September 2001
NSF 01/08/EPADW395

Environmental Technology Verification Report

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

Rosedale Products, Inc.
Bag and Rigid Cartridge Filter System
Model GFS-302P2-150S-ESBB

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 AND CARTRIDGE FILTER USED IN DRINKING WATER TREATMENT SYSTEMS**		
APPLICATION:	**PHYSICAL REMOVAL OF *GIARDIA*- AND *CRYPTOSPORIDIUM*-SIZED PARTICLES IN DRINKING WATER**		
TECHNOLOGY NAME:	**MODEL GFS-302P2-150S-ESBB BAG AND RIGID CARTRIDGE FILTER SYSTEM**		
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholders groups which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF) in cooperation with the EPA operates the Drinking Water Treatment Systems (DWTS) Pilot, one of 12 technology areas under ETV. The DWTS Pilot recently evaluated the performance of a bag and cartridge system used in drinking water treatment system applications. This verification statement provides a summary of the test results for the Rosedale Products, Inc. (RPI) Model GFS-302P2-150S-ESBB Bag and Rigid Cartridge Filter System. Cartwright, Olsen and Associates, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

The verification testing of the RPI Model GFS-302P2-150S-ESBB Bag and Rigid Cartridge Filter System occurred at the Minneapolis Municipal Water Works (MWW) facility during a 32-day verification test period conducted between March and April 2000. The system employed a Model GD-PO-523-2 bag filter element and a Model PL-520-PPP-141 rigid cartridge filter element. The source water was a blend of untreated river water and finished water. The system was operated for 23 hours per day with a one-hour stoppage. There were a total of 22 filter runs with an average flow rate of 9.7 gpm. The manufacturer specified 15 pounds per square inch (psi) as terminal headloss. Following a brief ripening period during each filter run, on-line turbidity on average over twenty-two filter runs was 1.08 NTU influent and 0.21 NTU effluent. Three fluorescent microsphere challenges were performed during three filter runs, for a total of nine challenges. The challenges occurred at the beginning of the run, at roughly the mid-point as determined by headloss, and then again at a point between 90% headloss and terminal headloss. The number of microspheres added to the feed water during the nine challenges was approximately 11,746 particles/mL. Fifty percent of the microspheres used were from a 3.4 µm microsphere stock solution (further evaluation of the 3.4 µm stock solution indicated that the stock solution actually contained microspheres with a mean size of approximately 3 µm) and the remaining 50% were 5 µm and 6 µm in size. Particle counters were used to measure the number of particles in the feed and finished water, and samples were collected of the feed and finished water and analyzed by microscopic enumeration. The RPI bag and cartridge system demonstrated 1.1 to 2.1 $\log_{10}$ removal of seeded microspheres (2.5-7.0 µm) based on the microscopic enumeration results, and 1.9 to 2.7 $\log_{10}$ removal of microspheres and indigenous particles sized 2.0 to 7.0 µm based on the on-line particle counter data that was adjusted for the number of fluorescent microspheres added (as described later).

TECHNOLOGY DESCRIPTION

The system consists of two connected stainless steel filter housings. The first housing contained a Model GD-PO-523-2 bag filter element. The second housing contained a Model PL-520-PPP-141 rigid cartridge filter element (which replaced the Model GLR-PO-825-2 filter element used during Phase I initial operations). Valves and other components are also made of stainless steel or of materials that will not degrade in water. The flow through both the bag and cartridge filter is from inside to outside. The filter housings are designed to accommodate a flow rate of 20 gpm, but were operated at 10 gpm during the verification testing to limit possible filter loadings by high turbidity levels. The system is designed to operate with surface waters that have turbidity levels of 1 NTU or less and with pressures of less than 60 psi. This testing used 15 psi as a terminal pressure loss value. Liquid chlorine bleach (sodium hypochlorite) was added during the verification testing to limit any microbial growth within the filters. The bleach-metering pump was stopped during microsphere challenge events.

The system is designed to act as a final barrier and to capture/contain particles in the size range of *C. parvum* (approximately 3-7 µm). Since *G. lamblia* cysts are larger than *C. parvum* oocysts, it is assumed that if the smaller oocysts are contained, the larger cysts will be contained at least the same level[1]. Accordingly, while this system is applicable to *G. lamblia* removal as well as *C. parvum* removal, focus was placed on *C. parvum* sized particles.

The filter system is suited to small public water systems where water treatment plant operators typically have minimal technical training. The system itself requires no additional chemicals beyond normal disinfection and relatively limited on-site supervision, for tasks such as reading pressure gauges and changing filters. No special licensing is required for the use of the filters. Training in bag/element

[1] Niemiinski, Eva C. *Removal of Cryptosporidium and Giardia through Conventional Water Treatment and Direct Filtration*. EPA/600/SR-97/025, 1997.

replacement is minimal and is explained in the Operations and Maintenance (O&M) Manual, as supplied by the manufacturer (see Verification Report).

VERIFICATION TESTING DESCRIPTION

Test Site

The host site for this demonstration was the Minneapolis Municipal Water Works (MWW) located in Fridley, Minnesota, a suburb adjacent to and directly north of the City of Minneapolis. The testing equipment was located in Pump House #5. Pump House #5 is the intake point from the Mississippi river.

Source Water

The source water for the verification testing was a blend of raw water from the Mississippi River and finished water from the MWW treatment plant. Water at the MWW is softened with lime and treated with alum for removal of color and turbidity. Powdered activated carbon and occasionally potassium permanganate are also added to remove taste and odor. The water is then treated with carbon dioxide to lower the pH and stabilize the remaining hardness prior to being pumped to one of two filtration plants. At the filtration plant, chlorine and ammonia are added for initial disinfection, fluoride is added for tooth decay prevention and ferric chloride is added as a coagulant to remove remaining color and turbidity. The water then enters a series of coagulation/sedimentation basins after which the water is filtered with single, dual or mixed media filters. Blended poly/ortho phosphate is later added as a corrosion control/inhibitor. The water is post-chlorinated for final adjustment of the disinfectant residual before being fed into the reservoirs and pumped into the distribution system. Finished water was blended with raw river water to obtain a turbidity level between 1-3 NTU.

Methods and Procedures

The verification test was divided into tasks that evaluated the system's treatment performance, specifically its ability to physically remove polystyrene microspheres in the size range of 3 to 6 µm from the feed water, and documented the system's operational parameters.

Prior to the 32-day verification test, cartridge filter elements underwent filter variability testing to evaluate the variations between and within filter production lots. Phase I was designed to determine variations *within* a production lot number of Model GLR-PO-825-2 cartridge filter elements. Based on the results of the first phase of variability testing, Rosedale chose to change the cartridge filter to the Model PL-520-PPP-141 cartridge filter for the remainder of the testing. Phase II variability testing was designed to show variations *between* production lots. Each phase included 10 days of system operation with 23 hours of operation and one hour off line (no flow).

The 32-day verification test was performed to evaluate the total number of gallons treated per filter system (bag and cartridge) and the finished water characteristics. The bags and cartridges were replaced if terminal headloss (15 psi) or turbidity breakthrough, as established by the manufacturer, was reached. Water quality parameters monitored during the verification test included: pH, temperature, turbidity, particle counts, free chlorine residual, alkalinity, total hardness, total organic carbon (TOC), ultraviolet absorbance (UVA) at 254 nanometers (nm), true color, aluminum, iron, manganese, algae, and total coliforms. Laboratory analyses were performed in accordance with the procedures and protocols established in *Standard Methods for the Examination of Water and Wastewater*, 19th Edition *(SM)* or EPA-approved methods as listed in the report.

During the testing, microspheres in the size range of 3 to 6 µm were injected into the pilot installation feed water via a metering pump to demonstrate 3+ $\log_{10}$ removal. Fifty percent of the microspheres used

were from a 3.4 µm microsphere stock solution (further evaluation of the 3.4 µm stock solution indicated that the stock solution actually contained microspheres with a mean size of approximately 3 µm) and the remaining 50% were 5 µm and 6 µm in size. Three microsphere challenges were performed during three filter runs, for a total of nine challenges. The challenges occurred at the beginning of the run, at roughly the mid-point as determined by headloss, and then again at a point between 90% headloss and terminal headloss. The feed and finished water were evaluated for the presence of microspheres by using on-line particle counters and enumeration of samples collected with hemacytometer techniques and/or membrane filtration.

Operating conditions were documented during each day of verification testing, including: filter flow rate, filter headloss, hours of operation, filtered water production, and frequency of filter replacement.

VERIFICATION OF PERFORMANCE

Filter Element Variability

Phase I filter element variability testing began on June 24, 1999, with three Model GLR-PO-825-2 cartridge filters from the same production lot (No. 88-4546). The bag filters, used as pre-filters within the filter train, all were from the same manufacturing lot. The flowrate was 20 gpm per filter and the target turbidity level was achieved by blending raw river water with finished water to approximately 3.0 NTU. By the second day of Phase I, the bags and cartridge filters had been replaced once and the filters were again approaching terminal headloss. Accordingly, the system was shut down on June 25 to reevaluate the operating parameters. After discussions with the manufacturer, it was decided to reduce influent turbidity to 1 NTU and decrease the flow rate to 10 gpm to reduce rate of filter loading. It was also decided that only finished drinking water would serve as the feed water when the equipment was not attended by an operator to avoid reaching terminal headloss during unmanned periods. Due to concerns expressed by the manufacturer regarding the cartridges from production lot No. 88-4546, the manufacturer provided replacement cartridges from a different production lot, No. 6-2-99. Phase I testing recommenced on June 29 and ended July 7, 1999. Bag and cartridge filters were replaced twice during the remaining portion of Phase I. Based on the results of Phase I, the manufacturer elected to address concerns pertaining to the manufacturing process of the Model GLR-PO-825-2 cartridge filter element. Subsequently, for Phase II of filter element variability testing, the manufacturer provided cartridge filter elements with a different model number (PL-520-PPP-141) and internal seals within the filter housing.

Phase II of the filter element variability testing occurred between January 10 through 20, 2000 with Model PL-520-PPP141 cartridge filters from 3 different production lots (Numbers 990541-5, 990541-4, 990541-3). Again, the bag filters used as pre-filters within the filter train were from the same manufacturing lot. Bag and cartridge filters were replaced twice during Phase II. Headlosses at time of filter replacement on January 13 were 12 psi, 8 psi, and 15 psi respectively for filter trains #1, #2, and #3. Corresponding $\log_{10}$ reductions of indigenous particles sized 2 to 15 µm as measured by particle counters were 1.4, 1.2, and 1.6. Head losses at time of filter replacement on January 17 were 12 psi, 8 psi, and 9 psi respectively for filter trains #1, #2, and #3 and corresponding 2-15 µm particle count $\log_{10}$ reductions were 1.5, 1.5, and 1.6. Head losses at time of shut-down on January 20 were 6 psi, 6 psi, and 5.5 psi respectively for filter trains #1, #2, and #3. Corresponding 2-15 µm particle count $\log_{10}$ reductions were 1.4, 0.81, and 1.4. Filter train #2 demonstrated comparatively poor particle reduction performances during Phase II. This was attributed to a faulty pressure differential gauge that bypassed feed water into the filtered water stream. Due to the limited number of filters evaluated within each production lot, conclusions regarding variation in filter performance between production lots cannot be offered with any degree of certainty.

Operation and Maintenance

The verification testing for the system began on March 7, 2000, and ended its 32-day period on April 20, 2000. The system was operated for 23 hours per day with a one-hour stoppage. There were a total of 22 filter runs (bag and cartridges replaced at the start of each filter run unless otherwise noted). The average flow rate over the 22 filter runs was 9.7 gpm. The average terminal headloss, volume of water produced, and duration of the 22 filter runs are summarized in the following table:

Operating Data – 22 Filter Runs (March 7 – April 20, 2000)

Filter Run Number	Terminal Headloss (psi)	Water Produced (Gallons)	Filter Run Duration (hours)
Average	16.3	22,789	38.04
Minimum	11.0	10,980	19.25
Maximum	25.5	74,173	135.25
Std Dev.	3.6	15,434	27.76
95% Confidence Interval	14.8, 17.9	16,340, 29,239	25.88, 50.18

The manufacturer supplied O&M Manual illustrates the equipment and shows the proper configuration of the housings. The system start up and element replacement procedures are instructive and thorough. A parts list is included.

Microsphere Removal

The fluorescent microsphere challenge was performed between April 16 and 20, 2000. Particle counters were used to measure the number of particles in the feed and finished water, and samples were collected of the feed and finished water and analyzed by microscopic enumeration and a laboratory optical particle counter. The system demonstrated 1.1 to 2.1 $\log_{10}$ removal of the seeded microspheres based on the microscopic evaluations by Huffman Environmental Consulting; however, it was noted by the laboratory that, upon visual inspection, a considerable number of microspheres were smaller than 3 µm. The 3.4 µm microsphere stock solution obtained from Bangs Laboratories was reanalyzed by Bangs and the results indicated that the true particle median size was not 3.4 µm as specified, but was actually 2.98 µm with a standard deviation of 0.66 µm or 21.2%. Further evaluation of the particle count data indicated that 1.9 to 2.7 $\log_{10}$ removals of particles sized 2 to 7 µm were achieved during the fluorescent microsphere challenge testing based on normalized on-line particle counter data which involved adding the number of seeding microspheres (approximately 11,746 particles/mL) to the source water's indigenous material particle counter value and comparing with the effluent particle counter value (details regarding the normalized particle count data are described in the Verification Report). The duplicate set of samples collected during the microsphere challenge were sent to Micro Measurement Laboratories, Inc. for analysis by a laboratory optical particle counter called an Accusizer. Log_{10} reductions calculated with the use data as analyzed with the Accusizer were not performed because an analysis of the control sample container demonstrated a suspected level of contamination (approximately 315 particles/mL). However, influent particle count data as provided from these analyses were helpful in validating influent particle/microsphere concentrations used to calculate $\log_{10}$ reductions of particles/microspheres sized between 2µm and 7µm. Results are summarized in the following table:

Log_{10} Reduction Analyses for Fluorescent Microsphere Seeding Challenges

Seeding	Microscopic Enumeration (2-7 µm microspheres)	Normalized On-Line Particle Counters (2-7 µm indigenous particles and microspheres)
First Challenge Run		
No headloss	1.1	1.9
Midpoint	2.1	2.3
90% headloss	1.8	2.0
Second Challenge Run.		
No headloss	1.5	1.9
Midpoint	2.1	2.7
90% headloss	1.9	2.6
Third Challenge Run.		
No headloss	1.5	2.0
Midpoint	1.8	2.7
90% headloss	1.6	2.7

Following the 50% headloss seeding challenges, the flow through the system was interrupted for a brief interval and then restarted to determine the level of particle sloughing following resumption of flow. Particles were sloughed for less than three recording cycles of the particle counter, or less than three minutes. The results are discussed more fully in the Verification Report but point to the necessity for a brief filter to waste cycle following an interruption in flow.

Water Quality

The following table summarizes the results of the influent and effluent samples collected during the verification testing period.

Feed/Filtered Water Quality (March 7-April 20, 2000)

Parameter	# of Samples	Average	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Temperature (°C)	38/0	7.3/-	3.9/-	11.0/-	2.2/-	6.7, 8.0/-
pH	37/0	8.5/-	8.0/-	8.9/-	0.2/-	8.4, 8.5/-
Total Alkalinity (mg/L)	7/7	70/66	55/54	110/100	18/16	57, 84/55,78
Total Coliform (cfu/100mL)	7/7	24/2	<1/<1	110/6	40/3	<1, 54/ <1, 4
Total Hardness (mg/L)	7/7	94/95	82/82	130/130	16/16	82, 107/ 83, 107
TOC (mg/L)	7/7	7.8/7.5	6.8/6.4	11/8.8	1.4/0.8	6.7, 8.9/ 6.9, 8.1
True Color (TCU)	7/7	14/10	10/5	25/15	6/4	10, 18/ 7, 13
UVA_{254} (cm^{-1})	7/7	0.140/0.130	0.180/0.109	0.229/0.156	0.042/0.017	0.109, 0.171/ 0.117, 0.143
On-line Turbidity (NTU)*	continuous	1.08/0.21	0.68/0.17	1.46/0.26	0.20/0.02	0.98, 1.16/ 0.20, 0.22
On-line Total Particle Counts (#/mL)*	continuous	7,329/91	3,784/39	10,056/300	1,737/59	6567, 8090/ 65, 117
Iron (mg/L)	7/7	0.1/0.1	<0.1/<0.1	0.4/0.6	0.1/0.2	<0.1, 0.2/ <0.1, 0.3
Manganese (mg/L)	7/7	0.02/0.1	<0.01<0.01	0.04/0.04	0.01/0.01	0.01, 0.03/ <0.01, 0.02
Total Chlorine (mg/L)	27/0	1.4/-	0.7/-	3.5/-	0.82/-	1.1, 1.7/-
Free Chlorine (mg/L)	27/0	0.6/-	0.1/-	2.5/-	0.6/-	0.4, 0.8/-

Note: All calculations involving results with below detection limit values used half the detection limit in the calculation.
*Measurements are the average of the filter run averages.

Turbidity removals were consistent and generally good throughout the verification period. Following a brief ripening period, the average on-line turbidity over the 22 filter runs was 1.08 NTU for the feed and 0.21 NTU in the filtered water. No algae were detected in the filtered water samples.

Original Signed by	*Original Signed by*
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Director	Vice President
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Office of Research and Development	NSF International
United States Environmental Protection Agency	

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 # 01/08/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 Treatment 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)

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Environmental Technology Verification Report

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

Rosedale Products, Inc.
Bag and Rigid Cartridge Filter System
Model GFS-302P2-150S-ESBB

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Notice

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Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for NSF International (NSF) and the United States Environmental Protection Agency (EPA) by Cartwright, Olsen and Associates, LLC, in cooperation with Rosedale Products Inc. The test was conducted during March and April of 2000 at the Minneapolis Municipal Water Works Pump House #5 in Fridley, Minnesota USA.

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 Drinking Water Treatment Systems (DWTS) ETV Pilot. A goal of verification testing is to enhance and facilitate the acceptance of small package drinking water treatment equipment by state drinking water regulatory officials and consulting engineers while reducing the need for testing of equipment at each location where the equipment's use is contemplated. NSF will meet this goal by working with manufacturers and NSF-qualified Field Testing Organizations (FTO) to conduct verification testing under the approved protocols.

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

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Abbreviations and Acronyms

APHA	American Public Health Association
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation
cfh	Cubic feet per hour
°C	Degrees Celsius
cfm	Cubic feet per minute
CFU	Colony-forming units
COA	Cartwright, Olsen and Associates, LLC
C. parvum	*Cryptosporidium parvum*
CV	Coefficient of Variation
DI	Deionized (demineralized) water
E. coli	Escherichia coli
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
°F	Degrees Fahrenheit
Flowrates	Flowrates are expressed as US gallons per minute (gpm)
FOD	Field Operations Document
FTO	Field Testing Organization
gallons	Gallons are expressed as US gallons, 1 gal = 3.785 liters = 1.2 gallons imperial 1 gallon imperial = 4.54 liters = .833 gallons US
GFS Filter System	Rosedale Products GFS-302P2-150S-ESBB Rigid Cartridge Filter System
G. lamblia	*Giardia lamblia*
gpm	Gallons per minute
hp	Horsepower
ICR	Information Collection Rule
IESWTR	Interim Enhanced Surface Water Treatment Rule
Log	Logarithm to the base 10
Ln	Logarithm to the base e
µm	Micron = 10^{-6} meter
mgd	Million gallons per day
mg/L	Milligram per liter
mL	Milliliter
MML	Micro Measurement Laboratories
MPA	Microscopic Particulate Analysis
MWW	Minneapolis Water Works
NIST	National Institute of Standards and Technology
NSF	NSF International, formerly known as National Sanitation Foundation
NTU	Nephelometric turbidity unit
O&M	Operation & Maintenance
(oo)cyst	Will be used to refer to both cysts and oocysts when used together
DWTS	Drinking Water Treatment Systems

PFW	Particle Free Water
pH	A measure of the degree of the acidity of the alkalinity of the solution as measured on a scale of 0 to 14.
PLC	Programmable Logic Computer
PQL	Practical Quantification Limit
psi	Pounds per square inch
psig	Pounds per square inch gauge
QA/QC	Quality Assurance/Quality Control
RPD	Relative percent difference
RPI	Rosedale Products Inc.
RPZ	Reduced Pressure Zone
SM	Standard Methods for the Examination of Water and Wastewater
SWTR	Surface Water Treatment Rule
TCU	Total Color Units
TOC	Total Organic Carbon
Ten State's Standards	Great Lakes-Upper Mississippi River Board of State Public Health and Environmental Managers, *Recommended Standards for Water Works*
USP	United States Pharmacopeia
USGS	U.S. Geological Survey
WEF	Water Environment Federation

Definitions

Bag Filter	A disposable, quickly replaceable fabric filter, normally non-rigid and contained either singly or in multiples within a pressure vessel. The flow of water is normally from inside to outside. The bags can be designed for a wide variety of filter applications and are commonly used without coagulating or pre-coat chemicals. Those designed for protozoan (oo)cyst capture have pore sizes that are uniform and while small enough to contain the (oo)cysts will pass bacteria, viruses and fine colloids.
Cartridge Filters	Rigid, or semi-rigid, disposable fabric or polymer elements that like the bag filter can be single or grouped into a filter pressure vessel. Unlike bag filters the common flow for cartridges is from the outside to the inner core of the filter. Pore sizes can be manufactured in many nominal or absolute sizes, with the pressure losses increasing as the pores decrease. As with bag filters, unnecessarily small pore sizes contribute to more rapid loading, pressure losses and thus more frequent element exchanges.
Filtration	Removal of particulate contaminants by flow through a porous media. Media can be granulated particles such as sand or coal, or fabric, fiber or membrane. Bag and cartridge filters are commonly fabric made from synthetic fibers.
Predisinfection	Chemical disinfection of the water prior to passage through the filter. This is often done to limit biofilm formation on the filter element that might limit effectiveness or foreshorten filter runs, and to assure a sanitary supply.
Prefiltration	Coarse, often backwashable granular media filtration and occasionally cartridge filtration or both prior to the bag or cartridge to eliminate larger material in the water stream, thus limiting the bag or cartridge filter element to the removal of finer particles in the size range of the (oo)cyst. Prefiltration reduces the number of more costly bag exchanges.

Acknowledgments

The Field Testing Organization, Cartwright, Olsen & Associates (COA), was responsible for all elements in the testing sequence, including collection of samples, calibration and verification of instruments, data collection and analysis, data management, data interpretation and the preparation of this report.

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Our gratitude to the Minneapolis Municipal Water Works staff for their generous cooperation and hospitality during the pilot operation. We especially wish to thank the personnel at Pump House #5 where the testing was performed.

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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 (as appropriate) testing, 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 Rosedale Products Inc. (RPI) GFS-302P2-150S-ESBB Rigid Cartridge Filter System (RPI GFS Filter System), which is a cartridge/bag filter system used in package drinking water treatment system applications. The system was evaluated during field testing to assess the system's $\log_{10}$ removal capabilities for particles of 3 micron (µm) or larger at flow rates of 10 gallons per minute (gpm). The verification testing included a seeding of microspheres sized 3 µm or larger as a non-pathogenic surrogate for *Cryptosporidium parvum (C. parvum).* This document provides the verification test results for the RPI GFS Filter System.

1.2 Testing Participants and Responsibilities

The ETV testing of the RPI GFS Filter System was a cooperative effort between the following participants:

NSF International
Cartwright, Olsen & Associates, LLC
Rosedale Products, Inc.
Analytical Laboratories
Minneapolis Municipal Water Works
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 reviewed the Field Operations Document (FOD) to assure its conformance with 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, Project Manager
Email: bartley@nsf.org

1.2.2 Field Testing Organization

Cartwright, Olsen & Associates (COA), a Limited Liability Company, conducted the verification testing of RPI GFS Filter System. COA is a NSF-qualified Field Testing Organization (FTO) for the DWTS ETV pilot project.

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 pilot testing, managed, evaluated and interpreted the data generated by the testing, as well as evaluated the performance of the technology. The FTO also prepared this verification report.

FTO associates and personnel provided by the Minnesota Department of Health conducted the onsite analyses and data recording during the testing. Oversight of the daily test activity was provided by the FTO's Project Manager.

Contact Information:

Cartwright, Olsen & Associates, LLC
19406 East Bethel Blvd.

Cedar, MN 55011
Phone: (763) 434-1300
Fax: (763) 434-8450
Contact: Philip C. Olsen, Project Manager
Email: p.olsen@ix.netcom.com

1.2.3 Manufacturer

The treatment system is manufactured by Rosedale Products, Inc. (RPI). RPI is a 20 year old, privately held company. RPI is one of the largest manufacturers of bag filter hardware in the world. The products range from simplex and duplex strainers, to automatic backwashing filters and *Giardia/Cryptosporidium* removal systems.

RPI was responsible for supplying a field-ready GFS Filter System equipped with all necessary components including treatment equipment, instrumentation and controls and an Operations and Maintenance (O&M) manual. RPI 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:
Rosedale Products, Inc.
3730 West Liberty Rd.
Ann Arbor Michigan 48106
Phone: (800) 821-5373
Fax: (734) 665-2214
Contact: Jim Arnold, Operations Manager
Email: jarnonld@rosedaleproducts.com

1.2.4 Analytical Laboratories

Analytical work performed in the laboratory was performed by Spectrum Labs, Inc. Spectrum's laboratory provided analytical services for Total Alkalinity, Total Hardness, Total Organic Carbon (TOC), UV_{254} Absorbance, True Color, Total Coliform, Algae (number and species), Iron and Manganese.

Contact Information:
Spectrum Labs Inc.
301 West County Road E2
St. Paul, MN 55112
Phone: (651) 633-0101
Fax (651) 633-1402
Contact: Gerard Herro, Laboratory Manager
Email: gherro@spectrum-labs.com

The microscopic particle analysis including fluorescent microspheres was performed by:

Contact Information:

Debra Huffman Environmental Consulting
6762 Millstone Drive
New Port Richey, FL 34655
Phone: (727) 553-3946
Fax: (727) 893-1189
Contact: Debra Huffman, Ph.D.
E-mail: dhuffman@marine.usf.edu

Additional particle counting analysis was provided by:

Contact Information:

Micro Measurement Laboratories, Inc.
1300 South Wolf Road
Wheeling, IL 60090
Phone: (847) 459-6540
Fax: (847) 459-3088
Contact: Dan Berdovich, Manager of Quality Control and Regulatory Affairs

1.2.5 Minneapolis Municipal Water Works

The Minneapolis Municipal Water Works (MWW) was established in 1867 for fire fighting protection, and in 1872 for drinking water distribution. The MWW service area has a combined population of nearly 500,000, with over 100,000 service connections, 14,000 valves and 8,000 hydrants. About 40% of the total city usage (excluding suburbs) is for residential purposes, 45% is for institutional, commercial, industrial, and 15% is municipal and other uses. The MWW campus used for this verification testing is located in Fridley, Minnesota, a suburb adjacent to and directly north of the City of Minneapolis. The testing equipment was located in Pump House #5.

Contact Information:

City of Minneapolis
Minneapolis Municipal Water Works
Pump House #5,
4100 Marshall Street NE
Fridley, Minnesota 55421-2600
Phone: (612) 661-4946
Fax: (612) 661-4914
Contact: Charles Kocourek

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 was peer reviewed and reviewed for technical and quality content by NSF and the EPA and recommended for public release.

1.3 Verification Testing Site

The verification testing of the RPI GFS Filter System took place at Pump House #5 on the campus of the Minneapolis Municipal Water Works. Pump House #5 is the intake point from the Mississippi river and as its name suggests consists of two levels of pumps. The lower level has raw water, high volume low pressure pumps; the upper level contains high volume, high pressure distribution pumps. The location had the advantage of being a busy, active facility subject to the many variations afforded by a major metropolitan water treatment facility. While it had the benefit of real world dynamics, it offered the FTO a challenge unlike that of a highly controlled, laboratory facility. The treatment plant, and the test station, were exposed to changes in flows and pressures, some predictable (such as the daily variations in demand in the AM and PM) and others unexpected. These variations were reflected in many instrument readings.

The location also limited certain aspects of the study since the study technicians were necessarily mindful of the presence and needs of the MWW staff. Motors and pumps were switched on and off in accordance with city demands and not test station convenience. Pressures fluctuated as demands changed and as valves were opened or closed, which added to the unpredictability of the flows and turbidities in the test station. The test station was nestled between 500, 1,000, 1,800 and 2,000 horsepower (hp) pumps and motors. Earplugs were required which made communication between technicians difficult, especially during seeding events. That considered, however, the test site offered excellent, comprehensive real world conditions.

1.3.1 Source Water

The source water for the verification testing was a blend of raw water from the Mississippi River and finished water from the MWW treatment plant. In Minnesota, the Mississippi River is in the Upper Mississippi River Basin area. Geology, geomorphology, climate, hydrology and land covering this area control the occurrence and flow of water, and the distribution of water-quality constituents. Landforms within this Upper Mississippi River Basin are primarily results of Pleistocene glaciation. Soils developed on glacial deposits range from heavy, poorly-drained clayey soils developed on ground moraine to light, well-drained sands on outwash plains. Agriculture is the dominant land use in the southern and western parts of the basin area: forests cover much of the northern and eastern parts of the basin area, and the Twin Cities Metro (location of the MWW) dominates the east-central part of the basin area (USGS, 1999).

The Upper Mississippi River's Basin is underlain by glacial sediments and by a thick sequence of limestone, shale, shaley sandstone and sandstone of Precambrian and Paleozoic age (USGS, 1999).

The climate of the Fridley, Minnesota area is sub-humid continental. The average monthly temperature ranges from –12 Celsius (°C) or 11 degrees Fahrenheit (°F) in January to 23°C (74

°F) in July. Average precipitation at the MWW is 30 inches. About three-quarters of the annual precipitation falls from April to September (USGS, 1999).

Mississippi River water is treated at the MWW. The treatment plant is the largest water utility in the upper Midwest. The MWW produces an average of 70 million gallons per day (mgd). Peak rate during the summer may be as high as 180 mgd.

At the MWW, water is withdrawn from the river at Pump House #5. From the pumping station, the water is delivered to a softening plant where lime is used for softening, and alum is used for removal of color and turbidity. Dilute lime and alum slurry precipitates and settles out during the softening process. Powdered activated carbon and occasionally potassium permanganate are also added to remove taste and order. The water is then treated with carbon dioxide to lower the pH and stabilize the remaining hardness prior to being pumped to one of two filtration plants.

At the filtration plant, chlorine and ammonia are added for initial disinfection, fluoride is added for tooth decay prevention and ferric chloride is added as a coagulant to remove remaining color and turbidity. The water then enters a series of coagulation/sedimentation basins after which the water is filtered with single, dual or mixed media filters. Blended poly/ortho phosphate is later added as a corrosion control/inhibitor. The water is post chlorinated for final adjustment of the disinfectant residual before being fed into the reservoirs and pumped into the distribution system.

