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Environmental Technology Verification Report

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

Kinetico Incorporated CPS100CPT Coagulation and Filtration System

Prepared by

NSF International

Under a Cooperative Agreement with

U.S. Environmental Protection Agency

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**COAGULATION AND FILTRATION USED IN DRINKING WATER TREATMENT SYSTEMS**	
APPLICATION:	**PHYSICAL REMOVAL OF *GIARDIA* CYSTS AND *CRYPTOSPORIDIUM* OOCYSTS IN DRINKING WATER**	
TECHNOLOGY NAME:	**CPS100CPT COAGULATION AND 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 coagulation and filtration system used in drinking water treatment system applications. This verification statement provides a summary of the test results for the Kinetico Incorporated CPS100CPT Coagulation and Filtration System. Cartwright, Olsen and Associates, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the Kinetico Incorporated CPS100CPT Coagulation and Filtration System was conducted for 12 days between March 24 and April 4, 2000, and three protozoan challenges were performed between April 24 to 26, 2000. Between March 24 and April 4, 2000, raw water characteristics were: average pH 8.3, temperature 12.3°C, and turbidity 3.4 Nephlometric Turbidity Units (NTU). The process flow rate through the pretreatment components was held at a constant 3.8 gpm while the flow rate through the filtration vessels was allowed to decrease against filter head resulting in an average filter flow rate of 2.8 gpm. The following coagulant doses were used: 266 mg/L of 2.64% Ferric Chloride (20.7 mg/L of 35% aqueous solution Ferric Chloride) and 351 mg/L of 3.47% AQM 100 (25.3 mg/L of 50% aqueous solution Aluminum Chlorhydrate), which were added into the influent water stream of the pretreatment components; and 182 mg/L of 0.10% C-1592 (0.54 mg/L of cationic, 34% aqueous solution Emulsion Polyacrylamide), which was introduced into the influent water stream of the filtration vessels. The average length per filter run was 56 hours and the average filtered water production was 1,024 gallons per run. The average effluent turbidity was 0.4 NTU. Source water conditions changed considerably during the 19-day period before the protozoan challenges. During the protozoan challenges the raw water characteristics were: average pH 8.7, temperature 15.9°C, and turbidity 14.7 NTU. The average effluent turbidity was 1.6 NTU. Results of the samples collected from the system effluent (i.e. combined pretreatment and filtration trains) indicate that *Giardia lamblia* (*G. lamblia*) $\log_{10}$ removals ranged from 2.6 to 3.6 and *Cryptosporidium parvum* (*C. parvum*) $\log_{10}$ removals ranged from 3.4 to 5.7 at filter train flow rates of 2.2 to 2.6 gpm over the challenge filter runs.

TECHNOLOGY DESCRIPTION

The Kinetico CPS100CPT has two distinct water treatment trains; a pretreatment train and a filtration train. The pretreatment train consists of an in-line static mixer, a settling tank and a clarifier. Within the pretreatment train, coagulants (2.64% Ferric Chloride and 3.47% AMQ 100) are introduced into the chlorinated raw water and mixed through an in-line static mixer. The coagulated raw water is allowed to floc and settle within a settling tank. Supernatant from the settling tank is further processed through a clarifier. An additional coagulant (0.10% C-1592) is added to the effluent from the clarifier prior to entry into the filtration train.

Within the filtration train, water is re-pressurized by a centrifugal pump and filtered through automatic backwashing, alternating filters. The alternating filters (designated A and B) contain Macrolite® media, a synthetic ceramic, filter media. The Macrolite® media meets the requirements of ANSI/NSF Standard 61 and is NSF listed as of the date of this report. Macrolite® of the 70/80 mesh size has a bulk density of 0.96 grams/cc. The specific gravity (as measured by 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 D 3102) 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 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

Kinetico performed an analysis of the 70 mesh media (lot # 352) employing a mercury/penetrometer Micromeritics Autopore II 9220 instrument to estimate the uniformity of the media in June 1998. Results were as follows:

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

During verification testing, the process flow rate through the pretreatment train was held at a constant 3.8 gpm while the flow rate through the filtration train was allowed to decrease against filter head. Typically filter flow rates decreased from 3.3 gpm to approximately 2.7 gpm. To accommodate decreases in filter flow, the pretreatment train included an overflow weir, discharging to waste, at the outlet of the clarifier.

Accessories and instrumentation included with the system included flow rate and pressure sensors and monitors, on-line turbidimeters, pressure gauges, and an electrical enclosure containing a programmable logic controller. The equipment also contained data transfer connections available for remote monitoring. Electrical power was required for operation of the re-pressurization pump, analytical instruments and system instrumentation.

The filtration train itself is skid mounted and is shipped absent of media. The total weight of the filtration train, without media, is approximately 300 pounds. The physical dimensions of the filtration train were 26¼" wide x 53½" long x 76" high. Physical dimensions of the settling tank were 36" diameter x 78" high. Physical dimensions of the clarifier were 22½" wide x 51¼" long x 51" high. The pretreatment and filtration trains together had a footprint of approximately 24.8 ft^2.

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. Chlorinated river water was supplied to the system.

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, alkalinity, total hardness, total organic carbon (TOC), ultraviolet absorbance (UVA) at 254 nanometer (nm), true color, aluminum, iron, manganese, algae, total coliforms, 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 as listed in the report.

Three seeding challenges employing *G. lamblia* cysts and *C. parvum* oocysts occurred between April 24 and 26, 2000. The protozoan analyses (identification and enumeration) were conducted using EPA Method 1623. The mixed cocktail of cysts and oocysts was added to the raw water upstream of the

pretreatment train. The analyses of the influent samples indicated that the cocktail contained 150, 260, and 363 *G. lamblia* cysts per liter, and 8,000, 21,000, and 45,000 *C. parvum* oocysts per liter, respectively, for each of the three seeding challenges. Samples for protozoa analyses were collected on a side-stream and filtered through Gelman capsule filters. Post clarifier and filter effluent samples were collected at time zero (based on tracer test data), and at times 1/2 hour, 1.0 hour, and 2.0 hour (if filter runs allowed) after time zero. Seeded influent source water was collected and filtered through a Gelman capsule filter throughout the duration of the microbial injection.

Operating conditions were documented during each day of verification testing, including: filter flow rate, coagulants used, chemical feed volumes and dose rates, filter headloss, occurrence and volume of backwashes, hours of operation, power use, filtered water production, and waste production.

VERIFICATION OF PERFORMANCE

Source Water

Between March 24 and April 4, 2000, average raw water characteristics were: pH 8.3, temperature 12.3°C, and turbidity 3.4 NTU. Source water conditions changed considerably during the 19-day period before the protozoan challenges. During the protozoan challenges, average raw water characteristics were: pH 8.7, temperature 15.9°C, and turbidity 14.7 NTU.

Operation and Maintenance

During the verification period of March 24 through April 4, 2000, there were 42 filter runs; 21 filter runs for each filter "A" and "B". Coagulants used included solutions of 2.64% Ferric Chloride and 3.47% AQM 100, which were added into the influent water stream of the pretreatment components, and a solution of 0.10 % C-1592, which was introduced into the influent water stream of the filtration vessels. The average length per filter run was 5.6 hours and the average filtered water production was 1,024 gallons per run. The average filtration flow rate was 2.8 gpm with an average minimum flow rate of 2.5 gpm and an average maximum flow rate of 3.1 gpm. The average effluent turbidity was 0.4 NTU. The following table summarizes the averages per filter run for several operating parameters.

Average Operating Conditions for 42 Filter Runs (March 24 through April 4, 2000)

	Filter Run Length (Hrs)	Ave. Pre-Treatment Train Flow Rate (gpm)	Ave. Filter-Train Flow Rate (gpm)	ΔPSI End Run (psig)	Total Volume (gal)	Backwash Volume (gal)
Average	5.61	3.8	2.8	19	1,024	80
Minimum	1.72	3.8	2.6	9	363	53
Maximum	8.57	3.9	3.1	20	1,657	98
Std. Dev	1.57	0.0	0.1	2	259	11
95% Conf. Int.	5.15, 6.07	NA	2.8, 2.9	18, 20	945, 1,103	77, 84

The failure of a pressure differential switch, which caused the operation of the filtration system to become non-automatic, combined with continuous monitoring required for the operation of the pretreatment train made the operation of the Kinetico CPS100CPT labor intensive. The system was staffed 24 hours per day during testing. Manual tasks included stabilization and monitoring of the coagulant chemistry, manual backwashing, and data recording. If coagulation chemistry is stabilized, such as what was experienced for an extended period during verification testing, and the filtration train is operating on an automatic basis, the Kinetico CPS100CPT could be operated with less technician interface. Minimal changes in source water characteristics may negatively influence performance of coagulation chemistry and continuous monitoring would be necessary to be aware when such changes occur so corrective action can be taken on a timely basis.

The O&M manual provided by the manufacturer primarily defined installation, operation and maintenance requirements for the filtration train of the Kinetico CPS100CPT. The O&M manual was reviewed for completeness and used during equipment installation, start-up, system operation, and trouble-shooting. The manual provided adequate instruction to perform these functions. In cases where system components failed, such was concluded based upon a review of the information in the O&M manual. Specific component failures included an on-line turbidimeter manufactured by Great Lakes International and a pressure differential switch manufactured by Orange Research. In both cases, Kinetico was responsive to remedy component failures. The Kinetico O&M manual did not contain information on the pretreatment train (settling tank and clarifier).

Coagulant Usage

Coagulant doses used between March 24 and April 4, 2000 included 266 mg/L of 2.64% Ferric Chloride (20.7 mg/L of 35% aqueous solution Ferric Chloride) and 351 mg/L of 3.47% AQM 100 (25.3 mg/L of 50% aqueous solution Aluminum Chlorhydrate), which were added into the influent water stream of the pretreatment components, and 182 mg/L of 0.10% C-1592 (0.54 mg/L of cationic, 34% aqueous solution Emulsion Polyacrylamide), which was introduced into the influent water stream of the filtration vessels. A total of 83.25 liters of 3.60% AQM 100, 62.80 liters of 2.72% Ferric Chloride, and 27.49 liters of 0.10% C1592 were used during the verification testing period between March 24 and April 4, 2000. These volumes, converted to undiluted solutions as provided by the chemical supplier, are equivalent to 3.00 liters of AQM 100, 1.71 liters of Ferric Chloride, and 0.03 liters of C1592.

Protozoan Contaminant Removal

The system (i.e. combined pretreatment and filtration trains) demonstrated 2.6 to 3.6 $\log_{10}$ reductions of *G. lamblia* cysts and 3.4 to 5.7 $\log_{10}$ reductions of *C. parvum* oocysts. These results were obtained at an average pretreatment train flow rate of 3.7 gpm and at a filter train flow rates of 2.2 to 2.6 gpm over the challenge filter runs. Filter runs during challenge testing were considerably short (4.4 hours) due to changes in the water quality of the Mississippi River. During the first challenge, effluent samples were only collected during the first hour after time zero before terminal head loss occurred across the filter. On the two subsequent challenges, effluent samples were collected during a two-hour period after time zero.

Finished Water Quality

The average effluent turbidity during the twelve days between March 24 and April 4, 2000 was 0.4 NTU. The average effluent turbidity during the protozoan challenges was 1.6 NTU. A summary of the influent and effluent water quality information for the verification period of March 24 through April 4, 2000 is presented in the following table.

Influent/Effluent Water Quality (March 24-April 4, 2000)

Parameter	# of Samples	Average	Minimum	Maximum
Total Alkalinity (mg/L)	11/11	150/140	140/140	150/140
Total Coliform (cfu/100mL)	2/2	NA/NA	<1/<1.2	>200/>200
E. coli (CFU/100mL)	2/2	NA/NA	<1/<1	1/7
Total Hardness (mg/L)	2/2	NA/NA	160/160	160/160
TOC (mg/L)	2/2	NA/NA	11/8.9	12/9.0
UVA_{254} (cm-l)	2/2	NA/NA	0.151/0.125	0.185/0.240
Turbidity (NTU)*	494/7,061	3.3/0.4	2.6/0.03	4.0/5.0

Note: All calculations involving results with below PQL values used 1/2 the PQL in the calculation.
NA = Average was not performed for data sets with two samples (i.e. n=2).
*Influent turbidity measurements involved a bench-top turbidimeter. Effluent turbidity measurements were made with an on-line turbidimeter.

Power Consumption

During the verification testing period of March 24 through April 4, 2000, the system used 196 kWh for 39,812 gallons through the filtration train. This equates to 203 gallons of filtered water per kWh.

Original Signed by
E. Timothy Oppelt *9/26/01*

E. Timothy Oppelt Date
Director
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Original Signed by
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Gordon Bellen Date
Vice President
Federal Programs
NSF International

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 # 01/12/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)

August 2001

Environmental Technology Verification Report

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

Kinetico Incorporated CPS100CPT Coagulation and Filtration System

Prepared for:
NSF International
Ann Arbor, Michigan 48105

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

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

The ETV DWTS Pilot 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
cfh	Cubic feet per hour
cfm	Cubic feet per minute
CFU	Colony Forming Units
cfs	Cubic feet per second
COA	Cartwright, Olsen, and Associates, LLC
DAF	Dissolved air flotation
DI	Deionized (demineralized) water
EPA	U.S. Environmental Protection Agency
ESWTR	Enhanced Surface Water Treatment Rule
ETV	Environmental Technology Verification
ºF	Fahrenheit
FOD	Field Operations Document
FTO	Field Testing Organization
gallons	Gallons are expressed as US gallons, 1 gal = 3.785 liters
gpm	Gallons per minute
ICR	Information Collection Rule
Kinetico	Kinetico Incorporated
Log	Logarithm to the base 10
Ln	Logarithm to the base e
mgd	Million gallons per day
mg/L	Milligrams Per Liter
MPA	Microbial Particulate Analysis
MWW	Minneapolis Water Works
µm	Micron
NIST	National Institute of Standards and Technology
NSF	NSF International, formerly known as National Sanitation Foundation
NTU	Nephelometric Turbidity Unit
(oo)cyst	A term used conventionally to refer to either or both cysts and oocysts
DWTS	Drinking Water Treatment Systems
PFW	Particle Free Water
PLC	Programmable Logic Computer
PQL	Practical Quantification Limit
psi	Pounds per square inch
psig	Pounds per square inch gauge
QA/QC	Quality Assurance/Quality Control
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*
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.

Coagulant
Although technically the coagulant is the product of a chemical reaction that is formed when chemicals are added to water containing colloidal suspensions, the term is often used to refer to the chemicals that are added. These include aluminum and ferric salts, along with organic polymers.

Coagulant aid
Activated silica when used to coagulate suspensions.

Coagulation
The destabilization of colloidal and suspended materials in water using coagulant chemicals, thus allowing the particles to agglomerate into floc.

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 through chemical coagulant addition and filtration, but excluding the sedimentation step.

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

Flocculation
The employment of stirring through hydraulic or mechanical means to agglomerate smaller floc into larger particles for more ready separation.

Granular Media Filter
A deep bed filter containing granular media used to filter water that has not been coagulated. 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 was performed by:

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The laboratory that conducted the protozoa analytical work of this study was:

BioVir Laboratories, Inc.
685 Stone Road
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Phone: (707) 747-5906 or (800) 442-7342
Fax: (707) 747-1751
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The laboratory that conducted the remaining laboratory analytical work of this study was:

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Phone: (651) 633-0101
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The Manufacturer of the Equipment was:

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COA wishes to thank NSF International, especially Mr. Bruce Bartley, Project Manger, and Carol Becker and Kristie Wilhelm, Environmental Engineers for providing guidance and program management.

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 staff 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 setup, and tear down as well as assistance during the 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) Pilot, one of 12 technology areas under ETV. The DWTS Pilot evaluated the performance Kinetico Inc.'s CPS100CPT Coagulation and Filtration System. The field testing included protozoan challenges to evaluate the system's capability to physically remove *Cryptosporidium parvum* (*C. parvum)* and *Giardia lamblia* (*G. lamblia)*. This document provides the verification test results for the Kinetico CPS100CPT Coagulation and Filtration System.

1.2 Testing Participants and Responsibilities

The ETV testing of the Kinetico CPS100CPT Coagulation and Filtration System was a cooperative effort between the following participants:

NSF International
Cartwright, Olsen & Associates, LLC
Kinetico Incorporated
Debra Huffman Environmental Consulting
BioVir Laboratories
Spectrum Laboratories, 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 (COA), a Limited Liability Company, conducted the verification testing of Kinetico CPS100CPT Coagulation and Filtration System. COA is a NSF-qualified Field Testing Organization (FTO) for the DWTS ETV Pilot.

COA was responsible for conducting the verification testing. COA provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. COA was responsible for ensuring that the testing location and influent water conditions were such that the verification testing could meet its stated objectives. COA prepared the FOD, oversaw the testing, managed, evaluated, interpreted and reported on the data generated by the testing, as well as evaluated and reported on the performance of the technology.

COA associates, in conjunction with the Minnesota Department of Health and the University of Minnesota St. Anthony Falls Hydraulic Laboratory conducted the onsite analyses and data recording during the testing. Oversight of the daily tests was provided by COA's Project Manager and Director.

Contact Information:

Cartwright, Olsen & Associates, LLC
19406 East Bethel Blvd., Cedar, MN 55011

Phone: (763) 434-1300
Fax: (763) 434-8450
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 Incorporated, a manufacturer of non-electric, demand operated water processing systems. The company was founded by two engineers to develop a non-electric, metered water softener and has grown rapidly into one of the largest manufacturers of water treatment systems worldwide. Headquartered in Newbury, Ohio,

Kinetico was responsible for supplying a field-ready model number CPS100CPT Coagulation and Filtration 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.

Contact Information:

Kinetico Incorporated
10845 Kinsman Road, Newbury, Ohio 44065
Phone: (440) 564-9111 or (800) 432-1166
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 was performed by:

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

Protozoan laboratory work was performed by BioVir Laboratories, Inc. of Benicia, California. 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 Statement is attached in Appendix A.

Contact Information:

BioVir Laboratories, Inc.
685 Stone Road, Benicia, CA 94510
Phone: (707) 747-5906 or (800) 442-7342
Fax: (707) 747-1751
Contact Person: Richard E. Danielson, Ph.D., Quality Assurance Officer, Principal Analyst/Supervisor

Spectrum Labs, Inc performed tests for coliform bacteria and off-site non-microbial work. Spectrum's laboratory provided analytical services for total coliform, total alkalinity, total hardness, true color, UV_{254} absorbance, aluminum, algae, (number and species), total suspended solids (TSS), iron and manganese, and total organic carbon (TOC).

Contact Information:

Spectrum Labs Inc.
301 West County Road E2, St. Paul, MN 55112
Phone: (651) 633-0101
Fax: (651) 633-1402
Contact Person: 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), Department of Civil and Mineral Engineering, located on Hennepin Island at the head of St. Anthony Falls in the heart of Minneapolis, 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 CPS100CPT Coagulation and Filtration 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 Person: 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 DWTS Pilot operating under the ETV Program. This document was reviewed for technical and quality content by the EPA.

1.3 Verification Testing Site

In March and April of 2000, the ability of the Kinetico CPS100CPT Coagulation and Filtration System to remove *C. parvum* oocysts and *G. lamblia* was tested at the University of Minnesota, SAFHL. The University of Minnesota, SAFHL, Department of Civil and Mineral Engineering is located on the Mississippi River at Third Avenue, S.E., Minneapolis, Minnesota, 55414-2196.

1.3.1 Source Water

The University of Minnesota St. Anthony Falls Hydraulic Laboratory has direct access to untreated and treated Mississippi river water. River water treated by the Minneapolis Water Works (MWW) treatment plant and supplied to the Hydraulic Laboratory through the Minneapolis potable water distribution system can also be blended with untreated water to achieve targeted turbidity levels during initial operations and verification testing.

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, or 11 degrees Fahrenheit (ºF)) in January to 23°C (74 ºF) in July. Average precipitation at the MWW is 30 inches. About three-quarters of the annual precipitation falls from April to September.

During initial operations of the ETV test period (March 8 through March 23, 2000), the influent water to the Kinetico CPS100CPT water exhibited the following average characteristics: turbidity of 6.7

Nephelometric Turbidity Unit (NTU); temperature 8.6°C, pH 7.8; total alkalinity of 126 mg/L; total hardness in the range of 120 to 160 mg/L; TOC concentration of 12.0 mg/L; UV_{254} absorption in the range of 0.254 to 0.273; true color between 40 and 45 Total Color Units (TCU); total coliform was not detected (Practical Quantification Limit [PQL] of 1 CFU/100 mL); iron 0.4 to 0.5 mg/L; aluminum in the range of <0.05 to 0.06 mg/L; and manganese of 0.05 mg/L. Based upon data collected during initial operations it was determined that untreated river water would be used during the ETV performance verification period.

A summary of the influent water quality information for the verification period of March 24 through April 4, 2000 is presented below in Table 1-1.

