September 2001
NSF 01/24/EPADW395

Environmental Technology Verification Report

Physical Removal of *Giardia*- and *Cryptosporidium*-Sized Particles in Drinking Water

Lapoint Industries Aqua-Rite Potable Water Filtration System

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:	**BAG FILTRAION USED IN DRINKING WATER TREATMENT SYSTEMS**	
APPLICATION:	**REMOVAL OF *GIARDIA*- AND *CRYPTOSPORIDIUM*-SIZED PARTICLES IN DRINKING WATER**	
TECHNOLOGY NAME:	**AQUA-RITE POTABLE WATER FILTRATION SYSTEM**	
COMPANY:	**LAPOINT INDUSTRIES**	
ADDRESS:	**48 COMMERCIAL STREET LEWISTON, ME 04240**	PHONE: **(207) 777-3100** FAX: **(207) 777-3177**
WEB SITE: EMAIL:	**www.lapointindustries.com dmosley@lapointindustries.com**	

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 Drinking Water Treatment Systems (DWTS) Pilot, one of 12 technology areas under ETV. The DWTS Pilot recently evaluated the performance of a bag filtration system used in package drinking water treatment system applications. This verification statement provides a summary of the test results for the Lapoint Industries Aqua-Rite Potable Water Filtration System. Gannett Fleming, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the Lapoint Industries Aqua-Rite Potable Water Filtration System was conducted from April of 2000 to January of 2001. The treatment system consisted of a prefilter and a bag filter connected in series. The treatment system underwent microsphere removal challenge testing at 0% headloss of the bag filter, at 50% headloss of the bag filter and at greater than 90% headloss of the bag filter. The microsphere challenges utilized microspheres of 3.7µm and 6.0µm size, which were selected due to their similarity in size to *Cryptosporidium* oocysts and *Giardia* cysts, respectively. The treatment system demonstrated a 3.2 log_{10} removal of the 3.7 µm microspheres and a 3.5 log_{10} removal of the 6.0µm microspheres during the 0% headloss challenge. The system demonstrated 1.9 log_{10} removal of the 3.7µm microspheres and a 2.4 log_{10} removal of the 6.0µm microspheres during the 50% headloss challenge. The system demonstrated 2.2 log_{10} removal of the 3.7µm microspheres and a 2.6 log_{10} removal of the 6.0µm microspheres during the greater 90% headloss challenge. Source water characteristics were: turbidity average 0.75 Nephlometric Turbidity Units (NTU), pH 7.1, and temperature 12.1°C. During the verification test, the system was operated at a flow rate of 20.69 gallon per minute (gpm). Each bag filter was operated to the 25 pounds per square inch (psi) of headloss and filtered on average 92,900 gallons. At approximately 20 gpm, each filter bag was in service for an average of 98 hours before changeout was required. Filter changeout was done manually and took approximately five minutes to complete. A total of eight bag filters and three prefilters were used during the testing.

TECHNOLOGY DESCRIPTION

Bag filtration is generally used for the removal of particulate material from ground water or high quality surface waters with turbidity less than or equal to 1 NTU that do not contain fine colloidal clays or algae. The Aqua-rite Potable Water Filtration System consisted of a prefilter mounted in a pressure vessel and a bag filter mounted in a pressure vessel. A bag filter is defined as a non-rigid, disposable, fabric filter in which flow generally is from the inside of bag to the outside. The filter bags are contained within pressure vessels designed to facilitate rapid change of the filter bags when the filtration capacity has been used up. The Aqua-Rite Potable Water Filtration System does not employ any chemical coagulation. The pretreatment employed consists of prefiltration. The manufacturer reports that the pore sizes in the filter bags designed for protozoa removal are generally small enough to remove protozoan cysts and oocysts but large enough that bacteria, viruses and fine colloidal clays would pass through.

The treatment system required a pressurized stream of feed water. Water passes first through the prefilter, which removes larger particulate material. This serves to exclude the larger debris from the feed water, which would tend to clog the finer pored bag filter and cause premature clogging of the bag. After prefiltration, the water passes through the bag filter itself where the finer particulate is removed.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification testing site was Burnside Borough's water system chlorination station located in the Borough of Burnside, Clearfield County, Pennsylvania. The chlorination building is located on Cemetery Road approximately 1 ¼ mile west of U.S. Route 219. The Aqua-Rite Filtration System was installed in the basement of the Burnside Borough's chlorination building.

The source water for the verification testing was from the water system's 208,000 gallon in-ground covered reservoir located approximately 100 feet in elevation and about one-half mile away from the chlorination building, which housed the treatment unit. The reservoir is primarily supplied by a natural spring identified as Spring No. 1 via gravity feed. Spring No. 2, a secondary supply that must be pumped up to the reservoir, was used on 208 days in 1999. A third spring, Chura Spring, flows into Spring No. 2.

There is a well that supplements the production of the springs at the reservoir site. It is used only on an as needed basis when the production from the springs is inadequate to meet system demand.

Methods and Procedures

All field analyses (i.e. pH, turbidity and temperature) were conducted daily using portable field equipment according to Standard Methods for the Examination of Water and Waste Water, 18th Ed., (APHA, et. al., 1992). Likewise, Standard Methods, 19th Ed., (APHA, 1995) were used for analyses conducted by CWM laboratory. These analyses included total alkalinity, total hardness, iron, manganese, total organic carbon (TOC), algae (number and species), and total coliform, Total alkalinity, total hardness, total coliform and TOC analyses were conducted monthly. Iron and manganese analyses were conducted twice during the verification testing. Algae analyses were conducted weekly.

Microsphere removal challenge testing was performed using fluorescent microspheres of 3.7µm and 6.0µm size. These sizes were selected due to their similarity in size to *Cryptosporidium* oocysts and *Giardia* cysts respectively. There were four separate challenges conducted. The first challenge was conducted at 0% of the terminal headloss of the bag filter the second and third challenges were done at approximately 50% of the terminal headloss of the bag filter, and the last challenge was conducted at greater than 90% of the terminal headloss of the bag filter. The seeding, sampling, and analyses were conducted using methods as outlined in the Protocol for Equipment Verification Testing for the Physical Removal of Microbiological and Particulate Contaminants (EPA/NSF, 1999). The microspheres were added to 500 ml of deionized water to which 0.01% of Tween 20 had been added. This suspension was constantly mixed and added as a slug dose to the treatment system using diaphragm pumps. The pumps were operated at about 250 ml per minute and were capable of overcoming the pressure in the feed water line of the pilot unit. Samples of the filtrate were collected into five gallon containers at a flow rate 10% of the system flow. A total of 20 gallons was collected and shipped to the laboratory for analysis. In addition, aliquots of the stock suspension and the feed water were collected and analyzed to calculate concentrations of the microspheres in the feed water. The two 50% headloss challenges included a stop and start of the treatment system to simulate conditions likely to occur during normal operation of the system.

VERIFICATION OF PERFORMANCE

System Operation

The treatment system was capable of normal operations without manual intervention. All operational data, flows, pressures, turbidity and particle counts were recorded on data logging software that was not provided as part of the treatment system. Manual intervention was required only to change out the spent prefilters and bag filters. Daily site visits were conducted to record the operational data, make adjustments as necessary to maintain the desired flow, and to conduct the required daily onsite testing and sample collection.

The average feed water flow rate during the ETV study was 20.69 gallon per minute (gpm) and ranged from 22.04 gpm to 18.12 gpm. The average bag filter effluent flow rate was 20.01 gpm and ranged from 21.19 gpm to 17.45 gpm. The difference between the feed water flow and the bag filter effluent flow was due to samples being drawn off for the online analytical equipment. The flow rate was recorded twice per day.

Headloss through the system was calculated from inlet and outlet pressure readings taken from the prefilter and bag filter. According to the manufacturer, maximum headloss permissible for the prefilter and the bag filter was 25 psi for each unit. Changeout of the prefilter and bag filter was conducted according to these criteria. On average, the bag filter produced 92,900 gallons of effluent for every bag filter used. The maximum amount of effluent produced with one bag filter was 237,600 gallons; the minimum effluent produced was 26,700 gallons. The reason for the differences in effluent production per bag filter is unknown but most likely relates to feed water quality. The average run time per bag filter was 98 hours. The maximum run time for a bag filter was 164 hours; the minimum run time was 24 hours. A total of eight bag filters were used during the testing. A total of three prefilters were used during the testing.

Water Quality Results

The initial evaluation of the treatment system involved a verification of consistent performance of bag filters from the same and from different production lots. This evaluation consisted of quantifying the rate of headloss development, turbidity and particle removal for bags from the same and different lots. Analysis of the collected data indicated that there was not a significant difference in bag filter performance for bag filters from the same and different lots.

The average effluent turbidities as measured by the online turbidimeters during the 10 day variability testing of filters from the same lot were 0.35, 0.30, and 0.30 NTU in housings #1, #2, and #3, respectively. The average effluent cumulative particle counts (>2 µm) during the 10 day variability testing of filters from the same lot were 15.09, 15.99, and 18.21 total counts per ml in housings #1, #2, and #3, respectively.

The average effluent turbidities as measured by the online turbidimeters during the 10 day variability testing of filters from three different lots were 0.85, 0.70, and 0.70 NTU in housings #1, #2, and #3, respectively. The average effluent cumulative particle counts (>2 µm) during the 10 day variability testing of filters from three different lots were 25.16, 25.62, and 31.39 total counts per ml in housings #1, #2, and #3, respectively.

The treatment system underwent microsphere challenge testing four times during the verification testing. During the 0% bag filter headloss microsphere challenge testing the system demonstrated a 3.2 $\log_{10}$ removal of the 3.7 µm microspheres and a 3.5 $\log_{10}$ removal of the 6.0µm microspheres. During the first 50% bag filter headloss microsphere challenge testing the system demonstrated a 1.9 $\log_{10}$ removal of the 3.7 µm microspheres and a 2.5 $\log_{10}$ removal of the 6.0µm microspheres. During the second 50% bag filter headloss microsphere challenge testing the system demonstrated a 1.9 $\log_{10}$ removal of the 3.7 µm microspheres and a 2.4 $\log_{10}$ removal of the 6.0µm microspheres. During the 90% bag filter headloss microsphere challenge testing the system demonstrated a 2.2 $\log_{10}$ removal of the 3.7 µm microspheres and a 2.6 $\log_{10}$ removal of the 6.0µm microspheres.

During the verification testing the Aqua-Rite Potable Water Filtration System samples of the feed water and bag filter effluent were tested for total alkalinity, total hardness, total coliform, iron, manganese, total organic carbon (TOC), and algae concentrations. No significant reductions were seen in total alkalinity, total hardness, iron, manganese or TOC. This was not unexpected since these constituents tend to be present in water in a soluble state and would not be removed by the straining process used by the bag filter. No reduction was seen in the presence of total coliform in the feed and filtered water. Although coliform bacteria are by their nature not soluble in water the small size of the organism would render it capable of passing through the bag filter unimpeded. Algae concentrations were reduced through the treatment system although given the low levels of algae in the feed water the difference between the feed water and bag filter effluent concentrations was not statistically significant.

The average turbidity concentration in the feed water was 0.75 NTU and 0.15 NTU in the bag filter effluent. Particle counts were reduced from an average of 451.017 total counts/ml (2-200µm) in the feed water to an average 21.518 total counts/ml (2-200 µm) in the bag filter effluent.

Temperature of the feed water during the verification testing was quite stable. The average temperature of the feed water was 12.2°C, and ranged from 11.0°C to 13.5°C.

The following table presents the results of the water quality testing of the feed water and filtered water samples collected during the verification testing:

Feed Water Quality / Filtered Water Quality
Lapoint Industries Aqua-Rite Potable Water Filtration System

	Total Alkalinity (mg/l)	Total Hardness (mg/l)	Total Coliforms (cfu/100 ml)	Iron (mg/l)	Manganese (mg/l)	TOC (mg/l)	Algae (cells/ml)	Benchtop Turbidity (NTU)	Particle Counts (particles/ml)
Average[1]	71/66	79/72	POS/POS	<0.05/ <0.05	0.028/ 0.029	<2.0/<2.0	1/<1	0.80/0.15	451/ 21.2
Minimum[1]	N/A	N/A	N/A	<0.05/ <0.05	0.021/ 0.022	N/A	<1/<1	0.50/0.05	123/0.450
Maximum[1]	N/A	N/A	N/A	<0.05/ <0.05	0.035/ 0.035	N/A	1/<1	1.2/0.50	1305/499
Std. Dev. [1]	N/A	N/A	N/A	N/A	N/A	N/A	1/NA*	0.20/0.10	----
95% Confidence Interval[1]	N/A	N/A	N/A	N/A	N/A	N/A	(<1,1)/ (N/A*)	(0.70, 0.80)/ (0.15, 0.20)	----

1 – Concentration of feed water/concentration of filtered water.
N/A = Not Applicable due to limited number of samples
N/A* = Not Applicable standard deviation = 0
---- = Statistical measurements on cumulative data not calculated.

Operation and Maintenance Results

Given the nature of the treatment system the maintenance requirements were minimal. Replacement of the prefilter and bag filter are the only major maintenance tasks required for operation. Care during the installation of new prefilter or bag filters should be exercised to assure that none of the components are damaged. Protection of the O-rings used to seal the system will minimize the need to replace these items.

The Operating and Maintenance (O&M) Manual provided by Lapoint outlined the procedures to be followed when relieving system pressure and installing new prefilters or bag filters. The manual was adequate although no trouble shooting procedures were provided to aid the operator in identifying possible causes rapid headloss increases, high filtrate turbidity, or other water quality or operational difficulties. Procedures to identify a mis-installation of the bag filter were not included.

Original Signed by
E. Timothy Oppelt *9/20/01*

E. Timothy Oppelt — Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original Signed by
Gordon Bellen *9/22/01*

Gordon Bellen — Date
Vice President
Federal Programs
NSF International

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

Availability of Supporting Documents

Copies of the *ETV Protocol for Equipment Verification Testing for Physical removal of Microbiological and Particulate Contaminants* dated May 14, 1999, the Verification Statement, and the Verification Report (NSF Report #01/24/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)

September 2001

Environmental Technology Verification Report

Physical Removal of *Giardia*- and *Cryptosporidium*-sized Particles in Drinking Water

Lapoint Industries
Aqua-Rite Potable Water Filtration System
Used in Drinking Water Treatment

Prepared for:

NSF International
Ann Arbor, Michigan 48105

Prepared by:

Gannett Fleming
Harrisburg, PA 17106

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

Jeffrey Q. Adams, Project Officer
National Risk Management Research Laboratory
Cincinnati, Ohio 45268

Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under Cooperative Agreement No. 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 the NSF International (NSF) and the United States Environmental Protection Agency (EPA) by Gannett Fleming, Inc., in cooperation with Lapoint Industries. The test was conducted between April 2000 and January 2001 in Burnside Borough Pennsylvania at the water system's chlorination station.

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 approaches to better protect the environment.

The EPA has partnered with NSF, an independent, not-for-profit testing and certification organization dedicated to public health, safety and protection of the environment, to verify performance of small package drinking water systems that serve small communities under the ETV Drinking Water Treatment Systems (DWTS) 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

$CaCO_3$	Calcium Carbonate
cfu	colony forming unit
^oC	degrees Celsius
DWTS	Drinking Water Treatment System
EPA	U.S. Environmental Protection Agency
ESWTR	Enhanced Surface Water Treatment Rule
ETV	Environmental Technology Verification
^oF	degrees Fahrenheit
FOD	Field Operations Document
FTO	Field Testing Organization
gpm	gallon per minute
GUDI	Ground water under the influence of surface water
mg/L	milligram per liter
N/A	Not Applicable
NIST	National Institute of Standards and Technology
NSF	NSF International (formerly known as National Sanitation Foundation)
NTU	Nephlometric Turbidity Units
O&M	Operations and Maintenance
PADEP	Pennsylvania Department of Environmental Protection
psi	pounds per square inch
QA/QC	Quality Assurance/Quality Control
SDWA	Safe Drinking Water Act
SWTR	Surface Water Treatment Rule
TOC	Total Organic Carbon
TSS	Total Suspended Solids

ACKNOWLEDGMENTS

The Field Testing Organization, Gannett Fleming, Inc., 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.

Gannett Fleming, Inc.
P.O. Box 67100, Harrisburg, PA 17106-7100
Contact Person: Mr. Gene Koontz, Project Administrator

The laboratory selected for analytical work of this study exclusive of the microsphere analyses was:

CWM Laboratories
220 S. Jefferson St., Kittaning, PA 16201
Contact: David Kohl, Laboratory Manager

The laboratory selected for the microsphere enumeration was:

Clancy Environmental Consultants
P.O. Box 314, St. Albans, VT 05478
Contact: Tom Hargy

The Manufacturer of the Equipment was:

Lapoint Industries
48 Commercial Street, Lewiston, ME 04240
Contact: Dan Mosley, Sales Manager

Gannett Fleming wishes to thank NSF International, especially Bruce Bartley, Project Manager, Carol Becker and Kristie Wilhelm, Environmental Engineers, for providing guidance and program management.

The Burnside Borough staff including Mr. Richard Hoover, Borough Council President, Mr. John Ciphert, and Mr. Ron Wolf provided invaluable analytical and operational assistance.

Mr. Dan Mosley, Senior Sales Engineer, Lapoint Industries, was the primary contact for manufacturer and provided the treatment system and technical and product assistance as necessary.

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 (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF) in cooperation with the EPA operates the Drinking Water Treatment Systems (DWTS) Pilot, one of 12 technology areas under ETV. The DWTS Pilot evaluated the performance the Lapoint Industries Aqua-Rite Potable Water Filtration System used in package drinking water treatment system applications. The system employs a non-rigid, disposable, fabric bag filter in which flow is from the inside of the bag to the outside.

The Aqua-Rite Potable Water Filtration System equipment capabilities and equipment performance relative to water quality regulations were evaluated. The equipment's ability to remove *Giardia*- sized particles and *Cryptosporidium*- sized particles was tested. Fluorescent microspheres in the *Giardia* and *Cryptosporidium* size range were utilized to demonstrate removal capability. This document provides the verification test results for the Aqua-Rite Potable Filtration System.

1.2 Testing Participants and Responsibilities

The ETV testing of the Aqua-Rite Potable Water Filtration System was a cooperative effort between the following participants:

NSF International
Gannett Fleming, Inc.
Lapoint Industries
Burnside Borough
U.S. Environmental Protection Agency

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

Contact Information:

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

1.2.2 Gannett Fleming, Inc.

Gannett Fleming, Inc., a consulting engineering firm, conducted the verification testing of the Aqua-Rite Potable Water Filtration System. Gannett Fleming is a NSF-qualified Field Testing Organization (FTO) for the ETV DWTS Pilot.

The FTO was responsible for conducting the verification testing. The FTO provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. The FTO was responsible for ensuring that the testing location and feed water conditions were such that the verification testing could meet its stated objectives. The FTO 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 technology.

The FTO with assistance from Burnside Borough conducted the onsite analyses and data recording during the testing. Oversight of the daily tests was provided by the FTO's Project Manager.

Contact Information:

Gannett Fleming, Inc.

P.O. Box 67100, Harrisburg, PA 17106-7100
Phone: 717-763-7211
Fax: 717-763-1808
Contact: Gene Koontz, Project Director
Email: gkoontz@gfnet.com

1.2.3 Manufacturer

The treatment system is manufactured by Lapoint Industries, a manufacturer of bag and cartridge filtration systems for municipal and industrial water users. Lapoint Industries is based in Lewiston, Maine.

The manufacturer was responsible for supplying a field-ready bag filtration system including filter housing, prefilters, bag filters, instrumentation and controls and O&M manual, for verification testing. The manufacturer was also 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:

Lapoint Industries
48 Commercial Street, Lewiston, ME 04240
Phone: (207) 777-3100
Fax: (207) 777-3177
Contact: Dan Mosley, Sales Manager
Email: dmosley@lapointindustries.com

1.2.4 Host

The verification testing was hosted by the Borough of Burnside. The borough is located in Clearfield County Pennsylvania. The water system serves a population of approximately 325 from its 208,000 gallon in-ground covered reservoir. Burnside Borough was interested in examining the use of bag filtration to treat water which had been stored in its covered reservoir. The reservoir is supplied by natural spring water.

Contact Information:

Burnside Borough
P. O. Box 31, Burnside, PA 15721
Phone: (814) 845-2376
Fax: (814) 845-7360
Contact: Rick Hoover, Borough President
Email: BLH@Never-ENUFF.net

1.2.5 Analytical Laboratory

CWM Laboratories provided analytical services for alkalinity, hardness, total organic carbon (TOC), iron, manganese, and algae (number and species). CWM Laboratories is certified by the

Pennsylvania Department of Environmental Protection (PADEP) for analysis of Microbiological Contaminants. CWM Laboratories utilized a sub contract lab, Analytical Laboratory Services of Middletown, Pennsylvania, for the inorganic analyses. The algae analyses were conducted under contract with CWM by Environmental Associates of Olean, NY.

