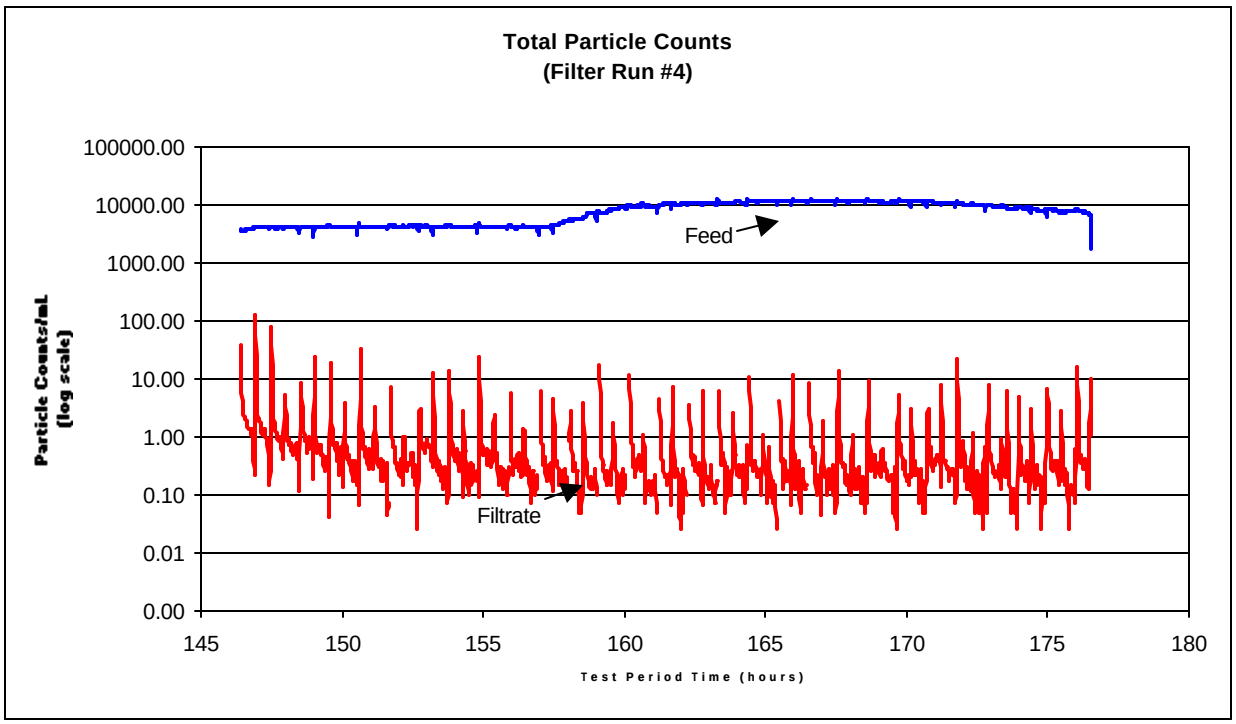

Figure 4-5. Cumulative Particle Counts for Test Period 4 on Log_{10} Scale

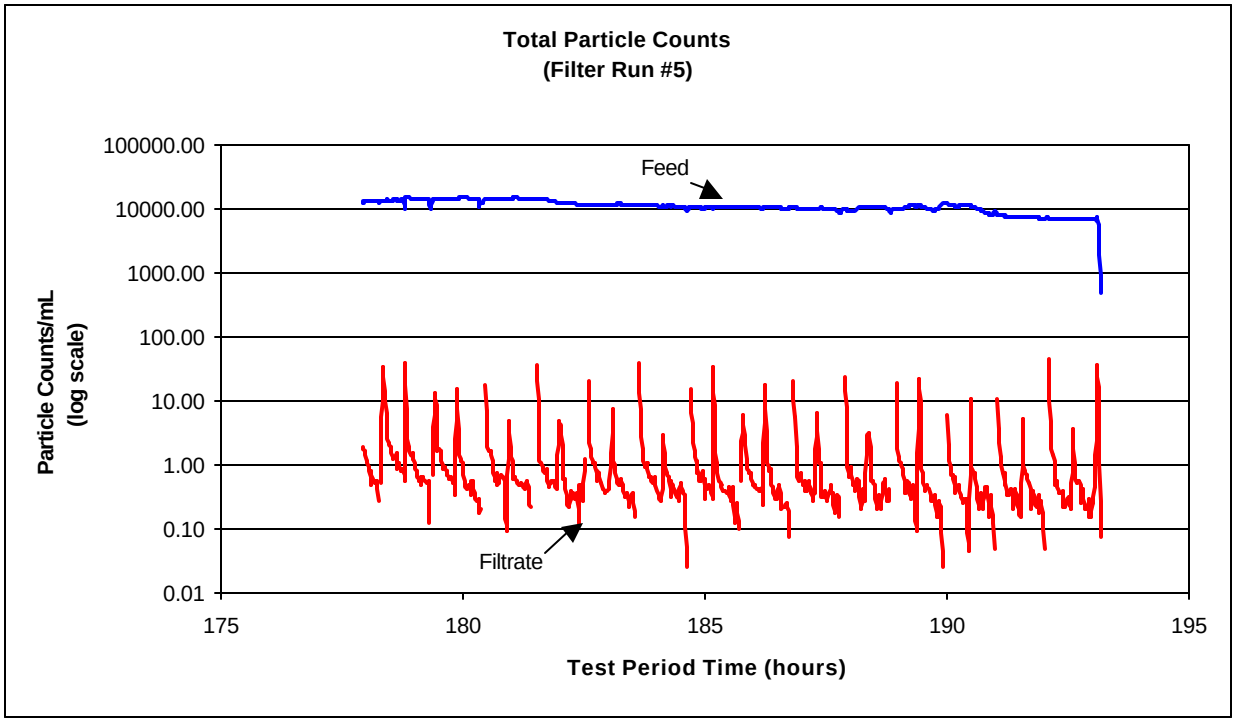

Figure 4-6. Cumulative Particle Counts for Test Period 5 on Log_{10} Scale

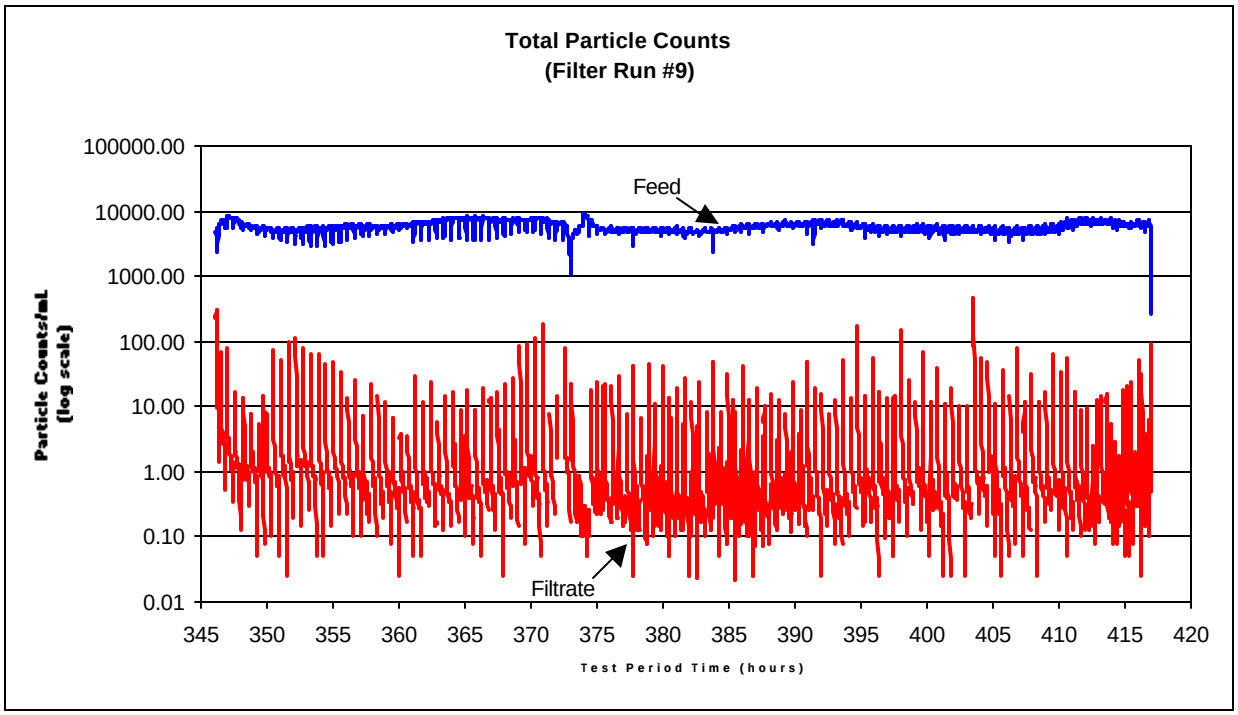

Figure 4-7. Cumulative Particle Counts for Test Period 9 on Log_{10} Scale

4.4.2 Turbidity

During the verification testing, the feed water turbidity values averaged 0.80 NTU. The filtrate averaged 0.03 NTU with a standard deviation of 0.01. Table 4-7 and Figure 4-8 represent the on-line turbidity data from the SCADA system during the test period. The printout of the on-line turbidity data is provided in Appendix E.

Table 4-7. On-Line Feed and Filtrate Turbidity Data

	Feed Turbidity (NTU)	Filtrate Turbidity (NTU)
Average:	0.80	0.03
Maximum value:	3.79	0.32
Minimum value:	0.07	0.00
Std. Deviation:	0.28	0.01
95% Conf. Interval:	(0.79, 0.81)	(0.03, 0.03)

Note: statistical analysis excludes RF and AS procedures.