Table 1-1. Influent Water Quality (March 24 - April 4, 2000)

Parameter	# of Samples	Average	Minimum	Maximum	PQL
Temperature (^oC)	11	12.3	11.3	14.1	---
pH	12	8.3	8.1	8.5	---
Algae (Algae/mL)	2	See discussion in Chapter 4	<1	See discussion in Chapter 4	1
Total Alkalinity (mg/L)	11	150	150	150	10
Aluminum (mg/L)	2	NA	<0.05	0.10	0.05
Total Coliform (cfu/100mL)	2	NA	<1	>200	1
E. Coli (CFU/100mL)	2	NA	<1	1	1
Total Hardness (mg/L)	2	NA	160	160	10
Iron (mg/L)	2	NA	<0.1	0.3	0.1
Manganese (mg/L)	2	NA	0.03	0.06	0.01
TOC (mg/L)	2	NA	11	12	0.05
UVA_{254} (cm^{-1})	2	NA	0.151	0.185	---
Free Chlorine (mg/l)	10	0.49	0.1	0.8	0.01*
Bench-top Turbidity (NTU)	494	3.3	2.6	4.0	---

Note: All calculations involving results with below PQL values used half the PQL in the calculation.
NA = Average was not performed on data sets with two samples (i.e. n=2).
* - This is the Estimated Detection Level (EDL) for free chlorine, this is not the same as the PQL. The EDL is the calculated lowest concentration in a deionized water matrix that is different from zero with a 99% level of confidence.

Two samples of the influent water were collected for total coliform analysis. One measurement was below the PQL of 1 CFU/100mL, while the other sample dated April 3, 2000, detected greater than 200 CFU/100mL. Two samples of the influent water were collected for *E. coli* analysis. The results indicated that *E. coli* was not detected in the first sample (PQL of 1 CFU/100mL), while the second sample dated April 3, 2000, measured 1 CFU/100mL. An algae sample dated March 27, 2000, reported positive algae, and is discussed further in Chapter 4 Results and Discussions.

Table 1-2 lists the influent water particle counts for the period March 24 through April 4, 2000.

Table 1-2. Influent Water Particle Count (counts/ml) (March 24-April 4, 2000)

	Particle Count Size Range				
	2 – 3 µm	3 – 5 µm	5 – 7 µm	7-10 µm	10 – 15 µm
Average	1,341	4,104	2,751	5,310	2,343
Minimum	318	247	70	36	5
Maximum	1,673	4,489	2,967	5,800	3,400
Standard Deviation	131	222	128	278	300
95% Confidence Interval	1,378, 1,343	4,100, 4,109	2,748, 2,754	5,304, 5,316	2,336, 2,349

1.3.2 Effluent Discharge

The effluent of the Kinetico CPS100CPT 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

Particles in colloidal suspensions, where electrostatic forces keep the particles dispersed, have proven to be a challenge to depth filtration. In many cases, chemical pretreatment, by agglomerating the particles into larger floc, will allow solids separation of water matrices that otherwise resist filtration. Protozoan (oo)cysts, especially *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).

Large water treatment systems have long employed coagulation, flocculation, settling and filtration for the production of quality water. Small systems have been more reluctant to build treatment plants that use coagulation because of the higher level of operator training required and the need for continuing monitoring. With the soon to be implemented Enhanced Surface Water Treatment Rules (ESWTR), however, coagulation technologies may need to be considered for smaller systems in order to meet tough new standards with a modest increase in costs.

Of the several treatment regimens that incorporate coagulation are those that include a settling basin, where the floc is allowed to settle by gravity and the supernatant decanted and filtered. This is a scheme common to municipal gravity filter systems.

Only in recent time has the scientific community 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 a small mass too large to move through the pores between the media granules; small particles are captured through other attachment mechanisms. Most of those mechanisms involve a surface charge attraction of the particle to granulated media and as a result many experiments have been performed to both better understand the process and to seek methods to improve it. Some particles are also assumed to be collected by impact on and adherence to the surface of the filter media granules; while the actual mechanisms are not clearly understood, straining is certainly among them.

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, operate at flow rates of 2 gpm per square foot (gpm/ft^2) or higher.

Also included among rapid sand filters are pressure filters, where the water is forced through a media bed by high head pressures, and where the media 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 advantage—especially to small systems—of rapid sand pressure filters are that they are relatively passive treatment systems, involve minimal operator attention, are low in cost, and are long lived.

Filtration systems used in municipal treatment may employ a coagulation process. Variations of this process include technologies useful to agglomerate small particles to enhance their removal by filtration, or to cause their separation from the process stream before to filtration. Processes used to enhance filtration typically employ the use of a coagulant injected into the filter influent, upstream of equipment used to ensure thorough mixing. Other processes used to cause removal of particulate matter previous to filtration employ one or a combination of the following technologies:

- sedimentation;
- sedimentation aided by tubes or plates;
- downflow contact clarification;
- upflow contact clarification;
- dissolved air flotation (DAF).

Of concern, however, is whether pressure filters, used in conjunction with a coagulation process, can contain particles that are small, and more importantly, particles that may pose a threat to public health, such as *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; 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 Kinetico CPS100CPT Coagulation and Filtration System is similar to conventional systems. The CPS100CPT includes two distinct water treatment trains: a pretreatment train and a filtration train. Chlorinated river water was supplied to the Kinetico CPS100CPT Coagulation and Filtration System.

Within the pretreatment train, a coagulant (Ferric Chloride) was introduced into the chlorinated raw water, mixed through an in-line static mixer, and allowed to floc and settle within a basin. Supernatant from the settling basin was further processed through a clarifier and a polymer was added previous to entry into the filtration train.

Within the filtration train, water was re-pressurized, and filtered through automatic backwashing, alternating filters.

The process flow rate through the pretreatment train was held at a constant 3.8 gpm while the flow rate through the filtration train was allowed to decrease against filter head. Typically filter flow rates would decrease from 3.3 gpm to approximately 2.7 gpm. To accommodate decreases in filter flow, the pretreatment train included an overflow weir, discharging to waste, at the outlet of the clarifier.

The process design of the CPS100CPT Coagulation and Filtration system is represented in Figure 2-1.

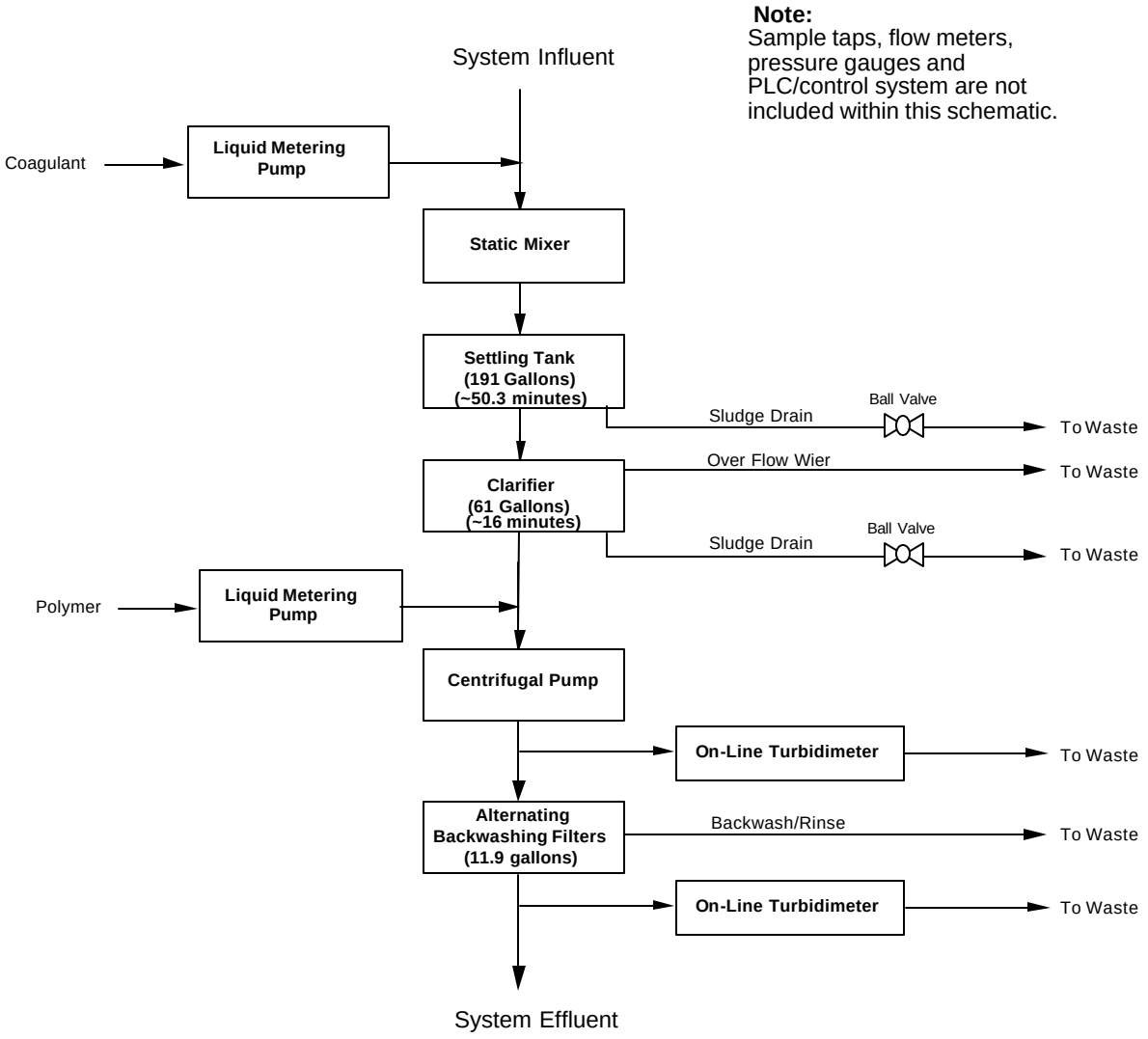

Figure 2-1. Process Design Schematic Of The ETV Test Station for the Kinetico CPS100CPT Coagulation and Filtration System

The Kinetico CPS100CPT components include the following:

Coagulant and polymer metering pumps: ProMinent® gamma/4b 1000 Programmable Smart Metering Pump.

Static mixer: Ross 1" x 6" Stainless Steel In-Line Static Mixer.

Settling Tank: The settling tank consisted of a high density polyethylene tank with an inside diameter of 35.11". Water entered this tank through an "H" type distributor near its bottom and exited 45.50 inches above this point through an outlet collection trough. Water volume between inlet distributor and outlet was 191 gallons. An outlet (with manual valve) was located below the tank inlet to serve as a means to periodically expel sedimentation from the tank bottom.

Clarifier: The Clarifier was a Lanco Model 5 - 5GPM - C3302, as manufactured by Waterlink and included a slant plate settler with pretreatment consisting of mixing and flocculation chambers. Total working volume was 61 gallons. The outlet of the clarifier was plumbed to a repressurization pump located on the filtration train skid. Located above and on an adjacent wall of the clarifier outlet sump a weir had been installed to discharge excess water to waste. The sediment collection sump located at the bottom of the clarifier was also plumbed for periodic discharge to waste if needed.

Repressurization: A Goulds Series XSH centrifugal pump.

Filtration: The equipment tested included two identical filters vessels identified as “A” and “B” operating alternately. Each filter vessel was 10 inches in diameter and 54 inches in height, constructed of fiberglass, and pressure rated to 100 pounds per inch (psi). Media bed depth was 24 inches. The filtration system supports an initial service flow rate of 9.2 gpm/ft^2 and is allowed to decrease until terminal head loss is achieved. Backwash flow requirement is 6.4 gpm/ft^2. Total water volume, allowing for media displacement, per filter is 11.9 gallons.

Filtration media: The filter media is Macrolite®, a synthetic ceramic, filter media and is not covered under 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 has been furnished by the manufacturer and is noted below.

Macrolite® of the 70/80 mesh size has a bulk density of 0.96 grams/cc. The specific gravity (as measured by 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 D 3102) is a nominal 7,000-psi for 10% and nominal 8000 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 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 Kinetico Inc. internal laboratory analysis in June of 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 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 (based on volume distribution curve)	53.7990 µm
Median pore diameter by area (based on area distribution curve)	52.5351 µm
Median pore diameter by 4V/A (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 Macrolite® is included as a part of Appendix B. Macrolite® media meets the requirements of ANSI/NSF Standard 61 and is NSF listed.

The specified flow rate for the system originally was 5 gpm (9.26 gpm/ft^2), however, after initial operations, the manufacturer elected to change and decrease flow rates through the system to optimize equipment performance at this site. The flow rate through the filtration system was established at 3.3 gpm (6.0 gpm/ft^2) and then allowed to decrease throughout each filter run as influenced by natural flow restrictions caused by filter loading. As terminal head loss approached, filtration flow typically

decreased approximately to 2.7 gpm. Flow rate through the pretreatment train was established at 3.8 gpm in order to assure adequate flow was available to the filter train during backwash cycles. Excess flow delivered by the pretreatment train was discharged to waste through an overflow weir located in the outlet sump of the clarifier.

Liquid holding volumes for the pretreatment train including the settling tank (191 gallons) and clarifier (61 gallons) is 252 gallons. Liquid holding volume for the filtration train is 11.9 gallons. Corresponding detention times are 66.32 minutes for the pretreatment train (at 3.8 gpm) and 3.61 to 4.41 minutes for the filtration train (respectively at 3.3 gpm to 2.7 gpm)

Interconnecting plumbing of between components is 1" schedule 80 PVC. Length of interconnecting plumbing is estimated at 8-ft for the 3.8 gpm flow and 10-ft for the 3.3 to 2.7 gpm flow. The only exception is a 2" x 3' schedule 80 section of non-flooded pipe used to gravity feed 3.8 gpm from the settling tank to the clarifier. Inner diameter of 1" schedule 80 pipe is 0.935". Gallons held per lineal foot = 0.0357 gallons. Total estimated volume of 8-ft of 1" pipe = .29 gallons. Total estimated volume of 10-ft of 1" pipe = 0.36 gallons. Detention time of 8-ft of 1" pipe @ 3.8 gpm flow rate = 0.08 minutes. Detention time of 10-ft of 1" pipe @ 3.3 gpm flow rate = 0.13 minutes. Detention time of 10-ft of 1" pipe @ 2.7 gpm = 0.15 minutes.

Total system detention time with a filter flow rate of 3.3 gpm = 71.31 minutes
Total system detention time with a filter flow rate of 2.7 gpm = 70.06 minutes

Accessories and instrumentation included with the Kinetico CPS100CPT Coagulation and Filtration System included flow rate and pressure sensors and monitors, on-line turbidimeters, pressure gauges, and an electrical enclosure containing a programmable logic controller. The equipment also contained data transfer connections available for remote monitoring.

The flow of water through the system was 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 had handles for manual activation.

Electrical power was required for operation of the re-pressurization pump, analytical instruments and system instrumentation.

The filtration train was shipped skid mounted and absent of media. Filter media was loaded on site. The total weight of the system, without media, was approximately 300 pounds. The physical dimensions of the filtration train were 26 ¼" Wide x 53 ½ Long x 76" High. The pretreatment train included a settling tank and clarifier. Physical dimensions of the settling tank were 36” diameter x 78” high. Physical dimensions of the clarifier were 22 ½ wide x 51 ¼” long x 51” high. Total footprint of the equipment, including settling tank, clarifier and filtration train, was approximately 24.8 ft^2.

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 Kinetico CPS100CPT Coagulation and Filtration System at SAFHL

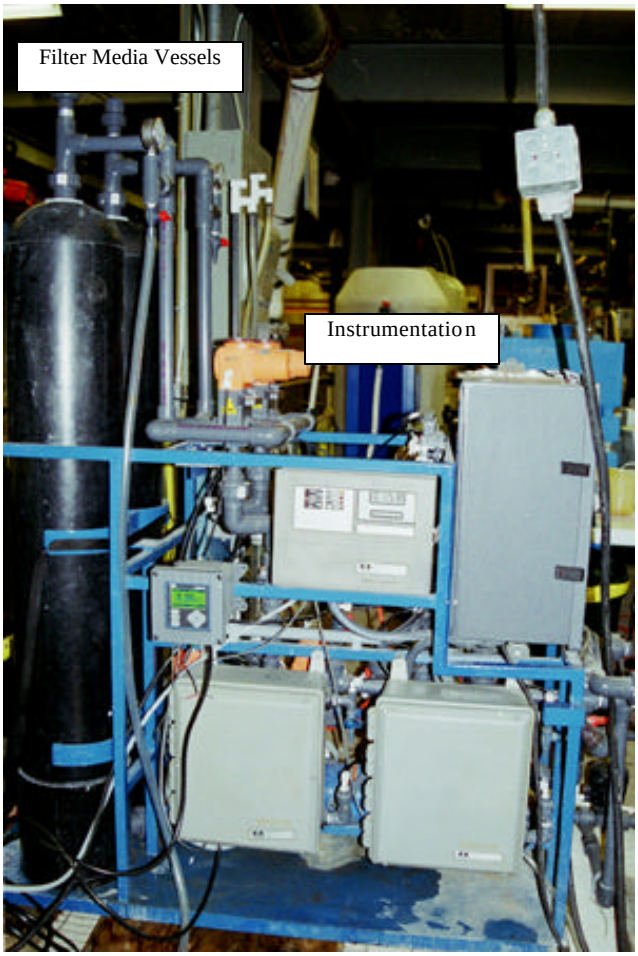

Photo 2. Side view of the Kinetico CPS100CPT Coagulation and Filtration System at SAFHL

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 most systems are installed on small systems not requiring a license. 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 CPS100CPT Coagulation and Filtration System treatment 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 CPS100CPT Coagulation and Filtration System for its capability of removing *C. parvum* oocysts and *G. lamblia* cysts. Specifically, this ETV test was undertaken to demonstrate that the Kinetico CPS100CPT was capable of providing a minimum of 1.5 $\log_{10}$ and 2-$\log_{10}$ respectively for *C. parvum* and *G. lamblia*. Challenge studies were conducted with viable *C. parvum* and *G. lamblia* to demonstrate reduction capabilities.

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*. Further, turbidity standards will be reduced to 0.3 NTU in year 2002.

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 and experiences during the daily operation were used to develop a subjective judgment of the operational requirements of this system. The Kinetico 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. The Kinetico O&M manual details various maintenance activities and their frequencies. This information, as well as experience with common pieces of equipment (i.e., pumps, valves, etc.) was used to evaluate the maintenance requirements of the treatment system.

3.1.1.4 Evaluation of Equipment Characteristics

The qualitative, quantitative and cost factors of the tested equipment were identified, in so far as possible, during the verification testing. The relatively short duration of the testing cycle creates difficulty in reliability identifying some of the qualitative, quantitative and cost factors. The qualitative factors examined during the verification were operational aspects of the Kinetico CPS100CPT, for example, susceptibility to changes in environmental conditions, operational requirements and equipment safety, as well as other factors that might impact performance. The quantitative factors examined during the verification testing process are costs associated with the system. Especially important are power and coagulant chemical requirements. The operating conditions were recorded to allow reasonable prediction of performance under other, similar conditions. Also to be noted and reported are any occasional, anomalous conditions that might require operator response such as unexpected turbidity breakthrough, chemical dosing or retention alterations, changes in disinfection levels, high levels of algae growth, excessive turbidity spikes or frequent filter clogging.

3.2 Verification Testing Schedule

The verification testing started on March 8, 2000 and continued for 27 days of operation and data recording. During this period a total of 209 filter cycles occurred. Daily testing concluded on April 26, 2000. Data was logged for a total of 657 hours of treatment system operation. The system was shut down 13 times for a total of 50.75 hours due to adjustment of the coagulation chemicals, retention process and plumbing adjustments. The system was also shut down for a total of 492 hours, between April 4 and April 23, 2000 due to problems found in EPA method 1623 associated with the testing of *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.

Following procurement of the *G. lamblia*, the system was restarted. *C. parvum* and *G. lamblia* challenge testing was performed on April 24 through April 26, 2000.

3.3 Initial Operations

The objective of the Initial Operations was to establish operational data including coagulant, filter run times and backwashing schedules, and to qualify the equipment for performance with the selected source water.

The suitability of the influent water to the application of this technology was reviewed before testing. Then 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. Information gathered during system start-up and optimization was used to refine the FOD.

The major operating parameters examined during initial operations were coagulant chemistry, filter loading rate, and verification of residence time.

3.3.1 Characterization of Influent Water Quality

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, Coliform, Total Alkalinity, Hardness, True Color, UV_{254} Absorbance, Aluminum, Algae, (number and species), iron and manganese, Total Organic Carbon (TOC), Total Coliform, *E. coli*.

3.3.2 Coagulant Chemistry

Optimization of coagulant chemistry is dependent on chemical composition and temperature of the source water, which is, subject to unpredictable change. Accordingly, it is of critical importance that coagulant chemistry be studied and tested immediately prior to performance verification. This was first accomplished with jar testing to identify suitable coagulant chemicals, dosage and contact time. Once jar testing was complete initial test runs were performed to both terminal head loss and turbidity breakthrough.

The following coagulants were used during initial test runs: Ferric Chloride, Aluminum Sulfate, Hydrochloric Acid (for pH adjustment), and Aluminum Chlorhydrate. Coagulants were used at various dosages, both independently and in combination.