Contact Information:

CWM Laboratories
220 S. Jefferson St., Kittaning, PA 16201
Phone: (724) 543-3011
Fax: (724) 543-6768
Contact: David Kohl, Laboratory Manager
Email: cwmlab@alltel.net

The microsphere enumeration analyses were conducted by:

Clancy Environmental Consultants
P.O. Box 314
St. Albans, VT 05478
Phone: (802) 527-2460
Fax: (802) 524-3909
Contact: Tom Hargy
Email: thargy@together.net

1.2.6 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 the Drinking Water Treatment Systems Pilot operating under the ETV Program. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release.

1.3 Verification Testing Site

The verification testing site was Burnside Borough's water system chlorination station located in the Borough of Burnside, Clearfield County, Pennsylvania. The chlorination building is located on Cemetery Road approximately 1 ¼ mile west of U.S. Route 219. The Aqua-Rite Filtration System was located in the basement of the Burnside Borough's chlorination building.

1.3.1 Source Water

The source water for the verification testing was from the water system's 208,000 gallon in-ground covered reservoir located approximately 100 feet in elevation and about one-half mile away from the chlorination building which housed the treatment unit. The covered reservoir is shown in Photograph 1-1. The reservoir is primarily supplied by a natural spring identified as Spring No. 1 via gravity feed. Spring No. 2, a secondary supply which must be pumped up to the reservoir, was used on 208 days in 1999. A third spring, Chura Spring, flows into Spring No. 2. There is a well that supplements the production of the springs at the reservoir site. It is used only on an as needed basis when the production from the springs is inadequate to meet system demand.

Photograph 1-1. Burnside Borough Reservoir

Reservoir Spring No. 1 is located at 40E48'25" latitude and 78E48'23" longitude, and produces a discharge of 5 to 10 gpm. This spring originates from an unnamed local perched aquifer near the top of the Glenshaw Formation of the Comemaugh Group. This formation is a variable sequence of sedimentary rock types, mainly silt and clay shales. Thin bedded sandstones are also found within limestone and calcareous claystones. Red beds from several feet to over 20 feet are commonly found. The groundwater systems are usually perched aquifers above the relatively impermeable red beds and claystone.

The watershed area surrounding Spring No. 1 is mainly wooded with rolling terrain. The soil group is the Rayne-Gilpin with 15-25% slopes, and on the edge of the Wharton Silt Loam, 3% to 8% slopes. Spring No. 1 is protected from surface runoff by its concrete springbox and a diversion ditch.

Spring No. 2 is located at 40^{o}48'25" latitude and 78^{o}48'22" longitude and produces a discharge of 3 to 7 gpm. This spring originates from an unnamed local perched aquifer near the middle of the Glenshaw Formation of the Conemaugh Group. This formation is a variable sequence of sedimentary rock types, mainly silt and clay shales. Thin bedded sandstones are found along with thin limestones and calcareous claystones. Red beds from several feet to over 20 feet are common. Spring No. 2 is primarily used from May to December.

The watershed area for Spring No. 2 is the same as Spring No. 1 except Spring No .2 is located on the bottom of the slope, approximately 55 feet below Spring No. 1.

Chura Spring is located at 40E41'28" latitude and 78E48'24" longitude and produces a discharge of 2 to 3 gpm. Chura Spring is primarily used from May to December. The geological and watershed data are the same as Spring No. 1.

The Reservoir Well is located at 40E48'28" latitude and 78E48'22" longitude and produces a discharge of 2 to 3 gpm. The static water level depth is 60.78' with casing and grout to 58'.

The covered reservoir and associated springs and well sources of supply are considered high quality supplies. Limited historical records indicate that normal turbidity levels are less than 1.0 NTU from Spring No. 1 and Chura Spring. Normal turbidity from Spring No. 2 is between 1.0 NTU and 2.0 NTU. Water quality data for each spring is presented in Appendix A. There are no historical water quality records available for the reservoir well; this supply is treated with a sequestering agent, indicating the presence of iron and/or manganese.

The PADEP has classified these springs and the reservoir as groundwater under the direct influence of surface water (GUDI); Burnside Borough is under a consent decree to provide filtration for these supplies. As such, the source water was considered adequate to verify the manufacturer's treatment claims.

During the verification testing, the feed water turbidity ranged from 0.50 to 1.2 NTU with an average of 0.75 NTU. pH was an average of 7.1. A single sample was collected for total alkalinity and was 71 mg/l as $CaCO_3$. Hardness as $CaCO_3$ was 79 mg/l as measured in a single sample. Total organic carbon (TOC) was less than 2.0 mg/l based on the results of a single sample. The feed water was coliform bacteria positive. The feed water cumulative particle counts averaged 451 counts/ml. Temperature averaged 12.2^{o}C. The alga levels during the verification testing averaged 1 cell/ml. Tables 1-1 and 1-2 present the feed water quality data.

Table 1-1. Lapoint Industries Aqua-Rite Potable Water Filtration System Feed Water Quality – Laboratory Analytes

Date	Total Alkalinity (mg/l)	Total Hardness (mg/l)	Total Coliforms (Neg., Pos.)	TOC (mg/l)	Algae (cells/ml)	Iron (mg/l)	Manganese (mg/l)
10/9/00	71	79	Pos.	<2.0	1	<0.05	0.021
10/19/00	--	--	--	--	1	<0.05	0.035
10/25/00	--	--	--	--	<1	--	--
11/9/00	--	--	--	--	<1	--	--
Average	71	79	Pos.	<2.0	1	<0.05	0.028
Minimum	N/A	N/A	N/A	N/A	<1	<0.05	0.021
Maximum	N/A	N/A	N/A	N/A	1	<0.05	0.035
Std. Dev.	N/A	N/A	N/A	N/A	1	N/A	N/A
95% Confid Int.	N/A	N/A	N/A	N/A	(0,1)	N/A	N/A

N/A = Not applicable because the sample size (n) was 1 or 2.
Pos. = Positive result from a presence / absence test.

Table 1-2. Lapoint Industries Aqua-Rite Potable Water Filtration System Feed Water Quality – On-Site Analytes

	Total Particle Counts (counts/ml)	Benchtop Turbidity (NTU)	pH
Average	451.017	0.75	7.08
Minimum	122.825	0.50	6.85
Maximum	1304.900	1.2	7.35
Std. Dev.	N/A	0.20	0.16
95% Confid Int.	N/A	(0.70, 0.80)	(7.02,7.13)
Number of Samples	183	36	35

N/A = Not applicable. Statistical measurements on cumulative data do not generate meaningful data.

1.3.2 Treatment System Effluent Discharge

The effluent of the system was discharged from the chlorination building to an existing swale. The PADEP issued a temporary permit for the discharge.

Chapter 2
Equipment Description and Operating Processes

2.1 Equipment Description

The equipment tested in this ETV program was Lapoint Industries Aqua-Rite Potable Water Filtration System. The system is a compact, package filtration system consisting of a prefilter and a bag filter. The prefilter was a Valu-Life (column) Bag Filter designated as AP1P2S8T. The filtration bag used in the system was the HPM-97 CC 2SS. The prefilter and bag filter were housed in stainless steel pressure vessels. The filters are supported inside the vessels by a stainless steel wire mesh basket. The filter housings are designed with a recessed basket and a volume displacer permanently welded to the top cover. A double O-ring seals the vessel cover to the housing to eliminate any potential bypass. The filter housings had a volume of 1.35 ft^3.

The manufacturer reports that the prefilter, the Valu-Life (8 Column) Bag, has greater effective filtration surface than a standard single layer filter bag. The nominal pore size of the prefilter is less than 5.0 µm. The greater surface area and increased depth this filter provides both longer life and higher efficiency.

The filtration bag incorporates a unique graduated layering of media design. The inner layer consists of a built-in prefilter and progresses to tighter outer layers. Particles are systematically removed as water travels through the multiple layers, with each individual layer removing a particular-size range of particles. The graduated layering of media aids in the prevention of premature blinding, reducing frequency of filter changeout. Due to this unique layering system there is a wide range of pore sizes in the bag filter itself. The nominal pore size of the "loosest" layers of the bag filter is less than or equal 1.0 µm with additional layers ranging down to 0.5 µm or less.

2.1.1 Data Plate

The data plate affixed to the treatment system contains the following information.

a. Equipment name: Aqua-Rite Potable Water Filtration System
b. Filter Model #: HPM-97 CC 2SS
c. Filter Housing Model #: AQ-2-2BSH
d. Prefilter: Valu-Life (column) Bag Filter SP1P2S8T
e. Prefilter Housing Model #: CQX1-180 – 2- B2NSB
f. Electrical requirements: None
g. Serial number: None
h. Warning and caution statements: None
i. Capacity or output rate: 20 – 25 gpm

2.2 Operating Process

2.2.1 Feed Water

The feed water is delivered via gravity into the filtration system.

2.2.2 Prefiltration

A disposable bag prefilter, Valu-Life (column) Bag Filter, removes large particles prior to the feed flow entering the final bag filter. The prefilter protects the final filter from the large debris and extends the life of the final filter. The feed water enters into the inside of the bag and is filtered as it passes through to the exterior of the bag. The pressure drop across the prefilter is monitored on a daily basis and it is replaced when the pressure differential reaches 25 psi. Replacement of the prefilter is accomplished by removing the spent prefilter and discarding it and replacing it with a new prefilter. The prefilter can not be cleaned and reused. The life of prefilter is dictated by the raw water quality.

2.2.3 Filtration

The bag filter, the HPM-97 CC 2SS, receives the prefiltered water. The water enters the inside of the bag, passes through the multiple layers of the filter and exits through the outside of the filter. The pressure drop across the bag filter is monitored on a daily basis and it is replaced when the pressure differential reaches 25 psi. Replacement of the filter is accomplished by removing the spent filter and discarding it and replacing it with a new filter. The filter can not be cleaned and reused. The life of filter is dictated by the raw water quality and the effectiveness of the prefilter. Figure 2-1 presents a schematic of the system.

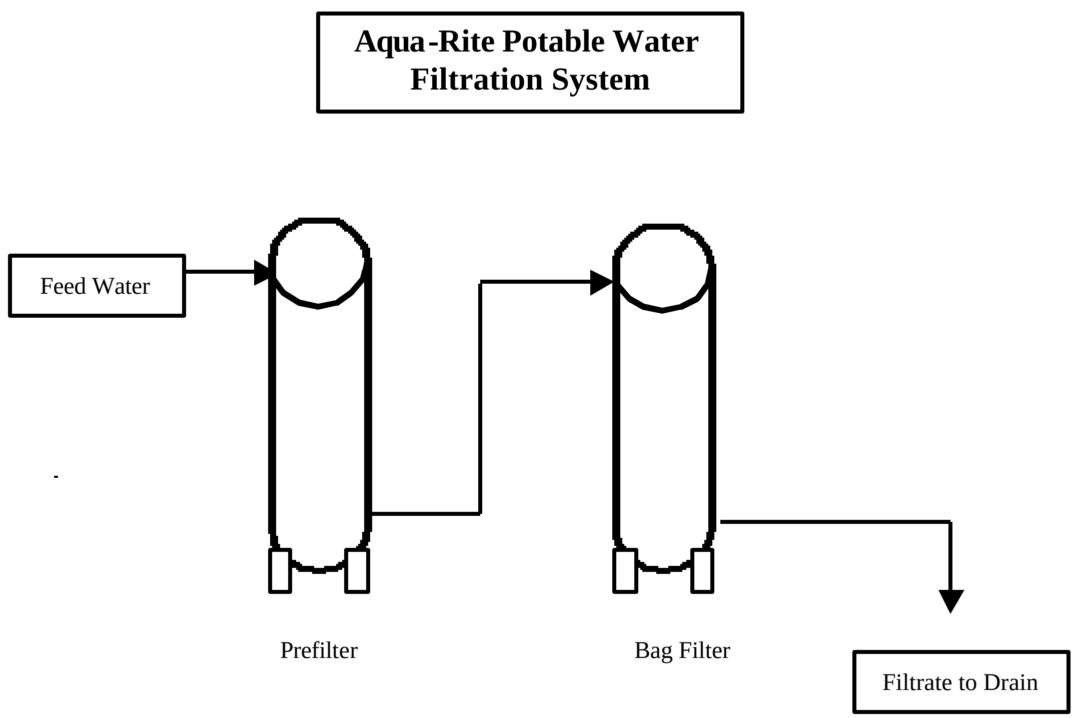

Figure 2-1. Flow Schematic

Photograph 2-1. Treatment System as Installed at Burnside Borough (including pressure vessels, pressure gauges and particle counters)

2.3 Operator Requirements

There are minimal operator requirements for the Aqua-Rite Potable Water Filtration System. The two primary requirements are monitoring the differential pressures across the prefilter and bag filter, and the replacing the prefilter and bag filter when terminal loss of head occurs. The manufacturer reports the equipment itself has no operational licensing requirements.

2.4 Safety

The primary safety concern is excessive pressure build-up in the prefilter and bag filter housings which could damage the equipment and possibly harm the operator. Lapoint Industries recommends the installation of a pressure relief valve to prevent over pressurization of the filter housings. Burnside Borough's chlorine station is fed via gravity flow from the raw water reservoir. As such, the pressure at the chlorine station can vary only slightly and averages 60 psi. Accordingly, over pressurization of the filter vessels can not occur.

2.5 Equipment Limitations

Pressure differential should not be allowed to exceed 25 psi in the filter bags. The pressure vessels themselves are rated for 150 psi continuous service.

2.6 Waste Production

Residue that is removed from the feed water stream is retained within the filter material. When prefiltered and filter bags become blinded, the filter bags and residue are disposed; they are not reused.

Chapter 3
Methods and Procedures

3.1 Experimental Design

The experimental design of this verification study was developed to provide accurate information regarding the performance of the treatment system. The impact of field operations as they relate to data validity was minimized, as much as possible, through the use of standard sampling and analytical methodology. Due to the unpredictability of environmental conditions and mechanical equipment performance, this document should not be viewed in the same light as scientific research conducted in a controlled laboratory setting.

Bag filtration is generally used for the removal of particulate material from ground water or high quality surface waters with turbidity less than or equal to 1 NTU that do not contain fine colloidal clays or algae. The test site for this verification was a public water supply utilizing spring water under the influence of surface water. The manufacturer stated that their treatment system, for this feed water, would not utilize chemical or mechanical pretreatment. One goal of the testing was to demonstrate whether this technology is suitable for the filtration of this type of source.

3.1.1 Objectives

The verification testing was undertaken to evaluate the performance of the Aqua-Rite Potable Water Filtration System equipment. The equipment capabilities and equipment performance were evaluated to assess the removal capabilities of particles in the size range of *Giardia* and *Cryptosporidium*. Also evaluated were the operational requirements and maintenance requirements of the system. The details of each of these evaluations are discussed below.

3.1.1.1 Evaluation of Equipment Capabilities

The Aqua-Rite Potable Water Filtration System equipment was tested to demonstrate its ability to remove particles in the size range of *Giardia* cysts and *Cryptosporidium* oocysts. Fluorescent microspheres were utilized to demonstrate acceptable removal capability.

3.1.1.2 Evaluation of Equipment Performance Relative to Water Quality Regulations

Drinking water regulations require, for filtration plants treating surface water and employing conventional treatment, a minimum of 3 $\log_{10}$ removal/inactivation of *Giardia* cysts from feed to finished waters and that finished water turbidity at no time exceeds 5 NTU and that at least 95% of the daily finished water turbidity samples be less than 0.5 NTU (EPA, Surface Water Treatment Rule [SWTR], 1989). Recently promulgated rules have modified the SWTR to include a lower turbidity standard, less than 0.3 NTU in 95% of the daily finished water turbidity samples, and a requirement to provide a 2 $\log_{10}$ removal of *Cryptosporidium* oocysts (EPA, Enhanced Surface Water Treatment Rule [ESWTR], 1999). Both of these rules grant the "log removal credit" if the treatment facility achieves the required turbidity levels.

The treatment system's ability to achieve required finished water turbidity levels was evaluated by examining the results of filter effluent turbidity measurements. Log removals for *Giardia* sized particles and *Cryptosporidium* sized particles were quantified using microsphere removal challenge testing although there is currently no provision for this type of testing in the regulations.

3.1.1.3 Evaluation of Operational Requirements

An overall evaluation of the operational requirements for the treatment system was undertaken as part of the verification. This evaluation was qualitative in nature. Tasks performed during daily operations and during bag changeout were used to develop a subjective judgment of the operational requirements of the system.

3.1.1.4 Evaluation of Maintenance Requirements

An attempt was made to evaluate the maintenance requirements of the treatment system during the testing. Due to the short duration of the testing there was no significant maintenance required. Suggested maintenance activities and experience with common pieces of equipment (valves etc.) were used to evaluate the maintenance requirements of the treatment system.

3.1.2 Equipment Characteristics

The qualitative, quantitative and cost factors of the tested equipment were identified, in so far as possible, during the verification testing. The relatively short duration of the testing cycle creates difficulty in reliably identifying some of the qualitative, quantitative and cost factors.

3.1.2.1 Qualitative Factors

The equipment was operated in such a way as to maintain its operating parameters within Lapoint Industries' recommendations. The nature and frequency of the changes (i.e. flow adjustment, prefilter and filter bag replacement, etc.) required to maintain the operating conditions were used in the qualitative evaluation of the equipment. Frequent and significant changes/adjustments would indicate relatively lower reliability and higher susceptibility to environmental conditions, and also the degree of operator experience that would be required.

The effect of operator experience on the bag filtration test results was evaluated. Any difficulties that the operator experienced in changing the filter bags as well as any instances of a mis-installation of a bag were used to aid in the evaluation of the effect of operator experience on the use of this system.

3.1.2.2 Quantitative Factors

The following cost factors were quantified by various means in this test:

- $Frequency of bag filter replacement (pre and final)
- $Length of operating cycle (number of hours of operation and gallons of water produced)
- $Estimated labor hours for operation and maintenance

$Impact of on/off operation on water quality

These quantitative factors were used as an initial benchmark to assess equipment performance and develop operation and maintenance costs factors.

3.2 Verification Testing Schedule

Verification testing activities included equipment setup, initial operations (which included filter variability testing), verification operations, sampling and analysis. Initial operations were conducted to be sure the equipment was functioning as intended, and was appropriate for the quality of the supply. The test schedule was developed to encompass all of these activities. There were two initial operations periods each 10 days in length during which bag filter variability within production lots and between production lots was evaluated. These periods were followed by a 30 day verification testing period.

The first initial operations period began on April 20, 2000. The second initial operations period commenced May 20, 2000. The verification testing commenced October 9, 2000 and ended January 26, 2001.

3.3 Verification Task Procedures

The procedures for each task of the verification testing were developed in accordance with the requirements in the EPA/NSF ETV Protocol (EPA/NSF 1999). The Verification Tasks were as follows:

- Task A: Characterization of Feed Water
- Task B: Initial Operations
- Task 1: Verification Testing Runs and Routine Equipment Operation
- Task 2: Test Runs for Feed Water and Finished Water Quality
- Task 3: Documentation of Operating Conditions and Treatment Equipment Performance
- Task 4: Microbial Contaminant Removal
- Task 5: Data Management
- Task 6: QA/QC

Detailed descriptions of each task are provided in the following sections.

3.3.1 Task A: Characterization of Feed Water

This goal of this task was to determine if the chemical, biological, and physical characteristics of the feed water were appropriate for the bag filtration equipment to be tested. Bag filters have limited capability to remove fine colloidal clays that cause turbidity in many surface waters and because feed waters having high concentrations of particulate matter such as algae, particles consisting of plant material, or sediment can rapidly clog bag filters, necessitating their replacement.

If the source water used as feed water for the testing program has an excessive amount of the fine turbidity-causing particles, the bag filtration or cartridge filtration equipment may not be able to attain sufficient turbidity removal to meet the requirements of the SWTR. Because bag filters do not remove viruses, the entire burden of virus control falls on the disinfection process when these filters are used for water treatment. Excessive turbidity in filtered water could present problems in attaining effective disinfection and would be a likely cause for rejection of bag filters by drinking water regulators.

If the source water used as feed water consistently has a very low turbidity and very low concentration of algae and other particulate matter, drinking water regulators may be reluctant to approve bag filters for applications in which the source water turbidity or particulate matter concentration is higher (Alaska Department of Environmental Conservation, 1994). The feed water quality chosen for Verification Testing can influence both performance of the filtration equipment and the potential for acceptance of testing results by state regulatory agencies.

For these reasons the characterization of the feed water was an important task in the verification testing.

The objective of this task was to obtain data from one or more years for the chemical, biological, and physical characterization of the feed water that will be entering the treatment system. Factors of particular interest include conditions that affect bag filter cycle lengths, such as turbidity in runoff events following heavy rainfall or snowmelt, or algae blooms.

3.3.1.1 Work Plan

This task was accomplished by compiling data obtained from the host utility. The host utility had limited feed water quality information but did have some historical water quality data for turbidity, pH, temperature, Total and Fecal Coliform, and conductivity. This information is presented in Appendix A.