The quality of the water is assured and controlled through the various stages of treatment by plant and laboratory tests. An average of 500 chemical, physical and bacteriological examinations are done each and every day (182,500 tests per year).

During the 32 days of the ETV test period, the blend of river water and treated water exhibited the following characteristics: turbidity concentrations average of 1.1 Nephelometric turbidity unit (NTU); temperature range of 3.9°C to 11°C; pH range 8.0–8.9; total alkalinity of 71 milligrams per liter (mg/L); total hardness of 96 mg/L; TOC concentration average of 7.8 mg/L; UVA_{254} range of 0.108 to 0.229 cm^{-1}, true color of 14 total color units (TCU), total coliform of 23 colony forming units per 100 milliliters (CFU/90 mL), iron equal to or less than 0.4 mg/L, manganese less than 0.04, free chlorine average of 0.6, and total chlorine average of 1.4. A summary of the feed water quality information is presented in Table 1-1 below.

Table 1-1. GFS Filter System Feed Water Quality (March 7 to April 20, 2000)

Parameter	# of samples	Average	Minimum	Maximum	Standard Deviation	95% Confidence Interval	Practical Quantification Limit (PQL)
Total Alkalinity (mg/L)	7	70	55	110	18	57, 84	10 mg/L
Total Hardness (mg/L)	7	94	82	130	16	82, 107	10 mg/L
True Color (TCU)	7	14	10	25	6	10, 18	1 TCU
Total Coliform (CFU/100/mL)	7	24*	<1	110	40	<1, 54	1 CFU
TOC (mg/L)	7	7.8	6.8	11.0	1.4	6.7, 8.9	0.4 mg/L
UVA_{254} (cm^{-1})	7	0.140	0.108	0.229	0.042	0.109, 0.171	-
On-line Turbidity (NTU)**	-	1.1	0.7	1.5	0.2	1.0, 1.2	-
Total Chlorine (mg/L)	27	1.4	0.7	3.5	0.82	1.1, 1.7	-
Free Chlorine (mg/L)	27	0.6	0.1	2.5	0.6	0.4. 0.8	-
Iron (mg/L)	7	0.1*	<0.1	0.4	0.1	<0.1, 0.2	0.1 mg/L
Magnesium (mg/L)	7	0.02*	<0.01	0.04	0.01	0.01, 0.03	0.01 mg/L
Temperature (°C)	38	7.3	3.9	11.0	2.2	6.7, 8.0	-
pH	37	8.5	8.0	8.9	0.2	8.4, 8.5	-

* All calculations involving results with below PQL values used half the PQL in the calculation.
** Turbidity values are the on-line values and the average results of each filter run.

1.3.2 Pilot Effluent Discharge

The effluent of the pilot treatment unit was discharged to Minneapolis Metropolitan sanitary sewer. The Metropolitan Environmental Authority, which encompasses the Minneapolis Metro Area, maintains a primary sewage treatment plant that discharges to the Mississippi River downstream of the MWW. No discharge permits were required.

Chapter 2
Equipment Description and Operating Processes

2.1 Historical Background

Conventional methods of water treatment, including gravity filtration and chlorination, have not been as effective against protozoan (oo)cysts, especially *Cryptosporidium parvum (C. parvum)* in part because of its size and resistance to chemicals. Treatment plants that are otherwise in compliance with public health treatment standards are thus vulnerable to outbreaks of disease (Kaminski, LeChevallier, Korich).

In recent years, protozoan cysts have been determined to be the cause of widespread illness. These cysts are more resistant to traditional disinfection practices and because of their small size and pliability, protozoan cysts and oocysts have been known to pass through fiber media filters. Two such microorganisms are the protozoan (oo)cysts *Giardia lamblia* (*G. lamblia)* and *C. parvum*. These pathogenic microbes can cause significant gastrointestinal distress, and even fatalities in the cases of immunocompromised individuals and are thus of considerable interest to the public health and water treatment communities. Assurances will be required before small public water systems throughout the country dependent on surface water sources that are likely contaminated with the pathogen can be confident in employing bag/cartridge filters as a part of their treatment regimen.

Filtration, in which particles are removed from a water stream by passing water through a medium that captures and contains them, has an ancient history. Earthen filters using granulated media such as sand or coal are used worldwide to clarify water. The exact mechanism of containment is not fully understood, however, it is generally agreed that one mechanism consists of "straining", where the particle is too large to pass through the pores between the media. In addition, electro-static forces inherent on the media cause the particles to attach. Still other mechanisms have been proposed that explain the process. In the case of porous fibers and cartridge filters straining or bridging is presumed to be the primary mechanism of capture (Maschio).

Filtration has progressed beyond that first employed by civil engineers. Newer, high strength materials engineered to withstand greater pressures and with a high degree of uniformity in pore size allows for application of bags and cartridges to more exotic filtration requirements. Bag and cartridge filters are routinely employed in process fluid applications, even in the cases of highly viscous fluids. RPI has designed a bag and cartridge filtration system for capture of protozoan cysts and oocysts, specifically *G. Lamblia* and *C. parvum.*

The advantages of Bag and Cartridge Filters include (NRC, 1997):

- Designed for simple operation; they do not use coagulant chemicals.

The limitations inherent with technology include (NRC, 1997):

- Limited to removal of particles from water; will not remove chemical contaminants present in solution.
- Limited to treatment of high quality water sources and not appropriate for waters with elevated turbidity without pretreatment.

2.2 Equipment Description

The RPI GFS Filter System (Model # GFS-302P2-1505 ESBB) is a bag and rigid cartridge system that consists of two connected filter housings, the first with a Model # GD-PO-523-2 bag filter element, and the second with a Model # PL-520-PPP-141 rigid cartridge filter element, which replaced the Model # GLR-PO-825-2 filter element used during initial operations. The ETV testing of the RPI GFS Filter System was concluded in April 2000. In 2001, Rosedale made a product modification on the Model # PL-520-PPP141 rigid cartridge filter element by changing the seals from an o-ring type seal to a u-cup type seal. The cartridge filter with the new u-cup seals is marketed under the Model # GLR-520-P2. The Model # GLR-520-P2 is NSF listed. The cartridge element with the new u-cup seals (Model # GLR-520-P2) will be the subject of a separate ETV evaluation.

Although the cartridge is rigid, the flow through the cartridge filter is like that of a bag, from inside to outside. The housings are designed to operate at 20 gpm but were operated at 10 gpm during the verification testing. It was determined during the initial operations period that the housing at this site should be operated at 10 gpm to reduce the filter load. During initial operations the filters loaded up overnight when operated at 20 gpm and at higher turbidities.

The equipment tested was a filter system designed to capture and contain particles in the size range of *C. parvum*. Since *G. lamblia* cysts are larger it is assumed that if the smaller oocysts are contained, the larger cysts will be contained at least the same level (Nieminski). Accordingly, while this filtration system is applicable to *G. lamblia* removal as well as *C. parvum* removal, focus will be on *C. parvum* sized particles. The system is designed as a final barrier to operate in waters of 1 NTU turbidity or less, and with pressures of less than 60 pounds per square inch (psi). This equipment is expected to be applied to small systems where the containment of *G. lamblia* and *C. parvum* is of concern. It is suitable for surface water of 1 NTU turbidity or less, or for a final barrier following roughing pre-filtration.

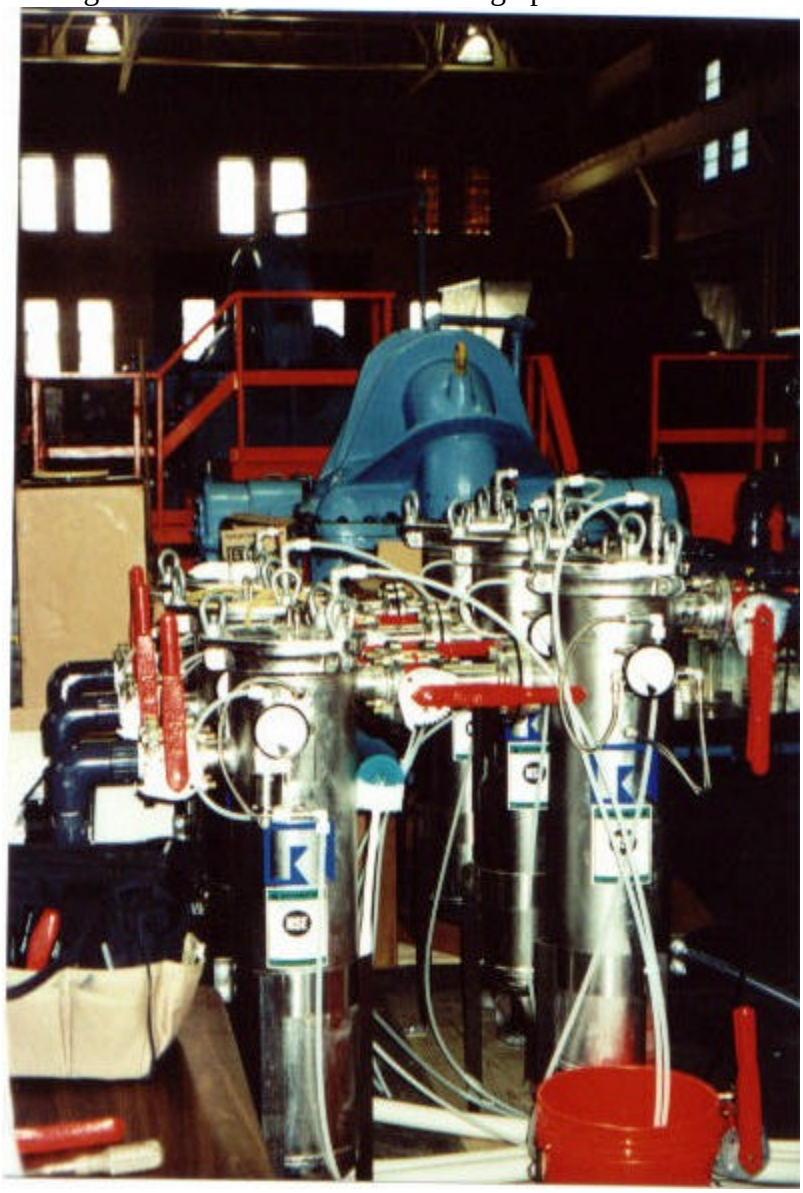
The filter housings are made of stainless steel. Valves and other components are also stainless or of materials that will not degrade in water.

The only chemical that was consumed in the operation of the equipment during the ETV verification test was liquid chlorine. Liquid chlorine bleach (sodium hypochlorite) was added during the verification period to limit any microbial growth within the filters. Adding bleach to feed water is commonly done for surface water systems in front of filters to limit microbial growth. The bleach-metering pump was stopped during verification challenges. Since the blend of raw and finished water already contained low levels of chlorine and chloramines, the bleach was added to compensate for the chlorine demand added by the raw river water. Bleach was also added to the container of spent elements to control odor prior to their inspection. The addition of chlorine did not represent an O&M issue as far as the Rosedale equipment was concerned.

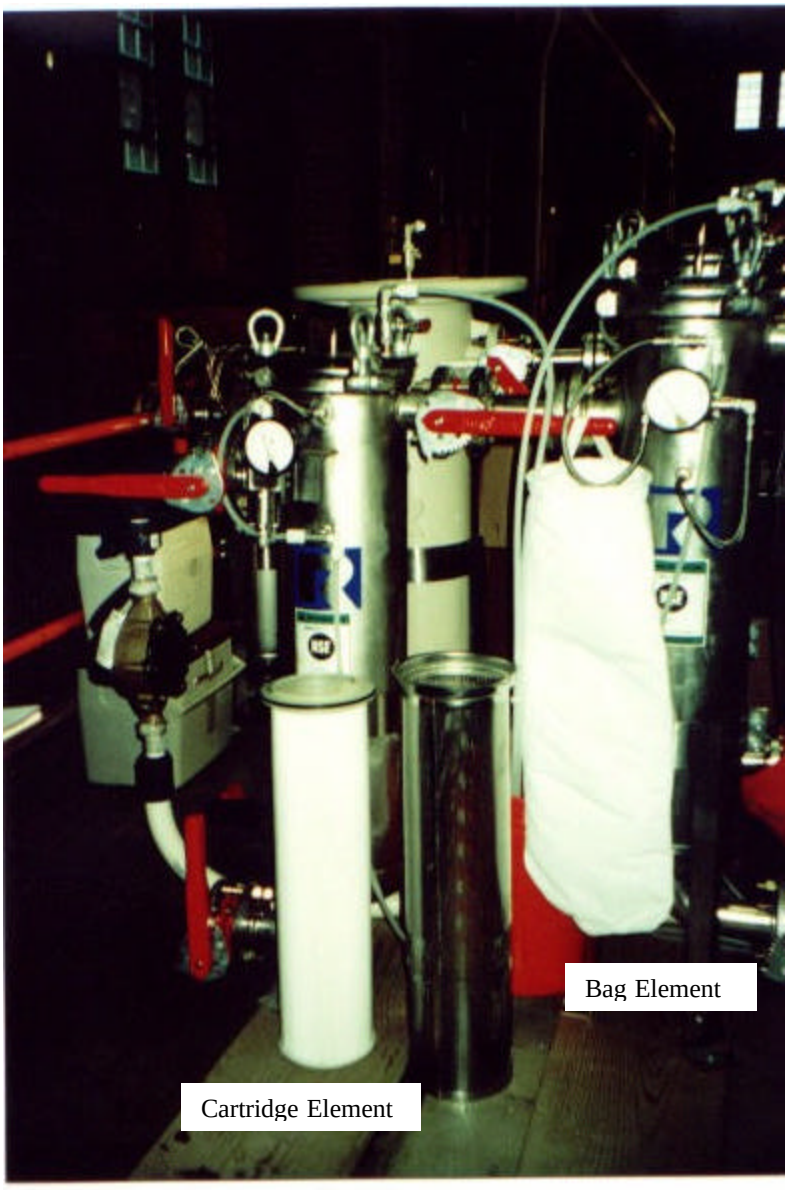
No special licensing is required for the use of the filters. Training in bag/element replacement is minimal and is fully explained in Appendix A, Operations and Maintenance Manual, as supplied by the manufacturer.

The filter system is suited to small public water systems where water treatment plant operators typically have minimal technical training. The system itself requires no additional chemicals beyond normal disinfection and relatively limited on-site supervision, for tasks such as reading pressure gauges and changing filters. Additional controls, meters, and other instrumentation can be added to facilitate ease in monitoring performance. The filter system itself requires no power. However, a source water pump may be required.

Photograph 1 illustrates the RPI GFS Filter Systems on location at the MWW. The bag and cartridge elements are shown in Photograph 2.



Photograph 1 – RPI GFS Filter System



Photograph 2 – Bag and Cartridge Filter Elements

Figure 2-1 is a schematic showing the position of the filters.

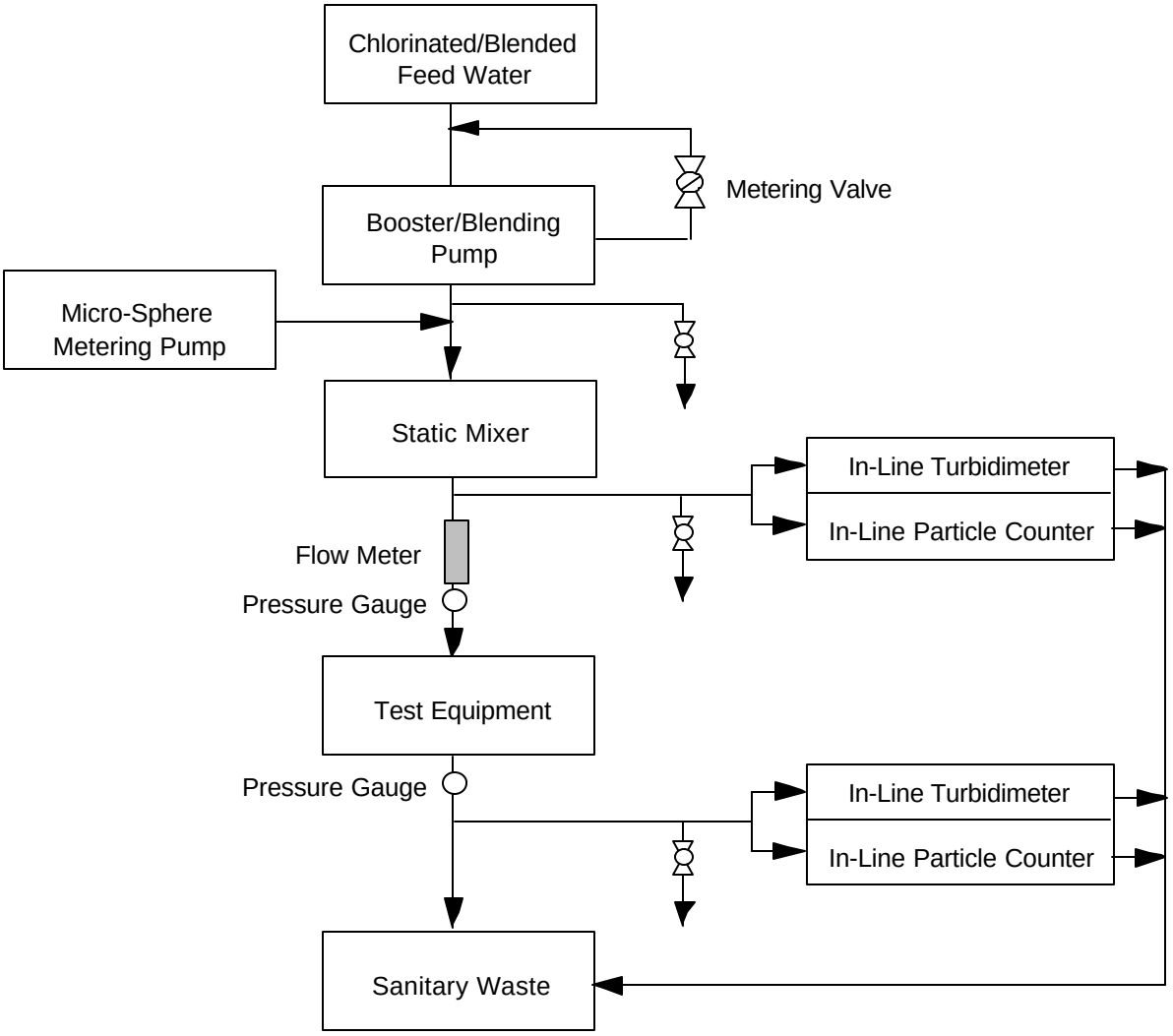


Figure 2-1. GFS Filter System Schematic

2.2.1 Equipment Installation

The connection to the train of filters for the initial operations, and later for the single filter during verification, was through a system for blending raw Mississippi river water with finished water supplied by the City of Minneapolis.

Pump House #5 which is at the Mississippi river intake location supplied raw water. The water was screened for large debris, and then pumped through a four-foot diameter pipe to the Lime Softening Plant. The connection to the pilot blending control valves was a two-inch flexible pipe attached to the top of this four-foot pipe. The raw water pressure at the pipe was approximately 20 psi. This was not sufficient pressure to supply the pilot, thus a 1.5 Horsepower (hp) booster pump was added.

After installation, and during initial operations, this pump lost its prime on occasion due to excess air in the line, so a detention tank with an air release valve was added. It was later determined that the air was introduced when one specific city raw water pump was placed on line without sufficient priming, hence the occasional, unpredictable and intermittent air events.

The finished city water came from a two-inch supply line, which while direct from the city service pumps, was a line used to supply the domestic needs of the pump house. A reduced pressure zone (RPZ) backflow preventor was placed between this supply line and the plumbing providing water to the ETV pilot installation.

The finished water was supplied at 103 psi, and was reduced through a metering valve to closely match the raw water pressure. Separate flow control valves allowed the operator to adjust proportions of raw and finished water. Following the blending station, an on-line static mixer was used for thorough mixing of blended water, chlorine, and microspheres. The blended water flowed through a balanced header and then into the three housings. Each housing had an influent and effluent butterfly valve and a third butterfly valve on the bottom to accommodate a drain line. Following initial operations, one of the filter trains was removed and the pipe and valve was used as a by-pass line.

The effluent from each housing was directed first through a water volume meter then through a flow rotometer, a metering valve, a pressure gauge, and into a discharge line. A sample port directed a proportion of this flow through a manifold system with valves that allowed the operator to select which of the three filter effluent lines would be directed to the particle counter and turbidimeter. Influent samples were withdrawn from a point following the static mixer. Effluent sample ports were located on the exit side of the rigid filter element vessel, at the pressure gauge port.

2.3 Operating Process

Operation of a bag and cartridge filtration system is straightforward. Water containing particulate matter is directed at a steady flow rate through the housings containing the filter elements and matter is trapped and contained within. Elements are changed when either the pressure loss through the housing is so great as to reduce the flow or to threaten to burst the element, or when matter is known to leak through the elements, which ever is first. With no power requirements (other than those added to monitor performance), simple replacement procedures and limited operator attention, these filters have been attractive to small, individual surface water treatment systems.

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.

One task of the verification testing involved challenging the RPI GFS Filter System with polystyrene microsphere surrogates in the size range of *C. parvum* oocysts were seeded into a blend of Mississippi River water and Minneapolis finished drinking water.

3.1.1 Objectives

The verification testing was undertaken to evaluate the performance of the RPI GFS Filter System. Specifically evaluated were RPI's stated equipment capabilities and equipment performance relative to water quality regulations. 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 Stated Equipment Capabilities

In March and April of 2000, the ability of the RPI GFS Filter System to remove particles in the range of *C. parvum* was tested at the City of Minneapolis Water Works. The testing employed polystyrene (latex) microspheres as a non-pathogenic surrogate. The accepted size of the *C. parvum* oocyst is subject to some discrepancy. Authoritative sources cite differing sizes for the oocyst ranging from 2 - 5 µm (US EPA April 1999) to 4.6 - 5.5 µm (Harter) to 3.9-5.9 µm (Medema). It is possible that different isolates may have slightly different average sizes as well. While *C. parvum* oocysts are most often considered to be 4-6 µm in size (Bukhari, Davis 1998), they are also known to be pliable and slightly disc shaped, thereby allowing for occasional passage through pores smaller than their average diameter. EPA methods 1622 and 1623 employ 1µm filters, and it is generally accepted that pores of this size will capture essentially all of the oocysts. The use of 3 µm particles was intended to compensate for this variation, although oocysts may be as small as 2 µm. Particle counter bins were set to conform to the ICR sizing, of 2-3 µm, 3-5 µm, 5-7 µm, 7-10 µm, 10-15 µm and 15+ µm, thus while the primary ranges of interest for this evaluation were 3-5 µm and 5-7 µm, particle counts in the bin size 2-3 µm may also be of value. Additional water quality data against which the equipment was tested are included so that state regulators may draw conclusions about possible performance in other field applications.

3.1.1.2 Evaluation of Equipment Performance Relative To Water Quality Regulations

With increased awareness of pathogens resistant to traditional disinfection and removal techniques and the fact that the EPA's rules for surface filtration are becoming increasing stringent, it is expected that the search for alternative disinfection and removal technologies will grow significantly. This verification study specifically addresses removal of particles in the size range of 3-7 µm.

Small public water treatment systems are particularly subject to changes in process flow and assurance that particles will not detach or be driven through the barrier during these episodes is of considerable concern by small system operators and purveyors. Tests to verify the performance under these conditions are included as part of the test plan, by stopping the flow at significant points following seeding and then restarting.

The system was tested for removal of particles of 3 µm or larger at flow rates of 10 gpm per system. While the upper limit of pressure differential for the pressure filtration system is 15 pounds per square inch gauge (psig), it was anticipated that turbidity breakthrough might occur at a lower pressure. While the equipment can withstand pressure differentials exceeding 15 psi, this test used 15 psi as a terminal pressure loss value.

3.1.1.3 Evaluation of Operational and Maintenance (O&M) Requirements

An overall evaluation of the operational requirements for the treatment system was undertaken as part of this verification. This evaluation was qualitative in nature. The manufacturer's O&M manual and experiences during the daily operation were used to develop a subjective judgment of the operational requirements of this system. The O&M manual is attached to this report as Appendix A.

Verification testing also evaluated the maintenance requirements of the treatment system. Not all of the system's maintenance requirements were necessary due to the short duration of the testing cycle. The O&M manual details various maintenance activities and their frequencies. This information, as well as experience with common pieces of equipment (i.e., valves, etc.) was used to evaluate the maintenance requirements of the treatment system.

3.1.1.4 Evaluation of 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. The qualitative factors examined during the verification were operational aspects of the RPI GFS Filter System, for example, the ease to which filter elements can be exchanged, the measurement of head loss, and the other operational factors that might impact on performance. Among quantitative factors examined during the verification testing are costs associated with filter element replacement, any occasional, anomalous conditions that might require operator response such as high levels of algae growth, excessive turbidity spikes or frequent filter clogging, and

length of operating cycle. This treatment system operated at 10 gpm with feed water turbidity of 1 $\pm$ 0.2 NTU. Costs will change with changes in flow or feed water quality.

3.2 Initial Operations

An initial operations period was performed to allow the equipment manufacturer to refine the unit's operating procedures and to make operational adjustments as needed to optimize treatment performance. Initial operations procedures included a characterization of feed water task, a system start-up task, and a filter element variability task. The MWW has extensive historical water quality data, which was reviewed prior to and concurrent with the first initial operations period.

Equipment information gathered during system start-up and optimizations were used to refine the test system. Adjustments made to the FOD included a reduction in process flow from 20 to 10 gpm, a redesign and replacement of the rigid filter element and a redesign and replacement of the housing seals. The redesign of the cartridge and seals delayed the start of Phase II of initial operations until after January 1, 2000.

3.2.1 Characterization of Feed Water

The primary purpose of this initial operations task was to determine the appropriateness of the feed water for this study. To that end, the characterization of the water included researching the watershed, including the nature of the water, the source, and the uses of the water upstream. This task was done in part prior to selection of the site as suitable for testing, and additionally during the initial operations phase, before the verification testing period.

The suitability of the feed water to the application of this technology was reviewed before testing during initial operations. Data from 1997 was obtained from the City of Minneapolis, Municipal Water Works department for the same time frame as the verification testing period (March and April). This data was compiled and analyzed with respect to the biological, physical and chemical characteristics of the water. Parameters studied at the verification testing site include the following: turbidity, temperature, pH, total alkalinity, total hardness, and true color. Review of this historical data as detailed in Chapter 4, Results and Discussions, indicated that the technology should be appropriate for the site.

Uses of the watershed, whether industrial, agricultural, or other human activity such as waste deposit, mining or boat traffic, which may have an impact on the character of the water, were examined. Incidental conditions, such as storms, ice-out, or unusual boat traffic, may have a consequence on the performance and were documented in the logs as they occurred.

As a part of this initial operations task the analysis of parameters of the water that affected the character of this test. Included are those parameters that were required as a part of the regular scheduled testing. They included: temperature, turbidity, UV_{254} absorbency, free chlorine, total organic carbon, true color, pH, total alkalinity, hardness, iron, manganese and total suspended solids. These were the same water quality parameters that were analyzed during the verification runs. Microbiological tests included coliform bacteria and algae.

3.2.2 Initial Test Runs

The purpose of initial test runs or start-up testing was to conduct and evaluate trial runs of the filtration system under study. COA and RPI supervised the installation of the equipment and start-up, and established initial operating conditions. Trial runs of the system were performed.

During this period COA additionally calibrated and standardized the testing apparatus, measured and controlled feed water blending to assure smooth test performance during the verification period. These runs were performed to evaluate operating conditions for the Verification Test and accordingly had no strict format.

3.2.3 Filter Element Variability Testing

The pilot installation for filter element variability testing consisted of three identical RPI GFS Filter Systems plumbed in parallel for simultaneous testing. This permitted a controlled study of filter bags and cartridges (rigid filter elements) with variations between and within manufactured lots.

The filter element variability testing period was divided into two phases. Phase I was designed to determine variations *within* a manufactured lot number of cartridge filter elements. Phase II was designed to show variations *between* manufactured lot numbers of cartridge filter elements. Prior to these two phases, the feedwater was characterized for suitability to this technology.

Each phase included of 10 days of system operation and data recording. During both phases the filter system was to be on-line for 23 hours and off line (no flow) for 1 hour. An operator was present 8 hours each day for data recording and operation of the filter system and test station.

The operating and data recording schedule for filter element variability testing were as follows: Data were recorded during 8 hours per day in split shifts, one four hour AM shift and one four hour PM shift. This was done to better monitor the pressure changes and to observe variability through the day. In addition, until the FTO was comfortable with the operation, it was important to have frequent records, especially of pressure differentials. During each four-hour shift, particle count, turbidity, flow rate, and pressure differentials were noted for each filter system once each hour. The system was shut down daily at about 16:00 for one hour then flow resumed at 17:00. Following daily shutdown it took between 30-60 minutes to once again stabilize influent turbidity and flowrates. Turbidity was maintained near 1 NTU during the shift periods, when an operator was on site; during the periods where no operator was on site, the turbidity was reduced to less than 1 NTU by allowing only finished water to pass through the system.

Terminal headloss for the filter element variability testing period was established at a 15-psi differential between influent and effluent pressure. Pressure differential was determined by gauges measuring pressure on the inlet and outlet of the system. Flowrates were maintained at 20 gpm per filter train. During Phase I and II, when terminal headloss was reached, or breakthrough occurred, the filter elements were replaced with another from the same lot and the run continued until the ten day period had elapsed.

Performance data from filter element variability testing included: turbidity, particle count, flow rate and head loss across each filter. Particle counts and turbidity measurements for each filter system were collected sequentially each hour during a minimum eight-hour daily workday. Thus, filter system #1 was measured at 20 minutes past the hour, filter system #2 at 40 minutes past the hour and filter system #3 on the hour. Each filter had 80 particle removal data points during the ten-day period, along with flow rate and head loss data. There were a total of 240 data entries for each of the two ten day periods.

During Phase I, the particle counter was set to count at the intervals required in the original test plan: 1-3 µm, 3-10 µm, 10-15 µm, < 2 µm and > 15 µm. Due to the small orifice size of the sensors used with the HIAC-Royco 8000A particle counters, they easily became plugged and were not conducive to field cleaning. Accordingly, the HIAC-Royco particle counters were replaced with MetOne PCX counters. The MetOne counters do not have a < 2 µm bin so the counters were set to the same bin sizes except the 1-3µm was replaced with 2-3µm.

COA used variability test data along with the following confidence formula, to determine the suitability of the manufactured lots for verification testing. The confidence formula employed was:

$$\textit{confidence interval} = \overline{X} \pm t_{n-1,\,1-\frac{a}{2}} \left(S / \sqrt{n}\right)$$

S = standard deviation
n = number of measurements in data set
t = distribution value with n-1 degrees of freedom
a = the significance level defined for 95% confidence as: 1- 0.95 = 0.05.