3.3.2 Filter Loading Rate

Initial filter runs were performed to both terminal headloss and turbidity breakthrough. Total filtered water volume was measured and characteristics of effluent water were evaluated throughout each filter run. Terminal head loss was considered when a filter experienced a 20-psi change in pressure between inlet and out. Turbidity breakthrough was considered reached when the turbidity in the effluent water exceeded 0.5 NTU. Backwashing was initiated automatically, when either 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. Filters were run in a rinse cycle to waste for a minimum of two bed volumes (approximately 20 gallons) before a filter was returned to service. Variations in backwash flow rate were also studied. Manufacturers specification for service flow rate was established at 9.2 gpm/ft^2 and was allowed to decrease throughout each filter run as filter loading increased. Backwash flowrate was established at 6.4 gpm/ft^2.

Upon return to service, the filter ripening period was monitored and timed. These data were used to better understand time requirements for backwash, rinse and especially the expected duration of service run cycles.

3.3.4 Verification of Residence Time

Tracer tests using sodium chloride were used to determine residence time of water held within the Kinetico CPS100CPT coagulation and filtration system. Flow rates for this test were established at 3.8 gpm for the pretreatment train (252 gallons) and 3.3 gpm for the filtration train (12 gallons) with the difference (0.8 gpm to 1.3 gpm) discharged to waste from the clarifier's outlet. These flow rates were within the range initially expected during the microbial challenge events.

Sodium chloride brine was introduced into the influent stream through a metering pump and injection port ahead of a static mixer located on the inlet of the coagulation, filtration system. Tracer test duration was timed by using a stopwatch and a Total Dissolved Solids (TDS) meter was used to detect increases in dissolved solids caused by elevated levels of sodium chloride. The use of sodium chloride over tracer dye in this application was preferable because it can be conveniently measured at small increments; it dissolves readily and hence is not itself impeded by the filter; and after it is rinsed clean it leaves no residual on the filter media.

In addition to verifying the contact time needed for coagulation chemistry, data from these tests were used to establish criteria for seeding and recovery studies such as determination sample collection intervals during microbial challenge tests.

3.4 Verification Task Procedures

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

- Task 1 Verification Testing Runs & Routine Equipment Operation
- Task 2 Influent and Effluent Water Quality Characterization
- Task 3 Documentation of Operating Conditions & 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 the manufacturer for a prescribed period of time and assess its ability to meet water quality goals and other performance characteristics specified by the Manufacturer.

Task 1 verification testing consisted of continuous evaluation of the treatment system, using the most successful treatment parameters defined in Initial Operations.
Temperature, turbidity, and other influent water quality parameters such as algae, natural organic matter, pH, alkalinity, and hardness, will influence coagulant chemistry and filtration. In order to offer a "worst case" challenge to the equipment under test, verification testing conditions included cold water of varying water quality.

The schedule required the equipment to be run continuously for 13.33 days. Preferably, this period was to occur after the equipment has reached steady state operation in context to coagulation chemistry requirements. Coagulation chemistry was monitored by comparing turbidity levels measured at three sample ports; influent water, filter influent (after coagulation) and filter effluent. The Kinetico CPS100CPT control functions allowed for differing conditions to initiate backwash. These conditions included filter headloss and turbidity breakthrough.

Filter runs were not stopped until terminal headloss or turbidity breakthrough occurred, with the exception of equipment maintenance or an interruption in power.

Standard operating parameters for filtration, backwash, and coagulant feed 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. Manufacturer operating performance criteria from which collected data will be compared to is presented in Table 3-1.

Table 3-1. Filtration Performance Capability Objectives

Characteristic	Definition	Criteria
Initial turbidity	Filtrate turbidity at 15 minutes into run	0.5 NTU or less
Length of ripening period	Time to reach 0.2 NTU	0.5 hours or less
Length of further ripening period	Time to reach 0.1 NTU	1.0 hour or less
Operating turbidity	Turbidity from matured filter	0.10 NTU or less
All turbidity	All data taken at equal intervals	0.5 NTU or less in 95% of all samples, or in all data from continuous turbidimeters
Time to reach turbidity breakthrough	Time to reach 0.5 NTU.	8 hours minimum
Water production	Volume of water during a filter run	5,000 gallons per sq. ft. (2,750 gallons)

3.4.2 Task 2 - Influent and Effluent Water Quality Characterization

Characterization of the treated water quality of the system was the driving force behind the development of the experimental design of the ETV. The water quality analyses were selected to demonstrate the effectiveness of the manufacturer's equipment. This task identified the water quality matrices of the influent water and effluent water and the composition of the removed particulate material, with the relationships to the terminal headloss and/or turbidity breakthrough point. This information was used to evaluate performance of the water treatment equipment relative to stated performance goals. Influent water and effluent water parameters were analyzed and recording during the verification period according to the schedule in Table 3-2.

Table 3-2. Analytical Data Collection Schedule

Parameter	Frequency	Influent	Treated
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	Weekly	X	X
Total Coliform	Semi-weekly	X	X
E. coli	Semi-weekly	X	X
Algae	Weekly	X	X
Aluminum	Weekly	X	X
Iron	Weekly	X	X
Manganese	Weekly	X	X

All testing was performed in accordance with the procedures and protocols established in *Standard Methods 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 daily by FTO staff. Evaluation of water quality in this task was related with respect to manufacturer's claims of performance in addition to the Surface Water Treatment Rule.

Turbidity data of influent, effluent and backwash water was recorded continuously electronically on-line. The on-line turbidity meter was checked daily against a bench turbidimeter, which was itself, checked daily against turbidity standards. Any occurrences where the filter produced water of > 0.5 NTU were recorded. These events were recorded separately for each filter, identified as "A" and "B".

Particle counts were evaluated and $\log_{10}$ removals calculated by recording the change between 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 1 and 12 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 process design of the pretreatment train of the Kinetico CPS100CPT coagulation and filtration system was largely a result of initial operations. Once coagulation chemistry was stabilized during the initial operations period, the equipment package included the following process, described in order of water flow: Coagulant injection ⇨ Mixing ⇨ Settling ⇨ Clarifier ⇨ Polymer injection ⇨ Repressurization ⇨ Filtration.
The test station used within the experimental design of this study consisted of flow rate monitors, regulating valves, pumps, metering pumps, static mixer, and sample collection stations for recovery of (oo)cysts during microbial challenge testing.

The manufacturer requires the Kinetico CPS100CPT System to be supplied with chlorinated feed water. Accordingly, the test station included a liquid sodium hypochloride metering pump to assure a measurable concentration of free chlorine was present within the blended feed water supply. Further, during protozoan seeding studies, injection of sodium hypochloride was discontinued several hours previous to the beginning of the filter run in which the challenge was to be conducted.

A Watts Reduced Pressure Zone (RPZ) backflow prevention device was installed on the untreated river water supply line to ensure (oo)cysts were not inadvertently introduced into this source water supply.

The process design of the test station is represented in Figure 3-1.

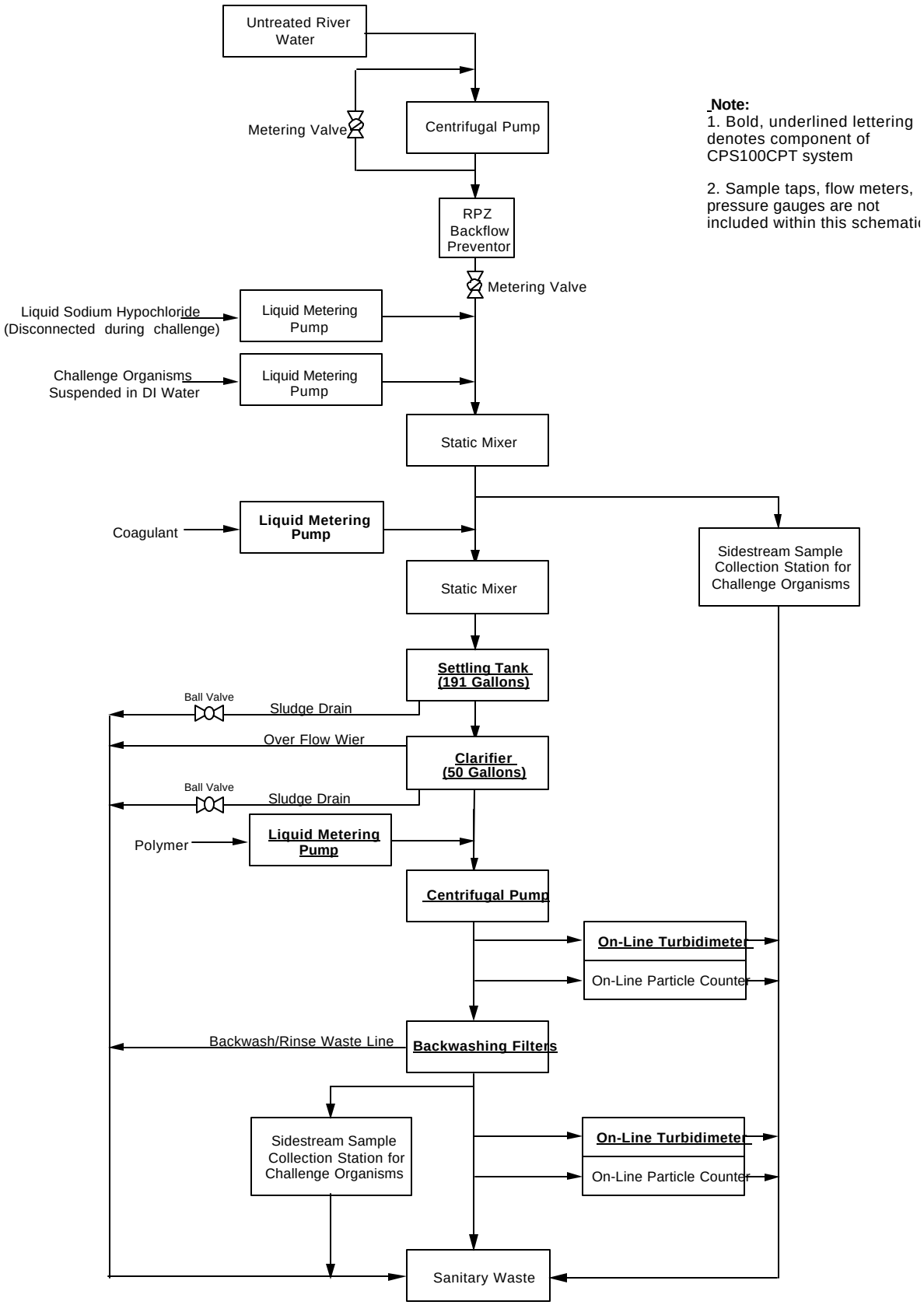

Figure 3-1. Process Design of the Kinetico CPS100CPT Test Station

During each day of Verification Testing, operating conditions were documented. The operational parameters and frequency of the readings are listed in Table 3-3 below. Documentation includes descriptions of pretreatment chemistry for coagulation and the treatment processes used and their operating conditions. Performance of the water treatment equipment including rate of filter head loss gain, frequency and duration of filter backwash and need for cleaning of pretreatment tankage and clarifiers were documented.

Treatment equipment operating parameters for both pretreatment and filtration were monitored and recorded on a routine basis. This included a complete description of pretreatment chemistry; mixing and flocculation intensities, operating parameters for clarification ahead of filtration; rate of flow; and filtration rate. Data on filter head loss and backwashing were also collected. Electrical energy consumed by the treatment equipment was also measured and recorded. Data for rates of waste production were also collected.

Table 3-3. Operational Data Collection

Parameter	Frequency
Coagulant Used	Name of chemical, supplier, strength, dilution from stock solution.
Chemical Feed Volume and Dose Rate	Checked rate and recorded every two hours, refill as required and note volume consumed and time.
Clarifier	Manufacturer, type, model and process flow rate. Record each time sludge is extracted from collection sump.
Influent water and Filter Flow	Checked and record every 30 minutes. Flow rates were allowed to decrease throughout filter runs to better represent actual system operating conditions.
Filter Headloss	Recorded at beginning of run and every 30 minutes, also recorded at end of run or when breakthrough occurs.
Backwashing	Recorded date, time, influent and filtered water meter reading and recorded filter effluent water volume. Noted terminal headloss prior to filter backwash. Described reason for backwash; noted backwash rate and volume for each backwash.
Electric Power	Read meter once daily at same time.
Hours of Operation	Continuous operation, Total recorded at end of verification period.
Filtered Water Production	Calculated total volume 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 on source water quality daily at end of shift.

3.4.4 Task 4 - Microbiological Contaminant Removal Testing

This task measured the ability of the filter to remove seeded microorganisms. This portion of the study was of central importance, as it was the ability of the filters to remove the target microorganisms *C. parvum* and *G. lamblia* that was the primary claim of the manufacturer, and of greatest interest to the public water community. The ability to remove oocysts and cysts in the range of 4-6 µm and 7-15 µm was challenged and verified. Analyses for *G. lamblia* cysts and *C. parvum* oocysts were conducted during the microbial removal phase removal phase of the evaluation. These analyses were conducted using EPA Method 1623.

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 at the time of the study, and were purchased from Waterborne Inc. The cysts were stored in phosphate buffered saline without preservatives. At a field lab near the site they were divided into the required number of doses, and into the required concentration of approximately 10^8 oocysts and approximately 10^7 cysts for injection into the water stream.

The doses were prepared by removing an aliquot of the enumerated cyst and oocyst suspension and diluting them with deionized water to a volume containing the target number of cysts and oocysts.

The inoculation point was through an injection probe at the intake of the static mixer. An inert carboy containing a diluted preparation of suspension and stirred by a magnetic stir bar was connected by tubing to an injection probe that reached into the axis of the static mixer. Each challenge test injected approximately 10^8 total oocysts and 10^7 total cysts in 600 milliliters of deionized, particle free water containing 0.01% Tween 20. There were no additional detergents, wetting agents or other chemicals added to the suspension.

Based on previous hydraulic tracer tests conducted with sodium chloride, at flow rates similar to what was experienced during the microbial challenge studies, steady state concentrations were achieved within 120 minutes after initiation of tracer injection. Accordingly, during each microbial challenge study, effluent samples collections did not begin until 120 minutes after continuous injection of (oo)cysts began.

When the carboy containing the seeded suspension was near empty, two volumes (600 milliliters) of particle free sanitized water was added to force the excess (oo)cysts through the injection line to the inoculation point.

During the seedings, 10-liter samples were filtered through a Gelman capture filter on a side stream for protozoan evaluation. These samples were collected at the influent to the pretreatment train, effluent of the pretreatment train, and the effluent of the filter train. These Gelman capsule filters were evaluated in accordance with the procedures indicated in EPA Method 1623.

A seeded suspension containing between 10^7 cysts and 10^8 oocysts is capable of indicating 3 $\log_{10}$ reduction as follows: The seeding introduced between 10^7 and 10^8 (oo)cysts concentrated into 600 mL of water for a density of approximately 1.66 x 10^5 cysts to 1.66 $\times$ 10^6 oocysts/mL into the process stream. The process stream diluted this concentration evenly into 1,360 liters for a concentration of approximately 7.5 cysts and 75 oocysts/mL. The seed was introduced evenly over the duration of the sample collection period. Time zero defined the point in time that steady state seed concentration could be expected at the filter outlet and effluent samples could be taken. Based on hydraulic tracer tests previously conducted with sodium chloride brine, time zero was established at 120 minutes after seeding commenced. Since a 10-liter grab sample was collected through a Gelman capsule filter for EPA Method 1623 (April 1999) evaluation, 10,000 milliliters was evaluated, potentially capable of a 3+$\log_{10}$ reduction evaluation if expected Gelman capsule recovery rates were realized.

3.4.4.2 Analytical Schedule

There were three challenges employing a mixed cocktail of *G. lamblia* cysts and *C. parvum* oocysts, which were added to the raw water upstream of the coagulant chemical and the mixing chamber.

During the seeding, 10-liter samples for protozoa evaluation (identification and enumeration) were collected on a side stream and filtered through Gelman capsule filters. Post clarifier and filter effluent samples were collected as follows:

1) At time zero (based on tracer test data)
2) At time 1/2 hour
3) At time 1.0 hour
4) At time 2.0 hour (as filter run time allows)

Seeded influent source water was collected and filtered through a Gelman capsule filter throughout the duration of the microbial injection.

Simultaneous with the seeding, in line particle counters located at the raw water intake, at the filter inlet following the static mixer, and at the effluent of the filter, recorded the particle analyses in the ranges of 2-3 µm, 3-5 µm, 5-7 µm, 7-10 µm, 10-15 µm, and 15+ µm.

This sequence was repeated for a total of three successive runs of the same filter. Since both filters are identical, only one filter of the two was employed for the seeding studies.

3.4.4.2 Data Evaluation

The 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. The particle counter was continuous, and recorded the particle analyses 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 presented as time series data to display trends of particle count over time.

Protozoa densities between influent and 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.

3.4.4.3 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 coagulation and filtration processes in the SWTR, and with respect to Kinetico expected values.

3.5 Recording Data

The chemical parameters and operator read operating data was maintained in a bound logbook and transferred to computer spread sheets. The control system for the Kinetico CPS100CPT included automatic data recording access and automatic systems were employed where possible. Other readings were manually logged.

In addition to the items noted in the data sheets (contained in Appendices C), any variations in the treatment plant regimen were noted. Among the changes possible were changes in chemical coagulants and retention in response to varying and unusual source water episodes, such as weather related incidents (ice outs, storms), unusual river traffic or contaminant spills. The source water during initial operations and the verification period initially was a chlorinated blend of finished and untreated river water. Eventually, source water was limited to chlorinated, unfiltered river water.

Table 3-2 lists the continuous, daily, weekly, and semi-weekly water quality analyses that were recorded. The results of continuous analysis were recorded in a computer, daily on-site analyses were recorded in the operations logbook, and semi-weekly analyses were recorded in the laboratory logbooks and also recorded on separate laboratory report sheets. The data spreadsheets are attached to this report as Appendix C.

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

3.5.1 Objectives

The objective was to tabulate the collection of data for completeness and accuracy, and to permit ready retrieval for analysis and reporting. In addition, the use of computer spread sheets allowed manipulation of the data for arrangement into forms, 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

The data handling procedures were used for all aspects of the verification test. Procedures existed for the use of the logbooks used for recording the operational data, the documentation of photographs taken during the study, the use of chain of custody forms, the gathering of on-line measurements, entry of data into the customized spreadsheets, and the method for performing statistical analyses.

3.5.2.1 Logbooks

COA as the FTO for the project was responsible for the maintenance of the logbooks and field notebooks. 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 which 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 influent water or the operation of the equipment (attached as Appendix D).

Each page of the logbook was sequentially numbered and identified as Kinetico Coagulation ETV Test. 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 will included a carbon copy of each page. The original logbook was stored on-site, the carbon copy sheets forwarded to the project engineer of COA at least once per week. This not only eased referencing the original data, but offered protection of the original record of results.

3.5.2.2 Photographs

Photographs were logged into the field logbook. These entries include time, date, and identify 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 On-line Measurements

Data from a computer recording continuous on-line 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 operators 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.

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 any and all off-site laboratory analyses.

The computer data was entered onto a computer on site and then was transferred to the COA office computer on diskette.

3.6 Calculation of Data Quality Indicators

3.6.1 Representativeness

Water quality parameter samples for the Kinetico CPS100CPT Coagulation and Filtration System were taken as indicated in Table 3-2. 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:

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

Where:

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.

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

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 gauge calibrations 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.

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: $$\%R = 100 \times \frac{Observed}{True}$$

Where:

%R	=	Percent recovery
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 and triplicate included on-site parameters such as: bench-top turbidity, pH and bench-top particle counts.

The equation employed for precision for duplicate samples was:

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

Where:

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

The equation employed for precision for triplicate samples was:

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

Where:

S	=	Standard deviation
$\bar{x}$	=	Mean of recovery values

3.7 Equipment

3.7.1 Equipment Operations

The operating procedures for the filtration train of the Kinetico CPS100CPT are described in an Operations Manual. The Operations Manual for the treatment system was maintained on-site and is attached to this document as Appendix B. Operating procedures and equipment descriptions are described in detail in Chapter 2 of this report. The manufacturer provided on-site instruction for the operation of the pretreatment train in lieu of an Operations Manual.

3.7.1.1 Analytical Equipment

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

- A Hach 2100P portable turbidimeter (serial number 96090012047) was used for benchtop 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 temperature.
- A rotometer (Blue and White model f-40750LN-12 (0 to 10 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: 951702969 and 971000352).
- Free chlorine measurements were taken with a HACH 2010 spectrophotometer.

3.8 Health and Safety Measures

There were two major safety concerns for on-site staff with respect to this testing procedure.

1) The equipment tested used various chemicals, which if not handled properly, could be dangerous,
2) The microbes used during testing were highly infectious.

Accordingly, 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.

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.

3.9 QA/QC Procedures

The objective of the QA/QC Procedures was to control the methods and instrumentation procedures such that the data were not subject to corruption. Adherence to analytical methods as published in *SM* or EPA methodology was assured. Moreover, instrumentation and standard reagents were referenced to NIST. Instruments used to gather data were standardized and calibrated in accordance with the schedules noted below.

3.9.1 QA/QC Verifications

Daily QA/QC Verifications included:

- On-line turbidimeter flow rates verified volumetrically with a 1,000 mL graduated cylinder and stopwatch;

- On-line turbidimeter readings standardized against a calibrated bench turbidimeter;
- pH meter calibration was verified at pH 7 and pH 10 with NIST-traceable pH buffers
- Benchtop turbidimeter calibration was verified against secondary standards of 0.5, 1 and 3 NTU;
- On-line particle counter flow rates were verified volumetrically with a 100 mL graduated cylinder and stopwatch;
- Two chemical feed pumps were used. Flow rates were verified volumetrically with a graduated cylinder and stopwatch.