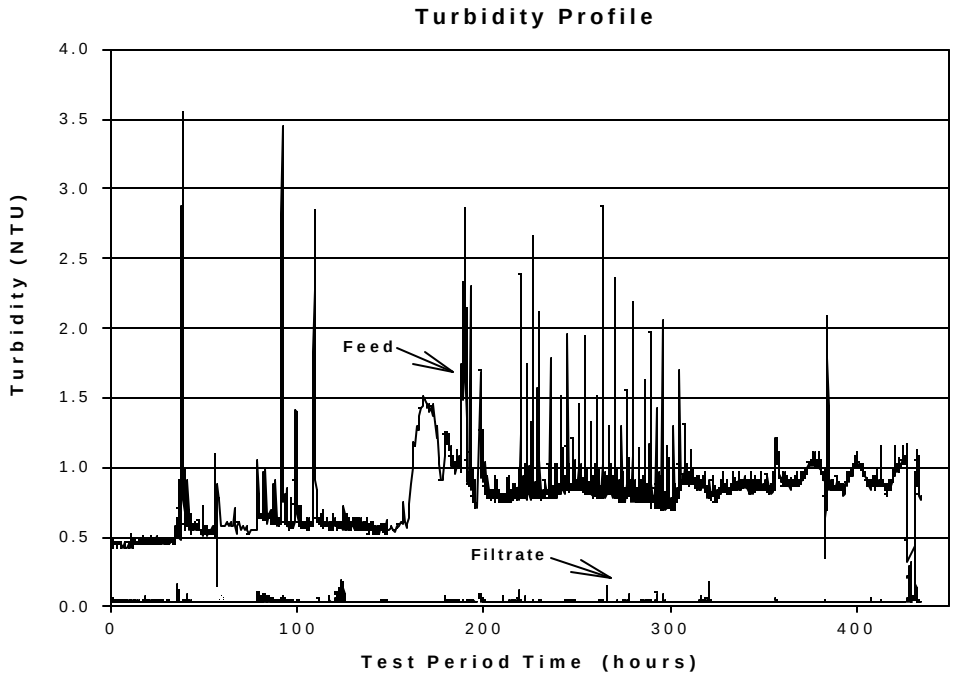

Figure 4-8. Turbidity Profile

4.4.3 Phytoplankton Analysis

Table 4-8 summarizes the results of the quantification and identification of the diatoms, algae, and pollen in the raw water collected at various dates during the testing period. These parameters were analyzed in the raw water to assess the type of contaminants that were fouling the membrane during operation. Filtrate samples were not collected for phytoplankton analyses. The analytical reports are provided in Appendix D.

Table 4-8. Feed Water Phytoplankton Analysis (Densities in no./mL)

Taxon	5/12/00	5/18/00	6/9/00	6/21/00	Average	Minimum	Maximum
(200X magnification)							
(Diatoms)							
Bacillariophyceae	59	141	141	40	95	40	141
(Algae)							
Chrysophyceae	30	59	90	8	47	8	90
Chlorophyceae	52	66	66	36	55	36	66
Cyanobacteria	7	7	6	11	8	6	11
Others	126	141	31	2	75	2	141
(400X magnification)							
Coccoid cyanobacteria	2219	3021	598	342	1545	342	3021
Unicell	425	69	209	46	187	46	425
Pollen (grains/ml)	0.04	0.02	0.22	0.007	0.07	0.007	0.22

The raw water phytoplankton levels are indicative of an average to above normal algal bloom for lakes located in the Northeast, during spring conditions. The unusual wet and cool weather experienced during the testing period appeared to have lengthened the duration of the algal bloom well into the summer months.

4.4.4 Other Water Quality Parameters

The pH of the feed water averaged 6.4 with a maximum value of 7.2 and a minimum value of 5.5 during the testing period. Tables 4-9 and 4-10 summarize the results of the feed and filtrate samples, respectively, for TOC and UV, and total iron, manganese, Hardness, TDS, and TSS. Data indicates that dissolved organics and inorganics were not effectively removed by the MF process, which was expected. Because only one sample was collected and analyzed for TSS and that sample indicated that TSS was not detected in the feed water, the TSS mass balance calculations were not completed. The presence of some TSS in the backwash (RF) could have been algae in the raw water that adhered to the membrane or to the plumbing in the system. Analytical reports can be found in Appendix G.

Table 4-9. Feed Water Quality

Date	TOC (mg/L)	UV Absorbance (1/cm)	Total Iron (mg/L)	Total Manganese (mg/L)	Alkalinity (mg/L)	Hardness (mg CaCo3/L)	TDS (mg/L)	TSS (mg/L)
5/11/00	4.77	0.136	---	---	---	---	---	---
5/12/00	4.69	0.133	---	---	---	---	---	---
6/9/00	4.76	0.125	0.073	0.015	---	---	---	---
6/14/00	---	---	0.16	0.013	---	---	---	---
6/21/00	5.09	0.119	---	---	3.5	11.2	79	<4
6/27/00	---	---	0.18	0.014	---	---	---	---
8/9/00	---	---	0.13	0.016	---	---	---	---
Average:	4.83	0.128	0.14	0.015	NA	NA	NA	NA
Maximum:	5.09	0.136	0.18	0.016	NA	NA	NA	NA
Minimum:	4.69	0.119	0.073	0.013	NA	NA	NA	NA

--- = Sample not collected on this date.
NA=Statistical calculations not performed because sample size =1.

Table 4-10. Filtrate Water Quality

Date	TOC (mg/L)	UV Absorbance (1/cm)	Total Iron (mg/L)	Total Manganese (mg/L)	Alkalinity (mg/L)	Hardness (mg CaCo3/L)	TDS (mg/L)	TSS (mg/L)
5/11/00	---	---	---	---	---	---	---	---
5/12/00	4.16	0.123	---	---	---	---	---	---
6/9/00	4.35	0.111	---	---	---	---	---	---
6/14/00	---	---	---	---	---	---	---	---
6/21/00	4.23	0.100	---	---	3.0	11.9	76	<4
6/27/00	---	---	---	---	---	---	---	---
8/9/00	---	---	0.03	0.005				
Average:	4.25	0.111	NA	NA	NA	NA	NA	NA
Maximum:	4.16	0.100	NA	NA	NA	NA	NA	NA
Minimum:	4.35	0.123	NA	NA	NA	NA	NA	NA

--- = Sample not collected on this date.
NA=Statistical calculations not performed because sample size =1.

Table 4-11 is a summary of the background raw water and filtrate total coliform, *E. coli*, *Bacillus* spore, and heterotrophic plate count analyses for the verification period. A majority of background filtrate samples did not show the presence of microbial contaminants but there were samples that indicated their presence. It is not clear from the background data whether the filtrate results were due to sample contamination, laboratory error or membrane performance. The membrane system was not sterilized before background sampling events.