A brief description of the watershed that provides the feed water was developed, to aid in interpretation of feed water characterization. The watershed description included a statement of the approximate size of the watershed, a description of the topography (i.e. flat, gently rolling, hilly, mountainous) and a description of the kinds of human activities that take place (i.e. mining, manufacturing, cities or towns, farming) or animal activities with special attention to potential sources of pollution that might influence feed water quality. The nature of the water source was also included.

3.3.1.2 Evaluation Criteria

Feed water quality was evaluated in the context of the treatment system's performance capabilities and the Surface Water Treatment Rule. The feed water was examined to determine if it provided a sufficient challenge the capabilities of the equipment but was not be beyond the range of water quality suitable for treatment by the equipment in question.

3.3.2 Task B: Initial Test Runs

Initial operations allowed the equipment manufacturer to refine the unit's operating procedures and to make operational adjustments as needed to successfully treat the source water.

Information gathered during system start up and optimization would have been used to refine the Field Operations Document (FOD), if necessary. No adjustment to the FOD was necessary as a result of the initial operations. The initial operations periods were used to evaluate the variability of the filter bags.

One objective of the initial test runs was to determine whether any pretreatment of the feed water was required prior to introduction to the system. Bag filtration may not be suitable for some feed waters. These feed waters may require some type of pretreatment prior to introduction to the bag filtration system. An evaluation of the historical feed water quality data may indicate the need for some type of pretreatment. Initial test runs may be necessary to demonstrate the suitability of the bag filtration system for the particular feed water. Treatment requirements may be different for feed waters from different test sites or for the feed water from the same site at different times of testing.

Another objective of the initial test runs was to determine the operating characteristics of the treatment system. Testing also was used to demonstrate the level of filtered water turbidity that the equipment can produce at the test site.

The first initial operations period examined the variability of three bags from the same lot and the second initial operations period examined the variability of three bags from different lots. The unit was on site and operating in April of 2000.

3.3.2.1 Work Plan

Initial tests were conducted using the filtration equipment that would be used for Verification Testing. During exploratory tests, filters were operated until sufficient data were collected to facilitate making reliable projections on the total volume of water that could be filtered through a filter bag before it clogs and must be replaced.

Initial test runs were also conducted to assess filter variability. Simultaneous testing of three filters from the same lot and receiving feed water from a single source was carried out for 10 days. Then the filter bags were changed out and replaced with one bag from the first lot tested and with two other bags from two different lots. Following the change of the bags, another 10 days of simultaneous testing was done with treatment of feed water from a single source. All filters were operated at the same rate of flow except for reductions in flow caused by head loss. During the 10 day filter variability testing periods, each filter was operated for 23 hours and stopped for 1 hour during each of the 10 days of operation.

The testing for water quality focused on turbidity and particle counting only, with no microbiological sampling done for detection of differences between bags, to obtain data using a sensitive monitoring technique, but at the same time minimizing the monitoring costs. Three particle counters were used to obtain continuous readings from each of the tested filters. Likewise, three on line turbidimeters were used to obtain readings form each of the three tested filters. Appropriate statistical analyses were carried out to assess the differences in performance among three bags of the same lot and among three bags from three different lots. Other data collected included rate of flow and head loss.

3.3.2.2 Bag Filter Effluent Turbidity

As previously discussed the major focus of the initial operations periods was to test the variability of the filter bags. One method to quantify this variability was to measure the turbidity in the effluent from each filter bag assembly. This was accomplished by using three Hach 1720D turbidimeters one connected to each bag filter effluent being tested. The collected data was statistically analyzed to determine if there was variability in the bag filters.

3.3.2.3 Bag Filter Effluent Particulate Levels

Bag variability was also quantified by examining the level of particulate material in the effluent from each bag filter assembly. The particle counting was done utilizing three Met One PCX particle counters.

3.3.2.4 Pressure Differential

Another important measure of filter bag variability was the pressure differential developed by each of the filter bags being tested. The pressure differential was calculated by subtracting the pressure of the water at the bag filter effluent from the pressure of the water at the bag filter inlet. The pressure differentials of each of the bag filter assemblies were compared to determine if there was a significant variation between filter bags.

3.3.2.5 Flow Rate

The flow rate was measured only on the inlet and outlet of the treatment array. While this information was not useful in determining filter bag variability it was useful in assuring that the treatment unit was being operated in a consistent manner.

3.3.2.6 Analytical Schedule

Because these runs were being conducted to define operating conditions for Verification Testing, a strictly defined schedule for sampling and analysis did not need to be followed.

3.3.2.7 Evaluation Criteria

The Manufacturer and FTO evaluated the data produced during the initial test runs to determine if the water treatment equipment performed so as to meet or exceed expectations with regard to water quality.

After the variability testing of multiple bags or cartridges had been completed, the FTO used the turbidity data and the particle count data collected during the variability testing to calculate 95% confidence intervals as described in "Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants" (NSF 1999).

3.3.3 Task 1: Verification Testing Runs

The objective of this task was to operate the treatment for period at least 30 days and to evaluate equipment performance under a range of circumstances including installation of new bags and attainment of terminal head loss. The water treatment equipment was operated for verification testing purposes, with the approach to treatment based on the results of the initial operations testing.

During the testing period, Tasks 1 through 6 were conducted simultaneously.

During verification testing, water treatment equipment was operated for 37 days. The treatment equipment was operated from start-up until terminal head loss was attained. During this period of time, the filtration equipment was operated for 23 hours and turned off for one hour each day. The one-hour shutdown was done to simulate the on-off operating mode that may be encountered in many small systems. The 23 hours of operation provided the opportunity for the FTO to log the maximum number of hours of equipment operation available each day, this helped to minimize the total number of days of operation needed to attain terminal head loss. When terminal head loss was attained, the clogged bag was removed and replaced with a new one, and operation resumed. The duration of each filter run from initial start to terminal head loss and the volume of water produced by the bag was recorded in the operational results.

3.3.3.1 Evaluation Criteria

The goal of this task was to operate the equipment, including time for changing prefilters and bag filters and other necessary operating activities, during verification testing. Data is provided to substantiate the operation for 37 days.

3.3.4 Task 2: Test Runs for Feed Water and Finished Water Quality

The water quality parameters selected for testing included all those necessary to permit documentation of the treatment systems performance capabilities. The performance of the prefilter with respect to water quality was also documented. Without such documentation the range of water quality for which the treatment system may be accepted could be considerably more restricted.

Table 3-1 lists the daily, weekly, and monthly water quality samples that were collected. The results of the daily on-site analyses were recorded in the operations log book. The weekly and monthly laboratory analyses were recorded in laboratory log books and reported to the FTO on separate laboratory report sheets. The data spreadsheets are attached to this report as Appendix B.

Table 3-1. Analytical Data Collection Schedule

Parameter	Frequency	Feed	Prefilter Effluent	Bag Filter Effluent
Onsite Analytes				
Temperature	Daily	1	0	0
pH	Daily	1	0	0
Turbidity	Daily	Continuous	Continuous	Continuous
Particle Counts	Daily	Continuous	Continuous	Continuous
Laboratory Analytes				
Total Alkalinity	Once/month	1	0	1
Total Hardness	Once/month	1	0	1
Total Coliforms	Once/month	1	0	1
TOC	Once/month	1	0	1
Iron	Twice/month	1	1	1
Manganese	Twice/month	1	1	1
Algae	Weekly	1	1	1

The manufacturer was responsible for establishing the filtration equipment operating parameters, on the basis of the initial test runs. The treatment system was operated as described in Section 3.3, Schedule. When terminal head loss was reached, the filter bag was replaced, and filtration operations was resumed and continued until the end of the test period.

The water quality parameters listed in Table 3-1 under the heading On Site Analytes were measured by the FTO. Analysis of the remaining water quality parameters was performed by a state-certified analytical laboratory. The methods used for measurement of water quality parameters in the field are described in the QA/QC section below and in Table 3-3. Where appropriate, the *Standard Methods* reference numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

Water quality samples that were shipped to the state-certified analytical laboratory for analysis were collected in appropriate containers (containing preservatives as applicable) prepared by the laboratory. These samples were preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory.

Turbidity of the feed and filtered water was measured and recorded using a continuous, flow-through turbidimeter. On a daily basis, a bench model turbidimeter was used to check the continuous turbidimeter readings.

The water quality parameters were selected to provide State drinking water regulatory agencies with background data on the quality of the feed water being treated and data on the quality of the filtered water. The parameters were selected to enhance the acceptability of the verification testing data to a wide range of drinking water regulatory agencies.

3.3.4.1 Evaluation Criteria

Evaluation of water quality in this task was related to determining whether the treatment system was capable of meeting the requirements of the Surface Water Treatment Rule.

- Turbidity removal equals or exceeds requirements of Surface Water Treatment Rule

- Water quality and removal goals specified by the Manufacturer
- Water quality improvement attained by prefiltration

The regulations proposed in the Enhanced Surface Water Treatment Rule (ESWTR) also provided guidance for the treatment goals established in the Manufacturer's statement of performance capabilities and was considered in the evaluation criteria.

3.3.5 Task 3: Documentation of Operating Conditions and Treatment Equipment Performance

The objective of this task was to accurately and fully document the operating conditions that applied during treatment, and the performance of the equipment. This task was intended to develop data that described the operation of the equipment and develop data to create cost estimates for operation of the equipment.

During each day of verification testing, operating conditions were documented. This included descriptions of treatment processes used and their operating conditions. In addition, the performance of the water treatment equipment was documented, including rate of filter head loss gain, water pressure at the inlet and outlet of the pre and bag filter pressure vessels, length of filter run and terminal head loss.

The operational parameters and frequency of readings are listed in Table 3-2 below.

Table 3-2. Operational Data Collection Schedule

Parameter	Frequency
Raw Flow	2/day
Filtrate flow	2/day
Prefilter inlet pressure	2/day
Prefilter outlet pressure	2/day
Bag filter inlet pressure	2/day
Bag filter outlet pressure	2/day

A complete description of each process was developed. Provided data on the filter included:
- flow capacity
- nominal pore rating of filter bag and the method used to determine this pore rating
- number of filter bags housed within the pressure vessel
- maximum operating pressure of filter vessel
- volume of filter vessel
- a complete description of the pre-filtration equipment

In addition, system reliability features including redundancy of components were observed. Spatial requirements for the equipment (footprint) were obtained. The above requirements were met by information provided by the manufacturer.

During each day of verification testing, treatment equipment operating parameters for treatment system were monitored and recorded on a routine basis. This included rate of flow, filtration rate, pressure at filter vessel inlet and outlet, and maximum head loss. Performance was evaluated to develop data on the number of gallons of water that was treated by each bag and on energy needed for operation of the process train being tested.

A daily log was kept in which events in the watershed are noted if they influenced source water quality. This included such things as major storm systems, rainfall, snowmelt, temperature, cloud cover, and upstream construction activities that disturbed soil.

The performance of the prefiltration equipment was documented in the same manner as the bag filtration portion of the treatment system.

3.3.5.1 Evaluation Criteria

The data developed from this task was analyzed to determine the treatment system's performance capabilities. The quantity of water that was produced and met quality criteria for acceptance was an important factor in this evaluation.

3.3.6 Task 4: Microbiological Contaminant Removal

Removal of microbiological contaminants is a primary purpose of filtration of surface waters. Consequently, the treatment system's microbial removal effectiveness was evaluated in this task. Assessment of treatment efficacy was made on the basis of removal of polymeric microspheres.

The bag filtration process removes particles from water by physically straining out the particles and trapping them in the bag filter. Because particle removal is accomplished primarily by straining out particles from water on the basis of the sizes of the particles and of the pores in the filter, the applicability of surrogate particles depends on their size, shape and pliability, rather than on their biological nature. Thus appropriately sized microspheres could be suitable surrogates for protozoan cysts and oocysts.

Cysts and oocysts are biological particles without hard shells or skeletons, so they are capable of deforming slightly and squeezing through pores that might seem to be small enough to prevent their passage. In addition, the pore sizes for filter bags are not absolute, and these filters have some pores that are larger and some that are smaller than the nominal size. Therefore they do not provide an absolute cutoff for particles at or slightly larger than their nominal size. For these reasons, microspheres used in challenge tests were slightly smaller than the smallest size for the protozoan organism for which the microspheres were a surrogate.

Removal of turbidity by bag filtration is not synonymous with removal of protozoan organisms because turbidity-causing particles can be much smaller than protozoa. This results in bag filters being able to remove protozoan-sized particles while passing particles in the size range of bacteria, or the micron-sized and sub-micron-sized particles that cause turbidity. Therefore turbidity removal is not a surrogate for protozoan removal in bag filtration.

Use of electronic particle counting to assess protozoan removal is appropriate only for feed waters containing large numbers of particles in the size range of *Cryptosporidium*. For *Cryptosporidium* oocyst removal, assessment of particle removal in the size range of 3 to 5 µm is appropriate. For a general evaluation of particle removal capabilities, total particles in the 2 to 15 µm range were also be counted. Sufficient concentrations of appropriately sized particles were not present in the feed water so the use of electronic particle counting was not capable of demonstrating adequately high log removals.

The objective of this task was to evaluate removal of particles and microbiological contaminants during verification testing by measuring removal of polystyrene fluorescent microspheres seeded into the feed water. Task 4 consisted of particle counting and tests involving seeded microspheres.

3.3.6.1 Seeding Technique

During seeding tests, the concentrated suspension of microspheres was gently stirred to maintain the particles in suspension. The concentrated microspheres were suspended in a solution of distilled water with 0.01% Tween 20. Before each run with seeded microspheres, the holding vessel was washed with hot water and laboratory glassware detergent and thoroughly rinsed with tap water. Microspheres were added to the feed water using variable speed chemical feed pumps. Mixing of seeded particles into the feed water was done with an in-line mixer that attains a head loss of about 0.3 to 0.5 feet of water during operation.

3.3.6.2 Electronic Particle Counting

Particle counts in feed water just before entry into the treatment system were measured to determine the concentration of particles before filtration, and particle counts in the filtered water were measured. For assessing *Cryptosporidium* oocyst removal, particles in the size range of 3 to 5 µm were counted. For assessing Giardia cyst removal, particles in the size range of 5 to 15 µm were counted. Since appropriately sized particles were not present in sufficient densities (concentrations) in the feed water to permit calculation of log removals consistent with the SWTR and ESWTR requirements, particle counting for log removal was done during microsphere challenge events. For a general evaluation of particle removal capabilities, total particles in the size range of 2 to 15 µm were counted.

3.3.6.3 Microspheres

Evaluation of microsphere removal was conducted by determining the number of microspheres added to the feed water in a slug dose and then measuring the total number of microspheres detected in the filtered water. Microspheres used as surrogates for *Cryptosporidium* oocysts were 3.69 µm (+/- 0.05 µm) in diameter. Microspheres used as surrogates for *Giardia* cysts were 5.68 µm (+/- 0.433 µm) in diameter. Both *Cryptosporidium* oocysts sized microspheres and *Giardia* cysts sized microspheres were used during the challenge tests in order to develop log removals for each organism.

The number of microspheres used were sufficient to permit calculation of log removals that exceed the removal capability as set forth in the SWTR and ESWTR requirements. Recovery of microspheres in filtered water provided data for use in calculating definite removal percentages. Fluorescent microspheres and an optical microscope equipped with ultraviolet illumination were used for the enumeration.

A slug dose of the microspheres of a concentration of approximately $3.6*10^8$ for the 3.69 µm and $2.1*10^8$ for the 5.68 µm microspheres were added instantaneously to the feed water influent. An aliquot of the stock feed suspension was collected for analysis to calculate the concentration of the stock feed suspension. Additionally, samples of the feed water after the addition of the microspheres were collected to calculate the concentration of microspheres added to the treatment system. A sample of the feed water was collected prior to the introduction of the microspheres to check for the presence of interfering fluorescent particles in the feed water. Ten percent of the filtrate flow was collected in a side stream sample. The side stream was run at two gallons per minute until 20 gallons has been collected. The resulting 20 gallons of filtrate was shipped on ice overnight to the analytical laboratory for analysis using EPA Method 1622. Concentration of the microspheres in the collected water samples was done based on methods described in EPA Method 1622 using the approved disk track side etch membrane filter. Elution of the microspheres from the membrane was done using the method published in the original EPA draft of Method 1622. The enumeration of the microspheres was done using the method used by Abbaszadegan et al. (1997) as referenced in the ETV Test Plan Protocol. (EPA/NSF ETV Protocol – NSF Equipment Verification Testing Plan Bag Filters and Cartridge Filters for the Removal of Microbiological and Particulate Contaminants, May, 1999).

3.3.6.4 Analytical Schedule

Feed and filtered water analysis was done using flow-through particle counters equipped with recording capability so data can be collected on a 24-hour-per-day basis during verification testing.

Microspheres were seeded for evaluating the performance of a continuously running filter three times during a run: at the start-up of the equipment after a new filter bag has been installed, near the middle of the run when headloss has approached one half of the recommended terminal headloss, and near the end of the run after headloss has exceeded 90 percent of recommended terminal headloss. In addition, after the seeding challenge and sampling event in the middle of the run had been completed, the filter flow was stopped and preparations were made for another round of sampling. The treatment system was restarted and sampling was done again to evaluate the effect of stopping and starting a filter that has removed a very large number of microspheres. Microsphere samples were analyzed by Clancy Environmental Consultants.

3.3.6.5 Evaluation Criteria

Performance of the Treatment System was evaluated in the context of the SWTR and ESWTR turbidity requirements and *Giardia* and *Cryptosporidium* removal goals. Turbidity results were analyzed to determine the percentage of turbidity data in the range of 0.50 NTU or lower, the percentage between 0.51 NTU and 1.0 NTU, the percentage between 1.0 and 5 NTU, and the percentage that exceed 5 NTU. The time intervals used for determining filtered water turbidity values were the same for all data analyzed, and because continuous turbidimeters were used to collect turbidity data, the intervals were every 15 minutes. In addition, the highest filtered water turbidity observed each day was tabulated.

Electronic particle count data were evaluated by calculating the change in total particle counts from feed water to filtered water, expressing the change as log reduction. Because of possible complications in conducting electronic particle counts on feed water, four hour time intervals were used for analysis of particle counting data for log reduction of particles. Total particle counts from the feed and finished water were selected from the ten minute "continuous" readings. These four hour readings were used to calculate a four hour log removal of total particle counts. The four hour readings are presented in a table and graphically and the log reductions are presented graphically.

Data on the density (concentration) of microspheres in feed water and filtered water were analyzed to determine the median log removal and 95th percentile log removal during the verification testing period. This analysis was done separately for each filter operating condition: at start-up with a new bag filter, midway through a run (with the previously discussed stop and restart of the filter system), and after 85 to 95 percent of terminal headloss has been attained.

3.3.7 Task 5: Data Management

Documentation of study events was facilitated through the use of logbooks, photographs, data sheets and chain of custody forms. Data handling is a critical component of any equipment evaluation or testing. Care in handling data assures that the results are accurate and verifiable. Accurate sample analysis is meaningless without verifying that the numbers are being entered into spreadsheets and reports accurately and that the results are statistically valid.

The data management system used in the verification testing program involved the use of computer spreadsheet software and manual recording methods for recording operational parameters for the membrane filtration equipment on a daily basis. Weekly and monthly water quality testing data were submitted to the FTO by CWM Laboratory representatives, verified, and entered into computer spreadsheets.

There were two primary objectives of the data handling portion of the study. One objective was to establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable operational data for the NSF for verification purposes. A second objective was to develop a statistical analysis of the data, as described in the "EPA/NSF ETV Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants" (EPA/NSF 1999).

The data handling procedures were used for all aspects of the verification test. Procedures existed for the use of the log books used for recording the operational data, the documentation of photographs taken during the study, the use of chains of custody forms, the gathering of inline measurements, entry of data into the customized spreadsheets, and the methods for performing statistical analyses.

3.3.7.1 Log Books

Field testing operators recorded data and calculations by hand in the field logbook. The field logbook provided carbon copies of each page. The original logbook was stored on-site; the carbon copy sheets were collected by the FTO at least once per week. This protocol not only eased referencing the original data, but also offered protection of the original record of results. Pilot operating logs include a description of the bag filtration equipment (description of test runs, names of visitors, description of any problems or issues, etc); such descriptions were provided in addition to experimental calculations and other items.

Field log books were bound with numbered pages and labeled with project name. The log book is attached to this report as Appendix C. Log books were used to record equipment operating data. Each line of the page was dated and initialed by the individual responsible for the entries. Errors had one line drawn through them and the line was initialed and dated. Although the FTO attempted to initial and date each page and individual line entries review of the log book at the conclusion of testing indicated that in a few instances the entries had not been initialed. Field testing operators recorded data and calculations by hand in laboratory notebooks. Daily measurements were recorded on specially prepared data log sheets. The laboratory notebook was photocopied weekly. The original notebooks were stored on-site; the photocopied sheets were stored at the office of the FTO. This procedure eased referencing the original data and offered protection of the original record of results. Treatment unit operating logs included a description of the treatment equipment (description of test runs, names of visitors, description of any problems or issues, etc); such descriptions were provided in addition to experimental calculations and other items.