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

3.3 Verification Task Procedures

The procedures for each task of the verification testing were developed in accordance with the requirements of the EPA/NSF ETV Protocol (EPA/NSF, 1998). The Verification Tasks were as follows:

- Task 1 - Verification Testing Runs and Routine Equipment Operation
- Task 2 - Feed And Finished Water Quality Characterization
- Task 3 - Documentation of Operating Conditions and Treatment Equipment Performance
- Task 4 - Microbiological Contaminant Removal

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

3.3.1 Task 1 - Verification Testing Runs and Routine Equipment Operation

The objectives of this task were to operate the equipment for the prescribed period of thirty days, or longer if required to reach terminal headloss or turbidity breakthrough, and to evaluate equipment control features.

During Task 1, treatment conditions of the blended feedwater were characterized with the differing water conditions caused by different blending ratios. Changes in the nature of the feedwater or in the individual nature of the river water character and or finished water pretreatment were annotated.

The total number of gallons, as measured per square foot (cartridge), as well as per filter system (cartridge and bag), were computed for each RPI GFS Filter System and logged to allow comparisons of water quality and volume.

Operating parameters of the equipment were logged during the 32-day test period. Frequency of filter element replacement, changes in pressure loss or turbidity breakthrough were recorded. Also incident to this task was the documentation of any repairs and maintenance required. The performance verification period included a single season; varying water quality parameters and other conditions impacted performance and were noted accordingly.

Factors that effected the treatment performance that were recorded and measured included:

- High turbidity and low turbidity periods and their cause, for example, changes due to ice out or snow melt, rainfall, or excessive river traffic.
- Algal blooms, incurred in summer and then again in late spring.
- Changes as the result of increased pumping requirements, often on a daily basis.
- Elevated natural organic matter from runoff.
- Changes in feed (blended) water quality.
- Changes in line pressures due to city demands.

3.3.2 Task 2 - Feed and Finished Water Quality Characterization

The purpose of this task was to provide water quality data relating to the test so that State, Municipal and other Public Health authorities can determine the applicability of a specific water source to this type of treatment. This task evaluated the water quality matrices of the influent water and effluent water and the relationships to the terminal headloss and/or turbidity breakthrough point.

Factors that could influence water chemistry, such as weather, recreational or commercial boat traffic, in and out-flows, and river bottom composition were recorded during testing when appropriate. Also included is a discussion of the human impact upon the source; for example, whether the source was utilized for other activities, or whether it accepted wastewater of any description.

The parameters, which were analyzed as part of this testing and the sampling frequency, are presented below in Table 3-1. Samples of both feedwater and filtered water were analyzed.

Table 3-1. Analytical Data Collection Schedule

Parameter	Frequency	Feed	Treated
On-Site Analyses			
Temperature	Daily	X	
pH	Daily	X	
Turbidity	Continuous	X	X
Particle Counts	Continuous	X	X
Free Chlorine	Daily	X	
Laboratory Analyses			
Total Alkalinity	Weekly	X	X
Total Organic Carbon	Weekly	X	X
Total Hardness	Weekly	X	X
UV Absorbance (254)	Weekly	X	X
True color	Weekly	X	X
Total Coliform	Weekly	X	X
Algae	Weekly	X	X
Iron	Weekly	X	X
Manganese	Weekly	X	X

All testing was performed in accordance with the procedures and protocols established in *Standard Methods (SM)* and/or EPA methods. All on-site testing instrumentation or procedures were calibrated and/or standardized at scheduled intervals by FTO staff.

Turbidity and particle counters were both continuous and on-line. The on-line turbidity meter was checked daily against a bench turbidimeter that was checked against turbidity standards. Particle counts were evaluated by recording the change between influent and effluent particle counts in the size ranges of 2-3 µm, 3-5 µm, 5-7 µm, 7-10 µm, 10-15 µm, and 15+ µm. Log_{10} removals were calculated for the ranges of concern, 3-5 µm and 5-7 µm particles continuously via computer during the verification period.

3.3.3 Task 3 - Documentation of Operating Conditions and Treatment Equipment Performance

The operation of the equipment was documented to demonstrate performance and applicability to small systems. Small systems are characterized by lower volume demands, and by lower flow rates, but more important to this task, they are also characterized by reduced maintenance and operating staff. Accordingly, important to the small system application is the ability to employ "hands off" operation, and the introduction of back up and alarm systems.

Among the items recorded daily as a part of this task were the readings or measurements of the equipment's performance, including the rates of flow through the system, total volume of water filtered, and condition of the filter elements, replacement frequency and production run readings The operational parameters and frequency of the readings are listed below in Table 3-2.

Table 3-2. Operating Data	
Parameter	Frequency
Feed and Filter Flow	Checked and recorded twice daily; flow was adjusted if it varied more than 10%.
Filter Headloss	Influent and effluent pressures recorded at the start of each filter run, and thereafter two times daily. Prefilter headloss prior to replacement or backwash was also noted, along with pressure readings at the start of each filter run, and thereafter two times daily.
Filtered Water Production	Recorded volume of water for each filter element for each run, and the daily total.
Element Replacement	Recorded the date and time for each replacement, the volume of water treated before replacement and the reason for replacement (headloss or turbidity breakthrough).
Element Condition	Recorded the visual condition of any replaced element for integrity, excessive inorganic fouling etc.
Hours of Operation	Recorded daily in logbook at beginning of first shift.
Electric Power	No action was required because the GFS-302PS-150S ESBB Rigid Cartridge Filter System has no power connection requirements.

Also documented were changes in the pretreatment chemistry or filtration rates. The condition of the pretreated water was measured (in Task 2 above) and identification of any changes to the pretreatment regimen was recorded.

Filter elements were replaced when the total pressure differential across the RPI GFS Filter System reached a 15-psi, when turbidity breakthrough was detected, or when it was expected that differential was reached during the next on line period. With the exception of a brief period during the verification test (Runs 17 and 18, for element conservation until stock could be re-supplied), filter elements were *always* replaced in pairs. The time, pressure differential and condition of each filter element was noted in the logbook. This information was tabulated, assembled and used in conjunction with performance data to include operations and maintenance factors.

3.3.4 Task 4 - Microbiological Contaminant Removal

The ability of the RPI GFS Filter System to remove particles to the size of *C. parvum* from water was the primary focus of this task.

During the verification period challenge, microspheres were injected into the pilot installation feed water via a metering pump at concentrations capable of demonstrating 3+ $\log_{10}$ removal through the RPI GFS Filter System. There were three challenges employing polystyrene monospheres added to the source water to demonstrate removal in each of three filter runs, for a total of nine challenges. The challenges occurred at the beginning of the run, at roughly the mid-point as determined by headloss, and then again at a point between 90% headloss and terminal.

Each seeding consisted of 10,000 particles per milliliter added to a half-liter of dilution water and was fed over a five-minute period through a metering pump. Downstream of the microsphere injection point an on-line static mixer was used to assure proper mixing of microspheres in the feedwater, previous to entry into the RPI GFS Filter System.

Continuous particle counting via electronic particle counter, and sample collection for enumeration were employed as a means of measuring the removal capabilities of the filter element. Particle counts were measured in both the influent water and the effluent water.

3.3.4.1 Preparation of Microbial Surrogate Doses

Microspheres in the size range of 3-6 µm were used to evaluate the removal capability of the RPI GFS Filter System. The polystyrene microspheres with a nominal diameter of 3-6 µm, of which at least 50% were in the 3-4 µm ranges, were employed for challenge testing. The three sizes employed were: 3.2 µm, 4.5 µm and 6 µm. The challenge mixtures were composed of 50% 3.2 µm and 25% each 4.5 µm and 6 µm.

The procedure for the preparation of microsphere suspensions was as follows:

A clean, 500-milliliter (mL) National Institute of Standards and Technology (NIST) traceable (C30913) volumetric flask was filled to the measure line with particle free water (PFW) as described in Section 3.8.2.5. The flask for the microsphere concentration was washed with hot water and a lab glass cleaner, and rinsed with PFW following each microsphere injection procedure and again prior to use. With a clean pipette, approximately 10 mL of dilution water was withdrawn and set aside. Tween 20 (to .01%) was added to the flask and swirled gently.

The concentrated microsphere suspensions in their shipping bottles were vortexed for 10 seconds, inverted and vortexed again for ten seconds. The appropriate volumes of each size microsphere concentrate were added to the flask using a wide mouth, disposable serological pipette.

If the microsphere shipping bottles contained the correct number of microspheres the entire content was added to the flask. The pipettes (or shipping bottles) were rinsed with PFW and the rinse added to the flask.

Following the addition of the microspheres, the withdrawn PFW was returned to the flask to the volume line. After which, a magnetic stir bar was rinsed with PFW and added to the flask.

The volume of suspension was 500 mL and was added at the rate of 100 mL per minute over five minutes.

The number of particles in the concentrated suspension is inversely related to the cube of the diameter of the microsphere, and is calculated by the following formula:

$$n/mL = \frac{6W \times 10^{12}}{\rho \times \pi \times f^3}$$

Where n is the number of particles, W = the grams of polymer per milliliter of latex (which varies for each size and manufacturer, but which is noted on each container), ρ = density of polymer (1.05 for polystyrene) and f = the diameter of particle in microns.

The microsphere suspension was injected by a variable pulse/stroke diaphragm-metering pump through an injection quill into the front of a static mixer. The metering pump was set at its maximum pulse frequency and the stroke was adjusted to achieve the designed microsphere injection rate. This rate was measured prior to the seeding by using dilution water. The rate was further measured by timing the duration of the seeding. The static mixer showed a headloss of 0.3 to 0.5 feet during seeding. During seeding, the suspension was continuously mixed with a magnetic stir bar.

Removal capabilities of the RPI GFS Filter System were demonstrated by measuring the particle distribution of influent and effluent streams, following the addition of 10,000 particles per mL, with on-line electronic optical particle counters. The resulting data were ambiguous.

The addition of a measured concentration of 10,000 particles per milliliter during seeding challenges did not result in the same increase over the indigenous particles in the influent water. In all trials with the addition of 10,000 particles per milliliter resulted in a net increase of only 4,000 to 5,000 particles per milliliter as measured by the on-line particle counter. An additional challenge was performed with a microsphere concentration of 20,000 particles per milliliter in which the on-line particle counter measured as a net increase of only 7,000 particles per milliliter.

These results were discussed with the manufacturer of the particle counter, the manufacturer of the microspheres and the writers of the referenced paper describing the methodology in question. It was concluded that on-line particle count data measuring high concentrations of microspheres in the filter influent water could not be employed with confidence to demonstrate filter performance. Thus, it was decided to augment the on-line particle counting and turbidity data with the technique described by Li, using hemacytometer counts of fluorescent microspheres (Li). Challenges were then repeated with fluorescent microspheres as detailed below.

3.3.4.2 Description of Fluorescent Microsphere Seedings

Fluorescent microspheres are not available in the sizes indicated in the test plan. Three sizes of fluorescing microspheres at 3.4 µm, 5 µm and 6 µm were available from three separate microsphere manufacturers:

Size	Manufacturer	Lot#
3.4 µm	Bangs Laboratories	2200
5.0 µm	Duke Scientific Corp.	21755
6.0 µm	Polysciences, Inc.	500045

The microspheres were prepared as in the case of the regular polystyrene spheres using effluent water as dilution water. The seedings were performed as described on April 17, 18 19, and 20, 2000, however, it was necessary to collect samples of the influent and effluent water for hemacytometer and microscopic evaluation. Those samples were collected from the discharge of the particle counter.

The particle counts were observed on the on-line particle counter and when the peak concentration was reached and stabilized, samples were collected from both the influent and effluent sample streams. The effluent sample lagged the influent by about 2 minutes. Each sample was distributed into two aliquots, one for shipment to Dr. Debra Huffman for examination and the other refrigerated as a back up.

Samples of the first challenge run were collected sequentially, with the first immediately followed by the second. The first was shipped to Dr. Huffman, and the second placed in refrigerated storage as a backup. Samples for the second and third challenge runs were collected in two single grabs from both the influent and effluent counter for three minutes, (300 mL). Those samples were then divided into two aliquots, one to be shipped overnight express to Debra Huffman Environmental Consulting, and the other refrigerated as a backup.

Challenges occurred as follows, with the details recorded as noted:

- Challenge Seeding #1, at 0 headloss: (date, computer time, volume reading, pressure loss etc.) Start time, stop time for injection of particles. During the injection, the particle counter readouts were observed to note appropriate distribution.
- Challenge Seeding #2, at mid-point of filter run (50% headloss): readings same as #1,
- Stop/Start: Filter flow was stopped for a brief period (approximately 5 minutes) and then resumed.
- Challenge Seeding #3, at 90% of terminal headloss: same as #1.

This schedule was repeated for each of the three filter runs.

3.3.4.3 Data Evaluation

Continuous electronic particle count data were evaluated by calculating the change in total particle count from feed water to filtered water, expressing the change in $\log_{10}$ reduction. The aggregate of particle counting data obtained during each verification testing period was analyzed to determine the average $\log_{10}$ removal and 95^{th} percentile $\log_{10}$ removal during the 32-day verification testing period.

One-minute time intervals were used for analysis of particle counting data for $\log_{10}$ reduction of particles in both unfiltered and filtered water. In addition, because particle count data was continuous, it was possible to present a trend of particle counts with passage of time.

Samples were collected and sent to the laboratory for microscopic enumeration of the fluorescent spheres using hemacytometer techniques and/or membrane filtration, as appropriate. The hemacytometer was used when the samples contained high numbers of particles (influent samples); when the counts were low (effluent samples) the particles were counted microscopically after filtration through a membrane.

3.4 Data Recording, Communications, Logistics and Data Handling Protocol

The objective of the data handling protocol was to tabulate the collection of data for completeness and accuracy, and to permit ready retrieval for analysis and reporting. In addition, the use of computer spread sheets allowed manipulation of the data for arrangement into forms, such as tables or charts, useful for evaluation. A second objective was the statistical analysis of the data as described in the "NSF/EPA Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants" (EPA/NSF 1998).

Documentation of study events was facilitated through the use of logbooks, photographs, data sheets, and chain of custody forms. The data management system used in the verification testing program also involved the use of computer spreadsheet software and manual recording methods for recording operational parameters on a daily basis.

The chemical parameters and operating data were maintained in a bound logbook (Appendix B) and on specially-prepared data log sheets (Appendix C). In addition to the items noted in the data sheets, variations in the treatment plant regimen were noted. Among the changes possible were changes intended to respond to varying biological contamination and turbidity due to unusual source water episodes, such as weather related incidents (ice outs, storms) or unusual traffic or contaminant spills.

3.4.1 Procedures

Procedures existed for the use of the logbooks used for recording the operational data, the documentation of photographs taken during the study, the use of chain of custody forms, the gathering of on-line measurements, entry of data into the customized spreadsheets, and the method for performing statistical analyses. The following is a description of these procedures.

3.4.1.1 Field Notebooks

COA as the FTO for the project was responsible for the maintenance of the field notebooks. Data were collected in a bound field notebook (Appendix B) and on specially-prepared data log sheets (Appendix C) from the instrumentation panels and individual testing instruments. The master field notebook contained flowrate, volume, and pressure variations across several portions of the system, headloss across the filter housings, bag replacement frequencies and other variables, as well as notes on the challenge seedings. On-line particle counters and turbidimeters were linked to a computer with appropriate software for automatic data logging. The test official time clock was that of the computer; other timepieces such as stopwatches and sweep hands were used to measure flows or processes.

Each page of the field notebook was sequentially numbered and identified as Rosedale ETV Test. After October 15, 1999, when on-site staff was notified, each log page was initialed by the on-site staff member. Prior to that date, since the log was for initial operations and not the verification period, staff members had understood that the daily visitor log, which they signed, would suffice for identification. Errors were crossed with a single line and initialed. Deviations from the FOD whether by error or by a change in the conditions of either the test equipment or

the water conditions were noted in the field notebook. The field notebook included a carbon copy of each page. The original field notebook was stored on-site, the carbon copy sheets forwarded to the project engineer of COA at least once per week. This not only eased referencing the original data, but offered protection of the original record of results.

The COA office was the central data collection point and all raw data and notes are on file.

3.4.1.2 Photographs

Photographs were logged into the field logbook. These entries include time, date, and identity of the photographer.

3.4.1.3 Chain of Custody

Original chain of custody forms traveled with the samples from the test site to the laboratory (copies of which are attached as Appendix D).

3.4.1.4 On-line Measurements

On-line measurements included particle counters (MetOne PCX) and turbidimeters (HACH 1720C). These instruments were linked to a computer with software designed to record data at selected intervals. Data were recorded every 2 minutes, except during the challenge testing when the frequency of recording was changed to one-minute intervals. These data were displayed in real time and digitally stored within a computer. Digitally stored information was backed up on a ZIP® disk daily and delivered to COA's office. Manual logbooks were used to record data not connected to automatic recorders such as flow rates, on-site chemical analysis and pressure. All data was maintained by the FTO and the data was entered into a spreadsheet database.

3.4.1.5 Spreadsheets

Table 3-1 (Section 3.2.2.2) lists the daily, weekly and monthly water quality samples that were collected. The results of the daily on-site analyses were recorded in the field notebooks. All details affecting the operation of the equipment, whether by COA staff, or by State of Minnesota, Department of Health staff, were also logged in the field notebooks, consolidated and entered into computer spreadsheets. The data spreadsheets are attached to this report as Appendix C.

A COA associate entered data into a computer spreadsheet program (Microsoft© Excel) on a daily basis from the field notebooks and any analytical reports. A back-up copy of the computer data was maintained off site. The database for the project was set up in the form of custom-designed spreadsheets. All data from the field notebooks were entered into the appropriate spreadsheet. All recorded calculations were checked at this time. Following data entry, the spreadsheet was printed out and the printout was checked against the handwritten field notebooks. 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 initialized by the COA operator or engineer performing the entry or verification step. This log is consistent with standard laboratory practices.

Data entered on-site was transferred to the COA offices on diskettes.

3.5 Calculation of Data Quality Indicators

3.5.1 Representativeness

Water quality parameter samples for the RPI GFS Filter System were taken as indicated in Table 3-1. Off-site samples were delivered to the laboratory for analysis. The holding times are those indicated in EPA 40 CFR, Ch. 1, § 136.3 and *SM* 1060. On-site samples were taken utilizing *SM* 1060 sampling techniques.

Operating data, such as flow rate, volume measurements and pressure gauges were recorded and the time noted. Operational parameters were recorded and graphed.

3.5.2 Statistical Uncertainty

Statistical 95% confidence calculations were performed for the water quality parameters listed in Table 3-1. Each of the water quality parameters was analyzed, and confidence intervals determined by taking a minimum of three discrete samples for each of the parameters at one operating set during the testing period.

The formula used for confidence interval calculations was:

$$\textit{confidence interval} = \overline{X} \pm t_{n-1,\,1-\frac{a}{2}} \left(S / \sqrt{n}\right)$$

S = standard deviation
n = number of measurements in data set
t = distribution value with n-1 degrees of freedom
a = the significance level defined for 95% confidence as: 1- 0.95 = 0.05.

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

3.5.3 Accuracy

For water quality parameters, the accuracy referred to the difference between the sample result and the true or reference value. Care in sampling, calibration and standardization of instrumentation and consistency in analytical technique ensured accuracy.

For operating parameters such as flow rates and pressures, high levels of accuracy were ensured by redundant testing by confirming flow meters with bucket and stopwatch measurements. Pressure gauges were verified by reference to NIST-traceable standard gauges.

Performance evaluation was established by calibration of instruments used on-site and by conformance to *SM* and EPA protocol.

Accuracy was measured by spiking a known value to a solute, or by using a standard sample. The spiked (or standard) sample was analyzed and the following equations were used:

For a spiked sample: $$\%R = 100\left[\frac{A - B}{S}\right]$$

For a standard: $$\%R = 100 \times \frac{\text{Observed}}{\text{True}}$$

where:

%R	=	Percent recovery
A	=	Result of spiked sample
B	=	Result of un-spiked sample
S	=	Spike value

3.5.4 Precision

Precision was the measure of the degree of consistency from test to test, and was assured by replication. In the case of on-site testing for water quality, precision was ensured by triplicate tests and averaging; for single reading parameters, such as pressure and flow rate, precision was ensured by redundant readings from operator to operator.

Travel blanks were not required for this testing.

Matrix and method blanks were used for turbidity measurements, pH standardization, and for calibration of the particle counter both with respect to enumeration and size distribution.

The equation employed for precision for duplicate samples was:

$$RPD = \frac{D_1 - D_2}{(D_1 + D_2)/2} \times 100$$

RPD	=	Relative percent difference
D1	=	First sample value
D2	=	Second sample value

The equation employed for precision for triplicate samples was:

$$\%\text{ Relative Standard Deviation} = \frac{S(100)}{\bar{x}}$$

where:

S	=	Standard deviation

$\bar{x}$ = Mean of recovery values

3.6 Verification Testing Schedule

The verification testing started on March 7, 2000, and consisted of a 32-day period conducted over a single season. Daily testing concluded with the final microsphere challenge on April 20, 2000. Data were logged for a total of 781 hours of treatment system operation. The system was shut down three times due to various problems. The first time the system was shut down on March 17, 2000, for one hour due to a failure of the raw water feed pump. Testing resumed when the back-up pump was placed on line. Data were lost due to a failure of the effluent on-line turbidimeter on March 18, 2000. The system was shut down for 25 hours between March 18 and March 19 while the turbidimeter was replaced with a back up instrument. The system was also shut down from April 11 through April 15, for a total of 5 days due to the lead-time needed to secure the fluorescent microspheres for reseeding, and obtaining additional bags and cartridges from Rosedale Products, Inc. The system was brought back on line on April 16 and data recording and challenge testing resumed as soon as the microspheres were received.

Fluorescent microsphere challenge testing was performed on April 16 through April 20, 2000.

During the verification period, aspects of the operation were evaluated to determine insofar as is possible over a brief period, the degree of maintenance and "hands on" attention required. For this observation the equipment was run continuously except for the one hour interruption or filter element replacement times and monitored 8 hours a day until the completion of a period of 32 days.

3.7 Field Operations Procedures

In order to assure data validity, the EPA/NSF Verification Test 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.

3.7.1 Operations

The operating procedures for the RPI GFS Filter System are described in the O&M Manual. The O&M Manual for the treatment system was maintained on-site and is attached to this document as Appendix A. Additionally, operating procedures and equipment descriptions were described in detail in Chapter 2 of this report. Analytical procedures are described in Spectrum Laboratory's Quality Assurance Plan, as detailed in the FOD.

3.7.2 Analytical Equipment

The following analytical equipment were used on-site during the verification testing:

- A Hach 2100P portable turbidimeter was used for benchtop turbidity analysis.
- Pressure gauges were Ametek 556L (0 to 100 psi.) with calibration field verified with a NIST-traceable pressure gauge. There were two gauges on the system, one measuring inlet

pressure to the RPI GFS filter system and one measuring outlet pressure. Filter elements were replaced when the total pressure differential reached 15 psi, when turbidity breakthrough was detected, or when it was expected that differential would be reached during a period when the pilot was not staffed.

- A NIST-traceable Miller Weber Thermometer, Model T-775/63CGC Serial Number 3CO611 was used for temperature. The temperature was measured in °C, in 0.1° increments.
- A rotometer (Blue and White model F451004LHN (0 to 40 gpm) was used to measure flow rate. Rotometer accuracy was verified using the bucket and stopwatch technique.
- On-line turbidity measurements were taken with HACH 1720C turbidimeter.
- On-line influent and effluent particle count measurements were taken with MetOne PCX particle counters.

3.8 QA/QC Procedures

The objectives of the Quality Assurance/Quality Control (QA/QC) procedures were to assure that the data collected during the verification test is representative of the equipment and that the data is not corrupted by either procedural or recording anomalies. To that end, the FTO was responsible for the administration of the test and for the flow of data, and the individual laboratories and agents are accountable for their areas of responsibility.

Adherence to analytical methods as published in *Standard Methods* or EPA approved methodology was assured. Moreover, instrumentation and standard reagents were referenced to NIST. Instruments used to gather data were standardized and calibrated in accordance with the schedules noted below.

3.8.1 QA/QC Verifications

Measurements of flowrate, volume, pressure variations across the several portions of the system, headloss across the filter housings, bag replacement frequencies and other variables were noted in the logbook. To the degree possible, all measurements were taken at the same interval during the 32-day verification period. All changes from either the expected or the prior measurement were noted.

Any failures in equipment, however incidental, were noted and the time and position in the testing cycle logged. Major equipment failures requiring cessation of the flow or major repairs were logged both as a means of establishing the value of the data recorded during the period of failure and as a means of determining the cause of failure.

Laboratory results of water quality parameters were reported in standardized formats. Microbiological surrogate testing were reported both as raw numerical data and in standard statistical formats. Particle count and distribution data and turbidity data were measured with the use of on-line sensors and logged digitally on a continuous basis.

All grab samples, filter cartridges, and travel blanks shipped to outside laboratories were collected, packaged and shipped as required by *SM* and/or EPA standards. Sample bottles were

provided by the laboratory and were shipped in coolers with ice packs. Chain of custody forms accompanied the samples.
Flowmeters were calibrated and verified using the bucket and stopwatch technique.

A totalizing water meter was included to accurately measure volume. These meters were calibrated by bucket and stopwatch as well. Flowmeters and totalizing meters were also compared to each other.

Daily QA/QC Verifications included:

- On-line turbidimeter flow rates were verified (bucket and stopwatch). Flows were measured with sweepwatch or stop watch and a 1,000 mL graduated cylinder. Although this was a task specified daily by the ETV test plan, the FTO found it prudent to verify turbidimeter flow much more often than required, to include any time the turbidimeter flow was stopped and resumed.
- On-line turbidity readings standardized against a calibrated bench turbidimeter.
- Batch and on-line particle counter flow rates were verified (bucket and stopwatch). Flows were verified with a 100 mL graduated cylinder and either a sweep watch or stopwatch.

Bi-Weekly QA/QC Verification included:

- Flow rate rotometers were verified with the use of calibrated 50 gallon tank and stopwatch.

QA/QC Verification at the beginning of each testing period included:

- Cleaning and recalibration of on-line turbidimeters.
- Verify particle counter calibration with gradated microspheres.
- Check differential pressure transmitter signal and pressure gauge readings with pressure meter. There was no differential pressure transmitter attached to this equipment. Gauges were verified by comparing the pressure showing on the gauge with the same pressure showing on a NIST-traceable pressure gauge. The NIST-traceable pressure gauge was connected to the same port via an in line "T".
- Visual inspection particle counter and turbidimeter tubing for unimpeded flow and integrity.

Further descriptions of these verifications are provided in the results and discussion sections below.

3.8.2 On-Site Analytical Methods

Specific Instrumentation methods for on site QA/QC accuracy were conducted during the verification testing. Water quality parameters were measured by analytical or instrument methods outlined in *SM*. On-site instruments were calibrated daily. Sample ports and sampling techniques remained consistent.

3.8.2.1 pH

pH was recorded in accordance with *SM* 4500-H^+. The pH meter calibration was verified daily with a two-point calibration against NIST-traceable pH standards at pH 7.0 and pH 10.0.

3.8.2.2 Temperature

Temperatures were recorded daily with a NIST-traceable thermometer accurate to 0.1°C, as per *SM* 2550. The temperature was taken by immersing the thermometer to an index line scribed on the body into running water and allowing the mercury to stabilize. The thermometer was held upright during the readings.

3.8.2.3 Turbidity

SM 2130 was used for both the bench-top and on-line turbidimeter. An on-line turbidimeter was correlated to a portable bench-top turbidimeter. The bench-top turbidimeter was calibrated at the beginning of the verification period, and daily thereafter against secondary standards generated by the calibration procedure, and then also against secondary standards of 0.1, 0.5, and 3.0 NTU. Since the measurement systems are different, it was not necessary to have identical readings between the bench-top and on-line turbidimeters however; measurements should be and were consistent and comparable.

Samples were collected from a sample tap at a slow steady stream and along the side of a triple rinsed dedicated beaker to avoid air entrapment. The sample was poured from the beaker into a double rinsed clean sample vial and inserted into the chamber. This was repeated for influent and effluent samples, and the reading of the on-line turbidimeter was noted when the sample was drawn

All glassware for turbidity measurements was kept clean and handled with lint-free laboratory tissue. Sample cells were additionally wiped with a silicone oiled velvet cloth.

3.8.2.4 Particle Counting

Particle counting is a rapid and efficient means of determining with some accuracy the size distribution and enumeration of particles in a sample. While it conveys more information than turbidity, it cannot alone identify the source or nature of any particle matter. The manufacturer generally calibrates particle counters against NIST microspheres. Particle counters used on site had a factory calibration certificate dated March 3, 2000, serial numbers 971000353 and 971000354. Calibration was again verified on site with NIST mono-sized polymer microspheres.

Dilution water was prepared by filtering commercially prepared deionized water through 0.2 micron filters. To one liter of dilution water an amount of particle suspension was added to measure approximately 2,000 particles per milliliter. The particle sizes were NIST-traceable for size and included 3µm, 10µm and 15µm particles. Batch and true sizes are noted in the logbook as follows:

Duke Scientific Corp	3.0 ± 0.027 µm
	10.0 ± 0.061 µm
	15.0 ± 0.08 µm

Particle counter verification was performed for size distribution only, although counts were corroborated. Particle counters cannot be field verified for count accuracy.

The procedure for monosphere verification noted in the test plan pertains to bench-top particle counters, however, the procedure can be and was amended for application to on-line particle counters as follows: Black teflon hoses as supplied by the particle counter manufacturer were attached to the influent and effluent ports of the counter's sensor. The influent hose was inserted into a flask containing either dilution water or the particle suspension, and the effluent hose attached to a metering pump.

A suspension containing 2,000 measured particles per milliliter of a single size was prepared. Dilution water was suctioned through the particle counter and the pump rate adjusted to 100 mL/min. The influent line to the particle counter was fed the low particle dilution water for several minutes, until the lines were flushed and a background count was obtained. When the counts and flows were stable, the influent hose was switched to the particle suspension, which was mixed gently with a magnetic mixer. Those particle counts were logged and the distribution noted to assure separation into the proper particle count bin, and the time noted for correlation to the computer data recorder. After several sensor readings (determined by the volume of suspension and the counter sample frequency), the hose was switched back to the dilution water to clear the sensor and to stabilize the counter.

This procedure was performed eight times, four each for the influent and effluent counters. Although the test plan specified 2 µm, 10 µm and 15 µm sizes, COA requested of NSF that the 2 µm size be replaced with 3 µm particles. Particle counting is done by segregating the particles into bins and since the lower limit of the counter was 2 µm, the count of particles at that level would be uncertain. The verifications were then performed with 3 µm, 10 µm 15 µm mono-sizes, and once with a mixture of all three sizes at the 1,000 particles per milliliter, or 3,000 counts/mL total.

The results of this verification procedure are discussed and displayed in Chapter 4 of this report.

During the procedure, the flow was carefully controlled at 100 mL/min, and exceptions noted since reductions or increases in the flow rate alter the counts significantly.

Maintenance of the particle counter is important. Manufacturer recommended maintenance was followed and noted in the logbook.

Procedures for particle counting were those as noted in *SM* 2560 (and subsections appropriate to the equipment in use).