Table 4-11. Summary Raw and Filtrate Water Quality Naturally Present Microbial Constituents

Date	Total Coliform Raw (#/100mL)	Total Coliform Filtrate (#/100mL)	HPC Raw (#/mL)	HPC Filtrate (#/mL)	*Bacillus* Spores Raw (#/100mL)	*Bacillus* Spores Filtrate (#/100mL)	*E. coli* Raw (#/100mL)	*E. coli* Filtrate (#/100mL)
05/03/2000	87	<1	---	---	290	<1	10	<1
05/03/2000	72	---	---	---	220	---	10	---
05/12/2000	250	<1	19	<1	---	---	300	<1
05/12/2000	450	<1	13	<1	---	---	<1	<1
06/13/2000	2000	<1	26	<1	---	---	<1	<1
06/13/2000	1600	190	39	<1	---	---	<1	7
06/13/2000	---	<1	---	<1	---	---	---	<1
06/21/2000	11200	19	760	35	---	---	<1	<1
06/21/2000	10000	28	570	8	---	---	<1	<1
07/03/2000	760	<1	<10	<10	---	---	---	---
07/03/2000	650	<1	<10	<10	---	---	---	---
07/03/2000	---	250	---	<10	---	---	---	---
08/09/2000	44	<1	31	21	---	---	6	<1
08/09/2000	5	6	57	<10	---	---	<1	0.2
Average	2260	39	154	9	255	NA	33	1.5
Max	11200	250	760	35	NA	NA	300	7
Min	5	<1	<10	<1	NA	NA	<1	0.2
St Dev	3954	82	274	10	NA	NA	94	1.9
95% C. I.	(23, 4497)	(<1, 83)	(<10, 323)	(3, 15)	NA	NA	(<1, 91)	(0.3, 2.7)

--- = Sample not collected on this date.
NA=Statistical calculations not performed because sample size =1 or 2.
Note: Calculations involving detection limit values (i.e. <1) used the detection limit value in the calculation as a conservative estimation.

4.5 Task 4: Reporting of Maximum Membrane Pore Size

The manufacturer reports that the maximum membrane pore size as determined by the use of ASTM Method F316-86 is less than 0.3 microns (µm) diameter. The manufacturer also reports that the membrane was challenged using 0.1 micron diameter latex spheres and the results indicated that 99% of the spheres were removed. This is provided for informational purposes only. These results are provided by the equipment manufacturer and were not verified during the ETV testing.

4.6 Task 5: Membrane Integrity Testing

Integrity testing was performed as per manufacturer's specification after each membrane chemical cleaning. The integrity test was performed over ten times during the testing period. The test involved fully wetting the membrane, draining the water from the membrane cartridge, opening the filtrate lines to the air and applying 20 psi of compressed air to the feed water side of the membrane. Less than a loss of 1 psi of air pressure over a 5-minute time period indicated a successful air integrity test. The time was measured with a stopwatch and the pressure gauge

was monitored visually at one-minute intervals. The integrity tests performed during the verification testing period indicated the membrane was intact.

Another indication of possible membrane integrity failure is the presence of a high particle counts level in the effluent. During the testing period, this occurrence was not observed. The TMP rose above the maximum allowable pressure and shut down the unit before integrity failure occurred. This was substantiated by the fact that the same membrane did not fail the integrity tests during the test period.

4.7 Task 6: Data Management

Data from the SCADA system was set up to take readings on temperature, flow rate, turbidity, transmembrane pressure, and retentate pressure. Data on particle counts were processed by use of VISTA™ software. This software accompanied the HACH particle counters. This system downloaded data every two minutes. Both the SCADA and VISTA data were then copied to an EXCEL spreadsheet for data analysis. Other water quality data were compiled from reports and field logbooks and transferred to an EXCEL spreadsheet for analysis. The EXCEL spreadsheet format was used to perform statistical analysis on the data.

4.8 Task 7: QA/QC

Quality assurance and quality control procedures were followed as described in Chapter 3 with exceptions as noted below. Samples were collected in containers supplied by the respective laboratories that performed the specific analysis. During the testing period, none of the testing equipment needed to be changed or recalibrated due to mechanical failure. The protocol for duplicate, field and trip blanks and samples was followed. The relative percent differences calculated for feed water and filtrate water samples collected in duplicate and analyzed for TOC, TDS, TSS, UV_{254}, hardness, and alkalinity were all below 4%. Quality assurance (QA) calculations are provided in Appendix J.

During the course of testing, weekly QA/QC checks were performed. This allowed the ability to take inventory of sample containers, check chain of custody forms, and create a check list of tasks that would performed before the next round of sampling occurred. The check list helped in safety issues as well as QA/QC since many of the tasks involved standard housekeeping and maintenance procedures.

The feed water and filtrate pressure gauges were checked against a NIST traceable pressure gauge prior to the start of testing. The difference between the NIST traceable and the pressure gauges used during testing was not greater than 3%, which was considered satisfactory. Results are recorded on pages 1 and 2 of Logbook #1 in Appendix B.

The feed and filtrate flow meter readouts were verified volumetrically (bucket and stop watch) at the start of testing. The meter values were within 6% of the values obtained volumetrically, which was considered satisfactory. Results of this verification are recorded on page 2 of Logbook #1 in Appendix B. Although the flow meter readouts are to be verified volumetrically every two weeks during testing, the FTO elected to only perform this check at the start of testing.

