June 2001
NSF 01/11/EPADW395

Environmental Technology Verification Report

Physical Removal of *Giardia* cysts and *Cryptosporidium* oocysts in Drinking Water

Kinetico Incorporated
SW224 Backwashable Macrolite® Pressure Filtration System

Prepared by

NSF International

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

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**BACKWASHABLE DEPTH FILTRATION USED IN DRINKING WATER TREATMENT SYSTEMS**	
APPLICATION:	**PHYSICAL REMOVAL OF *GIARDIA* CYSTS AND *CRYPTOSPORIDIUM* OOCYSTS IN DRINKING WATER**	
TECHNOLOGY NAME:	**SW224 BACKWASHABLE MACROLITE® PRESSURE FILTRATION SYSTEM**	
COMPANY:	**KINETICO INCORPORATED**	
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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 backwashable depth filter system used in drinking water treatment system applications. This verification statement provides a summary of the test results for the Kinetico Incorporated SW224 Backwashable Macrolite® Pressure Filtration System. Cartwright, Olsen and Associates, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the Kinetico Incorporated SW224 Backwashable Macrolite® Pressure Filtration System was conducted for 32½ days between March 24 and May 1, 2000, and three protozoan challenges were performed between April 24 and 27, 2000. Between March 24 and May 1, 2000, raw water characteristics were: average pH 8.6, temperature 10.3°C, turbidity 0.77 Nephlometric Turbidity Units (NTU), and total alkalinity 53 mg/L. Average calculated flow rate over the test period was 27.98 gpm. The filter runs averaged 11.7 hours, with an average of 21,075 gallons per filter run. The average effluent turbidity was 0.23 NTU. During the protozoan challenges the raw water characteristics were: average pH 9.2, temperature 11.4°C, turbidity 0.6 NTU, and total alkalinity in the range of 50-52 mg/L. The average effluent turbidity was 0.2 NTU. The system demonstrated 1.6 to 3.7 $\log_{10}$ reductions of *Giardia lamblia* (*G. lamblia*) cysts and 0 to 0.8 $\log_{10}$ reductions of *Cryptosporidium parvum* (*C. parvum*) oocysts. These results were obtained at an average flow rate of 28.4 gpm. Analysis of filter effluent samples suggest *G. lamblia* cysts and *C. parvum* oocysts were released from the filter bed as a result of the stop/start sequence.

TECHNOLOGY DESCRIPTION

The Kinetico SW224 is designed expressly for small system applications. Media vessels (filters) measured 24" in diameter and 72" in height and are offered in fiberglass or steel construction. Fiberglass reinforced polyethylene media tanks, pressure rated to 100 psi, were used for this study. The liquid volume capacity of each media vessel is 119 gallons without media. Filter media bed depth was 36".

Two identical filters are used within the Kinetico SW224 Filter System. Filters are identified as "T1A" and "T2A" and operating alternately. The filter media is Macrolite®, a synthetic ceramic, filter media.

Macrolite® of the 70/80 mesh size has a bulk density of 0.96 grams/cubic centimeter (g/cc). The specific gravity (as measured by American Society for Testing and Materials (ASTM) D2840) is 2.23 g/cc. The collapse strength for the media of this size has not been measured, however, for a larger sphere (30/50 mesh) the collapse strength (as measured by ASTM D3102) is a nominal 7,000 psi for 10% and nominal 8,000 psi for 20% collapse.

The uniformity of the Macrolite® 70/80 mesh media was analyzed in accordance with AWWA Standard B100-96 by Bowser-Morner, Inc in December, 1997. The results of this analysis are summarized below:

Uniformity of the Macrolite® 70/80 Mesh Media (AWWA Standard B100-96)

Sieve Size, USA Std.	Nominal, mm	Effective, mm	Percent passing
#45	0.355	0.360	100.0
#50	0.300	0.307	99.9
#60	0.250	0.249	79.8
#70	0.212	0.212	28.9
#80	0.180	0.180	7.2
#100	0.150	0.150	0.4

Effective Size: 0.19 mm
Uniformity Coefficient: 1.2

In addition, a June 1998 Kinetico internal laboratory analysis of 70 mesh media (lot # 352) employing a mercury/penetrometer Micromeritics Autopore II 9220 instrument produced the following results:

Uniformity of the Macrolite® 70/80 Mesh Media (Micromeritics Autopore)

Total intrusion volume	0.2098 mL/g
Total pore area	0.18 sq-m/g
Median pore diameter by volume	53.7990 µm
Median pore diameter by area	52.5351 µm
Median pore diameter by 4V/A	46.5685 µm

The flow of water through the system is controlled with hydro pneumatically actuated valves mounted on face piping constructed of Schedule 80 PVC. Automatic valves are actuated via a programmable logic controller. The valves also have handles for manual activation.

Accessories and instrumentation included with the Kinetico SW224 System included flow rate and pressure sensors and monitors, on-line turbidimeters, pressure gauges, backwash pumps and an electrical enclosure containing a programmable logic controller and a touch screen monitor. The equipment also contained data transfer connections available for remote monitoring.

The filters are shipped skid mounted and absent of media. Filter media was loaded on site. The total weight of the system, without media, is approximately 1,700 pounds. Spatial size of the Kinetico SW224 Filter System was 4'1¼" W x 9'6 ½L x 8'7¼" H.

VERIFICATION TESTING DESCRIPTION

Test Site

The host site for this demonstration was the University of Minnesota St. Anthony Falls Hydraulic Laboratory (SAFHL), which has direct access to untreated and treated Mississippi river water. SAFHL is located on the Mississippi River at Third Avenue S.E., Minneapolis, Minnesota 55414. Influent to the Kinetico SW224 system was a blend of river water and treated water from the Minneapolis Water Works.

Methods and Procedures

The verification test was divided into tasks that evaluated the system's treatment performance, specifically its ability to physically remove *G. lamblia* cysts and *C. parvum* oocysts from the feed water, and documented the system's operational parameters.

Water quality parameters that were monitored during the verification test included: pH, temperature, turbidity, particle counts, free chlorine residual, total alkalinity, total hardness, total organic carbon (TOC), ultraviolet absorbance (UVA) at 254 nanometer (nm), true color, iron, manganese, algae, total coliform, and *E. coli*. 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.

Three seeding challenges employing *G. lamblia* cysts and *C. parvum* oocysts occurred between April 24 and 27, 2000. The protozoan analyses (identification and enumeration) were conducted using EPA Method 1623. During seeding studies, sodium thiosulfate was injected into the blended feedwater stream in place of chlorine to reduce chlorine residuals within the filter influent water previous to the point of protozoan injection. A mixture of cysts and oocysts was added to the raw water through an injection probe at the intake of the static mixer. The analyses of the influent samples indicated that the mixture contained between 660,000 and 3,800,000 *G. lamblia* cysts per liter, and between 2,800,000 and 17,000,000 *C. parvum* oocysts per liter during the three seeding challenges. During the seedings, 10 liters were collected from a side stream at a rate of 170 milliliters per minute over a one-hour period (equivalent to 20 bed volumes) and filtered through a Gelman capsule filter for enumeration. The 10-liter samples filtered through a Gelman capsule filter were evaluated in accordance with the procedures indicated in EPA Method 1623. Filter influent and effluent grab samples were taken at initial start up, at the mid-

point of the filter run and at the end of the filter run, just prior to terminal headloss. These seedings allow determination of filter efficacy at several points in the filter cycle. In addition to these challenges, the flow of water through the Kinetico SW224 Filter System was discontinued soon after the midpoint (oo)cyst seeding study during each of the three challenge filter runs. Filter effluent water was directed to an (oo)cyst collection filter over a period of 60 minutes beginning immediately after the resumption of flow though the filter and analyzed for *G. lamblia* cysts and *C. parvum* oocysts. This sequence was termed a "stop/start event".

VERIFICATION OF PERFORMANCE

Source Water

Between March 24 and May 1, 2000, raw water characteristics were: average pH 8.6, temperature 10.3°C, turbidity 0.77 NTU, and total alkalinity 53 mg/L. During the protozoan challenges the raw water characteristics were: average pH 9.2, temperature 11.4°C, turbidity 0.6 NTU, and total alkalinity in the range of 50-52 mg/L.

Operation and Maintenance

The length per filter run varied over the test period, and although the system was not monitored 24 hours per day, a representative filter run at the beginning of the test period was 19.94 hours in length, in the middle of the test period was 17.95 hours and at the end of the test period was 6.50 hours. Recorded total filter run volumes ranged from 5,163 gallons (4/28/00) to 44,347 gallons (3/26/00) per filter run. The filter runs averaged 11.7 hours, with an average of 21,075 gallons per filter run. Continuous monitoring was not required and the technician was not on site during all filter runs; therefore data averages are representative of runs that occurred during technician monitoring. Average calculated flow rate over the test period was 27.98 gpm. The following table is representative of data compiled from two runs selected for the beginning, middle and end run cycles to replicate the data during that time frame.

Average Operating Conditions (March 24 through May 1, 2000)

Test Period Time Frame	Filter Run Time (hrs)	Beginning Flow Rate (gpm)	Ending Flow Rate (gpm)	Change in Pressure (psi)	Gallons Filtered	Backwash Rinse Volume (Gallons)	Backwash Volume (Gallons)	Backwash Flow Rate (gpm)
Beginning	19.94	29.70	28.47	13	34,037	146	287	16
Middle	17.95	30.24	26.52	12	30,847	183	285	16.5
End	6.50	30.15	27.27	11	10,237	157	339	16.8

The Kinetico SW224 Filter System is a packaged water filtration plant designed to provide a continuous process flow and automated to require minimal operator intervention. To support this design two filters are included within the Kinetico SW224 package. When one filter is in operation, the alternate filter is off-line. Filter run time is determined by one of the following events as monitored by the water treatment plant's PLC with timers and sensors/meters installed within the appropriate process stream: Head loss; Turbidity breakthrough; and Time. These values were initially set at 22 psi, 0.5 NTU and 24 hours, respectively. When one of these set-point values is exceeded, the filter run is discontinued and the alternate filter is rinsed and put on-line with minimal interruption in flow. During 50 filter runs that were observed in their entirety, it was noted that the equipment could virtually operate without operator interface.

The only recurring problem with the operation of the Kinetico SW224 filter system involved the on-line turbidimeters supplied with the equipment which required frequent cleaning and verification of calibration.

The O&M manual provided by the manufacturer primarily defined installation, operation and maintenance requirements for Kinetico SW224 Filter System. The manual provided information pertaining to basic installation, start-up, and operational process. A process schematic, trouble shooting guide, and associated O&M manuals for components used within the Kinetico SW224 Filter System were also provided. The O&M manual was reviewed for completeness and used during equipment installation, start-up, system operation, and trouble-shooting. It was found the manual provides adequate instruction for tasks required to perform these functions over the period of operation of the ETV test period. In cases where the operator desired to confirm his interpretation of instructions within the O&M manual, Kinetico's customer support department proved to be responsive.

Protozoan Contaminant Removal

The system demonstrated 1.6 to 3.7 $\log_{10}$ reductions of *G. lamblia* cysts and 0 to 0.8 $\log_{10}$ reductions of *C. parvum* oocysts. These results were obtained at an average flow rate of 28.4 gpm. Analysis of filter effluent samples suggest *G. lamblia* cysts and *C. parvum* oocysts were released from the filter bed as a result of the stop/start event. The number of (oo)cysts detected in the filter effluent during the stop/start event were considerably lower than the number detected during the midpoint seeding challenges and may be further reduced by lengthening the filter-to-waste.

Finished Water Quality

The average effluent turbidity during the 32½day verification testing period was 0.23 NTU. The average effluent turbidity during the protozoan challenges was 0.17 NTU. A summary of the influent and effluent water quality information for the verification period of March 24 through May 1, 2000 is presented in the following table.

Influent/Effluent Water Quality (March 24-May 1, 2000)

Parameter	# of Samples	Average	Minimum	Maximum
Total Alkalinity (mg/L)	6/6	53/54	47/49	62/63
Total Hardness (mg/L)	6/6	80/78	74/73	88/87
TOC (mg/L)	6/6	6.4/6.4	6.1/6.1	6.5/6.6
UVA_{254} (cm^{-1})	6/6	0.098/0.098	0.082/0.086	0.108/0.106
Iron (mg/L)	6/6	<0.1/<0.1	<0.1/<0.1	<0.1/<0.1
Manganese (mg/L)	6/6	0.01/<0.01	0.01/<0.01	0.02/0.01
pH	34	8.6/NA	7.2/NA	9.5/NA
Temperature (C)	34	10.3/NA	7.1/NA	15.4/NA
Free Chlorine (ppm)	11	0.78/NA	0.27/NA	1.48/NA

Notes: All calculations involving results with below PQL values used 1/2 the PQL in the calculation.
Effluent samples were not analyzed for pH, temperature or free chlorine.

Power Consumption

During the 32½day verification testing period the Kinetico SW224 Filter System unit used 147 kWh for 1,307,850 gallons of water filtered. This equates to 8,897 gallons of filtered water per kWh.

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

Availability of Supporting Documents

Copies of the *ETV Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants* dated May 14, 1999, the Verification Statement, and the Verification Report (NSF Report # 01/11/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)

Environmental Technology Verification Report

Removal of *Giardia* and *Cryptosporidium* in Drinking Water

Kinetico SW224 Backwashable Pressure Filtration System

Prepared for:
NSF International
Ann Arbor, Michigan 48105

Prepared by
Cartwright, Olsen and Associates, LLC

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

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Notice

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

Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for NSF International (NSF) and the United States Environmental Protection Agency (EPA) by Cartwright, Olsen & Associates, LLC, (COA) in cooperation with Kinetico, Inc. The test was conducted during March and April of 2000 at the University of Minnesota St. Anthony Falls Hydraulic Laboratory.

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 are made available to regulators, developers, consulting engineers, and those in the public health and environmental protection industries. This encourages more rapid availability of approaches to better protect the environment.

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

The ETV 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
°C	Degrees Celsius
cc	Cubic centimeters
C. parvum	*Cryptosporidium parvum*
cfh	Cubic feet per hour
cfm	Cubic feet per minute
CFU	Colony Forming Units
COA	Cartwright, Olsen, and Associates, LLC
DI	Deionized (demineralized) water
DWTS	Drinking Water Treatment Systems
E.coli	Escherichia coli
EPA	U.S. Environmental Protection Agency
ESWTR	Enhanced Surface Water Treatment Rule
ETV	Environmental Technology Verification
ºF	Degrees Fahrenheit
FOD	Field Operations Document
FTO	Field Testing Organization
G. lamblia	*Giardia Lamblia*
G. muris	*Giardia Muris*
gallons	Gallons are expressed as US gallons, 1 gal = 3.785 liters
gpm	Gallons per minute
HP	Horse power
ICR	Information Collection Rule
IMS	Immunomagnetic separation
Kinetico	Kinetico Incorporated
kW	Kilowatt
Log	Logarithm to the base 10
µm	Micron
mgd	Million gallons per day
mg/L	Milligram per liter
mL	Milliliter
MPA	Microscopic Particulate Analysis
MWW	Minneapolis Water Works
NAWQA	National Water-Quality Assessment
NIST	National Institute of Standards and Technology
NSF	NSF International, formally known as National Sanitation Foundation
NTU	Nephelometric Turbidity Unit
(oo)cyst	Conventionally used to refer to either cysts or oocysts
O&M	Operations and Maintenance

PFW	Particle Free Water
pH	A measure of the degree of the acidity or the alkalinity of a 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
PVC	Polyvinyl chloride
QA/QC	Quality Assurance/Quality Control
SAFHL	St. Anthony Falls Laboratory of the University of Minnesota
SM	Standard Methods for the Examination of Water and Wastewater, 19th Edition
SWTR	Surface Water Treatment Rule
TCU	Total Color Units
TDS	Total dissolved solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
Ten State's Standards	Great Lakes-Upper Mississippi River Board of State Public Health and Environmental Managers, *Recommended Standards for Water Works*
USGS	U.S. Geological Survey
UV	Ultraviolet
WEF	Water Environment Federation

Definitions

Backwashable Depth Filter
A granulated media filter intended to filter uncoagulated or coagulated water and designed to be backwashed when either turbidity breakthrough occurs or terminal headloss is reached.

Colloid
In water treatment the term refers to charged, suspended particles such as clays, metal salts and microbes that coagulate into larger agglomerates in water, thus allowing filtration.

Conventional filtration treatment
A treatment train involving coagulation, flocculation, sedimentation, and filtration.

Direct filtration
A process involving coagulation and filtration, but excluding the sedimentation step.

Filtration
A process for removing particulate matter from water by passage through porous media.

Granular Media Filter
A deep bed filter containing granular media used to filter water. These filters rely on straining particles out of the water, or by attachment of the particles to the media.

Sedimentation
Separation of solids prior to filtration by gravity settling or through other hydraulic means.

Ten State's Standards
A compilation of accepted civil engineering water treatment plant design standards, published as "Great Lakes-Upper Mississippi River Board of State Public Health and Environmental Managers, *Recommended Standards for Water Works*" (1992).

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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Challenge seeding and elution of filter cartridges for concentration of *Cryptosporidium parvum (C. parvum)* oocysts were conducted by:

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Glen Latimer, Manager Municipal Sales, Chip Fatheringham, Coordinator-Pilot Operations, Sam Mason, Research Scientist, Skip Wolf and Jeff Hoover, Kinetico Incorporated are to be commended for providing the treatment system and the excellent technical and product expertise.

The University of Minnesota St. Anthony Falls Hydraulic Laboratory staffs including Scott Morgan, M.S., P.E. Research Fellow, Jeff Marr, Research Fellow, Julie A. Tank, Jr. Engineer, and Jason McDonald, Jr. Engineer, are to be recognized for their assistance during the pilot setup, and tear down as well as assistance during the pilot operation.

COA also wishes to thank the Minnesota Department of Health, Drinking Water Protection for their invaluable analytical and operational assistance, especially Gerald Smith, P.E., Public Health Engineer, and Anita C. Anderson, Public Health Engineer.

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) project, one of 12 technology areas under ETV. The DWTS project evaluated the performance Kinetico, Inc. (Kinetico) SW224 Backwashable Macrolite® Pressure Filtration System (KI SW224 Filter System), which is a backwashable depth filter used in package drinking water treatment system applications. The testing of the system was conducted to verify the system's capability of removing *Cryptosporidium parvum* (*C. parvum*) and *Giardia lamblia (G. lamblia)*. This document provides the verification test results for the Kinetico SW224 Filter System.

1.2 Testing Participants and Responsibilities

The ETV testing of the Kinetico SW224 Filter System was a cooperative effort between the following participants:

NSF International
Cartwright, Olsen & Associates, LLC
Kinetico, Incorporated
Debra Huffman Env. Consulting
BioVir Laboratories, Inc.,
Spectrum Labs, Inc.
University of Minnesota St. Anthony Falls Hydraulic Laboratory
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 and primarily quality oversight of the verification testing. An audit of the field analytical and data gathering and recording procedures was conducted. 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.

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1.2.2 Field Testing Organization

Cartwright, Olsen & Associates, a Limited Liability Company, conducted the verification testing of Kinetico SW224 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 for 30 calendar days. 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 influent water conditions were such that the verification testing could meet its stated objectives. The FTO prepared the FOD, oversaw the pilot testing, managed, evaluated, interpreted and reported on the data generated by the testing, as well as evaluated and reported on the performance of the technology.

FTO associates and University of Minnesota staff conducted the onsite analyses and data recording during the testing. Oversight of the daily tests was provided by the FTO's Project Manager.

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Contact Person: Philip C. Olsen, Project Manager
E-mail: p.olsen@ix.netcom.com

1.2.3 Manufacturer

The treatment system is manufactured by Kinetico, a manufacturer of non-electric, demand operated water processing systems. Kinetico has grown rapidly into one of the largest manufactures of water treatment systems worldwide. Kinetico is headquartered in Newbury, Ohio

Kinetico was responsible for supplying a field-ready Kinetico SW224 Filter System equipped with all necessary components including treatment equipment, instrumentation and controls and an operations and maintenance manual. Kinetico was responsible for providing logistical and technical support as needed as well as providing technical assistance to the FTO during operation and monitoring of the equipment undergoing field verification testing.

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Fax: (440) 564-9541
Contact Person: Glen Latimer
E-mail: glatimer@kinetico.com

1.2.4 Analytical Laboratories

Challenge seeding and recovery of *G. lamblia* and *C. parvum* (oo)cysts:

Contact Information:

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

BioVir Laboratories, Inc. of Benicia, California, performed microbiological laboratory work. BioVir's laboratory is certified by the California Department of Health Services. Additionally, the laboratory has received Protozoa Laboratory Approval from the EPA under the Information Collection Rule (ICR) Program. A copy of the Laboratory Approval Statements is attached in Appendix A.
Contact Information:

BioVir Laboratories, Inc.
685 Stone Road
Benicia, California 94510
Phone: (707) 747-5906
Fax: (707) 747-1751
Contact: Richard E. Danielson, Ph.D., Quality Assurance Officer, Principal Analyst/Supervisor

Tests for Escherichia coli (E.coli), Coliform bacteria and off-site non-microbial work were performed by Spectrum Labs, Inc. Spectrum's laboratory provided analytical services for Total Alkalinity, Total Hardness, Total Organic Carbon (TOC), Ultraviolet $(UV)_{254}$ Absorbance, True Color, Total Coliform, Algae, (number and species), Iron and Manganese.