3.8.2.5 Particle Free Water

Particle free water (PFW) was a necessary component of the testing procedure and was prepared fresh and as often as storage limitations will allow. Fresh PFW was necessary to limit biological growth that could affect the particle counts. The PFW for this study was initially commercially available deionized water that had been additionally filtered through a 0.2 µm cartridge filter.

Field conditions made the production of PFW in accordance with *SM* difficult, however, although commercially prepared DI water, filtered on site thorough a 0.2 µm filter was considered suitable for particle counting and other reagent preparation in this application. This water was used for the NIST-traceable suspensions used to verify the particle counter accuracy.

In the case of the seeding suspensions however, particle free water, even DI water filtered through a 0.2 µm filter, was subject to contamination by airborne particles. Following consultation with the particle counter manufacturer, the FTO used the test equipment effluent water as dilution water for the seed suspension. This was deemed preferable to DI water since it had the same chemical composition as the feed water and the test equipment effluent contained near 100 particles per mL measuring between 2 to 7 microns in diameter. Particle count of the suspension was near 4.4 million/mL. Thus, there were 4.4 million particles/mL of seed to 100 particles/mL possible background particles in the dilution water. As with turbidity, glassware associated with the particle counters was dedicated and cleaned with laboratory glassware detergent, and then triple rinsed with PFW.

3.8.3 Off-Site Analysis For Chemical and Biological Samples

Tables 1a and 1b of the Code of Federal Regulations 40, Parts 136.3 cross-reference *SM*, EPA methods, American Society for Testing and Materials (ASTM) methods and U.S. Geological Survey (USGS) methods. Spectrum Labs follows EPA, *SM* or other accepted methodology for all of their analytical procedures. For example, to analyze alkalinity, EPA method §310.1 is used; this correlates to *SM* 2320B, which is the same as ASTM 1067-92 and USGS i-1030-85. All four of the testing methods are the same.

3.8.3.1 Organic Parameters, Total Organic Carbon and UV Absorbance

Samples for examination were collected in glass bottles furnished by the laboratory, prepared as in *SM* 5010B and shipped at 4°C to Spectrum Labs within 8 hours of collection. Samples were analyzed at the laboratory for TOC by EPA method 415.1. UV_{254} was analyzed using *SM* 5910B.

3.8.3.2 Microbial Samples: Coliform and Algae

Since the feedwater is surface water, microbiological samples were collected for analysis of coliform bacteria and algae. Samples were collected in glass bottles supplied by Spectrum Labs and kept at 4°C in the proper shipping cooler. Because the travel time was so brief and the samples were cooled, Spectrum Labs decided it was not necessary to use Lugol's solution as a preservative. Total Coliform Bacteria were analyzed at the laboratory using *SM* 9222B, algae analyzed using *SM* 10200F (when algae were found, *SM* 10900 was used for speciation), and E. coli Bacteria were analyzed using *SM* 9221F.

3.8.3.3 Inorganic Samples

Inorganic Samples were collected, preserved and shipped in accordance with *SM* 3010B and C and 1060 and EPA §136.3, 40 CFR Ch.1. Proper bottles and preservatives where required (Iron

and Manganese for example) was used. Sample bottles for metals analysis were supplied by the laboratory. Although the travel time was brief, samples were shipped cooled. Samples were analyzed at the laboratory in accordance with the following methods: total alkalinity - EPA method §310.2, color - EPA method §110.2, total hardness - EPA method §130.1, iron and manganese used EPA method §200.7

3.8.3.4 Microspheres

The samples for microscopic analysis were shipped to Debra Huffman Environmental Consulting. At Dr. Huffman's laboratory they were examined microscopically and the fluorescent spheres were counted using hemacytometer techniques and/or membrane filtration as appropriate. The hemacytometer was used when the samples contained high numbers of particles (influent samples); when the counts were low (effluent samples) the particles were counted microscopically after filtration through a membrane. Hemacytometer and membrane filtration counting was performed as outlined in EPA Method 1622, Section 11.3, EPA Method 1623, Section 11.0, and *SM* 10200F. Hemacytometer and membrane filtration counting was performed microscopically at the laboratory. EPA Methods 1622 and 1623 refer to the use of live cysts and oocysts, and *SM* 10200F refers to live organisms as well. Because this study employed synthetic microspheres, the requirement of preserving, dying and handling specific to live organisms was unnecessary. Accordingly, the techniques employed were those covered by standard microscopic evaluation procedures as outlined in *SM* 10200, but without the need for techniques specific to live organisms.

3.8.3.5 True Color

True color was measured in accordance with *SM* 2120 with a spectrophotometer at 455 nm. The samples were collected in glass vials and maintained at a temperature of 4°C during shipment to Spectrum Labs. The samples were warmed to room temperature before analysis. Samples were analyzed in accordance with EPA method §110.2.

Chapter 4
Results and Discussion

4.1 Introduction

Initial operations took place in two phases. The first phase began June 24, 1999 and ended July 9, 1999. The second phase began January 10, 2000 and ended on January 20, 2000. The verification testing for the RPI GFS Filter System commenced on March 7, 2000, and concluded a 32-day testing period on April 20, 2000. Microsphere challenge testing was conducted between April 6 and April 20, 2000 in two sessions, the first using regular polystyrene (latex) microspheres, and the second, from April 16 through April 20, 2000, using fluorescent microspheres.

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: initial operations, equipment characteristics, finished water quality, polystyrene microsphere surrogate removal, and QA/QC.

4.2 Initial Operations Period Results

The initial operations period allowed the manufacturer to characterize feed water quality and to optimize treatment efficiency of the equipment. This period was also used for filter element variability testing to identify variations in system performance attributable to the manufacturing process of the rigid cartridge filters identified by the manufacturer as the physical barrier of parasitic cysts within the equipment package. The bag filter was identified as a pre-filter to the rigid cartridge filter within the equipment package. Accordingly, bag filters from the same manufacturing lot were used throughout variability testing within, and between, manufacturing lots of rigid cartridge filters.

The filter element variability testing period was divided into two phases. Phase I was designed to determine variations *within* a manufactured lot number of cartridge filter elements. Phase II was designed to show variations *between* manufactured lot numbers of cartridge filter elements. Prior to these two phases, the feedwater was characterized for suitability to this technology.

There is a certain imprecision in the manufacture of filter elements causing pore sizes to vary slightly. To account for this variability, the RPI GFS Filter System containing filter elements from same manufacture lot number were subjected to the same influent water conditions during this phase of the testing. Particle counts were monitored to check filter lot performance. Turbidity was measured not as a surrogate, but because it represents the cumulative effect of substances that had the ability to load filters and shorten run times, thus contributing to the overall performance.

4.2.1 Characterization of Feed Water

Historical untreated surface water quality data was obtained from the City of Minneapolis, Municipal Water Works department, for the same time frame as the verification testing period (March and April of 1997). The untreated surface water exhibited the following characteristics:

the temperature varied from 0.3°C to 13.2°C; pH was in the range of 7.6 to 8.2; total alkalinity averaged from 103 mg/L to 169 mg/L; total hardness averaged between 122 mg/L and 188 mg/L; true color averaged between 31 and 69 TCU and turbidity averaged between 5.2 and 18.6 NTU.

During Initial Operations, between June 29, 1999, and July 9, 1999, untreated river water was blended with finished Minneapolis drinking water to achieve a level of turbidity near 1 NTU. Chlorination of blended water was maintained near 0.5 mg/L by injection of sodium hypochlorite. Additional characteristics of this blended water are as follows: Temperature varied from 22.9°C to 26°C; pH averaged 8.5; total alkalinity averaged 45 mg/L; total hardness of averaged 78 mg/L; TOC concentration less than or equal to 6.1mg/L; UV_{254} Absorption of 0.1; true color of 15 TCU; total coliform was not detected or was detected below the PQL of 1 CFU/100mL, iron was not detected or was below the PQL of 0.1 mg/L; manganese was less than 0.02mg/L; and the conductivity was 360 µmhos/cm. Algae were not detected or were below the PQL of 1 Algae/mL in the influent or effluent sample waters in the initial operations testing period.

4.2.2 Initial Test Runs

COA and RPI supervised the installation of the equipment and start-up, and established operation of the test station. Trial runs of the system were performed.

During this period COA additionally calibrated and standardized the test station and evaluated general functionality the station and specifically that of the untreated/treated water blending system. These exercises were performed previous to the controlled ETV test period and accordingly had no strict format or reporting requirements.

4.2.3 Filter Element Variability Testing

Phase I of filter element variability testing began at 12:33 on June 24, 1999. Cartridge filters with the same manufacturing lot number (88-4546) were inserted into the three filter trains. The flowrate was 20 gpm per filter, and turbidity was controlled by blending raw river water with finished city water to achieve approximately 3.0 NTU as measured by on-line turbidimeters. Terminal headloss had been established by the manufacturer at 15 psi across each filter train, consisting of a bag filter as a pre-filter, and the rigid cartridge filter, described above. Although each filter housing had an individual pressure differential gauge, it was the sum of the pressures across both housings that was registered by the pressure gauges located on the instrument panel that were used to determine system losses. At 17:58 on June 24, the operator's shift was complete and the equipment was left in operation until an operator returned the following morning.

By 9:15 June 25, the three filters showed pressure losses of (#1) 7.5 psi, (#2) 30 psi and (#3) 12.5 psi. Flowrates in the three systems had decreased to (#1) 19.5 gpm, (#2) 15.5 gpm and (#3) 12.5 gpm.

By 9:49 (within 34 minutes) the filters had the following headlosses (#1) 24 psi, (#2) 37 psi and (#3) 31 psi and the three filter trains were shut down for cleaning and filter element replacement. The cumulative volumes of water filtered at time of shutdown were:

Filter System 1	25,899 gallons
Filter System 2	21,997 gallons
Filter System 3	25,083 gallons

New bags and cartridges of the same manufacturing lot number were installed and the filters placed on line at 12:45. By 15:00 (within 3 hours, 15 minutes) the filter loading rates were excessive and it was clear that terminal head loss would be achieved within several hours after the operator's shift concluded. Accordingly, the system was shut down at that time (June 25, at 15:00 hours) to reevaluate the operating parameters.

After discussions with the manufacturer, it was decided that influent turbidity should be reduced to an average of 1 NTU and the flow rate decreased to 10 gpm. It was also decided that non-blended Minneapolis finished drinking water serve as the feed water overnight when the equipment was unattended by an operator. Further, due to concerns expressed by the manufacturer with the previous lot of cartridges, the manufacturer also provided replacement cartridges with a different manufacturing lot number (6-2-99).

Following cleaning and purging, the system was restarted with the new operating parameters and cartridges on June 29, 1999. Filter runs conducted after influent turbidity was reduced to 1 NTU and flow rate to 10 gpm are summarized in Table 4-1.

Table 4-1. Phase I Initial Operations Filter Run Summary

Filter System #	Dates	First Elements Gallons (total)	Element Replacement (Stop time)	Second Element Set Gallons
1	6/29-7/7	229,472	7/7 16:00	50,997
2	6/29-7/7	250,726	7/8 10:00	29,960
3	6/29-7/7	214,063	7/7 9:00	58,100

Headlosses for the second set of three filters at the end of the 10-day period were: (#1) 4 psi, (#2) 5 psi and (#3) 12 psi. These filter runs were shortened due to the conclusion of Phase I of the initial operations.

Phase I concluded with 261 hours, 32 minutes (10.90 days) of equipment operation. Based on the results of Phase I, the manufacturer elected to address concerns pertaining to the manufacturing process of the rigid cartridge filter element (model number GLR-PO-825-2). Subsequently, for Phase II of filter element variability testing, the manufacturer provided rigid cartridge filter elements with a different model number (PL-520-PPP141) and internal seals within the filter housing. Because the rigid cartridge filter and housing seals serve as primary components within the equipment package their replacement fundamentally changes the description of equipment package being marketed by the manufacturer. Accordingly inclusion of specific performance data collected during phase I is omitted from this report.

Phase II of the filter element variability testing began on January 10, 2000 at 14:20 and continued through January 20, 2000 to 18:30 for a total period of operation of 244:10 hours (10.21 days). The purpose of Phase II was to observe variability between manufacturing lots of rigid cartridge filters. Rigid cartridge filters from 3 different manufacturing lots were used (990541-5, 990541-4, 990541-3). The bag filters, used as pre-filters within the filter train, all

were from the same manufacturing lot (PO525A2). In addition to the amendments made to the equipment package, influent turbidity was reduced to an average of less than 1 NTU and was maintained at that level 24 hours/day. The filter flow rate was also reduced from 20 to 10 gpm.

Because of the improbability that terminal head loss would occur across each filter train within the 8 hours per day an operator was present, filters within all filter trains were replaced simultaneously when terminal head loss occurred within one filter train. It should be noted that while this practice inherently created performance data that understates true treatment capacity for each treatment train, differences in head losses (psi) recorded previous to each filter replacement suggest variability in treatment capacity between filter trains (refer to Table 4-4).

During Phase II the same schedule of data recording was followed as for Phase I with two shifts of four hours each, with each shift separated by several hours. Performance results for the individual filter runs for each of the three filter trains for Phase II are summarized in Tables 4-2, 4-3 and 4-4. Table 4-5 summarizes the operating data for individual filter runs for each of the three filter trains.

Table 4-2. Phase II Variability Testing RPI GFS Filter System Run #1 Particle Count & Turbidity Results

Filter Run	Filter Train 1 Mfg. Lot 990541-5			Filter Train 2 Mfg. Lot 990541-4			Filter Train 3 Mfg. Lot 990541-3		
	Ave.	Std. Dev.	95% Conf. Int.	Ave.	Std. Dev.	95% Conf. Int.	Ave.	Std. Dev.	95% Conf. Int.
Influent 3-7 µm Particle Counts (counts/mL)	1,466.37	290.70	1,354.63, 1,578.11	1,474.61	247.52	1,379.46, 1,569.75	1,446.40	278.77	1,339.25, 1,553.56
Effluent 3-7 µm Particle Counts (counts/mL)	63.10	24.65	53.62, 72.58	106.26	45.00	88.96, 123.56	36.65	15.17	30.82, 42.48
Particle Count Log_{10} Removal	1.4	0.2	1.3, 1.5	1.2	0.2	1.1, 1.2	1.6	0.2	1.6, 1.7
Influent On-Line Turbidity (NTU)	0.85	0.09	0.81, 0.88	0.86	0.08	0.83, 0.89	0.85	0.09	0.81, 0.88
Effluent On-Line Turbidity (NTU)	0.31	0.04	0.30, 0.33	0.32	0.03	0.31, 0.34	0.30	0.051	0.28, 0.32

Table 4-3. Phase II Variability Testing RPI GFS Filter System Run #2 Particle Count & Turbidity Results

Filter Run	Filter Train 1 Mfg. Lot 990541-5			Filter Train 2 Mfg. Lot 990541-4			Filter Train 3 Mfg. Lot 990541-3		
	Ave.	Std. Dev.	95% Conf. Int.	Ave.	Std. Dev.	95% Conf. Int.	Ave.	Std. Dev.	95% Conf. Int.
Influent 3-7 µm Particle Counts (counts/mL)	1,322.42	603.39	1,098.93, 1,545.92	1,312.02	604.08	1,088.27, 1,535.77	1,337.53	567.25	1,127.42, 1,547.63
Effluent 3-7 µm Particle Counts (counts/mL)	39.53	22.62	31.15, 47.91	42.29	24.12	33.93, 51.22	31.83	17.93	25.19, 38.47
Particle Count Log_{10} Removal	1.5	0.4	1.3, 1.6	1.5	0.4	1.3, 1.6	1.6	0.4	1.5, 1.8
Influent On-Line Turbidity (NTU)	0.95	0.19	0.88. 1.03	0.93	0.09	0.90, 0.96	0.93	0.08	0.90, 0.96
Effluent On-Line Turbidity (NTU)	0.31	0.05	0.29, 0.33	0.32	0.03	0.31, 0.33	0.31	0.02	0.30, 0.32

Table 4-4. Phase II Variability Testing RPI GFS Filter System Run #3 Particle Count & Turbidity Results

Filter Run	Filter Train 1 Mfg. Lot 990541-5			Filter Train 2 Mfg. Lot 990541-4			Filter Train 3 Mfg. Lot 990541-3		
	Ave.	Std. Dev.	95% Conf. Int.	Ave.	Std. Dev.	95% Conf. Int.	Ave.	Std. Dev.	95% Conf. Int.
Influent 3-7 µm Particle Counts (counts/mL)	658.47	346.41	522.68, 794.26	628.99	350.85	491.46, 766.52	616.75	347.75	480.44, 753.07
Effluent 3-7 µm Particle Counts (counts/mL)	22.99	12.59	18.05, 27.92	78.38	24.07	68.94, 89.81	19.94	6.67	17.32, 22.55
Particle Count Log_{10} Removal	1.4	0.4	1.3, 1.6	0.81	0.40	0.66, 0.97	1.4	0.4	1.3, 1.5
Influent On-Line Turbidity (NTU	0.77	0.13	0.72, 0.82	0.78	0.13	0.73, 0.83	0.78	0.13	0.73, .83
Effluent On-Line Turbidity (NTU)	0.33	0.10	0.29, 0.37	0.35	0.07	0.33, 0.38	0.32	0.08	0.29, 0.36

While these results suggest some variability in particle reduction performance between filter trains, the degree of variability can be attributed to variations in filter ripening caused by the method selected to initiate filter replacement, described above. Particle reduction performance generally improves as terminal head loss is approached. Accordingly, when the filters were replaced previous to terminal head loss, lower log_{10} reductions were noted. This is observed in run #1 (Table 4-2). Head losses at time of filter replacement on January 13 were 12 psi, 8 psi, and 15 psi respectively for filter trains 1, 2, and 3. Corresponding particle count log_{10} reductions were 1.4, 1.2, and 1.6.

During Phase II run # 2, filter train 1 approached terminal head loss near the end of the daily data collection period. Leaving the existing filters in operation over night would have caused head losses to significantly exceed terminal head loss previous to the next data collection shift the following morning. Accordingly, all filters were replaced. Head losses at time of filter replacement on January 17 were 12 psi, 8 psi, and 9 psi respectively for filter trains 1, 2, and 3. Corresponding particle count log_{10} reductions were 1.5, 1.5, and 1.6.

The conclusion of the Phase II filter variability testing period on January 20 caused the termination of run # 3. Head losses at time of shut-down were 6 psi, 6 psi, and 5.5 psi respectively for filter trains 1, 2, and 3. Corresponding particle count log_{10} reductions were 1.4, 0.81, and 1.4. During this filter run influent particle counts were significantly lower than what was observed during runs # 1 and # 2. Also, filter train 2 demonstrated comparatively poor particle reduction performances. This was attributed to a faulty pressure differential gauge. Table 4-5 is a summary of the volumes of water treated and the terminal headloss in the Phase II runs.

Table 4-5 Phase II RPI GFS Filter System Filter Operating Data

Filter Run #	Filter Train 1 Mfg. Lot 990541-5	Filter Train 2 Mfg. Lot 990541-4	Filter Train 3 Mfg. Lot 990541-3
Run #1			
Total Water Processed (gallons)	79,265.5	82,604.0	79,664.6
Max. Change In Pressure Drop (psi)	12.0	8.0	15.0
Run #2			
Total Water Processed (gallons)	57,826.0	62,020.0	61,767.0
Max. Change In Pressure Drop (psi)	12.0	8.0	9.0
*Run #3			
Total Water Volume (gallons)	44,338.2	43,925.6	44,743.4
Max. Change In Pressure Drop (psi)	6.0	6.0	5.5

* Filter Run #3 discontinued before to terminal headloss.

When the operating data described in Table 4-5 is compared to particle reduction data described in tables 4-1 and 4-2 it becomes somewhat evident that rigid cartridge filters used in filter train # 2 (lot # 990541-4) offered greater loading capacity. These data also suggest inconsistencies in performance from rigid cartridge filters used in filter train # 3 (lot 990541-3). Due to the limited number of filters evaluated within each manufacturing lot, conclusions regarding variation in filter performance between manufacturing lots cannot be offered with any degree of certainty.

It was also noted that filter train # 2 offered lower particle reduction values. Upon later examination, it was determined that of the Orange Research pressure differential gauges installed within each filter train, the one installed in filter train # 2 was faulty and had been bypassing influent water into the filtered water stream.

4.3 Verification Testing Results and Discussions

The results and discussions of testing runs, routine equipment operations, feed and finished water quality, operating conditions and equipment performance, and microbiological removal tasks of the verification testing are presented below.

4.3.1. Task 1 - Verification Testing Runs And Routine Equipment Operation

The objective of this task was to operate the equipment provided by the manufacturer for a minimum 30-day testing period and assess its ability to meet water quality goals and other performance characteristics specified by RPI.

The verification testing for the RPI GFS Filter System began on March 7, 2000, and ended its 32-day period on April 20, 2000. During the testing period, one RPI GFS Filter system was operated for 23-hours each day with flow stopped for one hour each day. The duration of each filter run from start to terminal headloss and the number of gallons of water produced during each run are summarized in the results discussion for Task 3, Section 4.2.3.

4.3.2 Task 2 - Influent and Effluent Water Quality Characterization

Results of testing for turbidity in the influent and effluent water were examined to verify the manufacturer's stated turbidity treatment ability. Examination of TOC and UVA_{254} testing

results, as well as testing results for the inorganic parameters total alkalinity, total hardness, true color, total coliform, iron and manganese are shown in Table 4-6. Samples for E. coli were collected on March 13, 2000 and March 30, 2000. E. coli was not detected or was below the PQL of 1 CFU/100mL. Samples for Aluminum analysis were collected on March 13, 2000; Aluminum was found in the influent samples at 0.83 mg/L.

Table 4-6. Influent Water Quality (March 7 – April 20, 2000)

Parameter	# of samples	Average	Minimum	Maximum	Standard Deviation	95% Confidence Interval	PQL
Total Alkalinity (mg/L)	7	70	55	110	18	55, 78	10 mg/L
Total Hardness (mg/L)	7	94	82	130	16	82, 107	10 mg/L
True Color (TCU)	7	14	10	25	6	10, 18	1 TCU
Total Coliform (CFU/100/mL)	7	24*	<1	110	40	<1, 54	1 CFU
TOC (mg/L)	7	7.8	6.8	11.0	1.4	6.7, 8.9	0.4 mg/L
UVA_{254} (cm^{-1})	7	0.140	0.108	0.229	0.042	0.109, 0.171	-
On-Line Turbidity (NTU)**	-	1.1	0.7	1.5	0.2	1.0, 1.2	-
Total Chlorine (mg/L)	27	1.4	0.7	3.5	0.82	1.1, 1.7	-
Free Chlorine (mg/L)	27	0.6	0.1	2.5	0.6	0.4, 0.8	-
Iron (mg/L)	7	0.1*	<0.1	0.4	0.1	<0.1, 0.2	0.1 mg/L
Magnesium (mg/L)	7	0.02*	<0.01	0.04	0.01	0.01, 0.03	0.01 mg/L
Temperature (°C)	38	7.3	3.9	11.0	2.2	6.7, 8.0	-
pH	37	8.5	8.0	8.9	0.2	8.4, 8.5	-

*All calculations involving results with below PQL values used half the PQL in the calculation.
** Turbidity values are the on-line values and the average results of each filter run.

One influent water sample for Total Coliform Bacteria did not contain a 100 mL water sample; therefore a 90 mL analysis was performed. Drinking water compliance samples (SDWA) must be 100 mL volumes to report <1 coliform/100mL. This sample analysis must therefore be reported as <1/90mL, or <1.1 per 100 mL (adjusting the PQL for the lower volume received and filtered). Therefore, Spectrum Labs deemed that due to adjusting the PQL, data could be produced from the 90 mL sample for analysis.

Algae were detected three times in the influent water samples collected during the verification testing period; those results are presented in Table 4-7.

Table 4-7. Influent Water Samples Algae (CFU/100mL)

Date	Asterionella	Nitzschia	Euglena	Navicula	Chlamydomonas	Fragilaria	Diatoma	Chloratella
03/15/00	175	560	35	175	245	70	105	NV
03/24/00	NV	NV	35	35	NV	NV	NV	NV
04/07/00	NV	312	NV	NV	NV	NV	104	234

* NV = below reported PQL of 1 CFU/100 mL.

Of the algae found, several (Asterionella, Navicula, Fragilaria, Diatoma) are know to contribute to excess filter loading. Others may also add to filtration loading or otherwise hamper filter performance. The presence of algae in river water was expected.

The results of the testing of the finished water for TOC, and UVA_{254} testing results, as well as testing results for the inorganic parameters total alkalinity, total hardness, true color, total

coliform, iron and manganese are shown in Table 4-8. No algae were detected in the finished water samples. Laboratory reports are provided in Appendix E.

Table 4-8. Effluent Water Quality (March 7 – April 20, 2000)

Parameter	# of samples	Average	Minimum	Maximum	Standard Deviation	95% Confidence Interval	PQL
Total Alkalinity (mg/L)	7	66	54	100	16	55, 78	10 mg/L
Total Hardness (mg/L)	7	95	82	130	16	83, 107	10 mg/L
True Color (TCU)	7	10	5	15	4	7, 13	1 TCU
Total Coliform (cfu/100 mL)	7	2*	<1	6	3	<1, 4	1 cfu/100 mL
TOC (mg/L)	7	7.5	6.4	8.8	0.8	6.9, 8.1	0.4 mg/L
UVA_{254} (cm-l)	7	0.130	0.109	0.156	0.017	0.117, 0.143	-
Iron (mg/L)	7	0.1*	<0.1	0.6	0.2	<0.1, 0.3	0.1 mg/L
Manganese (mg/L)	7	0.1*	<0.01	0.04	0.01	<0.01, 0.02	0.01 mg/L

*All calculations involving results with below PQL values used half the PQL in the calculation.

Several times throughout the testing period turbidity spikes were observed that could be directly related to work being performed on the water distribution system by MWW staff. These turbidity spikes occurred when the city pressure dropped below 100 psi and additional city pumps were brought on line. These spikes did not make any significant changes in the total run averages though. On March 31, it was observed that MWW workers were in the process of cleaning the intake screens. The cleaning of the screens may have had an effect on the turbidity readings for the period between March 23 and April 2. During the period of March 23 to April 2, the average turbidity was 1.16 NTU, the highest average for the testing period. The turbidity before this cleaning averaged 0.73 NTU, and the turbidity between April 3 and April 20 averaged 1.14. Turbidity spikes were unpredictable and gave no warning, thus operators could not quickly respond to adjust the blended water.

The influent turbidity between April 16 and April 20 may have been elevated due to increases in algal blooms. During the last run (#22), the average influent turbidity was 1.46 NTU, again likely due to algal blooms in the river water. The increase in turbidity and particle count continued past the verification period.

Water temperature of the blended Mississippi River water and the MWW plant water varied considerably during the verification period, due to the river water temperature warming up with the season. A high of 11°C, and a low of 3.9°C were measured in the influent water (average of 7.3° C). At one point (in January during Phase II) the raw Mississippi river water was only a few tenths above the freezing point. Feed water temperatures lagged river water temperatures by several days due to interim storage following treatment. Water temperature did not steadily increase during the period, but advanced and declined as the air temperature changed.

The pH of the feed water was stable during the testing period. pH ranged from a low of 8.0 to a high of 8.9 with an average pH of 8.4.

4.2.3 Task 3 - Documentation Of Operating Conditions And Treatment Equipment Performance

The purpose of this task was to accurately and fully document the operating conditions during treatment and the performance of the RPI GFS Filter System during verification testing. Table 4-9 lists the operating parameters that were documented during the verification testing period.

Table 4-9. Operating Parameters (Summary of 22 Filter System Runs)

Parameter	Average	Minimum	Maximum	Std Deviation	95% Confidence Interval
Flow Rate (gpm)	9.7	5.0	11.0	1.0	9.5, 9.9
Gallons per filter run	22,789.1	10,980.0	74,173.4	15,434.2	16,339.7, 29,238.5

The influent water flow rate for the verification period averaged 9.7 gpm. The flow naturally declined as the pressure drop across the filters increased; the flow was adjusted as per the test plan whenever it fell by more than 10%, occasional lower readings resulted from lower flows noted prior to adjustment.

Wastes consisted of spent filter elements, which were examined and then disposed of in solid waste containers on site. Filter elements are not considered hazardous and could be included with other site trash. Effluent water was directed to the Metropolitan Sewer System.

The RPI GFS Filter System had no power requirements. Therefore, the daily power consumption of the treatment system was not recorded.

Table 4-10 summarizes each filter run of the RPI GFS Filter System during the verification period. Note that filter runs 17 and 18 data are not included in the averaging because the FTO had run out of cartridge elements thus only the bag was replaced (water usage data is included for comparison only, and is not used in averages). This interruption was due to a shipping delay of additional bags and cartridges from the manufacturer.

Table 4-10. Filter Run Averages For Verification Period (March 7 – April 20)

Run Number	Average Total Influent Particles (2-15 µm) (counts/mL)	Average Total Effluent Particles (2-15 µm) (counts/mL)	Average Influent Turbidity (NTU)	Average Effluent Turbidity (NTU)	Max Pressure Change (psi)	Water Produced (Gallons)	Filter Run Duration (hours)
Filter Run 1	4,561.81	43.66	0.81	0.20	16	74,173.4	135.25
Filter Run 2	3,783.90	78.01	0.77	0.22	11	34,525.6	54.25
Filter Run 3	4,174.34	76.70	0.68	0.20	16	50,564.4	**82.5
Filter Run 4	6,235.43	178.05	1.05	0.26	14.75	16,488.4	27.00
Filter Run 5	6,124.01	39.06	0.97	0.21	14	19,567.1	31.75
Filter Run 6	6,430.37	299.54	1.03	0.22	12	23,824.8	39.50
Filter Run 7	6,947.62	60.14	1.06	0.23	16	27,846.1	45.50
Filter Run 8	8,268.76	63.93	1.17	0.18	14	19,840.7	32.50
Filter Run 9	8,719.92	57.79	1.34	0.20	25.5	14,393.6	23.50
Filter Run 10	8,695.56	124.43	1.28	0.21	21	21,245.7	35.25
Filter Run 11	6,750.24	65.28	0.93	0.19	16	29,920.0	52.00
Filter Run 12	9,290.52	112.39	1.33	0.21	15	12,690.0	19.75
Filter Run 13	8,452.42	60.80	1.16	0.21	17	14,950.0	25.50
Filter Run 14	7,541.34	69.35	1.06	0.19	20	14,020.0	23.25
Filter Run 15	7,268.12	90.02	0.97	0.17	16	17,042.4	27.75
Filter Run 16	7,935.23	85.53	0.99	0.20	12	12,454.8	19.25
Filter Run 17	-	-	-	-	-	*15,264.7**	-
Filter Run 18	-	-	-	-	-	*6,895.3**	-
Filter Run 19	8,486.83	89.03	1.12	0.22	22.5	14,665.6	23.75
Filter Run 20	9,385.81	108.55	1.26	0.23	18	10,980.0	19.25
Filter Run 21	7,463.88	67.38	1.10	0.21	15	14,150.0	23.25
Filter Run 22	10,055.87	47.60	1.46	0.23	15	12,440.0	19.50
Average	7,328.60	90.86	1.08	0.21	16.3	22,789.1	38.04
Minimum	3,783.90	39.06	0.68	0.17	11.0	10,980.0	19.25
Maximum	10,055.87	299.54	1.46	0.26	25.5	74,173.4	135.25
Std Dev.	1,737.35	58.74	0.20	0.02	3.6	15,434.2	27.76
95% Confidence	6567, 8090	65, 117	0.98, 1.16	0.20, 0.22	14.8, 17.9	16,339.7, 29,238.5	25.88, 50.18

* - Runs 17 & 18 water usage data not included in totals, data shown for comparison information only.