Bi-weekly QA/QC Verifications included:

- On-line flow meters were cleaned and flow verified volumetrically with a 55 gallon graduated container and stopwatch. The flow rate through the system as determined by stopwatch and calibrated bucket, and was 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;
- Verification of particle counter calibration using NIST microspheres at 3, 10 and 15 µm size;
- Pressure gauge readings were compared with that of a NIST-traceable gauge;
- Inspection of particle counters and turbidimeter tubing for unimpeded flow and integrity.

Further descriptions of these verifications are provided below.

3.9.2 On-Site Analytical Methods

Specific instrumentation methods for on-site QA/QC accuracy were conducted during verification testing. Water quality parameters were measured by analytical or instrument methods outlined in *Standard Methods (SM*). Specific instrumentation methods for on site QA/QC accuracy were as follows:

3.9.2.1 pH

Analysis was by *SM* 4500-H^+. A two-point calibration with NIST-traceable pH buffers were performed daily at pH 7 and pH 10. 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 taken 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 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, and the bench top turbidimeter was the calibration standard for the test. The benchtop turbidimeter was calibrated at the start of testing and then weekly, during the testing period, against standards of 0.1, 0.5 and 3.0 NTU, and with the Gelex standard prepared in accordance with manufacturers methods. 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. Manufacturers 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.

3.9.2.4 Particle Counting

Particle counters were factory calibrated by Pacific Scientific Instruments using polystyrene latex spheres traceable to the National Institute of Standards and Technology (certifications dated August 24, 1999 and March 3, 2000). Particle counter calibration was verified on-site with calibrated, mono-sized polymer microspheres on March 31, 2000. The procedure for monosphere verification was as described in the ETV Test Plan was designed for batch type particle counters, not on-line counters. On line particle distribution requires a different procedure that is described below.

Particle free water prepared off-site was used as dilution water. 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 in the logbook as follows:

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

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

This procedure was performed eight times, four each for the influent and effluent counters. Although the test plan specified 2 µm, 10 µm and 15 µm sizes, COA requested of NSF that the 2 µm size be replaced with 3µm 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 pc/mL 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.

This procedure was repeated for each particle size and for a cocktail consisting of approximately 1,000 particles of each size per mL.

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

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

3.9.2.5 Particle Free Water (PFW)

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 deionized (demineralized) water (DI) water, filtered on site thorough a 0.2 μm filter was suitable for particle counting suspension and other reagent preparation in this application. Particle free water, even DI water filtered through a 0.2 μm filter however, was subject to contamination by airborne particles. 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.

3.9.2.6 Pressure Gauges

The pressure gauges for this study were glycerin filled Ametek 556L. The pressure gauges used to determine headloss in the filters were verified against a NIST-traceable pressure gauge.

3.9.3 Off-Site Analysis For Chemical and Biological Samples

Table's 1a and 1b of the Code of Federal Regulations 40 Parts 136.3 cross-reference *SM*, EPA methods, ASPM methods and 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 ASPM 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

Total organic carbon, microbiological and solids load measurements were important to this study. Samples for analysis were collected in glass bottles supplied by Spectrum and were delivered by courier to Spectrum Labs (the travel time was approximately twenty 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. UV_{254} was analyzed 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 4ºC 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 deemed necessary to preserve algae samples in Lugol's solution. Total Coliform Bacteria and *E. coli* bacteria were analyzed at the laboratory using the EPA MI Agar Method, (EPA 600 R 00 013), and algae analyzed 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 Ch.1. Proper bottles and preservatives where required (Iron and Manganese for example) was 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 used EPA method §200.7

3.9.3.4 True Color

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

Chapter 4
Results and Discussion

4.1 Introduction

The verification testing for the Kinetico CPS100CPT system that occurred at the University of Minnesota St. Anthony Falls Hydraulic Laboratory in Minneapolis, Minnesota, commenced on March 8, 2000, and concluded on April 26, 2000. The system was operated for a period of 32 days during this period. Microbial challenge testing was performed twice. The first challenge test was performed using *G. muris* and *C. parvum* Method 1623. It was subsequently found that the DYNAL immunomagnetic separation (IMU) 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 *G. muris* cysts. Because it would not be possible to replicate identical source water quality 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 samples from the first challenge series. The Kinetico CPS100CPT system was then shut down for a total of 492 hours, between April 4 and April 23, 2000 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 through April 26, 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 coagulant, 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. This was achieved during January of 2000. The manufacturer was on-site during February, and was unable to stabilize the coagulation chemistry previous to the NSF mandated start date. Therefore, the verification period for Kinetico CPS100CPT system began before proper chemical stabilization was achieved. This resulted in 17 days of the performance verification period being dedicated to establishing stabilization of coagulation chemistry, which was achieved on March 24, 2000 at 17:22. In this report, the period of time between March 8, 2000 and March 23, 2000 is considered a continuation of initial operations.

The major operating parameters examined during initial operations were coagulant chemistry, filter loading rate, and establishment of residence time. Influent water characterization also occurred during the initial operations period.

4.2.1 Characterization of Influent Water Quality

Characterization of the influent water was an integral part of the initial operations phase. Historical raw surface water from 1999 were obtained from the City of Minneapolis, Municipal Water Works department, 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, and turbidity averaged between 5.2 and 18.6 NTU. Actual water samples taken for the initial operations period and analyzed by Spectrum Labs, showed the following water characteristics: total alkalinity ranged of 100 mg/L to 140 mg/L; aluminum was equal to or less than 0.06 mg/L, total hardness averaged 140 mg/L; true color ranged between 40 and 45 TCU, iron was equal to or less than 0.50 mg/L, manganese of 0.05 mg/L, TOC of 12 mg/L, and UVA_{254} between 0.254 and 0.273. Total coliform bacteria and *E. coli* were not detected or were below the PQL of 1 CFU/100mL.

During the initial operations phase (March 8 through March 23, 2000) influent raw water samples demonstrated the following compositions: average turbidity of 6.7 NTU, average temperature of 8.5°C and range of 6.9°C to 9.7°C, and average pH of 7.8. Water samples analyzed by Spectrum Laboratories exhibited the following characteristics: no total coliform was detected or was below the PQL of 1 CFU/100mL, total alkalinity averaged 126 mg/L, hardness ranged between 120 and 160 mg/L, true color ranged between 40 and 45 TCU, UV_{254} Absorbance ranged between 0.254 and 0.273, aluminum between <0.05 and 0.06 mg/L, iron equal to or les than 0.5 mg/L, manganese of 0.05 mg/L, and TOC of 12 mg/L. *E. coli* was not detected during the initial operations period.

Algae were detected in the influent water samples on March 20, 2000, as Chlamydomonas 490 Algae/mL, and Diatoma 245 Algae/mL. Effluent water samples taken on March 20, 2000, showed the following Algae results: Nitschia 735 Algae/mL, Navicula 140 Algae/mL, Chlamydomonas 245 Algae/mL, Chloratella 315 Algae/mL, Chlorella 240 Algae/mL, Diatoma 140 Algae/mL, Filamentous 70 Algae/mL, and Golenkinea 35 Algae/mL.

Review of all of the data collected during the initial operations period indicated that the technology should be suitable for this site.

4.2.2 Coagulant Chemistry

The following coagulants and chemicals were used during initial test runs: Ferric Chloride, Aluminum Sulfate, Hydrochloric Acid (for pH adjustment), Cationic Polyacrylamide, and Aluminum Chlorhydrate. Coagulants were used at various dosages, both independently and in combination. Jar testing in different combinations and doses augmented testing and adjustment of the system. Changes made to chemistry during the stabilization period are listed in Appendix G.

The system was shut down 13 times for a total of 50.75 hours due to adjustment of the coagulation chemicals, retention process and plumbing adjustments during the initial 17-day period. Stabilization was achieved on March 23, 2000. Coagulants required were identified as Ferric Chloride, AQM 100, and C-1592 (chemical specification/identification sheets provided in Appendix G). Changes to pretreatment equipment were also required to satisfy coagulation chemistry requirements of the source water. These changes included the addition of a 191-gallon settling tank and a clarifier (refer to Section 2.2).

4.2.3 Filter Loading Rate

During initial operations filter loading rates and characteristics were observed. Because filter performance was dependent upon stabilization of coagulation chemistry, filter performance remained inconsistent until the beginning of the verification period. During initial operations, COA concluded it would be in the best interest of future operators to evaluate coagulant technologies previous to evaluation of filter performance. The equipment under test was designed for automatic (unattended) operation. During initial operations filter run periods of less than 1 hour were observed. Because it was difficult to for an operator to maintain a targeted process flow rate without continuous monitoring, COA concluded that maintaining the process flow of the filtration system would not provide performance data that could be translated into meaningful information for field application. Accordingly, the filtration flow rate was allowed to decrease throughout each filter run as influenced by natural flow restrictions caused by filter loading. Flow rates were typically 3.3 gpm at the start of each filter run and decreased to 2.7 gpm as terminal head loss was approached.

4.2.4 Verification of Residence Time

The purpose of the tracer tests was to establish hydraulic characteristics of the Kinetico CPS100CPT prior to the *C. parvum* and *G. lamblia* challenge study. Tracer tests using sodium chloride were performed on March 28 and March 30, 2000, respectively. Samples were collected from the raw water, the water after the contact tank, the water after the clarifier, and the effluent water from the Kinetico CSP100CPT. Samples were analyzed for increases in Total Dissolved Solids (TDS) by a TDS monitor as a marker for sodium chloride concentrations. The following two graphs illustrate the results of the tracer tests.

Figure 4-1 illustrates the tracer test that was performed on March 28, 2000 with a concentration of Sodium Chloride in the range of 14 to 26 mg/l. The results of the first tracer test were inconclusive and it was determined that a second test should be performed. The second test was performed with a higher concentration of Sodium Chloride (range 702 to 784 mg/l). Samples were collected at the same sample locations as in the tracer test #1 and analyzed for TDS. Figure 4-2 represents the data of tracer test #2.

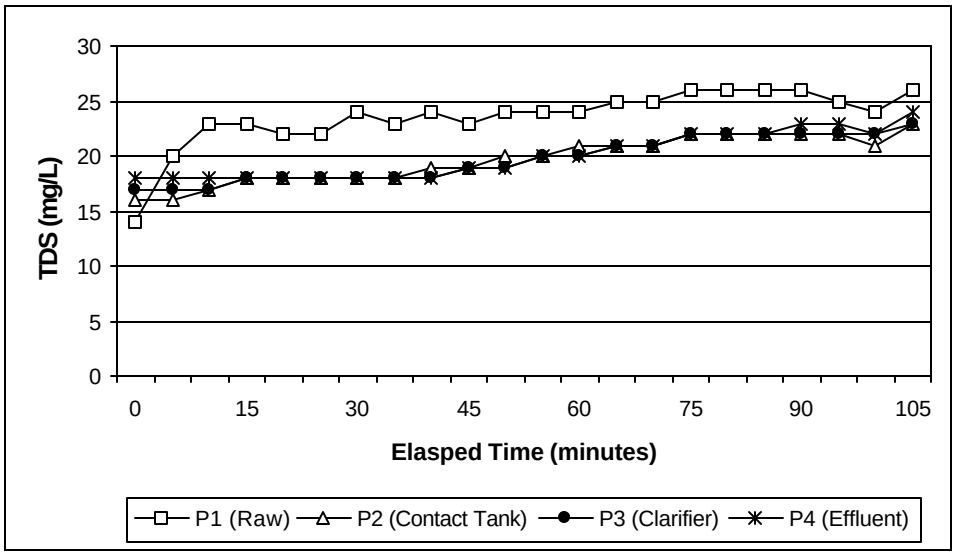

Figure 4-1. Tracer Test # 1

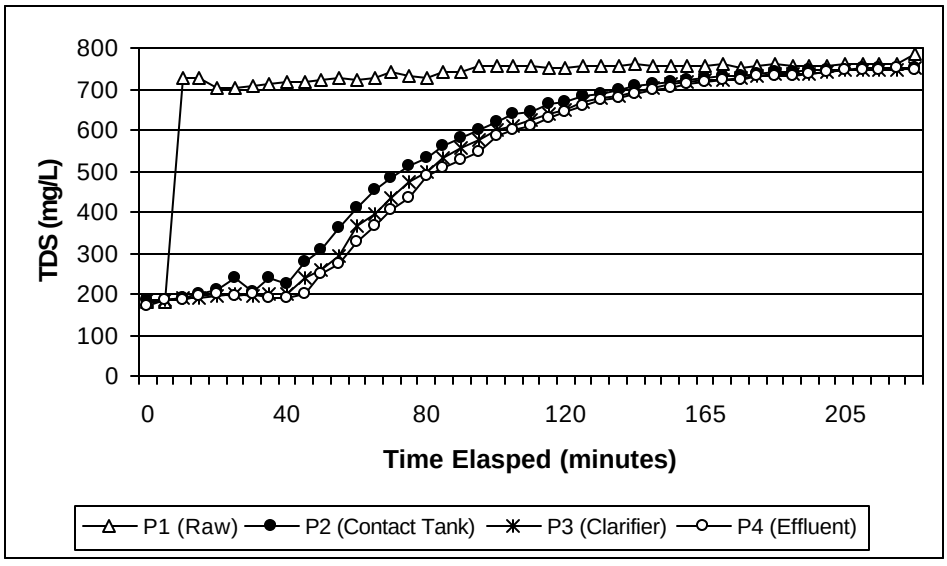

Figure 4-2. Tracer Test #2

During tracer test #2 Sodium Chloride was injected immediately after the 10-minute data collection point. The corresponding data on Figure 4-2, displays a sharp increase in effluent TDS at 45 minutes and steady state concentrations between system influent and effluent streams within approximately 120 minutes after initiation of sodium chloride injection. Within these 120 minutes, average flow rate through the pretreatment train (252 gallons) was 3.92 gpm and average flow rate through the filter train (11.9 gallons) was 3.42 gpm.

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 objective of this task was to operate the equipment provided by the manufacturer for a period of 13.33-days (320 hours) and assess its ability to meet water quality goals and other performance characteristics specified by Kinetico, Inc.

The verification testing for Kinetico CPS100CPT system started on March 24, 2000. During this period, coagulation chemistry and/or dose was changed or adjusted in some manner 4 times and a total of 42 filter cycles were monitored. During the performance verification period, the system was shut down for a total of 448.5 hours, between April 4 and April 23, 2000, due to problems found in EPA method 1623 associated with the testing 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 equipment was not operated continuously during the performance verification period. The time of equipment operation during the performance verification period was 13.6 days (327.35 hours).

Between April 4 and April 23, source water conditions changed considerably and the coagulation chemistry used previous to equipment shutdown only performed marginally 19 days later. This resulted in filter run times that were considerably shorter than what had previously been demonstrated between March 24 and April 4, 2000. Due to cost constrains and scheduling requirements, significant efforts to re-stabilize coagulation chemistry could not be pursued. For this reason, operational data from these two periods (March 24 - April 4, and April 23 - April 26) were analyzed separately. In addition, because microbial challenges were conducted between April 23 and April 26, operational data for that period is included in Task 4 - Microbiological Contaminant Removal Testing.

4.3.1.1 Flow Rate

The specified filter flow rate for the system was 5 gpm, however, during the initial operations and the chemical stabilization period, the manufacturer elected to reduce the overall flows through the system. The flow through the pretreatment train was set at 3.8 gpm. As previously described (see filter loading rate Section 4.2.3), the filter train flow rate was established at 3.3 gpm and then allowed to decrease throughout each filter run as influenced by natural flow restrictions caused by filter loading.

It was necessary to provide a consistent flow rate through the pretreatment system in order to maintain stabilization of coagulation chemistry. The pretreatment train flow rate of 3.8 gpm exceeds the maximum filter flow rate in order to provide 3.5 gpm for filter backwash and provide continuous flows through the filtration train influent on-line turbidimeter and particle counter. As filter head pressure

increased and flow decreased, excess water was directed to waste through a weir located at the outlet of the clarifier.

4.3.1.2 Automatic Operation

The filtration equipment provided by the manufacturer was to operate automatically and provide for automatic backwash cycles to occur based upon turbidity breakthrough, pressure differential, or elapsed filter run time. This automation failed due to a faulty pressure differential gauge/switch. The manufacturer attempted to secure a replacement gauge from its supplier (Orange Research) but, with no success. Accordingly, the backwash system was operated manually during the verification testing.

4.3.1.3 Pretreatment Train

The pretreatment train for the Kinetico CPT consisted of a settling tank, clarifier, chemical metering pumps, an in-line mixer, and various ancillary control valves and flow meters (Refer to equipment description in Section 2.2). With the exception of the chemical metering pumps, the pretreatment system was operated manually. Accordingly, the operator was required to monitor system flow and sedimentation rates on a continuous basis and perform adjustments when needed.

Coagulants used during the verification testing period included: AQM 100, Ferric Chloride, and C-1592. Chemical specification/identification sheets are provided in Appendix G.

Coagulants were supplied by the manufacturers as follows:

AQM 100:	Aluminum Chlorhydrate, 50% Aqueous Solution
Ferric Chloride 35%	Aqueous Solution
C-1592:	Emulsion Polyacrylamide, 34% Aqueous Solution

A diluted solution containing 3.60% AQM 100 and 2.72% Ferric Chloride introduced into the influent water stream of the pretreatment train with one metering pump through one injection point and a diluted solution containing 0.10 % of C-1592 was introduced into the influent water stream of the filtration train with a separate metering pump and injection point. With the operational data provided in Table 4-2 and 4-3, it is calculated that a total of 83.25 liters of 3.60% AQM 100, 62.80 liters of 2.72% Ferric Chloride, and 27.49 liters of 0.10% C1592 were used during the verification testing period between March 24 and April 4, 2000. These volumes, converted to undiluted solutions as provided by the chemical supplier, are equivalent to 3.00 liters of AQM 100, 1.71 liters of Ferric Chloride, and 0.03 liters of C1592.

During the verification test period of March 24 through April 4, 2000, the pretreatment train treated a total of 63,462 gallons of water and the filtration train of the Kinetico equipment package treated 39,812 gallons of water. Dosage requirements per gallon treated during this period are as follow:

Table 4-1 Dosage Requirements

Coagulant	Diluted Dose (L/1000 gallon)	Undiluted Dose, as supplied (L/1000 gallon)	Diluted Dose (mg/L)	Undiluted Dose, as supplied (mg/L)
AQM 100	1.31	0.0472	351	25.3
Ferric Chloride	0.99	0.0269	266	20.7
C1592	0.58	0.0006	182	0.54

Table 4-2 describes the coagulation chemistry requirements for the verification period. The coagulation chemistry was very sensitive to changes in influent water quality. This required continuous 24-hour monitoring by a technician in order to maintain stabilization of coagulant chemistry. Coagulation chemistries employed and changes made during initial operations and the performance verification period are included in Appendix G.

Table 4-2. Coagulant/Polymer Chemistry

Date	Time	Chemical (Undiluted as provided by supplier)	Peristaltic Pump Setting (Speed/Stroke)	Measured Chemical Addition Rate (mL/min)	Ave. Pre-treatment and Filter Train Flow Rate (gpm)	[1]Dosage (Diluted as introduced by peristaltic pump) (mg/L)	[1]Dosage (Undiluted as provided by supplier) (mg/L)
03/24/00	19:42	AQM 100	100/30	10.0	*3.8	401	28.9
		Ferric Chloride				305	23.5
		C-1592	20/40	1.8	2.95	161	0.47
03/25/00	10:06	AQM 100	100/30	8.3	*3.8	333	24.0
		Ferric Chloride				253	19.5
		C-1592	20/40	1.53	2.93	138	0.41
03/26/00	8:00	AQM 100	100/30	7.5	*3.8	301	21.7
		Ferric Chloride				228	17.6
		C-1592	20/40	1.7	2.88	156	.46
03/27/00	16:00	AQM 100	100/30	7.5	*3.8	301	21.7
		Ferric Chloride				228	17.6
		C-1592	20/40	1.7	2.87	156	0.46
03/28/00	17:05	AQM 100	100/30	7.5	3.8	301	21.7
		Ferric Chloride				228	17.6
		C-1592	20/40	1.7	2.83	159	0.47
03/29/00	19:16	AQM 100	100/30	7.5	3.85	297	21.4
		Ferric Chloride				226	17.4
		C-1592	20/40	1.7	2.93	153	0.45
03/30/00	17:31	AQM 100	100/30	7.5	3.85	297	21.4
		Ferric Chloride				226	17.4
		C-1592	20/40	1.7	2.88	156	0.46
03/31/00	12:40	AQM 100	100/30	10.0	3.8	401	28.9
		Ferric Chloride				305	23.5
		C-1592	20/40	1.6	2.73	155	0.46
04/01/00	16:58	AQM 100	100/30	10.0	3.8	401	28.9
		Ferric Chloride				305	23.5
		C-1592	20/40	1.6	2.77	153	0.45
04/02/00	15:20	AQM 100	100/30	10.0	3.8	401	28.9
		Ferric Chloride				305	23.5
		C-1592	20/40	1.6	2.65	160	0.47
04/03/00	17:18	AQM 100	100/30	10.0	3.8	401	28.9
		Ferric Chloride				305	23.5
		C-1592	20/40	1.6	2.70	157	0.46
04/04/00	8:06	AQM 100	100/30	10.0	3.8	401	28.9
		Ferric Chloride				305	23.5
		C-1592	20/40	1.6	2.75	154	0.45
04/04/00	11:30	Shut down until protozoan challenge series.					