3.3.7.2 Photographs

Photographs were logged in the field log book. These entries include time, date, direction, subject of photo and the identity of the photographer.

3.3.7.3 Chain of Custody

Samples which were collected by the FTO and hand delivered to the laboratory were logged into the laboratory's sample record upon arrival at the laboratory. Submitted samples were collected and hand delivered to the laboratory accompanied by chain of custody forms. The chain of custody forms are included in Appendix D.

3.3.7.4 Online Measurements

Data from the computers recording the online measurements were copied to disk at least on a weekly basis. This information was stored on site and at the FTO's office.

3.3.7.5 Data Management Spreadsheets

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

Each experiment (e.g. each filtration test run) was assigned a run number which was then tied to the data from that experiment through each step of data entry and analysis. As samples were collected and sent to the analytical laboratory, the data were tracked by use of the same system of run numbers. Data from the outside laboratory were received and reviewed by the FTO. These data were entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

3.3.7.6 Statistical Analysis

Water quality data developed from grab samples collected during filter runs, the operational data recorded in the logbook, and the online data were analyzed for statistical uncertainty. The FTO calculated the average, minimum, maximum, standard deviation, and the 95% confidence intervals. The statistics developed are helpful in demonstrating the degree of reliability with which water treatment equipment can attain quality goals. The FTO calculated a 95% confidence interval for selected parameters. These calculations were carried out on data from inline monitors and for grab samples of algae, pH, and temperature. The equation used is:

$$95\%\ \textit{confidence interval} = \overline{X} \pm t_{n-1,0.975}\left(S/\sqrt{n}\right)$$

where: $\overline{X}$ is the sample mean;
S is the sample standard deviation;
n is the number of independent measurements included in the data set; and
t is the Student's t distribution value with n-1 degrees of freedom.

Results of these calculations are expressed as the sample mean +/- the statistical variation.

3.4 Field Operations Procedures

In order to assure data validity NSF Verification Testing Plan procedures were followed. This ensured the accurate documentation of both water quality and equipment performance. Strict adherence to these procedures resulted in verifiable performance of equipment.

3.4.1 Equipment Operations

The operating procedures for the Aqua-Rite Potable Water Filtration System are described in the Operations Manual (Appendix E) (Lapoint 2001). Analytical procedures are described in CWM Laboratory's Quality Assurance Plan (Appendix F) (CWM 2000).

3.4.1.1 Operations Manual

The Operations Manual for the treatment system was not available during the testing but is attached to this report as Appendix E. An evaluation of the O&M manual was conducted to evaluate the instructions and procedures for their applicability.

3.4.1.2 Analytical Equipment

The following analytical equipment was used during the verification testing:

- A Fisher Accumet Model AP61 portable pH meter was used for pH analyses.
- A Hach 2100P portable turbidimeter was used for turbidity analyses.
- An Ertco 1003-FC NIST traceable thermometer was used for temperature analyses. The thermometer had a range –1 to 51°C with scale divisions of 0.1°C.
- Hach 1720D turbidimeters were used for feed, prefilter effluent, and bag filter effluent turbidity.
- Met One PCX particle counters were used for feed, prefilter effluent, and bag filter effluent particle analysis.

3.5 QA/QC Procedures

Quality assurance and quality control of the operation of the bag filtration equipment and the measured water quality parameters was maintained during the Verification Testing Program.

The objective of this task was to maintain strict QA/QC methods and procedures during the equipment verification testing. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

Equipment flow rates and associated signals were verified and verification recorded on a routine basis. A routine daily walk-through during testing was established to verify that each piece of equipment or instrumentation was operating properly. In-line monitoring equipment such as flow meters, etc. were checked to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

3.5.1 Daily QA/QC Verification Procedures

Daily QA/QC procedures were performed on the online turbidimeter and online particle counter flow rates and online turbidimeter readout.

3.5.1.1 Online Turbidimeter Flow Rate

The online turbidimeter flow rate was verified volumetrically over a specific time. Effluent from the unit was collected into a graduated cylinder while being timed. Acceptable flow rates, as specified by the manufacturer, ranged from 250 ml/minute to 750 ml/minute. The target flow rate was 500 ml/minute. Adjustments to the flow rate were made by adjusting the valve controlling flow to the unit. Fine adjustments to the flow rate were difficult to make. If adjustments to the flow rate were made they were noted in the field logbook by including the flow rate prior to adjustment in parentheses next to the description of what adjustment was made.

3.5.1.2 Online Particle Counter Flow Rate

The flow rates for the feed water and filtrate online particle counters were verified volumetrically over a specific time. Effluent from the units was collected into a graduated cylinder while being timed. Acceptable flow rates, as specified by the manufacturer, ranged from 90 ml/minute to 110 ml/minute. The target flow rate was 100 ml/minute. Care was taken to maintain the flow rate between 95 ml/minute and 105 ml/minute. Changes to the flow rate were made by adjusting the level of the discharge from the overflow weir. If adjustments to the flow rate were made they were noted in the field logbook by including the flow rate prior to adjustment in parentheses next to the description of what adjustment was made.

3.51.3 Online Turbidimeter Readout

Online turbidimeter readings were checked against a properly calibrated bench model. Samples of the feed prefilter effluent, and filtrate were collected and analyzed on a calibrated bench turbidimeter. The readout of the bench model and the online turbidimeters were recorded. Exact agreement between the two turbidimeters is not likely due to the differences in the analytical techniques of the two instruments.

3.5.2 Bi-weekly QA/QC Verification Procedures

Bi-weekly QA/QC procedures were performed on the online flow meter. Meter was checked to determine if cleaning was necessary and verification of flow was performed.

3.5.2.1 Online Flow Meter Clean Out

Examination of the online flow meters indicated that clean out was not required during the verification testing. This was due to the short duration of the study and the high quality of the feed water.

3.5.2.2 Online Flow Meter Flow Verification

Verification of the readout of the feed, and filtrate flow meters was conducted bi-weekly during the testing period. This was done by taking the instantaneous reading from the meter and comparing it to a volume collected over the time period.

3.5.3 Procedures for QA/QC Verifications at the Start of Each Testing Period

Verifications of the online turbidimeter, pressure gauges, tubing, and particle counters were conducted. These verification procedures follow.

3.5.3.1 Online Turbidimeter

The online turbidimeter reservoir was cleaned by removing the plug from the bottom of the unit and allowing the body to drain. The body of the unit was then flushed with water. The unit was recalibrated following manufacturer's recommendations.

3.5.3.2 Pressure Gauges

Pressure gauge readings were verified through the use of a dead weight test meter. Procedures for the use of the meter were included with the meter. Generally, the procedure consisted of placing the gauge on the meter adding weight to the meter and comparing the reading obtained to the known amount of weight.

3.5.3.3 Tubing

The tubing and connections associated with the treatment system were inspected to verify that they were clean and did not have any holes in them. Also, the tubing was inspected for brittleness or any condition which could cause a failure

3.5.3.4 Online Particle Counters

Calibration of the particle counter is generally performed by the instrument manufacturer. The calibration data were provided by the instrument manufacturer for entry into the software calibration program. Once the calibration data were entered it was verified using calibrated mono-sized polymer microspheres. Microspheres of 5µm, 10µm and 15µm were used for particle size verification. The following procedure was used for instrument calibration verification:

- Analyze the particle concentration in the dilution water;
- Add an aliquot of the microsphere solution to the dilution water to obtain a final particle concentration of 2,000 particles per ml;
- Analyze a suspension of each particle size separately to determine that the peak particle concentration coincides with the diameter of particles added to the dilution water;
- Prepare a cocktail containing all three microsphere solutions to obtain a final particle concentration of approximately 2,000 particles per ml of each particle size; and
- Analyze this cocktail to determine that the particle counter output contains peaks for all the particle sizes.

3.5.4 On-Site Analytical Methods

Procedures for daily calibration, duplicate analysis, and performance evaluation for pH, temperature, and residual chlorine are discussed in the following sections.

3.5.4.1 pH

Analysis for pH was performed according to *Standard Methods* 4500-H^+. A two-point calibration of the pH meter was performed each day the instrument was in use. Certified pH buffers in the expected range were used. After the calibration, a third buffer was used to check linearity. The values of the two buffers used for calibration, the efficiency of the probe (calculated from the values of the two buffers), and the value of the third buffer used as a check were recorded in the logbook.

pH measurements do not lend themselves to "blank" analyses. Duplicates were run once a week. Performance evaluation samples were analyzed during the testing period. Results of the duplicates and performance evaluation were recorded.

3.5.4.2 Temperature

Readings for temperature were conducted in accordance with *Standard Methods* 2550. Raw water temperatures were obtained once per day by submerging the thermometer in the feed water reservoir. A National Institute of Standards and Technology (NIST) certified thermometer having a range of – $1^{o}C$ to $+51^{o}C$, subdivided in $0.1^{o}C$ increments was used for all temperature readings.

Temperature measurements do not lend themselves to "blank" analyses. Duplicates were run on every sample. The temperature of the feed water was not recorded until two like readings were obtained, indicating that the thermometer had stabilized. Two equivalent readings were considered to be duplicate analyses.

3.5.4.3 Turbidity Analysis

Turbidity analyses were performed according to *Standard Methods* 2130. The bench-top turbidimeter was calibrated at the beginning of verification test and on a weekly basis using primary turbidity standards according to manufacturer's recommendations. Primary turbidity standards of 0.1, 0.5 and 5.0 NTU were checked after calibration to verify instrument performance. Deviation of more than 10 % of the true value of the primary standards indicated that recalibration or corrective action should be undertaken on the turbidimeter. Secondary standards were used on a daily basis to verify calibration.

3.5.5 Chemical and Biological Samples Shipped Off-Site for Analyses

CWM Laboratory conducted the analysis of chemical and biological parameters. CWM's QA Plan outlines sample collection and preservation methods (CWM 2000) (Appendix F). Sample collection was done by representatives of the FTO.

3.5.5.1 Total Organic Carbon

Sample(s) for analysis of TOC were collected in glass bottles supplied by the CWM laboratory and held at approximately 4EC during delivery to the analytical laboratory. These samples were preserved, held, and delivered in accordance with Standard Method 5010B. Storage time before analysis was minimized, according to *Standard Methods.* Specific QA/QC procedures are detailed in CWM's QA Plan included as Appendix F.

3.5.5.2 Microbial Parameters: Total Coliform and Algae

Total coliform samples were collected in bottles supplied by CWM Laboratories and held at approximately 4°C during delivery to the analytical laboratory. Total coliforms were analyzed using procedures presented in CWM's QA Plan. These procedures are based on *Standard Methods* 9222B. Samples were processed for analysis by CWM Laboratory within the time specified for the relevant analytical method. The laboratory kept the samples at approximately 4°C until initiation of analysis. Specific QA/QC procedures are detailed in CWM's QA Plan included as Appendix F.

Algae samples were analyzed according to *Standard Method* 10200 F. The samples were preserved with Lugol's solution after collection, stored and shipped in a cooler at a temperature of approximately 4°C, and held at that temperature range until counted. Specific QA/QC procedures are detailed in CWM's QA Plan included as Appendix F.

3.5.5.3 Inorganic Parameters

Inorganic chemical samples, including alkalinity, hardness, iron, and manganese, were collected, preserved and held in accordance with *Standard Methods* 3010B, paying particular attention to the sources of contamination as outlined in *Standard Method* 3010C. The samples were refrigerated at approximately 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4°C. The laboratory kept the samples at approximately 4°C until initiation of analysis. Specific QA/QC procedures are detailed in CWM's QA Plan included as Appendix F.

Total alkalinity analyses were conducted according to *Standard Methods* 2320 B. Total Hardness analyses were conducted according to *Standard Methods* 2340 C. Iron and manganese analyses were conducted according to *Standard Methods* 3113 B.

3.5.5.4 Microspheres

Filtrate samples for microsphere analysis were shipped overnight in a cooler and maintained at a temperature of approximately 2 to 8°C during shipment and in the analytical laboratory, until they were analyzed.

Recovery of microspheres from suspensions held in glassware was evaluated by preparing a suspension of microspheres in which the number of microspheres used to make the suspension is estimated, based on either the weight of dry microspheres or the volume of microspheres in liquid suspension as provided by the supplier. After the suspension was prepared and mixed until it was homogeneous, five aliquots were taken and counted in the hemocytometer. After the microsphere density (concentration) had been calculated, aliquots of the suspension were diluted and filtered through polycarbonate membrane filters having 1 μm pore size. The elution and concentration steps described in Task 4 of the NSF Equipment Verification Testing Plan Bag and Cartridge Filters were followed, and the microspheres were counted in a hemocytometer. This was done five times, so that statistics could be developed on the recovery of microspheres in the sampling procedure.

As a check on possible interference from fluorescing organisms in the feed water during three of the four verification testing runs in which fluorescent microspheres were used, a sample of feed water with no seeded microspheres was filtered through a polycarbonate membrane, and the particulate matter on the membrane was concentrated using the procedures for microsphere analysis, and the concentrate was examined in a hemocytometer by microscope, with UV illumination. If no objects of the size and shape of the microspheres are seen to fluoresce, displaying the same color as the microspheres, then fluorescent objects of the proper color seen in samples with seeded microspheres can be considered to be microspheres.

Microspheres may adhere to surfaces of tanks, vessels, and glassware. All glassware, holding tanks, and membrane filter manifolds were cleaned between seeding events or sampling events.

Analytical methodology is presented in Table 3-3.

Table 3-3. Analytical Methodology

Parameter	Facility	Standard Methods Number or Other Method Reference
Temperature	On-Site	2550 B
pH	On-Site	4500-H*
Total Alkalinity	Lab	2320 B
Total Hardness	Lab	2340 C
Total Organic Carbon	Lab	5310 C
Turbidity	On-Site	2130 B
Particle Counts (electronic)	On-Site	Manufacturer
Iron	Lab	3113 B
Manganese	Lab	3113 B
Algae, number and species	Lab	10200 F
Total Coliform	Lab	9222 B
Microsphere Counts	Lab	Abbaszadegan et al. (1997)

Chapter 4
Results and Discussions

4.1 Introduction

The verification testing for the Aqua-Rite Potable Water Filtration System occurred in the Borough of Burnside located in Clearfield County, Pennsylvania. The variability testing portion of the initial operations period occurred during two ten day periods. The first 10 day testing period began on April 20, 2000; the second 10 day test period began on May 20, 2000. The verification testing commenced October 9, 2000 and concluded its 30-day period on November 12, 2000. Microbial contaminant removal testing was conducted on October 9 and 25, 2000 and January 22 and 24, 2001.

This section of the verification report presents the results of the testing and offers a discussion of the results. Results and discussions of the following are included: equipment characterization results, characterization of feed water, initial operations, verification testing runs and routine equipment operation, documentation of operating conditions and treatment equipment performance, microbiological contaminant removal, feed and finished water quality, and QA/QC

4.2 Equipment Characteristics Results

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

4.2.1 Qualitative Factors

Qualitative factors that were examined during the verification testing were the susceptibility of the equipment to changes in environmental conditions, operational reliability, and equipment safety. Also an evaluation of the manufacturer's O&M manual was conducted.

4.2.1.1 Susceptibility to Changes in Environmental Conditions

Changes in environmental conditions that cause degradation in feed water quality can have an impact on the treatment system. The short duration of the testing cycle minimized the opportunity for significant changes in environmental conditions. The filtered water quality did degrade during the second 10 days of initial testing. This was apparent due to the fact that the filtered water turbidity did not increase during the second 10 days of testing as it had during the first 10 days of testing. This was most likely caused by a change in the feed water quality. Since the initial testing focused primarily on testing the variability of the filter bags themselves there was no feed water quality testing conducted and the cause for the degradation of the filtered water quality is unknown.

4.2.1.2 Operational Reliability

The treatment system consisted of a prefilter housing, a prefilter, a bag filter housing, and a bag filter. The system as provided was only capable of manual operation. The only process adjustment required was to adjust the inlet flow valve as the flow rate decreased due to increased head loss through the filters. The system required daily checks for flow rate head loss and feed and bag filter effluent turbidity.

4.2.1.3 Equipment Safety

Evaluation of equipment safety was conducted as part of the verification testing. Evaluation of the safety of the treatment system was done by examination of the components of the system and identification of hazards associated with these components. A judgment as to the safety of the treatment system was made from these evaluations.

The only safety hazards associated with the treatment system are due to the presence of pressurized filter vessels. The water pressure inside the treatment system was relatively low and did not represent an unusual safety risk. Procedures for depressurization of the filter vessel are detailed in the O&M manual (Lapoint 2000) which is presented in Appendix E.

No injuries or accidents occurred during the testing.

4.2.1.4 O&M Manual

The manufacturer supplied O&M manual was rather brief and discussed safety issues as they relate to pressure relief from the vessels and the filter changeout procedures. The manual was adequate although no trouble shooting procedures were provided to aid the operator in identifying possible causes rapid headloss increases, high filtrate turbidity, or other water quality or operational difficulties. Procedures to identify a mis-installation of the bag filter were not included.

4.2.2 Quantitative Factors

Quantitative factors that were examined during verification testing were power supply requirements, consumable requirements, waste disposal technique, and length of operating cycle.

Cost factors for the above items are discussed where applicable. It is important to note that the figures discussed here are for the Lapoint Aqua-Rite Potable Filtration System operated at an average flow rate of 20.68 gpm and treating the feed water at the test site. Costs will vary if the system is operated at different sites and different flow rates.

4.2.2.1 Power Supply Requirements

The treatment system itself had no electrical requirements.

4.2.2.2 Consumable Requirements

The only consumables required for operation are the prefilters and bag filters. The prefilter was changed two times during the testing; although this was not required given the operational performance of the prefilters. Change out of the bag filters due to high headloss was required seven times during the 37 days of testing. A total of eight bag filters and three prefilters were used during testing. The average amount of water filtered during a filtration cycle was 92,900 gallons. This equates to approximately one bag per 100,000 gallons of filtered water.

4.2.2.3 Waste Disposal

The only waste generated by the treatment system was the spent prefilters and bag filters. These can be disposed of in a sanitary landfill and would not contain hazardous materials assuming the feed water is free of hazardous particulates.

4.2.2.4 Length of Operating Cycle

The operating cycle of the treatment system during the verification testing averaged 92,900 gallons per bag filter. The average filter run lasted 98 hours. The length of the cycle will vary depending on feed water quality.

4.2.2.5 Estimated Labor Hours for O&M

The only repetitive O&M task required for the treatment system is the change out of the prefilter and bag filters. These tasks are relatively simple and can be accomplished in approximately 5 minutes per bag change. The operator should inspect the condition of the pressure vessel, the mesh basket that holds the filter, and the basket and cover gaskets during change out.

4.3 Characterization of Feed Water

The source water for the verification testing was from the water system's 208,000 gallon in-ground covered reservoir located approximately 100 feet in elevation and about one-half mile away from the chlorine building which housed the treatment unit. The reservoir is primarily supplied by Spring No. 1 via gravity feed. Spring No. 2, a secondary supply which must be pumped up to the reservoir, was used on 208 days in 1999. A third spring, Chura Spring, flows into Spring No. 2.

The covered reservoir and associated springs and well source are considered high quality supplies. Limited historical of the spring and well water quality exists. The data was developed during testing to determine if the Borough's sources were ground water under the influence of surface water (GUDI). Testing was conducted between October 1995 and January of 1996. Records indicate that normal turbidity levels are less than 1.0 NTU from Spring No. 1 and Chura Spring. Normal turbidity from Spring No. 2 is between 1.0 NTU and 2.0 NTU. Fecal and total coliform bacteria were detected in all of the spring supplies with the total coliform counts being greater than 500 colonies per 100 ml of water in all three springs. Water from Spring No. 1 contained 0.8 CFU/100 ml of fecal coliform and 726 CFU/100 ml of total coliform on average.

The average fecal coliform density in Spring No. 2 was 0.4 CFU/100 ml; the average total coliform density was 507 CFU/100 ml. Water from Chura Spring contained 0.4 CFU/100 ml of fecal coliform and 624 CFU/100 ml of total coliform on average. The pH of all three springs averaged 7. The conductivity of the water from Spring No. 1 averaged 82.9 umhos. The conductivity of the water from Spring No. 2 averaged 112.6 umhos. The conductivity of the water from Chura Spring averaged 74.0 umhos. Temperature of the water in Spring No. 1 and Spring No. 2 averaged 52^{o}F. The temperature of the water from Chura Spring averaged 55.8^{o}F. Historical water quality data for each spring is presented in Appendix A. There are no historical water quality records available for the reservoir well; this supply is treated with a sequestering agent, indicating the presence of iron and/or manganese.