** Run 3 was interrupted one hour to replace the raw water pump, and 25 hours because of turbidimeter failure. The raw water pump failure, which was not noticed immediately, had the effect of reducing the total flow through the system, and of eliminating the raw water flow so only finished city water was supplied. This accounts for the long run time to terminal headloss.

Note: Particle counter calibration and verification procedures were performed in Runs 5, 11, 15, and 17.

Filter runs 20, 21, and 22 were fluorescent microsphere challenge runs that are described in more detail in Task 4.

In the following text the verification runs are summarized showing turbidities, number of gallons processed, pressure drops and other relative comparisons. Included are explanations of interruptions and exceptions that should be considered when reviewing the run data.

Turbidity removals were consistent and generally good throughout the verification period. Following a brief ripening period, on-line turbidity on average over the twenty-two filter runs was: 1.08 NTU influent and 0.21 NTU effluent for an average 0.64 $\log_{10}$ reduction.

Figure 4-1 shows the relationship of the influent turbidity to the number of gallons processed per filter run. Note, filter run 17 and 18 data are not graphed in the Figure 4-1.

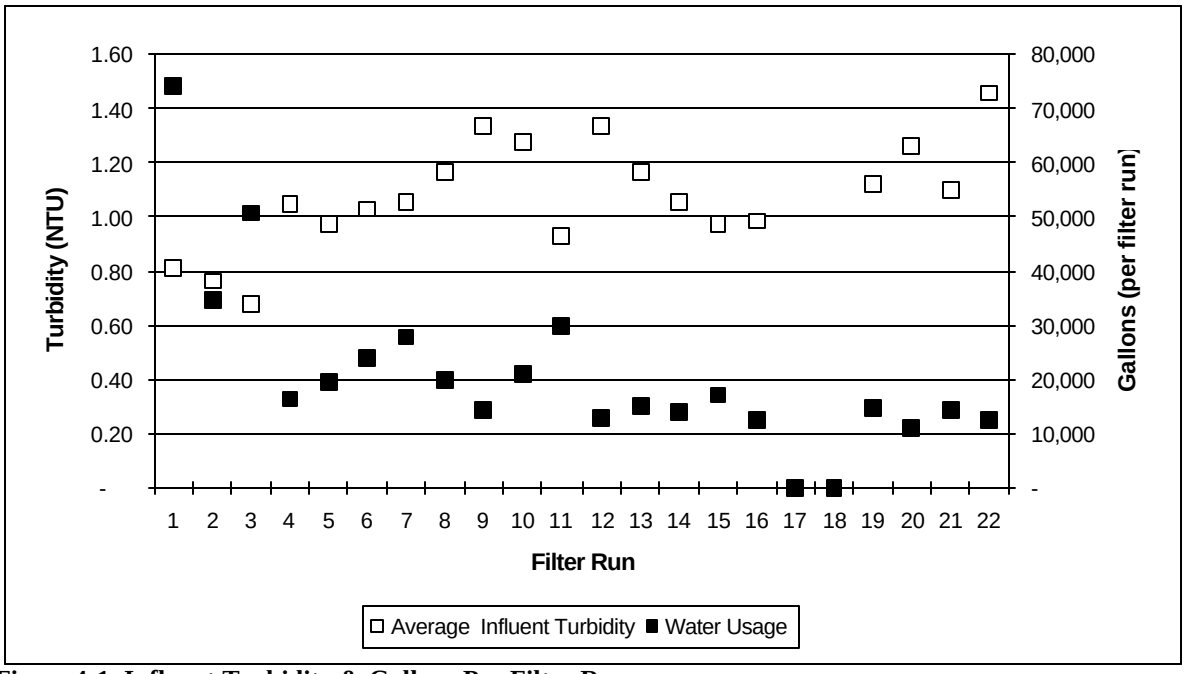


Figure 4-1. Influent Turbidity & Gallons Per Filter Run

Figures 4-2, 4-3 and 4-4 are representative of the data recorded during the individual filter runs. Figure 4-2 illustrates the average influent and effluent turbidity, Figure 4-3 graphs the average $\log_{10}$ reductions based on average influent/effluent particle counts per filter run, and Figure 4-4 presents the change in pressure drop per individual filter run. Note, filter run 17 and 18 data are not graphed in the following three figures.

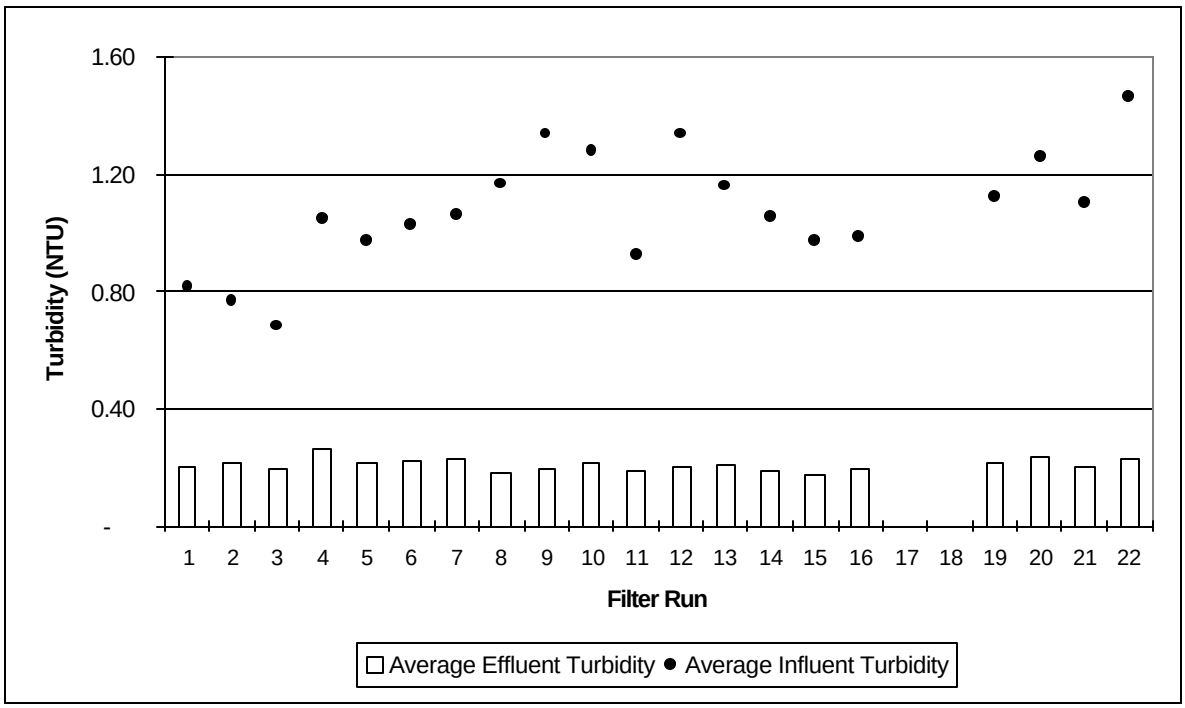


Figure 4-2. RPI GFS Average Filter Run Influent & Effluent Turbidity

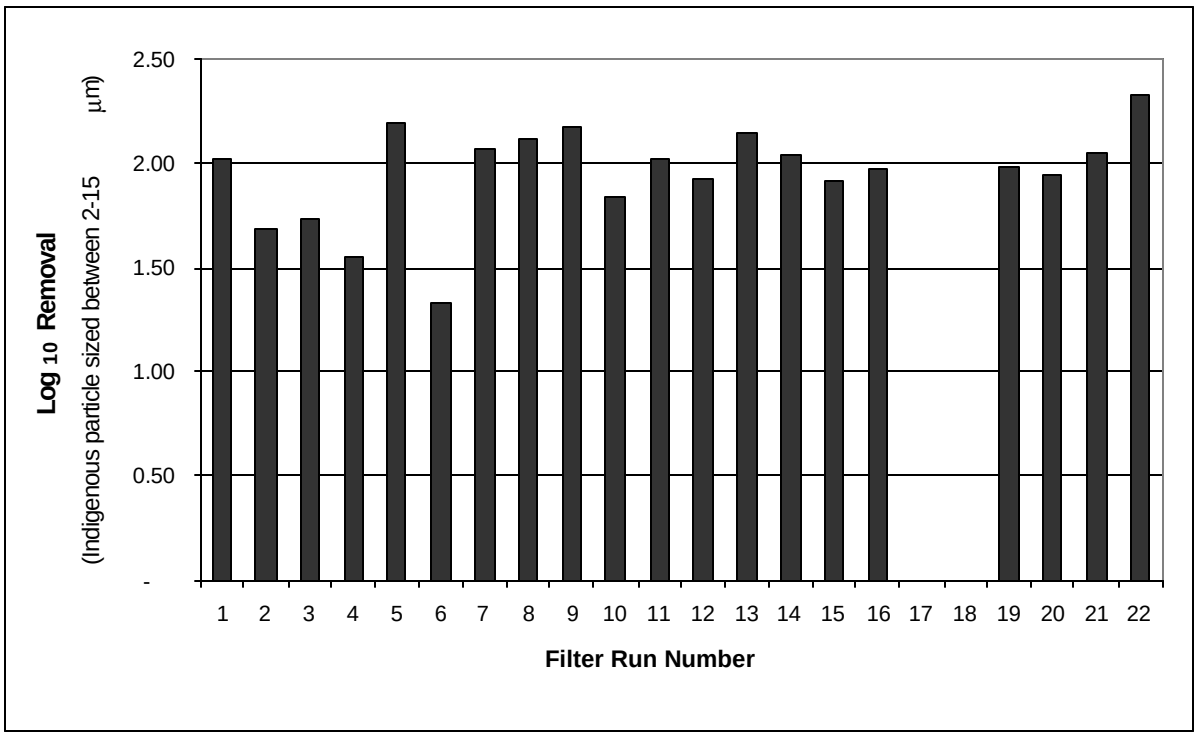


Figure 4-3. RPI GFS Log_{10} Removal For Indigenous Particle Sized 2-15㎜m

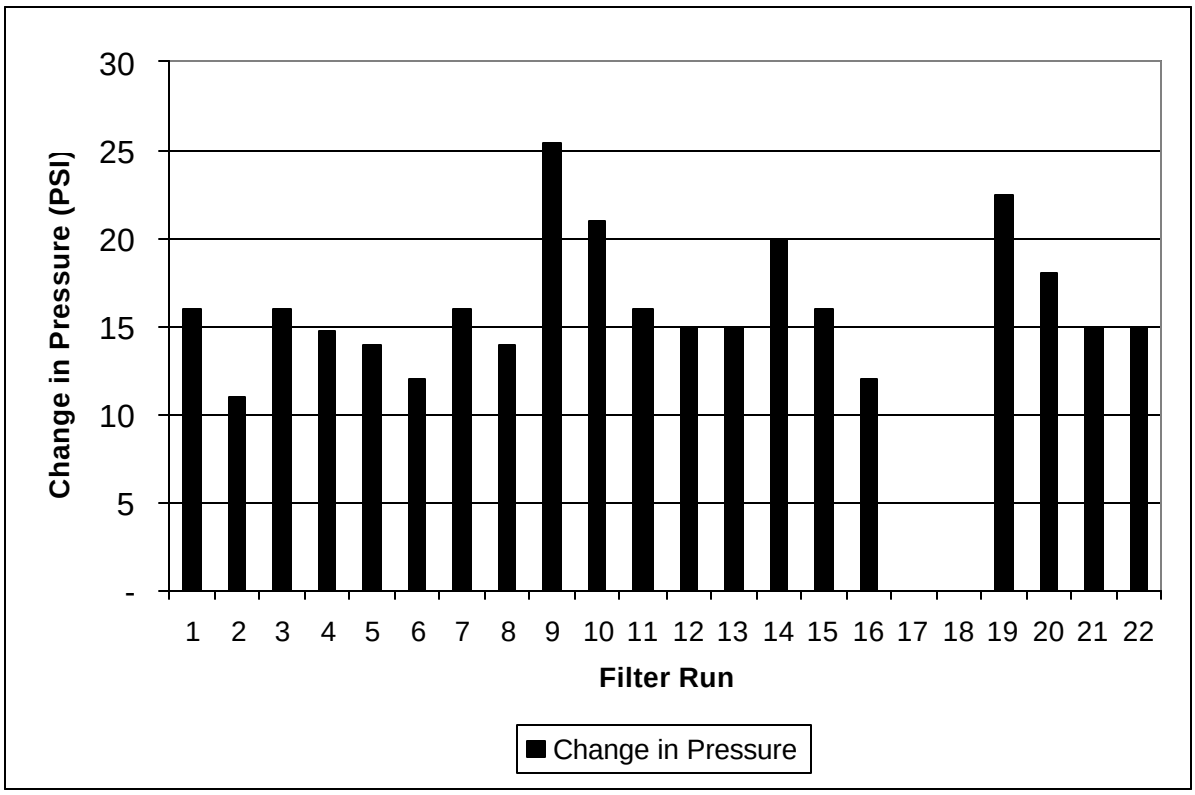


Figure 4-4. RPI GFS Average Filter Run Pressure Drop

Additional graphs showing the influent and effluent turbidity, particle count, flow rate and change in pressure per individual filter run are attached as Appendix F.

Run #3 was interrupted by the failure of a turbidimeter. The flow was stopped until a replacement turbidimeter could be installed, or about 25 hours. The flow was then resumed with no change of the filter elements and the run continued until terminal headloss. Run's #17 and #18 received only new bag elements when headloss was exceeded. The cartridge element was left in place.

For each filter run which lasted longer than 24 hours, a stop/start sequence was initiated. Table 4-11 lists the time required by the RPI GFS Filter System to stabilize following a stop/start. The stabilization period was defined as the length of time required after the resumption of flow to the point when the effluent particle counter displayed values that were similar to those prior to the cessation of flow. Because the particle counter displayed a new reading every minute, stabilization periods (minutes) include an error factor of up to 1 minute.

Table 4-11. Stop/Start Stabilization Time (based upon effluent on-line particle count data)

Filter Run Number	Minutes To Reach Stability
1.1	6
1.2	11
1.3	14
1.4	12
1.5	14
2	8
3	12
4	12
5	8
6.1	8
6.2	16
7	8
8	8
10	10
11.1	10
11.2	12
13	10
15	6
20	7
21	6
22	6
Average	9.4
Minimum	6
Maximum	16
Standard Deviation	3
95% Confidence Int.	8, 11

Particle count graphs for each filter run stop/start sequence are attached in Appendix F.

4.3.4 Task 4 - Microbiological Contaminant Removal

Microbiological removal capabilities were assessed by challenging the filter system with polystyrene (latex) monospheres. Microsphere challenge testing was conducted between April 6 and April 11, 2000 in two sections, the first using regular, non-fluorescing latex microspheres, and the second, from April 16 through 20, 2000, using fluorescing latex microspheres.

4.3.4.1 Non-Fluorescing Microsphere Challenge Results

The test plan specified that challenges be made over three filter runs, with monosphere injections at the beginning of a run, at the approximate midpoint (as determined by headloss) and again at a point between 90% and terminal headloss. The middle run was also to be followed by a "stop/start" sequence, and while no additional monospheres were to be added then, samples would be collected or particle counts enumerated to observe any particle breakthrough as the result of the interruption and resumption of flow.

Monospheres in a quantity sufficient to demonstrate $3+\log_{10}$ removal were to be injected, and the influent and effluent particle count and distribution measured and recorded by particle counter.

Accordingly, monospheres in three sizes, 3.2 µm, 4.5 µm and 6 µm were mixed in the ratio of 50% 3.2 µm and 25% each of 4.5 µm and 6 µm to a level of approximately 10,000 total particles per milliliter. This mixture was injected over a period of ten minutes at the rate of 100 mL/min into the feed stream and the particle counter observed. The monospheres obtained for this challenge are listed in Table 4-12.

Table 4-12. Monosphere Manufacturer Specification

Size	Manufacturer	Lot	CV
3.2µm	Duke Scientific	21693	43%
4.5µm	Duke Scientific	21328	20.0%
5.832µm	Polysciences, Inc.	493498	SD: 0.273µm

The particle counter was unable to measure the additional particles. Repeated trials resulted in the same condition: the addition of 10,000 microspheres to water containing indigenous particles were counted by the particle counter as an addition of only 3,000 to 5,000 microspheres. It was also noticed that there was no strict proportionality to the additions. In the initial seeding sequence, the increase in particles was fairly evenly distributed proportionate to the added particles, and the effluent particles were much lower, as expected. Anticipated $\log_{10}$ removals could not be calculated, however, due to the particle counter and computer recording only those particles seen by the particle counters, thus undercounting the influent stream.

In continuing discussions with the particle counter manufacturer, particle manufacturers and with the writers of the cited paper (Li and Goodrich from Li et al.) it was concluded that coincidence errors were the probable cause of unreliable influent counts. It appears that the particle counter cannot easily identify spherical or nearly spherical particles when included with high concentrations of natural, irregularly shaped particles, and errors are also introduced when the counter is inundated with particles smaller than the counter's detection limit. Other researchers have encountered the same difficulties (Van Gelder).

A summary of the 3-7 µm particle counts in tabular form, showing the particle counts following the addition of 10,000 counts/mL as measured by the on-line particle counters for challenge run number 1 follows as Table 4-13.

Table 4-13. Average 3-7 µm Particle Counts Non-Fluorescing Microsphere Challenge Filter Event #1

Challenge	Particle Count Immediately Before Seeding (Counts/mL)	Particle Count Peak Seeding (Counts/mL)	Particle Count Immediately After Seeding (Counts/mL)
Influent Particle Counts			
No headloss	3,692.6	6,401.3	3,605.6
Midpoint	4,111.2	6,881.8	4,057.2
90%	3,600.6	6,804.0	3,531.9
Effluent Particle Counts			
No headloss	55.1	136.9	55.5
Midpoint	26.7	50.2	29.5
90%	18.1	35.1	19.3

Note: Particle count results are average of three on-line particle counter measurements approximately one minute apart.

It was observed in challenge Event #1 with non-fluorescent microspheres—and later—that the addition of 10,000 particles, prepared in a suspension as detailed above, increased total influent counts by only a small fraction, with about 25-30% of the added particles. The lower, effluent particle counts can be viewed with more confidence however. Calculating $\log_{10}$ removal of only the 10,000 added microspheres against the measured effluent minus the averaged pre-challenge and post-challenge background effluent counts suggests that removals of 2.1 logs, 2.7 logs and 2.8 logs were reached in this trial at the no headloss, midpoint and 90% headloss seeding events, respectively.

The second challenge produced the same ambiguous influent particle count data and following the zero headloss seeding, this second challenge was abandoned.

On April 11, 2000, an additional seeding challenge with non-fluorescent microspheres (Challenge #3) was performed at the prescribed intervals, and the results of this challenge were similar to the first, as shown in the following Table 4-14.

Table 4-14. Average 3-7 mm Particle Counts Non-Fluorescing Microsphere Challenge Filter Event #3

Challenge	Particle Count Immediately Before Seeding (Counts/mL)	Particle Count Peak Seeding (Counts/mL)	Particle Count Immediately After Seeding (Counts/mL)
Influent Particle Counts			
No headloss	4,077.1	6,852.4	4,091.8
Midpoint	4,458.8	6,966.2	4,509.1
90%	4,362.5	7,019.9	4,187.8
Effluent Particle Counts			
No headloss	55.7	191.2	58.3
Midpoint	19.0	28.2	22.2
90%	19.2	27.9	19.9

* Particle count results are average of three in-line particle counter measurements approximately one minute apart.

Following discussions with NSF, arrangements were then made to repeat the three series of challenges with fluorescent microspheres, to allow enumeration via microscopic count.

4.3.4.2 Fluorescent Microsphere Challenge Results

Fluorescent spheres of the requisite sizes were not available from a single manufacturer, thus fluorescent microspheres were obtained from three separate manufacturers, and in the sizes 3.4 µm, 5 µm and 6 µm. The microspheres were blended as above, with 50% at 3.4 µm and the remaining 50% divided equally between the other two sizes.

The number of particles in the concentrated suspension is inversely related to the cube of the diameter of the microspheres, and is calculated by the following formula:

$$n/mL = \frac{6W \times 10^{12}}{\rho \times \pi \times f^3}$$

Where n is the number of particles, W = the grams of polymer per milliliter of latex (which varies for each size and manufacturer, but which is noted on each container), ρ = density of

polymer (1.05 for polystyrene) and f = the diameter of particle in microns. For the three sizes of fluorescent particles these values were:

Diameter	Particles/mL
3.4 µm	4.63×10^8
5.0 µm	1.46×10^8
6.00 µm	2.23×10^8

The concentration of 3.4 µm particles were confirmed with the manufacturer's Certificate of Analysis (Appendix G).

The microsphere suspensions were blended in accordance with the test plan to contain twice as many 3.4 particles as the other two sizes via the following calculation:

At 10 gpm, over five minutes there are 1.89×10^5 milliliters, and at 10,000 particles per milliliter, 1.89×10^9 total are required in suspension. For the 5 minutes, 500 mL injection at 10,000 particles per mL, the proportions were:

3.4 µm particles 2 mL = 9.26×10^8
5.0 µm particles 3 mL = 4.35×10^8
6.0 µm particles 2 mL = 4.46×10^8
= 18.07×10^8 total particles = 1.8×10^9

As before, the suspension was introduced in front of a static mixer over a period of five minutes at the rate of 100 mL/min. The particle counts were observed and when the peak concentration was reached and stabilized, forming a plateau, samples were collected from both the influent and effluent sample streams. The effluent sample lagged the influent by about 2 minutes. Each sample was distributed into two aliquots, one for shipment to Huffman Environmental Consulting for examination and the other refrigerated as a back up.

4.3.4.3 On-line Particle Counter Analysis During Fluorescing Microsphere Challenge

Again, the on-line particle counters detected only a small fraction of the additional particles introduced into the influent stream, which is similar to the situation observed during the non-fluorescent microsphere challenge. The probable cause again was attributed to particle counter coincidence error. An example of the seedings for the total 3-7 µm influent particles as read by the particle counter during the challenge runs, is shown as Table 4-15. Figure 4-5 illustrates the curve as shown by the particle counter.

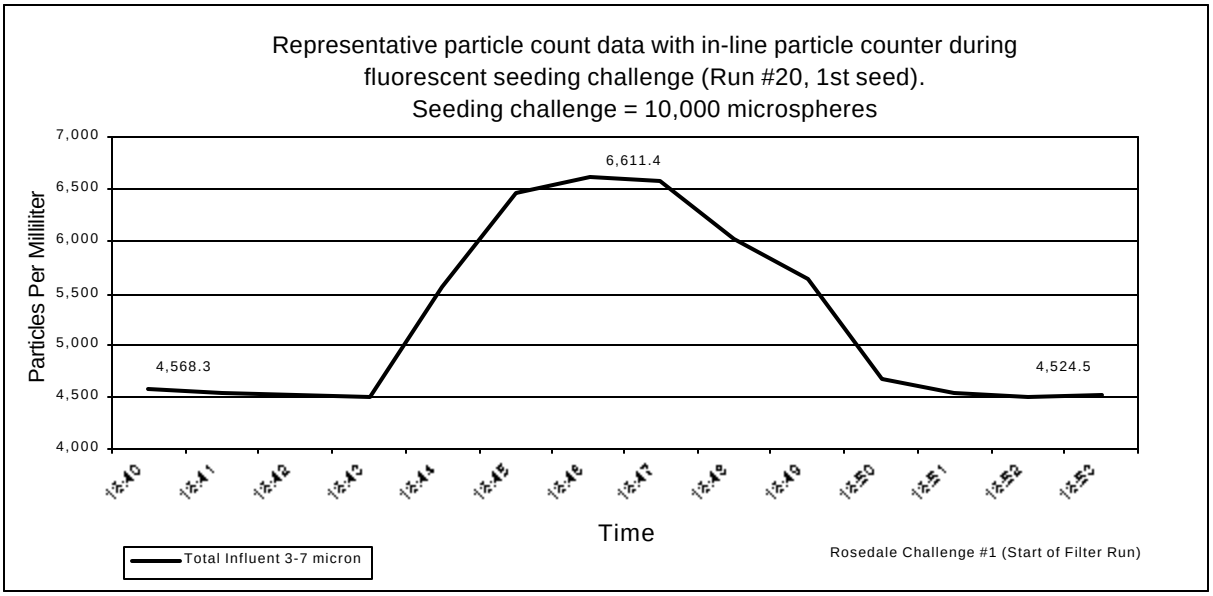


Figure 4-5. Representative Particle Count During Fluorescent Microsphere Seeding, Run #20, 1st Seed

Table 4-15. 3-7 µm Influent Particles During Fluorescent Microsphere Challenge (Filter Runs #20, 21 & 22)

Sample ID	Immediately Before Seeding (Counts/mL)	Peak Seeding (Counts/mL)	Immediately After Seeding (Counts/mL)
First Challenge Event			
No headloss	4,568.25	6,611.40	4,524.45
Midpoint	2,412.83	6,775.53	1,852.88
90% headloss	3,610.33	7,014.20	3,645.83
Second Challenge Event.			
No headloss	4,274.48	7,349.70	4,261.25
Midpoint	3,962.80	6,959.86	3,838.43
90% headloss	3,984.20	7,040.66	4,002.08
Third Challenge Event			
No headloss	4,459.91	7,362.15	4,455.30
Midpoint	5,018.20	7,667.60	4,814.53
90% headloss	4,577.68	7,093.10	4,621.75

Table 4-16 shows an abstraction of the 3-7 µm particle counts in the effluent as read by effluent particle counter during the challenge periods.

Table 4-16. 3-7 µm Effluent Particles During Fluorescent Microsphere Challenge (Filter Runs #20, 21 & 22)

Sample ID	Immediately Before Seeding (Counts/mL)	Peak Seeding (Counts/mL)	Immediately After Seeding (Counts/mL)
First Challenge Event			
No headloss	89.66	122.43	83.10
Midpoint	12.20	63.83	12.40
90% headloss	29.40	226.45	30.36
Second Challenge Event.			
No headloss	74.98	97.38	73.00
Midpoint	16.55	20.10	15.45
90% headloss	14.70	21.08	15.45
Third Challenge Event			
No headloss	42.48	75.88	42.73
Midpoint	12.88	16.38	13.08
90% headloss	13.90	19.58	14.15

On-line particle counters, although uncertain on the influent water stream during seedings, were valuable in confirming overall filter performance with effluent particle counts.

Figures 4-6, 4-7 and 4-8 present information on particle counts for each of the three fluorescent particle seeding runs, showing influent and effluent at 3-7 µm and at 2-7 µm. The data points were subjected to curve fitting via polynomial analysis to show the best fit. Note: arrows point to seeding events.

