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Environmental Technology Verification Report

Removal of Arsenic in Drinking Water

ORCA Water Technologies KemLoop 1000 Coagulation and Filtration Water Treatment 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 MEDIA FILTRATION USED IN DRINKING WATER TREATMENT SYSTEMS**
APPLICATION:	**REMOVAL OF ARSENIC IN DRINKING WATER**
TECHNOLOGY NAME:	**KEMLOOP 1000 COAGUALTION AND FILTRATION WATER TREATMENT SYSTEM**
COMPANY:	**ORCA WATER TECHNOLOGIES**
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The U.S. Environmental Protection Agency (EPA) supports 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 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, stakeholder groups (consisting 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 Systems (DWS) Center, one of six technology areas under the ETV Program. The DWS Center recently evaluated the performance of a coagulation and media filtration system for the removal of arsenic from drinking water. This verification statement provides a summary of the test results for the ORCA Technologies (ORCA) KemLoop 1000 Coagulation and Filtration Water Treatment System (KemLoop). The NSF Drinking Water Treatment Systems Laboratory (DWTS) performed the verification testing. The verification report contains a comprehensive description of the complete verification test.

The accompanying notice is an integral part of this verification statement.

ABSTRACT

Verification testing of the ORCA Water Technologies KemLoop 1000 Coagulation and Filtration Water Treatment System for arsenic removal was conducted at the St. Louis Center located in Washtenaw County, Michigan from March 23 through April 6, 2005. The source water was groundwater from two supply wells, and the raw water for the verification test was withdrawn from the pressure tank at the site. Verification testing was conducted at the operating conditions specified by the manufacturer. The raw water, with a pH in the range of 7.0 to 7.6, was treated with chlorine bleach to oxidize arsenic (III) to arsenic (V), as well as iron to coagulate the arsenic. When operated under the manufacturer's specified conditions at this site, at an average flow rate of 9.9 gallons per minute (gpm), the KemLoop System reduced the total arsenic concentration from an average of 22 micrograms per liter (µg/L) in the feed water (raw water after chemical addition) to 3 µg/L in the filtrate (treated) water.

TECHNOLOGY DESCRIPTION

The following technology description was provided by the manufacturer and has not been verified.

The ORCA process is based on chemical addition with mixing in a proprietary mixing loop to optimize coagulation, and granular media filtration with no intermediate solids separation process. The KemLoop System includes pretreatment with sodium hypochlorite to oxidize any arsenic (III) to arsenic (V), and iron present in the water supply. Ferric chloride is added to augment any natural occurring iron and optimize the iron dose. The chemically treated water (feed water) enters the mixing loop where coagulation of arsenic and iron occurs. The water exits the mixing loop and is applied directly to one of the two granular media filter modules. The water enters the top of the operating filter and flows through the granular media filter, exiting at the bottom of the module. The granular media filter removes the precipitate, including arsenic, iron, and any other precipitated constituents. The two-filter module system operates with the filters in parallel, one filter module is in active operation and one unit is in standby mode. When backwash of a filter module is required, the standby filter is brought online and the backwash cycle for the "dirty' filter module is initiated. Once the backwash cycle is complete, the clean filter module becomes the standby unit.

The KemLoop System is fully automated and programmed to control all aspects of the filter operation. The control system automatically initiates backwash cycles based on four criteria: differential pressure across the media filter, treated water turbidity compared to raw water turbidity, time, and volume, as set by the operator. The backwash frequency is dependent on the water quality conditions and the amount of solids generated in the coagulation process. The control system is a programmable logic control and personal computer (PLC/PC) based controller with data logging, trend display graphs, and a remote monitoring modem connection for off-site technical support. All the information is available to the on-site operator and to remote users

VERIFICATION TESTING DESCRIPTION

Test Site

The verification test site was the St. Louis Center, a residential community for people with developmental disabilities, located in Washtenaw County Michigan. The source water was groundwater from two wells located at this site, which pumped water to a common pressure tank that served as the raw water supply to the KemLoop System. Water quality data from historical information and the characterization test showed the wells had similar water quality. Total arsenic in the combined well water ranged from 14 to 32 ug/L and total iron ranged from 0.39 to 1.6 milligrams per liter (mg/L). The pH was in the 7.4 to 7.6 range with alkalinity of 250 to 260 mg/L as $CaCO_3$. Raw water turbidity was found to be <1 nephelometric turbidity unit (NTU) in 2004 and 1.2 NTU in the 2005 characterization test.

Methods and Procedures

Operations, sampling, and analyses were performed in accordance with the Product Specific Test Plan (PSTP) developed and approved for this verification test. The PSTP included a Quality Assurance Project Plan (QAPP) designed to assure the quality of the data collected and to provide an accurate evaluation of the treatment system under the field conditions. Testing included characterization of the raw water, an arsenic loss test (no chemical fed to the system), and a 14-day verification test.

The verification test was performed from March 23, 2004 through April 6, 2005. The KemLoop System was operated continuously for the 14-day verification test, independent of the well operations, by using water supplied from the pressurized supply tank. Flow rate(s), production volume, water temperature, and system pressure(s) were monitored and recorded daily. Raw, feed (after chlorine and iron addition), and filtrate (treated) water samples were analyzed on-site for pH, temperature, turbidity, free and total residual chlorine, color, and dissolved oxygen by the field operator. Grab samples were collected and delivered to the NSF Drinking Water Laboratory to be analyzed for alkalinity, calcium, magnesium, iron, manganese, sulfate, chloride, total organic carbon (TOC), total suspended solids (TSS), and fluoride. Samples for total arsenic were collected daily, plus 14 samples were collected during a 48-hour intensive survey. In addition to the 25 sets of samples for total arsenic, a total of four sets of arsenic samples were speciated during the test to determine the soluble arsenic concentration and the concentrations of arsenic (III) and the arsenic (V) present in the soluble fraction. Samples of backwash water were collected and analyzed to characterize the backwash wastewater.

Complete descriptions of the verification testing results and quality assurance/quality control (QA/QC) procedures are included in the verification report.

VERIFICATION OF PERFORMANCE

System Operation

ORCA performed the system startup and shakedown testing, which included optimization of the chemical feed rates, and determination of backwash frequency. The verification test was conducted under the manufacturer’s specified operating conditions. Chemical feeds were established to feed 1.0 mg/L of total chlorine. The ferric chloride feed rate was set to deliver 1.5 to 2.5 mg/L (as Fe) of iron to augment the naturally occurring iron of 0.5 mg/L. The flow rate for filtrate was set at 10 gpm to give a targeted surface-loading rate of 2940 gallons per day per square foot (gfd). The backwash system was set to backwash once per day or if the pressure differential across the filter exceeded 8 pounds per square inch (psi) or if turbidity of the filtrate exceeded the raw water for ten minutes. The backwash cycle used treated water, which was pumped at 50 gpm through the filter in an up flow mode to flush out the accumulated solids.

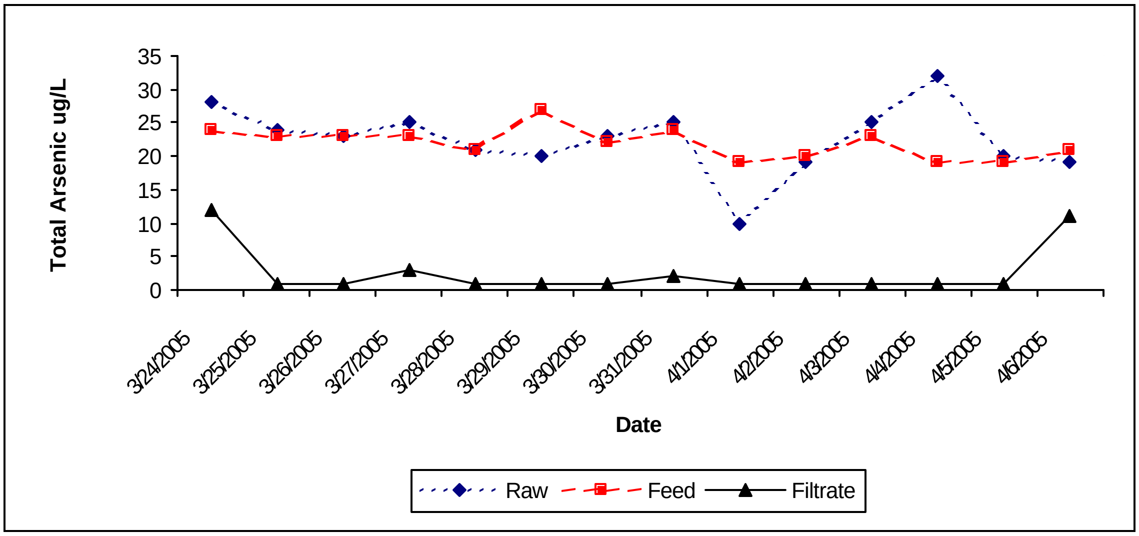
System pressure was monitored at three locations, raw water (from pressure tank), feed water (inlet to the filters), and filtrate (exit from the filters). There was very little change in head loss through the filter over each 24-hour operating period. The maximum pressure differential observed was 5.0 psi, with the filter inlet side averaging 5.8 psi and the filter outlet side averaging 2.0 psi. The automatic backwash cycle was not triggered due to pressure differential (head loss) or an increase in filtrate turbidity at any time during the verification test.

The filtrate flow rate remained steady for most days during the test yielding an average flow rate of 9.9 gpm over the 14 days. The total filtrate volume produced each day was also consistent, except for April 2 through 4 when volumes and flow rates were somewhat lower. It appears the pressure on the raw water supply tank at the St. Louis Center was periodically dropping below 40 psi (the setting on the pressure regulator). This caused periodic lower flow rates and lower volumes of filtrate to be produced over the

24-hour period. The average hydraulic loading through the filter was 2,890 gallons per square foot, based on the 24-hour filter run time between backwashes and the average daily filtrate production of 14,630 gallons.

Water Quality Results

The results of total arsenic analyses are shown in Figure VS-1. The raw water total arsenic averaged 23 µg/L with most of the arsenic as arsenic (III). Following chemical treatment, the feed water total arsenic concentration averaged 22 µg/L. While the soluble arsenic and arsenic speciation data showed some variability, the data indicate that pretreatment completely converted the raw water arsenic (III) to the arsenic (V). The filtrate water total arsenic concentration averaged 3 µg/L with the concentration being below the detection limit (1 µg/L) on six of 14 days. The filtrate exceeded 10 µg/L on the first and last day of the verification test. On the first day the total arsenic concentration was 12 µg/L with dissolved arsenic of <1 µg/L. It appears the high arsenic concentration was caused by an overdose of ferric chloride resulting in solids passing through the filter. After adjusting the iron feed rate, the turbidity in the filtrate dropped from 1.7 NTU to 0.10 NTU and the arsenic on Day 2 was 1 µg/L. The cause of the higher filtrate arsenic concentration (11 µg/L) on the last day is not known, as the iron feed rate, and iron concentration and turbidity level in the filtrate were low. The data collected during the 48-hour intensive survey were consistent with the data collected each day during the verification test. There was no indication of any transient or short time changes in the arsenic concentration or in any other monitored parameters.



Note: 48-hour intensive survey began on 3/30/05.

Figure VS-1. Total Arsenic Results

The raw water and filtrate alkalinity averaged 260 mg/L as $CaCO_3$, indicating that the chemical addition and filtration process had no impact on the alkalinity concentration. The pH of the raw water was steady in the range of 7.20 to 7.48 with a mean value of 7.30. The filtrate pH ranged from 7.22 to 7.46 with a median value of 7.30 showing that the addition of chlorine and ferric chloride had very little impact on pH. The average raw water iron concentration was 0.47 mg/L, and the feed water averaged 1.9 mg/L of iron after the addition of ferric chloride. The filtrate water iron concentration was 0.03 mg/L or less on ten out of fourteen days. On March 25 and 31, the iron concentration was 0.08 and 0.07 mg/L, respectively. The first day of the test, when the iron concentration in the feed was measured at a maximum concentration of 4.5 mg/L (chemical feed pump subsequently adjusted downward), the filtrate concentration was 1.7 mg/L. On March 27 the iron was 0.31 mg/L. These data show that the KemLoop System can produce a filtrate with <0.30 mg/L of iron. The KemLoop System lowered the turbidity levels with the filtrate turbidity averaging 0.30 NTU based on the bench-top turbidimeter and 0.20 NTU based on the inline turbidimeter. The bench top turbidity meter always gave higher turbidity readings compared to the inline units. The raw water turbidity based on the bench top unit averaged 2.4 NTU, whereas the average turbidity based on the inline unit was 0.60 NTU. It is believed that the bench top unit data may have been biased high due to temperature and fogging issues that can be problematic when collecting cold samples and transferring them to the bench top vials. Based on the bench-top meter measurements, the filtrate was below 0.5 NTU in 93% of samples, had no values between 0.5 and 1 NTU, and 7% of the readings (1 reading) were between 1 and 2 NTU. There were no turbidity levels above 2 NTU. The inline turbidimeter gave the same distribution of turbidity readings in the filtrate. During the 48-hour intensive survey the turbidity levels in the filtrate did tend to increase slightly near the end of each filter run, and then were lower again when the standby filter was brought on line. All inline turbidity measurements for the filtrate during the 48-hour intensive survey were below 0.2 NTU, even at the end of a 24-hour run.

The backwash water was sampled on four occasions and found to have an average total arsenic concentration of 760 µg/L, an average iron concentration of 120 mg/L, and an average TSS concentration of 250 mg/L. The backwash cycle occurred once every 24 hours and yielded an average of 220 gallons per day of backwash water. This represented 1.5% of the average daily treated water production. The backwash water was enriched in arsenic, iron, and TSS, as would be expected, given the removal of arsenic and iron as measured in the filtrate. Local disposal requirements determine whether this water is acceptable for discharge to a sanitary sewer system, some other discharge location, or if it will require further treatment prior to discharge. The backwash solids are not considered a hazardous waste based on Toxicity Characteristic Leaching Procedure (TCLP) arsenic results of 0.32 mg/L, which is below the 5.0 mg/L limit under the Resource Conservation and Recovery Act (RCRA).

Operation and Maintenance Results

The KemLoop System was found to be easy to operate and required little time for daily maintenance. The field staff was on-site for two to three hours per day. Most of the time on-site was spent performing field activities, including daily chemical analyses, flow checks, calibrations, etc. In a normal operation, the inline pH meters and turbidimeters would be used for system checks. The KemLoop System has a PLC/PC that records data for all key operating parameters, including flow data, pressure information, backwash cycles, etc. It is estimated that the time to check the system on-site would be minimal, possibly less than 30 minutes, except when chemical feedstocks needed to be replenished or inline instruments calibrated. The PLC can be setup for remote access; so main system parameters can be monitored without a site visit.