[1] Dosages are calculated based on daily average pretreatment train and filter train flow rates (gpm). AQM 100, Ferric Chloride was injected into the feed stream to the pretreatment train. C-1592 was injected into the feed stream to the filter train.

* = Estimated values.

4.3.1.4 Turbidimeters

Both on-line turbidimeters supplied with the equipment package required frequent cleaning and verification of calibration. The turbidimeters were cleaned and re-calibrated 22 times during the verification period.

Communications problems between the on-site computer monitor and the on-line filter train influent turbidimeter between March 24 and March 28 resulted in manual recording of on-line turbidity data every 30 minutes between March 24 and March 28. On March 31, the on-line filter train influent turbidimeter sensor failed and a replacement turbidimeter was installed on April 2. The Hach 2100P benchtop was used to record influent turbidity every 30 minutes during this time period.

4.3.2 Task 2 - Influent and Effluent Water Quality Characterization

A summary of the influent water quality information for the verification period of March 24 through April 4, 2000 is presented in Table 4-3.

Table 4-3. Influent Water Quality (March 24-April 4, 2000)

Parameter	# of Samples	Average	Minimum	Maximum	PQL
Temperature (°C)	11	12.3	11.3	14.1	---
pH	12	8.3	8.1	8.5	---
Algae (Algae/mL)	2	See discussion in text	<1	See discussion in text	1
Total Alkalinity (mg/L)	11	150	140	150	10
Aluminum (mg/L)	2	NA	<0.05	0.10	0.05
Total Coliform (cfu/100mL)	2	NA	<1	>200	1
E. coli (CFU/100mL)	2	NA	<1	1	1
Total Hardness (mg/L)	2	NA	160	160	10
Iron (mg/L)	2	NA	<0.1	0.3	0.1
Manganese (mg/L)	2	NA	0.03	0.06	0.01
TOC (mg/L)	2	NA	11	12	0.05
UVA_{254} (cm-l)	2	NA	0.151	0.185	---
Free Chlorine (mg/l)	10	0.49	0.1	0.8	0.01*
Pre-treatment Train Influent Turbidity (NTU)	494	3.3	2.6	4.0	---
Filter Train Influent Turbidity (NTU)**	515	7.7	0.3	25.1	---

Note: All calculations involving results with below PQL values used 1/2 the PQL in the calculation.

NA = Average was not performed on data sets with two samples (i.e. n=2).

* 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.

** Due to communications problems between computer and on-line monitors, filter train influent turbidity readings are based upon visual readings and manual recordings.

Temperature of the influent water varied during the testing period due to changes in the Mississippi River water temperature. It ranged from 11.3°C to 14.1°C. Water temperature steadily increased during the period as the air temperature changed. This difference in water temperature was to be expected due to seasonal warming changes. The pH of the influent water was stable during the testing period at an

average pH of 8.3. The following average influent water characteristics were also observed during the verification period of March 24 through April 4, 2000: total alkalinity averaged 150 mg/L, total hardness of 160 mg/L, and TOC concentration in two samples was less than or equal to 12.0 mg/L. Two samples of the influent water were collected for total coliform analysis. One measurement was below the PQL of 1 CFU/100mL, while the other sample dated April 3, 2000, detected greater than 200 CFU/100mL. Two samples of the influent water were collected for *E. coli* analysis. The results indicated that *E. coli* was not detected in the first sample (PQL of 1 CFU/100mL), while the second sample dated April 3, 2000, measured 1 CFU/100mL.

One sample of the influent water was collected for algae analysis during the verification testing period. Algae samples dated March 27, 2000, reported the following results: Cyclotella 70 Algae/mL, Asterionella 455 Algae/mL, Nitzschia 2200 Algae/mL, Chlamydomonas 70 Algae/mL, Fragilaria 35 Algae/mL, Chlorella 175 Algae/mL, Ankistodesmus 450 Algae/mL, Chloratella 35 Algae/mL, Staurastum 35 Algae/mL, Dinobyran 35 Algae/mL, and Rhodomonas 35 Algae/mL. The algae results were not unexpected as the Mississippi river is subject to variable alga blooms as the river undergoes different climatic and flow changes. Since the algae were not being used as surrogates, their identification is of less consequence, however, they do accelerate filter loading, resulting in shorter filter run times.

A summary of the effluent water quality information for the verification period of March 24 through April 4, 2000 is presented in Table 4-4.

Table 4-4. Effluent Water Quality (March 24-April 4, 2000)

Parameter	# of samples	Average	Minimum	Maximum	PQL
Algae (Algae/mL)	2	NA	<1	<1	1
Total Alkalinity (mg/L)	11	140	140	140	10
Aluminum (mg/L)	2	NA	<0.05	0.11	0.05
Total Coliform (cfu/100mL)	2	NA	<1.2	>200	1
E. coli (CFU/100mL)	2	NA	<1	7	1
Total Hardness (mg/L)	2	NA	160	160	10
Iron (mg/L)	2	NA	<0.1	0.3	0.1
Manganese (mg/L)	2	NA	0.01	0.07	0.01
True Color (TCU)	1	NA	10	10	1
TOC (mg/L)	2	NA	8.9	9.0	0.05
UVA_{254} (cm-l)	2	NA	0.125	0.240	---
On-Line Turbidity (NTU)	7,061	0.4	0.03	5.0	---

Note: All calculations involving results with below PQL values used half the PQL in the calculation.
NA = Average was not performed on data sets with one or two samples (i.e. n=1 or n=2).

The results of the testing of the effluent water are follows: total alkalinity of 140 mg/L, total hardness of 160 mg/L, true color of 10 TCU, and TOC concentration less than or equal to 9.0 mg/L. Two measurements were collected for total coliform analysis; the results of the first sample indicated that total coliform was not detected (PQL of 1.2 CFU/100mL), while >200 CFU/100mL of total coliform was detected in the other sample dated April 3, 2000.

No algae were detected at the PQL of 1 Algae/mL in the effluent water samples. *E. coli* was detected on April 3, 2000, at 7 CFU/100mL. *E. coli* from the sample collected on March 27, 2000 was below the PQL detection of 1 CFU/100mL during the testing period. The samples 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/100mL or <1 *E. coli*/100mL. This sample analysis must therefore be reported as <1/85mL, or <1.2 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 85 mL sample for analysis. No detection of Total Coliform Bacteria or *E. coli* was found in the 85 mL sample collected on March 27.

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 CPS100CPT. This task collected data that described the operation of the equipment and provided information to be used to develop cost estimates for operation of the equipment.

Table 4-5 lists the average operating conditions per filter run during the verification period of March 24 through April 4, 2000. Note that "Average Influent Flowrate" data is not available for the first five days of the testing period. During this period, influent and effluent flow rates were balanced at the start of each filter run. As the effluent flow rate decreased due to filter loading, flow was manually reduced between the contact tank and the clarifier with a valve and the excess influent volume would begin to occupy the remaining head of the contact tank. Due to the intensive level of monitoring and operator interaction required to maintain this balance, COA decided it was not practical to continue this routine. Accordingly, this routine was discontinued and documentation of both influent and effluent flow rates throughout each filter run commenced.

As described in Chapter 2, Equipment Description and Operating Processes, the Kinetico CPS100CPT system included two identical filters vessels identified as "A" and "B" operating alternately. For tracking purposes each "Run #" in Table 4-5 is identified with "A" or "B" and a sequential run numerical number (i.e., 1 to 21, or "A1", etc.).

Table 4-5. Average Operating Conditions Per Filter Run

Date	Run #	Length of Run (Hrs)	Ave. Influent Turbidity (NTU)	Ave. Effluent Turbidity (NTU)	Ave. Pre-Treatment Train Flow Rate (gpm)	Ave. Filter-Train Flow Rate (gpm)	Min. Filter Train Flow Rate (gpm)	Max. Filter Train Flow Rate (gpm)	ΔPSI End Run (psig)	Total Volume (gal)	Backwash Volume (gal)
3/24/00	A1	2.83	3.4	1.2	-	3.0	2.7	3.3	20	597	82
3/25/00	A2	3.75	3.3	0.7	-	3.0	2.8	3.3	20	845	77
3/25/00	A3	6.01	3.1	0.2	-	2.9	2.7	3.3	20	1203	76
3/26/00	A4	5.01	3.2	0.1	-	2.9	2.6	3.3	19	985	96
3/26/00	A5	4.15	3.3	0.4	-	2.9	2.6	3.2	20	803	97
3/27/00	A6	6.07	3.3	0.1	-	2.9	2.6	3.2	20	1178	53
3/27/00	A7	6.05	3.4	0.1	-	2.8	2.2	3.2	20	1199	98
3/28/00	A8	5.53	3.4	0.1	-	2.9	2.6	.32	20	1081	77
3/28/00	A9	6.03	3.4	0.2	3.8	2.8	2.6	3.2	20	1158	97
3/29/00	A10	6.10	3.3	0.2	3.8	3.0	2.6	3.2	20	1158	70
3/29/00	A11	5.50	3.2	0.3	3.9	2.9	2.6	3.2	20	1090	98
3/30/00	A12	4.70	3.4	0.4	3.9	3.0	2.7	3.2	18	593	78
3/30/00	A13	7.02	3.3	0.6	3.8	2.7	2.5	3.0	20	1206	96
3/31/00	A14	6.73	3.2	0.9	3.8	2.7	2.4	3.0	22	1089	73
3/31/00	A15	5.35	3.1	0.5	3.8	2.7	2.5	3.0	20	940	97
4/1/00	A16	7.23	3.3	0.3	3.8	2.9	2.5	3.0	20	1241	74
4/2/00	A17	7.73	3.2	0.4	3.8	2.7	2.5	3.0	21	1156	74
4/2/00	A18	5.73	3.2	0.6	3.8	2.7	2.4	3.0	20	931	69
4/3/00	A19	5.60	3.4	1.0	3.8	2.7	2.5	3.0	20	953	90
4/3/00	A20	5.08	3.2	0.4	3.8	2.7	2.5	3.0	20	846	71
4/4/00	A21	3.87	3.5	0.6	3.8	2.8	2.7	3.0	20	566	-
3/24/00	B1	5.00	3.3	0.3	-	2.9	2.6	3.3	20	1007	71
3/25/00	B2	3.07	3.4	1.3	-	2.9	2.6	3.3	20	621	-
3/25/00	B3	6.10	3.2	0.3	-	2.9	2.5	3.3	20	1175	95
3/26/00	B4	6.18	3.2	0.1	-	2.9	2.6	3.2	20	1184	77
3/26/00	B5	5.13	3.2	0.2	-	2.8	2.5	3.2	20	985	96
3/26/00	B6	4.02	3.4	0.5	-	2.6	2.2	3.2	20	745	74
3/27/00	B7	8.47	3.2	0.1	-	2.9	2.5	3.3	20	1657	77
3/28/00	B8	6.53	3.4	0.1	-	2.8	2.1	3.2	20	1275	75
3/28/00	B9	6.08	3.7	0.1	-	2.8	2.5	3.2	20	1137	75
3/29/00	B10	6.63	3.3	0.2	3.8	2.8	2.5	3.1	20	1239	77
3/29/00	B11	3.68	3.2	0.2	3.9	3.0	2.8	3.2	13	756	76
3/30/00	B12	1.72	3.2	0.3	3.8	3.1	3.0	3.2	9	363	74
3/30/00	B13	8.57	3.2	0.5	3.8	2.7	2.3	3.2	20	1451	67
3/31/00	B14	3.75	3.4	0.6	3.8	2.8	2.6	3.0	13	660	89
3/31/00	B15	6.08	3.2	0.3	3.8	2.7	2.3	3.0	20	1023	72
4/1/00	B16	7.85	3.2	0.3	3.8	2.7	2.3	3.0	20	1310	72
4/1/00	B17	3.00	3.0	0.2	3.8	2.7	2.4	3.0	20	1190	95
4/2/00	B18	7.25	3.1	0.3	3.8	2.6	2.3	3.0	20	1107	70
4/2/00	B19	6.05	3.4	0.9	3.8	2.6	2.4	3.0	20	976	93
4/3/00	B20	7.22	3.2	1.0	3.8	2.7	2.4	3.0	20	1188	71
4/4/00	B21	7.13	3.3	0.7	3.8	2.7	2.3	3.0	20	1155	72
Average		5.61	3.4	0.4	3.8	2.8	2.5	3.1	19	1,024	80
Minimum		1.72	3.0	0.1	3.8	2.6	2.1	3.0	9	363	53
Maximum		8.57	3.7	1.3	3.9	3.1	3.0	3.3	20	1,657	98
Std. Dev		1.57	0.1	0.3	0.0	0.1	0.2	0.1	2	259	11
95% Conf. Int.		5.15, 6.07	3.2, 3.3	0.3, 0.5	NA	2.8, 2.9	2.4, 2.6	3.1, 3.2	18, 20	945, 1,103	77, 84

- = No data recorded.

Power used by the Kinetico CPS100CPT was recorded by the use of a dedicated electrical power meter. During the verification testing and challenge period the Kinetico CPS100CPT System used 263 kWh for 48,031 gallons of water filtered. This equates to 183 gallons of filtered water per kWh.

Figure 4-3 is a graphic presentation of the gallons per filter run for both filter runs "A" and "B" and corresponding raw influent turbidity during the verification testing period. "Average Raw Turbidity" noted in Figure 4-3 is representative of incoming water from the river. As noted in the Table 4-3, the average raw turbidity (pre-treatment train) is 3.4 NTU, and the average total volume is 1,024 gallons.

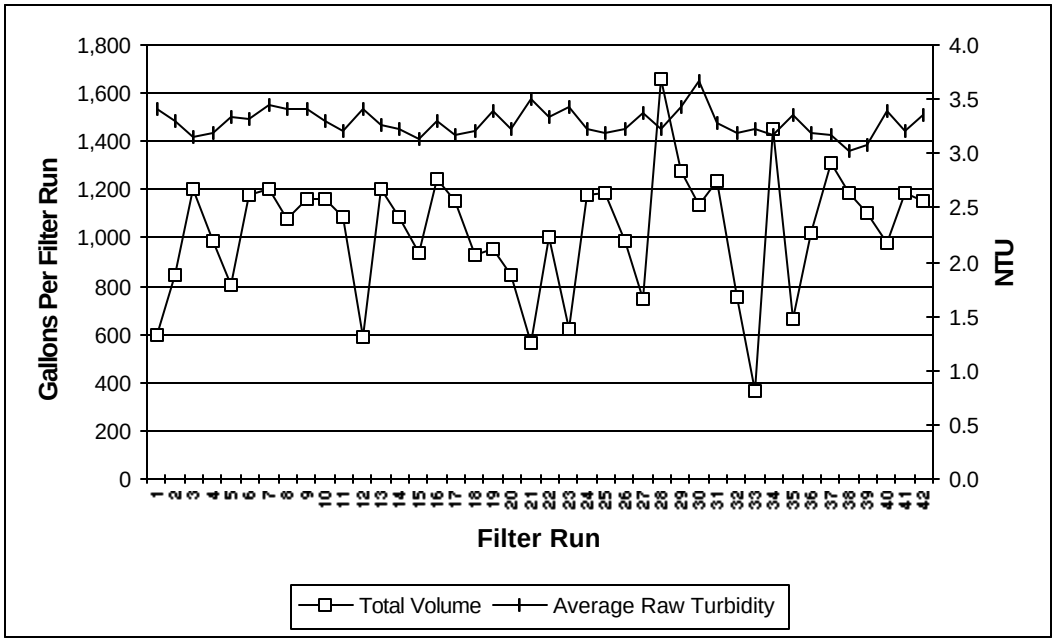

Figure 4-3. Gallons Per Filter Run & Raw Influent Turbidity

Table 4-6 lists the average on-line particle size and turbidity reading obtained during the verification testing period. The particle counts in the 3-7µm size range of interest for the raw influent water were: 3-5µm average of 4,104, and 5-7µm average size of 2,751. The particle count averages in the same 3-7µm size range for effluent water were: 3-5µm average of 587, and 5-7µm average of 227. Turbidity averages for the verification period were of 3.4 NTU for the pre-treatment train water influent, 7.7 NTU for the filter train influent, and 0.4 NTU for the filter train effluent.

Table 4-6. Average Particle Size & Turbidity (March 24 – April 4, 2000)

Parameter	# of samples	Average	Minimum	Maximum	Std. Dev	95% Confidence Interval
Particle Counts (counts/ml)						
Influent 2-3 µm	7,061	1,341	318	1,673	131	1,338, 1,343
Influent 3-5 µm	7,061	4,104	246	4,489	222	4,100, 4,109
Influent 5-7 µm	7,061	2,751	70	2,967	128	2,748, 2,754
Influent 7-10 µm	7,061	5,310	36	5,800	278	5,304, 5,316
Influent 10-15 µm	7,061	2,343	5	3,400	300	2,336, 2,349
Effluent 2-3 µm	7,061	436	19	2,006	249	430, 441
Effluent 3-5 µm	7,061	587	12	4,497	531	576, 599
Effluent 5-7 µm	7,061	261	4	2,837	281	255, 267
Effluent 7-10 µm	7,061	227	3	5,542	341	219, 234
Effluent 10-15 µm	7,061	78	1	3,181	146	74, 81
Turbidity (NTU)						
Bench-top Influent Turbidity	494	3.3	2.6	4.0	0.2	3.3, 3.3
On-line Effluent Turbidity	7,061	0.4	0.0	5.0	0.4	0.4, 0.4

Watershed events were noted in logbook. Data from the logbook and historical weather data from the Minnesota State Climatology Office (DNR Waters), and the U.S. Army Corp. of Engineers was compiled and is presented in Appendix H 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. Potential watershed events could lead to changes in water chemistry, which in turn could effect coagulant chemistries and filter performance. It is noted that performance of the Kinetico CPS100CPT system was very sensitive to changes in river water quality.

4.3.4 Task 4 - Microbiological Contaminant Removal Testing

The purpose of this task was to demonstrate the Kinetico CPS100CPT's ability to reduce *C. parvum* and *G. lamblia* within defined influent water quality specifications.

4.3.4.1 Water Characteristics

Chlorination was discontinued during protozoan challenge test runs. Accordingly, unfiltered river water served as the source water during these challenges. A summary of the influent water quality information for the challenge period of April 24 through April 26, 2000 is presented in Table 4-7. Two samples of

the influent water were collected for total coliform analysis; one measurement detected 4 CFU/100mL, while the other sample dated April 26, 2000, detected 290 CFU/100mL. Two samples of the influent water were collected for *E. coli* analysis; the sample dated April 25, 2000, detected 4 CFU/100mL; the second sample dated April 26, 2000, measured 8 CFU/100mL.

Algae were detected as 325 Algae/mL on April 26, 2000 during the verification testing challenges as the following parameters: Nitzschia 176 Algae/mL, Ankistodesmus 48 Algae/mL, Navicula 75 Algae/mL, and Golekinea 26 Algae/mL. Based upon the algae and the total coliform results, it can be stated that an "algae bloom" was in process in the source water during the third challenge test.

Table 4-7. Influent Water Quality During Protozoan Challenge Events (April 24-April 26, 2000)

Parameter	# of samples	Average	Minimum	Maximum	PQL
Algae (Algae/mL)	2	See discussion in text	<1	See discussion in text	1
Total Alkalinity (mg/L)	3	140	140	140	10
Aluminum (mg/L)	2	NA	<0.05	<0.05	0.05
Total Coliform (cfu/100/mL)	2	NA	4	290	1
E. coli (CFU/100mL)	2	NA	4	8	1
Total Hardness (mg/L)	2	NA	160	160	10
Iron (mg/L)	2	NA	0.2	0.2	0.1
Manganese (mg/L)	2	NA	0.06	0.08	0.01
TOC (mg/L)	2	NA	12	13	0.05
UVA_{254} (cm-l)	2	NA	0.250	0.254	---
Temperature (C)	4	15.9	14.5	16.9	---
pH	4	8.7	8.5	8.9	---
Bench-top Turbidity (NTU)	4	3.5	2.7	4.4	---

Note: All calculations involving results with below PQL values used half the PQL in the calculation.
NA = Average was not performed on data sets with two samples (i.e. n=2).

A summary of the effluent water quality information for the challenge period of April 24 through April 26, 2000 is presented in Table 4-8. Total coliform and *E. coli* were not detected or were below the PQL of 1 CFU/100mL in the influent samples collected.

Table 4-8. Effluent Water Quality During Protozoan Events (April 24-April 26), 2000)

Parameter	# of samples	Average	Minimum	Maximum	PQL
Algae (Algae/mL)	2	NA	<1	<1	1
Total Alkalinity (mg/L)	3	74	57	100	10
Aluminum (mg/L)	2	NA	<0.05	0.26	0.05
Total Coliform (cfu/100/mL)	2	NA	<1	<1	1
E. coli (CFU/100mL)	2	NA	<1	<1	1
Total Hardness (mg/L)	2	NA	160	190	10
Iron (mg/L)	2	NA	<0.1	0.2	0.1
Manganese (mg/L)	2	NA	0.11	0.13	0.01
TOC (mg/L)	2	NA	4.4	5.7	0.05
UVA_{254} (cm-l)	2	NA	0.031	0.036	---
On-line Turbidity (NTU)	404	1.6	0.2	5.0	---

Note: All calculations involving results with below PQL values used half the PQL in the calculation.
NA = Average was not performed on data sets with two samples (i.e. n=2).