Contact Information:

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

1.2.5 *University of Minnesota St. Anthony Falls Hydraulic Laboratory*

The University of Minnesota St. Anthony Falls Hydraulic Laboratory (SAFHL) structure is located on Hennepin Island at the head of St. Anthony Falls in the heart of Minneapolis. It is literally carved from the limestone ledge forming the falls on the Mississippi River.

SAFHL's primary purpose is to provide a research program to support graduate studies in water resources engineering and hydromechanics.

During the testing of the Kinetico SW224 Filter System, SAFHL provided the use of their facility, and assisted COA in the installation, initial operations and equipment operation and monitoring during the performance verification period.

Contact Information:

University of Minnesota
St. Anthony Falls Hydraulic Laboratory
Engineering, Environmental and Geophysical Fluid Dynamics

Department of Civil and Mineral Engineering
Mississippi River at Third Avenue S.E.
Minneapolis, Minnesota 55414-2196
Phone (612) 627-4010
Fax: (612) 627-4609
Contact: Scott Morgan, M.S., P.E. Research Fellow
E-mail: morga016@tc.umn.edu

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 Drinking Water Treatment Systems Pilot operating under the ETV Program. This document has been reviewed for technical and quality content by the EPA.

1.3 Verification Testing Site

In March through May of 2000, the ability of the Kinetico SW224 Filter System to remove *C. parvum* oocysts and *G. lamblia* was tested at the University of Minnesota SAFHL. A blend of untreated and treated water from the Mississippi River was used for this verification test.

The test site was accepted by the manufacturer to represent a challenging surface water condition as compared to an optimum condition for their equipment. While pH was not within the range the manufacturer considers their equipment to perform at its best, it is within what is often encountered in the field and as such appropriate for an ETV challenge.

1.3.1 Source Water

The SAFHL has direct access to untreated and treated Mississippi River water. Untreated river water was supplied directly from an intake operated by the SAFHL. The Minneapolis Water Works (MWW) treatment plant provided treated river water to the Hydraulic Laboratory through the Minneapolis potable water distribution system.

The Mississippi River, at SAFHL's location, is considered part of the Upper Mississippi River Basin area. The U.S. Geological Survey (USGS), U.S. Department of Interior, National Water-Quality Assessment (NAWQA) program provides the following description of this 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 clay 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 study area: forests cover much of the northern and eastern parts of the basin area, and the Twin Cities (location of the MWW) dominates the east-central part of the basin area.

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

The climate of the Minneapolis, Minnesota area is sub-humid continental. The average monthly temperature ranges from –12° Celsius (°C), (11º Fahrenheit (ºF)) in January to 23°C (74ºF) in July. Average precipitation at the MWW is 30 inches. About three-quarters of the annual precipitation falls from April to September.

Mississippi River water is treated at the Minneapolis Water Works. The treatment plant is the largest water utility in the upper Midwest, producing 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 and piped to the pumping station. From the pumping station, the water is delivered to a softening plant. At the softening plant, 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. Powered activated carbon is 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, chloramine (chlorine and ammonia) is added for initial disinfection, fluoride is added for tooth decay prevention and ferric chlorine 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 32½day ETV test period, influent water to the Kinetico SW224 Filter System, which was a blend of river water and treated water from the MWW, exhibited the following characteristics: turbidity concentration average of 0.77 nephelometric turbidity unit (NTU), temperature range from 7.1°C to 15.4°C, pH in the range of 7.2 to 9.5, total alkalinity of 53 Milligram per Liter (mg/L), total hardness of 80 mg/L, total organic carbon (TOC) concentration less than or equal to 6.4 mg/L, UV Absorbance @ 254 nm of 0.082 to 0.108 cm^{-1}, and true color of 10 Total Color Units (TCU). Iron was not detected or was below the Practical Quantification Limit (PQL) of 0.1 mg/L. Manganese was analyzed at 0.02 mg/L or below the PQL of 0.01 mg/L throughout the testing period. Total coliform was measured six times during the testing period. Five out of the six times no total coliform was measured or was below the PQL of 1 Colony Forming Units (CFU)/100 milliliter (mL). Total coliform was measured one time at 87 CFU/100 mL. During the testing period six samples were tested for algae. Five times out of the six algae were not detected or were below the PQL of 1 Algae/mL. One Algae sample contained

Nitzschia (genus within the group Diatoma of Algae) at a concentration of 25 Algae/100 mL. At the test site, the blended, untreated and treated Mississippi River water, was dosed with liquid sodium hypochloride to assure water supplied to the filtration equipment maintained a measurable, but low level of free chlorine. Free chlorine measured in the filter influent during the test period averaged 0.78 ppm. During protozoan seeding studies, sodium hypochloride was replaced with injection of sodium thiosulfate to assure any free chlorine residual from the treated water supply was reduced to a level that would not interfere with the seeding study. A summary of the influent water quality information is presented in Table 1-1 below.

Table 1-1. Influent Water Quality (March 24 – May 1, 2000)

Parameter	Average	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Total Alkalinity (mg/L)	53	47	62	5	49, 58
Total Hardness (mg/L)	80	74	88	5	76, 85
TOC (mg/L)	6.4	6.1	6.5	0.1	6.3, 6.5
UVA_{254} (cm^{-1})	0.098	0.082	0.108	0.011	0.088, 0.108
Turbidity (NTU)	0.777	0.31	2.52	0.15	0.76, 0.77
Free Chlorine (ppm)*	0.78	0.27	1.48	0.42	0.64, 0.92

* - Free chlorine measurements taken during normal equipment operation (see Section 4.3.4.1 for measurements taken during seeding).

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 Hydraulic Laboratory. No discharge permits were required.

Chapter 2
Equipment Description and Operating Processes

2.1 Historical Background

Filtration is the most ancient of all water treatment methods. The slow movement of water through granulated media, commonly sand, coal or charcoal, has been employed as a civil engineering technique for almost as long as water has been distributed in communities. Water that is muddied, discolored, or contains debris of varying sizes, has long been poured through filter media and the accumulated debris then scraped or backwashed away.

Only in recent times have scientists been able to quantify the collection of material within the filter bed, especially the particulate matter—including microbes—that lie below our visual capabilities. We now know that particles that we cannot see can also be removed by filtration. Still under study, however, are the mechanisms through which particulate matter, including microscopic life forms, are accumulated within the filter media.

It has been assumed that along with simple straining, which is the physical capture of particles too large to move through the pores between the media granules, smaller particles are captured through other attachment mechanisms. Most of those mechanisms involve a surface charge attraction of the granulated media to the particle. Many experiments have been performed to better describe the attraction process and to seek methods to improve it. Other mechanisms include particles that are collected by impact on the surface of filter media granules as well as multiple particles bridging between filter media granules.

The most common filtration system used in municipal treatment is the gravity filter, which uses the weight or head of the water to force it through the filter at very low flow rates. Normal gravity filters, often called "rapid" sand filters, have a normal flow rate of 3 gallons per minute (gpm) per square foot of surface, or less. Other filters, such as slow sand filters, have even slower service flow rates.

Also listed among rapid sand filters are pressure filters, where the water is forced through a media bed by high head pressures, and where the media bed is contained in a pressure vessel. They have long been used for iron and manganese removal, but have not been as readily accepted for surface water treatment where microbial matter is of concern (Ten State's Standards, 1992). The advantages—especially to small systems—of rapid sand pressure filters, are many. They are relatively passive treatment systems, involve minimal operator attention, are low in cost and long-lived. Of concern, however, is whether pressure filters can capture and contain particles that are small, and more importantly, particles that may pose a threat to public health, such as the protozoan oocyst *C. parvum*.

C. parvum oocysts are small, from 4 to 6 microns (µm) in diameter, relatively spherical in shape, and somewhat pliable. They have a slight electronegative surface charge which serves to keep them separated from each other; that is, they behave as colloids in water suspensions (Cushen, 1996, Drozd, 1996, American Water Works Association (AWWA), 1992, Ongerth, 1996, Harter, 2000). *G.*

lamblia cysts are slightly larger and elongated with one cross section 5 to 7 µm in diameter, and the other up to 15 µm in cross section.

2.2 Equipment Description

The equipment tested in this ETV program and shown in Figure 2-1, was the Kinetico SW224 Filter System. The Kinetico SW224 is designed expressly for small system applications. Spatial size of the Kinetico SW224 Filter System was 4' 1¼" W x 9' 6½ L x 8' 7¼" H.

Media vessels (filters) measured 24" in diameter and 72" in height and are offered in fiberglass or steel construction. Fiberglass reinforced polyethylene media tanks, pressure rated to 100 psi, were used for this study. The liquid volume capacity of each media vessel is 119 gallons without media. Filter media bed depth was 36". Sub-fill was not used. Total liquid volume capacity with media was at 87 gallons:

Tank manufacturer specifies 119 gallons as total tank capacity (or 15.91 ft^3). Filter bed depth = 36". Tank height is 72". Filter bed depth = 36", (or ½ of total tank volume of 15.91 ft^3). Total media within tank = ½ x 15.91 = 7.96 ft^3. Porosity of media is calculated from data found in Section 2.2, page 11. Porosity = Specific gravity (2.23 g/cc) x Total intrusion volume (0.2098 mL/g) = .47 mL/cc (or 47%).

Total displacement of water within 7.96 ft^3 of media bed with 47% porosity = (7.96 ft^3 x 7.48 gallons x 53%) = 30.96 gallons (or 31 gallons). Accordingly, total tank water volume = (119 gallons - 31.56gallons) = 87.04 gallons (or 87 gallons).

Two identical filters are used within the Kinetico SW224 Filter System. Filters are identified as "T1A" and "T2A" and operating alternately.

The filter media is Macrolite®, a synthetic ceramic, filter media and is not included in AWWA standards for filter media (B100-89). Standard B100-89 is a purchase guide for filter media and is not intended as a design standard; however, many of the testing parameters will be of interest to public health administrators, especially those physical characteristics that may impact on the longevity of the material. Thus, hardness, specific gravity, acid solubility, uniformity coefficients, particle sieve size distributions (within manufacturing lots and from lot to lot) and other similar physical data have been furnished by the manufacturer and are noted below.

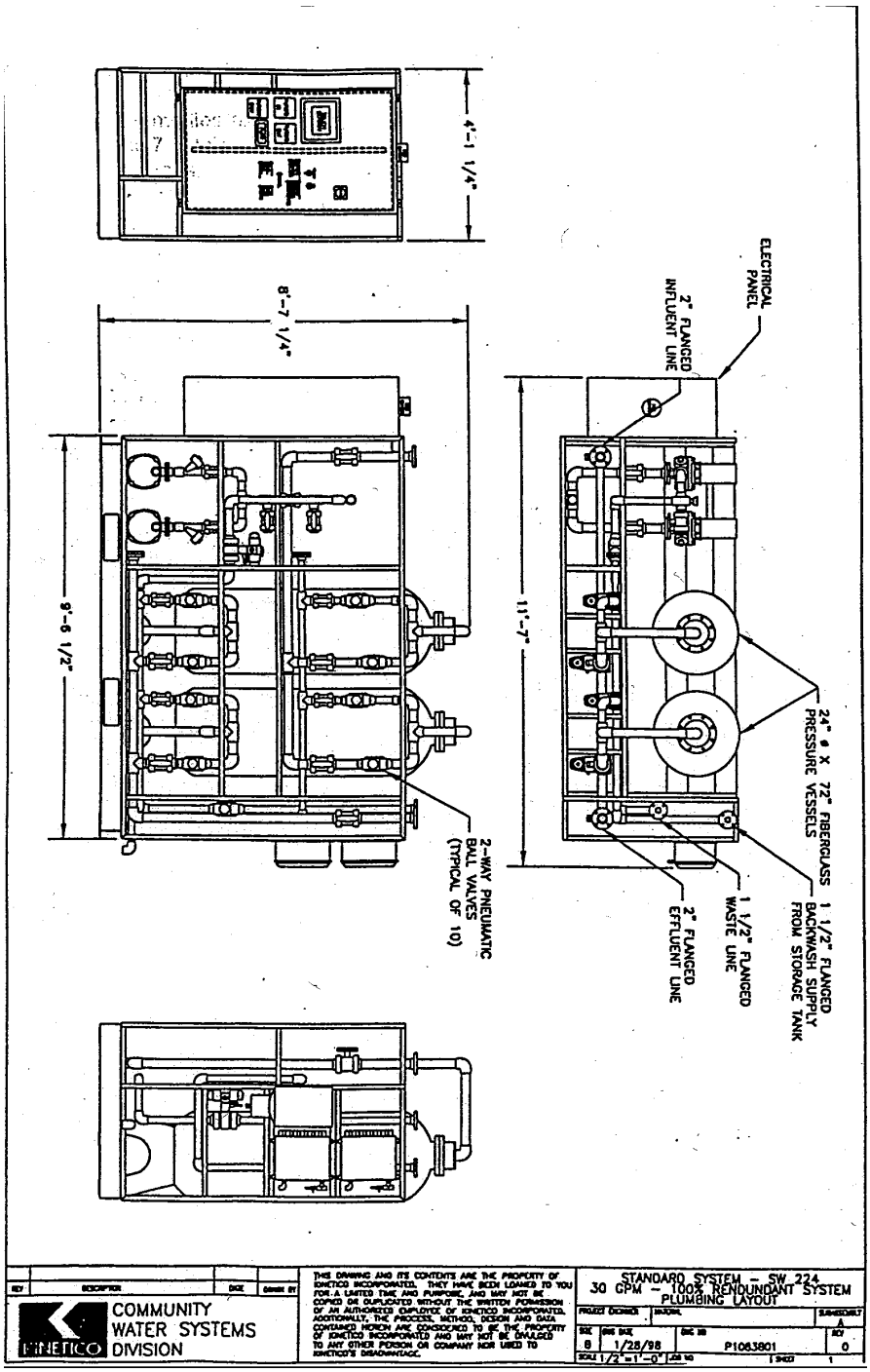

Figure 2-1. Schematic of the Kinetico SW224 Filter System

Macrolite® of the 70/80 mesh size has a bulk density of 0.96 grams/cubic centimeter (cc). The specific gravity (as measured by American Society for Testing and Materials (ASTM) D2840) is 2.23 g/cc. The collapse strength for the media of this size has not been measured, however, for a larger sphere (30/50 mesh) the collapse strength (as measured by ASTM D3102) is a nominal 7,000 psi for 10% and nominal 8,000 psi for 20% collapse.

The uniformity of the Macrolite® 70/80 mesh media was analyzed in accordance with AWWA Standard B100-96 by Bowser-Morner, Inc in December, 1997. The results of this analysis are summarized below in Table 2-1.

Table 2-1. Uniformity of Macrolite® 70/80 Mesh Media (AWWA Standard B100-96)

Sieve Size, USA Std.	Nominal, mm	Effective, mm	Percent passing
#45	0.355	0.360	100.0
#50	0.300	0.307	99.9
#60	0.250	0.249	79.8
#70	0.212	0.212	28.9
#80	0.180	0.180	7.2
#100	0.150	0.150	0.4

Effective Size: 0.19 mm
Uniformity Coefficient: 1.2

In addition, a Kinetico Inc. internal laboratory analysis in June 1998 of 70 mesh media (Lot #352) employing a mercury/penetrometer Micromeritics Autopore II 9220 instrument produced the following results as shown in Table 2-2.

Table 2-2. Uniformity of Macrolite® 70/80 Mesh Media (Micromeritics Autopore II 9220)

Total intrusion volume	0.2098 mL/g
Total pore area	0.18 sq-m/g
Median pore diameter by volume (based on volume distribution curve)	53.7990 µm
Median pore diameter by area (based on area distribution curve)	52.5351 µm
Median pore diameter (based on 4V/A)	46.5685 µm

The pore diameters are those measures by an instrument, AutoPore II, performing an intrusion study of the media. A measured volume of the media was placed in a glass penetrometer which was then degassed by vacuum. A known volume of mercury was introduced into the penetrometer which was then placed under pressure. As the mercury penetrates the interstitial spaces, the volume is electronically measured. The volumes and pore sizes are then calculated from the data by use of the Washburn Equation. The total intrusion volume is the maximum volume of mercury at the highest pressure; the total pore area is the area of the pore wall as calculated on the pore shape as a right cylinder. The Median Pore Diameter (volume) is the pore diameter at the 50^{th} percentile point on the volume distribution curve; the Median Pore Diameter (area) is the pore diameter at the 50^{th} percentile point on the area distribution curve and the Average Pore Diameter (4V/A) is based on the total pore diameter wall area of a right cylinder.

A Material Safety Data Sheet for the Macrolite® was included as part of the FOD. Macrolite® media meets the requirements of ANSI/NSF Standard 61 and is NSF certified.
Accessories and instrumentation included with the Kinetico SW224 System included flow rate and pressure sensors and monitors, on-line turbidimeters, pressure gauges, backwash pumps and an electrical enclosure containing a programmable logic controller and a touch screen monitor. The equipment also contained data transfer connections available for remote monitoring.

The flow of water through the system is controlled with hydro pneumatically actuated valves mounted on face piping constructed of Schedule 80 PVC. Automatic valves are actuated via a programmable logic controller. The valves also have handles for manual activation.

Electrical power was required for operation of backwashing pumps, air compressor, analytical instruments and system instrumentation.

The manufacturer claims the filter media is long lasting and estimates that less than 2% per year is lost to attrition.

The filters are shipped skid mounted and absent of media. Filter media was loaded on site. The total weight of the system, without media, is approximately 1,700 pounds.

A process design schematic of the Test Station, including the Kinetico SW224 Filter System, used to conduct this ETV test is shown in Figure 2-2.

The Test Station supplied a mixture of raw Mississippi river water and fully treated Minneapolis City water. The Test Station consisted of flow regulating valves, pumps, chemical metering pump, and storage containers to maintain a consistent blend as measured by turbidity. An injection probe and on-line static mixer were located at the outlet of the blending station for injection of (oo)cysts during microbial challenge testing.

A Watts Reduced Pressure Zone (RPZ) backflow prevention device was installed on both the untreated and treated water supply lines to the blending station to ensure (oo)cysts were not inadvertently introduced into either stream.

While the manufacturer requires the Kinetico SW224 be supplied with chlorinated feed water, chlorination equipment was not provided with the equipment package. Accordingly, the test station included a liquid sodium hypochloride metering pump to assure a measurable concentration of free chlorine was always present within the blended feed water supply. Further, during protozoan seeding studies, sodium hypochloride was replaced with injection of sodium thiosulfate to assure free chlorine residuals from the treated water supply was reduced to a level that would not interfere with the seeding study.

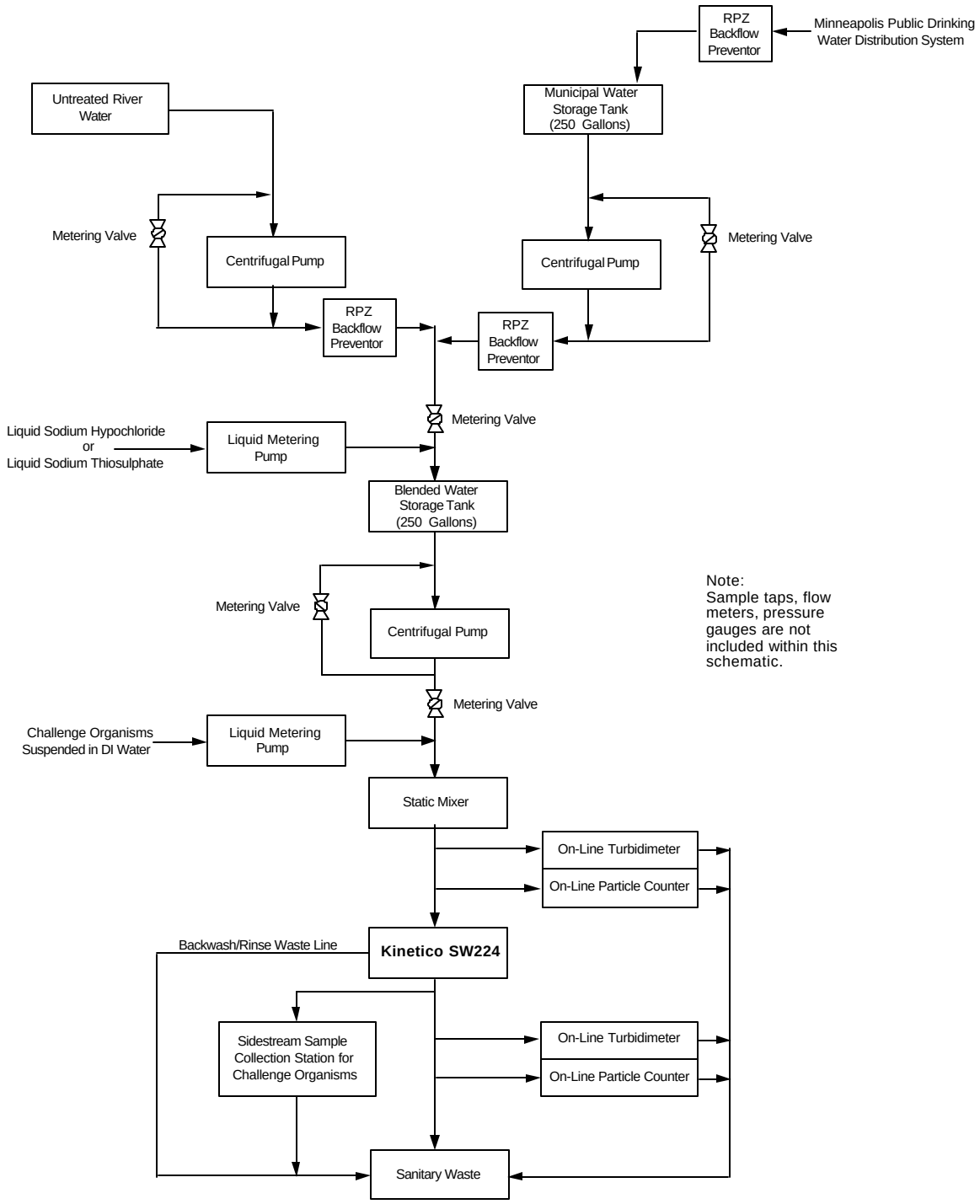

Figure 2-2. Process Design Schematic Of The ETV Test Station for the Kinetico SW224 Filter System

The following two photographs were taken of the equipment while it was on-site at the University of Minnesota Hydraulic Laboratory for the verification testing.