The ORCA operation and maintenance (O&M) manual provides a detailed description of the system, appropriate safety precautions, and detailed descriptions of operating procedures, capability and operation of the computer control system, and specific instructions for utility operators. The maintenance section of the manual includes some descriptions of required maintenance, but refers the reader to the individual equipment literature supplied by the various pump and instrument manufacturers. These manuals were provided in a notebook. The draft O&M manual did not contain specific checklists for routine site visits. The review of the O&M manual shows that the manual is well organized and easy to read.

Consumables and Membrane Chemical Cleaning

The KemLoop System used a 6% sodium hypochlorite (bleach) solution, made on site from a 12% stock solution. A total of 28 liters of 6% bleach solution was used to treat 204,870 gallons of raw water. This equates to an average concentration added to the raw water of 2.2 mg/L. The average total residual chlorine in the feed water after chlorine addition was 1.0 mg/L, indicating a chlorine demand in the water of 1.2 mg/L. Iron was added to the raw water using a 4.8% as iron (Fe) ferric chloride solution. A total of

23.9 L (6.3 gallons) was used to treat 204,870 gallons of raw water, yielding an average concentration of iron added to the water of 1.5 mg/L. The feed water concentration averaged 1.9 mg/L and the raw water concentration averaged 0.47 mg/L, indicating 1.43 mg/L of iron addition, which was close to the calculated 1.5 mg/L fed based on chemical use.

Electrical power consumption was estimated based on the raw water pump (not used at this site) and backwash pump horsepower. With miscellaneous electrical use by chemical feed pumps and the PLC/PC, power consumption is estimated to be 0.5 kilowatt-hr.

Quality Assurance/Quality Control

NSF provided technical and QA oversight of the verification testing as described in the verification report, including an audit of nearly 100% of the data. The NSF QA department conducted a technical systems audit during testing to ensure the testing was in compliance with the test plan and performed a QA review of the analytical data. A complete description of the QA/QC procedures is provided in the verification report.

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National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original Signed by
Robert Ferguson 10/5/05
Robert Ferguson Date
Vice President
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NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and NSF make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end-user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of corporate names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products. This report is not an NSF Certification of the specific product mentioned herein.

Availability of Supporting Documents

Copies of the *ETV Protocol for Equipment Verification Testing for Arsenic Removal* dated April 2002, the verification statement, and the verification report (NSF Report #04/10/EPADWCTR) are available from the following sources:
(NOTE: Appendices are not included in the verification report. Appendices are available from NSF upon request.)

1. ETV Drinking Water Systems Center Manager (order hard copy)
   NSF International
   P.O. Box 130140
   Ann Arbor, Michigan 48113-0140
2. NSF web site: http://www.nsf.org/etv (electronic copy)
3. EPA web site: http://www.epa.gov/etv (electronic copy)

September 2005

Environmental Technology Verification Report

Removal of Arsenic in Drinking Water

ORCA Water Technologies KemLoop 1000 Coagulation and Filtration Water Treatment System

Prepared for:

NSF International
Ann Arbor, Michigan 48105

Prepared by:

NSF International
And
Scherger Associates

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

Jeffrey Q. Adams, Project Officer
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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. R-82833301. This verification effort was supported by the Drinking Water Systems (DWS) Center, operating under the Environmental Technology Verification (ETV) Program. This document has been peer reviewed, reviewed by NSF and EPA, and recommended for public release.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

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Abbreviations and Acronyms

BOD	Biochemical Oxygen Demand
$CaCO_3$	Calcium Carbonate
CAWET	California Waste Extraction Test
°C	Degree Celsius
C.U.	Color Units
Center	St. Louis Center
°F	Degree Fahrenheit
DO	Dissolved Oxygen
DWS	Drinking Water Systems
DWTS	NSF International Drinking Water Treatment Systems Laboratory
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
$FeCl_3$	Ferric Chloride
ft^2	Square Feet or Square Foot
ft^3	Cubic Feet
FRP	Fiber-reinforced Polymer
FTO	Field Testing Organization
g	Gram
gfd	Gallons per Square Foot per Day
gpm	Gallon(s) Per Minute
gpd	Gallon(s) Per Day
hp	Horsepower
hr	Hour(s)
KemLoop	KemLoop 1000 Coagulation and Filtration Water Treatment System
L	Liter
LCS	Laboratory Control Sample
m	Meter
MCL	Maximum Contaminant Level (USEPA standard)
mL	Milliliter
mg	Milligram
mg/L	Milligram per Liter
ND	Not Detected or Non-Detect
NIST	National Institute of Standards and Technology
NRMRL	National Risk Management Research Laboratory
NSF	NSF International
NTU	Nephelometric Turbidity Unit(s)
O&M	Operation and Maintenance
ORCA	ORCA Water Technologies
PLC/PC	Programmable Logic Controller/Personal Computer
psi	Pounds per Square Inch
PSTP	Product Specific Test Plan
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act

RSD	Relative Standard Deviation
SMCL	Secondary Maximum Contaminant Level
S.U.	Standard Units
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
µg/L	Microgram(s) per Liter
VAC	Volts Alternating Current

Acknowledgements

The Field Testing Organization (FTO), NSF International (NSF) Drinking Water Treatment Systems Laboratory (DWTS) and its consultant, Scherger Associates, was responsible for all elements in the testing sequence, including collection of samples, calibration and check of instrumentation, data collection and analysis, data management, data interpretation, and the preparation of this report.

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The manufacturer of the equipment was:

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The NSF DWTS wishes to thank the following participants:

Mr. Bruce Bartley, Ms. Angela Beach, and Mr. Michael Blumenstein of the NSF Environmental Technology Verification (ETV) Drinking Water Systems (DWS) Center for their support, guidance, and program management.

The St. Louis Center staff, especially Mr. William Potter, for help during the initial site selection and water quality review process, and Mr. Randy Hoenes, who provided invaluable field support to ORCA and NSF by arranging all site installation requirements and providing mechanical and electrical utilities support for the test system throughout the installation, startup, and testing program.

ORCA Water Technologies for supplying the verification test unit and support services during the start-up period. Mr. John Crass coordinated building and shipping of the test unit. Ronald Tenny’s presence at the site to optimize the operation of the system and provide training to the NSF field operators is greatly appreciated.

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 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; with stakeholder groups consisting 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 responsive to the needs of stakeholders, conducting field demonstrations, 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.

The EPA has partnered with NSF International (NSF) under the ETV Drinking Water Systems (DWS) Center to verify the performance of small drinking water systems that serve small communities. A goal of verification testing is to enhance and facilitate the acceptance of small 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 meets this goal by working with manufacturers and NSF-qualified Field Testing Organizations (FTOs) to conduct verification testing under the approved protocols. It is important to note that verification of the equipment does not mean 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.

The DWS Center evaluated the performance of the ORCA Water Technologies (ORCA) KemLoop 1000 Coagulation and Filtration Water Treatment System (KemLoop System), which is a granular media filtration system used in drinking water treatment system applications for reduction of arsenic and dissolved iron in groundwater. This document provides the verification test results for the KemLoop System.

1.2 Testing Participants and Responsibilities

The ETV testing of the KemLoop System was a cooperative effort among the following participants:

NSF International

NSF International Drinking Water Treatment Systems Laboratory (DWTS) and its consultant, Scherger Associates
ORCA Water Technologies
The St. Louis Center
U.S. Environmental Protection Agency

The following is a brief description of all of the ETV participants and their roles and responsibilities.

1.2.1 NSF International

NSF is an independent, not-for-profit testing and certification organization dedicated to public health and safety and to 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 products bearing the NSF Name, Logo and/or Mark meet those standards. The EPA partnered with NSF to verify the performance of drinking water treatment systems through the EPA's ETV Program.

NSF provided technical oversight of the verification testing and conducted an audit of the field analytical and data gathering and recording procedures. NSF also provided review of the Product Specific Test Plan (PSTP) as well as this report.

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1.2.2 Field Testing Organization

The DWTS conducted the verification testing of the KemLoop System. The DWTS is an NSF-qualified FTO for the ETV DWS Center.

The FTO provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. The FTO was responsible for ensuring the testing location and feed water conditions were such that the verification testing could meet its stated objectives. The FTO and its consultant, Scherger Associates, prepared the PSTP; oversaw the pilot testing; managed, evaluated, interpreted, and reported on the data generated by the testing; and evaluated and reported on the performance of the technology. The FTO was responsible for completing the raw water characterization testing, monitoring the KemLoop System during the arsenic loss testing (24 hour test), and conducting the verification test over 14 calendar days.

DWTS employees conducted the on-site analyses and data recording during the test. The FTO's Project Manager and Project Director provided oversight of the daily tests.

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1.2.3 Manufacturer

The treatment system was the ORCA KemLoop 1000 Coagulation and Filtration Water Treatment System for the treatment of drinking water. The manufacturer was responsible for supplying a field-ready coagulation and filtration system equipped with all necessary components, including treatment equipment, instrumentation and controls, and an operation and maintenance (O&M) manual. The manufacturer was responsible for providing logistical and technical support, as needed, as well as technical assistance to the FTO during operation and monitoring of the equipment undergoing field verification testing.

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1.2.4 Analytical Laboratory

The NSF International Chemistry Laboratory in Ann Arbor, Michigan performed all water quality analyses.

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Backwash toxicity analyses were performed by:

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1.2.5 U.S. Environmental Protection Agency

The EPA, through its Office of Research and Development, has financially supported and collaborated with NSF under Cooperative Agreement No. R-82833301. This verification effort was supported by the DWS Center operating under the ETV Program. This document has been peer reviewed, reviewed by NSF and EPA, and recommended for public release.

1.3 Verification Testing Site

1.3.1 Site Background Information

The St. Louis Center (Center), located at 16195 Old US 12, Chelsea, Michigan, is a residential community for people with developmental disabilities. Founded by the Archdiocese of Detroit and operated by the Servants of Charity, the Center has been in continuous operation since it was first established as a boarding school in 1960. Sleeping quarters and additional facilities were completed in 1984 and 1988 to expand its ability to care for adults functioning at different levels.

The 180-acre site includes the main building with administrative offices, central kitchen and dining facilities, gymnasium, chapel, and residential facilities. Father Guanella Hall and St. Joseph Hall are freestanding residential buildings with complete kitchen and laundry facilities for the residents. In addition, there are separate facilities for guests and outdoor recreation activities. The Center is currently licensed for 73 residents.

Two groundwater production wells are installed at the Center to supply potable water. The wells, a pressurized water supply tank, boilers, and related equipment are housed in a separate building. The building has the necessary space and utilities to support the KemLoop System.

Both wells and a single pressurized water supply tank are used to deliver water to the Center. The water supply tank is a fixed wall tank with no bladder insert. When the water in the supply tank drops to a preset level, one well is activated to refill the tank. Once the tank is filled, the pump shuts off. When the water level drops again, the second pump turns on to refill the tank. This alternating cycle is the standard operating mode for the system. Therefore, the raw water taken from the supply tank for the verification test is a blend of the two wells. There are no chemicals added to the well water pumped to the supply tank or to the water delivered to the Center.

The average daily water use for the school is approximately 6,600 gallons per day (gpd) based on weekly meter readings. The average maximum water use based on the weekly readings is 12,000 gpd. Well #1 typically reaches a maximum pumping rate of approximately 145 gallons per minute (gpm), whereas Well #2 typically reaches a maximum pumping rate of approximately 125 gpm. Observation of the wells shows that Well #1 normally pumps for 4-5 minutes and Well #2 normally pumps for 5-6 minutes to refill the supply tank. The supply tank is replenished based on level control, and the time between pump activation depends on the demand for water. On average, a well pump is actively pumping (either #1 or #2) for approximately 5-6 minutes every 1-2 hours. Run time varies widely depending on demand, with greater demand in the morning and daytime, and less at night.

1.3.2 Source/Feed Water Quality

Tables 1-1 and 1-2 present raw water quality for samples taken from the individual wells and combined water from the supply tank. The St. Louis Center collected the historical data as part of a monitoring program from 1998-2003. NSF collected and analyzed samples in March and May 2004, when the site was evaluated as a potential test site. The water has total hardness of 240-350 milligrams per liter (mg/L) as calcium carbonate ($CaCO_3$), and the pH is normally about 7.6. Water quality data for total arsenic are available for the period between December 1998 and May 2004. These data show that total arsenic concentration varies between 14 and 48 micrograms per liter (µg/L). The predominate arsenic species is arsenic (III).

Table 1-1. Historical Raw Water Quality Data

Parameter	Units	Pressure Tank Water Supply Combined Wells 1 and 2						
		Dec. 1998	Nov. 2000	Feb. 2001	June 2001	June 2002	July 2003	Jan. 2003
Total Arsenic	µg/L	15	32	26	23	---	---	14
Hardness	mg/L as $CaCO_3$	---	---	---	---	352	328	---
Sodium	mg/L	---	---	---	---	12	15	---
Chloride	mg/L	---	---	---	---	33	23	---
Sulfate	mg/L	---	---	---	---	21	24	---
Fluoride	mg/L	---	---	---	---	0.7	0.8	---
Iron	mg/L	---	---	---	---	0.5	0.4	---
Nitrite	mg/L	---	---	---	---	<0.05	<0.05	---
Nitrate	mg/L	---	---	---	---	<0.4	<0.4	---
Selenium	µg/L	<5	1	---	---	---	---	<1

"---" = Not required or scheduled for analysis.

Table 1-2. Raw Water Quality Data – 2004

Parameter	**Units**	**Well #1**		**Well #2**		**Pressure Tank Water Supply – Combined Wells 1 and 2**	
		March 2004	May 2004	March 2004	May 2004	March 2004	May 2004
Total As	μg/L	25	30	48	34	24	31
Soluble As	μg/L	---	27	---	38	---	---
Arsenic (III)	μg/L	---	28	---	37	---	---
Arsenic (V) (calculated)	μg/L	---	<2	---	<2	---	---
pH	S.U.	7.56	---	7.66	---	7.64	---
Hardness	mg/L as $CaCO_3$	270	---	240	---	280	---
Alkalinity	mg/L as $CaCO_3$	260	---	260	---	260	---
Total Dissolved Solids (TDS)	mg/L	300	---	300	---	340	---
Chloride	mg/L	---	6.3	---	16	---	---
Sulfate	mg/L	21	29	10	8	21	---
Fluoride	mg/L	---	0.4	---	0.9	---	---
Iron	mg/L	0.36	1.6	2.8	2.8	0.50	1.6
Phosphate	mg/L	---	0.98	----	0.84	---	---
Manganese	μg/L	16	15	20	15	14	18
Molybdenum	μg/L	---	10	---	21	---	---
Selenium	μg/L	---	<4	---	<4	---	---
Vanadium	μg/L	---	<1	---	<1	---	---
Silica	mg/L	---	16.6	---	18.6	---	---
Total Suspended Solids (TSS)	mg/L	2	2	8	6	<2	---

“---” = Not required or scheduled for analysis.