4.3.4.2 Operational and Analytical Data

The Kinetico CPS100CPT was shut down for a total of 448.5 hours, between April 4 and April 23, 2000 due to problems found in EPA method 1623 associated with the testing of *G. muris* versus *G. lamblia*. Due to this interruption, the equipment was not operated continuously during the performance verification period. During this 19-day period, source water conditions changed considerably. Upon re-starting the equipment on April 23, COA and Kinetico were unable to stabilize coagulation chemistry to the point that had been achieved previous to April 4. Cost constrains and reporting deadlines prohibited a significant effort to re-stabilize coagulation chemistry. As a consequence, filter runs were considerably shorter during microbial challenge testing. Filter runs averaged 705 gallons during challenge testing as compared to 1,026 gallons previous to April 4, 2000.

The Kinetico CPS100CPT included two identical filters vessels identified as "A" and "B" operating alternately. During the challenge testing only filter "B" was used for the sample collection. Table 4-9 summarizes operating conditions for filter "B" during the challenge testing.

Table 4-9. Operating Conditions During Each Protozoan Challenge Event

Challenge #	Date	Temperature (°C)	pH
1	4/24/00	15.4	8.5
2	4/26/00	16.9	8.9
3	4/26/00	16.9	8.9

Table 4-10 lists the Kinetico CPS100CPT coagulant/polymer chemistry and dosage during the challenge events.

Table 4-10. Coagulant/Polymer Chemistry During Challenge Events

Date	Challenge Run #	Chemical	Peristaltic Pump Setting (Speed/Stroke)	Measured Chemical Addition Rate (mL/min)	Pretreatment and Filter Train Flow Rate (gpm)	[1]Dosage (Diluted as introduced by peristaltic pump) (mg/L)	[1]Dosage (Undiluted as provided by supplier) (mg/L)
04/24/00	1	AQM 100	80/95	60	3.7	2,471	128.5
		Ferric Chloride				1,877	145.9
		C-1592	20/40	3.7	2.6	376	1.11
04/26/00	2	AQM 100	88/100	68.3	3.7	2,813	202.6
		Ferric Chloride				2,137	166.1
		C-1592	20/40	3.1	2.2	372	1.09
04/26/00	3	AQM 100	88/100	68.3	3.7	2,813	202.6
		Ferric Chloride				2,137	166.1
		C-1592	20/40	3.1	2.2	372	1.09

[1] Dosages are calculated based on average flow rates shown in Table 4-10. AQM 100, Ferric Chloride was injected into the feed stream to the pretreatment train. C-1592 was injected into the feed stream to the filter train

Table 4-11 lists operating conditions per each protozoan challenge filter run.

Table 4-11. Average Operating Conditions Per Filter Run During Challenge Events

Date	Challenge Run #	Run Length (Hours)	[1] Average Influent Turbidity (NTU)	Average Effluent Turbidity (NTU)	Average Pre-Treatment Train Flow rate (gpm)	Average Filter-Train Flow rate (gpm)	ΔPSI End Run (psig)	Total Volume (Gallons)
4/24/00	1	4.0	2.6	0.6	3.7	2.6	20	649
4/26/00	2	4.75	3.7	1.6	3.7	2.6	20	790
4/26/00	3	4.53	3.7	18.4	3.7	2.2	32	677

[1]Influent turbidity samples for benchtop analysis were not taken during challenge due to operator safety concerns. Influent turbidity values above reflect measurements taken previous to challenge runs.

The flow rates during each of the challenge events are listed below in Table 4-12. A hydraulic tracer test (Section 4.2.4) established a time of 120 minutes to achieve equilibrium between tracer concentrations between influent and effluent streams. Average flow rates over this 120 minute period during the tracer test were 3.9 gpm through the pretreatment train (252 gallons) and 3.4 gpm through the filter train (11.9 gallons).

Table 4-12. Pretreatment and Filter Train Flow Rates During Challenge Events

Date	Challenge Run #	Pretreatment Train Flow Rate at Start of Run (gpm)	Filter Train Flow Rate at Start of Run (gpm)	[1]Pretreatment Train Flow Rate at 120 minutes (gpm)	[1]Filter Train Flow Rate at 120 minutes (gpm)	Pretreatment Train Flow Rate at end of run (gpm)	Filter Train Flow Rate at end of run (gpm)
4/24/00	1	3.4	2.9	3.4	2.8	3.3	1.6
4/26/00	2	3.5	3.0	3.7	3.0	3.7	2.5
4/26/00	3	3.5	3.2*	3.7	2.8	3.7	1.0

* 3.2 gpm is the measured value at time zero plus 49 minutes. The value recorded at time zero was 2.2 gpm, but it was concluded that this value was an anomaly.

Figure 4-4 shows the particle count $\log_{10}$ removal and turbidity results during the challenge test run #1 in the 3-7 µm range. Steady state injection of protozoan seed into the influent stream began at time 3:35 PM and concluded at time 6:35 PM. Log_{10} removals of particles sized 3-7 µm dropped from 4.02 to 1.66 during challenge #1 on April 24th. Filter influent turbidity ranged from 5.93 NTU to 24.91 NTU. A high turbidity spike occurred at 6:34 PM. This was caused by air entrapped within the turbidimeter cell. At 6:34 PM a small vortex occurred in the clarifier outlet. This allowed air to become entrained within the filter influent stream that supplies the turbidimeter. After this event the influent turbidimeter remained unstable until the end of the filter run. Filter effluent turbidity gradually increased over the filter run from 0.15 NTU at the beginning to 0.96 NTU near the end of the filter run.

Turbidity for the influent stream was performed with a benchtop as compared to an on-line turbidimeter. Accordingly, benchtop samples were not evaluated during the protozoan challenge period due to safety concerns of the personnel responsible for recording turbidity values. Accordingly, Figures 4-4 through 4-6 do not show turbidity values for the influent stream.

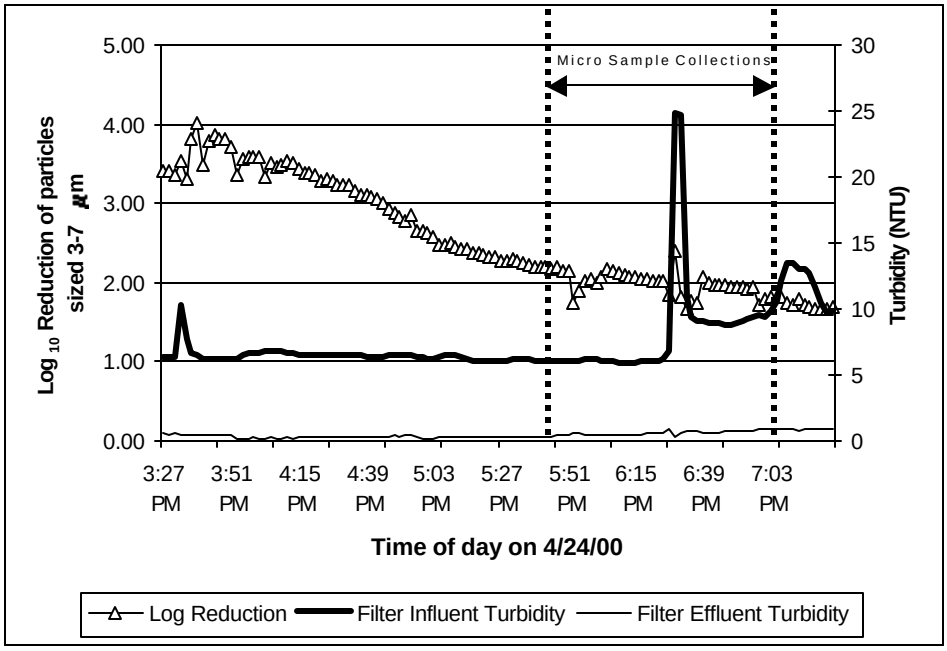

Figure 4-4. 3-7 µm Particle Count Log_{10} Removal During Challenge #1

Figure 4-5 shows the particle count log_{10} removal and turbidity results during challenge test run #2 in the 3-7 µm range. Steady state injection of protozoan seed into the influent stream began at time 7:10 AM and concluded at time 11:10 AM. Log_{10} removals of particles sized 3-7 µm dropped from 2.69 to 0.17 during challenge #2 on April 26. Filter influent turbidity decreased from 15.43 NTU to 2.65 NTU while filter effluent turbidity increased from 0.45 to 0.80 over the first 3 hours and 20 minutes of filter run #2. After that point, floc from the settling tank began to overflow into the clarifier and subsequently introduced into the filter influent stream. After that point (approximately 10:30 AM) turbidimeter and particle counter readings became unstable. Filter influent/effluent turbidities increased and log_{10} particle removals decreased.

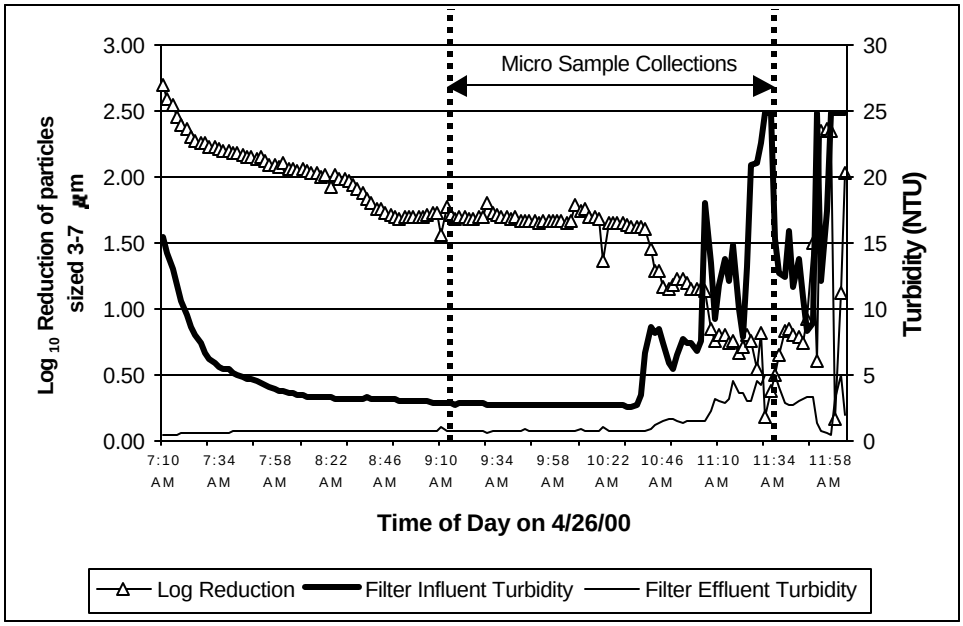

Figure 4-5. 3-7 µm Particle Count Log_{10} Removal During Challenge #2

Figure 4-6 shows the particle count log_{10} removal during the last challenge test run #3 in the 3-7 µm range. Steady state injection of protozoan seed into the influent stream began at time 4:15 PM and concluded at time 8:15 PM. Log_{10} removals of particles sized 3-7µm dropped from 2.94 to -0.12 during challenge #3 on April 26th. Filter influent turbidity increased from 9.69 to 74.74 NTU and filter effluent turbidity increased from 0.18 to 4.98 NTU over the course of this filter run. Significant decreases in log_{10} reductions and increases in turbidity values can be attributed to floc discharging from the clarifier into the filter influent beginning approximately 2 hours after the start of this filter run.

It is noted in the logbook that the operators were experiencing significant instability in coagulation chemistry throughout the period of microbial challenge testing. In addition to generally contributing to shorter filter run times, it can be observed in Figure 4-5 that during challenge #2 that log_{10} reductions of 3-7 µm micron particles decreased and influent turbidity increased considerably at the end of that filter run. During challenge #3, particle and turbidity reduction began to fall off precipitously after the first two hours of operation. Because challenge #3 was the last challenge that could be conducted given, time and financial constraints previously mentioned, it was decided to continue the filter run beyond the manufacturer's terminal head loss specification of 20 psi and continue to collect microbial samples.

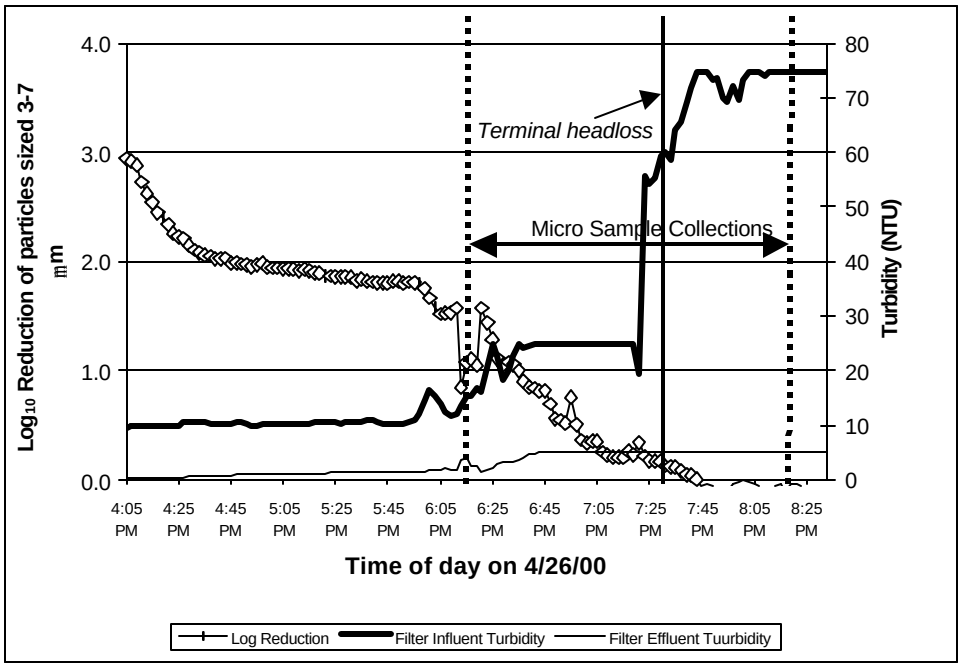

Figure 4-6. 3-7 µm Particle Count Log_{10} Removal During Challenge #3

Tables 4-13 and 4-14 illustrate the *G. lamblia* and *C. parvum* log_{10} removal rates achieved by the Kinetico CPS100CPT system as a result of the microbial challenge testing. Samples were collected from the raw seeded water, the clarifier effluent, and the filtration train effluent. Samples were analyzed in accordance with EPA method 1623. Resultant data from samples collected from the Kinetico CPS100CPT system effluent (i.e. combined pretreatment and filtration train) indicate that *G. lamblia* log_{10} removals ranged from 2.6 to 3.6 and *C. parvum* log_{10} removals ranged from 3.4 to 5.7 at a filter train flow rates of 2.2 to 2.6 gpm over the challenge filter runs.

Table 4-13. *G. lamblia* Log_{10} Removals

Run #	(1) Influent *Giardia*/L	(2) Effluent *Giardia*/L	(3) Log_{10} Removal
Run 1			
Raw seeded water	363		
Time zero clarifier	363	0.1	3.6
Time zero filter	363	<0.09	>3.6
Time ½hour clarifier	363	<0.1	>3.6
Time ½hour filter	363	<0.1	>3.6
Time 1-hour clarifier	363	<0.1	>3.6
Time 1-hour filter	363	<0.1	>3.6
Run2			
Raw seeded water	EST 260		
Time zero clarifier	260	<0.1	>3.4
Time zero filter	260	<0.1	>3.5
Time ½hour clarifier	260	<0.1	>3.4
Time ½hour filter	260	<0.1	>3.4
Time 1-hour clarifier	260	<0.1	>3.4
Time 1-hour filter	260	<0.1	>3.4
Time 2-hour clarifier	260	<0.1	>3.4
Time 2-hour filter.	260	<0.1	>3.4
Run3			
Raw seeded water	150		
Time zero clarifier	150	<0.1	>3.2
Time zero filter	150	<0.1	>3.2
Time ½hour clarifier	150	0.4	2.6
Time ½hour filter	150	0.2	2.9
Time 1-hour clarifier	150	<0.1	>3.2
Time 1-hour filter	150	0.4	2.6
Time 2-hour clarifier	150	<0.1	>3.2
Time 2-hour filter.	150	0.1	3.2

EST: Estimated value due organisms being too numerous to count.
(1) =BioVir result influent organisms per liter in capture filter
(2) = BioVir result effluent organism per liter in capture filter
(3) = Log_{10}(influent concentration/effluent concentration)

Table 4-14 presents the *C. parvum* challenge log_{10} results.

Table 4-14. *C. parvum* Log_{10} Removals

Run #	(1) Influent ***Crypto***/L	(2) Effluent ***Crypto***/L	(3) Log_{10} Removal
Run 1			
Raw seeded water	EST 45,000		
Time zero clarifier	45,000	0.3	5.2
Time zero filter	45,000	<0.09	>5.7
Time ½hour clarifier	45,000	0.2	5.4
Time ½hour filter	45,000	0.1	5.7
Time 1-hour clarifier	45,000	<0.1	>5.7
Time 1-hour filter	45,000	<0.1	>5.7
Run2			
Raw seeded water	EST 21,000		
Time zero clarifier	21,000	<0.1	>5.3
Time zero filter	21,000	0.3	4.8
Time ½hour clarifier	21,000	0.1	5.3
Time ½hour filter	21,000	0.3	4.8
Time 1-hour clarifier	21,000	1.5	4.1
Time 1-hour filter	21,000	<0.1	>5.3
Time 2-hour clarifier	21,000	1.8	4.1
Time 2-hour filter.	21,000	3.1	3.8
Run3			
Raw seeded water	8,000		
Time zero clarifier	8,000	<0.3	>4.4
Time zero filter	8,000	0.2	4.6
Time ½hour clarifier	8,000	6.7	3.1
Time ½hour filter	8,000	3.5	3.4
Time 1-hour clarifier	8,000	0.9	3.9
Time 1-hour filter	8,000	1.4	3.8
Time 2-hour clarifier	8,000	0.1	4.9
Time 2-hour filter.	8,000	2.3	3.5

EST: Estimated value due organisms being too numerous to count.
(1) =BioVir result influent organisms per liter in capture filter
(2) = BioVir result effluent organism per liter in capture filter
(3) = Log_{10}(influent concentration/effluent concentration)

4.3.4.3 Discussion of Results

Three seeding studies were performed for the removal of *G. lamblia* and *C. parvum* in accordance with EPA method 1623. During the course of each challenge, concentrations of 3-7 µm sized particles and turbidity were monitored continuously. Filter runs during challenge testing were considerably short. During the first challenge, effluent samples were only collected during the first hour after time zero before terminal head loss occurred across the filter. On the two subsequent challenges, effluent samples were collected during a two-hour period after time zero.

Resultant data from samples collected from the system effluent indicate that *G. lamblia* $\log_{10}$ removals ranged from 2.6 to 3.6 and *C. parvum* $\log_{10}$ removals ranged from 3.4 to 5.7 at a filter train flow rates of 2.2 to 2.6 gpm over the challenge filter runs. There were numerous effluent samples during the study that were below the detectable limit for both cysts and oocysts. During challenge #2 there were no *G. lamblia* cysts detected in any of the effluent samples, while *C. parvum* oocysts were detected in the filter effluent at times 0, ½and 2 hours, and in the clarifier effluent at time 1 and 2 hours. The greatest number of filter effluent samples containing cysts occurred during challenge 3, which yielded the lowest coagulation and filtration system removals of 2.6 $\log_{10}$ for *G. lamblia* and 3.4 $\log_{10}$ for *C. parvum*.

Turbidity and particle count data (3-7 µm sized particles), recorded simultaneously during the same filter runs, are incongruent with protozoan challenge results (refer to Figures 4-4 through 4-6). This difference is attributable to two factors. First, turbidity and particle count data was limited to filter influent and effluent streams while protozoan challenge data included filter influent, effluent and pretreatment (pre-coagulation) streams. Second, the results of the protozoan challenge study suggest the technologies employed within the CPS100CPT pretreatment train were very effective for the removal of *G. lamblia* and *C. parvum*. As a result, too few (oo)cysts remained within the filter influent stream to provide an adequate challenge of the filter train to establish protozoan reduction performance of the filter train, independent of pre-filtration technologies employed by the Kinetico CPS100CPT system.

As previously mentioned within this report, filter flow rates were allowed to decrease due to increasing filter head pressure during each filter run. The equipment package was operated in this manner in order to replicate true field operation. Further, and also previously mentioned within this report, pre-filtration technologies within this equipment package were subjected to a higher flow rate than the media filter. These flow rates were relatively similar at the beginning of each filter run with the difference primarily satisfying backwash flow demands in addition to on-line filter influent turbidimeter and particle counter demands. As the filter flow rate decreased due to filter loading, the excess available from the clarifier entered a discharge weir located at the clarifiers' outlet. Process flow rates experienced during each microbial challenge are presented in Figures 4-7 through 4-9.

Figure 4-7 illustrates process flow rates during challenge #1.