Photo 1. Front view of the was Kinetico SW224 Filter System at the University of Minnesota

Photo 2. Side view of the Kinetico SW224 Filter System at the University of Minnesota.

2.3 Operator Licensing Requirements

While limited operator experience is required, most states will require a licensed water treatment plant operator to operate and maintain the system on a regular (daily) schedule. Operator training for small systems filter operation is limited and offered by the manufacturer on delivery of a system. The manufacturer requires no special license beyond that required by the state of local public health authorities. Kinetico reports that licensing has not been an issue in prior installations of the equipment. Operators of community water supplies have requirements that vary from state to state. In Minnesota, there are four levels of community water plant operator qualification: A, B, C and D, depending on the size of the community. At this time there is no requirement for licensing for operators of non-community, non-transient public supplies; however the state is considering enacting such a requirement. There is also no requirement for licensing for operators of transient, non-community public water supplies, and there is little likelihood of such a requirement due to the nature of the owner/operator status of most such facilities. Other states may have requirements beyond those noted here, although it is expected that designers of public health water treatment installations will be familiar with any requirements specific to their state or municipality. There may be possible Federal requirements concurrent with the enactment of the Enhanced Surface Water Treatment Rule (ESWTR), but those are not yet in effect.

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 the 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.

3.1.1 Objectives

The verification testing was undertaken to evaluate the performance of the Kinetico SW224 Filter System. Specifically evaluated were Kinetico'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

The experimental design plan was prepared to challenge the Kinetico SW224 Filter System for its capability of removing viable *C. parvum* and *G. lamblia*.

3.1.1.2 Evaluation of Equipment Performance Relative To Water Quality Regulations

With increased awareness of pathogens resistant to traditional disinfection techniques, and with implementation of the ESWTR and the Groundwater Rule in the near future, it is expected that the search for alternative disinfection technologies will grow significantly. The current ESWTR requires a 2-$\log_{10}$ removal of *C. parvum*.

C. parvum oocysts are small, from 4 to 6 µm in diameter, relatively round in shape, and somewhat pliable. They have a slight electronegative surface charge that serves to keep them separated from each other; that is, they behave as a colloid in water suspensions (Cushen, 1996; AWWA, 1992; Ongerth, 1996; Harter, 2000). The purpose of the verification test is to demonstrate whether the Kinetico SW224 pressure filter can act as a suitable barrier for these particles, preventing their passage into drinking water.

3.1.1.3 Evaluation of Operational and Maintenance 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 Operations and Maintenance (O&M) manual, experiences, and events that occurred during the verification period 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 B.

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. Pump motors, flow meters and electronic monitoring devices required repairs as noted in the discussion sections below. The O&M manual details various maintenance activities and their frequencies.

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 operational and cost factors. The quantitative factors examined during the verification were operational aspects of the Kinetico SW224 Filter System, for example, the measurement of head loss, as well as other factors that might impact performance. The qualitative factors examined during the verification testing process included, ease of operation and troubleshooting. Costs associated with the system largely included power requirements. The operating conditions were recorded to allow reasonable prediction of performance under other, similar conditions. Also to be noted and reported were any occasional, anomalous conditions that might require operator response such as high levels of algae growth, excessive turbidity spikes or frequent filter clogging. It is important to note that the results obtained here are for the Kinetico SW224 Filter System. This treatment system operated at 8.25 to 9.75 gpm/ft^2 at 7.1°C to 15.4°C.

3.2 Verification Testing Schedule

The verification testing started on March 24, 2000 and continued for 32 ½days of operation and data recording. During this period a total of 78 filter cycles occurred. Data was logged for a total of 779.5 hours of treatment system operation. The system was shut down for a total of 132.5 hours, between April 12 and April 18, 2000 due to problems found in EPA Method 1623 associated with the testing of *Giardia muris* (*G. muris)* versus *G. lamblia*. The DYNAL immunomagnetic separation (IMS) technology used in EPA Method 1623 to concentrate and clarify protozoa samples cannot be used on *G. muris* due to an extremely low affinity for the *G. muris* cysts. The shut down on the test unit was due to the lead-time needed to secure the *G. lamblia* for the retesting. Original testing was performed with *G. muris* due to safety considerations, because *G. muris* is not a human pathogen.

Microbiological challenge testing was performed during March 27 through March 29, and again during April 24, 25 and 27, 2000. Daily testing concluded on May 1, 2000.

3.3 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 successfully treat the source water. Initial operations procedures included a characterization of influent water, and establishment of

operational data such as filter run times and backwashing schedules. Information gathered during system start-up and optimization was used to refine the FOD. Adjustments that were made to the FOD included:

- Water temperature was recorded once per day due to the stable water temperature conditions of the influent water.
- Blending raw river water with finished municipal drinking water to achieve influent turbidity of 1.0 NTU provided water quality of minimal color. Therefore, color was not measured after the first week of testing.
- The flow rate across the filter bed was allowed to decrease as pressure differential across the filter increased during each filter run. This was done to better emulate the true field operational conditions of the packaged water treatment plant under test.

The Kinetico SW224 Filter System was on site in November of 1999. Shortly thereafter, the test station was installed and plumbed to the filter system.

3.3.1 Characterization of Influent Water

The objective of the Initial Operations was to determine the suitability of the influent water to the application of the technology.

The suitability of the influent water to the application of this technology was reviewed before testing. Mississippi River data from past years from local and regional sources was compiled and analyzed with respect to the biological, physical and chemical characteristics of the water. Parameters studied at the verification testing site include (but were not limited to) the following: Turbidity, Temperature and temperature variations within a season, pH, Total Alkalinity, Hardness, TOC, UV_{254} Absorbance, True Color, Total Coliform, Algae (number and species), Iron, Manganese, and Free Chlorine. Review of this data indicated that the technology should be suitable for this site.

Due to blending untreated river water with water from the Minneapolis public drinking water distribution system chloramine residual was reduced. Accordingly, sodium hypochlorite was injected into the blended during normal operation to elevate free chlorine to a detectable level. During the *C. parvum* and *G. lamblia* seeding studies, injection of sodium hypochlorite was replaced with sodium thiosulfate to remove chloramines carried over from Minneapolis drinking water supply within the blended water.

The parameters, which were analyzed as part of this testing and the sampling frequency, are presented in Table 3-1, Section 3.4.

Intermittent factors that might influence water chemistry, such as weather, boat traffic, in and out-flows, and bottom composition were noted in the logbook where appropriate. The Mississippi River has, by the time it reaches this location, been exposed to municipal, industrial and agricultural use. The flow past this point varies with the season, however typically exceeds 3,000,000 gallons per minute, and has

been augmented by other rivers, somewhat less stressed by industry. The effects of most upstream activity have been diluted accordingly.

3.3.2 Initial Test Runs

The purpose of the initial test runs was to establish operational data such as filter run times and backwashing schedules, and to qualify the equipment for performance with the selected source water.

Initial test runs were performed to both terminal headloss and to turbidity breakthrough. Flow rate variations and the character of effluent water were also studied to determine optimum operational conditions. Backwashing was initiated when either a terminal headloss was reached or when turbidity breakthrough occurred. Filters were backwashed until the waste stream ran clear, as determined by turbidity of 5 NTU or less. Similarly, filters were rinsed (down flow) to waste until turbidity reached 0.5 NTU before they were put online. Terminal headloss was considered when a filter experienced a 22-psi pressure differential between inlet and outlet.

Upon return to service, the filter ripening period was monitored and timed. These data were used to determine the benchmarks for automatic backwash, rinse and run cycles during the testing and verification period.

During initial operations, tracer tests using sodium chloride brine of approximately 313,000 mg/L concentration were used to determine the amount of time required for a change in influent feed water quality to be detected in the filter effluent stream, and then, the amount of time required for the concentration of Total Dissolved Solids (TDS) in the effluent stream to become homogeneous with the concentration of TDS in the influent stream. This information was needed to establish the start time and length of effluent sample collection periods during microbial seeding challenges.

Tracer tests were conducted when the filter was in service and subjected to a process flow of 29 gpm. The brine solution was injected into the influent stream with a metering pump and injection probe previous to an in-line static mixer. Portable TDS meters were used to establish baseline concentrations (mg/L dissolved solids) previous to brine injection. Previous to brine injection the metering pump was primed and the tubing connected to the pump outlet to the injection probe was flooded with the brine solution. Also, previous to injection sample taps located close to the outlet of the in-line static mixer and on the filter effluent line were partially opened to allow a continuous flow rate of approximately 1 gpm. Filter flow rate was verified with a rotometer and influent and effluent TDS meters were calibrated against each other. A stopwatch was used to track time once the metering pump was started. Once the brine injection commenced, sample cells of two portable TDS meters were triple rinsed and samples collected every minute until the effluent sample TDS concentration elevated to the same concentration as the influent sample and then continued for several minutes after this equilibrium was achieved. After that point, the metering pump was stopped and injection of brine discontinued. Samples were collected after that point with the same frequency to determine if TDS concentrations decreased at the same rate and time as they had previously increased. Two tracer tests were conducted due to a TDS meter failure during the first two minutes of the first tracer test.

The use of sodium chloride brine over tracer dye in this application was preferable because dissolved sodium chloride can be conveniently measured at small increments, thereby demonstrating both initial and final concentrations; it dissolves readily and hence is not impeded by the filter; and after the tracer test is complete, it is rinsed clean it leaves no residual on the filter media.

3.4 Verification Task Procedures

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

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

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

3.4.1 Task 1 - Verification Testing Runs and Routine Equipment Operation

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

The ETV protocol required the equipment be run continuously for a minimum of 30 days. One verification test period was conducted over a total period of 32½days (779.5 hours). Verification testing consisted of continuous evaluation of the treatment system, using the most successful treatment parameters defined in Initial Operations. During this period the FTO attempted to provide influent water quality consistent with the Kinetico's statement of performance capability of the equipment. Influent water quality (turbidity and temperature) during this period ranged from 0.31 to 2.52 NTU, and 7.1°C to 15.4°C.

Temperature, turbidity, other influent water quality parameters such as algae, natural organic matter, and pH will influence filtration performance. In order to offer a "worst case" challenge to the equipment under test, verification testing conditions included water of varying quality. Under these conditions a total of 78 filter runs were monitored.

The Kinetico SW224 had control functions that allowed for differing conditions to initiate backwash. The control functions that allowed backwash initiation due to headloss were verified as well as the controls that initiated backwash based on turbidity breakthrough.

Also tested was the ability of the filter to attain previous filter performance following an interruption of flow. The Kinetico SW224 is configured to follow each interruption (stop-start) with a filter-to-waste cycle. This aspect and the resultant particle distribution were evaluated.

Flow rate and total gallons produced are among the factors that were recorded.

Standard operating parameters for filtration and backwash were established through the use of the manufacturer's O&M Manual and initial operations of the treatment system. After establishment of these parameters, the unit was operated under those conditions.

3.4.2 Task 2 - Influent and Effluent Water Quality Characterization

Characterization of the influent water quality of the system was an important consideration in the development of the experimental design of the ETV Test Plan. Water quality and microbial analyses were selected to demonstrate the effectiveness of the manufacturer's equipment.

Analyses for *G. lamblia*, *G. muris* cysts and *C. parvum* oocysts were conducted during the microbial removal phase of the evaluation. These analyses were conducted using procedures developed by the EPA for use during the ICR for the identification and enumeration of *G. lamblia* cysts and *C. parvum* oocysts, in particular Method 1623 (EPA, 1999). It was discovered during laboratory analysis that the DYNAL IMS technology (prescribed in EPA Method 1623) to concentrate and clarify protozoa samples could not be used on *G. muris* due to an extremely low affinity for the *G. muris* cysts. Therefore, the microbial challenge testing was repeated, and *G. lamblia* was used for the retesting.

This task evaluated the water quality matrices of the influent and effluent water and identified the composition of the removed particulate material with the relationship to terminal headloss and/or turbidity breakthrough point. The collection of water quality parameters was performed as in Table 3-1. Samples of both influent and effluent water were analyzed.

Table 3-1. Analytical Data Collection Schedule

Parameter	Frequency	Influent	Effluent
On-Site Analyses			
Temperature	Daily	X	
pH	Daily	X	
Turbidity	Continuous	X	X
Particle Counts	Continuous	X	X
Free Chlorine	Varied	X	
Laboratory Analyses			
Total Alkalinity	Daily	X	X
Total Organic Carbon	Weekly	X	X
Total Hardness	Weekly	X	X
UV Absorbance (254)	Weekly	X	X
True color	Once per period	X	X
Total Coliform	Semi-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 as in *Standard Methods for the Examination of Water and Wastewater* 19th Edition (*SM*) or EPA-approved methods. All on-site testing instrumentation or procedures were calibrated and/or standardized by FTO staff. Evaluation of water quality in this task was related with respect to manufacturer's claims of performance in addition to the SWTR.

Particle counts were evaluated and $\log_{10}$ removals calculated by recording the change between the $\log_{10}$ of the influent and effluent particle counts in the ranges of 2-3 µm, 3-5 µm, 5-7 µm, 7-10 µm, 10-15 µm, and 15+ µm. The aggregate of particle counting data obtained during verification testing was analyzed to determine the median $\log_{10}$ removal and the 95th percentile $\log_{10}$ removal during the test period. The filter runs varied between approximately 1 and 24 hours. Filter run performance is discussed further in Section 4.0, Results and Discussions.

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

The objective of this task was to denote the conditions surrounding the performance of the filter system, including the physical instrument measurement of pressure losses at and prior to turbidity breakthrough. Included in the performance parameters were flow rates (and any variations), pressures of influent and effluent streams, length of filter runs, and backwash lengths.

Flow rates were measured with Data Industrial Corp. on-line flow rate sensors and flow monitor (Series 2100). Accuracy was verified by bucket and stopwatch technique. A utility power meter, reading in kilowatt-hours, was attached to the power connection for the pilot plant.

The two filters were operated on an alternating basis near 30 gpm each at the beginning of each filter run, as specified by the Manufacturer, for a throughput flowrate of 9.55 gpm/ft^2 bed area. When one

filter approached the end of the run, as determined by one of the conditions noted above, the stand-by vessel was brought on line and the first filter was backwashed and placed into a standby mode. This process was automatically controlled by electrically activated, motorized ball valves, with no discernible loss of flow, and controlled automatically by the on-board programmable computer.

The Macrolite® media employed had a US sieve size of 70, as reported by the Manufacturer. This is equivalent to 0.008 inches (0.2 mm or 210 µm) average diameter for each sphere. The pore size for three such spheres that are touching leave a void that is 15.47% of the diameter of the spheres, or 32.5 µm, considerably larger than the size of *C. parvum* oocysts. Thus presumably, straining alone was not the sole mechanism of removal.

Surface attachment mechanisms, none of which are entirely understood, most likely did not influence contaminant removal. Some of the surface mechanisms had been related to pH and to ionic strengths as well as to surface charges. The performance claim established for this ETV test was not for removal of particulate matter only, but also for protozoan (oo)cysts; thus it was important to include challenges employing viable (oo)cysts in this testing.

Treatment equipment operating parameters for both pretreatment and filtration were monitored and recorded on a routine basis. This included a complete description of basis of initiation and operational parameters for filtration, backwash and rinse cycles. Data on filter head loss and frequency/duration of backwash cycles were also collected. Electrical energy consumed by the treatment equipment was also measured and recorded. Data for rates of waste production were also collected.

Operating data included in the evaluation during the ETV test are itemized below in Table 3-2.

Table 3-2. Operating Data

Parameter	Frequency
Influent water and Filter Flow	Checked and recorded 2 × /day. Recorded rates in logbook.
Filter Headloss	Recorded at beginning of run and at least twice daily; also recorded at end of run or when breakthrough occurred when technician was present.
Air Sparging	Recorded date, time and duration when technician was present.
Backwashing	Recorded date, time, influent and filtered water meter reading and calculated filter effluent water volume. Noted terminal headloss prior to filter backwash. Described reason for backwash; noted backwash rate and volume for each backwash when technician was present.
Electric Power	Read meter once daily at same time.
Hours of Operation	Recorded daily at beginning of first shift.
Filtered Water Production	Calculated total per filter run and total for each day per filter.
Watershed Events	Recorded weather, snow melt, construction, excessive traffic or other events that could impact source water quality daily at end of shift.

3.4.4 Task 4 - Microbiological Contaminant Removal Testing

The objective of this task was to measure the ability of the filter to remove seeded microorganisms. This portion of the study was of central importance, as it is the ability of the filters to remove the target

microorganisms *C. parvum* and *G. lamblia* that is the primary claim of the manufacturer, and of greatest interest to the public water community.

The mechanism for removal of viruses by the Kinetico SW224 was *not* under examination here (that is beyond the scope of this ETV study). Here, only the ability to remove *C. parvum* and *G. lamblia*, to detach them from the media during backwash, and to prevent re-entry into the process stream, was challenged and verified.

3.4.4.1 Preparation of Microbial Doses

The *C. parvum* isolate used in this study was purchased from the University of Arizona and is also referred to as the Harley Moon or Iowa strain. This strain was originally isolated from a calf and has been maintained by passage through neonatal calves. A lot number was assigned to each calf on the day the calf was infected and a batch number was given for the day the oocysts were shed. These lot and batch numbers are recorded to validate oocysts' age. The oocysts excreted in the feces of experimentally infected calves were isolated from the feces by discontinuous sucrose gradients followed by microcentrifuge-scale cesium chloride gradients (Arrowood and Sterling, 1987; Arrowood and Donaldson, 1996). The purified oocysts were stored at 4°C in 0.01% Tween 20 solution containing 100 units of penicillin, 100 µg of streptomycin, and 100 µg of gentamicin per mL to retard bacterial growth. Oocysts were used within 90 days of isolation in all experiments.

The *G. lamblia* cysts were less than four weeks old, and were purchased from Waterborne Inc. (additional information on the *G. lamblia* cysts is discussed in Chapter 4, Results and Discussions). The cysts were stored in phosphate buffered saline without preservatives. At a field lab near the site, Debra Huffman PhD., divided them into the required number of doses, and into the required concentration of 10^8 oocysts and 10^7 cysts for injection into the water stream. The doses were prepared by removing an aliquot of the enumerated (oo)cyst suspension and enumerating using the method described in EPA Method 1623 (April 1999).

3.4.4.2 Analytical Schedule

There were three challenges employing a mixed cocktail of *G. lamblia* cysts and *C. parvum* oocysts.

During seeding studies, sodium thiosulfate was injected into the blended feedwater stream in place of chlorine to reduce residuals within the filter influent water previous to the point of protozoan injection. Measurements for free chlorine were conducted more frequently at these times to verify residuals had been reduced to a level that would not impact *C. parvum* or *G. lamblia* during the study.

During the seedings, 10-liter samples for microbiological evaluation (identification and enumeration) were taken from a side stream and filtered through a Gelman capsule filter for enumeration. Filter influent and effluent grab samples were taken as follows:

#1—At initial start up

#2—At the mid-point of the filter run
#3—At the end of the filter run, just prior to terminal headloss

These seedings allow determination of filter efficacy at several points in the filter cycle.