1.3.3 Test Site Description

Structural

The entire water supply system, two wells, supply tank, controls, and piping were located inside a secure building. There was room in the building to add the needed piping to supply the test unit, and to store basic supplies and equipment needed by the FTO. The KemLoop System was housed in an insulated, 8 X 20 foot shipping container that had heaters to prevent freezing during the test. The containerized system was located immediately adjacent to the water supply building. The water supply from the pressurized main system storage tank was piped to the treatment unit. This test site provided the following advantages:

- Full electrical supply;
- Building to enclose the wells and pressure holding tank;
- Ease of accessibility; and

- All required utilities, including raw water supply, power, and drain locations for the discharge of the filtrate and backwash water to the on-site sewer system and wastewater treatment lagoon.

Handling of Filtrate and Residuals

All treated water (filtrate) was discharged to a sewer that discharges to the wastewater treatment lagoon. Backwash water was collected in a holding tank where solids settled to the bottom. The overflow from the backwash tank discharged at the same location as the treated water. The backwash water holding tank was discharged manually each day by the DWTS field personnel.

Discharge Permits

No special discharge permits were required for the discharge of the filtrate and backwash water from the test unit to the on-site wastewater treatment system.

Chapter 2
Equipment Capabilities and Description

2.1 Description of Equipment

The KemLoop System used during the verification was a standard, full-scale system supplied by ORCA for the treatment of groundwater. The KemLoop System is a self-contained, complete system that can connect to either a pressurized water supply (35-75 pounds per square inch [psi]) or to a non-pressurized supply source. If the source is not pressurized, a pump, supplied with the unit, can be used to pump the water through the treatment system. For this test, the filtrate was discharged to the Center's sewer system and ultimately entered the wastewater lagoon. In a normal installation, the treated water (filtrate) would be collected in a tank and pumped to the pressurized potable water distribution system. The KemLoop System used for the verification test was designed to treat flows at an average of 10 gpm with a maximum capacity of 20 gpm. Additional information on the equipment installation requirements and operation of the equipment is provided in the O&M Manual, presented in Appendix A.

The KemLoop System is fully automated and programmed to control all aspects of the filter operation. The control system automatically initiates backwash cycles based on four criteria: differential pressure across the media filter, treated water turbidity compared to raw water turbidity, time, and volume, as set by the operator. The backwash frequency is dependent on the water quality conditions and the amount of solids generated in the coagulation process. The control system is a programmable logic control and personal computer (PLC/PC) based controller with data logging, trend display graphs, and a remote monitoring modem connection for off-site technical support. The PLC/PC monitors and records data from the system operation. All the information is available to the on-site operator and to remote users.

2.2 Engineering and Scientific Concepts

Coagulation and precipitation of arsenic using iron as a coagulant is a well-known basic technology for arsenic removal. Various forms of iron (e.g., ferric chloride) are added to water, and the pH is adjusted to an optimal level to form iron floc. As part of the coagulation process, arsenic is co-precipitated with the iron. The mixing process helps to build the floc into larger particles that can be removed by various techniques (settling, filtration, etc.). Some treatment systems use flocculation tanks and clarifiers with or without post filtration to remove the precipitated iron and arsenic particulate. Other process trains use only chemical coagulation, mixing, and media filtration. The KemLoop System is based on chemical coagulation, a proprietary mixing loop to optimize the coagulation process, and granular media filtration with no intermediate solids separation process.

It is widely accepted in the scientific community that the precipitation of arsenic (V) with iron or similar coagulants is readily achieved and that settling or filtration can remove the precipitate. Arsenic (III), however, is not removed as easily to the low concentrations required to meet drinking water regulations. Water that contains arsenic (III) is often pre-treated with an oxidization step to convert the arsenic (III) to arsenic (V). Water quality data collected in 2004 show that arsenic (III) is the dominant form of arsenic in the groundwater at the Center, even after storage in the pressurized supply tank. The KemLoop System uses chlorine (fed as sodium hypochlorite) as a pretreatment step to convert arsenic (III) to arsenic (V).

2.3 Description of Treatment Train and Unit Processes

The KemLoop System includes pretreatment with liquid sodium hypochlorite to oxidize any arsenic (III) to arsenic (V), and to oxidize the iron present in the water supply. The sodium hypochlorite is pumped into the inlet line by a chemical metering pump. Total residual chlorine is targeted to a range of 0.5-1.0 mg/L. Ferric chloride ($FeCl_3$) is added to augment the naturally occurring iron in the groundwater and optimize the iron dose. The typical target range is 1.5-3.0 mg/L as iron. The actual dose is optimized during start-up/shakedown testing. The system can also include addition of sulfuric acid, if needed to adjust the pH to an optimal level, as determined during shakedown testing at the site; pH adjustment was not required for the test site raw water. This chemically treated water (feed water) enters the "mixing loop," a unique feature of the KemLoop System. This mixing loop consists of approximately 200 feet of 3 inch PVC pipe and includes a recirculation line.

The chemically treated water flows through the mixing loop, where precipitation and coagulation of the iron and arsenic occur without the need for a separate mixing tank. The coagulated water exits the mixing loop and is applied directly to one of the two granular media filter modules. The water enters the top of the operating filter and flows through the granular media filter, exiting at the bottom of the module. The granular media filter removes the precipitate, including arsenic, iron, and any other precipitated constituents. The two-filter module system operates with the filters in parallel; one filter module is in active operation and one unit is in standby mode. When backwash of a filter module is required, the standby filter is brought online and the backwash cycle for the "dirty" filter module is initiated. Once the backwash cycle is complete, the clean filter module becomes the standby unit.

The backwash cycle is triggered by an increase in differential pressure across the operating filter module or by an increase in turbidity in the filtered water. The backwash cycle can also be activated by time of operation or volume of water treated, as set by the operator. The differential pressure and turbidity levels that trigger a backwash cycle are set during the shakedown and start-up test period based on local requirements and operating characteristics at the site. The time cycle, based on experience at a site, is typically set to ensure that at a filter module is backwashed at least once every two days. The backwash cycle uses raw water or filtrate for the backwash water source. Backwash is accomplished by pumping raw or filtrate water at a rate of 75-100 gpm (15-20 gpm per square foot of filter surface area) through the filter module in an up flow mode, expanding the granular media bed, and flushing the solids from the media. Approximately 500 gallons of water are used for each five-minute backwash cycle. Backwash water is normally collected in a tank to allow sampling of the water and for treatment, if required. The water is then discharged to the on-site wastewater treatment system, local sanitary sewer system, or other approved discharge location.

For the ETV test, the raw water was obtained from the pressure tank at the site (both wells feed the tank on an alternating cycle basis), which normally operates at 55-90 psi. A pressure regulator, set at 40 psi, and a flow control valve were installed downstream of a double backflow preventer to control the flow rate of raw water to the system.

Chemical feed ports located in the inlet piping of the KemLoop System provide for injection of sodium hypochlorite, ferric chloride or other iron source, and acid, if needed. Acid for pH adjustment was not needed for the Center water. Chemical metering pumps were used to inject sodium hypochlorite and ferric chloride into the water. The liquid sodium hypochlorite was stored in a 5-gallon plastic container, and the ferric chloride was stored in a 15-gallon plastic container.

Sampling ports were installed before any chemical addition (raw water) and after the chemical addition points and after mixing occurred, near the inlet to the filter module (feed water). These sampling ports were valves placed in the line for collection of the samples of the raw water and the feed water to the filter module. A third sampling valve was installed on the treated water (filtrate) line downstream of the filters. This sampling valve was used to collect filtrate water samples.

The KemLoop System had two inline turbidimeters to monitor turbidity on a continuous basis. Turbidity was monitored and recorded for the raw water and the filtrate. The KemLoop System also had an inline total residual chlorine analyzer installed on the filtrate line.

A summary of the expected operating conditions, provided by ORCA, is presented in Table 2-1. The actual operating conditions during the verification test were close to the expected conditions and are described in Chapter 4.

Table 2-1. Test System Expected Operating Conditions

Parameter	Specification
Filtrate flow rate	10 gpm
Filter loading rate	2940 gallons per square foot per day (gfd)
Backwash flow rate	75-100 gpm
Backwash water per cycle	500 gallons
Pressure differential for backwash initiation	8 psi
Turbidity level in filtrate for backwash initiation	When filtrate is higher than raw water for 10 minutes
Feed water pressure	35-75 psi
Source water pressure	55-90 psi

The granular media filter material used for the verification test was a standard mix of sand, gravel, and garnet purchased locally. Specifications for the KemLoop System and granular media are given in Table 2-2. Figures 2-1 and 2-2 show a schematic and photograph of a typical system.

Table 2-2. KemLoop System Specifications

Name	ORCA KemLoop 1000 Coagulation and Filtration Water Treatment System
Model	1000
Filter Module Surface Area	4.9 ft^2
Filter Module Volume (approx without dome)	20 ft^3
Media Depth	32 inches
Number of Filter Modules	2 - Steel tanks lined with NSF certified epoxy coating
Filter Pressure Rating	75 psi max operating pressure
Mixed Media Per Filter Module	(1) 200 pounds course gravel; 4 inches deep; 1/4 X 3/8 gravel; uniformity coefficient 1.4 (2) 250 pounds fine gravel; 5 inches deep; 1/4 X 1/8 gravel; uniformity coefficient 1.4 (3) 250 pounds course garnet; 4.5 inches deep 8 X 12 coarse garnet; uniformity coefficient 1.37 (4) 200 pounds fine garnet; 3.5 inches deep; 30 X 40 mesh; uniformity coefficient 1.22 (5) 600 pounds #30 sand; 15 inches deep; uniformity coefficient <1.6 (6) 50 pounds of anthracite; 2 inches deep; 0.80-0.95 mm; uniformity coefficient 1.32
Skid	6 inch steel with 1.5 inch FRP grating (Note: Unit was an 8 X 20 ft shipping container for this test.)
Piping	Schedule 80 PVC

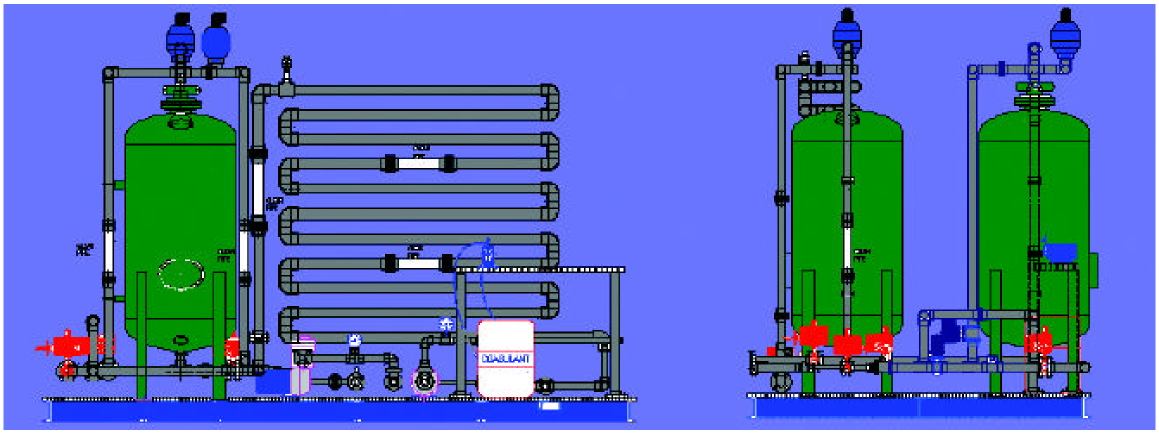

Figure 2-1. KemLoop System front and side view.

Figure 2-2. KemLoop System skid mounted unit photograph.

2.4 Description of Physical Construction and Components

The KemLoop System is a skid mounted, self-contained unit that weighs between 5,000 and 7,000 pounds. The granular media filter modules are steel tanks with inlet flow distributors, media support plates, and associated fittings, valves, and piping. Maximum operating pressure is approximately 75 psi. The standard unit is 14 ft (L) X 8 ft (W) X 8.75 ft (H). The main components of the unit are:

- 1.5 horsepower (hp) feed centrifugal pump (supplied but not used in this test);
- 1.5 hp backwash centrifugal pump;
- Two chemical metering pumps;
- One inline solid contact chlorinator (supplied but not used in this test);
- Schedule 80 PVC piping for water;
- Two filter modules;
- Two pressure transmitters;
- Three flow meters;
- Two inline pH meters;

- Two inline turbidimeters;
- Automated PLC/PC based control system; and
- One Hach 9184 Free Chlorine Analyzer.

Additional specifications and information are provided in Appendix A.

For the verification test, the equipment was constructed in a standard shipping container rather than using a skid mount design because the building at the Center was not large enough to enclose the skid-mounted unit. The shipping container protected the unit from Michigan winter weather and provided a heated environment. All equipment used in the containerized system was identical to the equipment used for the standard skid mounted unit.

2.5 Chemical Consumption and Production of Waste Material

2.5.1 Chemical Consumption

Two chemicals were used during the operation of the treatment system: sodium hypochlorite and ferric chloride. Sodium hypochlorite was fed to oxidize arsenic (III) to arsenic (V) and the naturally occurring iron in the raw water. A concentration of approximately 1.0 mg/L of total residual chlorine was shown to be sufficient during the shakedown period. Ferric chloride was added for arsenic removal by coagulation. The final feed rate for ferric chloride based on shakedown testing was determined to be 1.5-2.5 mg/L as iron. The raw water averaged approximately 0.5 mg/L, giving a target iron concentration in the feed water of 2.0-3.0 mg/L. Chemical use was monitored during the test, and storage containers were replenished as needed.

2.5.2 Waste Production and Physical and Chemical Nature of Wastes

Backwash water containing the solids (iron and arsenic) generated during the coagulation and precipitation process was expected to result in approximately 500 gallons per backwash cycle. It was anticipated that one or possibly two backwashes would occur per day during continuous operation, generating 500-1000 gallons per day of backwash water. The actual backwash generated was approximately 250 gallons per backwash. Actual backwash frequency was once per day on a time basis; pressure drop and turbidity did not trigger any additional backwashes during the verification test. For the verification test system, the backwash water was discharged to a holding tank, which was then manually discharged to the on-site wastewater system. No special permits were required for this discharge for the verification test.