Because flow rate is a critical performance parameter, the lack of the verification is a variance from the ETV test plan. The FTO notes that they did compare the feed and filtrate flow rates throughout testing and they were found to be consistent with each other.

The comparison of the desktop turbidity values and the in-line turbidimeters were as expected. Comparisons were performed on ten occasions during the months of May and June 2000. When you have instruments in-line that are approximately two orders of magnitude greater in accuracy than the bench top turbidimeter, the in-line values were expected to fall within the accuracy range of the bench tops. To try and get more accurate comparisons, the samples were taken over to the Manchester plant to analyze with their equipment. The relative percent difference of the on-line and desktop turbidity readings of the raw water ranged from 3.4% to 15.4%. The RPD of on-line and desktop turbidity readings of the filtrate ranged from 3.1% to 100%. Quality assurance (QA) calculations are provided in Appendix J. Representatives from Hach were present for the initial calibration of the turbidimeters, and provided insight as to how to maintain accuracy during the testing period. The in-line turbidimeters maintained their stated accuracy throughout the test period. Although daily checks of the in-line turbidimeter readings against a calibrated bench-top turbidimeter are required, the FTO elected to do these checks on ten occasions during four of thirteen filter runs. Because turbidity is a critical performance parameter, the lack of sufficient daily checks is a serious variance from the ETV test plan. The filtrate line however, was monitored by two inline Hach 1720D turbidimeters, one on the Pall Membrane System and one on the FTO monitoring board. A comparison of the logbook entries for the two inline turbidimeters showed that from May 10, 2000 to June 22, 2000, the Pall inline turbidimeter averaged 0.031 +/- 0.001 NTU, while the FTO inline turbidimeter average 0.029 +/- 0.005 NTU. The summary data is included in Appendix J. Flow rates through the turbidimeters were checked volumetrically each day by the FTO with a bucket and stopwatch method to assure that flows were within the manufacturers specified range of 250-750 mL/minute. In-line turbidimeter flowrates were not recorded in the FTO logbook and could not be independently verified.

The particle counters used during verification testing were Met One particles counters model # PCXCE155B. Both particle counters were manufactured in November 1999 and were factory calibrated by the manufacturer on November 17, 1999 according to the labels affixed to the particle counters. Field verification of the particle counter calibration was not performed according to the ETV Protocol, however the raw water particle counter measurements were compared to another Met One particle counter that was also simultaneously measuring the raw water particles. No significant deviation between the two particle counters was noted. Flow rates through the particle counters were checked volumetrically each day by the FTO with a bucket and stopwatch method to assure that flows were within the manufacturers specified range of approximately 100 mL/minute ± 5%. In-line particle counter flowrates were not recorded in the FTO logbook daily and could not be independently verified.

During the course of the testing, samples not sent to the laboratory on the day of collection were placed in a controlled refrigerated storage unit on the site, which provided protection against damage or loss until samples were sent to the laboratory. Samples placed overnight in this refrigerated storage unit included samples for TOC, UV, iron, and manganese. Temperature of this storage unit was not monitored. It is possible that this storage unit may have adversely

affected results of the TOC and UV samples, if the unit was not maintained at an appropriate temperature.

The raw water and filtrate water samples collected on May 3, 2000 for *Cryptosporidium* analyses were analyzed outside the specified hold time recommended in EPA Method 1622. Based on the date of the analytical report, the possible hold time deviation was between 4-7 days. The hold time deviation is not expected to influence the sample results because the samples were analyzed for total cyst concentration and not viability. Since the hold time deviation was prior to sample concentration, the up-take of the dye for the enumeration would not have been affected.

4.9 Task 8: Microbiological Removal Challenge

The Pall Corporation Microza™ Microfiltration 3-inch Unit was challenged three times with *Cryptosporidium oocysts* (2-5 microns), *E. coli* (<2 microns) and *Bacillus* Spores (<2 microns). During each challenge, a concentration of each microbial parameter was added to a known volume of water and filtered by the membrane system. Samples of the feed and the filtrate were collected and analyzed for each challenge. The challenges were performed at different intervals of the testing period. The May 3rd challenge was performed at the beginning of a filter run on a new clean membrane when the transmembrane pressure was at a low of approximately 8.2 psi. The June 21st and August 9th challenges were performed near the end of a filter run when the transmembrane pressure approached the 30 psi limit (performed at approximately 25 psi).

Cryptosporidium oocysts were not detected in the filtrate produced by the membrane system during the three challenges. The first *Cryptosporidium* challenge test was performed on May 3rd, 2000 and the system demonstrated a 6.6 $\log_{10}$ removal of *Cryptosporidium*. The May 3rd *Cryptosporidium* sample was not processed within the method's specified holding time; however, that is not expected to have influenced the sample results because the samples were analyzed for total cyst concentration and not viability (see Section 4.8 for QA discussion). The system demonstrated a 4.1 $\log_{10}$ removal of *Cryptosporidium* during the June 21, 2000 challenge. The third *Cryptosporidium* challenge was performed on August 9th and the system demonstrated a 5.6 $\log_{10}$ removal of oocysts. The SCADA system was not functional during the August 9th challenge, but operational parameters were noted in the logbook. The filtrate flow was 2.9 gpm, TMP ranged from 24.9 to 32.8 psi, the raw water was pH 6.79, the temperature was 24 ^{o}C and raw water turbidity was 1 NTU. Analytical reports are provided in Appendix H and results are summarized in Table 4-12 and Figure 4-9.