In addition, at a point in the middle of the run, the filter flow was stopped, and then restarted *without* a backwash sequence following a brief interruption. Grab samples (as well as particle counter and turbidity recordings) were taken immediately (within one bed volume) following the resumption of flow. The objective was to determine if interruption of flow allows previously captured organisms to detach from the filter media and re-enter the water stream. Pressure loss and flow data was also recorded before and after the interruption.

This sequence was repeated during three successive runs of the same filter; the second and third runs followed a run of the alternate, non-seeded filter. Since both filters are identical; only one filter of the two was employed for seeding studies.

The inoculation point was through an injection probe at the intake of the static mixer. A 100 milliliter graduated cylinder containing *C. parvum* and *G. lamblia* in suspension was connected by flexible tygon tubing to an injection pump and probe that extended into the axis of the static mixer. Each challenge test injected between 10^7 to 10^8 (oo)cysts concentrated into 100 milliliters of deionized water containing 0.01% Tween 20. There were no additional detergents, wetting agents or other chemicals added to the suspension. *C. parvum* and *G. lamblia* suspensions were injected into the influent stream as a slug dose over a period of two to four minutes. The 100 mL graduated container used for the original suspension was flushed three times with particle free sanitized water to void the excess (oo)cysts though the injection stream.

The influent concentration of (oo)cysts was determined by hemacytometer count (EPA Method 1623) based upon a grab sample from the influent container prior to injection.

The effluent concentration of (oo)cysts was determined based upon collection of a ten-liter sample using a one micron pore size Gelman capsule filter per EPA Method 1623. The $\log_{10}$ removal was determined as follows:

Effluent Concentration ((oo)cysts/L) x Process Flow Rate (L/minute) x Collection time (minutes) = Total (oo)cysts in the effluent.

The $\log_{10}$ removal was determined using the calculation N/N_0
where N= Total number of (oo)cysts in the effluent
N_0 = Total number of (oo)cysts in the influent

During the seedings, 10 liters were collected from a side stream at a rate of 170 milliliters per minute over a one-hour period (equivalent to 20 bed volumes) and filtered through a Gelman capsule filter for

enumeration. The 10 liter samples filtered through a Gelman capsule filter were evaluated in accordance with the procedures indicated in EPA Method 1623.

Simultaneous with the seeding, on-line particle counters located at the raw (seeded) water at the filter inlet following the static mixer and at the effluent of the filter, recorded at an interval of every two minutes for particles in the ranges of 2-3 µm, 3-5 µm, 5-7 µm, 7-10 µm, 10-15 µm, and 15+ µm.

3.4.4.3 Data Evaluation

Data from electronic particle counters were analyzed to determine the median $\log_{10}$ removal as well as the 95th percentile removal for the verification period. Particle count data were analyzed at one-hour intervals, except during challenge periods where additional particle count data was correlated to grab sample data times as closely as possible. The particle counter operated continuously, and recorded the particle counts in the ranges of 2-3 µm, 3-5 µm, 5-7 µm, 7-10 µm, 10-15 µm, and 15+ µm. The data was recorded electronically to display trends of particle count over time.

Turbidity was also evaluated continuously in two-minute intervals. The turbidity was recorded electronically and correlated to the particle count data.

Protozoa densities of filtered water were analyzed by EPA Method 1623 for median $\log_{10}$ removal and 95th percentile $\log_{10}$ removal for each of the operating points noted above: startup following backwash, midpoint, stop/start, and 85%-95% of terminal headloss.

3.4.4.4 Evaluation Criteria

All particle counting and turbidity data taken during the challenge period were correlated with the microbial samples. Microbial results were compared with the $\log_{10}$ removals for filtration processes in the SWTR, and with respect to Kinetico's expected values of a 1.5-$\log_{10}$ removal of *C. parvum*, and a 2-$\log_{10}$ removal of *G. lamblia*.

3.5 Recording Data

The parameters and operating data collected by the technician were maintained in a bound logbook and transferred to computer spreadsheets on a daily basis. Documentation of study events was facilitated through the use of logbooks, photographs, data sheets and chain of custody forms. In addition any variations in the treatment plant regimen were noted, such as changes in disinfection levels in response to varying biological contamination and unusual source water episodes (i.e., weather related incidents (ice outs, storms), unusual river traffic or contaminant spills).

Data handling is a critical component of any equipment evaluation testing. Care in handling data assures that the results are accurate and verifiable. Accurate sample analysis is meaningless without verifying that the numbers are being entered into spreadsheets and reports accurately and that the results are statistically valid.

The control system for the Kinetico SW224 Filter System included automatic data recording access and automatic systems were employed where possible.

3.5.1 Objectives

The objective was to tabulate the collected data for completeness and accuracy, and to permit ready retrieval for analysis and reporting. In addition, the use of computer spreadsheets allowed manipulation of the data for arrangement into forms, useful for evaluation. A second objective was the statistical analysis of the data as described in the "NSF/EPA ETV Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants" (EPA/NSF 1999).

3.5.2 Procedures

Data handling procedures were used for all aspects of the verification test. Procedures existed for the use of 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.

3.5.2.1 Logbooks

COA as the FTO for the project was responsible for the maintenance of the logbooks and field notebooks. Operational data was read and recorded for each day of the testing cycle. Data was collected in bound logbooks and on charts from the instrumentation panels and individual testing instruments. There was a single field logbook containing all on-site operating data that remained on site and contained instrument readings, on-site analyses and any comments concerning the test run with respect to either the nature of the feedwater or the operation of the equipment.

The logbook was identified as Kinetico Backwash ETV Test and each page of the logbook was sequentially numbered. Each completed page was signed by the on-duty FTO staff. 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 logbook. The logbook included a carbon copy of each page. The original logbook was stored on-site; the carbon copy sheets were 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.

3.5.2.2 Photographs

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

3.5.2.3 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 E).

3.5.2.4 Inline Measurements

Data from a computer recording continuous inline measurements for turbidity and particle counts were printed on a hard copy and copied to a disk on a daily basis. The data transfer disks were stored off site, at the FTO's office.

3.5.2.5 Spreadsheets

A COA technician entered data into a computer spreadsheet program (Microsoft© Excel) on a daily basis from the logbook and from 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 laboratory notebooks and the data logbook were entered into the appropriate spreadsheet. COA technicians conducted data entry. All recorded calculations were checked at this time. Following data entry, the spreadsheet was printed out and the printout was checked against the handwritten data sheet. Corrections were noted on the hard copies and corrected on the screen, and then a corrected version of the spreadsheet was printed out. The COA operator or engineer performing the entry or verification step initialized each step of the verification process. The data spreadsheets are attached to this report as Appendix C.

Each challenge test run was numbered for coordination with the on-site data from that run along with the laboratory testing data. The operating conditions for each test run were entered into the logbooks and onto the spreadsheet. The spreadsheet consolidated the information from Tasks 2, 3, 4, and the results from off-site laboratory analyses.

Computer data was transferred by the physical transfer of data disks.

3.6 Calculation of Data Quality Indicators

3.6.1 Representativeness

Water quality parameter samples for the Kinetico SW224 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.

3.6.2 Statistical Uncertainty

Statistical 95% confidence calculations were performed for critical water quality data. 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 is:

$$\text{Confidence Interval} = \overline{X} \pm t_{n-1,1-\frac{\alpha}{2}}\left(\frac{S}{\sqrt{n}}\right)$$

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.

$$95\%\ \text{Confidence Interval} = \overline{X} \pm t_{n-1,0.975}\left(\frac{S}{\sqrt{n}}\right)$$

3.6.3 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 protocols. Although Spectrum Labs could perform similar analyses to those performed on-site, the nature of the samples for pH, turbidity, temperature and chlorine levels, all tests of which were subject to change upon transport and time delay.

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	=	Recovery percent
A	=	Result of spiked sample
B	=	Result of un-spiked sample
S	=	Spike value

3.6.4 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.

Samples analyzed in duplicate or triplicate included bench-top turbidity measurements associated with verification of calibration of the on-line turbidimeter.

The equation employed for precision was:

$$\%RSD = D_1/D_2 \times 100$$

%RSD	=	% Relative standard deviation
D_1	=	Standard deviation of sample set
D_2	=	Mean of recovery values (of replicates)

3.7 Equipment

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

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

- A Hach 2100P portable turbidimeter (serial number 96090012047) was used for bench-top turbidity analysis.

- Pressure gauges were Ametek 556L (0 to 100 psi) with calibration field verified with a National Institute of Standards and Technology (NIST) traceable pressure gauge. There were four gauges on the system. Pressure gauges were located on the inlet and outlet of each filter vessel.
- NIST-traceable Miller Weber Thermometer, Model P63C Serial number 3E7652 was used for measurement of temperature.
- A rotometer (Blue and White model F451004LHN) (0 to 40 gpm) and a paddle wheel (Burkart, model #423-927B) were used to measure flow rates.
- On-line turbidity measurements were taken with Great Lakes Model 95T/SS4 turbidimeters.
- On-line particle count measurements were taken with Met One PCX particle counters (Serial numbers: 000100288 and 000100292).
- Chlorine measurements were taken with a HACH 2010 spectrophotometer.
- Pressure were glycerin-filled Ametek 556L and Orange Research Differential pressure gauges.

The operating procedures for the Kinetico SW224 Filter System are described in Kinetico's O&M Manual. The O&M Manual for the treatment system was maintained on-site and is attached to this document as Appendix B. Additionally, operating procedures and equipment descriptions were described in detail in Chapter 2, Equipment Description and Operating Process, of this report.

3.8 Health and Safety Measures

There was only one major safety concern for on-site staff with respect to this testing procedure. The microbes used during the testing were highly infectious. For protection against accidental infection by oocysts, strict environmental laboratory procedures were followed. Protective clothing such as gloves, glasses and lab coats was on hand and used when appropriate. The capture filters removed from the filtration housing were double bagged for shipment in protective containers. Laboratory personnel trained in biological safety performed the handling of all live oocysts and oocyst-containing materials.

Built into the equipment were a number of safety features. Since this equipment has been designed for installation in water treatment plants, interlock connections, breakers and other protective devices have been included in its manufacture.

3.9 QA/QC Procedures

The objective of the Quality Assurance/Quality Control (QA/QC) procedures was to control the methods and instrumentation procedures such that the data were not subject to corruption. Adherence to analytical methods, both on site and off site, as published in *Standard Methods* or EPA-approved methods was assured. Moreover, instrumentation and standard reagents were used in accordance to NIST. Instruments used to gather data were standardized and calibrated in accordance with the schedules noted below.

3.9.1 QA/QC Verifications

QA/QC verifications were performed at the beginning of each testing period included instrumentation checks, cleaning and maintenance of the turbidimeters, pressure gauges, tubing and other components. Flow meters were calibrated with the "bucket and stopwatch" technique. Turbidimeters were tested for volumetric accuracy and standardized. The particle counters were verified using calibrated microspheres in the 2, 5 and 15 µm levels.

Results of the several verification and QA/QC procedures are detailed in the Chapter 4, Results and Discussions section.

Daily QA/QC Verifications included:

- On-line turbidimeter flow rates verified volumetrically with a 2,000 mL graduated cylinder and stopwatch.
- On-line turbidimeter readings standardized against a calibrated bench-top turbidimeter.
- pH meter calibration verified at pH 7 and pH 10 with NIST-traceable pH buffers.
- Bench-top turbidimeter calibration verified against standards of 0.1, 0.5 and 3.0 NTU.
- On-line particle counter flow rates verified volumetrically with a 100 mL graduated cylinder and stopwatch.

One-time QA/QC Verifications included:

- On-line flow meters cleaned and flow verified volumetrically with a 55 gallon graduated container and stopwatch. The flow rate through the system determined by stopwatch and calibrated bucket, and compared to the flow rate as indicated on the flow meters and the results noted in the logbook.

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

- Cleaning and re-calibration of on-line turbidimeters; although required at the beginning of the verification period, the nature of the test was such that the turbidimeters needed to be cleaned much more frequently, a result to be discussed below.
- Verification of particle counter calibration using NIST microspheres at 3, 5 and 15 µm size. This procedure is noted in section 3.9.2.4 below.
- Verification of pressure gauges with NIST-traceable gauge.
- Inspection of particle counter and turbidimeter tubing for unimpeded flow and integrity.

Further descriptions on verifications of on-site instrumentation are provided below.

3.9.2 On-Site Analytical Methods

Specific instrumentation methods for on-site QA/QC are described below:

3.9.2.1 pH

Analysis of pH was performed according to *SM* 4500-H^+. A two-point calibration with NIST-traceable pH buffers of pH 7 and pH 10 was performed daily. Between tests the pH probe was kept wet in KCl solution. For on-site determination of pH, field procedures were used to limit absorbance of

carbon dioxide to avoid skewing results by poorly buffered water. The samples were collected in a dedicated beaker and promptly analyzed.

3.9.2.2 Temperature

Temperatures were measured in accordance with *SM* 2550 daily. The thermometer used was a NIST-traceable thermometer, marked in 0.1°C increments. During initial operations, temperature did not significantly fluctuate during any 24-hour period. Therefore, during the verification period, temperature was measured once per day, rather than twice per day as proposed within the FOD.

3.9.2.3 Turbidity

The on-line turbidimeters remained on during the duration of the testing period. On-line and bench-top turbidimeters were used for measurement of turbidity. The bench-top turbidimeter was the calibration standard for the test. The on-line turbidimeters were further verified against a standardization cell provided by the manufacturer, Great Lakes. The bench-top turbidimeter was calibrated at the start of testing and then weekly according to manufacturer's instructions at 20, 100 and 800 NTU with freshly-prepared Formazin suspensions. The provided Gelex vials were correlated with the turbidimeter for verification between calibrations. In addition, prepared Formazin standards of 0.1, 0.5, 1.0 and 3.0 NTU were used to verify turbidimeter calibration. The bench-top turbidimeter was a Hach 2100P, and is designed to shut off automatically after a specified period of inaction to preserve the battery; accordingly, it was not left on at all times. Manufacturer's procedures for maintenance were followed and the schedules for maintenance and cleaning noted in the logbook.

Samples were taken from a sample tap at a slow steady stream and along the side of a triple-rinsed dedicated beaker to avoid air entrapment. 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 were kept clean and handled with lint-free laboratory tissue. Sample cells were additionally wiped with a silicone-oiled velvet cloth. *SM* 2130 protocol was employed for measurement of turbidity.

3.9.2.4 Particle Counting

Two particle counters were used. Particle counters were factory calibrated by Hach Company using polystyrene latex spheres traceable to NIST (certifications dated January 11, and 12, 2000). Particle counter calibration was verified on-site with calibrated, mono-sized polymer microspheres. During the verification period the calibration was verified by the use of NIST-traceable mono-sized particles. 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 was as follows, and as described in the ETV Test Plan.

1) Establish an initial analysis of particle concentration in the dilution water with the use of a particle counter.
2) To that dilution water add a sample of each size of the monospheres (2, 10, and 15 µm) to achieve a close approximation to 50,000 particles in 25 mL, swirl each suspension in turn.
3) Quickly run suspension through the particle counter to determine that the peak concentration lies at the size of the added monospheres.
4) Prepare a suspension that combines all three of the particle sizes in a concentration of 1,000 particles of each of the three sizes (3,000 total) in 1 mL; swirl the suspension.
5) Quickly run the suspension through the particle counter to determine that the particle counter peaks at each of the three particle sizes, and in approximately the proper enumeration.

The above procedure, as described in the test plan, was designed for bench-top, batch type particle counters and not on-line counters. The in line-counters require a different approach which is explained below.

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 3 µm, 10 µm and 15 µm particles. Batch and true sizes are noted by Duke Scientific Corp. in the logbook as follows:

3.0 ± 0.027 µm
10.0 ± 0.061µm
15.0 ± 0.08 µm

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 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 particles per milliliter total.

Specially equipped hoses were attached to the influent and effluent ports of the particle counter sensor. The influent hose was inserted into a flask containing either dilution water or the particle mixture, and the effluent hose attached to a pump.

Dilution water was suctioned through the particle counter and the pump rate adjusted to 100 mL/min. 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, the hose was switched back to the dilution water to clear the sensor and to stabilize the counter. 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 conducted as described in *SM* 2560 (and subsections appropriate to the equipment in use).

3.9.2.5 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 would allow. Fresh PFW was necessary to limit biological growth that could affect the particle counts. Field conditions made the production of PFW in accordance with *SM* difficult; however, commercially prepared DI water, filtered on site thorough a 0. µm filter was suitable for particle counting suspension and other reagent preparation in this application. PFW was subject to contamination by airborne particles after filtration. There was no clean room available on site. Following consultation with the particle counter manufacturer, the FTO used MWW water filtered off-site as dilution water. Since the particle counts were low (less than 99/mL), this was suitable dilution water. As with turbidity, glassware associated with the particle counters was dedicated and cleaned with laboratory glassware detergent, then triple rinsed with PFW.

3.9.3 Off-Site Analysis For Chemical and Biological Samples

Analytical procedures are described in BioVir's and Spectrum Laboratory's Quality Assurance Plans (located in FOD). Tables 1a and 1b of the Code of Federal Regulations 40 Parts 136.3 cross-reference *Standard Methods*, EPA Methods, 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.

3.9.3.1 Organic Parameters: Total Organic Carbon and UV_{254} Absorbance

Samples for analysis of TOC and UV_{254} were collected in glass bottles supplied by Spectrum and were delivered by courier to Spectrum Labs (the travel time was approximately 20 minutes). Samples were preserved, held and shipped in accordance with *SM* 5010B and *SM* 1060. Samples were analyzed at the laboratory for TOC by EPA Method 415.1. Samples were analyzed for UV_{254} using *SM* 5910B.

3.9.3.2 Microbial Samples: Coliform and Algae

Samples were collected in glass bottles supplied by Spectrum Labs and kept at 4°C in the proper shipping cooler. Coliform samples were preserved with sodium thiosulfate. Because of the brief travel time (less than 20 minutes) it was not considered necessary by the Spectrum Labs, to preserve algae samples in Lugol's solution. Samples were analyzed for Total Coliform Bacteria and *E. coli* bacteria at

the laboratory using the EPA MI Agar Method, (EPA 600 R 00 013), and algae using *SM* 10200F (when algae were found, *SM* 10900 was used for speciation).

3.9.3.3 Inorganic Samples

Inorganic Samples were collected, preserved and shipped in accordance with *SM* 3010B and C and 1060 and EPA §136.3, 40 CFR Chapter 1. Proper bottles and preservatives where required (Iron and Manganese for example) were used. 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 - EPA Method 200.7, and manganese - EPA Method 200.7.

3.9.3.4 True Color

True color was measured in accordance with *SM* 2120 at the beginning of the verification period. True color readings did not impact on filter removal performance, unlike its effect on disinfection processes, and were not measured after the first week.

Chapter 4
Results and Discussion

4.1 Introduction

The verification testing for the Kinetico SW224 Filter System that occurred at the University of Minnesota St. Anthony Falls Hydraulic Laboratory in Minneapolis, Minnesota, commenced on March 24, 2000, and concluded on May 1, 2000. The system was operated for a period of 32½ days during this period. Microbial challenge testing was performed twice. The first challenge test was performed using *G. muris* and *C. parvum* as prescribed in EPA Method 1623. It was subsequently found that the DYNAL IMS technology (also prescribed in EPA Method 1623) to concentrate and clarify protozoa samples could not be used on *G. muris* due to an extremely low affinity for the *G. muris* cysts. Because it would not be possible to replicate identical source water conditions at a later date, comparative performance data for the reduction of *G. muris* and *C. parvum* could not be provided by completing the analyses for only *C. parvum* from the first challenge series. Due to this limitation, in addition to cost constraints, analyses for *C. parvum* were discontinued on sample from the first challenge series. The Kinetico SW224 Filter System was then shut down between April 12 and April 18, 2000, for a total of 132.5 hours due to the lead-time needed to secure the *G. lamblia* for the retesting. *C. parvum* and *G. lamblia* challenge testing was performed on April 24, 25 and April 27, 2000.

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, effluent water quality, *C. parvum* and *G. lamblia* removal, and QA/QC.

4.2 Initial Operations Period Results

The objective of the initial operations period was to establish operational data including filter run times and backwashing schedules, and to qualify the equipment for performance with the selected source water. The initial operations period allowed the equipment manufacturer to refine the unit's operating procedures and to make operational adjustments as needed to successfully treat the source water.

The unit was on site at the University of Minnesota in October of 1999 and was operated during initial operations to establish the optimum treatment scheme prior to initiation of verification testing.

The major operating parameters examined during initial operations were characterization of influent water, filter runs times and backwashing schedules.

4.2.1 Characterization of Influent Water

The SAFHL offered the FTO the ability to blend untreated river water with finished municipal drinking water to achieve and maintain filter influent turbidity at a level specified by the equipment manufacturer.

Historical untreated surface water quality data that was obtained from the City of Minneapolis Municipal Water Works department and reviewed for the same time frame as the verification testing period (March and April) 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 ranged from 103 mg/L to 169 mg/L; total hardness ranged between 122 mg/L and 188 mg/L; true color ranged between 31 and 69 TCU and the turbidity range was between 5.2 and 18.6 NTU.