At some permanent installations, the backwash water may need to be sent to a sanitary sewer system or a liquid-solids separation process may be required to clean the backwash water prior to discharge or return to the raw water feed. If solids are settled or filtered, they will contain higher levels of iron and arsenic and may require special handling for disposal.

2.6 Licensing Requirements

There were no special licensing requirements to operate the KemLoop System during the ETV test since the treated water was discharged to the sewer system and not used as a potable water supply.

2.7 Statement of Performance Objectives

The ORCA KemLoop 1000 Coagulation and Filtration Water Treatment System is a granular media filtration system used in drinking water treatment system applications for removal of arsenic and dissolved iron from groundwater. This document provides the actual verification test results for the KemLoop System.

2.8 Advantages of the ORCA KemLoop Process

According to ORCA, the main advantages of the KemLoop process for removing arsenic from water are as follows:

- The process is simple and compact;
- The granular filtration system is a standard filtration technology;
- Fully automated control system allows operation with only periodic operator attention;
- Unique mixing loop eliminates the need for large mixing tanks, coagulation tanks, and clarifiers or settling basins;
- System is compatible with chlorine and other common treatment chemicals; and,
- Modular construction on skids provides for ease of installation and expansion.

2.9 Potential Limitations of the Equipment

The KemLoop process for the treatment of raw drinking water with respect to source water quality has the following potential limitations.

- Poor source water quality can cause high solids loadings to the filter, increasing backwash frequency and quantity of solids generated.
- A disposal location, such as a settling basin, on-site wastewater treatment plant, or a sanitary sewer system, is needed to handle the backwash water generated on a daily basis.
- While the system is automated and operation should be easy, a moderate level of operator skill maybe required for successful use of the system. Variable source water quality may require adjustment of the chemical feeds in order to maintain optimal removal efficiency.
- A heated structure is recommended when freezing temperatures are encountered.
- Routine maintenance includes brief visual inspection to check pumps, pipes, fittings, and valves for leaks. Inline pH and turbidimeters require calibration. Chemicals need replenishment to ensure adequate supplies are available for injection into the system.

Chapter 3
Methods and Procedures

3.1 Quantitative and Qualitative Evaluation Criteria

As defined in the ETV protocol, the objectives of the verification test are to evaluate equipment in the following areas:

- The actual results obtained by the equipment as operated under the conditions at the test site;
- The impacts on performance of any variations in feed water quality or process variation;
- The logistical, human, and other resources necessary to operate the equipment; and
- The reliability, ruggedness, ranges of usefulness, and ease of operation of the equipment.

To address these objectives, the verification test employed the quantitative and qualitative factors listed in Table 3-1 in evaluating the KemLoop System performance.

Table 3-1. Quantitative and Qualitative Evaluation Criteria

Quantitative Factors	Qualitative Factors
• Feed water flow rate	• Ease of operation
• Treated water quality	• Safety
• Length of operating cycle	• Susceptibility to environmental conditions
• Frequency of backwash cycles	• Impact of operator experience on successful operation
• Power consumption	
• Chemical use	
• Maintenance requirements	
• Required level of operator attention	
• Spatial requirements	
• Discharge requirements	
• Waste disposal	

The primary applications of the KemLoop System are the removal of dissolved inorganic chemicals that can be precipitated by chemical addition. In the case of this verification, the primary application was total arsenic removal.

3.2 Key Water Quality Parameters

3.2.1 KemLoop System Water Quality Operating Range

The operating range of the KemLoop System as specified by ORCA is summarized in Table 3-2.

Table 3-2. Operating Range of the KemLoop System

Parameter	Range
Total arsenic	Less than 200 µg/L (1)
pH	5-10 S.U.
Turbidity	0-1000 NTU(2)

(1) During verification testing, the range of total arsenic in the feed water was 19-27 µg/L.

(2) During verification testing, low turbidity groundwater was tested (0.70-6.8 nephelometric turbidity units [NTUs]).

3.2.2 Key Water Quality Parameters for Evaluating Equipment Performance

Key water quality parameters used for evaluation of the KemLoop System are listed in Table 3-3. The Water Quality and Inorganic Parameter columns are the key parameters for evaluating the treatment process and water quality. The Other Parameters should not have an immediate impact on the treatment process, but are important parameters in drinking water supplies.

Table 3-3. Key Filtrate Water Quality Parameters

Water Quality	Inorganic Parameters	Other Parameters
• Temperature	• Arsenic	• Manganese
• Alkalinity	• Iron	• True Color
• Hardness	• TSS (backwash water)	• Total Organic Carbon (TOC)
• pH		• Chloride
• Turbidity		• Sulfate
• Residual Chlorine		• Fluoride
		• Dissolved Oxygen

3.3 Definition of Operational Parameters

The following are definitions used in this report and for designation of sampling locations:

Filtrate is defined as the water produced by the granular media filtration process, the treated water.

Feed water is defined as the water introduced to the granular media filter after all chemical additions.

Raw water is the source water supply. In this test, the raw water is the water supplied from the pressurized supply tank.

Differential pressure is the pressure across the granular media filtration module, equal to the feed water pressure at the inlet to the filter minus the filtrate pressure at the outlet of the filter module:

$$DP = P_f - P_o \qquad (3\text{-}1)$$

Where: DP = differential pressure (psi, bar)
P_f = inlet pressure to the feed side of the filter (psi, bar)

P_o = outlet pressure on the discharge side of the filter (psi, bar)

3.4 Operations and Maintenance

ORCA provided a draft O&M manual with the KemLoop System, which is included in Appendix A. As part of the verification testing, the ETV DWS Center reviewed the O&M documentation for the KemLoop System. Results of the review are included in this ETV report. In addition, the following aspects of operability are addressed in the report:

- Fluctuation of flow rates and pressures through unit (the time interval at which resetting is needed);
- Presence of devices to aid the operator with flow control adjustment;
- Availability of pressure measurement;
- Measurement of raw water rate of flow;
- Pace of chemical feed with raw water;
- Adequacy and ease of use of the PLC/PC control system.

The test unit was a full-scale system, which allowed observation of its design and operation. The control system and the backwash operation were identical to those used in commercial systems. Therefore, it was possible to evaluate the following operability issues directly during the verification test:

- Length of filter runs between backwash cycles;
- Change in pressure across the granular media filter module over time;
- Frequency and ease of backwash;
- Ease of operating the computer control system;
- Availability of process data to the operator; and
- Requirements for control and maintenance of the chemical feed systems.

3.5 Field Operations Procedures

Acting as the FTO, the DWTS, conducted the testing of the KemLoop System as described in this PSTP. DWTS field personnel performed field analytical work using field laboratory equipment and procedures for pH, temperature, chlorine, turbidity, dissolved oxygen, and true color. The NSF Chemistry Laboratory performed water quality analytical work.

The test unit was operated 24 hours a day, seven days per week. DWTS staff were on site each day to operate the system and collect water quality data during the verification test.

3.6 Environmental Technology Verification Testing Plan

A PSTP was prepared for the KemLoop System verification test in accordance with the ETV Protocol. The PSTP divided the work into three main tasks (A, B, C) with Task C, the verification test itself, divided into six tasks. These tasks are:

Task A: Raw Water Characterization

Task B: Initial Test Runs
Task C: Verification Test
    Task 1: Verification Testing Runs
    Task 2: Raw Water, Feed Water, and Filtrate Water Quality
    Task 3: Operating Conditions and Performance
    Task 4: Arsenic Removal
    Task 5: Data Management
    Task 6: Quality Assurance/Quality Control (QA/QC)

The PSTP, which included a Quality Assurance Project Plan (QAPP), specified procedures to be used to ensure the accurate documentation of both water quality and equipment performance.

An overview of each task is provided below with detailed information on testing procedures presented in later sections.

3.6.1 Task A: Raw Water Characterization

The objective of Task A was to obtain a chemical and physical characterization of the raw water. Information on the groundwater supply that provides the raw water was needed to aid in interpretation of feed water characterization.

3.6.2 Task B: Initial Test Runs

During Task B, ORCA evaluated equipment operation to determine the optimal chemical dosages and other pretreatment conditions needed to provide effective treatment of the raw water. ORCA performed all start-up and shakedown testing.

3.6.3 Task C: Verification Test Procedures

Task 1: Verification Testing Runs

The KemLoop System was operated for 14 days (336 hours) to collect data on equipment performance and water quality for purposes of performance verification. The verification test period exceeded the 320-hour minimum time specified by the ETV Technology Specific Test Plan for Coagulation Filtration and the PSTP for the KemLoop System.

Task 2: Raw Water, Feed Water, and Filtrate Water Quality

During verification testing, raw water, feed water (after coagulation), and filtrate water samples were collected and appropriate sample analyses performed. For example, samples were analyzed for iron to monitor the coagulation process, in addition to the analyses for arsenic to evaluate arsenic removal.

Task 3: Operating Conditions and Performance

During verification testing, operating conditions and performance of the water treatment equipment were documented. Equipment performance information collected included data on filtrate flow rate and total filtrate volume produced, pressure differential across the granular media filters, and frequency and duration of backwash.

Task 4: Total Arsenic Removal

Total arsenic in the raw, feed, and filtrate waters were measured to evaluate total arsenic removal during verification testing..

Task 5: Data Management

The objective of this task was to establish an effective field protocol for data management at the field operations site, and for data transmission between the FTO and the ETV DWS Center. Master field logs were prepared and field sheets for data collection were used to ensure all scheduled activities were performed. The logs were delivered to the ETV DWS Center project coordinator on a weekly basis.

Task 6: Quality Assurance/Quality Control (QA/QC)

An important aspect of verification testing was the development of specific QA/QC procedures. The objective of this task was to assure accurate measurement of operational and water quality parameters during the verification test.

3.7 Task A: Raw Water Characterization

3.7.1 Site Background Information

Section 1.3 provides a description of the St. Louis Center, its two production wells, and related water distribution equipment. Historical data, collected by the Center and by NSF, are presented in Tables 1-1 and 1-2.

3.7.2 Additional Analytical Data

During Task A, additional grab samples of the raw water were collected for characterization purposes. These data, along with historical data for the groundwater source, provided characterization of the raw water prior to the startup of the KemLoop System.

Table 3-4 shows the parameters that were analyzed on the initial characterization sample of raw water in the pressurization tank. A second set of grab samples was collected from each individual well and from the combined water in the pressure tank for total arsenic analysis. Information on sampling and analysis methods and procedures is provided later in this chapter.

Table 3-4. Water Quality Parameters for Raw Water Characterization

Raw Water Parameters	
pH	Iron
Temperature	Manganese
Turbidity	Chloride
Alkalinity	Sulfate
Residual Chlorine	TOC
Dissolved Oxygen	Fluoride
True Color	Calcium(1)
Total Arsenic	Magnesium(1)
Arsenic (speciation)	

(1) Hardness was calculated from calcium and magnesium measurements.

3.7.3 Evaluation Criteria

The raw water characteristics were evaluated in the context of the ORCA statement of performance to confirm that the water source was appropriate for verification testing.

3.8 Task B: Initial Test Runs

3.8.1 Objectives

The primary objective of this task was to determine the proper chemical dose for the chlorine pretreatment and the iron addition to properly co-precipitate arsenic present in the raw water. The test unit was set up and operated to ensure the unit was properly installed for the verification test.

3.8.2 Work Plan

ORCA technical support staff worked with the Center's staff to install the equipment and ready the test system for operation. ORCA staff was on site to direct final connections and the startup of the equipment. Once the system was ready for operation, ORCA ran the initial startup and shakedown tests to determine the proper operating conditions, including the optimal chemical doses for chlorine and iron addition. Results from the shakedown testing are on file at NSF.

Once ORCA confirmed the operating conditions and chemical feed rates recommended for the verification test, they forwarded the information to NSF. These conditions were the operating conditions used for the verification test.

3.8.3 Arsenic Loss Test

After ORCA had completed the shakedown testing, the unit was backwashed and then flushed for two hours using raw water with no chemical feed in preparation for the arsenic loss test. This test was performed to determine if there was any total arsenic loss in the system when chlorine and coagulant were not being used. Samples of raw water, feed water, and filtrate were collected after 6, 12, 18, and 24 hours of continuous operation. Only one backwash cycle based on time (at end of the 24-hour test) was performed, because the unit pressure and turbidity remained within specifications throughout the 24-hour test. Operating conditions (flow rate, pressure, etc.) were monitored and confirmed by the DWTS field staff at the start of the test and every six hours thereafter. Once this testing was complete and all operating parameters had been confirmed, the verification test was ready to begin.

3.8.4 Analytical Schedule

During the clean water test run (no chemical addition), grab samples were collected at the times specified. The four sets of samples (two or three sampling locations per set) were analyzed for basic water quality parameters and for total arsenic, as shown in Table 3-5. The first and last samples (6 hours and 24 hours) were analyzed for dissolved arsenic, arsenic (III), and arsenic (V) to confirm the distribution of arsenic species in the water.

Table 3-5. Water Quality Parameters – Arsenic Loss Test

Parameter	Frequency(1)	Location
pH	4/24 hours	Raw, Feed & Filtrate Water
Temperature	4/24 hours	Raw, Feed & Filtrate Water
Bench Top Turbidity	4/24 hours	Raw, Feed & Filtrate Water
Inline Turbidity	Continuous	Filtrate Water
Alkalinity	4/24 hours	Raw, Feed & Filtrate Water
Residual Chlorine	4/24 hours	Raw, Feed & Filtrate Water
True Color	1/24 hours	Raw, Feed & Filtrate Water
Calcium(2)	1/24 hours	Raw & Filtrate Water
Magnesium (2)	1/24 hours	Raw & Filtrate Water
Total Arsenic	4/24 hours	Raw, Feed & Filtrate Water
Arsenic (speciation)	2/24 hours	Raw, Feed & Filtrate Water
Iron	4/24 hours	Raw, Feed & Filtrate Water
Manganese	1/24 hours	Raw & Filtrate Water
Chloride	1/24 hours	Raw, Feed & Filtrate Water
Sulfate	1/24 hours	Raw, Feed & Filtrate Water
Fluoride	1/24 hours	Raw & Filtrate Water
TOC	1/24 hours	Raw & Filtrate Water
Dissolved Oxygen	4/24 hours	Raw & Filtrate Water

(1) Samples were collected after 6, 12, 18, and 24 hours of operation.
(2) Hardness was calculated from calcium and magnesium measurements.