Table 4-12. Feed and Filtrate *Cryptosporidium* Results

Sample Date	May 3rd* feed (#/20L)	May 3rd* filtrate (#/20L)	June 21st feed (#/20L)	June 21st filtrate (#/20L)	August 9th feed (#/20L)	August 9th filtrate (#/20L)
	2.4×10^6	<1	1.5×10^4	<1	3.8×10^5	<1
	4.4×10^6	<1	5.5×10^3	<1	1.7×10^5	<1
	3.9×10^6	<1	2.1×10^4	<1	6.1×10^5	<1
Average:	3.6×10^6	<1	1.4×10^4	<1	3.9×10^5	<1

*The samples were analyzed after the recommended hold time (see Section 4.8 for QA discussion).

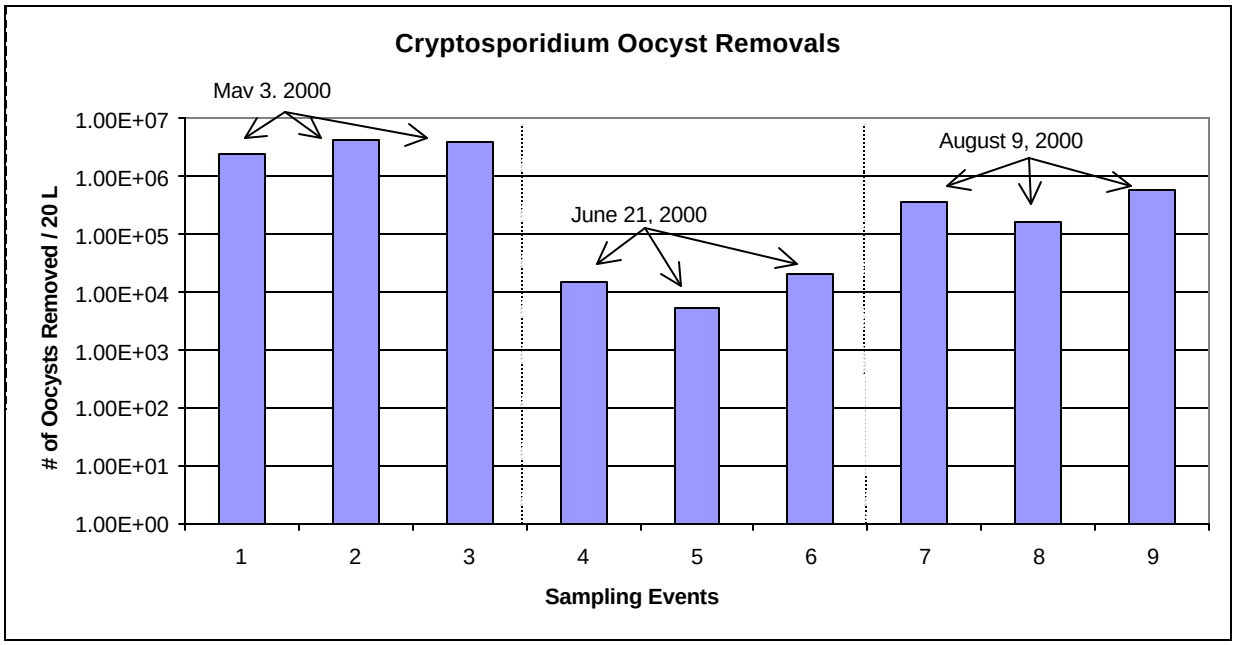

Figure 4-9. Bar Chart of Log_{10} Removal of Seeded Cryptosporidium

The first *Bacillus* spore challenge test was performed on May 3rd, 2000 and the system demonstrated a 4.0 log_{10} removal of *Bacillus* spores. The second *Bacillus* spore challenge test was performed on June 21st and the results were inconclusive because the influent sample result revealed a too numerous to count (TNTC) level. The third *Bacillus* spore challenge test was performed on August 9, 2000 and the system demonstrated a 7.1 log_{10} removal. *Bacillus* spores were not detected in the filtrate during two of the challenges. Analytical reports are summarized in Appendix I. Log removal calculations are based on 100 mL samples. Results are summarized in Table 4-13.

Table 4-13. Feed and Filtrate *Bacillus* Spore Results

	May 3rd Feed (#/100mL)	May 3rd Filtrate (#/100mL)	June 21st Feed (#/100mL)	June 21st Filtrate (#/100mL)	August 9th Feed (#/100mL)	August 9th Filtrate (#/100mL)
	10,500	<1	TNTC	20	11,300,000	<1
	11,000	< 1	TNTC	10	12,000,000	<1
	10,700	<1	TNTC	8	10,900,000	<1
Average:	10,700	<1	TNTC	14	11,400,000	<1

TNTC = Too numerous to count.