Table 4-1. Historical Water Quality Results – Spring No. 1

	Parameter					
	Turbidity	pH	Total Coliforms	Fecal Coliforms	Temperature	Conductivity
Date	NTU		CFU/100 ml	CFU/100 ml	^{o}F	(cells/ml)
Number of Samples	30	30	5	5	30	30
Average	0.85	7	726	0.8	52	82.9
Minimum	0.6	7	166	0	52	66.8
Maximum	1.2	7	1484	4	52	113.7

Table 4-2. Historical Water Quality Results – Spring No. 2

	Parameter					
	Turbidity	pH	Total Coliforms	Fecal Coliforms	Temperature	Conductivity
Date	NTU		CFU/100 ml	CFU/100 ml	^{o}F	(cells/ml)
Number of Samples	30	30	5	5	30	30
Average	1.8	7	506.8	0.4	52	112.6
Minimum	1.1	7	87	0	52	72.8
Maximum	3.1	7	1100	2	52	147

Table 4-3. Historical Water Quality Results – Chura Spring

	Parameter					
	Turbidity	pH	Total Coliforms	Fecal Coliforms	Temperature	Conductivity
Date	NTU		CFU/100 ml	CFU/100 ml	^{o}F	(cells/ml)
Number of Samples	30	30	5	5	30	30
Average	0.80	7	624	0.4	55.8	74.0
Minimum	0.35	7	77	0	52	54.4
Maximum	2	7	1529	2	56	103.3

The PADEP has classified these springs and the reservoir as a GUDI; Burnside Borough is therefore under a consent decree to provide filtration for these supplies. As such, the source water should be adequate to verify the manufacturer’s treatment claims. The determination was made the feed water was suitable for use in the verification testing program.

4.4 Initial Operations Period Results

The initial test runs were used to determine the operating characteristics of the treatment system. Also, initial test runs were conducted to facilitate simultaneous testing of multiple bags to document any performance variability between bags within one production lot and between bags of different manufacturing lots. The first initial operations period lasted 10 days and examined variability among bags from the same production lot (Lot # 22435). The second period lasted 10 days and examined variability among bags from different production lots (Lot #22853 and 22854). Another objective of the initial operations was to determine whether any pretreatment of the feed water is required prior to introduction to the system. Bag filtration may not be suitable for some feed waters. These feed waters may require some type of pretreatment prior to introduction to the bag filtration system.

The performance of the filters was evaluated by examining the flow through the system, the differential pressure, the turbidity, and particle counts from each bag filter.

4.4.1 Flow

The flow rate of the treatment system ranged from 15.2 to 17.4 gpm during the first 10 days of testing. The average flow rate was 16.7 gpm. During the second 10 days of initial testing the flow rate to the system averaged 17.3 gpm and ranged from 16.6 to 18.3 gpm.

4.4.2 Pressure Differential

The pressure drop across the filter in housing #1 was 0.5 psi after the first 10 days of testing. The pressure gauges monitoring the inlet and outlet pressures in housing #2 actually showed a slight increase in the pressure through the filter. The pressure increased a total of 0.6 psi after the first 10 days of testing. This was undoubtedly caused by slight differences in the performance of the pressure gauges themselves at the very low levels of pressure differential exhibited. The pressure change across the filter in housing #3 likewise increased by 0.4 psi. There was not a significant difference in the pressure differential exhibited by the three tested filters during the first 10 days of testing.

The pressure drop across the filter in housing #1 was 0.9 psi during the second 10 days of testing. The filter in housing #2 again showed a slight increase of 0.2 psi during the second ten days of testing. The pressure drop across the filter in housing #3 was 0.3 psi during the second 10 days of testing. There was not a significant difference in the pressure differential exhibited by the three tested filters during the second 10 days of testing.

4.4.3 Turbidity

The average effluent turbidity as measured by the online turbidimeter produced by the filter in housing #1 during the first 10 days (testing variability of filters from the same lot) of testing was 0.35 NTU. The average effluent turbidity as measured by the online turbidimeter produced by the filter in housing #2 during the first 10 days of testing was 0.30 NTU. The average effluent turbidity as measured by the online turbidimeter produced by the filter in housing #3 during the first 10 days of testing was 0.30 NTU.

The average effluent turbidity as measured by the online turbidimeter produced by the filter in housing #1 during the second 10 days of testing (testing variability of filters from the three different lot) was 0.85 NTU. The average effluent turbidity as measured by the online turbidimeter produced by the filter in housing #2 during the second 10 days of testing was 0.70

NTU. The average effluent turbidity as measured by the online turbidimeter produced by the filter in housing #3 during the second 10 days of testing was 0.70 NTU.

Table 4-4. Online Turbidimeter Effluent Turbidity Results from Bag Filter Variability Tests – Same Lot

	Housing #1 NTU	Housing #2 NTU	Housing #3 NTU
Number of Samples	11	11	11
Average	0.35	0.30	0.30
Minimum	0.20	0.20	0.15
Maximum	0.75	0.70	0.65
Std. Deviation	0.15	0.15	0.15
95% Confidence Interval	(0.25, 0.45)	(0.20, 0.40)	(0.20, 0.40)

Table 4-5. Online Turbidimeter Effluent Turbidity Results from Bag Filter Variability Tests – Different Lots

	Housing #1 NTU	Housing #2 NTU	Housing #3 NTU
Number of Samples	10	10	10
Average	0.85	0.70	0.70
Minimum	0.55	0.55	0.55
Maximum	1.7	0.95	0.90
Std. Deviation	0.30	0.15	0.10
95% Confidence Interval	(0.65, 1.0)	(0.65, 0.80)	(0.65, 0.75)

Analysis of this data indicates that there is not a significant difference in the turbidity produced by bag filters from the same or different production lots.

There was some concern given the high levels of turbidity passing through all of the bag filter canisters during the second 10 days of initial testing. All three filter effluent turbidities averaged greater than the current requirements of the SWTR and ESWTR (EPA 1989, 1999). It is most likely that this change in performance was caused by a change in feed water quality. Since the function of the initial operations task was to test variability in the filter bags themselves there is no data on the feed water turbidity or particle counts for the initial operations period. Therefore the supposition that a change in feed water quality caused the change in bag filter effluent quality is not verifiable. Due to this substandard turbidity removal performance Lapoint Industries agreed to provide a final cartridge filter for use during times that the bag filter effluent turbidity was in excess of 0.5 NTU. Use of the cartridge filter was for turbidity removal was not required during the 37 days of verification testing.

4.4.4 Particle Counts

The average effluent cumulative particle counts (>2 µm) produced by the filter in housing #1 during the first 10 days (testing variability of filters from the same lot) of testing was 15.09 total counts per ml. The average effluent cumulative particle counts (>2 µm) produced by the filter in housing #2 during the first 10 days of testing was 15.99 total counts per ml. The average effluent cumulative particle counts (>2 µm) produced by the filter in housing #3 during the first 10 days of testing was 18.21 total counts per ml.

The average effluent cumulative particle counts (>2 µm) produced by the filter in housing #1 during the second 10 days of testing (testing variability of filters from the three different lot) was 25.16 total counts per ml. The average effluent cumulative particle counts (>2 µm) produced by the filter in housing #2 during the second 10 days of testing was 25.62 total counts per ml. The average effluent cumulative particle counts (>2 µm) produced by the filter in housing #3 during the second 10 days of testing was 31.39 total counts per ml.

Table 4-6. Effluent Cumulative Particle Count Results from Bag Filter Variability Tests – Same Lot

	Housing #1 Total Counts / ml	Housing #2 Total Counts / ml	Housing #3 Total Counts / ml
Number of Samples	11	11	11
Average	15.09	15.99	18.21
Minimum	6.63	8.17	10.24
Maximum	28.84	34.45	43.96
Std. Deviation	8.39	8.41	9.48
95% Confidence Interval	(10.13, 20.05)	(11.02, 20.96)	(12.61, 23.81)

Table 4-7. Effluent Cumulative Particle Count Results from Bag Filter Variability Tests – Different Lots

	Housing #1 Total Counts / ml	Housing #2 Total Counts / ml	Housing #3 Total Counts / ml
Number of Samples	10	10	10
Average	25.16	25.62	31.39
Minimum	14.04	10.50	13.17
Maximum	38.96	49.34	54.29
Std. Deviation	8.40	11.38	15.66
95% Confidence Interval	(20.19, 30.12)	(18.90, 32.35)	(22.13, 40.65)

Analysis of this data indicates that there was not a significant difference in the cumulative particle counts produced by bag filters from the same or different production lots.

4.5 Verification Testing Results and Discussion

The results and discussions of verification testing runs and routine equipment operation, test runs for feed water and finished water quality, documentation of operating conditions and treatment equipment performance, and microbiological contaminant removal tasks of the verification testing are presented below.

4.5.1 Task 1: Verification Testing Runs

The verification testing runs in this task consisted of continued evaluation of the treatment system, using the operational parameters defined in the initial test runs.

Verification testing commenced on October 9, 2000 and concluded its normal testing on November 12, 2000. One verification testing period, lasting 35 days, was used to evaluate the performance of a treatment system. Additional testing was conducted during the month of January 2001 to accommodate additional microsphere challenge testing. During the 35 day period of time, the filtration equipment was operated for 23 hours and turned off for one hour each day. The one-hour shutdown was done to simulate the on-off operating mode that may be encountered in many small systems. The 23 hours of operation provided the opportunity for the FTO to log the maximum number of hours of equipment operation available each day. When terminal head loss was attained, the clogged bag was removed and replaced with a new one, and operation resumed. The duration of each filter run from initial start to terminal head loss and the volume of water produced by the bag was recorded in the operational results. The bag filter was changed seven times during the 37 days of operation. The prefilter was changed twice during the testing. Specific operating parameters such as the duration of each filter run, number of gallons of water produced during each filter run, rate of pressure loss through the filter during each filter run were recorded during the testing. The results of these readings are presented in Section 4.4.3.

4.5.2 Task 2: Test Runs for Feed Water and Finished Water Quality

The objective of this task was to quantify parameters of interest in the feed and finished water quality during the verification testing. Testing was conducted of feed water, prefilter effluent, and bag filter effluent during the verification testing according to the schedule presented in Table 3-2.

4.5.2.1 Water Quality Analytical Results – Laboratory Analytes

Analyses for total alkalinity, total hardness, total coliforms, iron, manganese, total organic carbon, and algae were conducted by a contract laboratory.

Table 4-8 presents the results of testing conducted by the contract laboratory on the feed water for total alkalinity, total hardness, total coliforms, iron, manganese, total organic carbon, and algae.

Table 4-8. Feed Water Testing Results – Laboratory Analytes

			Parameter				
Date	Total Alkalinity (mg/l)	Total Hardness (mg/l)	Total Coliforms (Neg., Pos.)	TOC (mg/l)	Algae (cells/ml)	Iron (mg/l)	Manganese (mg/l)
10/9/00	71	79	Pos.	<2.0	1	<0.05	0.021
10/19/00	--	--	--	--	1	<0.05	0.035
10/25/00	--	--	--	--	<1	--	--
11/9/00	--	--	--	--	<1	--	--
Average	71	79	Pos.	<2.0	1	<0.05	0.028
Minimum	N/A	N/A	N/A	N/A	<1	<0.05	0.021
Maximum	N/A	N/A	N/A	N/A	1	<0.05	0.035
Std. Dev.	N/A	N/A	N/A	N/A	1	N/A	N/A
95% Confid Int.	N/A	N/A	N/A	N/A	(0,1)	N/A	N/A

N/A = Not applicable because the sample size (n) was 1 or 2.
Pos. = Positive result from a presence / absence test.

Table 4-9 presents the results of testing conducted by the contract laboratory on the prefilter effluent for iron, manganese, and algae.

Table 4-9. Prefilter Effluent Testing Results– Laboratory Analytes

	Parameter		
	Iron (mg/l)	Manganese (mg/l)	Algae (cells/ml)
10/9/00	<0.05	0.021	<1
10/19/00	<0.05	0.035	<1
10/25/00	--	--	<1
11/9/00	--	--	<1
Average	<0.05	0.028	<1
Minimum	<0.05	0.021	<1
Maximum	<0.05	0.035	<1
Std. Deviation	N/A[1]	N/A[1]	0
95% Confidence Interval	N/A[1]	N/A[1]	N/A

N/A= Not Applicable because standard deviation = 0.
N/A[1]= Not applicable because the sample size (n) was 2.

Table 4-10 presents the results of testing conducted by the contract laboratory on the bag filter effluent water for total alkalinity, total hardness, total coliforms, iron, manganese, total organic carbon, and algae.

Table 4-10. Bag Filter Effluent Testing Results– Laboratory Analytes

	Parameter						
	Total Alkalinity (mg/l)	Total Hardness (mg/l)	Iron (mg/l)	Manganese (mg/l)	Total Coliforms (cfu/100 ml)	TOC (mg/l)	Algae (cells/ml)
10/9/00	66	72	<0.05	0.022	Pos.	<2.0	<1
10/19/00	--	--	<0.05	0.035	--	--	<1
10/25/00	--	--	--	--	--	--	<1
11/9/00	--	--	--	--	--	--	<1
Average	66	72	<0.05	0.029	Pos.	<2.0	<1
Minimum	N/A	N/A	<0.05	0.022	N/A	N/A	<1
Maximum	N/A	N/A	<0.05	0.035	N/A	N/A	<1
Std. Deviation	N/A	N/A	N/A[1]	N/A[1]	N/A	N/A	0
95% Confid Int.	N/A	N/A	N/A[1]	N/A[1]	N/A	N/A	N/A[1]

N/A = Not applicable because the sample size (n) was 1 or 2.
N/A[1]= Not Applicable because standard deviation = 0.
Pos. = Positive result from a presence / absence test.

4.5.2.2 Discussion of Results

The treatment system had little or no effect on the total alkalinity, and total hardness for the conditions tested. This was not unexpected since these parameters are not present in the water as solid constituents and are not amenable to reduction by physical straining.

Likewise there was no reduction in the manganese concentrations in the bag filter effluent. This would seem to indicate that these constituents are present in the water in a dissolved state and therefore not removable by physical straining.

The results indicate that the algal concentration of the bag filter effluent was less than the feed water concentration in two of the four samples tested. In the other two samples no algae were detected in the feed water so removal could not be demonstrated. The reader is cautioned that due to the very low concentration of algae in the feed water, one cell in two of four samples, the treatment unit's ability to consistently remove algae from feed water is unproven.

Total coliform bacteria were observed in both the feed and finished water. One sample of the feed and one sample of the bag filter effluent were examined for the presence of total coliform. Each produced a positive result. This may indicate that the treatment unit is not capable of removing total coliform bacteria. This would tend to indicate that the individual bacteria are small enough to pass through the bag filter.

No iron or total organic carbon was detected in the feed water so removal of those constituents could not be demonstrated.

4.5.2.3 Water Quality Analytical Results – On Site Analytes

The onsite analyses conducted during the verification testing were turbidity, particle counts, pH, and temperature.

Results of testing for turbidity in the feed and finished water were examined to verify the stated turbidity treatment ability. Table 4-11 presents the results of turbidity readings from the feed, prefilter effluent, and bag filter effluent and the amount removed from feed to bag filter effluent.

Table 4-11. Turbidity Analyses Results and Removal – Bench Top Turbidimeter

Sample Parameter	Feed Turbidity (NTU)	Prefilter Effluent Turbidity (NTU)	Bag Filter Effluent Turbidity (NTU)	Amount Removed (NTU)
Number of Samples	36	36	36	
Average	0.75	0.45	0.15	0.60
Minimum	0.50	0.25	0.05	0.25
Maximum	1.2	0.90	0.50	0.90
Standard Deviation	0.20	0.15	0.10	0.15
95% Confidence Interval	(0.70, 0.80)	(0.40, 0.50)	(0.15, 0.20)	(0.55, 0.65)

Turbidity of the feed, prefilter effluent, and bag filter effluent were also measured on a continuous basis using online turbidimeters. That data was used to create four hour turbidity measurements for the feed, prefilter effluent, and bag filter effluent. Table 4-12 presents the average, minimum, maximum, standard deviation and confidence interval for these four hour readings.

Table 4-12. Turbidity Analyses Results and Removal – Four Hour Online Turbidimeter Results

Sample Parameter	Feed Turbidity (NTU)	Prefilter Effluent Turbidity (NTU)	Bag Filter Effluent Turbidity (NTU)
Number of Samples	159	163	180
Average	0.65	0.40	0.10
Minimum	0.30	0.20	<0.05
Maximum	1.2	0.90	0.50
Standard Deviation	0.15	0.15	0.10
95% Confidence Int.	(0.65, 0.70)	(0.40, 0.45)	(0.10, 0.10)

Figure 4-1 shows the results of the four-hour feed water, prefilter effluent, and bag filter effluent turbidity readings. Due to problems associated with the data logging equipment the feed water turbidity readings from run time 688 hour to 768 hour and the prefilter effluent turbidity readings from run time 636 hour to 700 hour were lost and are not available.

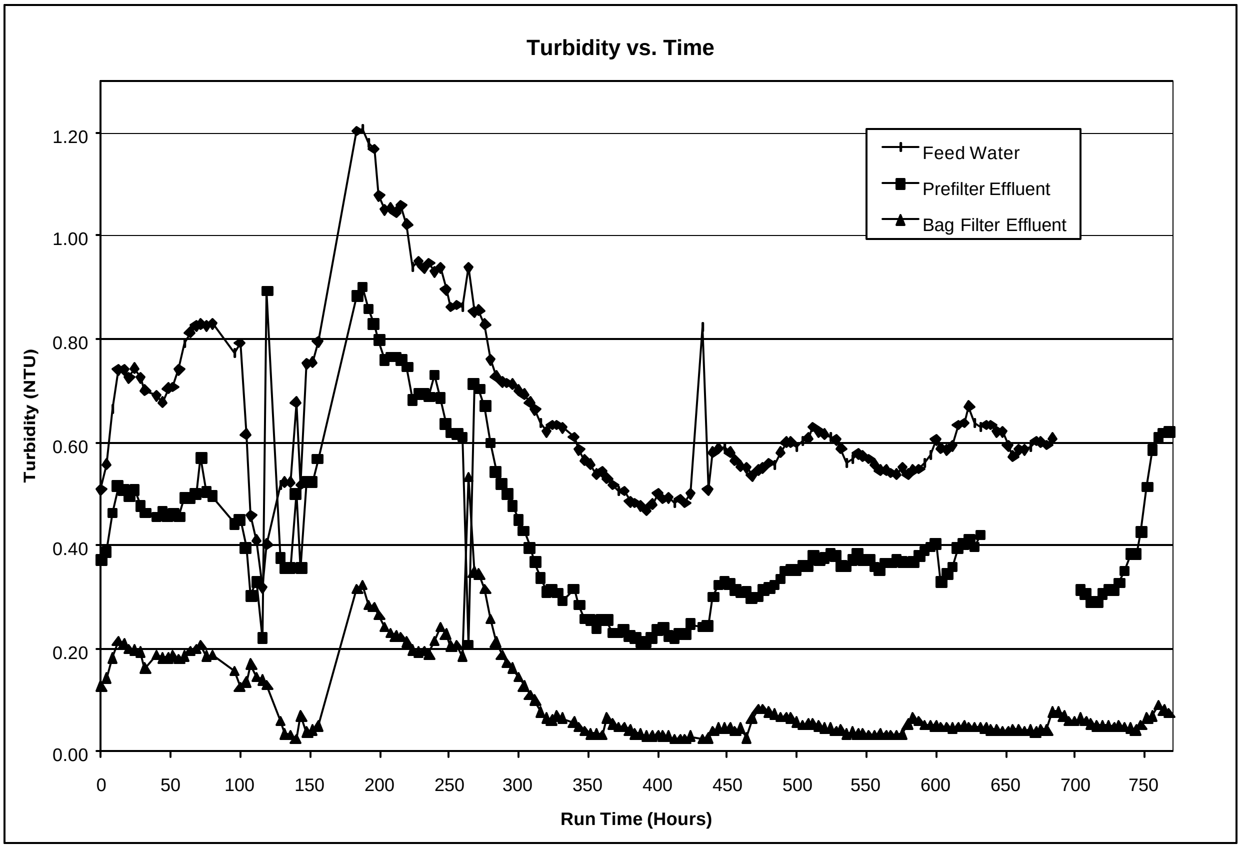

Figure 4-1. Four-Hour Online Turbidity

The bag filter effluent online turbidimeter readings averaged 0.10 NTU; the benchtop turbidimeter readings averaged 0.15 NTU. While this may initially appear to be a significant difference, it is most likely due to the low level of turbidity in the bag filter effluent and the differences in methodology of the two pieces of analytical equipment. The discrepancy between these two results can be explained by differences in the analytical techniques between the online and benchtop turbidimeter and the low level of turbidity in the bag filter effluent. The benchtop turbidimeter uses a glass cuvette to hold the sample; this cuvette can present some optical difficulties for the benchtop turbidimeter. The inline turbidimeter has no cuvette to present a possible interference with the optics of the instrument. The low level of turbidity in the bag filter effluent also can create analytical difficulties, particularly for the benchtop.