3.8.5 Evaluation Criteria

The data provided by ORCA for optimal chemical doses and system operating conditions were reviewed by the FTO. The evaluation focused on the total arsenic removal performance and the ability of the unit to meet the stated performance objective. These data indicated that the unit was meeting the performance objective. Therefore, the FTO began preparation for the verification test using the recommended chemical feed rates and system operating conditions for the verification test. The total arsenic loss test data were evaluated to determine if total arsenic was removed or lost in the system when no chemicals were added. This information is presented in Section 4.4.

3.9 Task C: Verification Test

3.9.1 Introduction

The verification test was run for 336 hours (14 days), which exceeded the minimum of 320 hours stated in the Protocol and the PSTP. The test unit was operated continuously, 24 hours a day, seven days per week. Water quality data for the raw water, feed water, and filtrate were collected in accordance with the schedule described in the following sections. All samples were grab samples collected from the sampling ports installed at the site.

The PSTP described six tasks to be performed to achieve a successful verification test. Each of these tasks is described in this section.

3.9.2 Experimental Objectives

The objective of this task was to assess the ability of the KemLoop System to remove arsenic from a groundwater source, as indicated in the Statement of Performance Objectives (Section 2.7). The verification test was designed to collect and analyze arsenic performance data, equipment operating performance data and characteristics, and other water quality information to achieve this objective. Statistical analyses (standard deviation and confidence intervals) were performed on all analytes, with eight or more discrete samples collected over the verification period.

3.9.3 Task 1: Verification Testing Runs

Introduction

The 336-hour verification test used the optimal configuration and filtration operating conditions, as determined by the shakedown testing, to measure the performance of the KemLoop System for an extended operating period. The test was typical of operating conditions expected at a public water supply site using groundwater as the supply source. The quality of the raw water was not expected to vary significantly over the test period, as deep groundwater sources are usually fairly stable in quality.

The filtrate produced during the verification was not used for potable water supply purposes. The filtrate was discharged to the on-site wastewater treatment system.

Operating Schedule

The KemLoop System was operated continuously during the verification test. Flow was maintained to the system 24 hours per day, seven days per week. During the 336-hour test, the DWTS field operators recorded daily measurements of the routine operating parameters, as shown in Table 3-6. In addition, the PLC/PC system also collected and recorded operating data for the system. Sampling and analyses included one 48-hour intensive survey period. Daily and weekly sampling and analyses were also performed as described in Section 3.9.4.

To meet the goals of the verification testing for equipment employing coagulation and granular media filtration, the following conditions were achieved.

- Water treatment equipment was operated continuously for a minimum of 320 hours (the equivalent of 13 full days plus one 8-hour work shift).
- The water treatment equipment was operated continuously from start-up until turbidity breakthrough or terminal head loss was attained, or the maximum cycle time specified was achieved. ORCA specified a backwash at least once every 24 hours for this site and test.
- Interruptions in filtration occurred only as needed for backwashing of the filters during the 336 hours of testing that began on March 24, 2005.
- Filter runs were not stopped before turbidity breakthrough or terminal head loss was achieved or the maximum cycle time specified was achieved, with the exception of equipment failure or power interruption.
- The duration of each filter run and the number of gallons of water produced per square foot of filter area were recorded in the operational results.

Evaluation Criteria

Field logs were used to record all of the information shown in Table 3-6. The hours of operation needed to meet the protocol requirements were documented. Backwash cycles and times were recorded. All data are summarized in this final report, including:

- Duration of each filter run;
- Gallons treated per run; and
- Gallons produced per square foot of filter surface.

Table 3-6. On-site Equipment Operating and Monitoring Data Schedule

Parameter	Monitoring Frequency	Monitoring Method
Feed/filtrate water production	Check & record once per day.(1)	System water totalizer meter.
Feed/filtrate water flow rate	Check & record once per day (adjust when 5% above or below target; record before and after adjustment).(1)	System water flow meter.
Feed water pressure	Record initial clean bed total head loss at start of filter run. Check & record once per day.(1) Record terminal head loss at end of filter run.	Feed water pressure gauge.
Filtrate water pressure	Record initial clean bed total head loss at start of filter run. Check & record once per day.(1) Record terminal head loss at end of filter run.	Filtrate water pressure gauge.
Backwash flow rate	Check & record when on site and backwash is occurring.(2)	Determine backwash volume from holding tank; use stopwatch to time length of backwash. Calculate flow rate.
Total backwash volume and duration	Check & record when on site and backwash is occurring.(2)	Determine volume by reading tank depth before and after backwash. Determine cycle length by stopwatch.
Chemical feeds:		
Liquid ferric chloride and sodium hypochlorite (bleach)	Check & record tank height once per day. Check metering pump setting once per day or calibrate flow rate.	Measure with measuring tape depth of chemical remaining and, as required, quantity of chemical refill. Calibrate flow rate with attached graduated cylinder and stopwatch.
Chemicals used	Whenever a new batch of feed chemicals is made.	Record name of chemical, supplier, commercial strength, and dilution used for making batch solution.
Operating hours	Record once per day the total hours of operation since last site visit.(1)	Based on PLC/PC and total volume meters, determine total hours.
Inline pH meters	Verify these meters are operating and data are recorded daily.(1)	Compare to bench top meter; calibrate as needed.
Inline turbidimeters	Verify these meters are operating and data are recorded daily. Verify sample flow rate daily.(1)	Compare to bench top meter; calibrate as needed. Sample flow rate by volumetric measurement over a specific time.
Inline chlorine analyzer	Verify these meters are operating and data are recorded daily.	Calibrate as needed.
Power use	Determined at end of test.	Power use calculated based on equipment horsepower ratings.
Labor hours	Determine labor hours required.	Record time on-site daily in logbooks.

(1) PLC recorded these data on a continuous basis (one-minute increments) and stored the data for retrieval to document the operating parameter throughout the verification test.

(2) PLC recorded these data throughout the verification test for each backwash cycle. Manual readings were made when backwash occurred during a time when operators were present on site.

3.9.4 Task 2: Raw Water, Feed Water, and Filtrate Water Quality

Introduction

Water quality data were collected for the raw, feed, and filtrate water on a regular basis during the verification test, including one 48-hour intensive survey. These data were the basis for determining the total arsenic removal performance of the system and documenting the water quality achieved. The sampling and analysis plan also included data collection to monitor the changes or effects of the coagulant addition (ferric chloride) on water quality.

Work Plan

Monitoring of water quality parameters in the feed water and filtrate water streams provided data to calculate the changes in the total arsenic concentration and in other inorganic chemicals that might be affected by the treatment system. Table 3-7 provides a list of the water quality parameters that were monitored during the verification test, along with the frequency of sampling for each parameter. In addition to the regular sample collection schedule, one intensive sampling and analysis period focused on total arsenic removal and the concentration of related process chemicals, such as iron, pH, turbidity, and residual chlorine. The intensive sampling period is described further in Section 3.9.6.

Table 3-7. Sampling Schedule

Parameter	Sampling Frequency	Test Streams to be Sampled
Temperature	Daily	Raw, Feed, & Filtrate Water
pH	Daily	Raw, Feed, & Filtrate Water
Alkalinity	Daily	Raw, Feed, & Filtrate Water
Bench Top Turbidity	Daily	Raw, Feed, & Filtrate Water
Inline Turbidity	PLC (1/min)	Raw & Filtrate Water
Hardness(1)	Weekly	Raw & Filtrate Water
Calcium	Weekly	Raw & Filtrate Water
Magnesium	Weekly	Raw & Filtrate Water
TOC	Weekly	Raw & Filtrate Water
Total Iron	Daily	Raw, Feed, & Filtrate Water
Manganese	Weekly	Raw & Filtrate Water
Total Arsenic (2)	Daily	Raw, Feed, & Filtrate Water
Sulfate	Weekly	Raw, Feed, & Filtrate Water
Chloride	Weekly	Raw, Feed, & Filtrate Water
True Color	Weekly	Raw, Feed, & Filtrate Water
Residual Chlorine	Daily	Raw, Feed, & Filtrate Water
Fluoride	Weekly	Raw & Filtrate Water
Dissolved Oxygen	Daily	Raw Water
TSS(4)	Weekly	Backwash Water
Total Arsenic (3)	Weekly	Backwash Water
Total Iron(3	Weekly	Backwash Water
pH (3)	Weekly	Backwash Water
Residual Chlorine(3)	Weekly	Backwash Water

(1) Hardness was calculated from calcium and magnesium measurements.
(2) Arsenic samples were speciated once per week for raw, feed, and filtrate samples.
(3) Samples were collected on a continuous basis during backwash flow from the backwash inlet line to the holding tank. One of the weekly samples was collected during the 48-hour intensive survey. The other weekly sample was collected when a backwash occurred while the operators are on site.

The FTO field staff measured many of the water quality parameters described in this task while on site. The NSF Chemistry Laboratory performed analyses of the remaining water quality parameters. Table 3-8 identifies the methods used for measurement of water quality parameters and the analysis locations. Further discussion of analytical methods is presented in the QAPP in the PSTP.

Table 3-8. Analytical Methods

Parameter	Facility	Standard Method[1]	EPA Method[2]	Hach Method[3]
Field Tests				
pH	On-site	4500-H^+ B		
True Color[4]	On-site	2120B		
Turbidity	On-site		180.1	
Temperature	On-site	2550		
Chlorine (total and free)	On-site			8167 (total) 8021 (free)
Dissolved Oxygen	On-site	4500-G		
NSF Drinking Water Laboratory Tests				
Arsenic (total)	Laboratory		200.8	
Arsenic [As (III) and dissolved]	Laboratory		200.8	
Calcium	Laboratory		200.7	
Magnesium	Laboratory		200.7	
Iron	Laboratory		200.7	
Manganese	Laboratory		200.8	
Sulfate	Laboratory		300.0	
Chloride	Laboratory		300.0	
TOC	Laboratory	5310 C		
TSS	Laboratory	2540 D		
Fluoride	Laboratory		300.0	
Alkalinity	Laboratory	2320B		
Hardness	Laboratory[5]	2340 B		
Contract Lab Tests				
Toxicity Characteristic Leaching Procedure (TCLP)	TriMatrix		1311	
California Waste Extraction Test (CAWET)	TriMatrix		Special CA method and metals by SW846 6010 and 7470a	

(1) *Standard Methods for the Examination of Water and Wastewater*. 1999. 20th edition. APHA, AWWA, and WEF, Washington D.C.
(2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).
(3) *Hach Water Analysis Handbook* (1992). Hach Company, Loveland, Colorado.
(4) The true color test was performed without filtering the sample that is required by the method.
(5) Hardness was calculated from calcium and magnesium measurements.

For the water quality parameters submitted to the NSF Chemistry Laboratory, samples were collected in appropriate containers (containing necessary preservatives as applicable) prepared by the NSF Chemistry Laboratory. The samples were stored in coolers and delivered to the laboratory each day; no commercial shipping was required. All samples were analyzed in accordance with appropriate procedures and holding times. Table 3-9 shows the sample containers, preservatives, and holding time for each parameter.

Table 3-9. Sample Bottles, Preservation, and Holding Time

Parameter	Bottle Type	Preservation	Holding time
Field Tests			
pH	Plastic	None	Analyze immediately
True Color	Glass	Cool to 2-6 ^{0}C	24 hours
Turbidity	Glass	None	Analyze immediately
Temperature	Plastic	None	Analyze immediately
Chlorine (total and free)	Plastic	None	Analyze immediately
Dissolved Oxygen	BOD glass bottle	None	Analyze immediately
NSF Lab Tests			
Arsenic (total)	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months
Arsenic (As [III] and dissolved)	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months
Calcium	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months
Magnesium	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months
Iron	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months
Manganese	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months
Sulfate	Plastic	Cool 2-6 ^{0}C	14 days
Chloride	Plastic	Cool 2-6 ^{0}C	14 days
TOC	Glass	H_2SO_4, Cool 2-6 ^{0}C	28 days
TSS	Plastic	Cool 2-6 ^{0}C	7 days
Fluoride	Plastic	Cool 2-6 ^{0}C	14 days
Alkalinity	Plastic	Cool 2-6 ^{0}C	14 days
Hardness	Plastic	HNO_3, Cool to 2-6 ^{0}C	6 months

Analytical Schedule

The sampling schedule shown in Table 3-7 was designed to frequently monitor the parameters that are critical to the coagulation and filtration process. General water quality parameters were monitored on a less frequent basis to provide water quality characteristics. Dissolved oxygen (DO) concentrations in the raw water were monitored because DO can impact the oxidation of iron, which is critical to achieve the proper conditions for arsenic coagulation and removal.

All of the water quality parameters listed in Table 3-7 were sampled during the one arsenic challenge operating condition. The 48-hour intensive survey, described in Section 3.9.6, occurred during the second week of the 336-hour test. When the intensive arsenic sampling test was performed, the daily and weekly samples were collected as part of the 48-hour period.

The raw, feed, and filtrate water were monitored daily for pH because pH is an important part of the coagulation process. No pH adjustment was needed for the water at this test site. Turbidity measurements of the raw and filtrate water were made continuously with inline turbidimeters. These inline units were checked daily using a bench top turbidimeter.

The backwash water was sampled for TSS concentration once per week during a backwash cycle. Backwash samples were also analyzed for total arsenic, total iron, pH, and residual chlorine. Samples were obtained continuously to make a composite sample from the inlet line to the backwash water holding tank.

Typically, the KemLoop System only produces sludge for disposal if the backwash water is passed through a solids separator or sent to a settling basin to remove suspended solids prior to discharge. In other applications, the backwash water is discharged to a sewer system and treated at a wastewater treatment facility. Measuring the TSS, iron, and total arsenic in the backwash water provides the needed data to assess the quality of the backwash water and its acceptability to a wastewater treatment plant.

To collect a sample of the solids produced by the backwash, a holding tank was installed to collect the backwash water. The backwash water was allowed to settle for 24 hours before the water was manually discharged from the tank. Solids accumulated on the bottom of the tank over the entire 14-day verification test. Samples of the solids, which represented a composite of all backwashes that occurred during the 14-day test, were collected to measure the metals that might leach from the solids produced from the system. The TCLP and CAWET leaching procedures were both used for these tests. These samples were sent to TriMatrix Laboratories in Grand Rapids, Michigan, for analysis. TriMatrix Laboratories was approved by NSF to perform these analyses for purposes of the verification test.

Water Quality Sample Collection

Water quality data were collected at the specified intervals during the testing period. The monitoring frequency for the water quality parameters is shown in Table 3-7. To the extent possible, analyses for inorganic water quality parameters were performed on water sample aliquots obtained simultaneously from the same sampling location, in order to ensure the maximum degree of comparability between water quality analytes.