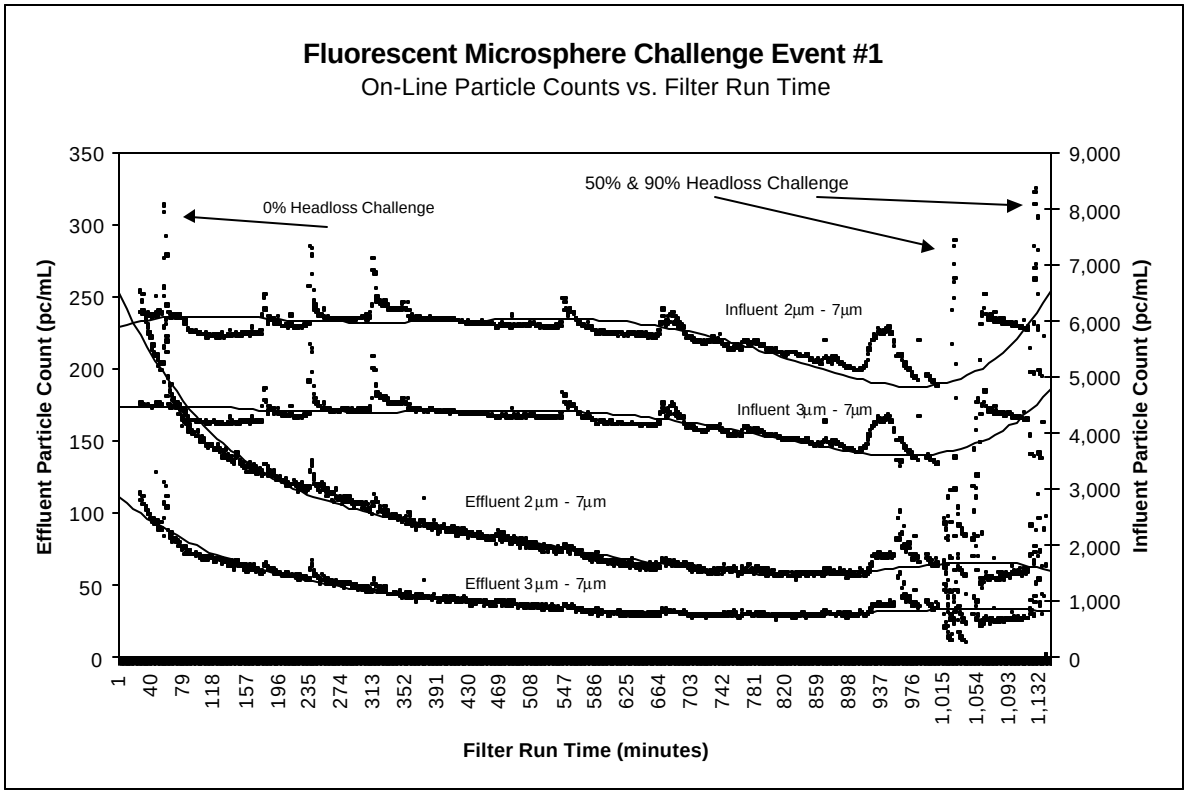


Figure 4-6. Fluorescent Microsphere Challenge Event #1 - On-Line Particle Count vs. Filter Run Time

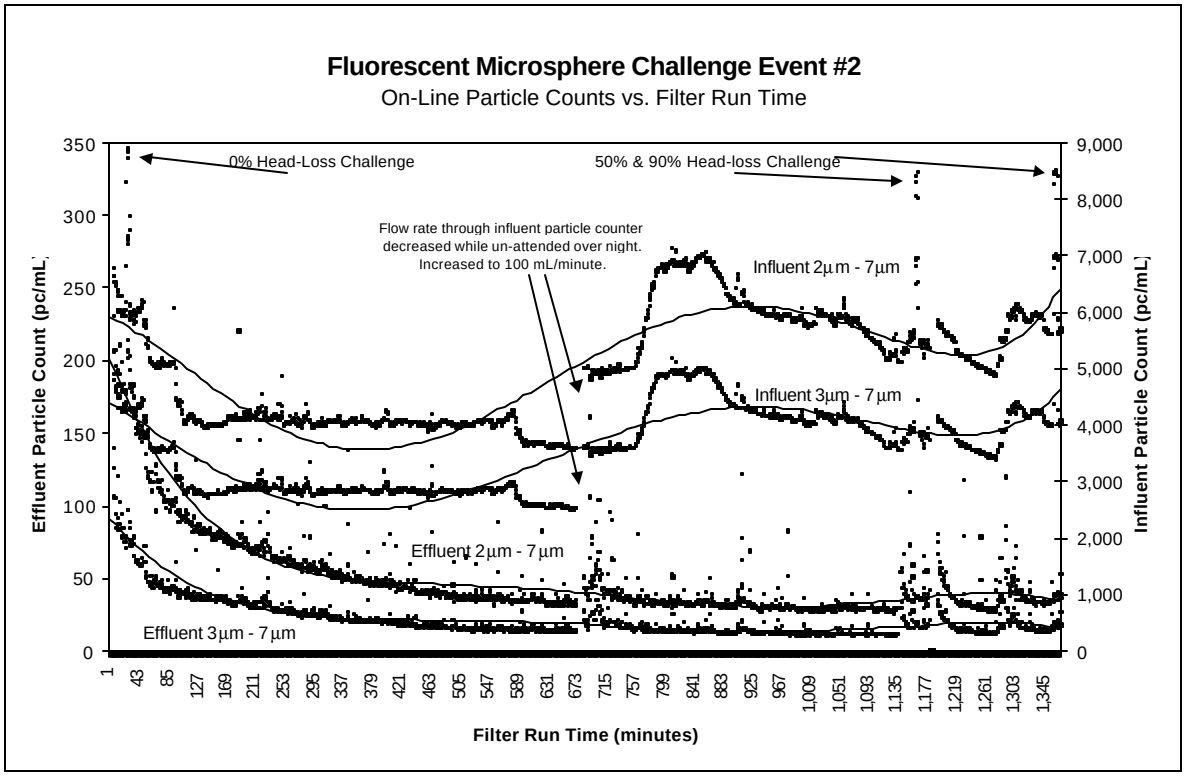


Figure 4-7. Fluorescent Microsphere Challenge Event #2 - On-Line Particle Count vs. Filter Run Time

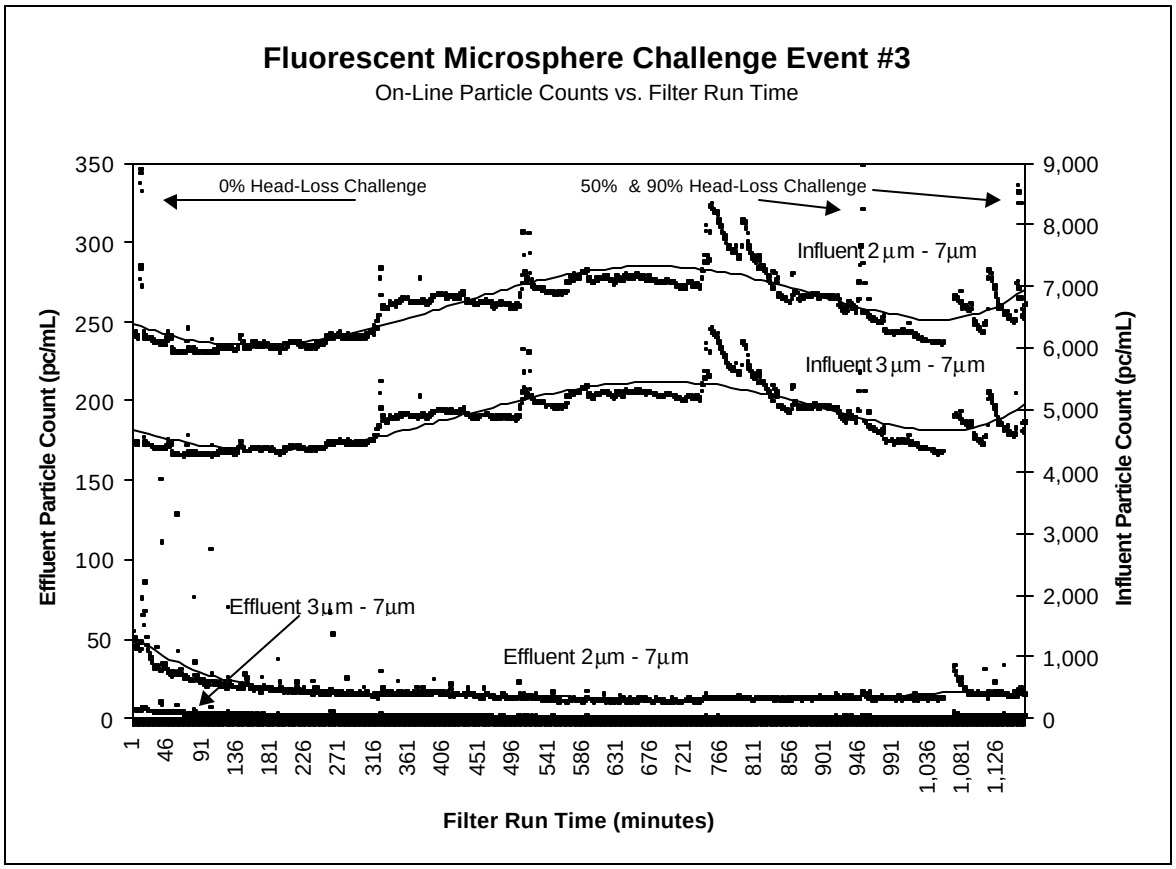


Figure 4-8. Fluorescent Microsphere Challenge Event #3 - On-Line Particle Count vs. Filter Run Time

4.3.4.4 Microscopic Analysis

The samples shipped to Huffman Environmental Consulting were examined microscopically and the fluorescent spheres were counted using hemacytometer techniques and/or membrane filtration as appropriate. The results of those analyses are tabulated below. The hemacytometer was used when the samples contained high numbers of particles (influent samples); when the counts were low (effluent samples) the particles were counted microscopically after filtration through a membrane. Hemacytometer and membrane filtration counting was performed as outlined in EPA Method 1622, Section 11.3, EPA Method 1623, Section 11.0, and *SM* 10200F, however by amending the procedure as appropriate to recognize the employment of synthetic, fluorescing microspheres and not dyed/fluorescing oocysts. Tables 4-17 and 4-18 summarize the results of the microscopic analyses for the influent and effluent samples, respectively. Based on the microscopic analyses results presented in Tables 4-17 and 4-18, removal calculations are provided in Table 4-19.

Table 4-17. Influent Microscopic Analysis Results Of Fluorescent Challenge Events

Sample ID	Enumeration Method	Raw Count (Mean±S.D)	Volume Filtered	Raw Count/hem. (Mean±S.D)	Count/mL
First Challenge Event					
No headloss	Hemacytometer			1, 1, 2, 1 (1.2±0.5)	0.3×10^4
Midpoint	Hemacytometer			11,4,6,8 (7.2±3)	1.8×10^4
Stop/Start ♦	Membrane filter	70	120 mL		0.6
90% headloss	Hemacytometer			4, 3, 4, 4 (3.8±0.5)	1.0×10^4
Second Challenge Event					
No headloss	Hemacytometer			2,7,3,3 (4.0±2.0)	1.0×10^4
Midpoint	Hemacytometer			3,3,3,2 (3±0.5)	0.8×10^4
Stop/Start	Membrane filter	66,60 (63±4.0)	20 mL		3.2
90% headloss	Hemacytometer			4,2,5,3 (3.5±1.0)	0.9×10^4
Third Challenge Event					
No headloss	Hemacytometer			4,4,4,2 (3.5±1.0)	0.8×10^4
Midpoint	Hemacytometer			2,2,5,5 (3.5±2.0)	0.8×10^4
Stop/Start	Membrane filter	100,74 (87±18)	10 mL		8.7
90% headloss	Hemacytometer			2,1,1,3 (2.0±1.0)	0.5×10^4

♦ Entire grab sample was filtered

Table 4-18. Effluent Microscopic Analysis Results of Fluorescent Challenge Events

Sample ID	Enumeration Method	Membrane Volume filtered	Raw Count (Mean±S.D)	Count/mL
First Challenge				
No headloss	Membrane	1.0 mL	238, 220 (229±13)	2.3×10^2/mL
Midpoint	Membrane	1.0 mL	157,152 (154±3.5)	1.5×10^2/mL
Stop/Start	Membrane	1.0 mL	30, 28 (29±1.4)	2.9×10^1/mL
90% headloss	Membrane	1.0 mL	168, 122 (145±32)	1.5×10^2/mL
Second Challenge.				
No headloss	Membrane	1.0 mL	300,290 (295±7)	3.0×10^2/mL
Midpoint	Membrane	1.0 mL	56,76 (66±14)	6.6×10^1/mL
Stop/Start	Membrane	50.0 mL	149,150 (149±1)	3.0/mL
90% headloss	Membrane	1.0 mL	115, 127 (121±8)	1.2×10^2/mL
Third Challenge				
No headloss	Membrane	1.0 mL	265, 200 (232±46)	2.3×10^2/mL
Midpoint	Membrane	1.0 mL	158, 110 (134±34)	1.3×10^2/mL
Stop/Start	Membrane	50.0 mL	65, 58 (61±5.0)	6.1×10^1/mL
90% headloss	Membrane	1.0 mL	115, 136 (125±15)	1.3×10^2/mL

Table 4-19. Microscopic Analysis Calculation of Percent Removal, Fluorescent Challenge Events

Sample ID	Influent count/mL	Effluent counts/mL	Percent Removal	Log_{10} Removal
First Challenge				
No headloss	0.3×10^4	2.3×10^2	92.3 %	1.1
Midpoint	1.8×10^4	1.5×10^2	99.2 %	2.1
90% headloss	1.0×10^4	1.5×10^2	98.5 %	1.8
Second Challenge.				
No headloss	1.0×10^4	3.0×10^2/mL	97.0 %	1.5
Midpoint	0.8×10^4	6.6×10^1/mL	91.8 %	2.1
90% headloss	0.9×10^4	1.2×10^2/mL	98.7 %	1.9
Third Challenge				
No headloss	0.8×10^4	2.3×10^2/mL	97.1 %	1.5
Midpoint	0.8×10^4	1.3×10^2/mL	98.4 %	1.8
90% headloss	0.5×10^4	1.3×10^2/mL	97.4 %	1.6

NA = Not Applicable as effluent values were greater than influent values.

The microscopic analyses of the samples clearly indicate the seeded microspheres did in fact enter the water and flow into the filters where the majority was captured. This examination included analysis of florescent microspheres exclusively and did not count particles indigenous to the source water, although, the samples were characterized by the examiner as being very "muddy".

The microscopic examination also revealed a significant number of fluorescing microspheres smaller than those suggested by the sizes seeded. It was suspected that some of these were calcite particles formed by the lime softening process, and much smaller than the 3 µm threshold. This may indeed be the case for some of the particles, however, following the microscopic examination under UV light, it was concluded that only fluorescing microspheres were measured in Huffman Environmental Consultings' examination and included in the results above although many were below 3 µm in diameter.

Discussions with the particle manufacturer, Bangs Laboratories, and further analysis of the batch by Bangs with a Particle Sizing Systems, Inc., Model 770 AccuSizer, revealed that the true particle median size was not 3.4 µm as specified, but was actually 2.98 µm with a standard deviation of 0.66 µm or 21.2%. The histographic spectrum showed 50% were below 2.98 µm and 90% of the particles were below the stated diameter of 3.45 µm.

Table 4-20 is the size analysis as provided by Bangs Laboratories on the Lot in question (#2200) showing the distribution of the particles and the true standard deviation. The particles tail off below 2.5 µm, peak to the median at 2.98 µm, and again tail off above 5.5 µm. Eighty percent of the particles in this batch lie between 2.66 µm and 3.45 µm. The FTO also obtained standard deviation data from the two other microsphere suppliers. Those particles had much narrower size distribution curves. The 5 µm particles from Duke Scientific (G0500) had a measured mean diameter of 5.1 µm and a coefficient of variation (CV) of < 5%, and the 6 µm particles from Polysciences, a measured number average of 5.8950 µm with a standard deviation of 0.3750 µm and a CV of 6.4%. The contribution of these batches outside the area of interest was negligible.

For the 3.4 µm Bangs lot 2200 however, the contribution below 3 µm is significant and is shown in Table 4-20 and in the accompanying histogram.

Table 4-20. Summary of Number Weight Cumulative Distribution by Histogram

% Of Particles	Micron Size
5% of total particle number <	2.56 microns
10% of total particle number <	2.66 microns
15% of total particle number <	2.73 microns
20% of total particle number <	2.77microns
25% of total particle number <	2.82 microns
30% of total particle number <	2.85 microns
35% of total particle number <	2.89 microns
40% of total particle number <	2.92 microns
45% of total particle number <	2.95 microns
50% of total particle number <	2.98 microns
55% of total particle number <	3.01 microns
60% of total particle number <	3.04 microns
65% of total particle number <	3.08 microns
70% of total particle number <	3.11 microns
75% of total particle number <	3.15 microns
80% of total particle number <	3.20 microns
85% of total particle number <	3.28 microns
90% of total particle number <	3.45 microns
95% of total particle number <	4.64 microns
99% of total particle number <	5.55 microns

Figure 4-9 shows the histogram provided by Bangs Laboratories, Inc. It has been scaled to show the particles found in the 2 to 5.47 µm size range. This historgram displays the distribution of the 3.4 um particles supplied by Bangs Laboratories. The particle counter employed was an Accusizer 770. The sample size was 60 ml with a dilution factor of 1.33.

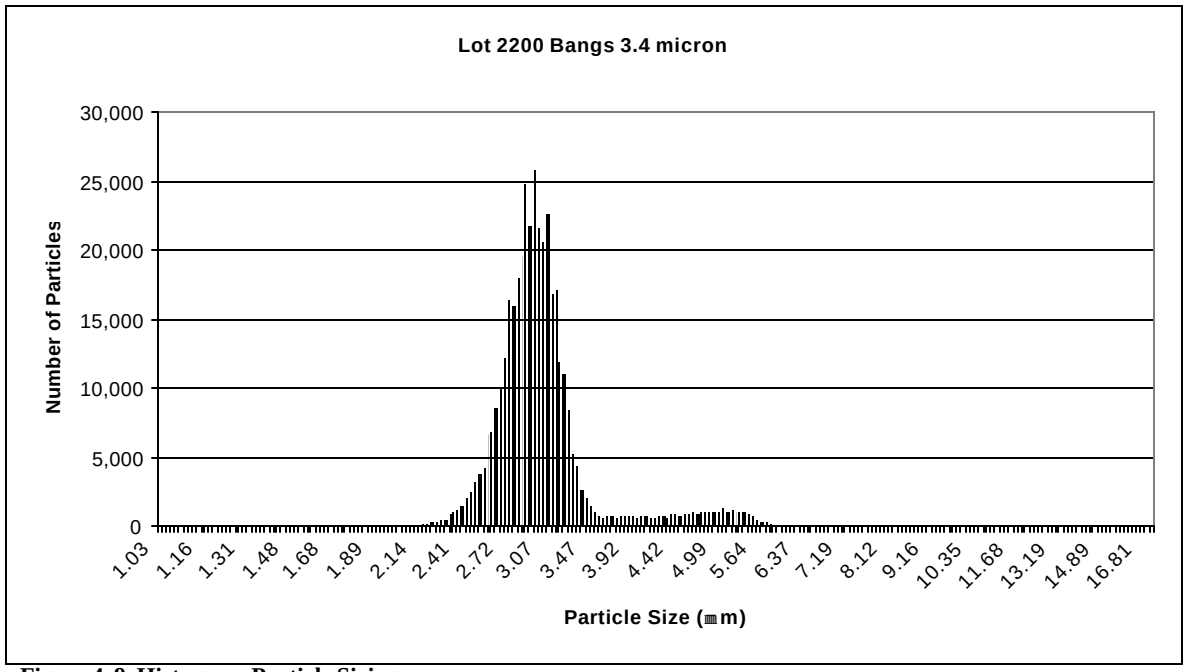


Figure 4-9. Histogram Particle Sizing
Note: COA discussed the discrepancy with Bangs Laboratories and NSF. From these discussions, it was decided to reevaluate the fluorescent challenges using the backup set of samples by laboratory optical particle analysis.

The 3.4 µm fluorescent microspheres were not distributed around 3.4 µm as the laboratory reported. For the 3.4 µm Bangs lot 2200, the contribution below 3 µm skews the curve downward and produces a median diameter of 2.98 µm. Using the diameter of 2.9 µm in place of 3.4 µm, the particles per mL in the concentrated suspension were recalculated as follows:

Diameter	Particles/mL
2.98 µm	6.87×10^8
5.0 µm	1.37×10^8
6.00 µm	2.35×10^8

The size distributions of the two other microsphere lots were much narrower. The 5 µm particles from Duke Scientific (G0500) had a measured mean diameter of 5.1 µm and a coefficient of variation (CV) of < 5%, and the 6µm particles from Polysciences, a measured number average of 5.8950 µm with a standard deviation of 0.3750 µm and a CV of 6.4%. The contribution of these batches outside the area of interest was negligible, and while the contribution of the 6 µm particles was larger than previously calculated it was partially offset by the reduced contribution of the 5 µm particles.

If the particle distribution is recalculated, using the 2 mL volume of concentrated suspension, but at the higher contribution from the Lot 2200 particles, the suspension had a different profile, as follows:

$$2\text{ mL} \quad 2.98 \text{ particles} = 1.34 \times 10^9 = 13.4 \times 10^8$$
$$3\text{ mL} \quad 5.1 \text{ particles} = 4.11 \times 10^8$$
$$2\text{mL} \quad 6.0 \text{ particles} = 4.70 \times 10^8$$
$$= 22.2 \times 10^8 = 2.22 \times 10^9$$

Thus, the actual suspension seeded contained approximately 11,746 particles/mL as measured by pipette, with 4,661 of those as a contribution from the 5 µm and 6 µm particles.

The three fluorescent microsphere seeding challenges were recalculated in the following manner. The influent was established by adding 11,746 to the average of the pre-and post-seeding background particle counts. These calculated influent counts were confirmed with corresponding Accusizer influent particle counts (as discussed in Section 4.3.4.5). The effluent particle count values were the particle counts as determined by the on-line particle counts measured during the seeding plateau. Counts were compared within the range of 2 µm to 7 µm rather than 3 µm to 7 µm to account for microspheres $\geq$2.5 µm and $\leq$ 3.0 µm. Table 4-21 summarizes the on-line particle count values before adding the 11,746 particles/mL that were seeded as fluorescent microspheres and the corresponding $\log_{10}$ reductions (see Appendix H).

Table 4-21 On-line Particle Counts and Added Microsphere Log_{10} Reductions (2.0 -7.0 µm)

Seeding	On-line Particle Counts Pre/Post Seeding[1] (counts/ml)	Influent On-line Particle Counts Plus Microspheres[2] (counts/mL)	Effluent On-line Particle Counts[3] (counts/mL)	Reduction ($\log_{10}$)
First Verification Challenge Run1				
No headloss	6,125	17,871	228	1.9
Midpoint	2,279	14,025	76	2.3
90% headloss	5,418	17,164	169	2.0
Second Verification Challenge Run				
No headloss	5,974	17,720	204	1.9
Midpoint	5,471	17,217	38	2.7
90% headloss	5,648	17,394	40	2.6
Third Verification Challenge Run.				
No headloss	6,188	17,934	163	2.0
Midpoint	6,662	18,408	35	2.7
90% headloss	6,536	18,282	40	2.7

[1]Influent counts from on-line particle counter represent the average of approximately 20 data points recorded every 60 seconds. Data points included in this average generally represent 10 data points prior to and after the seeding event.
[2]Sum of on-line particle counts pre/post seeding and added fluorescent microspheres (11,746 particles/ml).
[3]Effluent on-line particle counts represent the average of 3 data points recorded on plateau of elevated counts during microsphere seeding.

The analysis of adding the number of seeded microspheres to the particle count results suggests the RPI bag and cartridge filter system demonstrated 1.9 to 2.7 $\log_{10}$ reductions of microspheres and indigenous particles sized 2.0 µm to 7.0 µm during the fluorescent microsphere challenge events.

Also of significance is the comprehensive display of each of these runs, showing numerical reductions on both sides of the seedings. Figures 4-10 through Figure 4-12 are illustrations for each of the last three runs, which included fluorescent particle seeding, showing influent, and effluent at 2-7 µm and at 3-7 µm. Note: the data points were curve fitted using a polynomial curve fitting program.

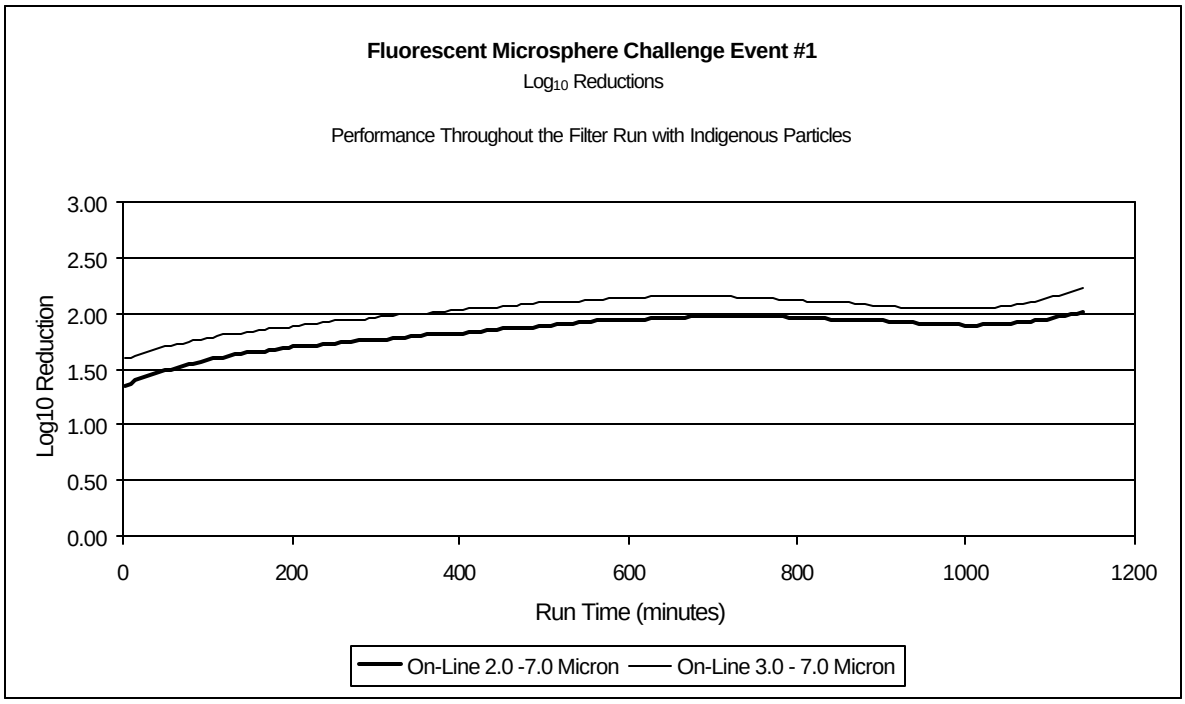


Figure 4-10. Fluorescent Microsphere Challenge Event #1 – Log_{10} Reductions Performance Throughout the Filter Run with Indigenous Particles

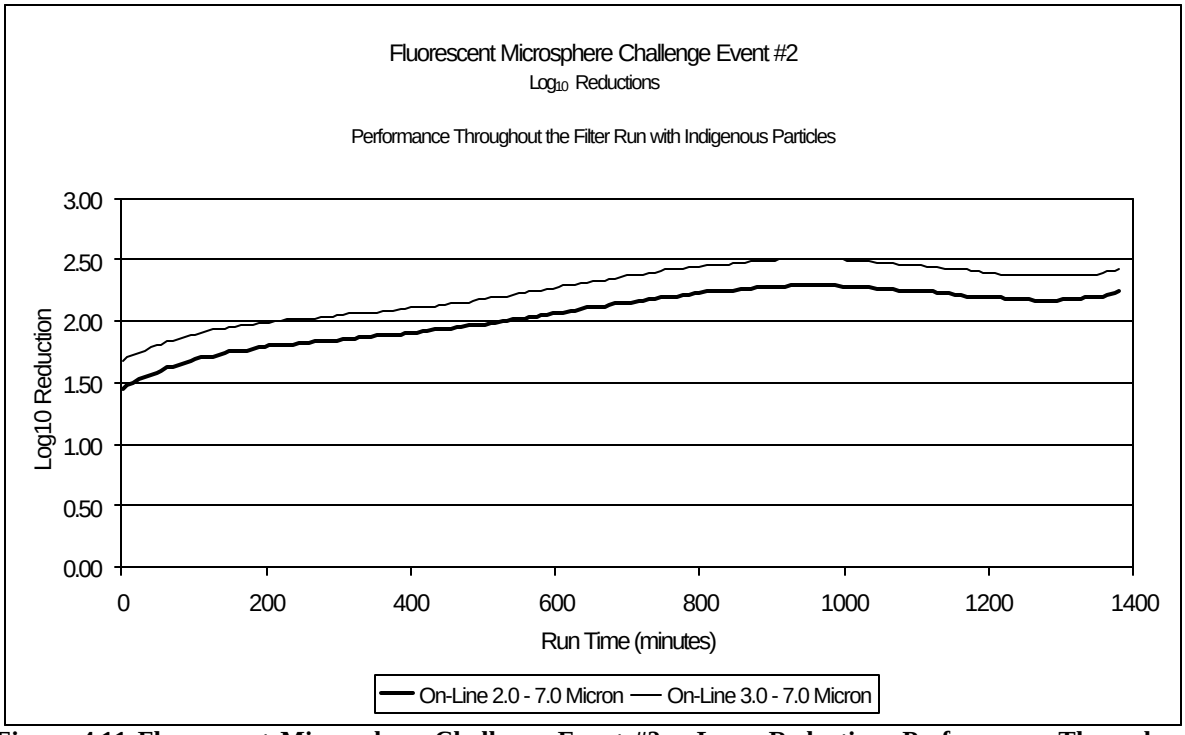


Figure 4-11 Fluorescent Microsphere Challenge Event #2 – Log_{10} Reductions Performance Throughout the Filter Run with Indigenous Particles

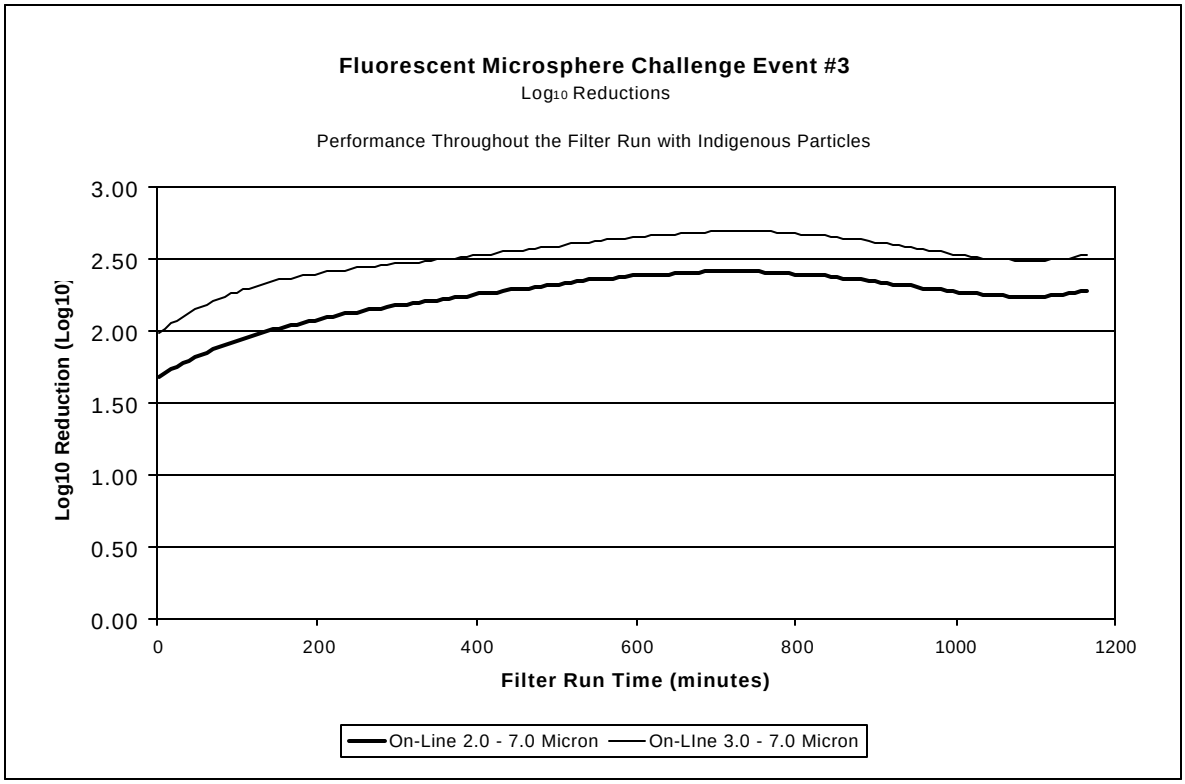


Figure 4-12 Fluorescent Microsphere Challenge Event #3 – Log_{10} Reductions Performance Throughout the Filter Run with Indigenous Particles

4.3.4.5 Laboratory Optical Particle Analysis

The instrument employed for this evaluation was a laboratory optical particle counter, an Accusizer, often used in the evaluation of materials for the pharmaceutical industry. The Accusizer has a broad range of both count and sizing accuracy as noted by its application to the determination of particle sizing for particulate matter in the preparation of injectibles such as vaccines and serums, United States Pharmacopeia (USP) Reference Standard 788. It is capable of sizing particles from 0.5 µm to 400 µm in as many as 512 individual bins. QA/QC procedures for this instrument and employed in this analysis were in accordance with USP Reference Standard 788 and ASTM 658.

The second set of samples, collected as a back-up for the microscopic analyses described above, were forwarded to Micro Measurement Laboratories (MML) where they were analyzed by the Accusizer in accordance with USP Reference Standard 788 and ASTM 658. Because the analyses originally planned for these samples were for fluorescing microspheres exclusively, sample contamination from non-fluorescing, natural particles introduced from the environment or the sample container itself was considered of no consequence. No efforts had been undertaken to establish a clean room environment on site nor was there a concern for particle free sample bottles. It should be noted that the Accusizer counted indigenous particles in the sample as well as fluorescent microspheres.

As a control, two empty sample collection containers were forwarded to MML to measure the level of possible sample contamination. Analysis of the control sample container demonstrated a suspected level of contamination (approximately 315 particles/mL). While this represents a very small fraction of the total particles measured within the influent samples, they do represent a very large fraction of total particles measured within the effluent samples. Control samples for the Accusizer evaluations are discussed below in Section 4.5.7.