Particle count testing was conducted on the feed, prefilter effluent, and bag filter effluent during the verification testing. Particle count readings were taken on a continuous basis and recorded every 10 minutes. Average particle count calculations were calculated from these readings. The feed water cumulative counts (>2 µm) averaged 451.017 particles per ml. The prefilter effluent cumulative counts (>2 µm) averaged 220.518 particles per ml. The finished water cumulative counts (>2 µm) averaged 21 counts per ml. The average $\log_{10}$ removal for the cumulative counts was 1.76. The low particle counts for each size range in the bag filter effluent indicated good system performance throughout the testing period. The treatment system seems to be an effective removal mechanism for particle removal.

Average feed water particle counts are presented in Table 4-13. Table 4-14 presents the average prefilter effluent particle counts. The bag filter effluent average particle counts are presented in Table 4-15. A complete data table is presented in Appendix B. Figures 4-2, 4-3, and 4-4 depict results of four hour particle counts for feed water, prefilter effluent, and bag filter effluent respectively. Figure 4-5 graphically depicts daily $\log_{10}$ removals for cumulative particle counts.

Table 4-13. Feed Water Particle Counts (particles/ml)

	Size						
	2-3µm	3-5µm	5-7µm	7-10µm	10-15µm	>15µm	Cumulative
Number of Samples	183	183	183	183	183	183	183
Average	253.803	171.704	14.929	7.865	1.452	1.265	451.017
Minimum	36.875	39.350	3.600	1.050	0.075	0.000	122.825
Maximum	656.125	528.225	78.375	97.500	73.150	60.725	1304.900
Standard Deviation	111.973	82.392	12.383	9.520	5.679	6.126	N/A
95% Confidence Interval	(237.445, 270.160)	(159.667, 183.740)	(13.120, 16.738)	(6.474, 9.256)	(0.622, 2.282)	(0.370, 2.160)	N/A

N/A = Not applicable. Statistical measurements on cumulative data do not generate meaningful data.

Table 4-14. Prefilter Effluent Particle Counts (particles/ml)

	Size						
	2-3µm	3-5µm	5-7µm	7-10µm	10-15µm	>15µm	Cumulative
Number of Samples	146	146	146	146	146	146	146
Average	126.548	80.662	6.131	3.461	1.082	2.634	220.518
Minimum	8.275	3.925	0.475	0.225	0.050	0.000	13.325
Maximum	455.025	444.175	74.175	68.850	38.150	174.000	1114.950
Standard Deviation	81.165	62.324	8.873	7.573	4.108	15.503	N/A
95% Confidence Interval	(113.382, 139.713)	(70.553, 90.771)	(4.692, 7.570)	(2.233, 4.690)	(0.416, 1.748)	(0.119, 5.149)	N/A

N/A = Not Applicable. Statistical measurements on cumulative data do not generate meaningful data.

Table 4-15. Bag Filter Effluent Particle Counts (particles/ml)

	Size						
	2-3µm	3-5µm	5-7µm	7-10µm	10-15µm	>15µm	Cumulative
Number of Samples	185	185	185	185	185	185	185
Average	11.794	5.512	0.564	0.317	0.108	2.945	21.240
Minimum	0.200	0.250	0.000	0.000	0.000	0.000	0.450
Maximum	307.800	76.675	10.700	9.700	4.675	155.300	499.250
Standard Deviation	37.164	11.348	1.239	0.940	0.454	16.796	N/A
95% Confidence Interval	(6.439, 17.149)	(3.877, 7.148)	(0.385, 0.742)	(0.181, 0.452)	(0.043, 0.174)	(0.525, 5.365)	N/A

N/A = Not Applicable. Statistical measurements on cumulative data do not generate meaningful data.

Table 4-16. Daily Average Cumulative Particle Counts - Feed and Bag Filter Effluent, Log_{10} Particle Removal

Date	Feed (particles/ml)	Filtrate (particles/ml)	Log_{10} Removal (particles/ml)
10/11/00	222.20	4.66	1.68
10/12/00	270.11	7.60	1.55
10/13/00	598.86	29.24	1.31
10/14/00	1178.04	57.24	1.31
10/15/00	680.23	297.51	0.36
10/16/00	258.89	285.80	-0.04
10/17/00	628.77	27.93	1.35
10/18/00	649.33	8.26	1.90
10/19/00	649.42	6.90	1.97
10/20/00	523.68	8.54	1.79
10/21/00	467.72	9.45	1.69
10/22/00	409.91	4.88	1.92
10/23/00	352.26	3.09	2.06
10/24/00	311.68	2.27	2.14
10/25/00	392.56	3.81	2.01
10/26/00	262.27	1.61	2.21
10/27/00	258.56	1.20	2.33
10/28/00	301.95	1.24	2.39
10/29/00	369.61	2.11	2.24
10/30/00	360.57	3.09	2.07
10/31/00	371.30	3.29	2.05
11/01/00	366.78	2.89	2.10
11/02/00	350.86	3.57	1.99
11/03/00	335.01	3.77	1.95
11/04/00	364.49	4.43	1.92
11/05/00	395.58	5.39	1.87
11/06/00	383.79	6.35	1.78
11/07/00	364.09	7.47	1.69
11/08/00	401.27	21.59	1.27
11/09/00	443.94	6.34	1.85
11/10/00	426.12	6.01	1.85
11/11/00	476.54	7.88	1.78
11/12/00	458.49	6.88	1.82

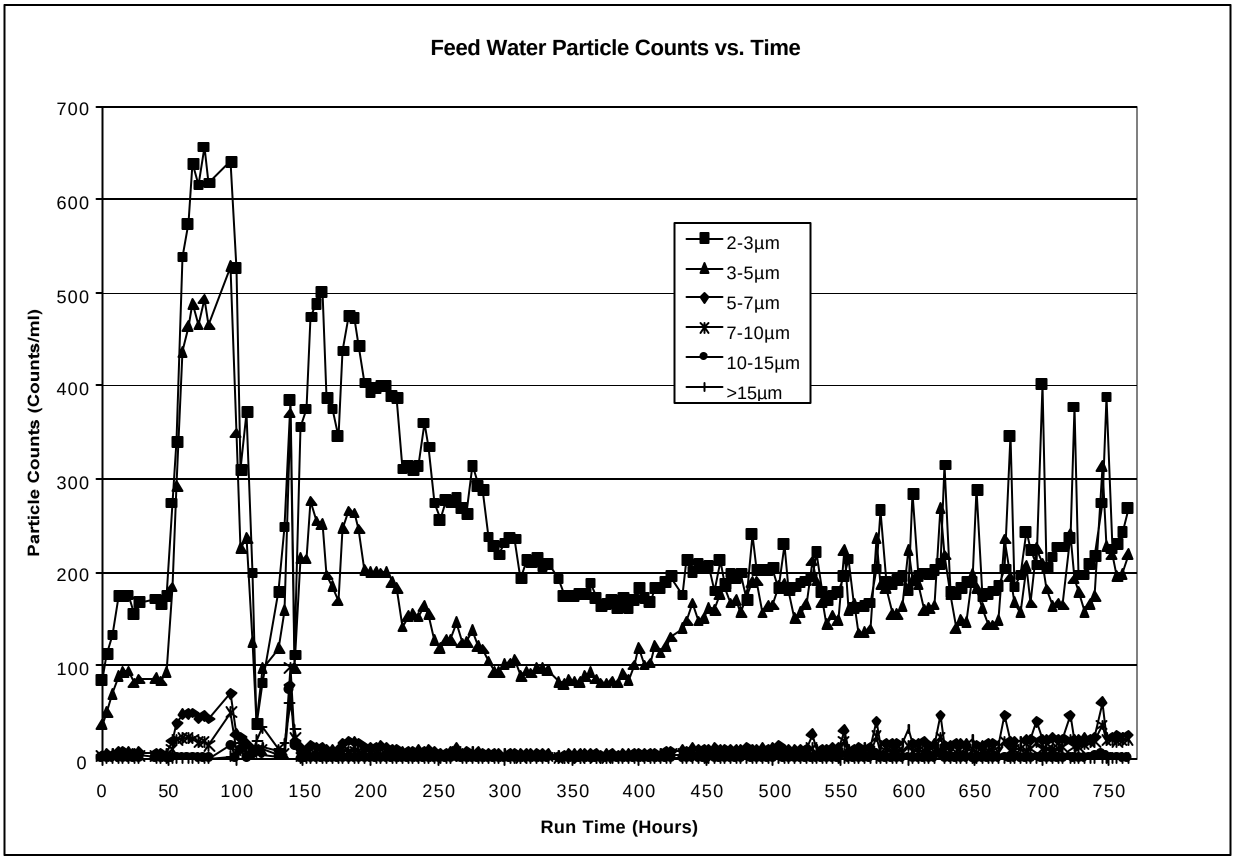

Figure 4-2. Four Hour Feed Water Particle Counts

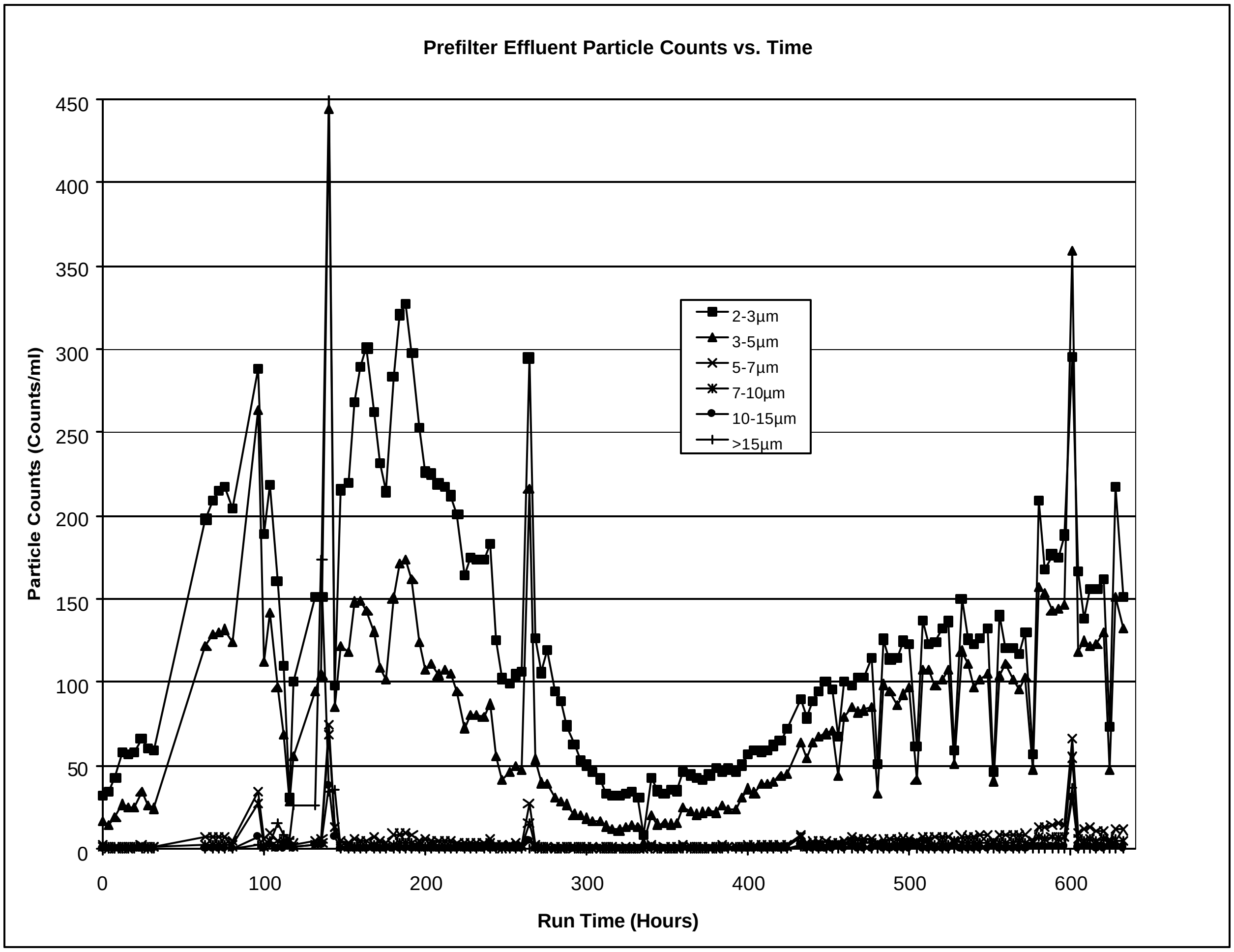

Figure 4-3. Four Hour Prefilter Effluent Particle Counts

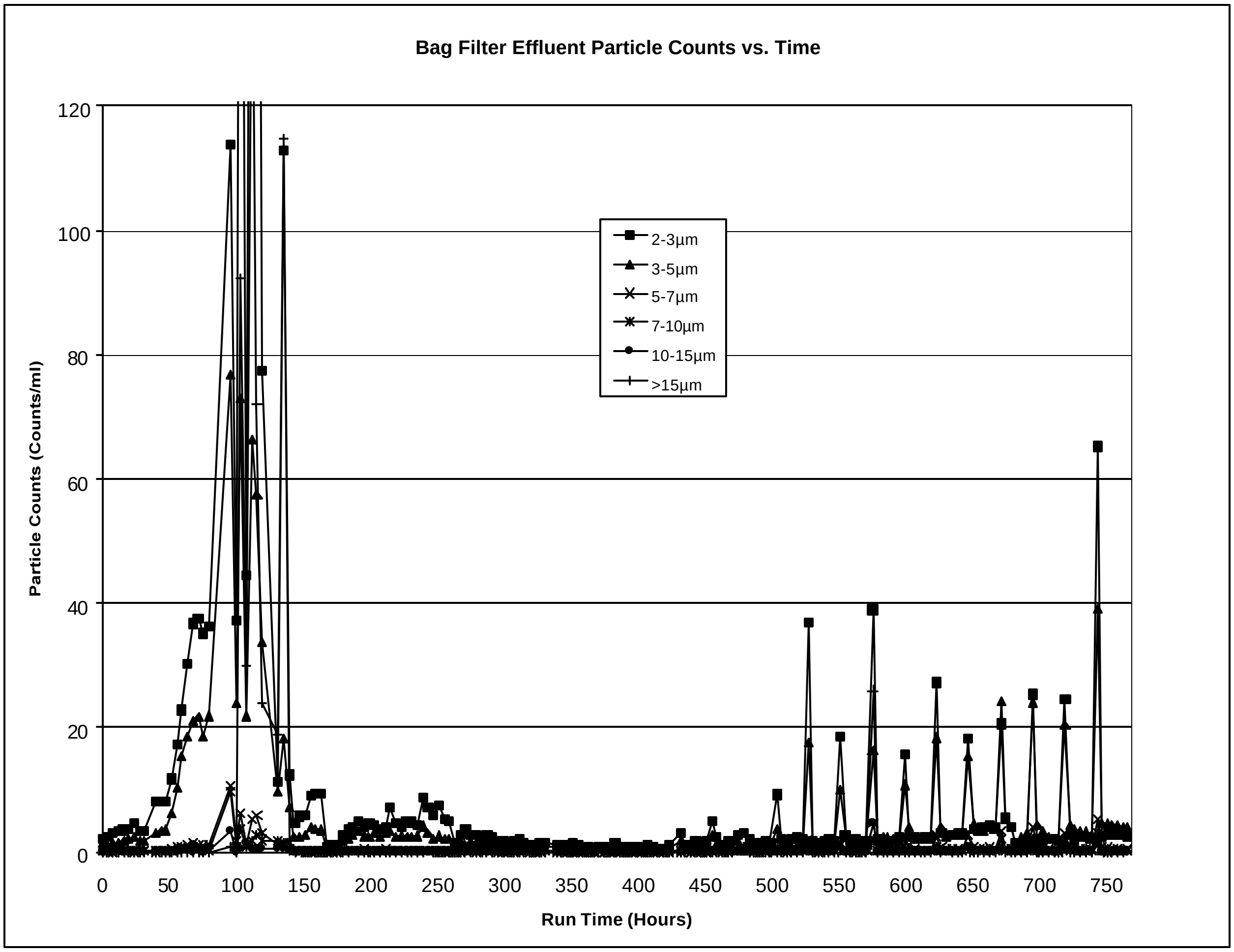

Figure 4-4. Four Hour Bag Filter Effluent Particle Counts

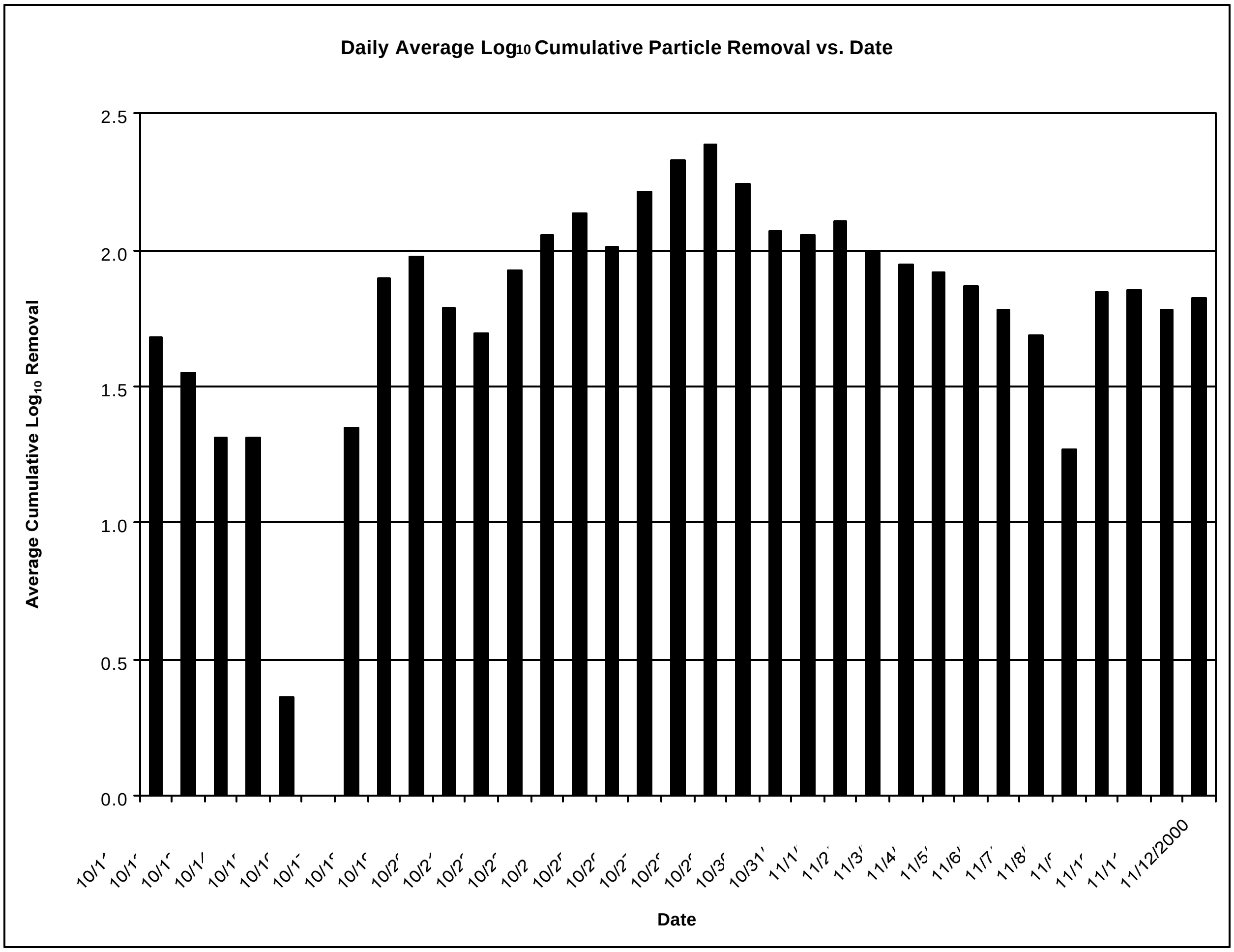

Figure 4-5. Daily Average Log_{10} Cumulative Particle Removal Graph

Temperature of the feed water was fairly stable during the thirty day testing from a high of 13.5°C to a low of 11.0°C. The average temperature was 12.2°C.

The pH of the feed water averaged 7.08. The pH ranged from a high of 7.35 to a low of 6.85 during the verification testing.

Table 4-17. Feed Water Quality – On-Site Analytes

	Temperature °C	pH
Number of Samples	35	35
Average	12.2	7.08
Minimum	11.0	6.85
Maximum	13.5	7.35
Std. Deviation	0.6	0.16
95% Confidence Interval	(12.0, 12.4)	(7.02,7.13)

4.5.2.4 Discussion of Results

The results of the testing indicated that the system was capable of treating the feed water and producing a turbidity of less than 0.3 NTU on average during the 37 days of verification testing. The turbidity standards as presented in the ESWTR are that the filter effluent turbidity must be less than or equal to 0.3 NTU in at least 95 percent of the measurements taken each month. (EPA 1999). As noted, the bag filter effluent turbidity measurements during one of the 10-day initial operations periods and six measurements during the verification test were in excess of 0.3 NTU. The use of a post cartridge filter may be required at some times of the year in order to comply with regulatory requirements for filtered water turbidity for the feed water tested.