All samples were grab samples collected from the sampling valves installed in the test system. Samples were collected from a raw water sample tap prior to chlorine addition, at the feed water sample port after all chemical additions and mixing just prior to the filtration unit, and from the filtrate (treated water) sample tap, located downstream of the granular media filter module. Prior to collecting the sample, each valve was flushed for at least five seconds to be sure fresh water was obtained from the process lines. The samples were collected directly into a clean, large container. Aliquots of samples were then poured into the required containers for laboratory analysis or on-site analysis. Samples from all three locations were collected within less than 15 minutes so that data were representative of the current conditions.

Backwash samples were taken continuously over the entire backwash cycle from the inlet line to the holding tank. These samples represented the average concentration over the backwash cycle.

Special sampling procedures were used for turbidity. Grab samples were taken by running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

Temperature measurements were performed by collecting a sample into a clean container and immediately immersing the thermometer into the water.

Evaluation Criteria and Minimum Reporting Criteria

Performance was evaluated in the context of the manufacturer's statement of performance objectives.

Since iron was used as the coagulant, the filtered water data were tabulated and the concentration of iron in filtered water was compared to the Secondary Maximum Contaminant Level (SMCL) of 0.3 mg/L.

Given that the verification test was for a groundwater source, turbidity results were analyzed to determine the percentage of turbidity data in the ranges of 0.50 NTU or lower, 0.51-1.0 NTU, 1.1-2.0 NTU, and exceeding 2.0 NTU.

Other water quality data are presented in this final report in either graphical or tabular format. Daily analyses are plotted against time, while weekly parameters are summarized in a tabular format. Information includes:

- A graph plotting the daily turbidity, pH, alkalinity, and iron for the raw, feed, and filtrate water over the test period.
- A table summarizing the raw, feed, and filtrate water concentrations of hardness, manganese, TOC, sulfate, chloride, and true color.
- A table summarizing the residual chlorine data and calculation of total chlorine fed to the system (mass or volume).
- Appendices containing all data collected during the verification test.

3.9.5 Task 3: Operating Conditions and Treatment Equipment Performance

Introduction

The objectives of this task were to accurately and fully document the operating conditions during treatment and evaluate the equipment performance. Operating conditions, including flow rates through the granular media filter, pressure drop across the filter, frequency and duration of filter backwash cycles, and any maintenance required, were documented during each day of verification testing. Electrical use was calculated from the horsepower ratings for the pumps and other equipment.

Work Plan

A description of the equipment, granular media filter characteristics, and test system operating conditions was presented in Chapter 2. During verification testing, operating parameters were routinely monitored by the DWTS on-site staff. Table 3-6 presented a list of the normal operating parameters that were monitored to document the equipment performance during the verifications test.

The following items were monitored, collected, recorded, or analyzed:

- Treatment equipment operating parameters for both pretreatment and filtration, including:
  - Monitoring iron dose and pH for the coagulation system; and
  - Monitoring the chlorine pre-oxidation.
- Filter head loss before and after backwash cycles, and backwashing data (frequency, flow rate, volume).
- Chemical dosages for all chemicals used including oxidants and ferric chloride were monitored. Chlorine was used as an oxidant. The chlorine dosage and residual chlorine were measured daily, including when total arsenic samples were collected. Iron concentrations in the raw and feed water were analyzed to track iron dose, in addition to monitoring the iron usage.
- Electrical energy consumed by the treatment equipment based on the aggregate horsepower of all pumps and mixers was calculated and reported.

Schedule for Operating Parameter Data Collection

Table 3-6 shows the list of operating parameters that were monitored during the verification test and the frequency of the observations.

Evaluation Criteria

The data developed from this task were used to present operating data on system flow rate, head loss (pressure drop) across the filter module, and frequency and duration of filter backwash cycles.

The results of operating and performance data were tabulated and included:

- Average volume of flow treated, gpd;
- Average filtrate water flow rate, gpm;
- Average filtration rate, gfd;
- Average run length, hours, and volume of water treated per filter run;
- Average daily chemical usage;
- Average pressure drop across the module;
- Average daily backwash water production; and

- Typical suspended solids in the backwash.

3.9.6 Task 4: Arsenic Removal

Introduction

Total arsenic removal was the primary objective of the coagulation and granular media filtration process evaluated in this verification test. Assessment of the treatment efficiency was based on total arsenic removal.

Work Plan

Task 4 was performed concurrently with Task 1. The treatment equipment was operated using the chemical treatment conditions and system operating conditions that provide effective coagulation and filtration.

Evaluation of total arsenic removal was performed by analyzing total arsenic in the raw, feed, and filtrate waters. The total arsenic evaluation included monitoring total arsenic concentration on a daily basis, as shown in Table 3-7, and during one intensive sampling period over 48 hours. The intensive sampling period was performed during the second week of the verification test, beginning on Day 7 and ending on Day 9. During this intensive sampling period, samples were collected at the start (time zero), 1, 3, 6, 12, 18, and 24 hours. The filter then entered a backwash cycle based on time. When the backwash cycle ended, the sampling schedule was reset to time zero for the start of the next sampling on a clean filter module. Samples were collected at time 0, 1, 3, 6, 12, 18, and 24 hours, which completed the 48-hour intensive survey. A total of 14 samples were collected over the 48-hour period.

Analytical Schedule

In addition to monitoring arsenic concentration, the concentration of iron, which was used as the coagulant to co-precipitate arsenic, was measured in each raw, feed, and filtrate water sample. The complete list of parameters monitored, sampling frequencies, and location of samples are shown in Table 3-10.

Chlorine dose and residual chlorine were monitored daily throughout the verification. During the intensive sampling period, residual chlorine was analyzed on every sample. The KemLoop process included a pre-oxidation step with chlorine to covert any arsenic (III) to arsenic (V) and to oxidize iron species in the raw water. It has been demonstrated by many researchers that arsenic (V) removal by coagulation and filtration is much more effective than arsenic (III) removal. Thus, ORCA has implemented the preferred approach and used pre-oxidation to convert all arsenic to arsenic (V) to attain the most effective results.

Turbidity in raw water and filtrate was determined using continuous flow turbidimeters equipped with recording capability via the PLC. Data were collected on a 24-hour-per-day basis during verification testing. The recording increment in the PLC for turbidity and other operating data was one minute. The inline turbidity readings were also recorded once per day in the field log.

Raw water, feed water and filtrate turbidity was monitored once per day using a bench top turbidimeter. The bench top results were used to check the calibration of the inline units.

The regular daily and weekly sample analyses for total arsenic and other water quality parameters were discussed in Section 3.9.4, Task 2. Total arsenic samples were collected daily, and one sample each week was speciated. The sampling schedule was summarized in Table 3-7. During the week of the 48-hour intensive survey, the results from the 48-hour test were used to satisfy the daily or weekly requirements for those days and that week.

The KemLoop System had a maximum detention time in the mixing loop of approximately five minutes. The first samples at time zero were collected approximately 30 minutes after the backwash cycle was completed to ensure the filter was operating at a steady state condition.

Evaluation Criteria

KemLoop System performance was evaluated based on the data collected and in the context of the manufacturer's statement of performance objectives. The following information is summarized and discussed in Chapter 4 of this report:

- Valence of the arsenic being treated by the process (i.e., arsenic [III] or arsenic [V]);
- pH of coagulated water;
- Turbidity levels associated with each sample for total arsenic;
- Coagulant chemical used;
- Coagulant dosage or concentration of iron coagulant; and
- Concentration of chlorine added.

Since iron was used as the coagulant, the filtrate data were tabulated and the concentration of iron in filtrate was compared to the SMCL of 0.3 mg/L.

The following data are presented in Chapter 4:

- The total arsenic data are plotted against sample time to show trends and variations in performance.
- The turbidity, pH, and iron for the raw, feed and filtrate over the 48-hour intensive survey are presented.
- A table summarizing the raw, feed, and filtrate water concentrations of hardness, manganese, TOC, sulfate, chloride, and true color.
- A table summarizing the residual chlorine data and a calculation of the amount of chlorine fed to the system each day.

All field logs with recorded operating data and field analytical data, NSF laboratory reports, and spreadsheets summarizing the results are presented in Appendices B, C, and D.

Table 3-10. Parameter List for the 48-Hour Intensive Survey

Parameter	Sampling Frequency	Test Streams Sampled
Total Arsenic	All samples(1)	Raw, Feed, & Filtrate Water
Arsenic Speciation	0, 24, 48 hours	Raw, Feed, & Filtrate Water
Temperature	0, 24, 48 hours	Raw, Feed, & Filtrate Water
pH	All samples	Raw, Feed, & Filtrate Water
Alkalinity	0, 24, 48 hours	Raw, Feed, & Filtrate Water
Bench Top Turbidity	0, 24, 48 hours	Raw, Feed, & Filtrate Water
Inline Turbidity	For all arsenic samples by continuous meter	Filtrate Water
Hardness(2)	Once at 24 hrs	Raw & Filtrate Water
Calcium	Once at 24 hrs	Raw & Filtrate Water
Magnesium	Once at 24 hrs	Raw & Filtrate Water
TOC	Once at 24 hrs	Raw & Filtrate Water
Iron	All samples	Raw, Feed, & Filtrate Water
Manganese	Once at 24 hrs	Raw & Filtrate Water
Sulfate	Once at 24 hrs	Raw, Feed, & Filtrate Water
Chloride	Once at 24 hrs	Raw, Feed, & Filtrate Water
Fluoride	Once at 24 hrs	Raw & Filtrate Water
True Color(3)	Once at 24 hrs	Raw, Feed, & Filtrate Water
Residual Chlorine	All samples	Raw, Feed, & Filtrate Water
Dissolved Oxygen	0, 24, 48 hours	Raw & Filtrate Water
TSS (3)	Every backwash cycle	Backwash Water
Total Arsenic (4)	Every backwash cycle	Backwash Water
Total Iron(4)	Every backwash cycle	Backwash Water
pH(4)	Every backwash cycle	Backwash Water
Residual Chlorine(4)	Every backwash cycle	Backwash Water

(1) All samples refers to time 0, 1, 3, 6, 12, 18, 24, and time 0, 1, 3, 6, 12, 18, 24 after the first backwash occurred after 24 hours of operation.

(2) Hardness was calculated from calcium and magnesium measurements.

(3) The true color test was performed without filtering the sample that is required by the method.

(4) Samples were collected on a continuous basis during backwash flow from the backwash inlet line to the holding tank. Samples were collected for each backwash that occurred during the 48-hour intensive survey.

3.9.7 Task 5: Data Management

Introduction

The data management system used in the verification test included the use of computer spreadsheets and manual (or inline) recording of operational parameters for the equipment on a daily or weekly basis. The FTO field staff collected the information and entered it into logbooks and prepared field log sheets. All field activities were documented. Field documentation included field logbooks, photographs, field data sheets, and chain-of-custody forms. The procedures for logbook format and entries followed the procedures outlined below:

- Field notes were kept in a bound logbook;
- Pre-prepared log sheets were used to record all water treatment equipment operating data;
- Each log sheet was labeled with the project name and the verification day number;

- Completed pages were signed and dated by the individual responsible for the entries; and
- Errors were corrected by drawing a single line through the error. The line was initialed and dated.

Any deviations from the approved final PSTP were documented in the field logbook and included in the report. A copy of the PSTP was available on site.

Chain-of-custody forms accompanied all samples delivered to the analytical laboratory. Copies of field sheets and chain-of-custody forms for all samples were provided at the time of QA/QC inspection and are included in Appendices B and C.

Objectives

The objectives of this task were to: 1) establish a viable structure for the recording and transmission of field testing data such that the FTO provided sufficient and reliable data for verification purposes, and 2) develop a statistical analysis of the data, as described in the document: *EPA/NSF ETV Protocol for Equipment Verification Testing for Arsenic Removal: Requirements For All Studies* and Chapter Three of the same document.

Work Plan

The DWTS field operators recorded on-site data and calculations (e.g., calculating calibration flow rates using the "bucket and stop watch" technique and other similar routine calculations) by hand in field logbooks and field log sheets. Daily measurements were recorded on specially prepared data log sheets. The original logbooks were stored on site. Copies were forwarded to the project coordinator at NSF weekly during the testing period. Operating logs included a description of the equipment, description of test runs, names of visitors, description of any problems or issues, and so forth.

A database for the project was set up using standard spreadsheets. The spreadsheets were capable of storing and manipulating each monitored water quality and operational parameter from each task, sampling location, and sampling time. All data from the on-site laboratory logbooks and data log sheets were entered into the appropriate spreadsheets. Scherger Associates, the consultant to the DWTS, performed the data entry. Following data entry, the spreadsheets were printed, and the printout was checked against the handwritten data sheet. NSF DWS Center project coordinators checked 100% of the spreadsheet entries and provided written notes on the corrections that needed to be made. Final versions of the spreadsheets were checked to ensure all corrections had been made and all entries were correct.

As samples were collected and sent to the NSF Chemistry Laboratory, they were tracked by use of chain-of-custody forms. Each sample had its location name, date, time of collection, and the parameters written on the label. These laboratory data were entered into data spreadsheets, corrected, and verified in the same manner as the field data.

The KemLoop System PLC/PC stored and archived operating data monitored by the unit. The PLC acquired data in one minute or more frequent (5 minute, 10 minute, etc.) increments.

The data for parameters such as flow and pressure were averaged on an hourly basis, and maximum and minimum values were determined. The PLC stored the data for the two-week period. The on-site laptop PC was used to access the PLC data. The PLC data were downloaded to a PC for display and storage at the end of the test. The PC data were backed at the end of the verification test. A copy of the PLC data is located in Appendix B.

3.9.8 Task 6: Quality Assurance/Quality Control

Introduction

QA/QC of the operation of the KemLoop System and the measured water quality parameters were maintained during verification testing by following the QAPP developed as part of the PSTP (Chapter 5). The QAPP included accuracy and precision objectives for the analytical work, discussion of the need to meet representativeness and completeness criteria, and calibration requirements for field meters and analytical equipment/methods.

On-site Equipment Checks

Equipment flow rates were documented and recorded on a daily basis. A daily walkthrough during testing was established to verify that each piece of equipment or instrumentation was operating properly. Inline monitoring equipment, such as flow meters and so forth, were checked to confirm that they were operating properly.

The items listed below were performed in addition to any specified checks outlined in the analytical methods.

Daily QA/QC Verifications:

- Turbidity calibration of the inline meters checked by comparison with bench top turbidimeter results; and
- Change in chemical tank volumes calculated to confirm calibration of each metering pump.