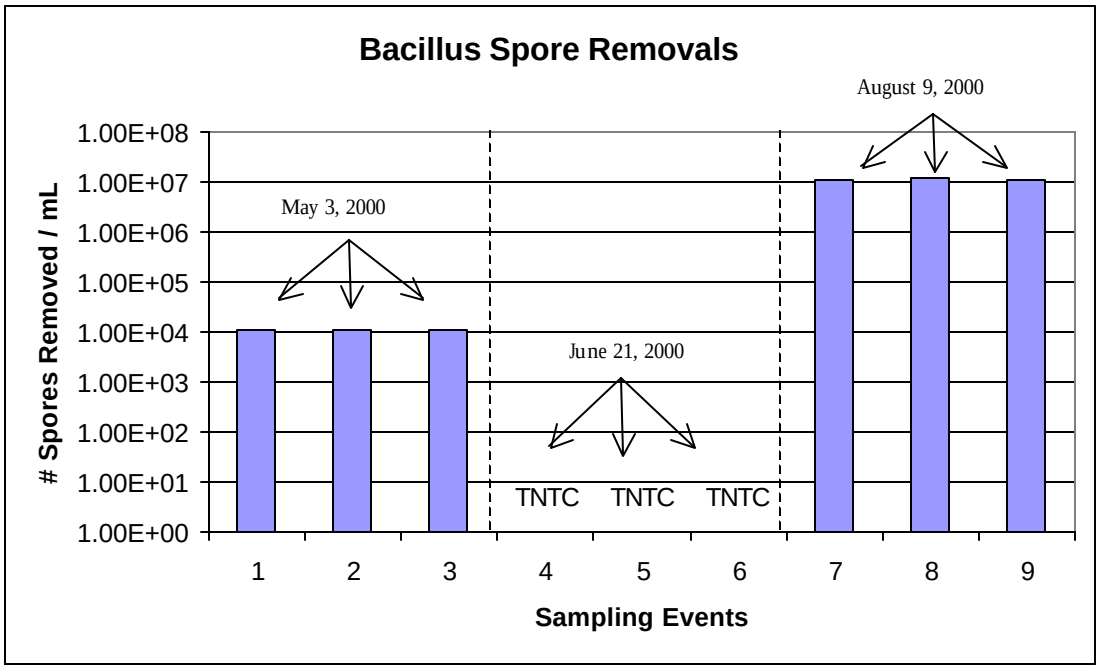

Figure 4-10. Bar Chart of Log_{10} Removal of Seeded *Bacillus* Spores

The first *E. coli* challenge test was performed on May 3rd, 2000 and the system demonstrated a 6.7 log_{10} removal of *E. coli*. The second *E. coli* challenge test was performed on June 21st and the system demonstrated a 3.9 log_{10} removal of *E. coli.* The third *E. coli* challenge test was performed on August 9, 2000 and the system demonstrated a 6.5 log_{10} removal. Analytical reports are summarized in Appendix I. Log removal calculations are based on 100 mL samples. Results are summarized in Table 4-14.

Table 4-14. Feed and Filtrate *E. coli* Results

	May 3rd Feed (#/100mL)	May 3rd Filtrate (#/100mL)	June 21st Feed (#/100mL)	June 21st Filtrate (#/100mL)	August 9th Feed (#/100mL)	August 9th Filtrate (#/100mL)
	5,200,000	<1	4,500,000	500	17,000,000	6
	5,600,000	<1	4,300,000	540	16,500,000	2
	5,450,000	<1	4,100,000	510	17,300,000	6
Average:	5,420,000	<1	4,300,000	520	16,900,000	5

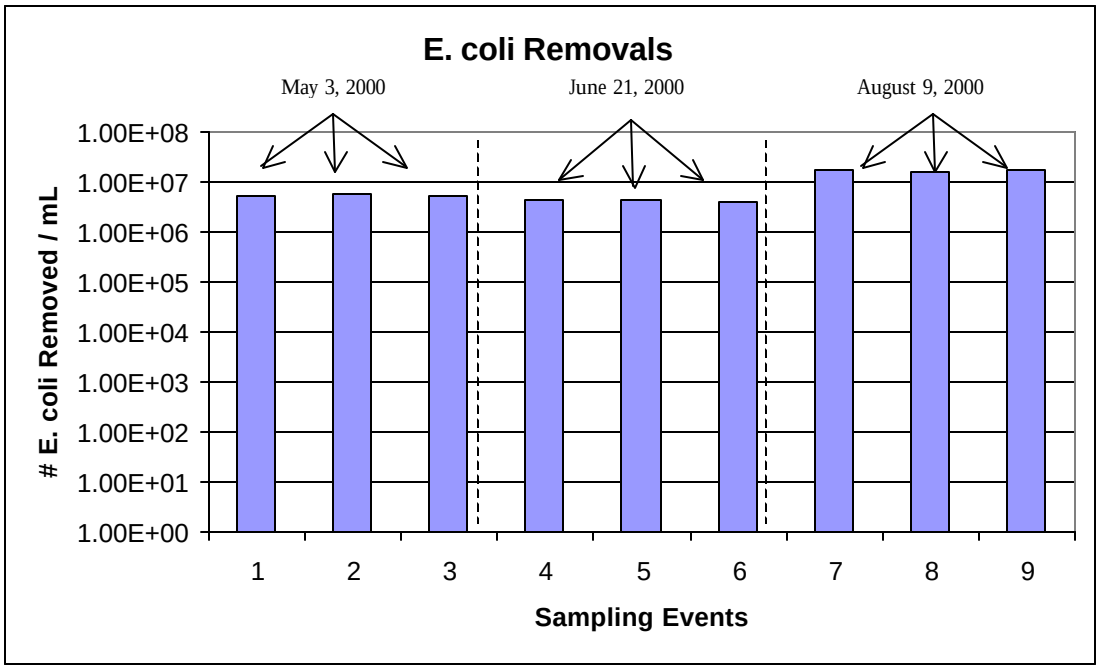

Figure 4-11. Bar Chart of Log_{10} Removal of Seeded *E. coli*

E. coli was detected in the filtrate during the June 21st microbial challenges in low, but countable numbers. Background samples taken prior to the challenge did not indicate contamination of the filtrate line. *E. coli* was also detected during the final August 9, 2000 challenge in significantly lower numbers, which were technically too few to count. The May 3rd and August 9th results considered together indicate that the June 21st results may have been partially due to sampling or laboratory contamination. The background and microbial challenge results indicate however that the membrane system was either not successful in removing all of the *E. coli* present in the raw water or some contamination developed within the piping system.