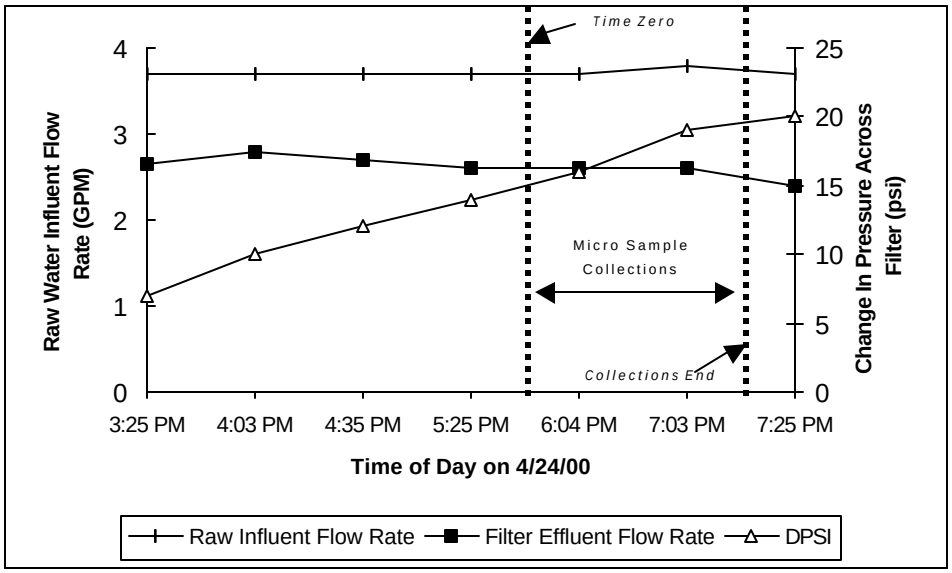

Figure 4-7. Challenge #1 Process Flow Rate Characteristics vs. Change In Pressure Across Filter

Figure 4-8 illustrates process flow rates during challenge #2.

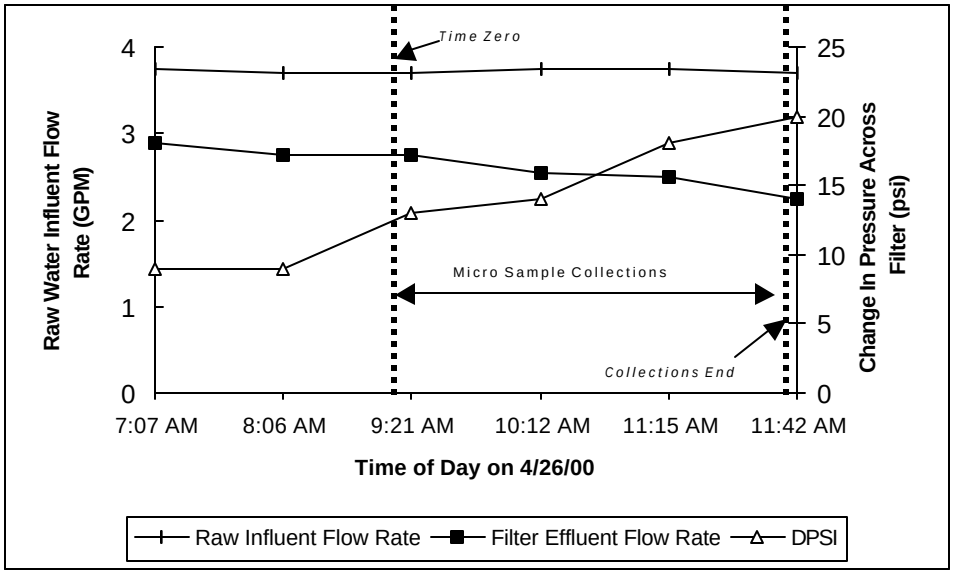

Figure 4-8. Challenge #2 Process Flow Rate Characteristics vs. Change In Pressure Across Filter

Figure 4-9 illustrates process flow rates during challenge #3. Note terminal head loss (20 Δpsi) was reached at 7:20 PM. As discussed above, the filter run was continued and microbial samples were taken beyond the point of terminal head loss.

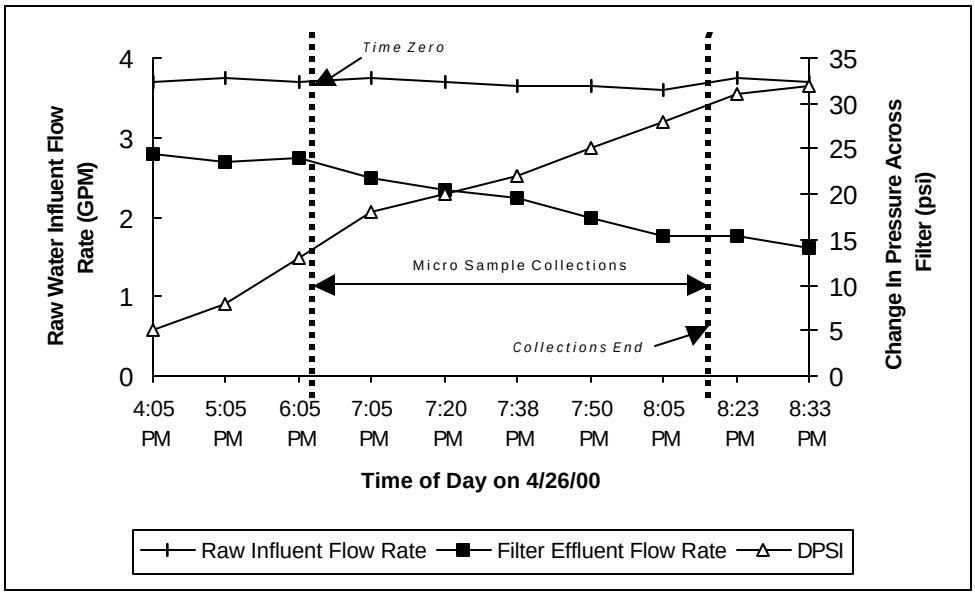

Figure 4-9. Challenge #3 Process Flow Rate Characteristics vs. Change In Pressure Across Filter

During the verification microbial challenge testing conducted April 24–26, 2000, the Kinetico CPS100CPT system demonstrated 2.6 to 3.6 $\log_{10}$ reductions of *G. lamblia* cysts and 3.4 to 5.7 $\log_{10}$ reductions of *C. parvum* oocysts. These results were obtained at an average pretreatment train flow rate of 3.8 gpm and average filtration train flow rate of 2.2 to 2.6 gpm, which is below the manufacturer's specified flow rate of 5 gpm.

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 CPS100CPT, 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

Equipment performance was very sensitive to changes in source water characteristics influenced by environmental conditions. This susceptibility was specific to the performance of the pretreatment train.

During the beginning of this test optimizing the coagulant usage was especially problematic due to rapid changes in river water quality caused from the occurrence of unseasonably warm climatic temperatures, rain, and snow melt. Fifteen days were required after system start-up to identify the correct coagulant chemistry to attain satisfactory performance results so performance verification testing could begin.

Data obtained from the U.S. Army Corp of Engineers, St. Anthony Falls Locks and Dams (location of SAFHL) shows that the Mississippi River stream discharge flow increased dramatically previous to the start of the ETV testing period of March 8th (Figure 10). This increase is primarily attributable to spring snow melt and associated run-off into the Mississippi river. Flow rates sharply increased during the last week of February and peaked on March 3rd. Thereafter, spring runoff declined until the approximate start of the ETV performance verification period (March 24th). Thereafter, river flow rates remained comparatively stable.

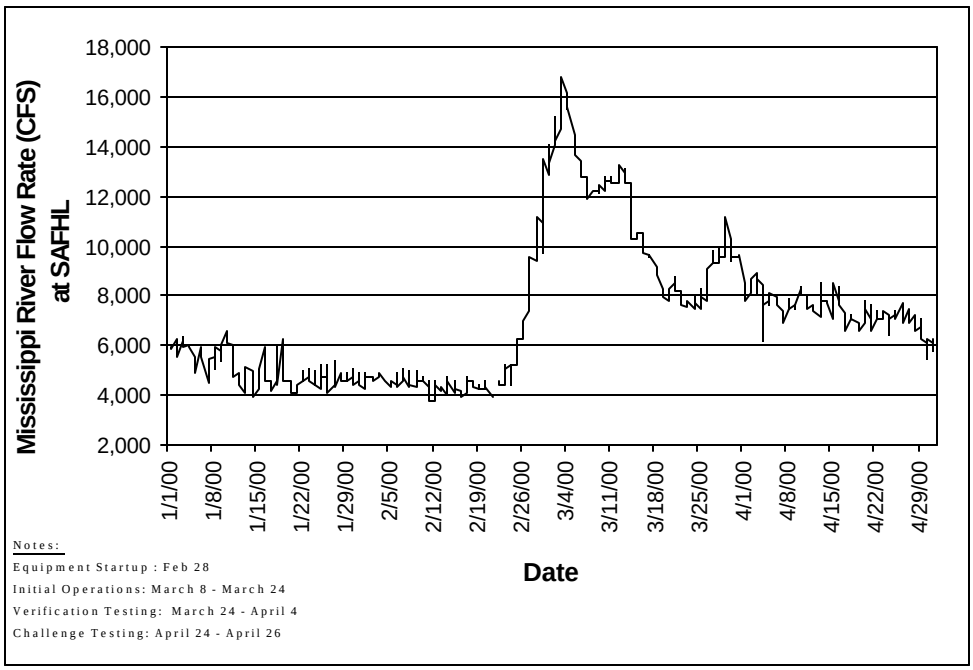

Figure 4-10. Mississippi River Flow Rate (CFS) at SAFHL (January 1 – May 1, 2000)

To what degree feed water conditions changed beyond what was measured is unknown. Although, it is noteworthy to observe that attempts to stabilize coagulation chemistry were not successful until river flow rates began to stabilize after spring run-off.

Further, and as described previously in this report, operation of the equipment was discontinued for 19 days during the performance verification period due to problems associated with EPA method 1623 (Section 4.3.4.2). During this equipment shut-down period, source water conditions changed to a point where previous coagulation chemistries did not perform as well upon resumption of testing. The most notable changes in source water conditions that were measured are described in Table 4-15. While measured changes were minimal, average filter run time decreased from 5.6 hours to 4.4 hours. Decrease in filter run time was directly attributable to carryover of floc from the pretreatment train into

the filtration train. Average filter influent turbidity increased from 8.2 NTU to 23.9 NTU between these two respective periods, while system influent (untreated river water) only increased from 3.3 NTU to 3.5.NTU.

Table 4-15. Notable Changes In Source Water Conditions

Parameter	Average (March 24-April 4, 2000)	Average (April 24-April 26, 2000)
Temperature (ºC)	12.3	15.9
pH	8.3	8.7
Untreated River Water Turbidity (NTU)	3.3	3.5

Water quality appeared to have had a significant impact on the coagulation chemistry of the Kinetico CPS100CPT System. Accordingly, it is suspected that the unstabilization of coagulation chemistries experienced during the challenge testing period can be attributed to changes in water quality parameters that were not measured and/or a mechanical aberration within the equipment being tested.

4.4.1.2 Operational requirements

The failure of a pressure differential switch, causing the operation of the filtration system to become non-automatic, combined with continuous monitoring required for the operation of the pretreatment train made the operation of the Kinetico CPS100CPT very labor intensive. During the initial operations and verification testing periods, the Kinetico CPS100CPT Coagulation and Filtration System was staffed 24 hours per day. Manual tasks included stabilization and monitoring of the coagulant chemistry, manual backwashing, and data recording. If coagulation chemistry is stabilized, such as what was experienced for an extended period during verification testing, and the filtration train is operating on an automatic basis, the Kinetico CPS100CPT could be operated with less technician interface. Minimal changes in source water characteristics may negatively influence performance of coagulation chemistry and continuous monitoring would be necessary to be aware when such changes occur so corrective action can be taken on a timely basis.

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 the filtration train of the Kinetico CPS100CPT. 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 CPS100CPT 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 CPS100CPT's process and design. The Kinetico O&M manual did not contain information on the pretreatment train (settling tank and clarifier).

The O&M manual was reviewed for completeness and used during equipment installation, start-up, system operation, and trouble-shooting. It was found that the manual provides adequate instruction for all tasks required to perform these functions. In cases where CPS100CPT system components failed,

such was concluded based upon the use of the O&M manual. Specific component failures included an on-line turbidimeter manufactured by Great Lakes International and a pressure differential switch manufactured by Orange Research. In both cases, Kinetico was responsive in their efforts to remedy component failures. Great Lakes International also was responsive in providing replacement equipment in addition to field assistance. Orange Research was non-responsive.

4.4.1.4 Safety

The Kinetico CPS100CPT did not introduce safety concerns beyond what is normally expected in the operation of a small coagulation/filtration system. Primary safety concerns dealt with handling of chemicals used to chlorinate and to enhance coagulation of source water. Standard safety precautions must be followed when handling these chemicals and Material Safety Data Sheets must be located in the same vicinity where they are being handled.

4.4.2 Quantitative Factors

The quantitative factors examined during the verification testing were power and coagulant chemical requirements. Operating conditions were recorded to allow reasonable prediction of performance under other, similar conditions.

4.4.2.1 Power Requirements

Power used by the Kinetico CPS100CPT was recorded by the use of a dedicated electrical power meter. During the verification testing period of March 24 through April 4, 2000, the system used 196 kWh for 39,812 gallons through the filtration train. This equates to 203 gallons of filtered water per kWh.

4.4.2.2 Coagulant Chemical Requirements

A diluted solution containing 3.47% AQM 100 and 2.64% Ferric Chloride was introduced into the influent water stream with one metering pump through one injection port and a diluted solution containing 0.10 % of C-1592 was introduced into the influent water stream with a separate metering pump and injection port. Given the data provided in Table 4-1 (Section 4.3.1.3) it is calculated that a total of 83.25 liters of 3.60% AQM 100, 62.80 liters of 2.72% Ferric Chloride, and 27.49 liters of 0.10% C1592 were used during the verification testing period between March 24 and April 4, 2000. These volumes, converted to undiluted solutions as provided by the chemical supplier, are equivalent to 3.00 liters of AQM 100, 1.71 liters of Ferric Chloride, and 0.03 liters of C1592.

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 H.

4.5.1 Data Correctness

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

- Representativeness
- Statistical Uncertainty
- Accuracy
- Precision

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

4.5.1.1 Representativeness

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

4.5.1.2 Statistical Uncertainty

Ninety-five percent confidence intervals were calculated for the water quality parameters with a minimum of three discrete samples for each parameter at one operating set. These include influent and effluent turbidity, particle count, flow rates, and various other filter runs performance data as discussed in Task 3 – Documentation of Operations Conditions and Treatment Equipment Performance.

4.5.1.3 Accuracy

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

4.5.1.4 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. Precision was ensured by calculating the relative percent standard deviation or the relative percent difference, and having it be equal to or less than 30%. For single reading

parameters, such as pressure and flow rates, precision was ensured by redundant readings from operator to operator. The pH meter was calibrated with NIST-traceable standards previous to each daily measurement. Precision of temperature measurement was ensured by use of a NIST-traceable thermometer.

4.5.2 Daily QA/QC Results

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

The on-line influent turbidimeter flow rate averaged 1,360 mL/minute during the verification period of March 24 though April 4, 2000. This average was calculated only to show that the limits were observed. The maximum rate during the testing period was 1760 mL/minute, the minimum was 900 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. Influent flow rates were verified daily with a 2,000 mL graduated cylinder and stopwatch.

The on-line effluent turbidimeter flow rate averaged 1,499 mL/minute. This average was calculated only to show that the limits were observed. The maximum rate during the testing period was 2,050 mL/minute, the minimum was 940 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. Effluent flow rates were verified daily with a 2,000 mL graduated cylinder and stopwatch.

The on-line influent turbidity readings were checked daily against the bench-top turbidimeter, and the readings were within acceptable limits of 20% of RPD. The readout from the GLI Model 95T/8320 on-line influent turbidity averaged 7.7 NTU during the verification period of March 24 through April 4, 2000; the average from the Hach 2100P benchtop turbidimeter was 6.3 NTU. The discrepancy between the two turbidimeters (on-line and benchtop) of 7.7 NTU and 6.3 NTU is acceptable and within limits. Communications problems between the on-site computer monitor and the on-line filter train influent turbidimeter between March 24 and March 28 resulted manual recording of on-line turbidity data every 30 minutes between March 24 and March 28. The influent turbidimeter (LMI Model GLI 8220) sensor failed on March 31 and a replacement turbidimeter (LMI Model GLI 8320) was installed on April 2. The Hach 2100P benchtop was used to record influent turbidity every 30 minutes between these dates.

The readout from the GLI Model 95T/8320 on-line effluent turbidity averaged 0.4 NTU during the period; the average from the Hach 2100P benchtop turbidimeter was 0.4 NTU. The effluent turbidity readings were checked daily, and the readings were within acceptable limits. Due to the recording

limitations of the on-line and the bench-top turbidimeter, the RPD is not within the expected 30% for those reading beneath 0.2 and above 50 NTU. Maximum readings are suspect due to this limitation (i.e., on-line reading at 20:33 on 4/26 was 74.72 NTU, the bench-top reading recorded at 20:33 on 4/26 was 91.10 NTU). This limitation was also evident in low level readings (i.e. on-line reading at 15:34 on 3/27 was 0.06 NTU, the average of 3 bench-top readings for 15:34 on 3/27 was 0.13 NTU). The average of all on-line and bench-top turbidity values recorded during the verification testing period are equal (0.4 NTU).

To assure ongoing calibration of the on-line turbidimeters, their sensor cell was cleaned and recalibrated each time turbidimeter flow rates were verified.

The influent water particle counter flow rate averaged 101 mL/minute. To determine the flow rate of the on-line influent water particle counter the flow rate was measured using a graduated cylinder and stopwatch. The maximum flow rate measured was 104 mL/minute, the minimum was 99 mL/minute. The target flow rate specified by the manufacturer is 100 mL/minute. Efforts were made to keep the flow rate between 95 mL/minute to 105 mL/minute and the flow was adjusted whenever those boundaries were crossed. The effluent water particle counter flow rate averaged 101 mL/minute. The flow was measured using a graduated cylinder and stopwatch.

The temperature was recorded daily with a NIST-traceable Miller Weber Thermometer, Model P63C.

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

During each day chemical feed pump flow and stroke settings were repeatedly verified and documented in the logbook. Flow rates were verified volumetrically with a graduated cylinder and stopwatch. A 100 mL graduated cylinder was used for the pump injecting a polymer (C-1592) at a rate of 1.5 to 3.2 mL/minute. A 1,000 mL graduated cylinder was used for the pump injecting coagulants (Ferric Chloride/AQM100) at a rate of 8.3 to 68.3 mL/minute.

4.5.3 Bi-Weekly QA/QC Verification Results

Digital flow meter readings were verified by bucket and stopwatch using a measured container on April 4, 2000. Flows were measured at 3.66 and 2.76 gpm respectively for the coagulation and filtration system. Comparative flows displayed by the digital flow meters were 3.81 and 2.89 gpm. This represents a factor of error of -0.15 gpm for the coagulation, and -0.13 gpm for the filtration respectively for each flow meter. This was within acceptable limits.

Flow rate rotometer readings were verified (bucket and stopwatch) using a measured container on March 18, 2000. Flows were measured at 5.80 and 4.47 gpm respectively for the coagulation and filtration system. Comparative flows displayed by the rotometer were 5.75 and 4.75 gpm. This

represents a factor of error of -0.05 gpm (0.9% for coagulation) and +0.28 gpm (6% for filtration) respectively for each rotometer. These error factors are within acceptable limits.

The test period only required one scheduled verification of the on-line flow meters. The on-line flow meters were verified (bucket and stopwatch), using a measured container on March 18, 2000. The rotometer flow was measured at 4.75 gpm. The bucket/stopwatch was measured three times at 4.47 gpm. This represents an error of 6%, or 0.28 gpm, which was within an acceptable range.

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

The tubing and all water lines used on the treatment system were inspected before verification testing began (March 18, 2000). The tubing and lines were good condition and replacements were not necessary.

Particle counters used on site were Met One PCX models. The particle counters were calibrated by Pacific Scientific Instruments using polystyrene latex spheres traceable to NIST standards. Particle counters used on site had factory calibration certificates from Pacific Scientific (dated: August 24, 1999, and March 3, 2000).

Calibration was verified on site with NIST mono-sized polymer microspheres on March 31, 2000 as described in 3.9.2.4 above. The following figures show the distribution as counted by the MetOne particle counter during the verification of calibration using NIST-traceable microspheres. Approximately 2,000 particles per milliliter of microspheres were added each time.

Figure 4-11 shows the particle counts during the influent 3 µm verification. The Figure shows the addition of the added particles as would be expected.