Weekly QA/QC Verifications:

- Inline flow meters cleaned of any fouling buildup, as needed. Flow rate verified volumetrically using the bucket and stop watch or tank fill time;
- Inline totalizer meter cleaned of any material buildup as needed. Production rate verified volumetrically and volume monitored and recorded over time based on calibrated flow rate;
- Tubing, piping, and connections verified to be in good condition and replaced as necessary; and,
- Chemical metering pumps flow rate verified by graduated cylinder attached and stop watch.

One-Time QA/QC Verifications:

- Accuracy of pressure gauges was confirmed based on receiving a manufacturer's calibration statement. All gages were new.

Analytical Methods

The analytical methods utilized in this verification test for laboratory samples and for on-site monitoring of water quality are shown in Table 3-8.

Sampling procedures are described in Section 3.9.4. All samples were grab samples taken at designated sampling ports. The sampling valves were flushed for a minimum of five seconds before a grab sample was collected.

The QAPP provided specific calibration procedures for the analytical methods performed on site and also a summary of the laboratory calibration requirements based on the analytical methods.

The NSF Chemistry Laboratory performed all water quality analyses using EPA or Standard Methods procedures as shown in Table 3-8. All of the required calibration curves and quality control procedures were documented in accordance with the published methods, and as described in the QAPP in the PSTP.

3.10 Operation and Maintenance

A draft O&M manual was received from ORCA when the KemLoop System was installed. NSF reviewed the O&M manual and evaluated the instructions and procedures for their applicability during the verification test and for overall completeness. Results of the O&M manual review are reported in Chapter 4.

3.10.1 Maintenance

Evaluation during the verification test and review of the O&M manual included confirmation whether the manufacturer provided readily understood information on the recommended or required maintenance schedule for the following:

Operating equipment:

- Pumps,
- Valves,
- Pressure gauges,
- Flow meters,
- Chemical feeders,
- Motors,
- Flow meters, and
- Continuous turbidimeters and pH meters.

Non-mechanical or non-electrical equipment:

- Tanks,
- Piping, and
- Filter modules.

3.10.2 Operation

The following operating aspects were evaluated.

Pre-oxidant generation/feed:

- Measurement of pre-oxidant concentration fed.

Chemical feeder pumps:

- Calibration check;
- Settings and adjustments, with instructions on changing; and
- Dilution of chemicals, including proper procedures.

Granular media filtration:

- Control of filtration flow and rate; and
- Observation and measurement of head loss across the media during the filter run.

Granular media backwashing:

- Programming of automated frequency,
- Use of alternative water source,
- Proper backwash venting and disposal,
- Appropriate backwash rate, and
- Observation during return of filter to service.

Monitoring and observing operation:

- Filtered and raw water turbidity,
- Filtered and raw water pH,
- Filter head loss,
- Measurement of the iron coagulant dose, and
- Measurement and control of the pH of coagulated water.

The protocol recommends that a manufacturer provide a troubleshooting guide with a simple checklist of what to do for a variety of problems, including:

- No raw water (feed water) flow to plant;

- Inability to control rate of flow of water through equipment;
- No chemical feed;
- Loss of pre-oxidant feed;
- Calibration and maintenance of inline pH monitoring instruments, problems of erratic pH or drifting pH readings;
- Inability to backwash filter or to change backwash rate of flow;
- No reading on turbidimeter;
- Automatic operation (if provided) not functioning;
- Filtered water turbidity too high;
- Excessive and rapid filter head loss build up;
- Valve stuck or inoperable;
- Low feed pump pressure;
- Pump cavitation; and
- No electric power.

The O&M manual was reviewed for the information and degree of detail provided on these and other operating conditions observed during the verification test.

3.10.3 Operability Evaluation

The following formed the basis of the review and evaluation for equipment operability during verification testing. These aspects of plant operation were reported to the extent practical in the verification report.

The factors considered included:

- Fluctuation of chemical feed rate from the desired value:
  - How long can feed pumps hold the feed rate on a set value?
  - How frequently is resetting needed?
- Ability to maintain desired pre-oxidant feed rate.
- Presence of devices to aid the operator with chemical dosage selection:
  - Influent and filtered water continuous turbidimeters provided?
  - Inline pH meter provided?
  - Inline free chlorine analyzer provided?
- Can automatic backwash be initiated by:
  - Reaching a set value for head loss?
  - Reaching a set turbidity level in the treated water?
  - Default minimum time?
- Does plant have multiple feed points for chemicals:
  - For pH adjustment?
  - For coagulant chemical feed?
  - For oxidants?
- Is granular media pressure differential measurement provided?
- Is rate of flow of raw water measured?
- Is chemical feed paced with raw water flow?

- Can coagulation pH be maintained automatically if raw water flow changes?
- Is backwash rate of flow measured and variable?
- Is backwash duration (time) variable?

Other factors and questions included:

- Does the equipment have sensors or monitoring equipment that can detect an equipment malfunction, unsatisfactory filtrate water quality, or operating conditions that exceed allowable limits?
- If so, during such situations can the equipment be automatically shut down?
- Upon automatic shutdown, can notification be provided if the operator is not present on site?

Chapter 4
Results and Discussion

4.1 Introduction

The verification test program for the KemLoop System began with equipment installation at the St. Louis Center in Chelsea, Michigan, on February 22, 2005 and ended with the completion of the verification test on April 6, 2005. The test site was described in Section 1.3. The KemLoop System was described in Chapter 2.

The equipment was installed the week of February 20, 2005. ORCA conducted start-up and shakedown testing through March 11, 2005. Raw water characterization samples were collected on February 24 and March 9, 2005. The arsenic loss test was performed from March 14-15, 2005. The 14-day (336 hour) verification test, including a 48-hour intensive survey, was performed from March 23 through April 6, 2005.

This chapter presents a summary of the water quality and operating data collected during the verification test. Activities and data collected during the start-up and shakedown of the equipment, raw water characterization, and the arsenic loss test describe activities performed prior to the actual 14-day verification test. The results for the 14-day verification test are presented, including data on raw water, feed water, and filtrate water arsenic and other water quality parameters. Operating data are presented to describe the flow rates, volume of treated water produced, backwash volumes and frequency, pressure differential across the filter, and related operating information. QA/QC information, as described by the QAPP in the PSTP for this verification test, is presented at the end of the chapter.

4.2 Equipment Installation, Start-up, and Shakedown

ORCA personnel installed the equipment at the site with assistance from the Center staff during the week of February 20, 2005. The unit was shipped as a complete system inside of a standard 8 X 20 foot shipping container, except for the filtrate water and backwash water holding tanks. Piping was installed to route raw water from the pressure supply tank inside the building to the KemLoop System, which was placed outside the building. The raw water line included a back flow preventer and pressure regulator to control pressure and flow to the unit. The KemLoop System included locations in the raw water line to inject sodium hypochlorite (source of chlorine) and ferric chloride (coagulant), using chemical metering pumps supplied by ORCA. The system installation was completed over a three-day period.

During the week of February 28, ORCA ran a series of tests that included operating at varying doses of ferric chloride and residual chlorine in the feed water to the mixing loop. The inline analyzers for pH and turbidity were used to monitor the system, along with a field test kit to check the iron concentration in the feed and filtrate water. Samples of raw water, feed water (after chemical addition), and filtrate water were collected for laboratory analysis for total arsenic. Eight filtrate samples were collected under varying operating conditions and analyzed for arsenic concentration. Six of the eight samples were below the detection limit of 1 µg/L; the other two results were in the 1-3 µg/L range.

The data obtained by ORCA are on file at NSF. Based on the data, ORCA set the basic operating conditions that were used for the verification test.

Results of the shakedown tests showed that arsenic could be removed at a total residual chlorine concentration of 1 mg/L in the filtrate, and with the addition of approximately 1.5-2.5 mg/L (as Fe) of ferric chloride, supplementing the naturally occurring iron in the raw water (approximately 0.5 mg/L). Results showed that pH adjustment was not needed. The data suggested that lower doses of ferric chloride could achieve similar results, but ORCA determined that the best operating condition for this water was to use 2 mg/L (as Fe) of ferric chloride, and 1 mg/L total residual chlorine with no pH adjustment. These concentrations of oxidant and coagulant were the target chemical concentrations used for the 14-day verification test.

The pressure differential on the filter only increased slightly after two days of operation without backwashing the filters, and the filtrate turbidity remained low. Therefore, ORCA determined that backwash cycles would be set to operate on time, in addition to pressure differential and turbidity differential. Backwash was set to occur once every 24 hours. The PLC was set to initiate a backwash if the pressure differential increased to 8 psi or when the effluent turbidity increased to a level higher than the raw water turbidity for more than ten minutes.

The KemLoop System was operated from March 3-14, 2005, when the unit was backwashed and prepared for the arsenic loss test. During this time, ORCA staff monitored the system from their office using the on-site laptop PC and an Internet connection. The ORCA staff also checked on the unit on a regular basis and filled the chemical feed tanks as needed.

4.3 Task A: Raw Water Characterization

Historical water quality data collected by NSF at the Center for the individual wells and the combined water were obtained in the initial planning stage for this verification test. As shown in Table 1-1 and 1-2, the total arsenic concentrations were in the range of 14-48 µg/L, and total iron ranged from 0.36-2.8 mg/L. A sample of the combined water in the pressure tank, which was the raw water source for this verification test, was collected on February 24, 2005. The chemical analyses included total arsenic and arsenic speciation (arsenic [III] and [V]) and other water quality parameters.

The results of the initial raw water characterization test are presented in Table 4-1. The data confirmed that the raw water quality was similar to the historical water quality used to plan the verification test. However, the results for total and speciated arsenic had high detection limits due to an apparent interference in the raw water sample in the laboratory. Therefore, additional samples, including samples of each well and the combined raw water as it was fed to the KemLoop System, were collected on March 9, 2005, for total arsenic analysis. The treatment unit was operating at this time, so a sample of filtrate was also collected. These data are included in Table 4-1. The second set of samples confirmed that the raw water contained total arsenic at levels that had been measured in the past and were acceptable for the verification test.

Table 4-1. Raw Water Characterization Data – February 24 and March 9, 2005

Parameter	Units	Combined Wells[1]	Well #1	Well #2	Filtrate
Date		2/24/05			
pH	S.U.	7.41	---	---	---
Temperature	^{o}C	11.1	---	---	---
Turbidity	NTU	1.2	---	---	---
Free Chlorine	mg/L	<0.05	---	---	---
Total Chlorine	mg/L	<0.05	---	---	---
Dissolved Oxygen	mg/L	6.4	---	---	---
True Color[2]	C.U.	13	---	---	---
Alkalinity	mg/L as $CaCO_3$	250	---	---	---
Total Arsenic	µg/L	<2	---	---	---
Dissolved Arsenic	µg/L	<20	---	---	---
Arsenic (III)	µg/L	<20	---	---	---
Arsenic (V)	µg/L	<20	---	---	---
Iron	mg/L	0.39	---	---	---
Manganese	µg/L	12	---	---	---
Chloride	mg/L	33	---	---	---
Sulfate	mg/L	20	---	---	---
TOC	mg/L	0.6	---	---	---
Fluoride	mg/L	0.6	---	---	---
Calcium	mg/L	71	---	---	---
Magnesium	mg/L	28	---	---	---
Hardness	mg/L as $CaCO_3$	290	---	---	---
Date		3/9/05			
Total Arsenic	µg/L	18	16	19	<2

"---" = Not required or scheduled for analysis.

(1) Combined sample taken from pressure tank.

(2) High color may be due to oxidation of iron. In addition, color sample was not filtered before analysis.

4.4 Task B: Initial Test Runs

4.4.1 Arsenic Loss Test

The arsenic loss test, to determine if arsenic is removed and retained by the system without chemical addition, was performed over a 24-hour period beginning on March 14, 2005. The system had to be clean prior to starting the test. Therefore, a backwash cycle was initiated prior to testing. The unit was placed in normal treatment mode at a flow rate of approximately 10 gpm with all chemical feeds turned off. The system was operated for two hours prior to starting the arsenic loss test. This provided an ample flushing time in case any residual chemically treated water remained in the mixing loop, which had a retention time of approximately five minutes.

The operating data and results from the 24-hour arsenic loss test are shown in Table 4-2. A fairly steady flow rate averaging 10.3 gpm was maintained during the test run. The total volume processed during the 24-hour period was 14,970 gallons. The pressure differential between the feed water (filter inlet) and the filtrate (filter outlet) did not increase during the 24-hour period, varying from 0-4 psi.

Table 4-2. Arsenic Loss Test Operating Data

Date	Time	Raw Pressure (psi)	Feed Pressure (psi)	Filtrate Pressure (psi)	Pressure Delta[1] (psi)	Flow Rate (gpm)	Total Volume Treated (gal)
3/14/05	11:30	32	4	0	4	9.9	0
	18:02	42	5	2	3	11.6	3,710
3/15/05	00:01	40	4	1	3	10.8	6,520
	06:10	36	3	3	0	10.3	11,470
	12:00	38	3	0	3	9.0	14,970

(1) Pressure Delta is the pressure differential or head loss through the filter as measured by the pressure difference between the feed and filtrate.

Tables 4-3 and 4-4 show the water quality for the arsenic loss test. All statistical calculations of these data are presented in Appendix D. There was only a small loss of arsenic through the system over the 24-hour test, with feed water total arsenic averaging 19 µg/L and the filtrate averaging 16 µg/L. Arsenic (III) was the predominate arsenic species in the raw water. Only a slight oxidation of the arsenic was observed as the water came in contact with oxygen and passed through the system. The small arsenic loss was most likely associated with arsenic coagulated with the naturally occurring iron and removed with the iron on the filters. Turbidity, iron, and color were removed by the filtration system as expected. All other water quality indicators remained steady and passed through the filter. It should be noted that the raw water sample was taken from the pressure tank outlet line where it entered the treatment system shipping container. The high color in the raw water is not typical of a deep groundwater. Naturally occurring iron oxidizing in the pressure tank may have caused the high color. Also, the sample was not filtered prior to measuring the color.