The low particle counts for each size range in the bag filter effluent indicated good system performance throughout the testing period. The treatment system seems to be an effective removal mechanism for particle removal.

4.5.3 Task 3: Documentation of Operating Conditions and Treatment Equipment Performance

The performance of the water treatment equipment was documented by recording daily the parameters of flow and pressure at the inlet and outlet of the prefilter and bag filter. These readings were used to calculate rate of filter head loss gain, length of filter run (to terminal headloss), and total water produced during each filter run. The daily readings for these parameters are presented in Appendix B. In addition, daily observations of meteorological conditions that may have impacted the feed water quality were recorded. Summaries of the data are tabulated below. Graphs depicting rate of headloss gain and flow rate are presented below.

4.5.3.1 Flow Rate

The average feed water flow rate during the verification testing was 20.69 gpm. During the verification testing the maximum feed water flow rate was 22.04 gpm; the minimum was 18.12 gpm. The average bag filter effluent flow rate during the verification testing was 20.01 gpm. During the verification testing the maximum feed water flow rate was 21.19 gpm; the minimum was 17.45 gpm. The difference between the feed water flow and the bag filter effluent flow was due to samples being drawn off for the online analytical equipment.

Figure 4-6 presents a graph of the feed water flow and bag filter effluent flow readings taken during the verification testing.

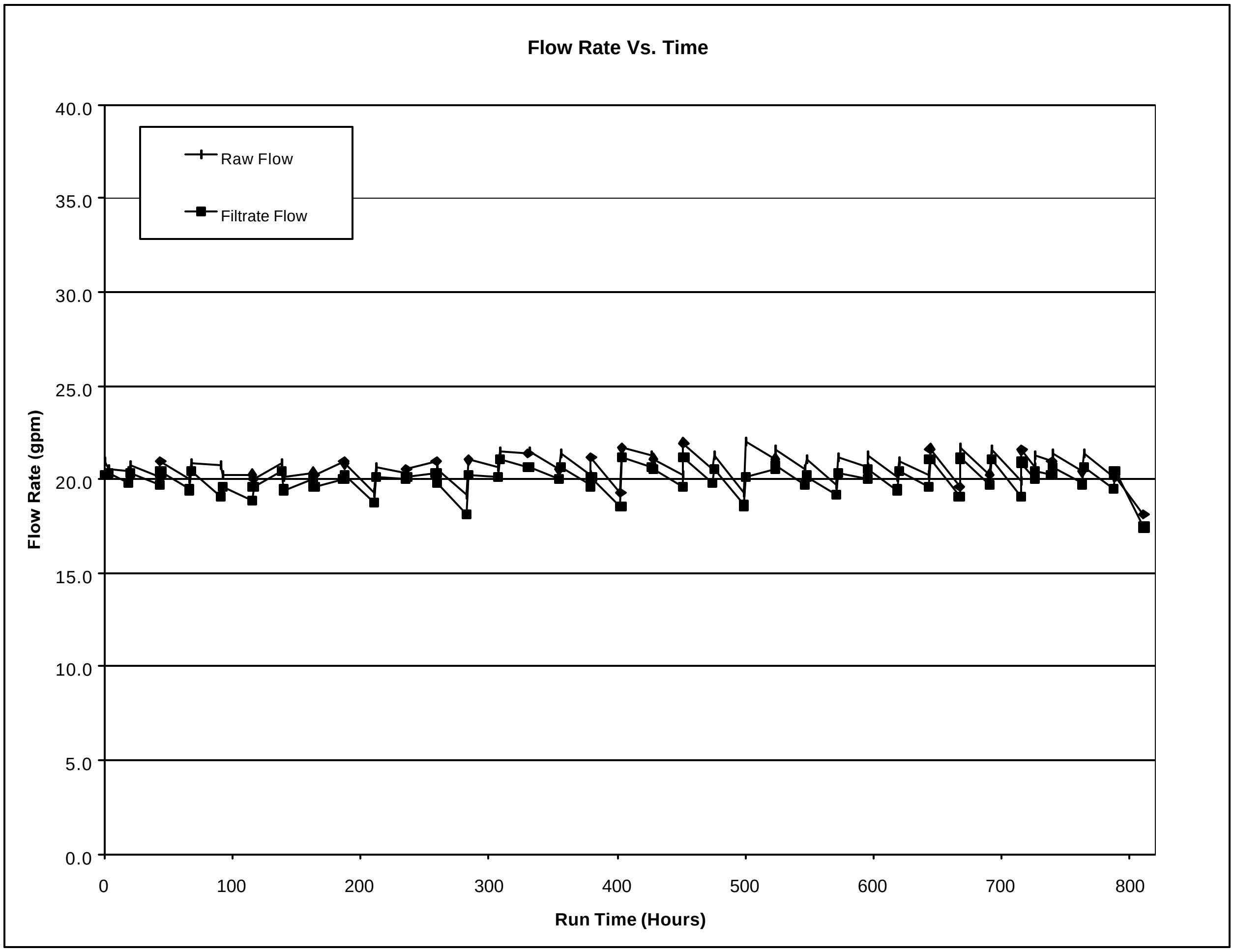

Figure 4-6. Daily Feed Water and Bag Filter Effluent Flow

4.5.3.2 Head Loss

The maximum terminal headloss of the bag filter system as reported by the manufacturer is 25 psi. The bag filter was replaced according to this criteria during the verification testing. A total of seven bag filter changes were required during the verification testing. The prefilter was changed out twice during the testing but the pressure differential did not dictate that the change be made. The average life of the bag filter was 98 hours. The minimum life was 24 hours and the maximum life was 164 hours. The average amount of water produced during each bag filter run was 92,900 gallons. The minimum amount of water produced during a bag filter run was 26,700 gallons. The maximum amount of water produced during a bag filter run was 237,600 gallons. The large difference between the minimum and maximum amounts of filtered water produced is presumably due to differences in the feed water quality during the two filter runs. However, examination of feed water particle count and turbidity data does not reveal significant differences in the feed water between the two filter runs. The reason for the difference in performance during the minimum and maximum production run is unknown.

By comparing the headloss obtained during each run to the amount of water produced during the runs, it is possible to calculate an average minimum and maximum amount of water produced per psi of headloss. The average amount of water produced to psi headloss is 3,760 gallons. The minimum amount of water produced per psi of headloss is 1,030 gallons.

Table 4-18 presents data on the number of filter runs, the length of the runs, the amount of water produced during each run, and the headloss at the end of each run.

Table 4-18. Filtration Runs

Run Number	Length of Run (Hours)	Amount of filtrate (Gallons)	Headloss (psi)
1	164	237,600	23.0
2	24	26,700	26.0
3	95	82,300	27.0
4	95	80,700	27.0
5	103	83,900	26.0
6	112	109,300	28.0
7	106	68,500	26.0
8	85	53,800	22.0

Figure 4-7 depicts the headloss development profile generated during the verification testing.

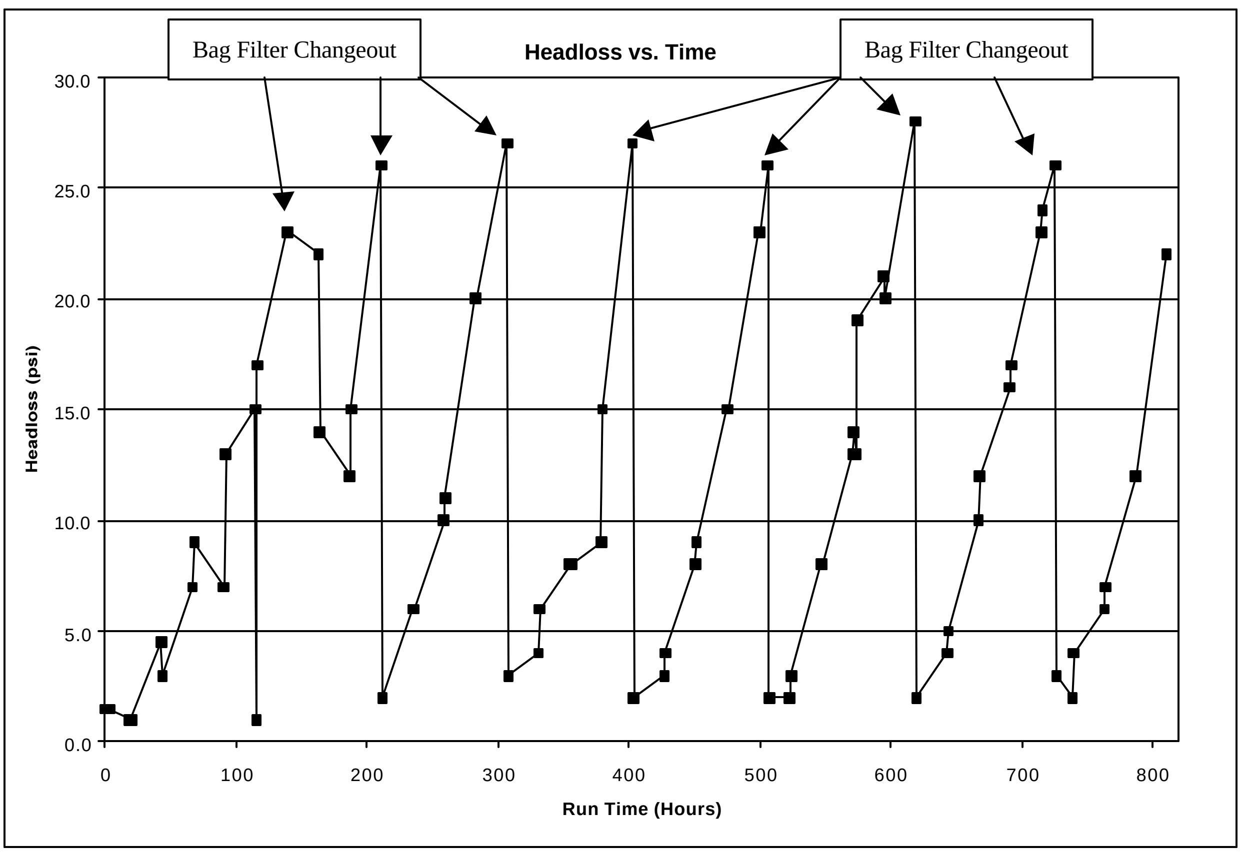

Figure 4-7. Headloss of Bag Filter System

4.5.4 Task 4: Microbiological Contaminant Removal

The purpose of this task was to demonstrate the treatment unit's ability to remove *Giardia* and *Cryptosporidium* sized particles. Challenges were conducted at the start of a filter run, when the bag filter had reached 50% of its terminal headloss, and when the bag filter had reached greater than 90% of its terminal headloss. Two of the 50% headloss challenges were conducted due to less than expected results obtained during the first 50% headloss challenge. The microsphere removal challenges took place on October 9 and 25, 2000 and January 22 and 24, 2001. During the challenge of 10/9/00 the system operated at a flow rate of 20.52 gpm. During the challenge of 10/25/00 the system operated at a flow rate 21.19 gpm. During the challenge of 1/22/01 the system operated at 23.00 gpm. The flow rate for the final challenge was 25.20 gpm.

Table 4-19. Microsphere Challenge Events

Challenge	Filter Run	Date	Flow Rate
0% Terminal Headloss	#1	10/9/00	20.52
50% Terminal Headloss	#4	10/25/00	21.19
50% Terminal Headloss	Additional Run	1/22/01	23.00
90% Terminal Headloss	Additional Run	1/24/01	25.20

4.5.4.1 Feed Water Testing Results

During the 0% headloss challenge testing the feed water had a pH of 6.85, a benchtop turbidity reading of 0.55 NTU, and a temperature of 13.5^{o}C. During the 50% headloss challenge testing of October 25 the feed water had a pH of 7.25, a benchtop turbidity reading of 0.65 NTU, and a temperature of 13.0^{o}C. During the 50% headloss challenge testing of January 22 the feed water had a pH of 7.55, a benchtop turbidity reading of 0.35 NTU, and a temperature of 4.8^{o}C. During the 90% headloss challenge testing of January 24 the feed water had a pH of 7.00, a turbidity of 0.35 NTU, and a temperature of 4.8^{o}C. The online feed water turbidity readings taken during the addition of the microspheres to the feed water indicate that the feed water turbidity did not change during the microsphere addition. No online turbidity readings are available for the October 9 challenge due to the loss of the online data caused by a computer malfunction.

Based on the results of the analysis of the stock suspension the suspension contained 7,000 of the 3.7µm spheres per ml of system flow and 700 of the 6.0µm spheres per ml of system flow during the 0% headloss challenge of October 9. No feed water samples, before or during the dosing procedure, were collected. Due to problems with the particle counting software the feed water particle counts for this challenge were lost.

The analysis of the stock suspension that was used for the 50% headloss October 25 challenge indicated that the concentration of the 3.7µm spheres was 2,300 spheres per ml of system flow and the concentration of the 6.0µm spheres was 340 spheres per ml of system flow. The slug dosing procedure was used to add the stock suspension to the treatment system. This created a difficulty in collecting a representative feed water sample after the addition of the microspheres. The collection was conducted during the two minutes that the stock suspension was being added to the treatment system. Because of the use of the slug dosing procedure and the questionable nature of the results of the analysis of the feed water sample the log removal calculations are based on the stock suspension concentration. Analysis of a sample of the feed water collected prior to the addition of the microspheres indicated that there were no interfering fluorescing compounds in the feed water. Results of the analyses of the stock suspensions and feed water samples are attached in Appendix B. It was believed that due to the high levels of particles which would be in the feed water and the short duration of the slug dosing of the microspheres that the feed particle counter would be saturated and not generate reliable feed water particle count results. For that reason a sample of the feed water was collected, diluted by a factor of 50 and fed through the particle counter for enumeration. Based on the diluted sample results the feed water 2 – 7 µm particle counts averaged 99,662.25 counts per ml.

The third challenge test, at 50% headloss, was conducted on January 22. Analysis of the stock suspension revealed that 2,000 of the 3.7µm spheres per ml of system flow were added to the feed water. Six hundred and ninety of the 6.0µm spheres per ml of system flow were added to the feed water. As previously mentioned the use of the slug dose technique rendered the data generated by the analysis of the feed water sample after the addition of the spheres questionable.

The final challenge test, at 90% headloss, was conducted on January 24. Analysis of the stock suspension indicated that 4,400 of the 3.7µm spheres and 1,000 of the 6.0µm spheres per ml of system flow were added to the feed water. A sample of the feed water collected before the addition of the spheres indicated that there was a fluorescing compound present in the feed water. Investigation indicated that it was a 3.7µm sphere which most likely was a remnant of a previous challenge. The concentration was 0.012 sphere per ml of system flow which was an insignificant amount compared to the feed water concentration after the addition of the microspheres. No other fluorescing compounds were detected. The use of the slug dose technique rendered the feed water concentration results questionable.

The results of the analyses of the stock suspension are listed in Table 4-20. Bench data sheets and report from the laboratory are enclosed in Appendix G. Particle count results of the enumeration of the diluted feed water to which the stock suspension had been added are presented in Tables 4-21, 4-22, and 4-23.

Table 4-20. 3.7µm and 6.0 µm Spheres Stock Suspension Concentration (counts per ml of system flow)

Date (Challenge Description)	10/9/00 (0% Headloss)		10/25/00 (50% Headloss)		1/22/01 (50% Headloss)		1/24/01 (90% Headloss)	
Replicate	3.7µm spheres	6.0 µm spheres	3.7µm spheres	6.0 µm spheres	3.7µm spheres	6.0 µm spheres	3.7µm spheres	6.0 µm spheres
1	6400	660	2200	360	1800	670	5100	1200
2	6900	680	1900	340	1900	690	2500	950
3	7800	760	2700	330	2200	700	5600	950
Average	7,000	700	2,300	340	2000	690	4,400	1,000
Standard Deviation	710	53	400	15	210	15	1,700	140
95% Confidence Interval	(6,200, 7,800)	(640, 760)	(1,800, 2,700)	(330, 360)	(1,700, 2,200)	(670, 700)	(2,500, 6,300)	(840, 1,200)

Table 4-21. Feed Water Particle Counts with Stock Suspension Addition (concentration per ml of system flow) - 10/25/2000 (50% Headloss Challenge)

	Size						
	2-3µm	3-5µm	5-7µm	7-10µm	10-15µm	>15µm	Cumulative
Number of Samples	5	5	5	5	5	5	5
Average	3,202.08	4,147.78	1,362.47	680.34	317.22	137.10	9,847.01
Minimum	2,677.00	3,456.25	1,192.75	552.50	254.35	110.65	8,244.65
Maximum	3,937.90	5,057.75	1,627.60	821.25	368.75	172.00	11,946.50
Std Dev	545.74	666.20	179.51	112.87	55.289	26.145	N/A
95% Confid Interval	(2,723.73, 3,680.43)	(3,563.84, 4,731.72)	(1,205.13, 1,519.81)	(581.41, 779.27)	(268.76, 365.68)	(114.18, 160.02)	N/A

N/A = Not Applicable. Statistical measurements on cumulative data do not generate meaningful data.

Table 4-22. Feed Water Particle Counts with Stock Suspension Addition (concentration per ml of system flow) - 1/22/2001 (50% Headloss Challenge)

	Size						
	2-3µm	3-5µm	5-7µm	7-10µm	10-15µm	>15µm	Cumulative
Number of Samples	5	5	5	5	5	5	5
Average	3,758.15	4,875.13	1,328.46	1,522.34	859.47	357.02	12,701.05
Minimum	3,619.95	4,712.88	1,285.00	1,484.63	787.20	277.75	12,315.25
Maximum	4,020.33	5,167.70	1,388.00	1,584.25	928.63	432.43	13,168.25
Std Dev	161.986	181.842	43.2528	39.9989	51.257	59.870	N/A
95% Confid Interval	(3,616.16, 3,900.13)	(4,715.74, 5,034.51)	(1,290.54, 1,366.37)	(1,487.28, 1,557.40)	(814.54, 904.40)	(304.54, 409.49)	N/A

N/A = Not Applicable. Statistical measurements on cumulative data do not generate meaningful data.

Table 4-23. Feed Water Particle Counts with Stock Suspension Addition (concentration per ml of system flow) - 1/24/2001 (90% Headloss Challenge)

	Size						
	2-3µm	3-5µm	5-7µm	7-10µm	10-15µm	>15µm	Cumulative
Number of Samples	5	5	5	5	5	5	5
Average	982.85	1,234.78	283.78	269.52	155.01	87.93	3,013.86
Minimum	648.38	878.43	199.63	201.80	116.18	61.58	2,106.00
Maximum	1,799.58	2,048.75	417.08	359.88	224.83	148.75	4,862.33
Std Dev	481.915	490.954	94.5496	78.5755	44.208	34.659	N/A
95% Confid Interval	(560.44, 1,405.25)	(804.45, 1,665.11)	(200.91, 366.65)	(200.65, 338.39)	(116.26, 193.76)	(57.55, 118.31)	N/A

N/A = Not Applicable. Statistical measurements on cumulative data do not generate meaningful data.

4.5.4.2 Bag Filter Effluent Testing Results

The bag filter effluent was collected and analyzed for the presence of the 3.7µm and the 6.0µm microspheres. Analyses were also conducted for bag filtrate turbidity and particle counts during the challenge events. The bag filter effluent turbidity as measured by the online turbidimeter during the 0% headloss challenge is unavailable due to a computer malfunction. The bag filter effluent turbidity as measured by the online turbidimeter during the first 50% headloss challenge averaged 0.05 NTU. The average online bag filter effluent turbidimeter reading for the day was 0.05 NTU. The bag filter effluent turbidity as measured by the online turbidimeter during the second 50% headloss challenge averaged 0.05 NTU. The average online bag filter effluent turbidimeter reading for the day was 0.05 NTU. The bag filter effluent turbidity as measured by the online turbidimeter during the 90% headloss challenge averaged 0.05 NTU. The average online bag filter effluent turbidimeter reading for the day was 0.05 NTU. There was not a significant difference in the average turbidity of the bag filter effluent produced during the challenges compared to the average bag filter effluent turbidity produced during the entire day the challenges were conducted.

The bag filter effluent particle counts were recorded during the challenges of October 25, January 22 and January 24. The results of these analyses are presented in Tables 4-24, 4-25, and 4-26.

Samples of the bag filter effluent collected during the challenges were analyzed for the presence and concentration of the 3.7µm spheres and the 6.0µm spheres. The results of the analysis of the bag filter effluent from the 0% headloss challenge indicated that the effluent contained 4.2 of the 3.7µm spheres and 0.30 of the 6.0µm spheres per ml of system flow. Table 4-27 presents the results of these analyses.