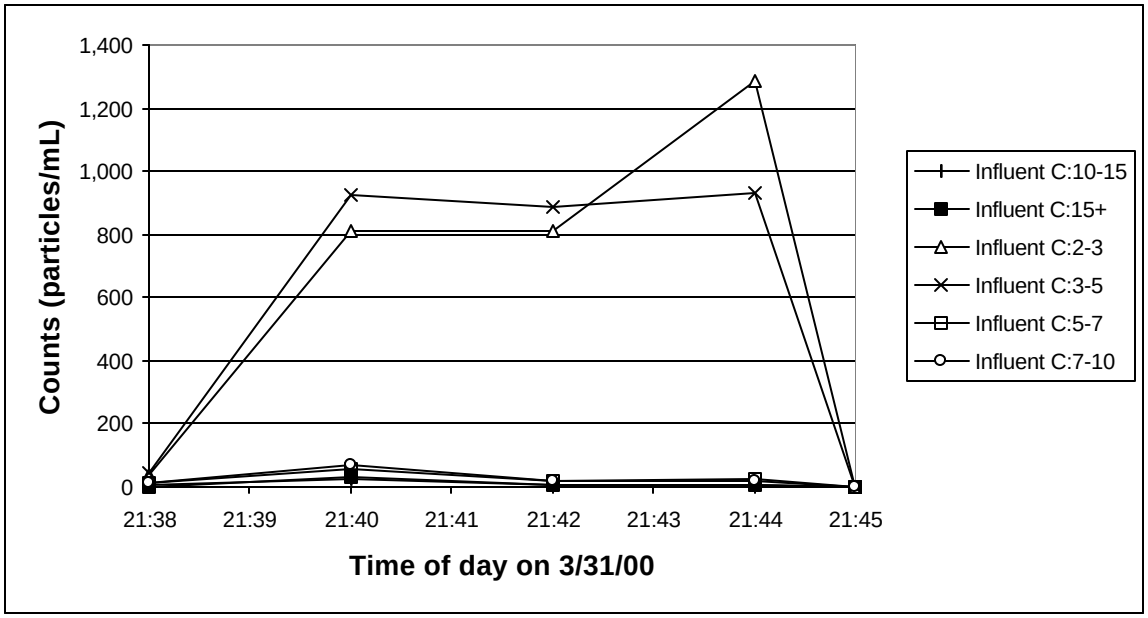

Figure 4-11. Verification of 3 µm Influent Particles

Figure 4-12 shows the particle counts during the influent 10 µm verification. The Figure shows the addition of the added particles as would be expected.

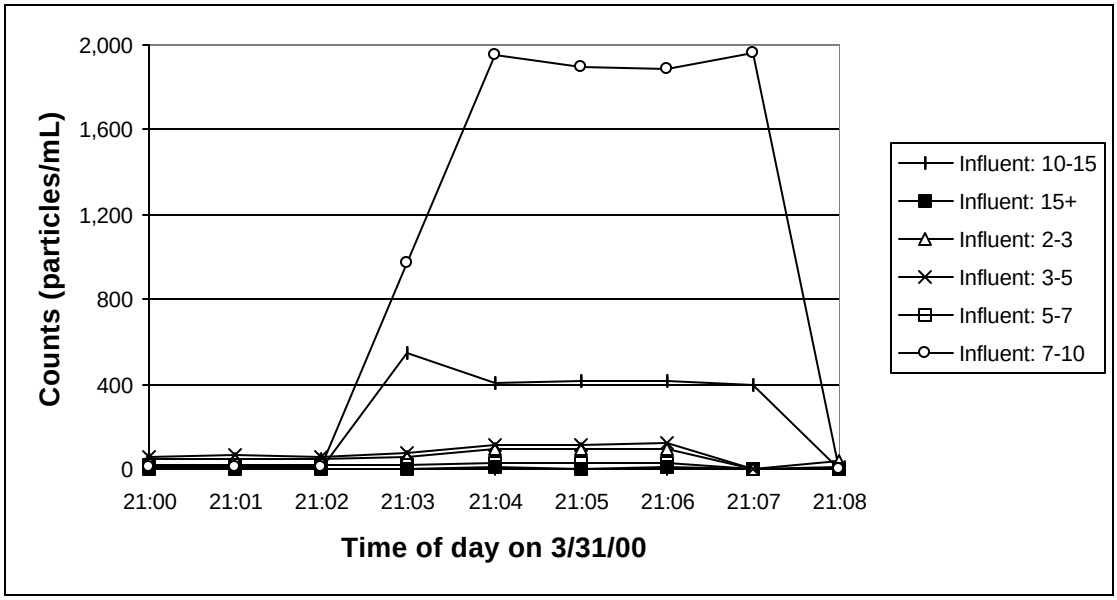

Figure 4-12. Verification of 10 µm Influent Particles

Figure 4-13 shows the particle counts during the influent 15 µm verification. The Figure shows the addition of the added particles as would be expected.

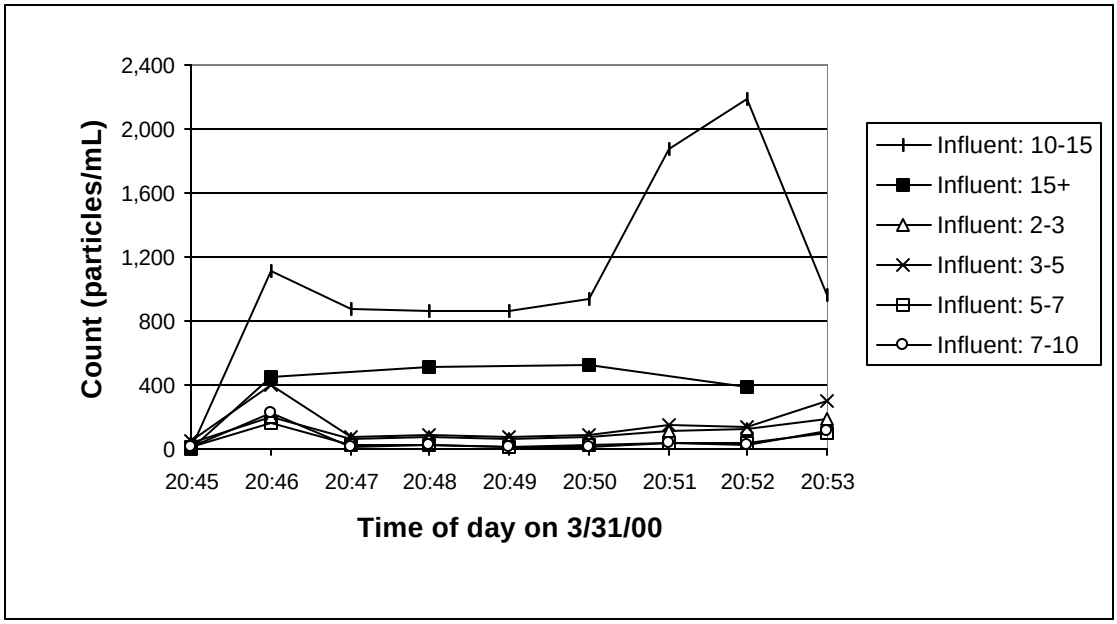

Figure 4-13. Verification of 15 µm Influent Particles

Figure 4-14 shows the particle counts during the influent "cocktail" mix of 3, 10 and 15 µm verification. The Figure shows the addition of the added particles as expected.

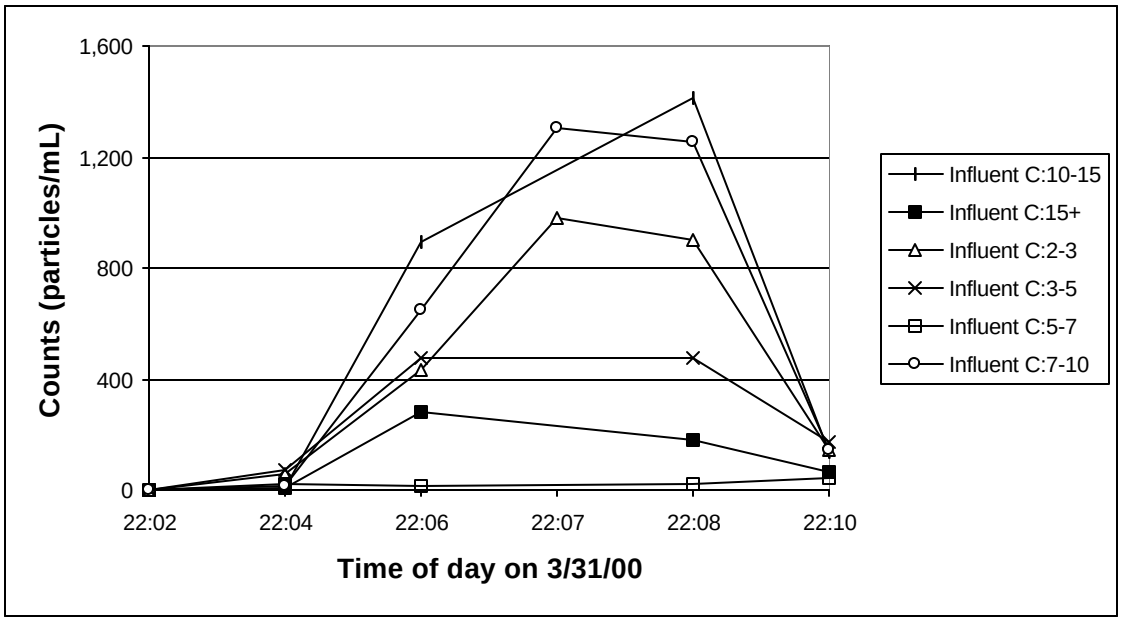

Figure 4-14. Verification of Mix of 3, 10 & 15 µm Influent Particles

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

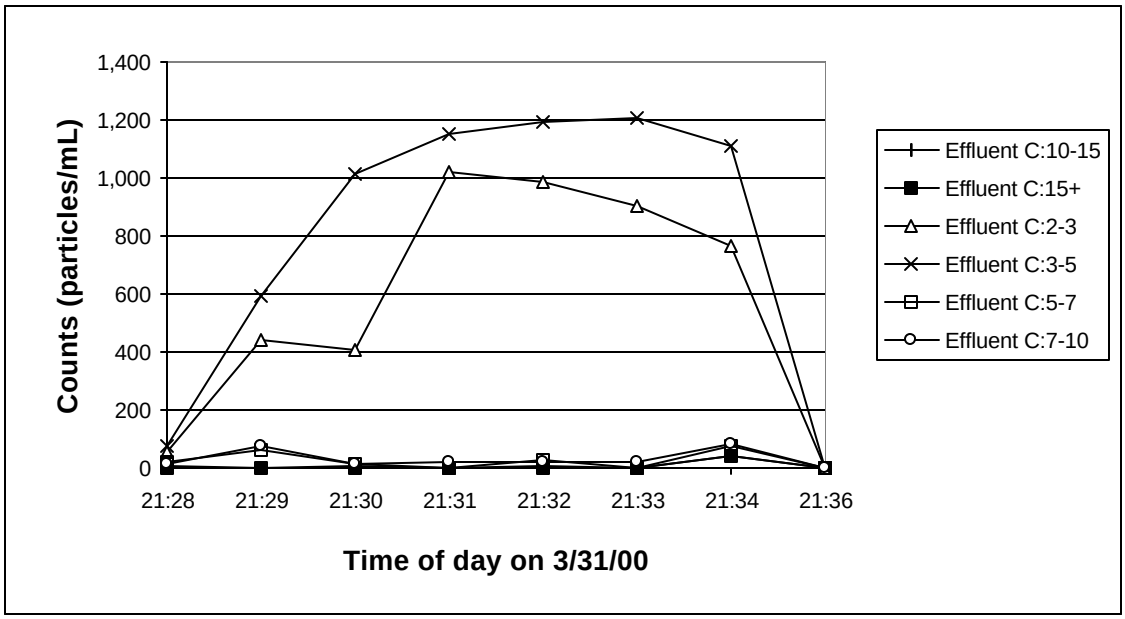

Figure 4-15. Verification of 3 µm Effluent Particles

Figure 4-16 illustrates the particle counts during the 10 µm effluent verification. The Figure shows the addition of the added particles in the 10 µm size range as expected.

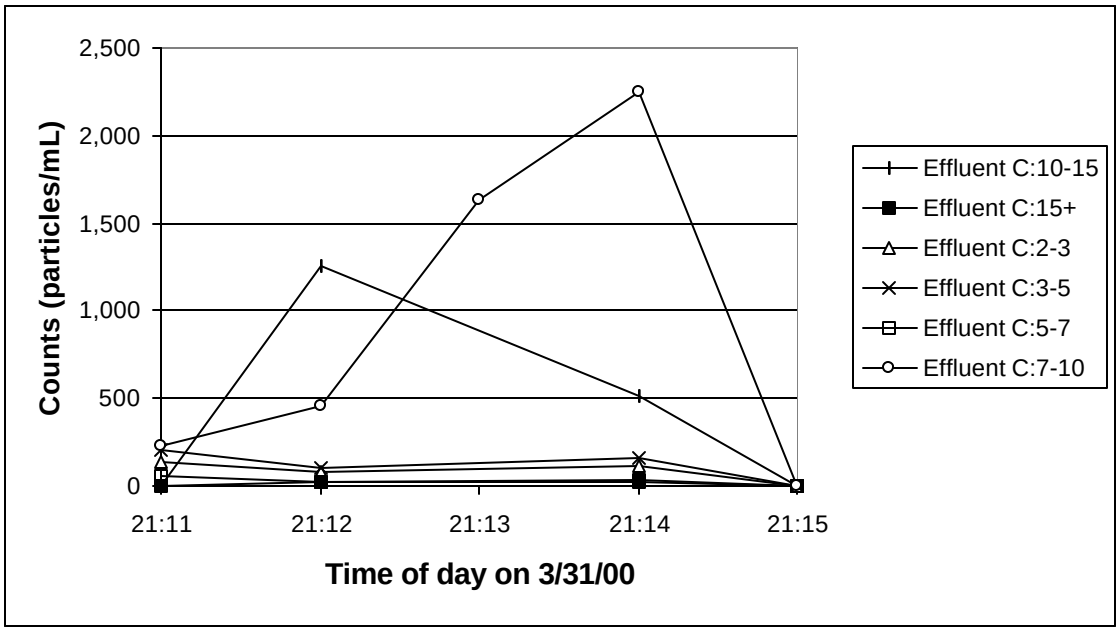

Figure 4-16. Verification of 10 µm Effluent Particles

Figure 4-17 illustrates the particle counts during the 15 µm effluent verification. The Figure shows the addition of the added particles in the 15 µm size range as expected.

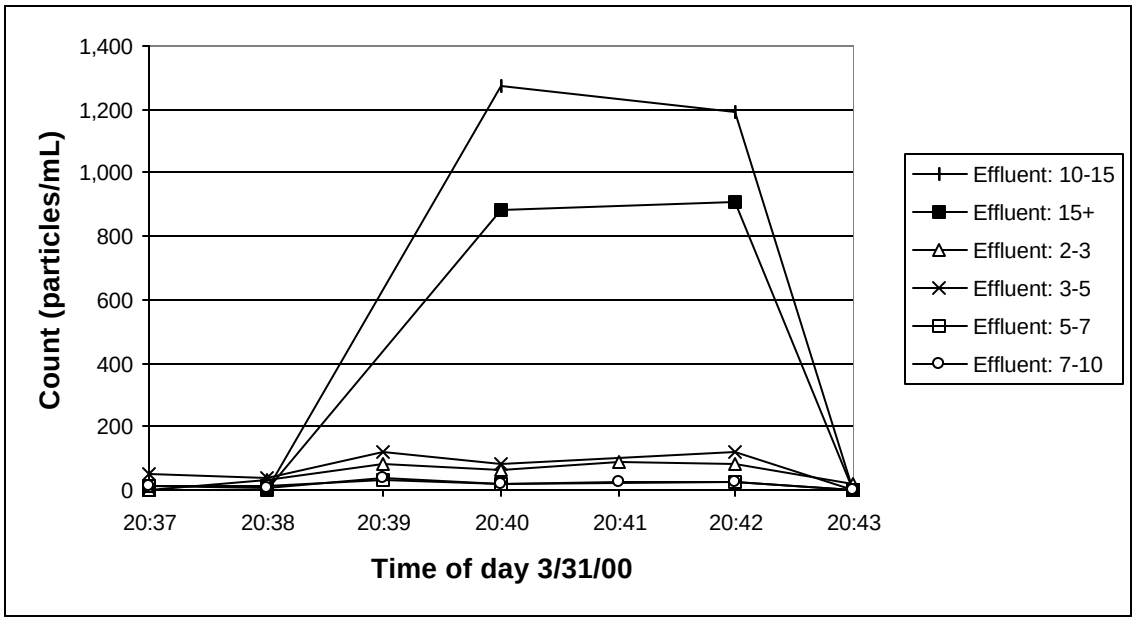

Figure 4-17. Verification of 15 µm Effluent Particles

Figure 4-18 illustrates the particle counts during the "cocktail" mix of 3, 10, and 15 µm effluent verification. The Figure shows the addition of the added particles in the 3, 10, and 15 µm size range as expected.

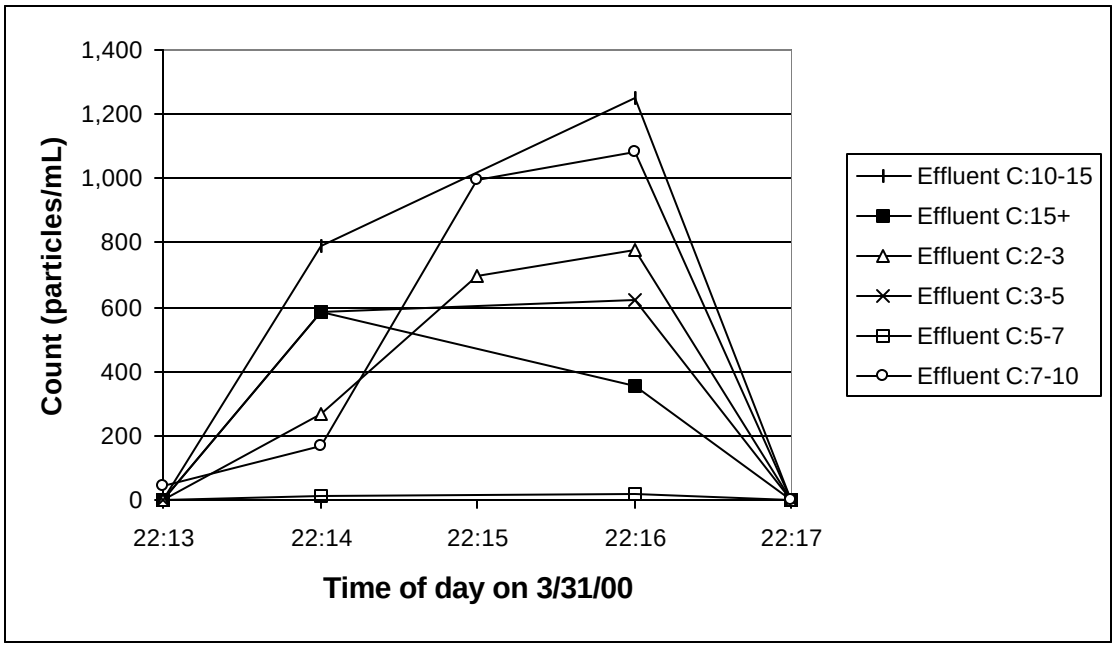

Figure 4-18. Verification of 3, 10 & 15 µm Effluent Particles

Particles that were added included:

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.

Pressure gauges were verified on March 18 and 19, 2000 by comparing the pressure shown on the gauge with the pressure shown on a NIST-traceable pressure gauge (Identification Number 9286-11). The NIST-traceable pressure gauge verified the pressure gauges on March 18 and 19. Tank B at inlet 44 pounds per square inch gauge (psig), NIST at 45 psig, outlet Tank B inlet 22 psig, NIST 22. This represents a factor of error of 2% (inlet) and 0% (outlet) respectively for each gauge. Tank A gauges were verified on the inlet 44 psig, NIST 44 psig, outlet 27 psig, NIST 27 psig. This represents a factor of error of 0% (inlet) and 0% (outlet) respectively for each gauge. These error factors are within acceptable limits.

COA performed calibration procedures on the benchtop, Hach 2100P turbidimeter on March 17, 2000. The instrument was calibrated to the manufacturer's recommended standards of 20, 100 and 800 NTU with fresh Formazin suspensions. The manufacturer explains that since the response signal is linear from 0-20 NTU efforts to standardize to lower levels are fruitless and may instead throw the readings off. Calibration standards are further required to be at least 65 NTU apart. In addition,

weighting the curve to the range of interest (in this case at levels less than 5 NTU) also provides the opportunity for increasing error. The manufacturer's recommended settings were also observed in subsequent calibrations.

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

Fixed Gelex secondary standards were calibrated to the instrument following manufacturers instructions following the instrument calibration. This is done each time the instrument is calibrated with Formazin suspension thereby standardizing the Gelex cells to that instrument for that period. When the instrument is recalibrated, the Gelex cells are also. Additional secondary standards of 0.1, 0.5, 1 and 3 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 and 3 NTU were relatively stable, the reference of 0.1 NTU was somewhat ambiguous as it is at or near the limit of detection for this instrument.

Turbidity samples were collected from a sample tap at a slow steady stream and along the side of a triple rinsed dedicated beaker to avoid air entrapment. The sample was poured from the beaker into a double rinsed clean sample vial. All glassware for turbidity measurements was kept clean and handled with lint free laboratory tissue. The sample cells were further wiped with velvet, silicon oilcloth.

4.5.4 Analytical Laboratory QA/QC

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

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.

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

Chapter 5
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