Accordingly, $\log_{10}$ reductions calculated with the use of the effluent data, as analyzed with the Accusizer are not included within this report. However, influent particle count data as provided from these analyses were helpful in validating influent particle/microsphere concentrations used to calculate $\log_{10}$ reductions of particles/microspheres sized between 2µm and 7µm (see Appendix H).

4.3.4.6 Discussion of Results of Fluorescent Microsphere Challenges

The data from on-line particle counters became uncertain at a concentration above approximately 10-12,000 particles per milliliter, regardless of the particle size. It appears that when inundated with smaller particles, even if beneath the threshold of the instrument, the counters reached coincidence error. Since the influent count was uncertain—and well below the calculated level—the $\log_{10}$ reduction observed through the filters was lower than expected.

The microscopic analysis was accurate, however, because the fluorescent microspheres were significantly smaller than expected, and because the microscopic enumeration counted only particles that fluoresced, those counts included a high number of particles beneath the level of interest. The influent counts were determined by hemacytometer because of the high

concentration of microspheres, while the effluent counts were determined by filtration through membrane and microscopic count. These counts were statistically extrapolated to establish concentration per milliliter.

The Accusizer, as a laboratory instrument subject to rigorous calibration and quality control, was better able than the on-line particle counters to size the particles in the samples, however the data represent a single momentary sample in each case. Again, unlike the microscopic analysis, which was performed visually for only fluorescent particles, the Accusizer counted *all* of the particles in the sample, not just those fluorescent microspheres that were added during the challenge seedings. Hence, the counts from the Accusizer included both natural particles and the fluorescent microspheres with no ability to distinguish between them. Moreover, because backup samples originally secured for microscopic analysis of florescent microspheres were used, sample contamination from non-fluorescing, natural particles introduced from the environment or the sample container itself, originally offering no consequence, may have influenced the results of the AccuSizer analyses. While the suspected level of sample contamination (315 particles/mL) represents a very small fraction of the total particles measured within the influent samples, they do represent a very large fraction of total particles measured within the effluent samples. Because $\log_{10}$ reductions calculated with the use of these data would be misleading, they have not been included within this report. However, Accusizer data representative of influent particle/microsphere concentrations were used to validate calculated influent particle/microsphere concentrations used to calculate $\log_{10}$ reductions of particles/microspheres sized between 2µm and 7µm (see Appendix H).

Direct comparisons of the data must be exercised with caution to avoid misleading interpretations. At the same time however, the availability of two sets of data representing the same test offers an opportunity unique to the testing of bag and cartridge filters (refer to Tables 4-22 and 4-23). Note the on-line particle counter counted particles, both natural and fluorescent, in the range of 2.0-7.0 µm. Further, the microscopic analysis only accounts for the fluorescing particles, thus the total counts cannot be expected to be comparable. However, the reductions, when expressed as a logarithm are comparable. Table 2-22 provides a summary of the microscopic enumeration log reductions and a summary of the on-line particle counter plus the addition of the seeded microspheres log reductions are presented in Table 4-23.

Table 4-22. Microscopic Microsphere Counts and $\log_{10}$ Reductions (2.5 -7.0 µm)

Seeding	Influent Microscopic (counts/mL)	Effluent Microscopic (counts/mL)	Reduction ($\log_{10}$)
First Verification Challenge Run1			
No headloss	3,000	230	1.1
Midpoint	18,000	150	2.1
90% headloss	10,000	150	1.8
Second Verification Challenge Run.			
No headloss	10,000	300	1.5
Midpoint	8,000	66	2.1
90% headloss	9,000	120	1.9
Third Verification Challenge Run.			
No headloss	8,000	230	1.5
Midpoint	8,000	130	1.8
90% headloss	5,000	130	1.6

Table 4-23 On-line Particle Counts Plus Microspheres Log_{10} Reductions (2.0 -7.0 mm)

Seeding	Influent On-line + Microspheres (counts/mL)	Effluent On-line (counts/mL)	Reduction (log_{10})
First Verification Challenge Run1			
No headloss	17,871	228	1.9
Midpoint	14,025	76	2.3
90% headloss	17,164	169	2.0
Second Verification Challenge Run.			
No headloss	17,720	204	1.9
Midpoint	17,217	38	2.7
90% headloss	17,394	40	2.6
Third Verification Challenge Run.			
No headloss	17,934	163	2.0
Midpoint	18,408	35	2.7
90% headloss	18,282	40	2.7

* Based on calculations described in section 4.3.4.4

Log_{10} reductions calculated from data secured during fluorescent microsphere challenges were expected to be higher than what is demonstrated between challenges with much lower influent counts of particles indigenous to the source water. During each challenge microsphere counts of the size of interest were sufficient to allow effluent counts high enough to not be significantly affected by limitations of counting instrumentation and analyses while supporting the log_{10} reductions expected. Figures 4-13, 4-14, and 4-15 provide a comparison of log_{10} reductions from the various analyses and the log_{10} reductions, between the ranges of 2-7 µm and 3-7 µm, achieved throughout each filter run which challenges were conducted. In review of these figures it can be noted that log_{10} results generated from microscopic data from seeding challenges (Figure 4-23) typically demonstrate lower reductions than reductions calculated from on-line particle counter data secured between challenges with lower influent counts. Conversely, analyses of on-line particle count data (Figure 4-24) demonstrated significantly higher log_{10} reduction values.

In summary, the RPI bag and cartridge system demonstrated 1.1 to 2.1 log_{10} removal of seeded microspheres (2.5-7.0 µm) based on the microscopic enumeration results, and 1.9 to 2.7 log_{10} removal of microspheres and indigenous particles sized 2.0 to 7.0 µm based on normalized on-line particle counter data.

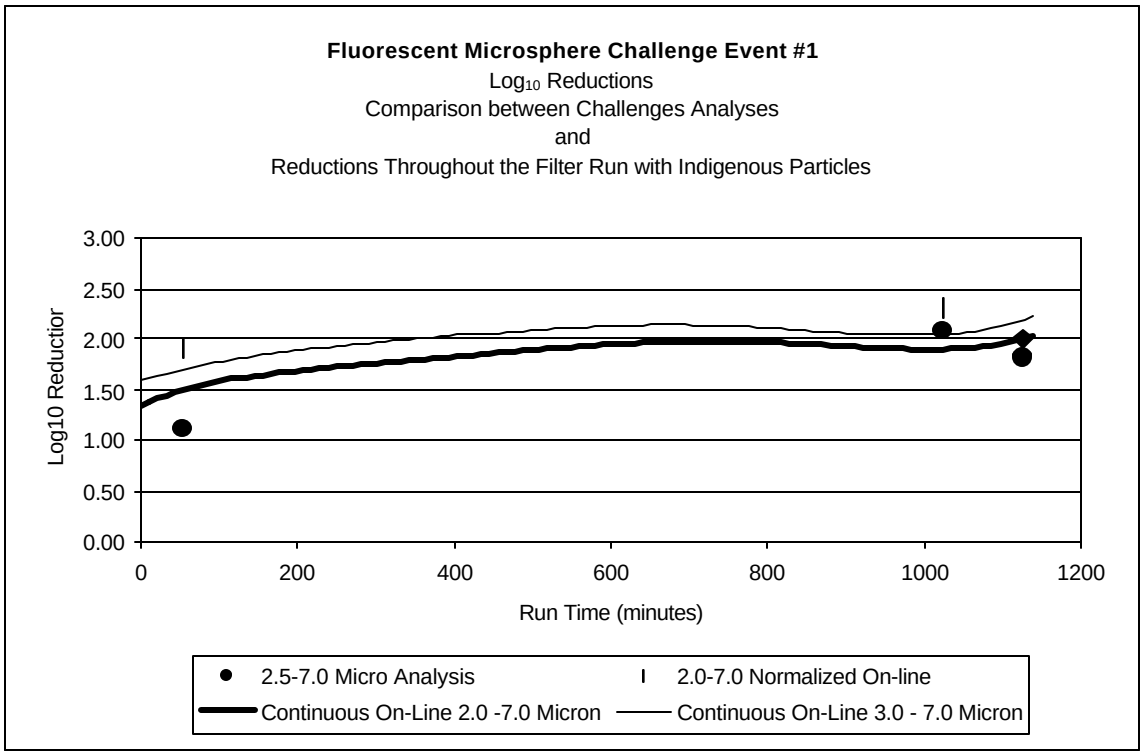


Figure 4-13. Fluorescent Microsphere Challenge Event #1 – Log_{10} Reductions Comparison between Challenges Analysis and Reductions Throughout the Filter Run with Indigenous Particles

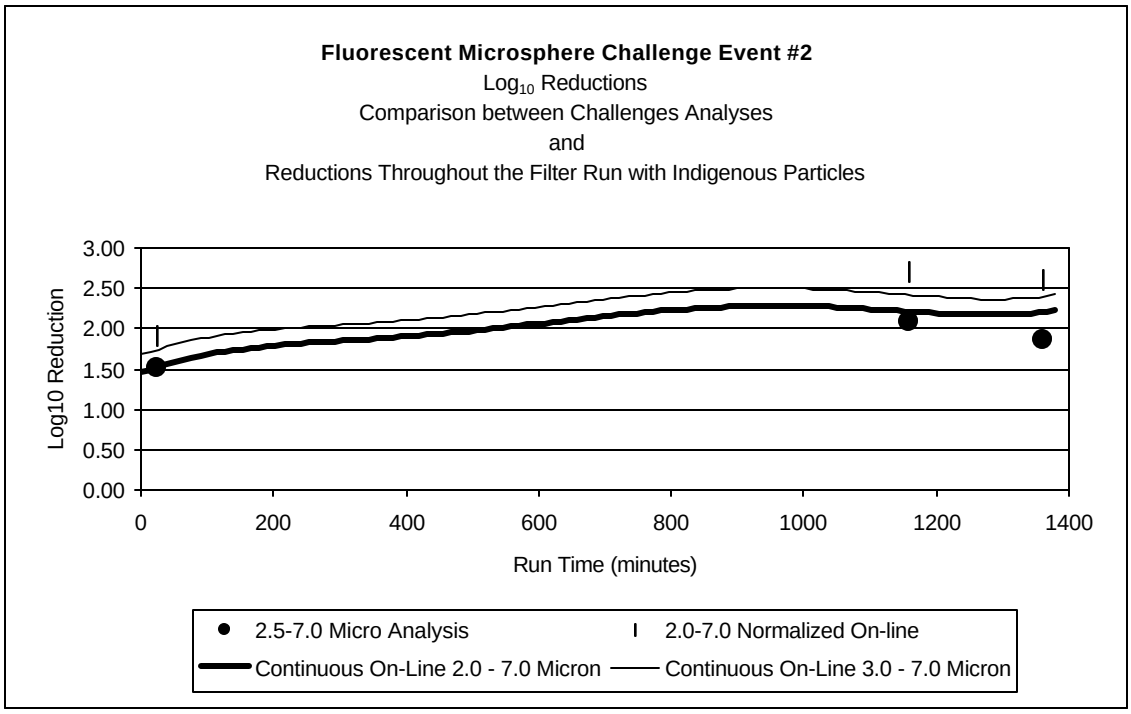


Figure 4-14. Fluorescent Microsphere Challenge Event #2 – Log_{10} Reductions Comparison between Challenges Analysis and Reductions Throughout the Filter Run with Indigenous Particles

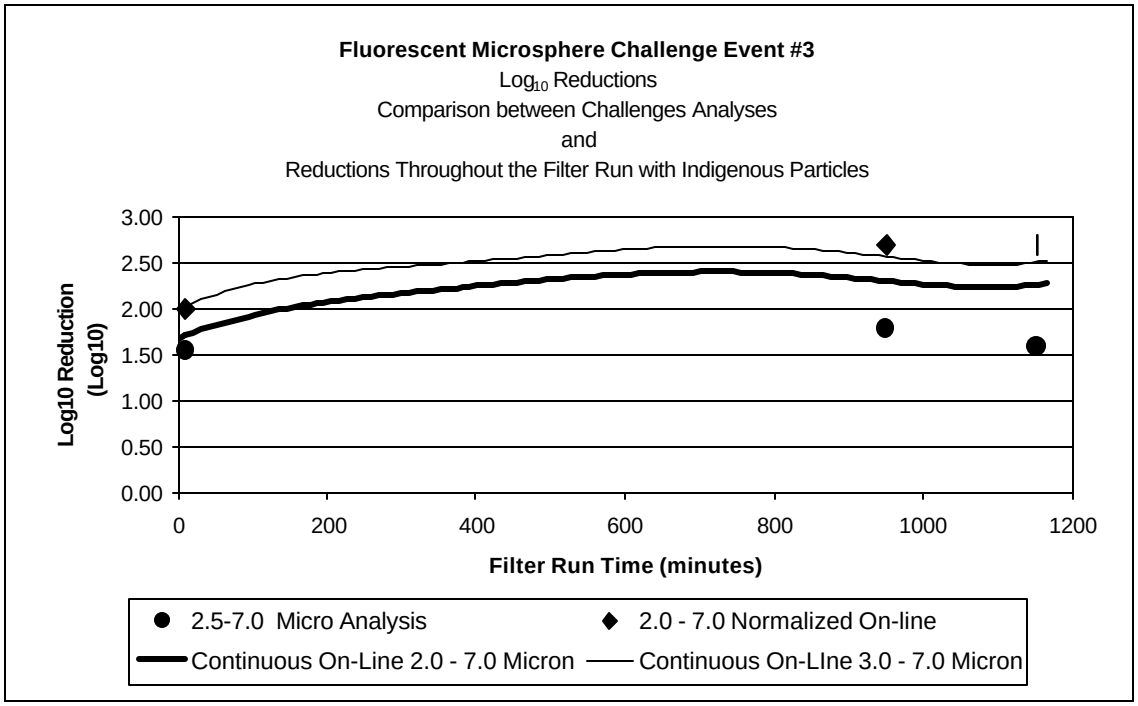


Figure 4-15. Fluorescent Microsphere Challenge Event #3 – Log_{10} Reductions Comparison between Challenges Analysis and Reductions Throughout the Filter Run with Indigenous Particles

4.3.4.7 Stop/Start Event Evaluation

Stop/Start data generated during filter runs was evaluated by analyzing the microscopic data provided by Huffman Environmental Consulting in addition to the discussion on stabilization time as discussed in Section 4.2.3, Task 3.

Assuming that microspheres did not break through or slough off the filter media during steady state operation between challenge events, filter removal efficiencies with one stop/start event were evaluated given results of the microscopic analyses presented in Tables 4-17 and 4-18. The microsphere concentrations from influent and effluent samples were compared to evaluate filter efficiency. Results are provided below in Tables 4-24 and 4-25.

Table 4-24.Calculation of Filter Efficiency With 1st and 2nd Seeding Events and One Stop/Start Event

Sample ID	Influent No headloss + Midpoint seedings (count/mL)	Effluent No headloss + Midpoint seedings + stop/start (count/mL)	Percent Removal (%)	Log_{10} Removal
First Challenge Stop/Start	21,000	309	98.5	1.83
Second Challenge Stop/Start	18,000	369	98.0	1.69
Third Challenge Stop/Start	16,087	421	97.4	1.58

Table 4-25. Calculation of Filter Efficiency With 2nd Seeding Event and one Stop/Start Event

Sample ID	Influent No headloss + Midpoint seedings (count/mL)	Effluent No headloss + Midpoint seedings + stop/start (count/mL)	Percent Removal (%)	Log_{10} Removal
First Challenge Stop/Start	18,000	179	99.0	2.00
Second Challenge Stop/Start	8,000	69	99.1	2.06
Third Challenge Stop/Start	8,000	191	97.6	1.62

The purpose of a cessation and resumption of flow is also designed to indicate the duration of time in which previously captured particles are released if flow is interrupted then resumed. The analysis of a single sample is then of less interest than the determination of a peak following a stop, and the duration of the peak. From that view, the actual number of particles is of less interest than an approximation of the size distribution, and the length of time until the filter is back to normal performance. For these evaluations, the in-line particle counter data, along with sizing data from the Accusizer, and both confirmed by the microscopic data is of some interest. The duration of the peak following interruption is short, two to three minutes; and the loss in performance is, as would be expected, greater with the smaller particles. However, reductions shown as log_{10} removal are relatively small in the range of interest, at approximately 0.5 log_{10}.

The following graphs (Figures 4-16 through 4-18) illustrate the particle breakthrough against time in the range of 3 µm to 7 µm and the duration of breakthrough. The duration of the spike is approximately 3 to 4 minutes. The length depends some on the point in the sensor cycle that the particle count resumes, but it is clearly a brief jump whereupon the filter stabilizes and returns to the prior levels.

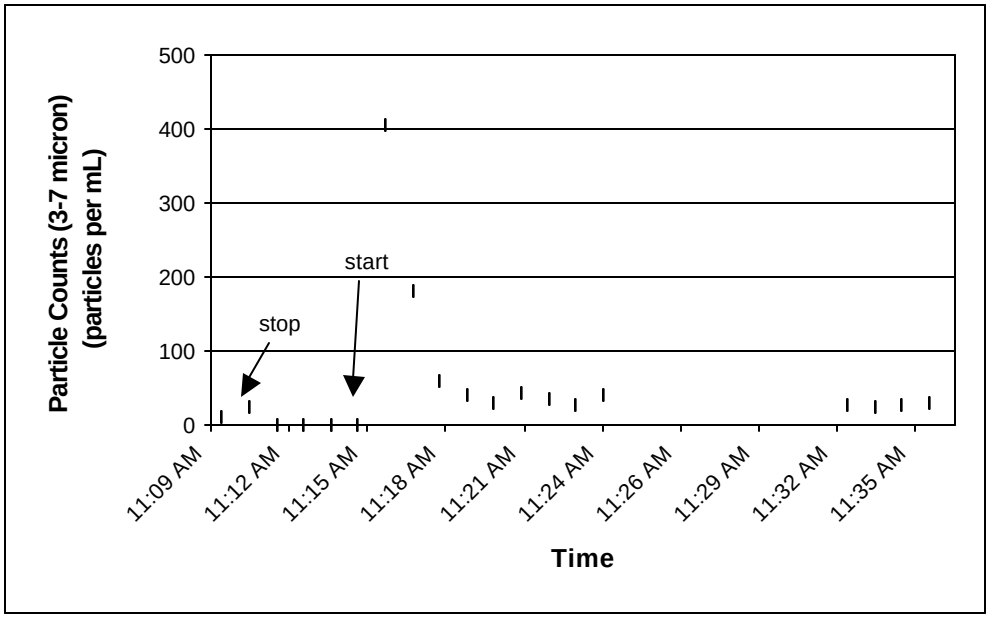


Figure 4-16. Rosedale Filter Run #20 Effluent 3-7 mm Particle Count Stop/Start

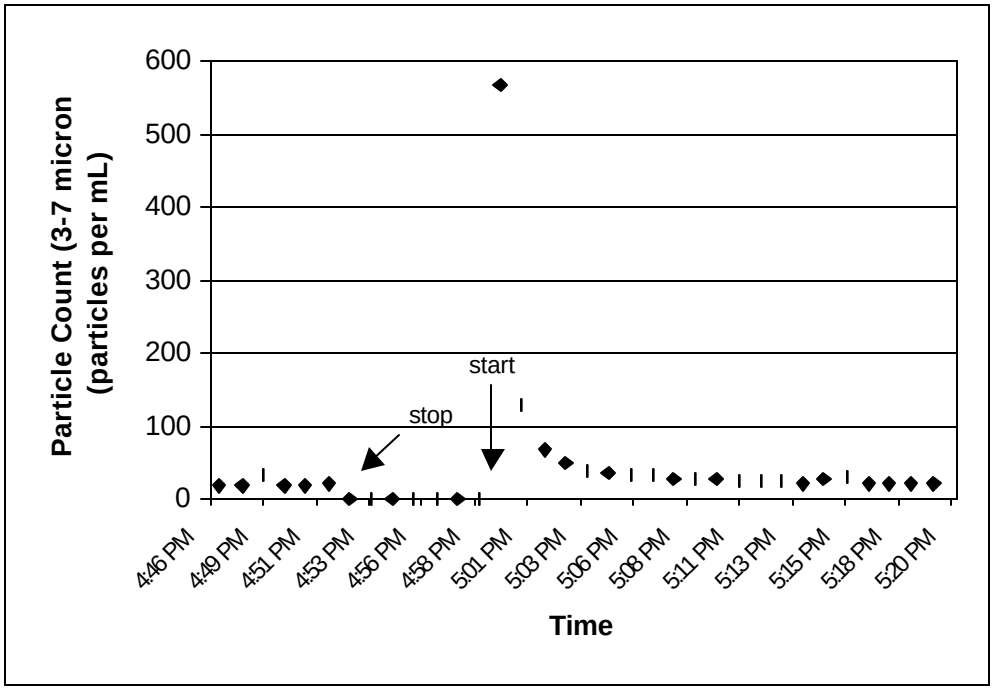


Figure 4-17. Rosedale Filter Run #21 Effluent 3-7 mm Particle Count Stop/Start

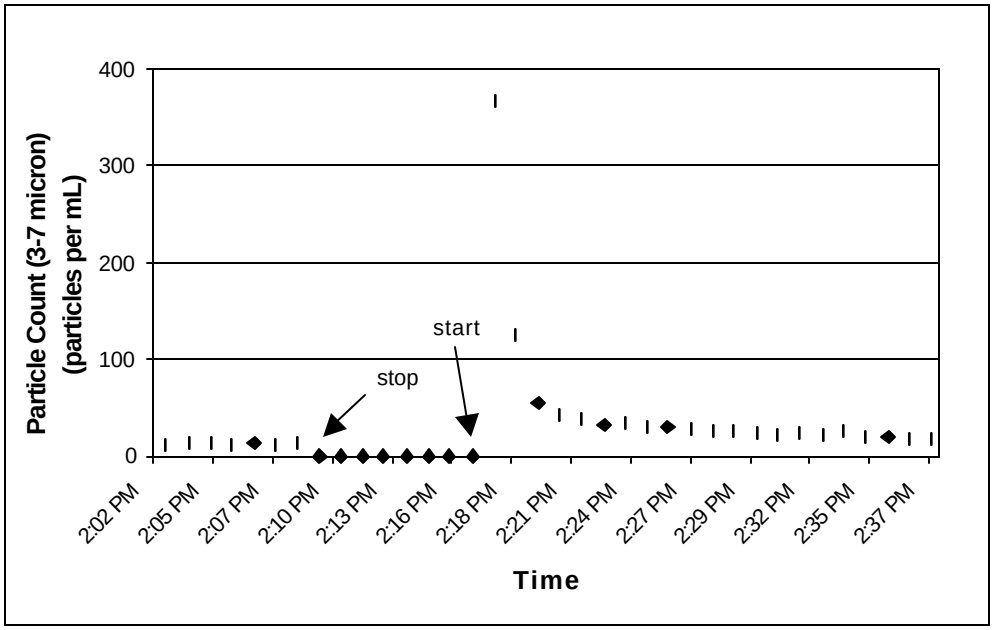


Figure 4-18. Rosedale Filter Run #22 Effluent 3-7 ㎛ Particle Count Stop/Start

The following graphs (Figures 4-19 through Figure 4-21) illustrate the turbidity peak following a stop/start sequence. As in the case of the particle counts, the duration is brief, however, since turbidity is composed of a large number of particles beneath the level of interest (that is, below 3µm) the duration is slightly longer. Moreover, the response time of the turbidimeter is somewhat longer than that of the particle counter.

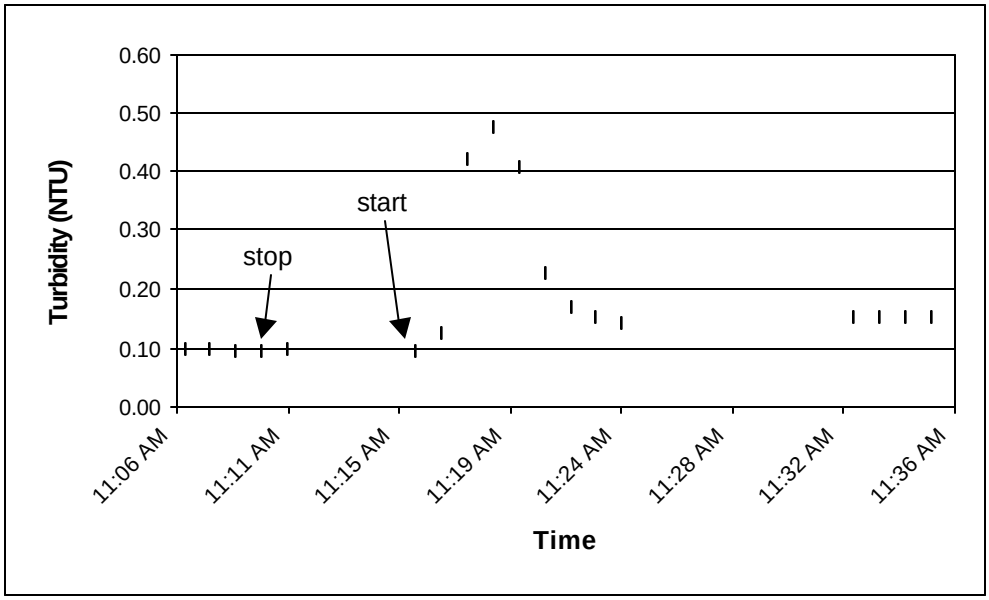


Figure 4-19. Rosedale Filter Run #20 Effluent 3-7 ㎛ Turbidity Stop/Start

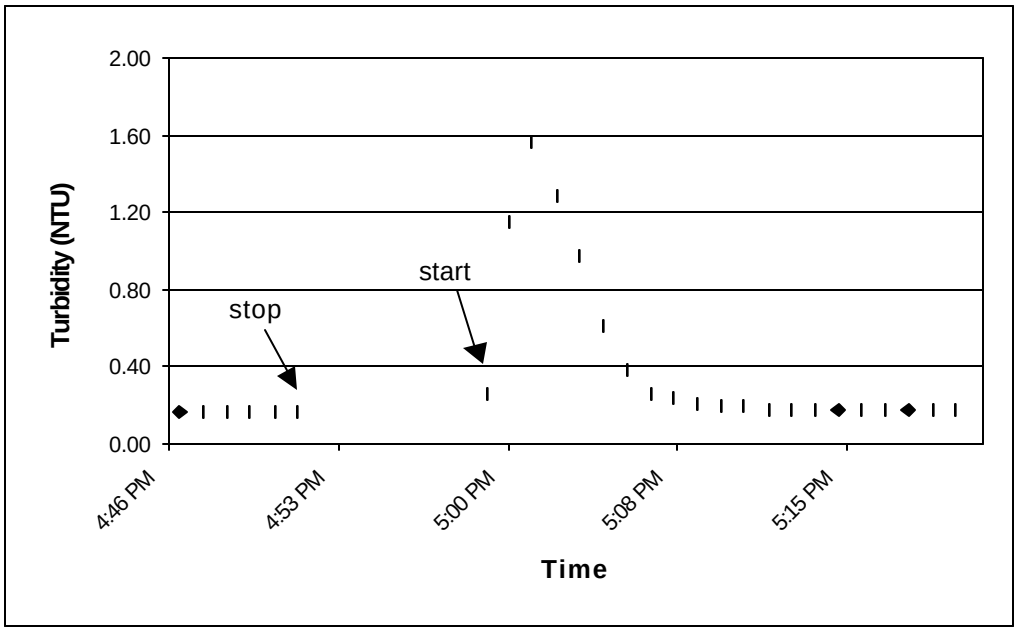


Figure 4-20. Rosedale Filter Run #21 Effluent 3-7 mm Turbidity Stop/Start

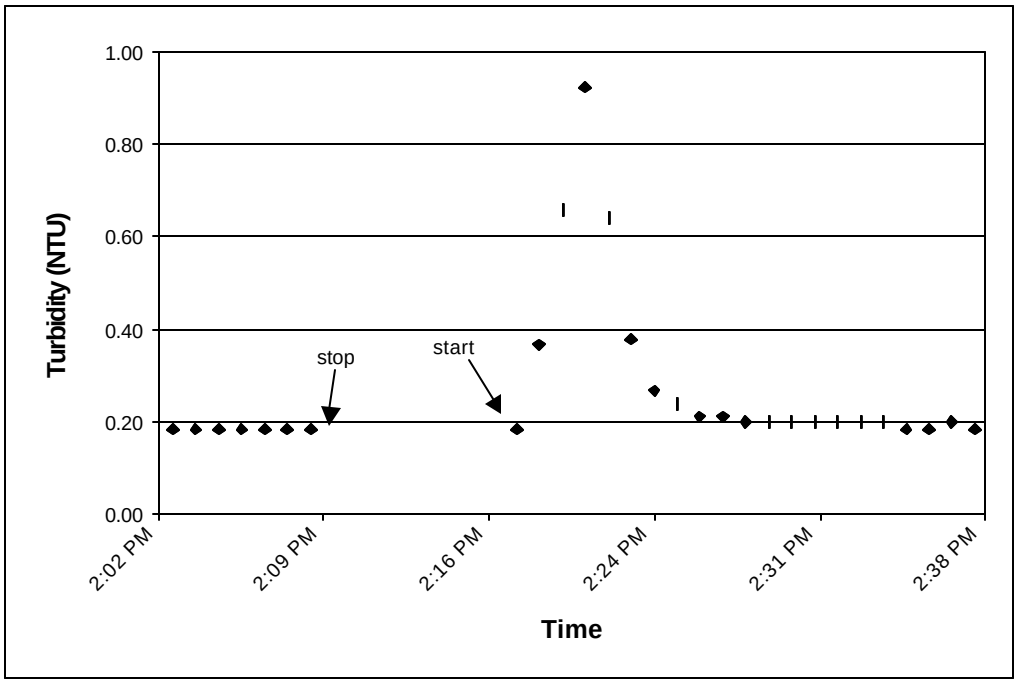


Figure 4-21. Rosedale Filter Run #22 Effluent 3-7 mm Turbidity Stop/Start

4.4 Equipment Characteristics Results

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

4.4.1 Qualitative Factors

Qualitative factors that were examined during the verification testing were the ease of which filter elements were exchanged, measurement of head loss, and other operational factors that might impact on performance of the equipment.

4.4.1.1 Filter Element Replacement

Filter elements on the RPI GFS Filter System were replaced when the headloss across the system approached 15 psi. Filter elements were replaced in pairs, except for one period (filter runs 17 and 18) when only the first element, the bag, was replaced to conserve cartridge elements. During the filter replacement seals in the top of the basket were also routinely replaced. In normal operation replacement of the seals is not necessary. Only on one occasion was the seal found to be defective. Additionally, an 'O' ring on top of the housing was replaced on one occasion when it was determined to have been pinched during replacement of the elements.

Replacement of both elements took about 15 minutes, including the time required to drain down the housing and purge the air following replacement. If rushed it could take still less time, although the operators of the system usually took longer in order to assure that the housings and elements were properly placed. Instructions for replacement included in the operating instructions supplied by the manufacturer were helpful.

Installation of the bag requires that it be fully pushed into the basket, and smoothed, and that the top rim be within the basket and held in place by a spring. The rigid element is also placed in the basket, and should be pushed firmly and fully snug so the seal at the top is in place. Wetting the seal and rim of the basket with filtered water allowed for an easier fit.