Actual measurements taken by the City of Minneapolis Municipal Water Works for treated water used during the verification testing period exhibited the following characteristics: the temperature varied from 0.2°C to 16.2°C; pH in the range of 8.0 to 9.2; total alkalinity ranged from 35 mg/L to 53 mg/L; total hardness ranged between 67 mg/L and 96 mg/L; true color ranged between 3 and 11 TCU; and the turbidity range was between 0.09 and 0.36 NTU. Review of this data previous to, and during the testing period, confirmed that this site was suitable to conduct this equipment performance verification test.

The water was blended from both sources to achieve the optimum characteristics for the system under test. Filter influent turbidity levels were initially maintained close to 1 NTU. During the microbial challenge test, this was reduced to an average of 0.6 NTU due to shorter filter runs being experienced at that time.

4.2.2 Initial Test Runs

Some of information gathered during system start-up was used to refine the FOD. The adjustments that were made included the following:

- Water temperature was recorded once per day due to the stable water temperature conditions of the influent water.
- Blending untreated river water with effluent municipal drinking water to achieve influent turbidity of 1.0 NTU provided water quality of minimal color. Therefore, color was not measured after the first week of testing.
- The flow rate across the filter bed was allowed to decrease as pressure differential across the filter increased during each filter run. This was done to reflect actual operating conditions of the packaged water treatment plant.

During the initial operations period the following items were also noted:

Before the verification testing period began, the Kinetico SW224 Filter System filters were backwashed to remove media dust. This procedure was completed when the backwash turbidity meter values stabilized. It required approximately sixteen backwash cycles per filter with city water to stabilize the backwash turbidity.

Upon initial start up of filter runs, it was observed that the outlet turbidimeter indicated a value above the programmed trip point of 0.5 NTU. This would send the filter on-line at that time into backwash mode.

By inspecting the location of the sample port used to measure outlet turbidity, it was concluded that a representative sample of the filtered water was not being supplied to the turbidimeter. Accordingly, the manufacturer changed the location of the outlet turbidity meter sample port to a point where a representative sample of filtered water could be supplied on a continuous basis.

It was noted that the pressure in the water line supplying blended water to the pilot was not adequate to satisfy backwash flow requirements of one filter while the other filter was in service. Therefore, the backwash water source was relocated. Finished city water was taken from an open storage tank and repressurized via a backwash water pump (already incorporated into the pressure filtration module) to satisfy filter backwash requirements.

Because filter effluent water was directed to the sanitary sewer (non-elevated) as compared to a water tower (elevated), outlet sample taps remained non-pressurized. Therefore a manual metering valve was installed downstream to create the backpressure necessary to make the outlet sample taps functional.

The Kinetico SW224 Filter System was run through multiple filter runs and backwash cycles during initial operations. It was observed during this period that filter runs exceeded 24 hours when the system's PLC was programmed to allow filter runs to continue beyond 24 hours. During initial operations, backwash cycles were initiated based on turbidity breakthrough (established at 1 NTU) or pressure drop (established at 22 psig). During the performance verification period the system's PLC was programmed to discontinue a filter run if it exceeded 24-hours, regardless of headloss or effluent turbidity values.

During air sparge it was observed that a little water would exit from the backwash turbidity meter reservoir lid. Kinetico was consulted, and they indicated that the filter drain interval prior to air sparge was too short. Kinetico then changed the drain interval factor in the software via modem connection. This corrected the problem.

4.2.3 Hydraulic Flow Tracer Study

The purpose of the hydraulic flow tracer study was to establish hydraulic characteristics of the Kinetico SW224 Filter System previous to microbiological challenges. Information from this study was used to determine the start time and length of effluent sample collection periods relative to seeding during microbial challenges. The flow rates used for these hydraulic flow tracer studies were the same as for the testing period (approximately 30 gpm).

Two tracer studies were performed using sodium chloride on March 27 and March 28, 2000 (Figure 4-1 and 4-2). At the start of the first study a TDS meter failed during the first two minutes of the study and was replaced with an alternate for the remainder of the study. Therefore COA conducted a second study. The second study was conducted the same as the first and with the same process stream sample ports.

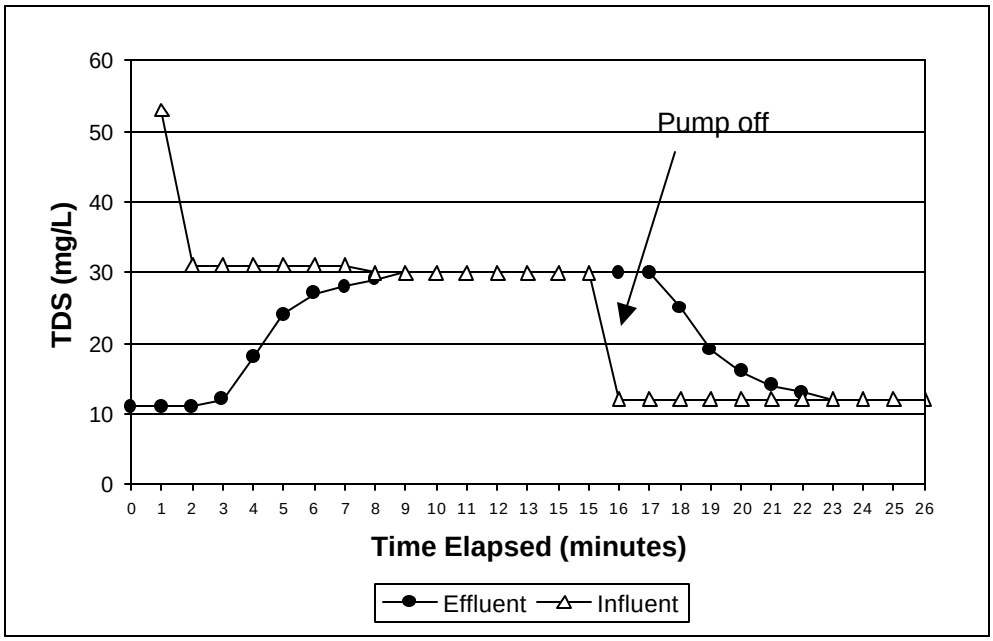

Figure 4-1. Tracer Study #1

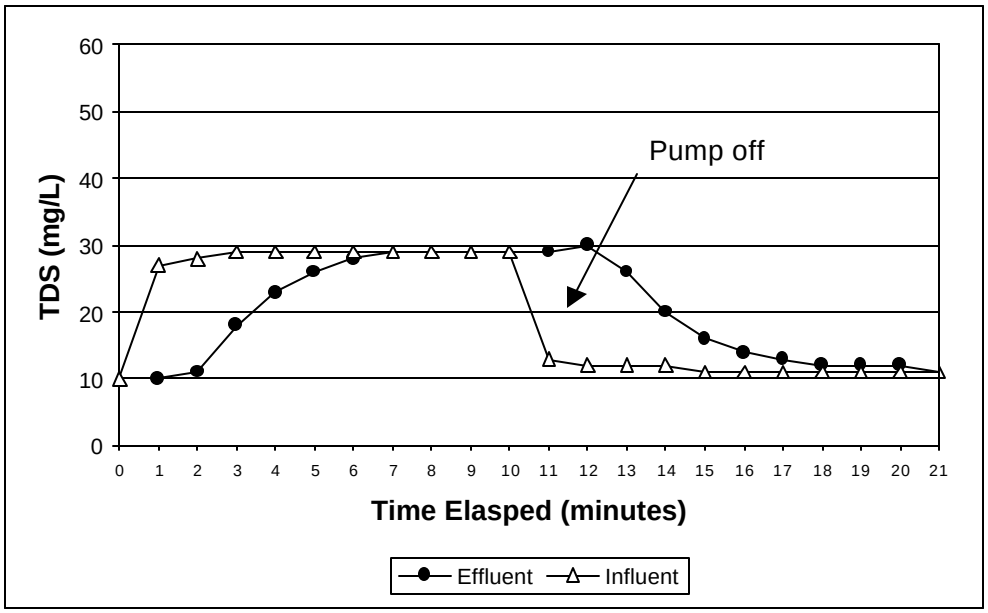

Figure 4-2. Tracer Study #2

Based upon the results of the above tracer studies, it was concluded that the one-hour side-stream microbial sample collection period was sufficient and it should begin simultaneously with the slug-dose injection of (oo)cysts.

4.3 Verification Testing Results and Discussions

The results and discussions of testing runs, routine equipment operations, influent and effluent 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 objectives of this task were to operate the equipment provided by the manufacturer for the 32½day testing period and assess its ability to meet water quality goals and other performance characteristics specified by Kinetico, Inc.

The verification testing for the Kinetico SW224 Filter System started on March 24, 2000 and continued for 32½days of operation and data recording. During the performance verification period the equipment was shut down for a total of 132.5 hours between April 12 and April 18, 2000 due to problems encountered by the microbiological laboratory when using EPA Method 1623 for recovering of *G. muris* versus *G. lamblia*. This shut down was due to the lead-time needed to secure the *G. lamblia* for retesting. Due to this interruption, the Kinetico SW224 Filter System was not operated continuously during the performance verification period. The actual time of equipment operation during the performance verification period was 779.5 hours (32½days).

By instruction of the Manufacturer, the initial target influent turbidity of 1.0 NTU was decreased to 0.60 and then to 0.70 NTU to help increase filter run duration.

The equipment provided by the manufacturer was designed to operate automatically, providing for automatic backwash cycles to occur based upon turbidity breakthrough, pressure differential, or elapsed filter run time of 24 hours. Because the ETV test protocol requires continued monitoring of performance until terminal head loss occurs, the automatic backwash option based upon elapsed filter run time was discontinued.

The only recurring problem that was problematic to the operation of the Kinetico SW224 filter system involved the on-line turbidimeters. On-line turbidimeters supplied with the equipment package required frequent cleaning and verification of calibration. Influent turbidimeter sensor cells were cleaned and re-calibrated 25 times during the verification period. Effluent turbidimeter sensor cells were cleaned and re-calibrated 63 times during the verification period. When turbidity readings began to increase uncharacteristically fast, or when the PLC status screen alerted the operator of a turbidimeter problem sensor cells were inspected and cleaned. The effluent water turbidimeter required the most maintenance. Based upon visual inspection, filter media fines were typically found deposited within this sensor cell. After completion of this ETV study, filter media was removed from the pressure vessels in preparation to ship the Kinetico SW224 filter system. At that time significant loss of filter media was not apparent. Kinetico estimates media loss at 2% per year to attrition.

The backwash/rinse turbidimeter also required frequent cleaning and verification of calibration. The backwash turbidimeters were cleaned and re-calibrated 21 times during the verification period. As in the case with the effluent turbidimeters, filter media fines were typically found deposited within the backwash turbidimeter sensor cell.

The filter runs averaged 11.7 hours, with an average of 21,075 gallons per filter run. Continuous monitoring was not required and the technician was not on site during all filter runs; therefore data averages are representative of runs that occurred during technician monitoring.

4.3.2 Task 2 - Influent and Effluent Water Quality Characterization

Temperature of the blended influent water varied during the testing period due to changes in the Mississippi River water temperature. It ranged from a low of 7.1°C to a high of 15.4°C. Water temperature did not steadily increase during the period, but advanced and declined as the air temperatures changed. Fluctuations in water temperature were expected due to seasonal climatic changes.

Results of on-line turbidity measurements taken throughout the entire verification period in the influent and effluent water are presented in Table 4-1 below.

Table 4-1. Influent and Effluent Water On-Line Turbidity (March 24 – May 1, 2000)

Parameter	Average (NTU)	Minimum (NTU)	Maximum (NTU)	Standard Deviation	95% Confidence*
Influent	0.77	0.31	2.52	0.15	0.76, 0.77
Effluent	0.23	0.05	1.16	0.13	0.23, 0.23

* Note: Because on-line turbidity readings were taken every 2 minutes during the entire verification period (over 23,000 entries), the confidence interval is very small due to significant digits rounding.

Figure 4-3 demonstrates turbidity reductions achieved during the performance verification test period.

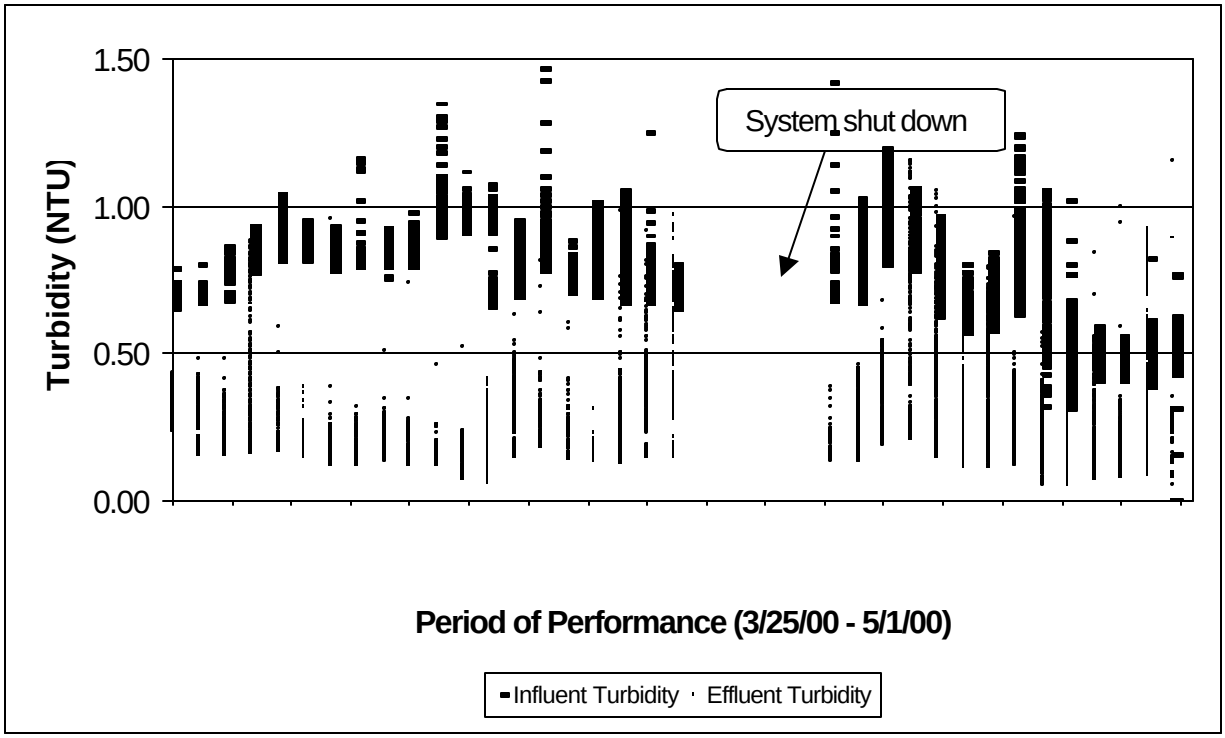

Figure 4-3. Daily Scatter Plots of Influent and Effluent Turbidity Values

A summary of the influent water quality information is presented in Table 4-2. Detailed laboratory reports are provided in Appendix F. One sample for color detected 10 TCU. E.coli analyses were conducted six times. Five samples of the six measured below the PQL of 1 CFU/100 mL. One sample dated April 27, 2000, measured E.coli at 1 CFU/100 mL. Six samples were taken for Total Coliform Bacteria. Analyses of five samples of the six did not detect Total Coliform Bacteria or measure above the reported PQL of 1 CFU/100 mL. One sample of Total Coliform Bacteria taken on April 27, 2000, recorded 87 CFU/100 mL.

One influent water sample dated March 27, 2000, for Total Coliform Bacteria and E.coli did not contain a sufficient sample volume for a 100 mL analysis, thus an 80 mL analysis was performed. Drinking water compliance samples (SDWA) must be 100 mL volumes to report <1 coliform/100 mL or <1 E.coli/100 mL. This sample analysis must therefore be reported as <1/80 mL, or <1.25 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 80 mL sample for analysis. No detection of Total Coliform Bacteria or E.coli was found in the 80 mL sample.

Algae were detected once in the influent water during the verification testing period on April 27, 2000, as Nitzschia at a concentration of 25 Algae/mL. This detection for Algae in the influent water is not considered outside the expected influent water conditions of this study.

Table 4-2. Influent Water Sample Characteristics (March 24 – May 1, 2000)

Parameter	# of Samples	Average	Minimum	Maximum	Std. Dev.	95% Confidence Interval	PQL
Total Alkalinity (mg/L)	6	53	47	62	5	49, 58	10 mg/L
Total Hardness (mg/L)	6	80	74	88	5	76, 85	10 mg/L
TOC (mg/L)	6	6.4	6.1	6.5	0.2	6.2, 6.5	0.01 mg/L
UVA_{254} (cm^{-1})	6	0.098	0.082	0.108	0.011	0.088, 0.108	-
Iron (mg/L)	6	<0.1	<0.1	<0.1	0.0	NA	0.1 mg/L
Manganese (mg/L)	6	0.01	0.01	0.02	<0.01	NA	0.01 mg/L
pH	34	8.6	7.2	9.5	0.4	8.5, 8.7	-
Temperature (C)	34	10.3	7.1	15.4	2.0	9.5, 10.9	-
Free Chlorine (ppm)*	11	0.78	0.27	1.48	0.42	0.64, 0.92	0.01**

Note: All calculations involving results with below PQL values used 1/2 the PQL in the calculation.
NA – Not Applicable because Standard Deviation = 0.
* - Free chlorine measurements taken during normal equipment operation (see Section 4.3.4.1 for absence of free chlorine measurements during seeding studies).
** - This is the Estimated Detection Level (EDL) for free chlorine, this is not the same as the PQL. Hach (manufacturer of the DRT/2010 Spectrophotometer) provides a value called the Estimated Detection Limit for USEPA accepted and approved programs. The EDL is the calculated lowest concentration in a deionized water matrix that is different from zero with a 99% level of confidence.

A summary of the effluent water quality information is presented in Table 4-3 and a detailed report is presented in Appendix F. One sample for color was analyzed during the testing period at 5 TCU. Six samples were taken for Total Coliform Bacteria. One sample dated April 27, 2000 reported 45 CFU/100 mL. Four of the other samples tested did not detect Total Coliform Bacteria above the PQL of 1 CFU/100 mL. No algae were detected at the PQL of 1 Algae/mL in the effluent water samples. E.coli was detected once on 4/26/00 at 1 CFU/100 mL. The remaining samples of E.coli were below the PQL detection of 1 CFU/100 mL during the testing period. These low counts of Total Coliform Bacteria and E.coli can be attributed to the practice of maintaining free chlorine residual in the influent water (Table 4-2).

One effluent water sample dated March 27, 2000, for Total Coliform Bacteria and E.coli did not contain a sufficient sample volume for a 100 mL analysis. Drinking water compliance samples (SDWA) must be 100 mL volumes to report <1 coliform/100 mL or <1 E.coli/100 mL. This sample analysis must therefore be reported as <1/90 mL, or < 1.15 per 100 mL (adjusting the PQL for the lower volume received and filtered). Accordingly, Spectrum Labs deemed that due to adjusting the PQL, data could be produced from the 90 mL sample for analysis. No detection of Total Coliform Bacteria or E.coli was found in the 90 mL sample.

Table 4-3. Effluent Water Sample Characteristics (March 24 – May 1, 2000)

Parameter	# of Samples	Average	Minimum	Maximum	Std. Dev.	95% Confidence Interval	Practical Quantification Limit
Total Alkalinity (mg/L)	6	54	49	63	6	49, 59	10 mg/L
Total Hardness (mg/L)	6	78	73	87	5	74, 82	10 mg/L
TOC (mg/L)	6	6.4	6.1	6.6	0.2	6.2, 6.5	0.4 mg/L
UVA_{254} (cm^{-1})	6	0.098	0.086	0.106	0.008	0.091, 0.105	-
Iron (mg/L)	6	<0.1	<0.1	<0.1	0.0	NA	0.1 mg/L
Manganese (mg/L)	6	<0.01	<0.01	0.01	0.0	NA	0.01 mg/L

NA – Not Applicable because the Standard Deviation = 0.

Due to the low residence time (Figure 4-2) and lack of chemical addition, effluent water temperature and pH were not recorded.

Beyond these observations, there were no other significant changes in the influent or effluent water quality characteristics during the verification testing period.

Table 4-4 and Figure 4-4 demonstrate the Kinetico SW224's ability to remove $\geq$ 3 µm, $\leq$ 7 µm sized particles indigenous to the source water.