4.10 Task 9: Evaluation of O&M Manual

The manual is well written and easy to follow. Sections include: System Description, Module Installation and Rinse-Up, Safety Instruction, System Operation, System Control Interface, and Clean-In-Place Procedures. The only technical assistance needed that the manual did not include involved problems incurred with membrane failure due to the abundance of algal growth in the source water, solenoid switch failure due to excessive water introduced by an undersized compressor, and corrections in factory setting to alleviate overheating in the control panel during normal operation.

4.11 Equipment Characteristics Results

The qualitative and quantitative factors of the equipment were identified during verification testing, in so far as possible. The results of these factors are limited due to the relatively short duration of the testing cycle.

4.11.1 Qualitative

Qualitative factors that were examined during the verification testing were the susceptibility of the equipment to changes in environmental conditions and equipment safety.

4.11.1.1 Susceptibility to Changes in Environmental Conditions

The membrane system tested was designed to be operated in an enclosed location. The system was mounted on a stainless steel skid with wheels, which allowed it to be easily positioned once on site. System operation was affected by the environmental conditions experienced at the site during the testing period. The problems however, were readily resolved once they occurred. The SCADA system for the unit shutdown because of the high temperatures at the test location caused by the weather and the heat generated by pumps at the site. An adjustment of the acceptable range of temperatures within the control panel resolved the emergency shutdown problems. The air compressor (6.5 scfm) initially supplied with the membrane system was sufficient for most conditions but was undersized for periods of extreme demand, which caused the system to shutdown. The original compressor was replaced with a larger compressor (10.3 scfm). The larger compressor had sufficient capacity to supply enough compressed air for the highest periods of demand. The pneumatic control valves for the flow control valves were protected by a moisture trap and a canister containing desiccant. The trap was emptied periodically and the desiccant was regenerated by removing it from the canister and drying it in an oven. The compressor tank was drained periodically to minimize the accumulation of moisture from the humid summer air and to avoid unnecessarily overloading the protective trap and desiccant.

Changes in the environmental conditions of the raw water caused a degradation in feed water quality, namely presence of algae. System operation was terminated seven times because the TMP termination criteria (30 psi) was reached. The terminations were believed to be a direct result of high concentrations of algae in the feed water. Use of a source water with high concentrations of algae and/or iron bacteria in the feed water is not typical for MF technology and presented a worst case scenario feed water for the Pall unit. For additional information on operation and maintenance of the system, refer to a previous ETV Report (#00/09/EPADW395), which documents operation and maintenance results on a cleaner water source.

4.11.1.2 Equipment Safety

There were no equipment safety incidents during the testing period. The system was well contained and operating instructions were clear and manufacturer support, if problems arose, was timely.

4.11.2 Quantitative

Quantitative factors that were examined during the verification testing were power usage, consumables, waste disposal, and length of operating cycle.

4.11.2.1 Power Usage

Average power usage during system operation was approximately 203 gallons/kWh.

4.11.2.2 Consumables

The cleaning chemicals used during the testing period were 680 grams of sodium hydroxide, 960 mL of 5.25% sodium hypochlorite and 3.0 kg of citric acid in the production of 56,500 gallons of filtrate.

4.11.2.3 Waste Disposal

The two waste streams generated during the operation of the equipment were waste water from the RF cycle and the chemical cleaning solution volumes. The approximate RF volume during the testing period was 3800 gallons or 6.7% (6.7 gal/100 gal) of the total permeate produced. Chemical cleaning volumes collected during the four chemical cleaning events were 135 gallons of caustic/chlorine cleaning solution and 101 gallons of citric acid cleaning solution.

The caustic/chlorine cleaning solutions, the citric acid cleaning solutions, and the rinse solutions were kept separate in plastic storage barrels. After the project was completed they were transported to UNH and were subsequently disposed of by the Hazardous Waste Management Department at UNH.

4.11.2.4 Length of Operating Cycle

Two operating cycles occurred during operation: the filtrate cycle and the interval between chemical cleanings. The lengths of these cycles are site specific. The filtration cycle is the length of time between reverse filtration (RF) and air scrub (AS) physical cleanings. The RF and AS cleanings are an integral element of the daily operation of the membrane system. The RF cycle was initially set to occur each 30 minutes for 30 seconds. During the course of testing, the frequency and duration of RF and AS cycles were altered to optimize performance. To reduce the rate of increase of the TMP, frequencies of the RF and AS cycles were changed to 20 and 40 minutes, respectively. This change did not dramatically alter the rate of increase to the TMP. After a chemical cleaning, the duration of the RF was increased from 30 to 60 seconds and the frequency of the AS was increased from every 60 minutes to every 30 minutes. The adjustment stopped the rapid increase in the TMP and lowered the TMP from 15 psi to a steady 10 psi. When the filtrate flow rate was increased from 2.1 to 2.5 gpm the TMP resumed its increase at a similar rate. Four chemical cleanings took place during the 436 hours of testing (May 9, May 18, June 7, and July 10). The chemical cleaning was effective in consistently returning the TMP to starting levels of 11 psi on average. The results of this portion of the study could be attributed to the biological fouling caused by the algae present in the feed water. The algae present in the raw water reduced run times by approximately 75% as estimated by the manufacturer, who anticipated run times on the order of 30 days between cleanings at this site.

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