The analysis of the bag filter effluent sample from the first 50% headloss challenge indicated that the effluent contained 25 of the 3.7µm spheres and 1.3 of the 6.0µm spheres per ml of system flow. As prescribed by the Protocol, a second set of bag filter effluent samples were collected after flow to the treatment system was stopped and then restarted. The results of the analysis of the second sample indicated that the effluent contained 4.9 of the 3.7µm spheres and 0.17 of the 6.0µm spheres per ml of system flow. By combining the results of the analyses of the two sets of samples analyzed an overall concentration of 30 of the 3.7µm spheres and 1.4 of the 6.0µm spheres per ml of system flow was obtained. Table 4-27 presents the results of these analyses. Table 4-24 presents the results of bag filter effluent particle counts that were taken during the challenge.

The analysis of the bag filter effluent sample from the second 50% headloss challenge indicated that the effluent contained 22 of the 3.7µm spheres and 2.2 of the 6.0µm spheres per ml of system flow. Since this challenge was conducted as a repeat of the 50% headloss challenge the system flow was stopped and restarted and a second set of bag filter effluent samples were collected. The results of the analysis of the second sample indicated that the effluent contained 1.0 of the 3.7µm spheres and 0.074 of the 6.0µm spheres per ml of system flow. By combining the results of the analyses of the two sets of samples analyzed an overall concentration of 23 of the 3.7µm spheres and 2.3 of the 6.0µm spheres per ml of system flow was obtained. Table 4-27 presents the results of these analyses. Table 4-25 presents the results of bag filter effluent particle counts that were taken during the challenge.

The 90% headloss challenge was conducted on January 24. The analysis of the bag filter effluent sample from that challenge indicated that the effluent contained 38 of the 3.7µm spheres and 3.2 of the 6.0µm spheres per ml of system flow. The results of these analyses are presented in Table 4-27. Table 4-26 presents the results of bag filter effluent particle counts that were taken during the challenge.

Table 4-24. Bag Filter Effluent Particle Counts During Challenge Sample Collection (counts per ml) - 10/25/2000 (50% Headloss Challenge)

				Size			
Time	2-3µm	3-5µm	5-7µm	7-10µm	10-15µm	>15µm	Cumulative
10:23	1.900	0.950	0.075	0.075	0.025	0.100	3.125
10:33	82.950	136.800	10.000	0.225	0.000	0.000	229.975
10:43	1.050	0.950	0.025	0.025	0.000	0.025	2.075
11:17	2.100	0.975	0.125	0.000	0.000	0.000	3.200

Table 4-25. Bag Filter Effluent Particle Counts During Challenge Sample Collection (counts per ml) - 1/22/2001 (50% Headloss Challenge)

				Size			
Time	2-3µm	3-5µm	5-7µm	7-10µm	10-15µm	>15µm	Cumulative
11:03	1.400	1.225	0.500	0.250	0.000	0.125	3.500
11:05	4.575	3.575	0.425	0.575	0.475	1.375	11.000
11:07	5.625	3.175	0.400	0.750	0.950	14.325	25.225
11:09	2.725	1.375	0.425	0.350	0.000	0.200	5.075
11:11	1.825	1.575	0.350	0.350	0.000	0.125	4.225
11:13	16.700	10.600	1.275	1.425	1.700	15.225	46.925
11:15	19.500	22.625	2.775	1.675	1.450	16.525	64.550
11:17	88.650	157.525	15.950	1.750	2.150	17.650	283.675
11:19	81.375	140.900	15.125	2.175	2.075	21.700	263.350
11:21	29.200	40.725	4.525	1.600	2.000	22.000	100.050
11:23	10.850	9.525	1.525	1.125	1.900	21.800	46.725
11:25	8.375	7.225	1.125	0.700	1.875	22.475	41.775
11:27	7.175	3.900	0.825	0.700	0.275	4.950	17.825
11:29	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11:31	0.125	0.000	0.075	0.000	0.000	0.075	0.275
11:49	21.950	44.275	22.675	13.200	3.075	3.800	108.975
11:51	7.875	8.900	2.075	0.900	0.250	0.625	20.625
11:53	5.075	6.100	1.150	0.475	0.075	0.850	13.725
11:55	3.475	3.275	0.700	0.250	0.025	0.975	8.700
11:57	2.225	2.275	0.300	0.225	0.000	0.200	5.225
11:59	2.725	2.175	0.350	0.225	0.100	1.050	6.625

Table 4-26. Bag Filter Effluent Particle Counts During Challenge Sample Collection (counts per ml) - 1/24/2001 (90% Headloss Challenge)

				Size			
Time	2-3µm	3-5µm	5-7µm	7-10µm	10-15µm	>15µm	Cumulative
10:08	2.025	1.350	0.375	0.050	0.050	0.200	4.050
10:18	1.575	1.275	0.225	0.025	0.025	0.150	3.275
10:28	5.500	8.100	1.225	0.325	0.025	0.650	15.825
10:38	1.825	1.550	0.400	0.100	0.000	0.100	3.975
10:46	1.850	1.350	0.150	0.125	0.000	0.200	3.675
10:48	1.400	1.850	0.350	0.175	0.000	0.050	3.825

Table 4-27. 3.7µm and 6.0 µm Spheres Effluent Concentration During Challenge (per ml of system flow)								
Date (Challenge Description)	10/9/00 (0% Headloss)		10/25/00 (50% Headloss)		1/22/01 (50% Headloss)		1/24/01 (90% Headloss)	
Replicate	3.7µm spheres	6.0 µm spheres	3.7µm spheres	6.0 µm spheres	3.7µm spheres	6.0 µm spheres	3.7µm spheres	6.0 µm spheres
1	4.7	0.39	31	1.5	21	2.0	32	2.7
2	5.4	0.45	32	1.5	26	2.6	41	4.0
3	2.6	0.070	28	1.3	22	2.2	42	2.9
Average	4.2	0.30	30	1.5	23	2.2	38	3.2
Std. Dev.	1.5	0.20	2.1	0.12	2.5	0.30	5.5	0.70
95% Confid Int.	(2.6, 5.9)	(0.072, 0.53)	(28, 32)	(1.3, 1.6)	(20, 26)	(1.9, 2.6)	(32, 45)	(2.4, 4.0)

4.5.4.3 Log_{10} Removal

The log_{10} removal of 3.7µm spheres and of the 6.0µm spheres was calculated from the stock suspension concentration and the effluent concentration. This was done due to the previously discussed difficulties in obtaining an accurate feed water concentration while using the slug dosing technique. The log_{10} removal was calculated by converting the concentration of the 3.7µm spheres and of the 6.0µm spheres in the stock suspension and the bag effluent to their log_{10} equivalent and subtracting the log_{10} of the bag filter effluent concentration from the log_{10} of the stock feed suspension concentration. The resulting difference was the log_{10} removal of the treatment system for the 3.7µm spheres and of the 6.0µm spheres.

Using this method, the log_{10} removal for the 3.7µm and the 6.0µm spheres during the initial challenge on a new filter bag was 3.2 and 3.5 respectively. The log_{10} removal for the 3.7µm spheres during the 50% headloss challenge was 1.9. The log_{10} removal for the 6.0µm spheres during this challenge, which was conducted on October 25, was 2.4. Due to the change in the log_{10} removal performance the manufacturer requested that the 50% headloss challenge be repeated. This was done on January 22. The log_{10} removal for the 3.7µm spheres during this challenge was again 1.9. The log_{10} removal for the 6.0µm spheres during this challenge was 2.5. The log_{10} removal for the 3.7µm spheres during the 90% headloss challenge was 2.0. The log_{10} removal for the 6.0µm spheres during this challenge, which was conducted on January 24, was 2.5. A summary of these results is presented in Table 4-28.

Table 4-28. 3.7µm and 6.0 µm Spheres Feed and Effluent Log_{10} Concentrations and Removal During Challenge (per ml of system flow)								
Date	10/9/00 (0% Headloss)		10/25/00 (50% Headloss)		1/22/01 (50% Headloss)		1/24/01 (90% Headloss)	
	3.7µm spheres	6.0 µm spheres	3.7µm spheres	6.0 µm spheres	3.7µm spheres	6.0 µm spheres	3.7µm spheres	6.0 µm spheres
Log_{10} Feed Concentration	3.8	2.8	3.4	2.5	3.3	2.8	3.6	3.0
Log_{10} Bag Filter Effluent Concentration	0.6	-0.5	1.5	0.2	1.4	0.3	1.6	0.5
Log_{10} Removal	3.2	3.4	1.9	2.4	1.9	2.5	2.0	2.5

4.5.4.4 Discussion of Results

The 3.7µm spheres were used as surrogates for *Cryptosporidium* oocysts. The ESWTR requires an overall minimum 2 $\log_{10}$ removal of *Cryptosporidium* oocysts (EPA, 1999). During the four challenges the minimum removal of the 3.7µm spheres was 1.9 $\log_{10}$. The 6.0µm spheres were used as surrogates for *Giardia* cysts. The SWTR requires an overall minimum 3 $\log_{10}$ removal/inactivation of *Giardia* cysts (EPA, 1989). According to the Pennsylvania DEP's Public Water Supply Manual the design of filtration processes must ensure a minimum 99% (or 2 $\log_{10}$) removal of *Giardia* cysts (PADEP, 1997). During the four challenges the minimum removal of the 6.0µm spheres was 2.4 $\log_{10}$.

The $\log_{10}$ removal was less during the higher pressure differential challenges. This decline in the removal efficiency may be due to the increase in the pressure differential.

4.6 QA/QC Results

The daily, bi-weekly, initial, and the analytical laboratory QA/QC verification results are presented below.

4.6.1 Daily QA/QC Results

Daily readings for the inline turbidimeter flow rate and readout and online particle counter flow rate QA/QC results were taken and recorded.

The online feed water turbidimeter flow rate averaged 531 ml/minute. The flow rate was verified volumetrically using a graduated cylinder and stop watch. The maximum rate measured, during the testing was 700 ml/minute; the minimum was 300 ml/minute. The acceptable range of flows as specified by the manufacturer is 250 ml/minute to 750 ml/minute. The target flow rate for the turbidimeter was 500 ml/minute. Flow rates within +/- 40% of the target were considered acceptable. The flow rate required adjustment on two of the 37 days of testing.

The online prefilter effluent turbidimeter flow rate averaged 526 ml/minute. To determine the flow rate of the online prefilter turbidimeter, the flow was measured using a graduated cylinder and stop watch. The maximum rate measured during the testing was 680 ml/minute; the minimum was 420 ml/minute. The acceptable range of flows as specified by the manufacturer is 250 ml/minute to 750 ml/minute. The target flow rate for the turbidimeter was 500 ml/minute. Flow rates within +/- 40% of the target were considered acceptable. The flow rate did not require adjustment during the 37 days of testing.

The online bag filter effluent turbidimeter flow rate averaged 570 ml/minute. To determine the flow rate of the online prefilter turbidimeter, the flow was measured using a graduated cylinder and stop watch. The maximum rate measured during the testing was 750 ml/minute; the minimum was 450 ml/minute. The acceptable range of flows as specified by the manufacturer is 250 ml/minute to 750 ml/minute. The target flow rate for the turbidimeter was 500 ml/minute. Flow rates within +/- 40% of the target were considered acceptable. The flow rate required adjustment once during the 37 days of testing.

The feed water particle counter flow rate averaged 97 ml/minute. To determine the flow rate of the inline filtrate turbidimeter, the flow was measured using a graduated cylinder and stop watch. The maximum flow rate measured was 108 ml/minute; the minimum was 92 ml/minute. The target flow rate specified by the manufacturer is 100 ml/minute. Efforts were made to keep the flow rate between 95 ml/minute to 105 ml/minute or within 5% of the target flow rate. Adjustments to the flow rate were not required during the verification study.

The prefilter effluent particle counter flow rate averaged 98 ml/minute. To determine the flow rate of the inline filtrate turbidimeter, the flow was measured using a graduated cylinder and stop watch. The maximum flow rate measured was 108 ml/minute; the minimum was 91 ml/minute. The target flow rate specified by the manufacturer is 100 ml/minute Efforts were made to keep the flow rate between 95 ml/minute to 105 ml/minute or within 5% of the target flow rate. Adjustments to the flow rate were not required during the verification study.

The finished water particle counter flow rate averaged 97 ml/minute. The flow rate was verified using a graduated cylinder and stop watch. The maximum flow rate measured was 105 ml/minute; the minimum was 90 ml/minute. The target flow rate specified by the manufacturer is 100 ml/minute. Efforts were made to keep the flow rate between 95 ml/minute to 105 ml/minute or within 5% of the target flow rate. Adjustments to the flow rate were not required during the verification study.

4.6.2 Bi-weekly QA/QC Verification Results

Every two weeks checks were made on the feed and effluent flow meters; the meters were cleaned out if necessary and the flow readouts were verified. Clean out of the meters was not necessary due to the high quality of the feed and finished water. The flow meter readout was compared to the results obtained from the actual amount measured using a graduated cylinder and stopwatch. The acceptable range of accuracy for the feed and finished meters was +/- 10% of the target flow. The feed water meter readout averaged 2.3% higher than actual according to the results obtained during the flow verification. None of the readings obtained during the four flow meter verifications was greater than +/- 10% of the target flow. The effluent meter readout averaged 1.7% higher than actual according to the results obtained during the flow verification. None of the readings obtained during the four flow meter verifications was greater than +/- 10% of the target flow.

4.6.3 Results of QA/QC Verifications at the Start of Each Testing Period

At the start of the testing period the online turbidimeter was cleaned out and recalibrated, the pressure gauges/transmitters readouts were verified, the tubing was inspected, and the online particle counter calibration was checked.

The online turbidimeter reservoir was drained and cleaned and the unit was recalibrated according to manufacturer's recommendations. No corrective action was required as a result of these activities.

The inlet and outlet pressure gauges on each of the filter housings were checked prior to the start of testing. Dead weights of 0, 5,15, 25, 35, 45, 55, 65, 75, and 85 pounds were used on the inlet and outlet of housing #3. The inlet water pressure gauge averaged 3.0 psi higher than actual. The outlet pressure gauge read, on average, 3.0 psi higher than actual. Dead weights of 0, 10, 20, 30, 40, 50, 60, 70, and 80 pounds were used on the inlet and outlet of housings #1, #2, and the prefilter housing. The inlet pressure gauge on housing #2 agreed with the dead weights used at all the weights tested. The outlet to housing #2 agreed, on average with the dead weights used. The zero reading on the housing #2 outlet pressure gauge read 2.0 psi and the 30 pound dead weight produced a reading of 30.5 psi. All the other readings agreed with the dead weights. The inlet pressure gauge on housing #1 (which was the housing used to house the bag filter during the 30 day test) read on averaged about 2.0 psi higher than the dead weights. The effluent pressure gauge of housing #1 read 0.5 psi higher than the dead weight at 60, 70, and 80 psi. The readings obtained from the prefilter housing inlet pressure gauge equaled the dead weight values except for the 10 pound weight which produced a reading of 11.0 psi. The prefilter housing outlet pressure gauge equaled the dead weight values except for the 10 pound weight which produced a reading of 11.0 psi and the 60, 70, and 80 pound dead weights which produced readings 1.0 psi less than actual on the gauge. A complete table listing the results of the calibration is presented in Appendix B.

The tubing used on the treatment system was inspected for cracks and flaws which could have caused unexpected failure prior to the initiation of testing. The tubing was in good condition and replacement was not necessary. It was noted during the NSF field audit that some of the waste tubing from the turbidimeters had become discolored. The tubing was replaced.

The calibration of the online particle counters was checked twice during the study. The first check was done prior to the start of the initial operations period. The second calibration check was conducted prior to the start of the 30 day test. This second check was done due to the long delay between the completion of the initial testing and the start of the 30 day test as well as the fact that the particle counters were sent back for repair prior to the start of the 30 day test.

Calibration was carried out by preparing a cocktail of microspheres to create an initial concentration of 2,000 particles/ml for each of the 5 µm, 10 µm, and 15 µm sized particles.

During the first calibration the particle counter designated as "C" (which became the feed water particle counter during the 30 day test) showed an average response for the 5 µm size of 1841.86 counts/ml; the 10 µm size showed an average response of 1873.28 counts/ ml; the 15 µm size showed an average response of 1899.16 counts/ ml. This corresponds to a difference of 8.59%, 6.76%, and 5.31% respectively in particle counts.

The first calibration of the particle counter designated "B" (which became the prefilter effluent during the 30 day test) showed an average response for the 5 µm size of 1820.06 counts/ml; the 10 µm size showed an average response of 1956.85 counts/ ml; the 15 µm size showed an average response of 1886.82 counts/ ml. This corresponds to a difference of 9.89%, 2.21%, and 6.00% respectively in particle counts.

The results of the first calibration of the particle counter designated "A" (which became the bag filter effluent particle counter during the 30 day test) showed an average response for the 5 µm size of 1859.77 counts/ml; the 10 µm size showed an average response of 1777.64 counts/ ml; the 15 µm size showed an average response of 1751.21 counts/ ml. This corresponds to a difference of 7.54%, 12.51%, and 14.21% respectively in particle counts. The 10 µm and 15 µm results were outside of the generally recognized range of +/- 10 %. As previously mentioned the particle counters were sent back for recalibration prior to the start of the 30 day test.

The results of the second calibration of the feed water particle counter showed an average response for the 5 µm size of 1844.80 counts/ml; the 10 µm size showed an average response of 1803.58 counts/ ml; the 15 µm size showed an average response of 1898.59 counts/ ml. This corresponds to a difference of 8.41%, 10.89%, and 5.34%, respectively, in particle counts. Although the 10 µm size results were slightly in excess of 10% the decision was made to commence the testing rather than returning the unit for service.

The results of the second calibration of the prefilter effluent particle counter showed an average response for the 5 µm size of 1905.54 counts/ml; the 10 µm size showed an average response of 1875.74 counts/ ml; the 15 µm size showed an average response of 1821.65 counts/ ml. This corresponds to a difference of 4.96%, 6.62%, and 9.79% respectively in particle counts.

The second calibration of the bag filter effluent particle counter showed an average response for the 5 µm size of 1882.24 counts/ml; the 10 µm size showed an average response of 1884.37 counts/ ml; the 15 µm size showed an average response of 1833.68 counts/ ml. This corresponds to a difference of 6.26%, 8.84%, and 9.07% respectively in particle counts.

The particle counters used during the testing were Met-One PCX models. The units had capabilities of measuring particles as small as 2 µm and a coincidence error of less than 10 %. Particle counter model, serial number, calibration certificate, and calculation of coincidence error are included in Appendix H.

4.6.4 On-Site Analytical QA/QC

Samples for pH, turbidity, and temperature were examined onsite.

The results of the pH analyses were evaluated for accuracy and precision. Accuracy was determined by analyzing a known sample and comparing the result to the true value of the sample. The average accuracy of the pH analyses was 101.2%. The minimum accuracy of the pH analyses was 100%; the maximum accuracy was 104%. Precision of the pH analyses was determined by calculating the relative percent deviation of the duplicate analyses. The average relative percent deviation of the pH analyses was 0.45%. The minimum relative percent deviation of the pH analyses was 0%; the maximum was 1.61%.

The results of the turbidity analyses were evaluated for accuracy and precision. Accuracy of the benchtop turbidimeter was determined by analyzing a known sample and comparing the result to the true value of the sample. The average accuracy of the turbidity at the 0.1 NTU level was 99%. The average accuracy of the turbidity at the 0.5 NTU level was 102%. The average accuracy of the turbidity at the 5.0 NTU level was 104%. Precision of the turbidity analyses was determined by comparing the results obtained from the online analyzers to the results obtained using the benchtop turbidimeter and calculating the relative percent deviation of the analyses. The average relative percent deviation for the feed water turbidity analyses was 4.0%. The average relative percent deviation for the prefilter effluent turbidity analyses was 4.9%. The average relative percent deviation for the bag filter effluent turbidity analyses was 16.0%. The discrepancy between these two results can be explained by differences in the analytical techniques between the online and benchtop turbidimeter and the low level of turbidity in the bag filter effluent. The benchtop turbidimeter uses a glass cuvette to hold the sample; this cuvette can present some optical difficulties for the benchtop turbidimeter. The online turbidimeter has no cuvette to present a possible interference with the optics of the instrument. The low level of turbidity in the bag filter effluent also can create analytical difficulties, particularly for the benchtop.

The thermometer used for temperature analyses was a NIST traceable thermometer. The analytical procedure for temperature was to allow the thermometer to sit in a stream of running feed water until two equivalent readings were obtained. Therefore, the temperature results recorded were the result and the duplicate analysis. For this reason the relative percent deviation would always equal zero and the results are not tabulated.

4.6.5 Analytical Laboratory QA/QC

Analyses conducted on feed and finished water are listed in Table 3-1. QA/QC procedures are based on Standard Methods, 19th Ed., (APHA, 1995).

Calibration results of the analytical instrumentation used to conduct the analyses listed in Table 3-1 on finished water is recorded and kept on file at the contract laboratory.

Chapter 5
References

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

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