Table 4-4. Summary of Filter Influent and Effluent Particle Counts of $\geq$3 µm $\leq$ 7 µm Sized Particles Indigenous to the Source Water from On-Line Particle Counters

	Average (#/mL)	Minimum (#/mL)	Maximum (#/mL)	Standard Deviation	95% Confidence Interval (#/mL)
Influent $\geq$ 3µm, $\leq$ 7µm	3,179.16	209.85	7,942.20	573.56	3,171.75, 3,186.57
Effluent $\geq$ 3µm, $\leq$ 7µm	439.04	5.90	1,384.98	132.33	437.33, 440.75

Note average $\log_{10}$ reduction of indigenous particles $\geq$ 3 µm, $\leq$ 7 µm = 0.87

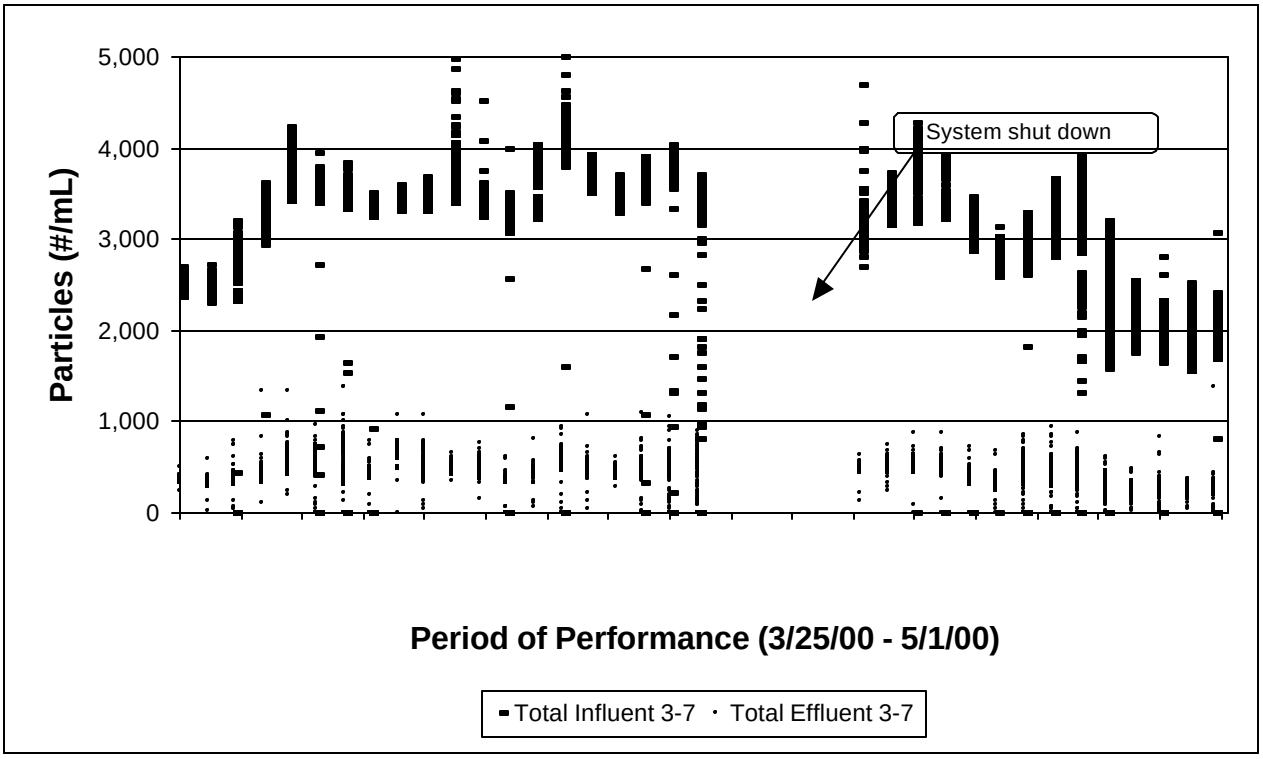

Figure 4-4. Daily Scatter Plots of Influent and Effluent Particle Count Values of ≥ 3 µm, ≤ 7 µm Sized Particles Indigenous to the Source Water

4.3.3 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 Kinetico SW224 Filter System during the Verification Testing run. During this task, data was collected that described the operation of the equipment and provided information to be used to develop cost estimates for operation of the equipment.

The following observations were also noted:

As described in Chapter 2, Equipment Description and Operating Processes, the Kinetico SW224 Filter System is a packaged water filtration plant designed to provide a continuous process flow and automated to require minimal operator intervention. To support this design two filters are included within the Kinetico SW224 package. When one filter is in operation, the alternate filter is off-line. Filter run time is determined by one of the following events as monitored by the water treatment plant's PLC with timers and sensors/meters installed within the appropriate process stream: Head loss; Turbidity breakthrough; and Time. These values were initially set at 22 psi, .5 NTU and 24 hours, respectively. When one of these set-point values is exceeded, the filter run is discontinued and the alternate filter is rinsed and put on-line with minimal interruption in flow.

The filtration system tested was designed for automatic vs. manual operation. Thus, it operated 24 hours per day. Due to this level of system automation, in conjunction with filter runs exceeding the 8-hour technician-monitoring schedule, operational data such as maximum head loss were rarely recorded immediately before the termination of a filter run.

It is observed from the operational data log (Appendix C) that during the performance verification period, filter runs were usually terminated based upon a filter exceeding the maximum head loss set point as compared to turbidity or run time set points. If terminal head loss did not occur during an operator's shift the filters automatically alternated. Clean bed and terminal head losses could not be recorded in such instances. COA recorded operational data beyond the required 8 hours/day, to 13 hours/day and manually recorded operational data every hour in order to increase the probability of being present as filter columns alternated. Even with this schedule, COA was not present to record these data on a consistent basis. Listed below in Table 4-5 is a representative sample where data was recorded throughout a filter run during the start, middle and end of the verification testing period.

Figure 4-5. Average Run Cycles At Beginning, Middle & End Of Performance Testing Period

Test Period Time Frame	Filter Run Time (hrs)	Beginning Flow Rate (gpm)	Ending Flow Rate (gpm)	Change in Flow Rate (gpm)	Beginning Change in Pressure (psi)	Ending Change in Pressure (psi)	Change in Pressure (psi)	Gallons Filtered	Backwash Rinse Volume (Gallons)	Backwash Volume (Gallons)	Backwash Flow Rate (gpm)
Beginning	19.94	29.70	28.47	-1.2	9	22	13	34,037	146	287	16
Middle	17.95	30.24	26.52	-3.7	9	21	12	30,847	183	285	16.5
End	6.50	30.15	27.27	-2.9	11	22	11	10,237	157	339	16.8

The Table 4-5 data is representative of data compiled from two runs selected for the beginning, middle and end run cycles to replicate the data during that time frame. The data is also representative of runs cycles in which a technician was able to observe and record the entire cycle.

Filter run times became shorter near the end of the verification test period. It is also noted that the effluent turbidity set point was increased from 0.5 NTU to 10 NTU on 4/18/00. This change was in response to problems that were being experienced with the outlet turbidimeter and occasional presence of filter media within its sensor cell (as described in section 4.3.1) that caused the system to experience multiple filter run - backwash cycles when an operator was not present to monitor and service the outlet turbidimeter sensor. The maximum head loss set point was increased to 30 psi during microbial seeding challenges to prevent the possibility of the filter run being automatically terminated during the 90% of terminal head loss sample collection period.

A total of 1,307,850 gallons of water were filtered over a period of 32½days of operation (779.5 hours) including 78 filter runs. Average calculated flow rate for this period is therefore 27.98 gpm. Recorded flow rates range from 24.72 gpm (4/25/00 @ 3:43 PM) to 30.48 gpm (4/26/00 @ 2:16 PM). Average calculated filter run volume is therefore 16,767 gallons. Technician recorded total filter run volumes range from 5,163 gallons (4/28/00) to 44,347 gallons (3/26/00).

During the 32½day verification testing period the Kinetico SW224 Filter System used 147 kWh for 1,307,850 gallons of water filtered. This equates to 8,897 gallons of filtered water per kWh.

Watershed events were noted in logbook. Data from the logbook and historical weather data from the Minnesota State Climatology Office (DNR Waters) was compiled and is presented in Appendix G detailing daily climatic events. A mild winter and extraordinarily high temperatures in February and March lead to the occurrence of spring run-off and area lake ice-out dates to coincide with the ETV test period. Lighter than average snowfalls, (typically 50 to 75 percent of average) and mild weather contributed to reduced stream discharge (i.e., lower than average turbidity and particle count). Though potential watershed events could lead to changes in water chemistry, which in turn could change filter performance, these watershed events were minimized by the blending of river water and treated water from the MWW.

4.3.4 Task 4 - Microbiological Contaminant Removal Testing

The purpose of this task was to demonstrate the Kinetico SW224 Filter System's ability to provide reduction of *C. parvum* and *G. lamblia* within defined influent water quality specifications at a flow rate of approximately 30 gpm. The challenge testing was performed on April 24, 25 and 27, 2000.

4.3.4.1 Water Characteristics

A blend of raw river and finished water served as the source water for this performance verification test. The following influent water characteristics were observed during the challenge period: temperature averaged 11.4°C; pH averaged 9.2; total alkalinity in the range of 50 to 52 mg/L; total hardness from 76 to 79 mg/L; TOC concentration of 6.4 mg/L; and UV_{254} absorbance in the range of 0.087 to 0.104 cm^{-1}. Total coliform was measured twice during the challenge period. One sample result of the two was below the PQL of 1 CFU/100 mL, the second sample measured 87 CFU/100 mL. Two samples were tested for E.coli. The first sample was below the PQL of 1 CFU/100 mL, and the second E.coli sample dated April 27, 2000 measured 1 CFU/100 mL. Iron was below the PQL of 0.1 mg/L. Manganese was detected once at 0.01 mg/L. The second sample of Manganese was measured below the PQL of 0.01 mg/L. Two samples were tested for Algae. Algae was detected in one influent water sample on April 27, 2000 as Nitzschia at a concentration of 25 Algae/mL. The other sample of Algae was below the PQL of 1 Algae/mL.

During seeding studies, the liquid metering pump previously used for chlorine injection was supplied with sodium thiosulfate to assure the blended water did not contain free chlorine residuals at a level that would negatively impact this study. Free chlorine measurements taken during the challenge period had an average of 0.02 ppm, which is near the estimated detection limit (0.01 ppm) of the measurement instrument (HACH DR/2010 Spectrophotometer).

The on-line influent turbidity during the microbial challenge testing ranged from 0.45 to 0.77 NTU, with an average of 0.63 NTU. The on-line effluent turbidity during the challenge test ranged from 0.09 to 0.27 NTU, with an average of 0.17 NTU.

The influent water temperature and pH during the microbial challenges were recorded as following: challenge #1 temperature reading of 10.4°C and pH of 9.1; challenge #2 temperature of 10.8°C, and pH of 9.5; challenge #3 temperature of 13.1°C, and pH of 8.8.

The following effluent water quality parameters during challenge testing period were observed: total alkalinity in the range of 50 to 52 mg/L, total hardness between 75 and 78 mg/L, TOC concentrations between 6.3 and 6.6 mg/L, and UV_{254} absorbance in the range of 0.089 to 0.102 cm^{-1}. Total coliform was measured twice during the challenge period. One sample of the two was below the PQL of 1 CFU/100 mL; a second sample had a reading of 45 CFU/100 mL. E.coli was below the PQL of 1 CFU/100 mL. Iron and manganese were not detected above the PQL of 0.1 mg/L and 0.01 mg/L respectively during the challenge testing period.

4.3.4.2 Operational and Analytical Data Tables

The Kinetico SW224 Filter System included two identical filter vessels identified as "T1A" and "T2A" operating alternately. During the challenge testing only filter "T2A" was used for the challenge. Table 4-6 summarizes the operating conditions on filter "T2A" during the challenge testing.

Table 4-6. Operating Conditions During Each Protozoa Challenge Event

Challenge #	Date	Average Filter Flow Rate (Digital gpm)	Total Gallons Filtered
1	4/24/00	28.8	17,384
2	4/25/00	28.3	11,608
3	4/27/00	28.2	8,977

Figure 4-5 shows that the Kinetico SW224 Filter System removed an average of 0.75 log_{10} (95% Confidence Interval of 0.74, 0.76) of particles in the 3-7 µm size range during challenge test #1 on April 24, 2000. During this challenge #1, the average on-line influent turbidity as shown below in Figure 4-5 was 0.70 NTU, and the average on-line effluent turbidity was 0.29 NTU. It is also suspected the influent turbidity did not increase during the first half of the filter run as figure 4-5 suggests. The sharp decrease detected in influent turbidity at the approximate midpoint of the filter run coincides with an entry within the field log book noting the influent turbidimeter sensor cell was cleaned at that time.

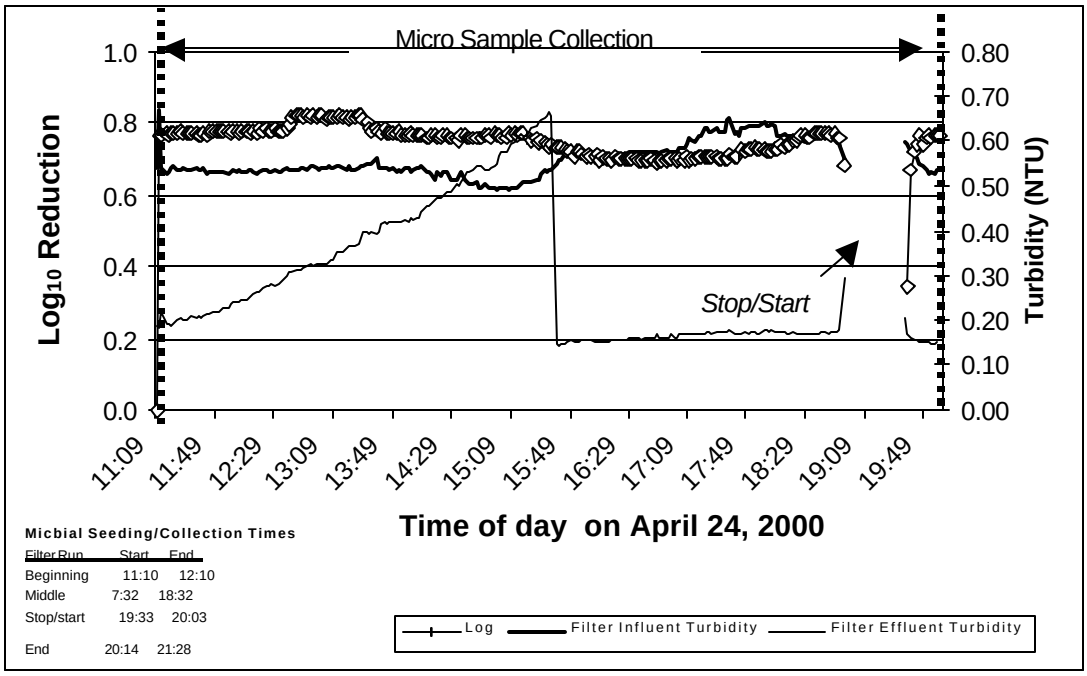

Figure 4-5. 3-7 mm Particle Count Log_{10} Removal and Turbidity Measurements During Challenge #1

Figure 4-6 shows the particle count log_{10} removal and the turbidity measurements during challenge test #2. This figure shows that the Kinetico SW224 Filter System removed an average of 0.82 log_{10} (95% Confidence Interval of 0.81, 0.84) of particles in the 3-7 µm size range during challenge test #2 on April 25, 2000. During this challenge test #2, the average on-line influent turbidity as shown below in Figure 4-6 was 0.73 NTU, and the average on-line effluent turbidity was 0.15 NTU.

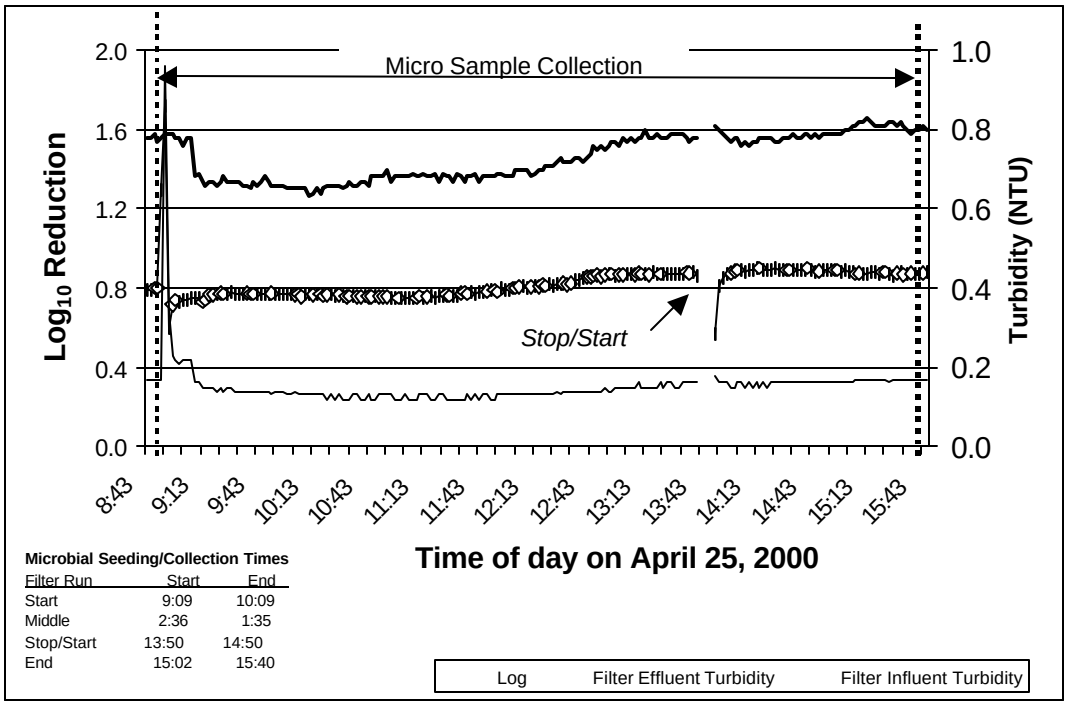

Figure 4-6. 3-7 mm Particle Count Log_{10} Removal and Turbidity Measurements During Challenge #2

Figure 4-7 shows the particle count $\log_{10}$ removal and turbidity measurements during challenge test #3. This figure illustrates that the Kinetico SW224 Filter System removed an average of 0.85 $\log_{10}$ (95% Confidence Interval of 0.84, 0.86) of particles in the 3-7 µm size range during challenge test #3 on April 27, 2000. During challenge test #3, as shown below in Figure 4-7, the average turbidity as read by the on-line turbidimeter was 0.54 NTU for the influent, and 0.16 NTU for the effluent. Again, as noted in Figure 4-5, the sharp decrease in influent turbidity in figure 4-7 coincides with a cleaning of the turbidity sensor cell.

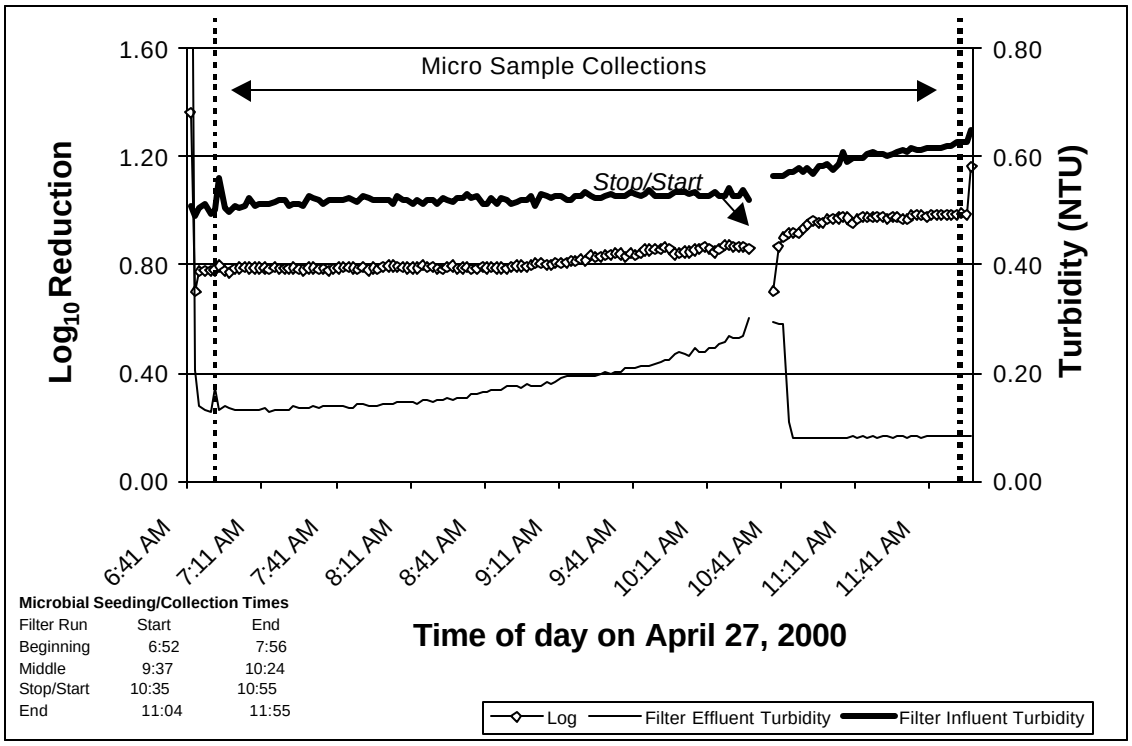

Figure 4-7. 3-7 µm Particle Count $\log_{10}$ Removal and Turbidity Measurements During Challenge #3

4.3.4.3 Discussion of Results

The results of the three replicate challenge filter runs for *Giardia lamblia* are presented in Table 4-7. The average cyst removal per filter run ranged from 1.6 $\log_{10}$ to 3.7 $\log_{10}$ with a mean of 2.4 $\log_{10}$, a standard deviation of 0.6 $\log_{10}$, and a 95% confidence interval of ±0.4 $\log_{10}$.