Removal of the elements should be accomplished by removing the baskets from the housings and then the elements from the basket. Because of the force of the seal plate and spring at the top, these elements resisted removal in most cases, and the operators found it was better done with two people pulling in opposition.

The bag and cartridge filter element fabric contained a chemical that produced milky foam when wetted. It is important to bleed off this residue before placing the filters on line, to prevent introduction into the filtrate stream and cause erroneous readings in the turbidimeters and particle counters. Although care was exercised during replacement, occasional spikes in turbidity and counts especially immediately following replacement may be the product of this material.

4.4.1.2 Head Loss

Headloss across the filters was determined by pressure gauges showing influent and effluent pressures. Manufacturer supplied Orange Research differential pressure gauges mounted on the housings were ambiguous and were removed previous to the beginning of the verification period. After examination of the pressure differential gauge located on the bag filter housing in filter train #2 it was discovered the diaphragm separating the influent from the effluent chambers was ruptured and decayed, thus allowing bypass between the chambers. This may have contributed to rigid cartridge filters loading during the initial operations period. Examination of other Orange Research gauges indicated others too had failed during initial operations. Of the six gauges supplied, only two were functional. The broken differential gauge was replaced with two pressure gauges, but these readings were disregarded except as an indication of overall housing pressure during bag replacement. Throughout the verification study, pressure gauges mounted on the instrument panel that measured inlet and outlet pressures across both housings were used as the pressure measurement of record. These gauges were verified against a NIST-traceable pressure gauge.

As expected, headlosses accelerated toward the end of a filter run. With the variation in river water turbidity, even with stable flows predicting filter run lengths was difficult and uncertain

The filter headloss was established by the manufacturer at 15 psi and was not challenged to breakthrough by the FTO. Casual observation noted that performance improved toward the end of a filter run, as headlosses increased, likely due to particle bridging.

4.4.1.3 Other Operational Factors

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.

Prior to opening the filter housings, pressure must be relieved. Pressure was simply bled off through the air release valve at the top of the housing and offered no difficulty. Replacement of the filters without some water spillage however proved to be nearly impossible, thus it was important to mop up the area following replacement to prevent slips and falls.

No injuries or accidents occurred during verification testing.

A handle on one of the butterfly valves, provided by Bray Manufacturing, broke during normal operation and was replaced. Examination of the handle showed that it had been cast poorly, with a flaw that had not been noticed. There was evidence of a crack almost through the entire casting but covered with paint. There was no interruption of either testing or the flow through the system because of this failure.

4.4.1.4 Evaluation of O&M Manual

The manufacturer supplies an O&M Manual that illustrates the equipment and shows the proper configuration of the housings. The filter start up and filter media element replacement procedures are instructive and thorough. A spare parts list used for the RPI GFS Filter System was included. The manufacturer also describes warrantees pertaining to the RPI GFS Filter System.

The O&M manual was reviewed for completeness and used during equipment installation, start-up, and system operation. The manual is brief and concise, however it appears to be a general O&M booklet intended to be applicable to a number of similar systems. Since the system supplied is a simple filter system with only pressure gauges as instruments, the discussion of operational or performance procedures is necessarily limited in scope. However, since this system is being marketed in a public health arena, some attention to operational considerations relating to health performance could be included. While it was found the manual provides adequate instruction for the ETV tasks, additional operational guides might be helpful.

The use of a differential pressure gauge might be unsuitable in some applications and separate gauges for the influent and effluent pressure ports of each housing could be added, along with instructions on their use. Sample taps can also be added at those points. Dimensions, especially those relating to the sizes and threads of fittings and to housing mounting distances could aid in installation. In addition, some discussion on what to look for in assessing seal and gasket integrity might be useful to inexperienced operators.

4.4.2 Quantitative Factors

4.4.2.1 Filter Elements Replacement

A total of 20 bags and 20 cartridge filter elements were used during the study. In field practice, bags and filter elements would not necessarily be replaced at the same time. The less costly bag is likely to be replaced more frequently than the more expensive rigid cartridge. In many cases where seasonal algae or sediment loads are heavier, small system users may benefit from pre-filtration, to limit the bag and rigid element removal to smaller suspended matter.

4.4.2.2 Anomalous Conditions That Require Operator Response

Operator response is required primarily to observe and monitor pressure losses as an indication of the filter system performance.

4.4.2.4 Length of Operating Cycle

As would be expected, the length of operation of a filter element is directly proportional to the loading rate as measured by the turbidimeter and particle counter. The loading rate could be controlled by changing the blend of raw and finished water. To what degree changing the blend would directly effect the loading rate was not measured. Operators allowed a slight variation in turbidity to occur naturally, responding to changes only when they exceeded predetermined

limits. It is likely that small systems operators will employ additional pretreatment, so the RPI GFS system will be used as a final barrier.

In addition, the test plan required that the flow be adjusted whenever it strayed from the determined rate. In many small system applications, the filters are allowed to follow a declining rate, and in those cases improved performance or extended filter life may be possible. Typically filter rates slowed as the headloss increased, and at the same time removal was slightly improved. It should also be noted that within this performance evaluation, the filter train is treated as a whole. As such both the pre-filter and final filter were replaced when terminal head loss across the filter train had been met. It is expected in field applications filters will be replaced based upon individual, as compared to combined, head loss. Thus, increasing the probability of extending the life of the final filter.

4.5 QA/QC Results

The objective of this task is to assure the high quality and integrity of all measurements of operational and water quality parameters during the ETV project. QA/QC verifications were recorded in the laboratory logbooks or spread sheets. QA/QC documentation and calibration certifications are attached to this report as Appendix G.

4.5.1 Data Correctness

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

- Representativeness
- Statistical Uncertainty
- Accuracy
- Precision

Calculation of all of the above data quality indicators were outlined in the Chapter 3, Methods & Procedures. All water quality samples were collected according to the sampling procedures specified by the EPA/NSF ETV protocols, which ensured the representativeness of the samples.

4.5.1.1 Representativeness

Operational parameters graphs and discussions are included under Task 3 – Documentation of Operations Conditions and Treatment Equipment Performance. Individual operational parameters, such as flow rate, particle count data, turbidity data, and testing equipment verification are presented below in discussions on Daily, Bi-Weekly and Start of Testing Period QA/QC Results.

4.5.1.2 Statistical Uncertainty

Ninety-five percent confidence intervals were calculated for the water quality parameters of the RPI GFS Filter System. These include influent and effluent turbidity, particle count, flow rates, and various other filter runs performance data as discussed in Task 3 – Documentation of

Operations Conditions and Treatment Equipment Performance. Ninety-five percent confidence intervals were also presented in the water samples summary tables in the discussion of Task 2 – Influent and Effluent Water Quality Characterization.

4.5.1.3 Accuracy

For this ETV study, the accuracy refers to the difference between the sample result, and the true or reference value. Calculations of data accuracy were made to ensure the accuracy of the testing equipment in this study. Accuracy of parameters as flow rate, particle count data, turbidity data, and testing equipment verification are presented below in discussions on Daily, Bi-Weekly and Start of Testing Period QA/QC Results.

4.5.1.4 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. Precision was ensured by calculating the percent relative standard deviation or the relative percent difference, and having it be equal to or less than 30%. For single reading parameters, such as pressure and flow rates, precision was ensured by redundant readings from operator to operator. Samples were analyzed in triplicate for those on-site parameters consequential to the testing: bench-top turbidity, pH and bench-top particle counts associated with the calibration of the equipment. These calibration procedures and results are presented in discussions on Daily, Bi-Weekly and Start of Testing Period QA/QC Results.

4.5.2 Daily QA/QC Results

Daily readings for water quality were listed in the logbook and then transcribed to computer format. Logbooks contained carbon paper second sheets that were separated and maintained off site at the COA offices. Computer diskettes were used to download data and then transferred physically to the COA offices.

The influent on-line turbidimeter flow rate averaged 458 mL/minute. The effluent on-line turbidimeter flow rate averaged 446 mL/minute. These averages were calculated only to show that the limits were observed. To determine the flow rate of the on-line turbidimeters the flow was measured with stopwatch or sweep-watch and a 1,000 mL graduated cylinder. The maximum rate during the testing period for the influent turbidimeter was 660 mL/minute, the minimum was 310 mL/minute for the effluent turbidimeter the maximum rate during the testing period was 740 mL/minute, the minimum was 272 mL/minute The acceptable range of flows as specified by the manufacturer is 250 mL/minute to 750 mL/minute. The turbidimeter readings are accurate within those ranges; however, the time from beginning of flow to stable turbidity indication is lengthened with the slower flows. The manufacturer notes that the first step response time is 2.5 seconds and 90% stability is reached in 5 minutes when the flow is 750 mL/min.

The influent readout from the Hach 1720C on-line turbidity averaged 1.09 NTU during the period; the average from the Hach 2100P benchtop turbidimeter was 1.08 NTU. The effluent readout from the Hach on-line turbidity averaged 0.28 NTU during the period; the average from

the Hach 2100P benchtop turbidity was 0.24. This narrow difference is accidental as the on-line and bench turbidimeters are not expected to read the same, only to track in a relative manner. The on-line and bench-top readings were compared daily. Ten (of 22 readings) for effluent turbidity were outside the 30% RPD due to the proximity of turbidity to the instrument's measuring limit. One (of 22 readings) for influent turbidity was outside the 30% RPD. The bench-top readings were within acceptable limits of 30% of RPD. Additional documentation and tables can be found in Appendix I.

The influent feed water particle counter flow rate averaged 102 mL/minute. To determine the flow rate of the on-line feed water turbidimeter the flow rate was measured using a graduated cylinder and stopwatch. The maximum flow rate measured was 110 mL/minute, the minimum was 97 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 and the flow was adjusted whenever those boundaries were crossed. The finished water particle counter flow rate averaged 98 mL/minute. The flow was measured using a graduated cylinder and stopwatch.

The temperature was recorded daily in the evening with a NIST-traceable Miller Weber Thermometer, Model T-775/63CGC.

The pH meter was calibrated daily against NIST-traceable pH buffers at 7.00 and 10.00 daily. The pH meter was a Cole Palmer Oakton® WD-35615 Series. The pH calibration buffers were Oakton pH Singles 7.00 (model #35653-02), and pH Singles 10.00 (model #35653-03). The pH calibration was performed prior to the recorded influent pH measurement.

The tubing and all water lines used on the treatment system were inspected before testing began and daily after March 15, 2000. The tubing and lines remained in good condition and replacements were not necessary.

4.5.3 Bi-Weekly QA/QC Verification Results

Every two weeks checks were made on the on-line flow meters, the meters were cleaned out if necessary, and the flow readouts were verified. The flow meters were supplied with clean, filtered water and did not foul. The 30-day test period only required one scheduled verification of the on-line flow meters. The on-line flow meters were verified (bucket and stopwatch), using a measured container on March 18, 2000. The flow was measured at 10 gpm x four times. The deviation was found to be 1 second in 4 minutes at 10 gpm over 40 gallons.

4.5.4 Results Of QA/QC Verifications At The Start Of Each Testing Period

The particle counters were calibrated by Pacific Scientific Instruments using polystyrene latex spheres traceable to NIST standards. Particle counters used on site were MetOne PCX models. The MetOne particle counters had a factory calibration certificate dated March 3, 2000, serial numbers 971000353 and 971000354. Calibration was again verified on site with NIST mono-sized polymer microspheres as described in Section 3.8.2.4 above. Particle counter verification was performed for size distribution only, although counts were corroborated.

The following figures show the distribution as counted by the MetOne particle counter during the NIST-traceable verification.

Figure 4-22 shows the particle counts during the influent 3 µm verification. The Figure shows the addition of the added particles as would be expected.

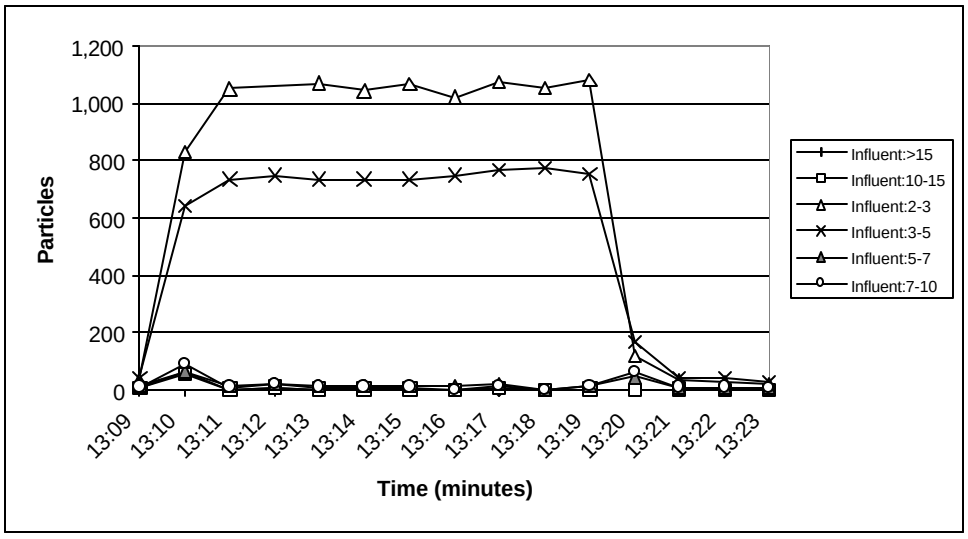


Figure 4-22. Verification of 3 µm Influent Particles

Figure 4-23 shows the particle counts during the influent mix of 3, 10 and 15 µm verification. The Figure shows the addition of the added particles as expected.

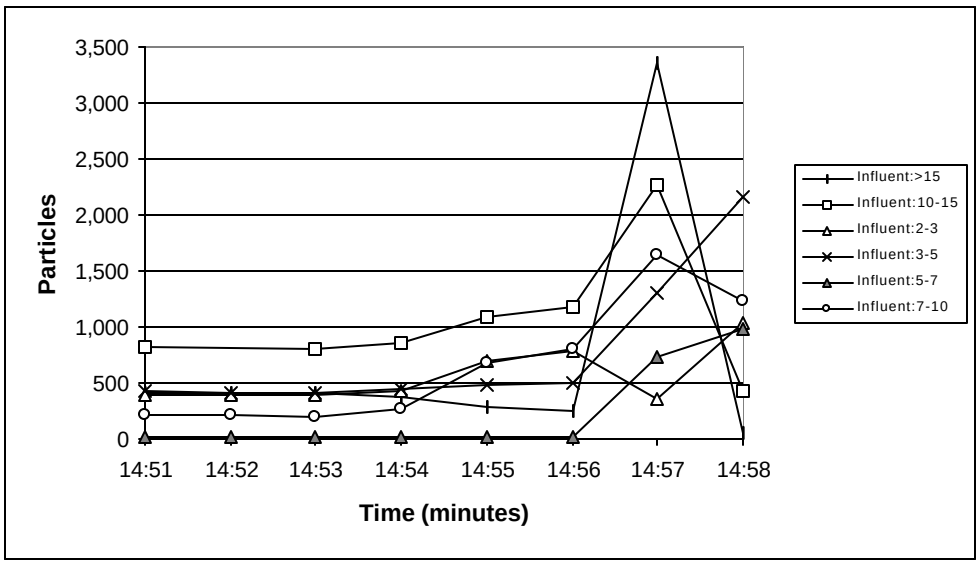


Figure 4-23. Verification of Mix of 3, 10 & 15 µm Influent Particles

Figure 4-24 shows the particle counts during the effluent 3 µm verification. The Figure shows the addition of the added particles in the 3 µm size range as expected.

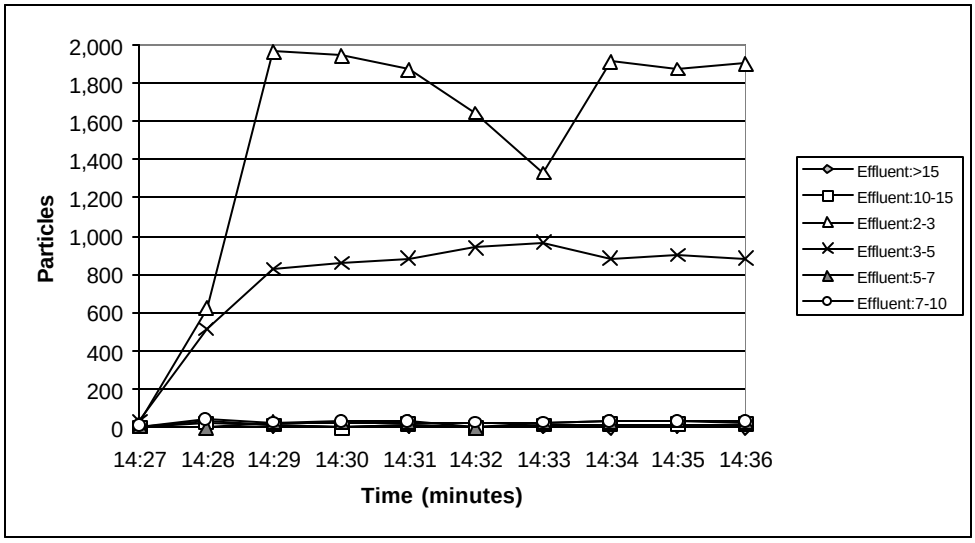


Figure 4-24. Verification of 3 µm Effluent Particles

Figure 4-25 illustrates the particle counts during the 10 µm effluent verification. This Figure shows the addition of the added particles in the 10 µm size range as expected.

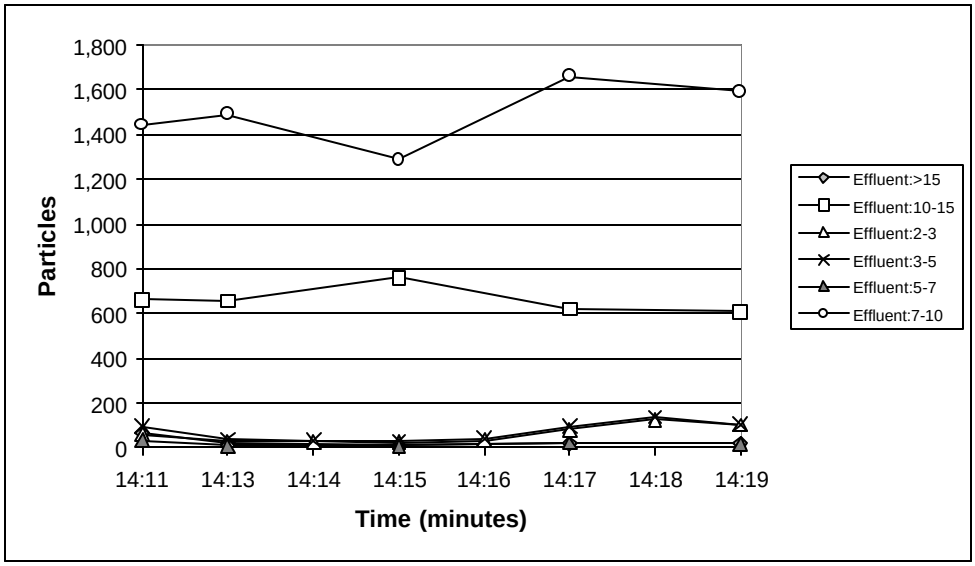


Figure 4-25. Verification of 10 µm Effluent Particles

Figure 4-26 illustrates the particle counts during the 15 µm effluent verification. The Figure shows the addition of the added particles in the 15 µm size range as expected.

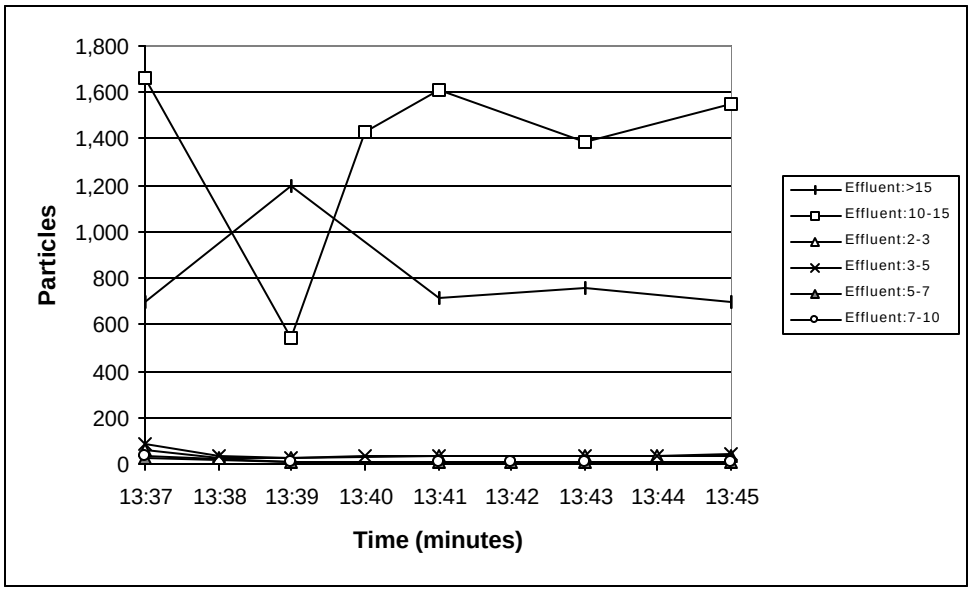


Figure 4-26. Verification of 15 µm Effluent Particles

Figure 4-27 illustrates the particle counts during the mix of 3, 10, and 15 µm effluent verification. The Figure shows the addition of the added particles in the µm size range as expected.

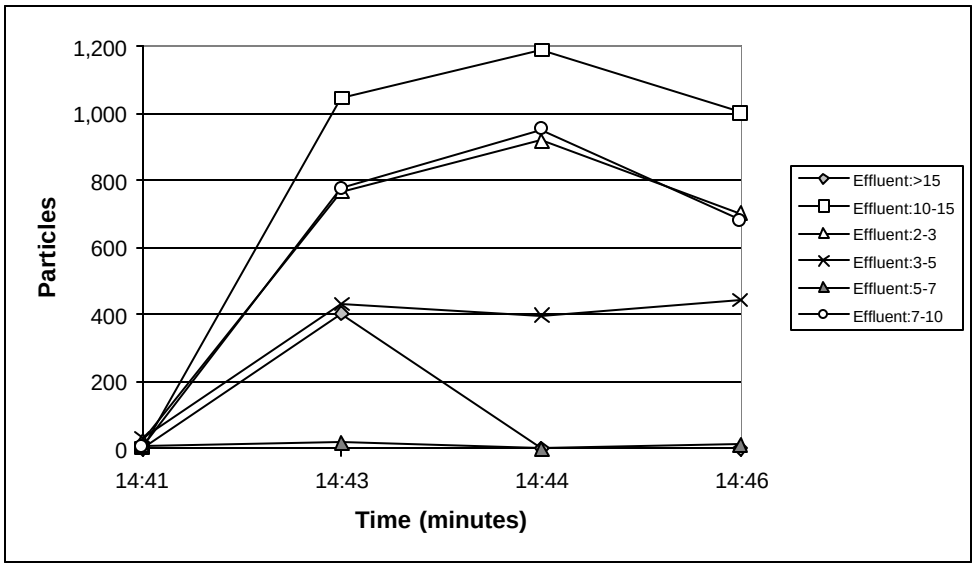


Figure 4-27. Verification of 3, 10 & 15 µm Effluent Particles

Particles that were added were:

Duke Scientific Corp	3.0 ± 0.027µm
	10.0 ± 0.061µm
	15.0 ± 0.08µm

Visual inspections of the particle counter and turbidimeter tubing at the beginning of testing and daily thereafter showed unimpeded flow and integrity. The tubing was in good condition and replacements were not necessary.

There was no differential pressure transmitter attached to this equipment. Gauges were verified on March 15, 2000 and again on April 2, 2000 by comparing the pressure shown on the gauge with the same pressure shown on a NIST-traceable pressure gauge. The NIST-traceable pressure gauge verified the board pressure gauges at 30 psig.

The effluent turbidimeter failed on March 18, and was replaced with a back up on March 19, 2000. The replacement meter was calibrated with Formazin suspension to 20 NTU in accordance with manufacturer's instructions following restart.

Before the challenge testing of the RPI GFS Filter System began, the Minnesota Department of Health performed calibration procedures on the bench top, Hach 2100P turbidimeter. The instrument was calibrated to the manufacturer's recommended standards of 20, 100 and 800 NTU with fresh Formazin suspensions. The manufacturer explains that since the response signal is linear from 0-20 NTU efforts to standardize to lower levels are fruitless and may instead throw the readings off. Calibration standards are further required to be at least 65 NTU apart. In addition, weighting the curve to the range of interest (in this case at levels less than 5 NTU) also provide the opportunity for increasing error. The manufacturer's recommended settings were also observed in subsequent calibrations.

The turbidimeter was calibrated against freshly prepared Formazin dilutions from a standard suspension (4000 NTU). The standards were prepared using NIST-traceable glassware, including pipettes and volumetric flasks.

Gelex secondary standards were also calibrated following manufacturer's instructions during the instrument calibration, and additional secondary standards were prepared or purchased from Hach. These standards were referenced daily in the ranges of concern. While the standards at 0.5, 1 and 3 NTU were relatively stable, the reference of 0.1 NTU was somewhat ambiguous as it is at or near the limit of detection for this instrument.

Turbidity samples were collected from a sample tap at a slow steady stream and along the side of a triple rinsed dedicated beaker to avoid air entrapment. The sample was poured from the beaker into a double rinsed clean sample vial.

All glassware for turbidity measurements was kept clean and handled with lint free laboratory tissue. The sample cells were further wiped with velvet, silicon oilcloth.

4.5.5 Analytical Laboratory QA/QC

Samples for analyses conducted on feed and finished water are listed in Table 4-2 and Table 4-3. QA/QC procedures are based on *SM*, 19^{9h} Ed., (APHA, 1995) and Methods for Chemical Analysis of Water and Wastes, (EPA, 1995).

Calibration results of the analytical instrumentation used to conduct the analyses listed in Table 4-3 on finished water is recorded and kept on file at Spectrum Labs, Inc. QA/QC procedures and documentation pertinent to this verification test are on file at Spectrum Laboratories and Cartwright, Olsen & Associates, LLC.

It was noted that the Spectrum QC data documentation lacked the reviewer's initials and the date of review. The written response from Spectrum regarding this issue indicated that they believed that the review occurred, however, the documents lack the notation of the review. A review of the QC data and results of analytical instrumentation indicate that adequate controls were in place to render the data obtained acceptable.

4.5.6 Microbiological Laboratory QA/QC

Influent analyses used hemacytometer procedures, and effluent counts, which were much lower, used membrane filtration and microscopic counting. Hemacytometer and membrane filtration counting was performed as outlined in EPA Method 1622, Section 11.3, EPA Method 1623, Section 11.0, and *SM* 10200F but altered for the counting of synthetic, fluorescing microspheres.

A review of all QA/QC procedures and results of analytical instrumentation indicate that adequate controls were in place to render the data obtained acceptable.

4.5.7 QA/QC Procedures for Accusizer Measurements

QA/QC procedures for the Accusizer measuring system were based on protocols established by Standard Methods, ASTM 658 and the Pharmaceutical Industry USP 788.

Prior to testing the Accusizer was calibrated to known particle sizes with NIST-traceable particles at 2 µm and 5 µm, and additionally at 2.92 µm and 3.7 µm. A review of size accuracy suggests that the accuracy of optical particle devices is ± 5% at near and below 2 µm and at near and above 5 µm, but closer to ± 10% at the interval of 2.6 µm to 4.0 µm. This anomaly is due to electronic characteristics of optical particle counting instruments and should be taken into account in interpreting any data. Unfortunately, this distortion is at the range of interest in this study.

The instrument sensor was also standardized to size against voltage, and the curve for that procedure is attached in the Appendix G.

The samples were kept cool from the time of sampling and shipped chilled. When received they were refrigerated until removed for testing. Each sample was labeled to indicate challenge run

and seed and whether influent or effluent. The samples were contained in Dow Chemical snap cap containers, and were approximately 100-120 mL each in volume.
When tested, each sample was sonicated for 30 seconds, and then inverted 25 times. This was done to limit any air bubbles, break up agglomerated particles and to mix homogeneously so the particles would be distributed throughout the sample. The required volume (15 mL) was then drawn from the sample and injected into the counter.

Two empty, unused containers were sent to MML as a control to determine the number of particles introduced into the test samples from sample containers used. Since the intent of these samples were originally to back-up samples for fluorescing microscopic analysis, procedures that might have limited to the contribution of non-fluorescing particulates, including sample container selection itself, were not taken into consideration at the time of sample collection.

PFW was added to the empty sample containers and prepared as other test samples, with sonification and inversion to eliminate air and break up agglomerated particles. The distribution of particles from these control containers suggests contribution to the test samples of 315 particles/mL between 3 µm to 7 µm. Because negative effluent counts would result if measured data alone were used in Table 4-21, counts were adjusted to include sample container contribution of 315 particles/mL.

A review of all QA/QC procedures and results of analytical instrumentation indicate that adequate controls were in place to render the data obtained acceptable.

4.6 Limitations

Measurements used to characterize filter performance included on-line turbidimeters and particle counters, both of which had severe limitations. The turbidity limitation has been addressed by others; all that can safely be stated is that there is a vague relationship between turbidity reduction and filtration. Its use as a defining factor however, is suspect. Turbidity can be the product of a few large particles, or many smaller ones, and their nature is not revealed.

The use of on-line particle counting also has limitations, especially when it is used to calculate $\log_{10}$ removals. The lower level of particle counts, for example in either fully finished water or in water that has been filtered, has confidence. The upper levels, especially when particle counts exceed 10,000 per milliliter in the sizes seen by the sensor, or when there are high numbers of smaller particles, are uncertain. As a means of establishing policy, the strict application of particle count data may be severely limited; as a means of evaluating filter performance however, particle counting can be a rapid and insightful method of determining effectiveness.

Also limiting in this study were the hemacytometer counts of the influent particles. Other researchers have noted: "recovery values calculated using hemacytometer counts were consistently lower and significantly different from the recovery values calculated using membrane counts" (Klonicki). The effect of the hemacytometer count reductions may have influenced the reduced $\log_{10}$ removal values suggested by microscopic analysis.

Bench particle counting, using laboratory instrumentation such as a Coulter counter or the Accusizer employed in this study, can be performed with greater accuracy, especially when using dilutions and automatic pipettes, however, these tests do not lend themselves to field applications where sample contamination is probable and rapid feedback is required (Van Gelder).

The same is true with the use of fluorescent microspheres where, again, laboratory analyses allow for a single sample, and determination of particle counts require statistical methodology and a high degree of measuring precision, not easily performed in the field (Li, et. al.).

Recommendations that can be drawn without contention include the need for proper bag and element installation and the requirement that there be a minimum of two bed volumes of filtered water discharged to waste cycle following an interruption in flow. In addition, other operational details, such as flow rate limitations and allowable pressure differentials may also be inferred from these data that may aid regulators and small system designers in the application of this technology to small community water supplies.

Chapter 5
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