Table 4-7. Run 1-3 *G. lamblia* Log_{10} Removal

Run #	(1) *Giardia*/L Influent	(2) *Giardia*/L Effluent	(3) Process Flow Liters/min	(4) Collection Time in Min	(5) Total *Giardia* oocysts	(6) Log_{10} Influent	(7) Log_{10} Effluent	(8) Log_{10} Removal
Run 1								
Start	700,000	0.2	116.77	54.0	1,261	5.8	3.1	2.7
Middle	1,000,000	1.0	107.27	60.0	6,436	6.0	3.8	2.2
Stop/Start		0.8	103.60	60.0	4,973			
End	960,000	1.1	100.72	60.0	6,648	6.0	3.8	2.2
Run 2								
Start	660,000	0.2	116.20	60.0	1,394	5.8	3.1	2.7
Middle	960,000	0.7	105.60	59.0	4,361	6.0	3.6	2.4
Stop/Start		0.4	101.17	60.0	2,428			
End	840,000	0.4	96.21	38.0	1,462	5.9	3.2	2.7
Run 3								
Start	3,800,000	0.1	116.50	64.0	746	6.6	2.9	3.7
Middle	2,000,000	6.6	107.95	47.0	33,486	6.3	4.5	1.8
Stop/Start		2.5	106.85	20.0	5,343			
End	2,800,000	12.8	99.47	51.0	64,934	6.4	4.8	1.6

(1) = BioVir result/5 (BioVir reported results/1 liter; actual influent volume was 200 mL)
(2) = BioVir result organisms in capture filter (per liter)
(3) = Average process flow during collection time (liters per minute)
(4) = Effluent capture filter collection time (minutes)
(5) = Columns 2 x 3 x 4 (total effluent organisms)
(6) = Total number of organisms seeded (Log_{10} of column 1)
(7) = Total number of organisms released from filter system (Log_{10} of column 5)
(8) = Column 6 - Column 7

The results of the three challenge filter runs for *Cryptosporidium parvum* are presented in Table 4-8. The calculated average oocyst removal per filter run ranged from 0 to 0.8 log_{10} with a mean of 0.4 log_{10}, a standard deviation of 0.3 log_{10}, and a 95% confidence interval of ±0.2 log_{10}.

Table 4-8. Run 1-3 *C. parvum* Log_{10} Removal

Run #	(1) *Crypto*/L Influent	(2) *Crypto*/L Effluent	(3) Process Flow Liters/min	(4) Collection Time in Min	(5) Total *Crypto* oocysts	(6) Log_{10} Influent	(7) Log_{10} Effluent	(8) Log_{10} Removal
Run 1								
Start	4,600,000	344.8	116.77	54.0	2,175,164	6.7	6.3	0.4
Middle	4,600,000	135.3	107.27	60.0	670,818	6.7	5.9	0.8
Stop/Start		5.5	103.60	60.0	34,188			
End	3,600,000	137.7	100.72	60.0	832,149	6.6	5.9	0.7
Run 2								
Start	2,800,000	239.0	116.20	60.0	1,666,308	6.4	6.2	0.2
Middle	3,200,000	158.8	105.60	59.0	989,388	6.5	6.0	0.5
Stop/Start		8.0	101.17	60.0	48,562			
End	2,800,000	131.2	96.21	38.0	479,665	6.4	5.7	0.7
Run 3								
Start	13,000,000	1,999.0	116.50	64.0	14,904,544	7.1	7.2	-0.1
Middle	9,600,000	716.0	107.95	47.0	3,632,733	7.0	6.6	0.4
Stop/Start		6.7	106.85	20.0	14,318			
End	17,000,000	4,048.0	99.47	51.0	20,535,383	7.2	7.4	-0.1

(1) = BioVir result/5 (BioVir reported results/1 liter; actual influent volume was 200 mL)
(2) = BioVir result organisms in capture filter (per liter)
(3) = Average process flow during collection time (liters per minute)
(4) = Effluent capture filter collection time (minutes)
(5) = Columns 2 x 3 x 4 (total effluent organisms)
(6) = Total number of organisms seeded (Log_{10} of column 1)
(7) = Total number of organisms released from filter system (Log_{10} of column 5)
(8) = Column 6 - Column 7

The removal of *G. lamblia* cysts during each challenge were significantly greater than the removal of *C. parvum* oocysts. This was expected as the *G. lamblia* cysts (9 – 12 µm) are larger than the oocysts of *C. parvum* oocysts (4 – 6 µm) (Medema, 1998).

4.3.4.4 Stop/Start Event Evaluation

The flow of water through the Kinetico SW224 Filter System was discontinued soon after the midpoint (oo)cyst seeding study during each of the three challenge filter runs. Filter effluent water was directed to an (oo)cyst collection filter over a period of 60 minutes beginning immediately after the resumption of flow though the filter. The collection period for the third challenge run was limited to 20 minutes due to an unexpectedly short filter run. Turbidity and particle distribution counts were also recorded every two minutes with the use of on-line sensors during each protozoan sample collection period.

4.3.4.4.1 Protozoan Sample Analyses

Analysis of filter effluent samples suggest *G. lamblia* cysts and *C. parvum* oocysts were released from the filter bed as a result of this stop/start sequence. The number of (oo)cysts detected in the filter effluent were considerably lower than the number detected during the midpoint seeding challenges. Results specific to the stop/start sequence are presented in Table 4-9.

Table 4-9. Run 1-3 Release of *G. Lamblia, C. parvum* Associated with Cessation and Resumption in Flow

Run #	(1) (oo)cyst/L Effluent	(2) Process Flow Liters/min	(3) Side-Stream Capture Filter Collection Time in Min	(4) Total (oo)cysts
Run 1				
G. Lamblia	0.8	103.60	60.0	4,973
C. parvum	5.5	103.60	60.0	34,188
Run 2				
G. Lamblia	0.4	101.17	60.0	2,428
C. parvum	8.0	101.17	60.0	48,562
Run 3				
G. Lamblia	2.5	106.85	20.0	5,343
C. parvum	6.7	106.85	20.0	14,318

(1) = BioVir result organism per liter in capture filter
(2) = Filtration system flow rate in liters per minute
(3) = Effluent capture filter collection time in minutes
(4) = Columns 1 x 2 x 3 (total effluent organisms)

4.3.4.4.2 Turbidity and Particle Count Analyses

The above analyses represent the total number of (oo)cysts released from the filter bed based upon the number collected within a single sample collection filter for up to one hour after the resumption of flow. While the results provide a representation of the number of (oo)cysts released, there is some interest in when they were released during the collection period. Of specific interest is the duration of time oocysts were stripped from the filter bed as a result of the stop/start event as compared to what could be expected from normal filter operation with uninterrupted flow. While this information cannot be provided from the microbial analyses above, a study of turbidity and particle counts over the protozoan collection period may provide some insight.

Because turbidimeters and particle counters cannot differentiate between (oo)cysts and other particles, they cannot be used for direct measurement of (oo)cyst concentrations. Despite this limitation, there is some confidence that (oo)cysts would be released into the filter effluent stream in the same pattern as similarly sized indigenous particles following the cessation and resumption of flow. Accordingly, on-line particle count data collected from the effluent stream were analyzed to determine the pattern of release of particles close to the size of *C. parvum* oocysts (3 µm to 7 µm). These analyses are presented below.

In Figure 4-8, flow was discontinued after the midpoint seeding of the first challenge run then re-started at 19:33 hours. Effluent particle counts were recorded as zero previous to this point due to lack of flow through the particle counter. Because the on-line particle counter recorded counts every two minutes, the first value (1,417 particles per mL) was recorded after resumption of flow at 19:35 hours. At 19:37 hours, counts decreased considerably and were nearly stable after that point. Effluent turbidity values demonstrated the same trend characteristics. Influent particle counts and turbidity remained relatively stable between 19:33 and 19:37 hours.

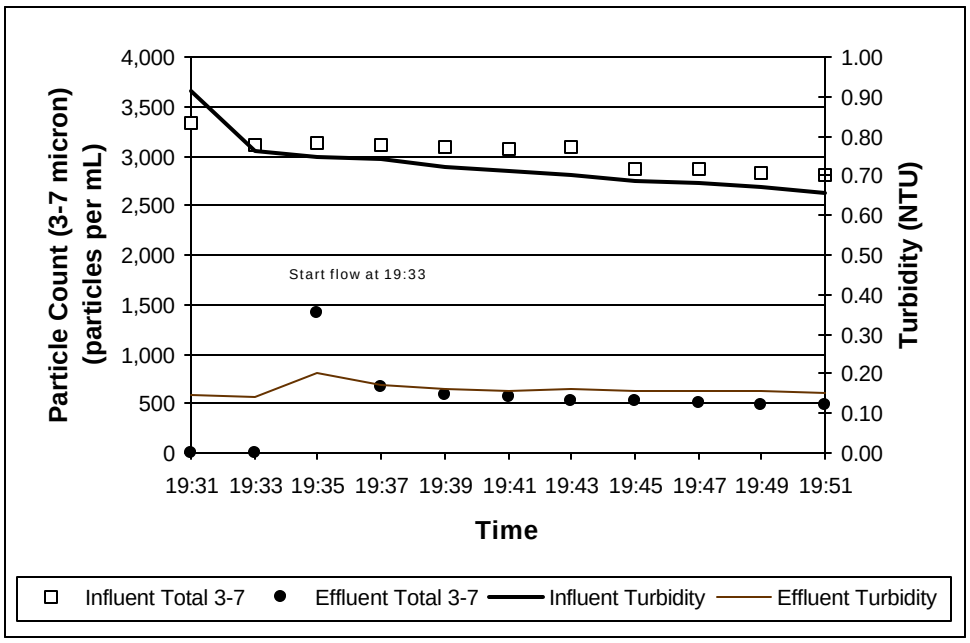

Figure 4-8. Turbidity and 3-7 µm Particle Count Stop/Start During Protozoa Challenge #1

In Figure 4-9, flow was discontinued after the midpoint seeding of the second challenge run then re-started at 13:50 hours. The first value recorded after resumption of flow was 942 particles per mL at 13:51 hours. At 13:53 hours counts decreased considerably and were nearly stable after that point. Effluent turbidity values demonstrated the same trend characteristics. Influent particle counts and turbidity remained relatively stable between 13:50 and 13:53 hours.

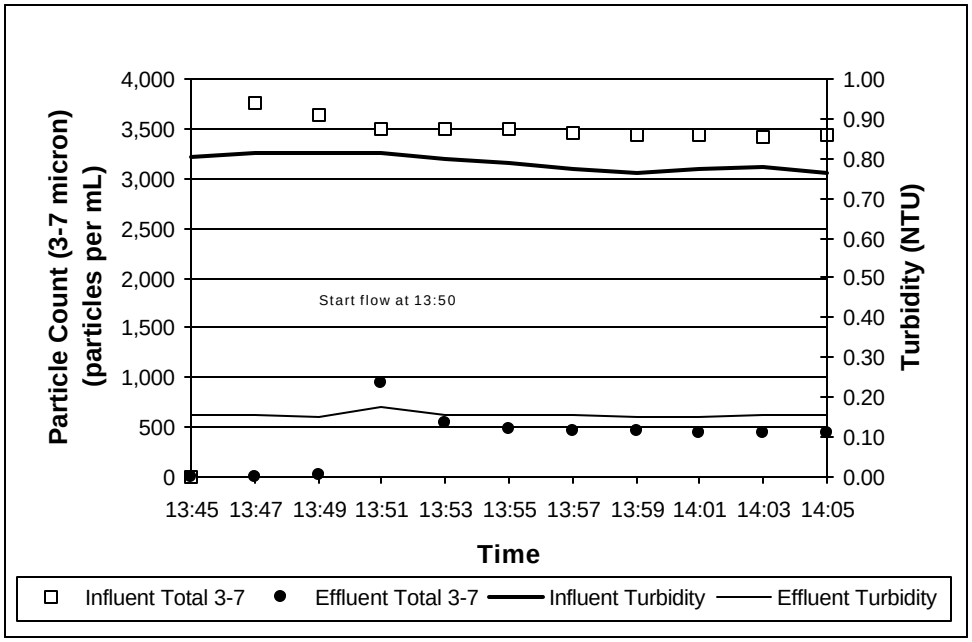

Figure 4-9. Turbidity and 3-7 µm Particle Count Stop/Start During Protozoa Challenge #2

In Figure 4-10 flow was discontinued after the midpoint seeding of the third challenge run then re-started at 10:35 hours. The first value recorded after resumption of flow was 602 particles per mL at 10:37 hours. At 10:39 hours, counts decreased and were nearly stable after that point. Effluent turbidity values did not demonstrate the same trend characteristics. In this case, and as described in Section 4.3.4.2, it is suspected that effluent turbidity values within Figure 4-10 were not accurate at this time and until the sensor was cleaned and recalibrated at 10:43 hours. Influent particle counts and turbidity remained relatively stable between 10:35 and 10:39 hours.

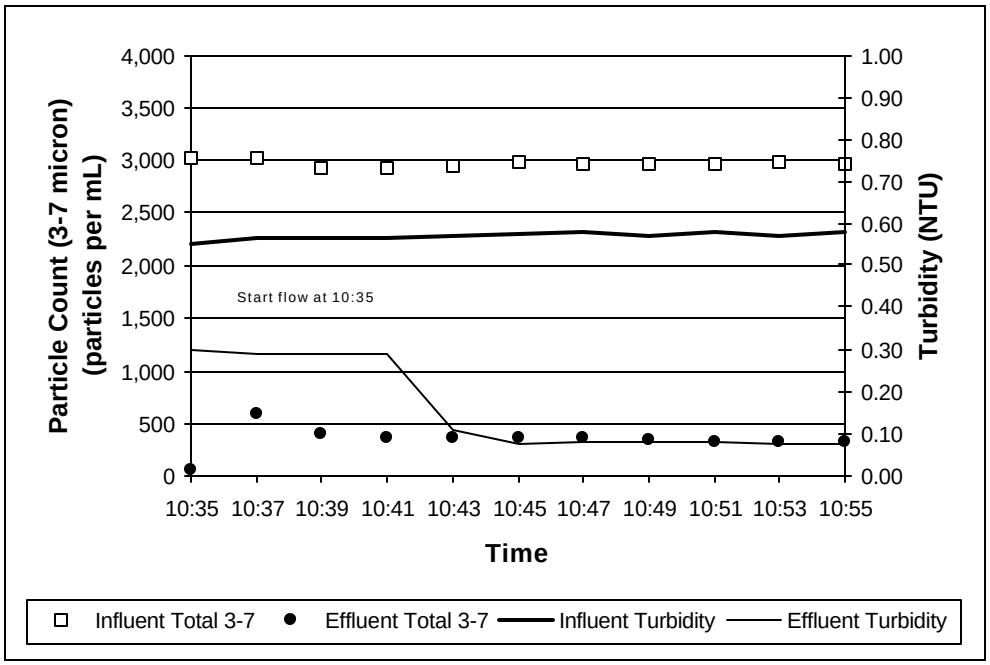

Figure 4-10. Turbidity and 3-7 µm Particle Count Stop/Start During Protozoa Challenge #3

The above analyses suggest that indigenous particles of same approximate size of oocysts were released from a filter bed within four minutes after the resumption of flow. To what degree this shedding period is comparable to the period of time oocysts were also released is unknown, but it is suspected they would be released in a similar pattern as indigenous particles of the same size.

To prevent high concentrations of particles from entering the filter effluent stream in the event of a stop/start occurrence, the Kinetico SW224 Filter System employs a rinse to waste cycle previous to the resumption of flow into the filter effluent stream. This rinse to waste cycle did occur in each of the three stop/start episodes described above and likely accounts for the low effluent (oo)cyst concentrations detected in the effluent stream during this stop/start evaluation. However, because elevated (oo)cyst counts were detected once flow was directed to the filter effluent stream, consideration should be given to increasing the duration of filter-to-waste cycle.

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

The qualitative factors examined during the verification were operational aspects of the Kinetico SW224 Filter System, specifically, susceptibility to changes in environmental conditions, operational requirements and equipment safety, as well as other factors that might impact performance.

4.4.1.1 Susceptibility to Changes in Environmental Conditions

Changes in environmental conditions will influence the performance of the Kinetico SW224 Filter System if they alter suspended particulate and/or algae concentrations, or pH. Higher concentrations of suspended particulate matter will shorten filter run time between backwash cycles. Algae blooms, especially of species known to disrupt filter performance will also decrease filter run times. Although, given the alternating filter process design of the Kinetico SW224, shortened filter run times are of little consequence other than elevating backwash and rinse water volumes.

Duration of filter runs decreased throughout the verification 32-½ day test period. While influent turbidity was controlled not to exceed 1 NTU, filter runs initially exceeding 24 hours decreased to less than 5 hours near the end of the test period. Because untreated water was blended with treated water to achieve a 1 NTU equipment influent water quality specification, changes in raw water quality due to spring run-off were minimized. Measured water quality parameters confirm this. Accordingly, it is suspected that shortened filter runs can be attributed to changes in water quality parameters that were not measured and/or a mechanical aberration within the filtration equipment being tested.

As stated by the Manufacturer, because the surface charge of filter media used within the Kinetico SW224 filtration system is positive between pH 2.3 to 8.0 with a maximum positive charge between pH 3 to 4, filtration performance for the removal of *G. lamblia* cysts and *C. parvum* oocysts are enhanced between this pH range.

The test site offered influent water conditions intended to present a worst case challenge for the Kinetico SW224's ability to filter *C. parvum* and *G. lamblia*. Under more optimal conditions, with influent water pH between 2.3 and 8.0, greater $\log_{10}$ reductions may be exhibited.

4.4.1.2 Operational Requirements

The Kinetico SW224 Filter System was staffed eight hours per day. The operator was not on site for the entire period of each of the 78 filter runs, therefore, a complete set of data for all of the filter runs was not recorded. During 50 filter runs that were entirely observed by operators, it was noted that the

equipment could virtually operate without operator interface. This being said, the recurring problems encountered with the operation of the on-line turbidimeters, as previously described in Section 4.3.1, would not allow for such hands-off operation of the treatment equipment.

4.4.1.3 Evaluation of O&M Manual

The O&M manual provided by the manufacturer primarily defined installation, operation and maintenance requirements for Kinetico SW224 Filter System. The manual provided information pertaining to basic installation, start-up, and operational process. A process schematic, trouble shooting guide, and associated O&M manuals for components used within the Kinetico SW224 Filter System were also provided. Warranty policies described within the O&M manual included those pertaining to equipment and labor. The manufacturer also describes guarantees pertaining to the Kinetico SW224 Filter System's process and design.

The O&M manual was reviewed for completeness and used during equipment installation, start-up, system operation, and trouble-shooting. It was found the manual provides adequate instruction for tasks required to perform these functions over the period of operation of the ETV test period. In cases where the operator desired to confirm his interpretation of instructions within the O&M manual, Kinetico's customer support department proved to be responsive. In one such case, during initial operations, Kinetico changed minor timing sequences controlled by the equipment's PLC via a phone line modem connection.

4.4.1.4 Safety

The Kinetico SW224 Filter System did not introduce safety concerns beyond what is normally expected in the operation of a small filtration system.

4.4.2 Quantitative Factors

Quantitative factors examined during the verification testing are limited to the review of power requirements.

4.4.2.1 Power Requirements

Power use by the Kinetico SW224 Filter System was recorded by the use of a dedicated power meter. During the 32½day verification testing period the Kinetico SW224 Filter System unit used 147 kWh for 1,307,850 gallons of water filtered. This equates to 8,897 gallons of filtered water per kWh.

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

Calculations 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, One-Time 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 Kinetico SW224 Filter System. These include influent and effluent turbidity, particle count, 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 particle count data, turbidity data, and testing equipment verification are presented below in discussions on Daily, One-Time and Start of Testing Period QA/QC Results.

4.5.1.4 Precision

Precision is a measure of the degree of consistency from test to test, and can be measured by replication. Precision was ensured by verifying replicated field and lab measurements were within 30% of the relative standard deviation of each sample set. Both influent and effluent turbidity was within 30% of the relative standard deviation. For single reading parameters, on-site, such as pressure, pH and flow rates, precision was ensured by calibration of analytical equipment and redundant readings from operator to operator. Calibration procedures and results are presented in QA/QC Results.

4.5.2 Daily QA/QC Results

The on-line influent turbidimeter flow rate averaged 1,192 mL/minute. This average was calculated only to show that the limits were observed. The maximum rate during the testing period was 2,280 mL/minute; the minimum was 880 mL/minute. The acceptable ranges of flows as specified by the manufacturer are 190 mL/minute to 26,582 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 lower flows. The on-line effluent turbidimeter flow rate averaged 2186 mL/minute. The maximum rate during the testing period was 2,320 mL/minute; the minimum was 2,020 mL/minute.

Values from the GLI Model 95T/8320 on-line influent and effluent turbidimeters averaged 0.77 and 0.23 NTU respectively during the verification test period. Values from the Hach 2100P bench-top turbidimeter averaged 0.64 and 0.25 NTU respectively for filter influent and effluent water samples. On-line turbidimeter readings were compared against bench-top turbidimeter readings daily. The RPD between these sets of comparative online vs. benchtop values for influent and effluent samples, were not within 30% on a consistent basis (refer to Appendix G). This variation is thought to be partly attributable to measurement of turbidity values near the limitations of measurement of the sensors, and partly attributable to possible scratches on the on-line turbidity sensor caused by the occasional presence of media fines within the sensor cells.

The influent water particle counter flow rate averaged 100 mL/minute. The flow rate of the on-line influent water particle counter was determined using a graduated cylinder and stopwatch. The maximum flow rate measured was 103 mL/minute; the minimum was 98 mL/minute. The target flow rate specified by the manufacturer is 100 mL/minute. Efforts were made to keep the flow rate at 100 mL/minute and the flow was adjusted whenever those boundaries were crossed. The effluent water particle counter flow rate averaged 100 mL/minute. The flow was measured using a graduated cylinder and stopwatch.

The pH meter was calibrated daily against NIST-traceable pH buffers of 7.0 and 10.0. The pH meter was a Cole Palmer Oakton® WD-35615 Series. The pH calibration buffers were Oakton pH Singles 7.0 (model #35653-02), and pH Singles 10.0 (model #35653-03). The pH calibration was performed prior to the recorded inlet pH measurement. pH meters were calibrated to standards previous to each pH measurement to ensure accuracy of measurement.

4.5.3 One-Time QA/QC Verification Results

Verifications of the on-line flow meters were performed once during the testing period.

Digital flow meters provided with the test unit were verified by bucket and stopwatch using a measured container on April 30, 2000. Flows were measured at 29.03 gpm three times. Comparative flow displayed by the digital flow meters 29.07, 28.80, and 29.10 gpm. This represents an average error of -0.04 gpm, or 0.14%. This was within acceptable limits.

Flow rate rotometer readings were verified by bucket and stopwatch using a measured container on April 30, 2000. Flows were measured at 29.03 gpm three times. Comparative flows displayed by the rotometers were 29.8 gpm three times. This represents a factor of error of -0.77 gpm or 2.65%. This was within acceptable limits.

The Burkert 8035 on-line flow meter was verified by bucket and stopwatch using a measured container on April 30, 2000. The Burket flow was measured at 30.72, 30.90, & 30.80 gpm. The bucket/stopwatch was measured at 29.03 gpm three times. This represents a factor of error of +1.77 gpm, or 5.8%.

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

Accuracy of on-line flow rate meters were verified once at the end of the testing period when plumbing revisions could be made to accommodate this procedure.

The tubing and all water lines used on the treatment system were inspected at the beginning of the testing period (March 25, 2000). The tubing and lines were checked periodically throughout the testing period. They remained in good condition and replacements were not necessary.

Particle counters used on site were Met One PCX models. The particle counters were calibrated by HACH Company using polystyrene latex spheres traceable to NIST standards. Particle counters used on site had a HACH Company factory calibration certificate dated January 11, and 12, 2000.

Calibration was verified on site with NIST mono-sized polymer microspheres on April 29, 2000 as described in Section 3.9.2.4 above. The following figures show the distribution as counted by the MetOne particle counter during the NIST-traceable verification of calibration using 500 mL of a microsphere dilution as detailed below for each verification test.

Figure 4-11 shows the particle counts during the influent 3 µm verification using 500 mL of a microsphere dilution (5×10^7/mL, 0.04 mL concentration to 1 Liter PFW). The Figure shows the addition of the added particles in the 3 µm size range as would be expected.

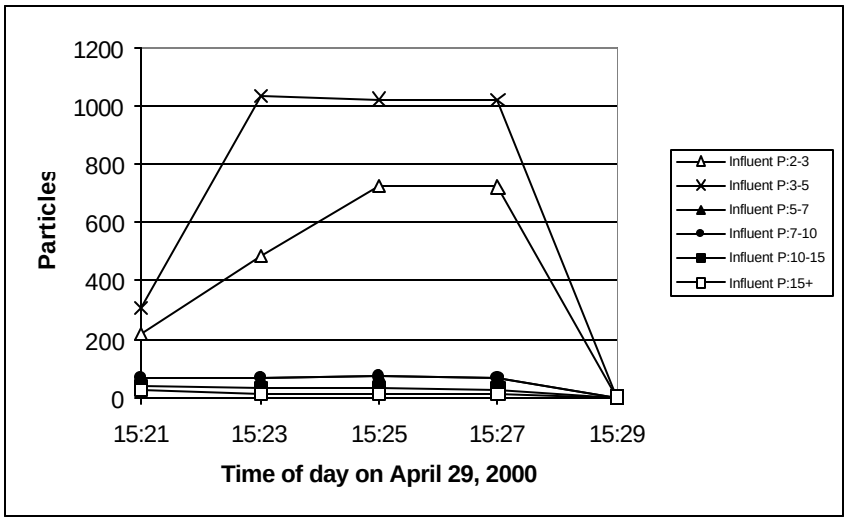

Figure 4-11. Verification of 3 µm Influent Particles

Figure 4-12 shows the particle counts during the influent 10 µm verification using 500 mL of a microsphere dilution (1 x 10^6/mL, 2 mL concentration to 1 Liter PFW). This Figure shows the addition of the added particles as would be expected in the 10 µm size range.

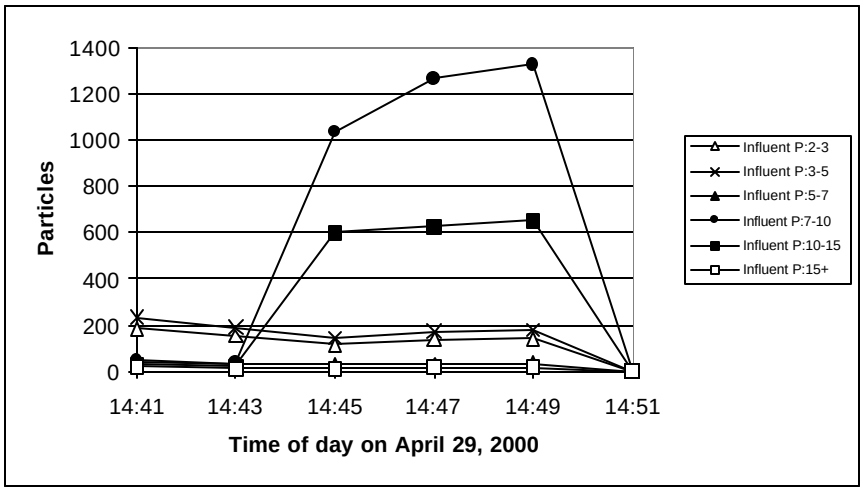

Figure 4-12. Verification of 10 µm Influent Particles

Figure 4-13 shows the particle counts during the influent 15 µm verification using 500 mL of a microsphere dilution (1 x 10^6/mL, 2 mL concentration to 1 Liter PFW). This Figure shows the addition of the added particles in the 15 µm range as expected.

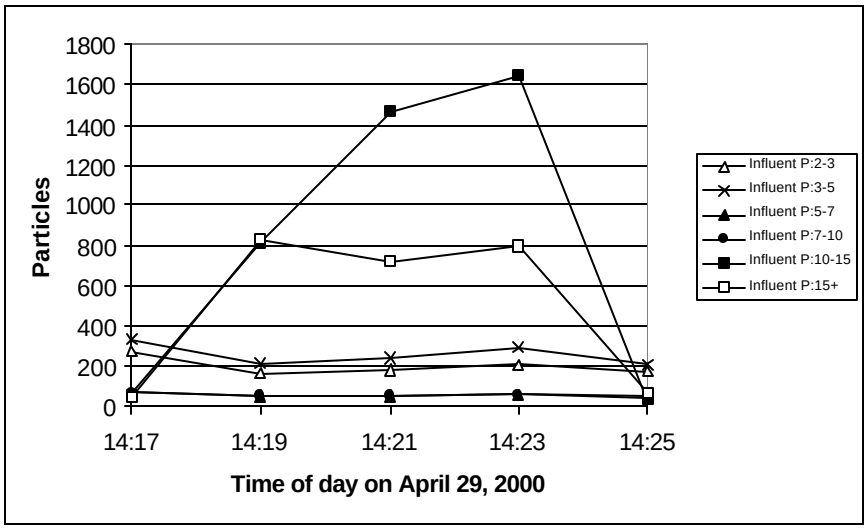

Figure 4-13. Verification of 15 µm Influent Particles

Figure 4-14 shows the particle counts during the influent "cocktail" mix of 3, 10 and 15 µm verification using 500 mL of a microsphere dilution (1 mL of 15 µm, 1 mL of 10 µm. 0.02 mL of 3 µm to 1 Liter PFW). The Figure shows the addition of the added particles in the 3, 10 and 15 µm size range as would be expected.

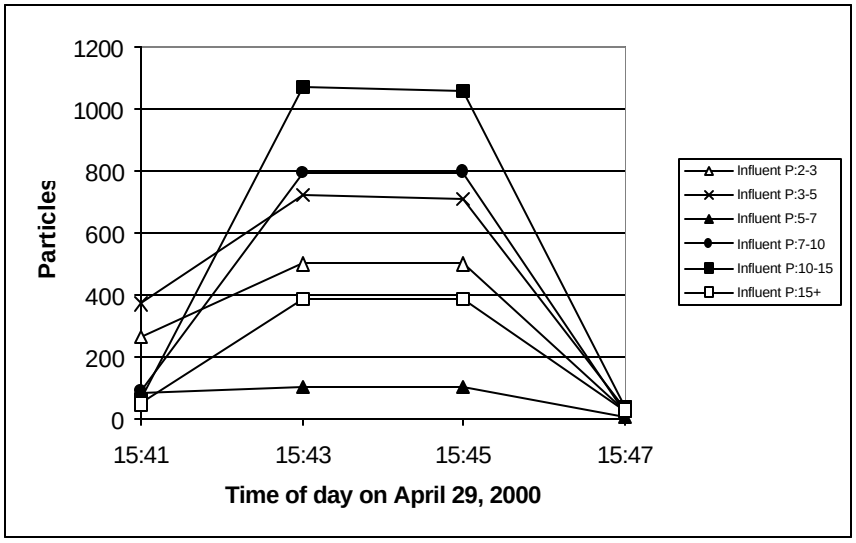

Figure 4-14. Verification of Mix of 3, 10 & 15 µm Influent Particles

Figure 4-15 shows the particle counts during the effluent 3 µm verification using 500 mL of a microsphere dilution (5 x 10^7/mL, 0.04 mL concentration to 1 Liter PFW). The Figure shows the addition of the added particles in the 3 µm size range as expected.

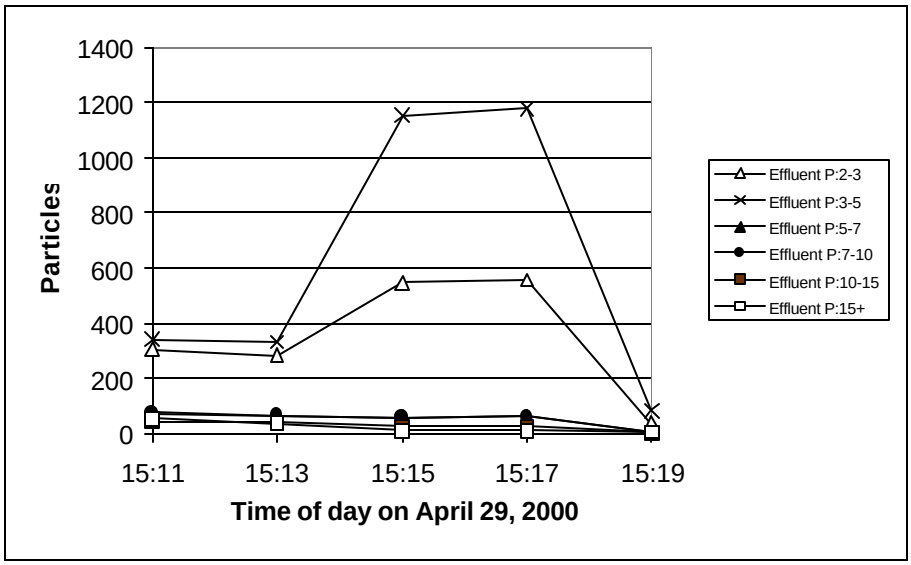

Figure 4-15. Verification of 3 µm Effluent Particles

Figure 4-16 illustrates the particle counts during the 10 µm effluent verification using 500 mL of a microsphere dilution (1 x 10^6/mL, 2 mL concentration to 1 Liter PFW). The Figure shows the addition of the added particles in the 10 µm size range as expected.

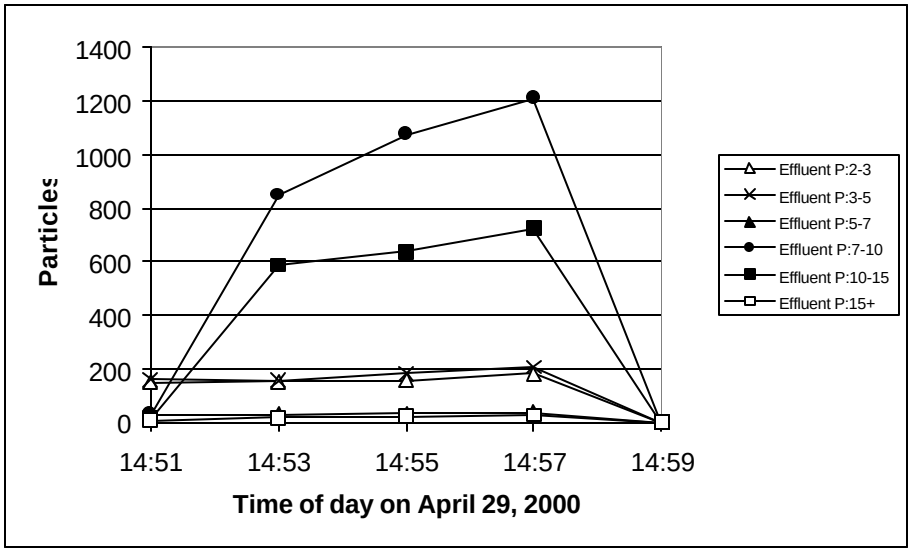

Figure 4-16. Verification of 10 µm Effluent Particles

Figure 4-17 illustrates the particle counts during the 15 µm effluent verification using 500 mL of a microsphere dilution (1 x 10^6/mL, 2 mL concentration to 1 Liter PFW). The Figure shows the addition of the added particles in the 15 µm size range as expected.

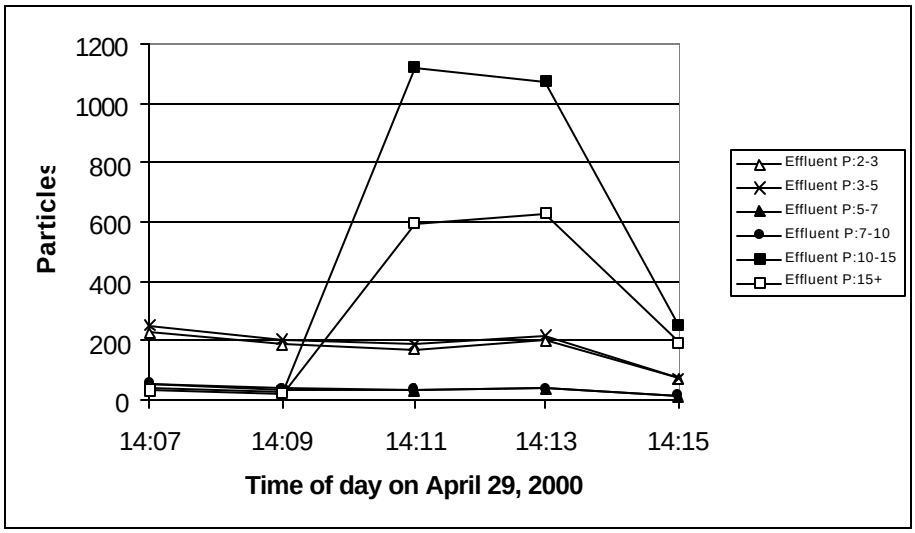

Figure 4-17. Verification of 15 µm Effluent Particles

Figure 4-18 illustrates the particle counts during the "cocktail" mix of 3, 10, and 15 µm effluent verification using 500 mL of a microsphere dilution (1 mL of 15 µm, 1 mL of 10 µm, 0.02 mL of 3 µm to 1 Liter PFW). The Figure shows the addition of the added particles in the 3, 10 and 15 µm size range as expected.

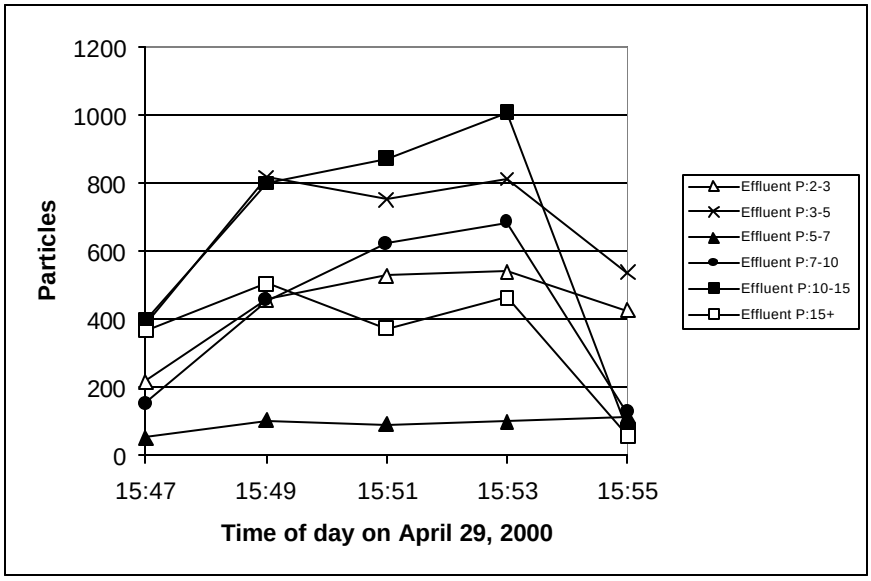

Figure 4-18. Verification of 3, 10 & 15 µm Effluent Particles

The addition of particles in the effluent and influent samples were recorded via the particle counter during the verification process.

Particles that were added were:

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

Visual inspections of the particle counter and turbidimeter tubing showed unimpeded flow and integrity. The tubing was also inspected periodically throughout the testing period, no replacements were necessary.

Pressure gauges were verified on March 28, 2000 by comparing the pressure shown on the gauge with the pressure shown on a NIST-traceable pressure gauge (Identification Number 9286-11). The inlet gauge had a reading of 53 psig, while the corresponding NIST-traceable gauge had a reading of 53.25 psig. The outlet gauge had a reading of 41 psig, and the corresponding NIST-traceable reading was 41 psig. Differences between the gauges were acceptable, and no further verification was needed.

COA 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. Standards were made with dilutions from a standard Formazin suspension of 4,000 NTU. NIST-traceable glassware, including pipettes and volumetric flasks were used.

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 provides the opportunity for increasing error. The manufacturer's recommended settings were also observed in subsequent calibrations.

Fixed Gelex secondary standards were correlated with the instrument following calibration, which was performed according to the manufacturer's instructions with Formazin standards. This was done each time the instrument was calibrated with Formazin suspensions thereby standardizing the Gelex cells to that instrument for that period. When the instrument is recalibrated, the Gelex cells are also recalibrated. Additional secondary standards of 0.1, 0.5, 1.0 and 3.0 NTU were prepared from fresh Formazin stock, or purchased as a standard from Hach. These standards were referenced daily. While the comparison of the readings to the standards at 0.5, 1.0 and 3.0 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.

4.5.5 Analytical Laboratory QA/QC

QA/QC procedures for laboratory analyses were based on *SM*, 19th Ed. (APHA, 1995) and Methods for Chemical Analysis of Water and Wastes (EPA, 1995).

The QA/QC for the field collection of water samples using EPA Method 1623 was achieved throughout the pilot testing. All samples collected using the Gelman filter cartridges were maintained at 4^{0}C prior to

and during shipping to BioVir Laboratories where the filters were processed. All samples were processed to completion within 72 hours of sample collection as stated in EPA Method 1623.

Calibration results of the analytical instrumentation used to conduct the analyses on effluent 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.

Chapter 5
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