Table 4-3. Arsenic Loss Test Water Quality Results

Parameter	Units	Raw Water				Feed Water				Filtrate			
		3/14/05	3/15/05			3/14/05	3/15/05			3/14/05	3/15/05		
		18:02	00:01	06:10	12:00	18:02	00:01	06:10	12:00	18:02	00:01	06:10	12:00
Total Arsenic	µg/L	20	18	19	20	20	19	19	19	15	15	20	16
Dissolved Arsenic	µg/L	19	---	---	16	20	---	---	18	17	---	---	10
Arsenic (III)	µg/L	16	---	---	14	14	---	---	14	12	---	---	7
Arsenic (V)	µg/L	3	---	---	2	6	---	---	4	5	---	---	3
Iron	mg/L	0.38	0.39	0.38	0.38	0.35	0.34	0.33	0.33	<0.02	0.05	<0.02	0.07
pH (bench top)	S.U.	7.35	7.39	7.06	7.48	7.43	7.40	7.39	7.38	7.44	7.44	7.47	7.44
pH (inline)	S.U.	7.44	7.46	7.45	7.46	7.50	7.48	7.48	NR	---	---	---	7.48
Temperature	^{0}C	11.3	11.0	11.0	11.3	11.4	11.9	11.6	11.5	11.6	12.2	11.4	13.0
Turbidity (bench top)	NTU	1.14	1.18	1.01	0.19	0.89	1.02	1.31	0.86	0.15	0.28	0.33	0.19
Turbidity (inline)	NTU	0.908	0.761	0.901	0.485	---	---	---	---	0.054	0.053	0.05	0.309
Alkalinity	mg/L as CaCO$_3$	270	280	270	270	270	270	270	270	270	270	270	280
Free Residual Chlorine	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Residual Chlorine	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Dissolved Oxygen	mg/L	4.5	4.0	6.3	4.0	---	---	---	---	4.0	4.2	5.0	5.2

Note: Turbidity monitored at start of test (11:30 AM) – Raw water: 0.71 NTU; Filtrate: 0.06 NTU.
pH monitored at start of test (11:30 AM) – Raw water: 7.41; Feed: 7.22; Filtrate: 7.26.
Dissolved oxygen monitored at start of test (11:30 AM) – Raw water: 4.6 mg/L; Filtrate: 4.4 mg/L.
NR = Not Recorded.
"---" = Not required or scheduled for analysis.

Table 4-4. Arsenic Loss Test Daily Water Quality Results

Parameter	Units	Raw	March 15, 2005 12:00 Feed	Filtrate
Manganese	µg/L	11	---	11
Calcium	mg/L	74	---	74
Magnesium	mg/L	23	---	23
Hardness	mg/L as $CaCO_3$	280	---	280
Chloride	mg/L	11	11	11
Sulfate	mg/L	19	19	19
Fluoride	mg/L	0.5	---	0.5
TOC	mg/L	0.6	---	0.6
True Color(1)	C.U.	7	14	<1

"---" = Not required or scheduled for analysis.

(1) The true color test was performed without filtering the sample that is required by the method.

At the end of the arsenic loss test, the filter was backwashed and a sample of the backwash water was collected and analyzed. The backwash contained 240 µg/L of total arsenic and 31 mg/L of iron. The TSS concentration was 86 mg/L. The total residual chlorine and free residual chlorine results showed a concentration of 1.0 mg/L residual chlorine in the backwash water. However, this was a false positive reading due to the presence of a yellow color in the backwash water that interfered with the residual chlorine test. The backwash water pH was 7.56.

4.5 Task C: Verification Test

4.5.1 Operating Results

The KemLoop System was backwashed and the verification test started on March 21, 2005. The KemLoop System was set to the operating criteria established by ORCA during the shakedown testing. Chemical feeds were established to supply sufficient bleach to maintain total residual chlorine in the feed water of approximately 0.5-1.0 mg/L. The ferric chloride feed rate was set to deliver 2 mg/L of ferric chloride (as Fe) to the raw water. Based on the previous operating data, the flow rate for filtrate was set at 10 gpm to give a target filter surface-loading rate of 2,940 gfd, based on 24-hour filter runs. The backwash system was set to backwash the filter every 24 hours unless initiated automatically due to a pressure differential of 8 psi or if the filtrate turbidity was higher than the raw turbidity for 10 minutes. The backwash cycle was set to four minutes in length at a flow rate of approximately 55-60 gpm.

On March 22, it was discovered that the ferric chloride metering pump had fallen off its stand, and ferric chloride had leaked from a broken inlet pipe. The spilled material was cleaned up, the problem was fixed, and the system was placed back in operation. The verification test was scheduled to restart on March 23. The KemLoop System backwash was set to backwash every

24 hours at approximately 10:40 AM. Therefore, the verification test started officially at 11:40 AM on March 23, following completion of the backwash cycle and approximately one half hour for the system to stabilize. The verification test ended on April 6 at 11:40 AM, 336 hours (14 days) later. During the verification test, the KemLoop System operated continuously 24-hours per day.

Table 4-5 shows the daily operating data for the verification test. The filtrate flow rate remained steady for most days during the test, yielding an average flow rate of 9.9 gpm over the 14 days. The total filtrate volume produced each day was also consistent, except for April 2-4, when volumes and flow rates were somewhat lower. It appears the pressure on the raw water supply tank at the Center was periodically dropping below 40 psi (the setting on the pressure regulator). This caused periodic lower flow rates and lower volumes of filtrate to be produced over the 24-hour period. The average hydraulic loading through the filter was 2,890 gfd, based on the 24-hour filter run time between backwashes and the average daily filtrate production of 14,630 gallons.

The pressure on the system was monitored at three locations: raw water, feed water (inlet to the filter), and filtrate (exit of the filter). There was very little change in head loss through the filter over each 24-hour operating period. The maximum pressure differential observed was 5.0 psi. The filter was set to backwash automatically if the pressure differential reached 8.0 psi. The automatic backwash cycle was not triggered due to pressure differential (head loss) at any time during the verification test.

The filter was backwashed every 24 hours on a time basis. The successful completion of the backwash cycle was confirmed each day by the DWTS field staff. All backwash water was collected in a holding tank. Each day the on-site operator checked the water level in the holding tank to confirm how many backwashes had occurred. The operator then emptied the tank manually. The operators reported that one backwash had occurred each day during the verification test. In each case this backwash was based on the maximum time of 24 hours between backwashes having been achieved.

The time to complete the backwash cycle was measured once during the arsenic loss test and four times during the verification test. Backwash cycle time varied from 4 minutes to 4 minutes 10 seconds. The backwash volume was monitored on eight days during the verification test by observing the volume of water generated during the previous 24-hour period. The total backwash volume generated averaged 220 gallons per backwash.

Table 4-5. Operating Data

Date	Filtrate Flow Rate (2) (gpm)	Total Filtrate Volume (3) (gal)	Raw Pressure (psi)	Feed Pressure (psi)	Filtrate Pressure (psi)	Filter Pressure Difference (psi)	Operating Hours (hours)
3/23/05(1)	14.4	0	38	21	17	4.0	0
3/24/05	11.1	15,180	43	5.0	3.0	2.0	24
3/25/05	10.7	15,650	37	5.5	3.0	2.5	24
3/26/05	10.5	14,280	45	7.5	3.0	4.5	24
3/27/05	9.6	15,190	32	6.8	2.5	4.3	24
3/28/05	9.9	15,600	37	7.0	3.0	4.0	24
3/29/05	10.8	15,310	40	5.0	1.0	4.0	24
3/30/05	9.7	14,960	34	6.0	3.5	2.5	24
3/31/05	10.3	15,070	38	5.5	2.5	3.0	24
4/1/05	10.0	15,700	40	5.5	3.0	2.5	24
4/2/05	9.9	12,750	40	6.5	3.0	3.5	24
4/3/05	6.1	12,620	35	5.5	1.0	4.5	24
4/4/05	8.5	11,280	34	5.0	0.0	5.0	24
4/5/05	10.2	15,950	40	5.0	0.0	5.0	24
4/6/05	10.7	14,940	40	5.0	0.0	5.0	24
Number of samples	14	14	14	14	14	14	14
Average	9.9	14,630	38	5.8	2.0	3.7	24
Maximum	11.1	15,600	45	7.5	3.5	5.0	24
Minimum	6.1	11,280	32	5.0	0.0	2.0	24
Std. Deviation	1.2	1420	3.6	0.85	1.3	1.1	NC
95% Conf. Interval	(9.1,10.6)	(13,810, 15,450)	(36,40)	(5.3,6.3)	(1.3, 2.8)	(3.1,4.3)	NC

(1) The March 23rd data are for day zero and are the readings taken at the start of the test. These data are not included in the statistical calculations. They are provided for information only.

(2) Flow rate was the instantaneous reading each morning when the field staff checked the system.

(3) The gallons produced per filter run correspond to the daily filtrate volume, as the filter was backwashed once every 24 hours.

NC = Not Calculated.

4.5.2 Arsenic Results

The determination of total arsenic removal using the KemLoop System was the primary objective of the verification test. This section presents the arsenic results for the raw, feed, and filtrate water monitored daily during the verification test. Also included are the results from the 48-hour intensive survey, when samples for arsenic analysis were collected on a more frequent basis. The total arsenic data are presented in Tables 4-6 and 4-7. Arsenic speciation data are presented in Table 4-8. Figure 4-1 shows the arsenic results plotted for the 14-day test.

The total arsenic in the raw water and feed water averaged 23 µg/L and 22 µg/L, respectively, based on the daily sample results. Over the 14-day period, the maximum total arsenic was 32 µg/L in the raw water and the minimum was 19 µg/L. The arsenic speciation data for the raw water showed that most of the arsenic was present as arsenic (III).

The KemLoop System removed total arsenic to less than detection limit (1 µg/L) on 6 of the 14 days tested. Total arsenic exceeded 10 µg/L, the maximum contaminant level (MCL), on two days, the first and last days of the test. The average filtrate concentration was 3 µg/L. The average value and other statistics shown in Tables 4-6 and 4-7 were calculated by using the value of the detection limit for concentrations reported below the detection limit of 1 µg/L. The samples that had an elevated detection limit of <10 µg/L where excluded from the statistics so that the statistics were not biased by these elevated detection limit results.

The total arsenic result for the first day (March 25) was above 10 µg/L, which is the MCL for drinking water. The elevated arsenic filtrate level on the first sampling day can be attributed to an overdose of ferric chloride that occurred during the previous 24 hours of operation. Also, the turbidity level in the filtrate was above 1 NTU, the highest turbidity level recorded during the verification test. The high turbidity occurred during the last two hours of the filter run prior to backwash; the filtrate sample was collected just before the backwash occurred after 24 hours of operation. In addition, the soluble arsenic for this sample was <1 µg/L, indicating the arsenic in the filtrate was in the particulate form. The data indicate that the arsenic was being precipitated in the mixing loop, but some of the particulate was passing through the filter. After the first day, the filtrate arsenic levels dropped to near or below the detection limit until the last day of the test, when a filtrate concentration of 11 µg/L was recorded. There was no significant change in the filtrate turbidity or iron concentration on this day; both were low and in the typical range of previous days. No explanation could be found as to why the filtrate arsenic concentration was elevated on this day.

The laboratory noted a matrix interference in three filtrate samples. The samples required a dilution of 10:1, which raised the detection limit to 10 µg/L. A similar interference was found in the raw water samples collected in February for raw water characterization. The source of the interference was not known.

The chemical addition of sodium hypochlorite (targeted to maintain 1 mg/L of total residual chlorine) and ferric chloride (target feed of 2 mg/L as Fe) was effective in oxidizing the arsenic (III) to arsenic (V) and precipitating and coagulating the arsenic in the raw water. As shown in Table 4-8, most of the arsenic present in the raw water was in the soluble form, as arsenic (III). The feed water data show that after chemical oxidation and coagulation, all of the arsenic was present in the particulate form, and there were generally low to non-detectable levels of soluble arsenic in the feed water. The effectiveness of this oxidation and precipitation process was key to the results obtained by the KemLoop System. After chemical treatment, all or most of the arsenic was in the particulate form, which the granular filtration system was able to remove. The result was a filtrate with a low level of arsenic.

The data collected during the 48-hour intensive survey were consistent with the data collected each day during the verification test. There was no indication of any transient or short time changes in the arsenic concentration or in any other monitored parameters.

Table 4-6. Daily Total Arsenic Results (µg/L)

Date	Raw	Feed	Filtrate(1)
3/24/05	28	24	12
3/25/05	24	23	1
3/26/05	23	23	<1
3/27/05	25	23	3
3/28/05	21	21	1
3/29/05	20	27	<1
3/30/05	23	22	<1
3/31/05	25	24	2
4/1/05	<10(2)	19	<10(3)
4/2/05	19	20	<1(4)
4/3/05	25	23	<1
4/4/05	32	19	<1
4/5/05	20	19	1(4)
4/6/05	19	21	11
Number of samples	13	14	13
Average	23	22	3
Maximum	32	27	12
Minimum	19	19	<1
Std. Deviation	3.8	2.3	4
95% Conf. Interval	(21, 26)	(21, 23)	(<1, 5)

(1) Concentrations reported as <1 set equal to the detection limit for calculating statistics.

(2) Raw water value considered an outlier; not included in statistics.

(3) This result is not included in the statistics due to the high detection limit.

(4) These results are from the duplicate analyses for these samples. The first sample in both cases was reported as <10 µg/L.

Table 4-7. Total Arsenic Results for 48-Hour Intensive Survey (µg/L)

Date	Time	Raw	Feed	Filtrate(1)
3/30/05	11:15	23	22	<1
3/30/05	12:30	23	20	<1
3/30/05	14:30	23	22	<1
3/30/05	17:25	23	24	2
3/30/05	23:30	25	20	<1
3/31/05	05:30	22	21	<1
3/31/05	11:30	25	24	2
3/31/05	11:45	25	25	<10(2)
3/31/05	12:30	27	23	1
3/31/05	14:30	24	23	1
3/31/05	17:15	18	19	1
3/31/05	23:22	20	19	<1
4/1/05	05:40	23	24	2
4/1/05	11:10	<10(3)	19	<10(2)
Number of samples		13	14	12
Average		23	22	1
Maximum		27	25	2
Minimum		18	19	<1
Std. Deviation		2.3	2.1	0.4
95% Conf. Interval		(22, 25)	(21, 23)	(<1, 2)

(1) Concentrations reported as <1 set equal to the detection limit for calculating statistics.

(2) These results are not included in the statistics due to the high detection limit.

(3) Raw water value considered an outlier; not included in statistics.

Table 4-8. Arsenic Speciation Data (µg/L)

Date		Total Arsenic			Dissolved Arsenic			Arsenic (III)			Arsenic (V)		
		Raw	Feed	Filtrate	Raw	Feed	Filtrate	Raw	Feed	Filtrate	Raw	Feed	Filtrate
3/24/05	Day 1	28	24	12	23	<1	<1	21	<1	<1	2	<1	<1
3/24/05	Duplicate	28	23	12	22	<1	<1	21	<1	<1	1	<1	<1
3/30/05	Day 7	23	22	<1	20	12	3	17	2	<1	3	10	3
3/31/05	Day 8(1)	25	24	2	62	4	15	22	2	1	40	2	14
4/1/05	Day 9	<10	19	<10	<10	<10	<10	21	<1	<1	<10	<10	<10

(1) March 31 Day 8 sample results appear to be anomalous.

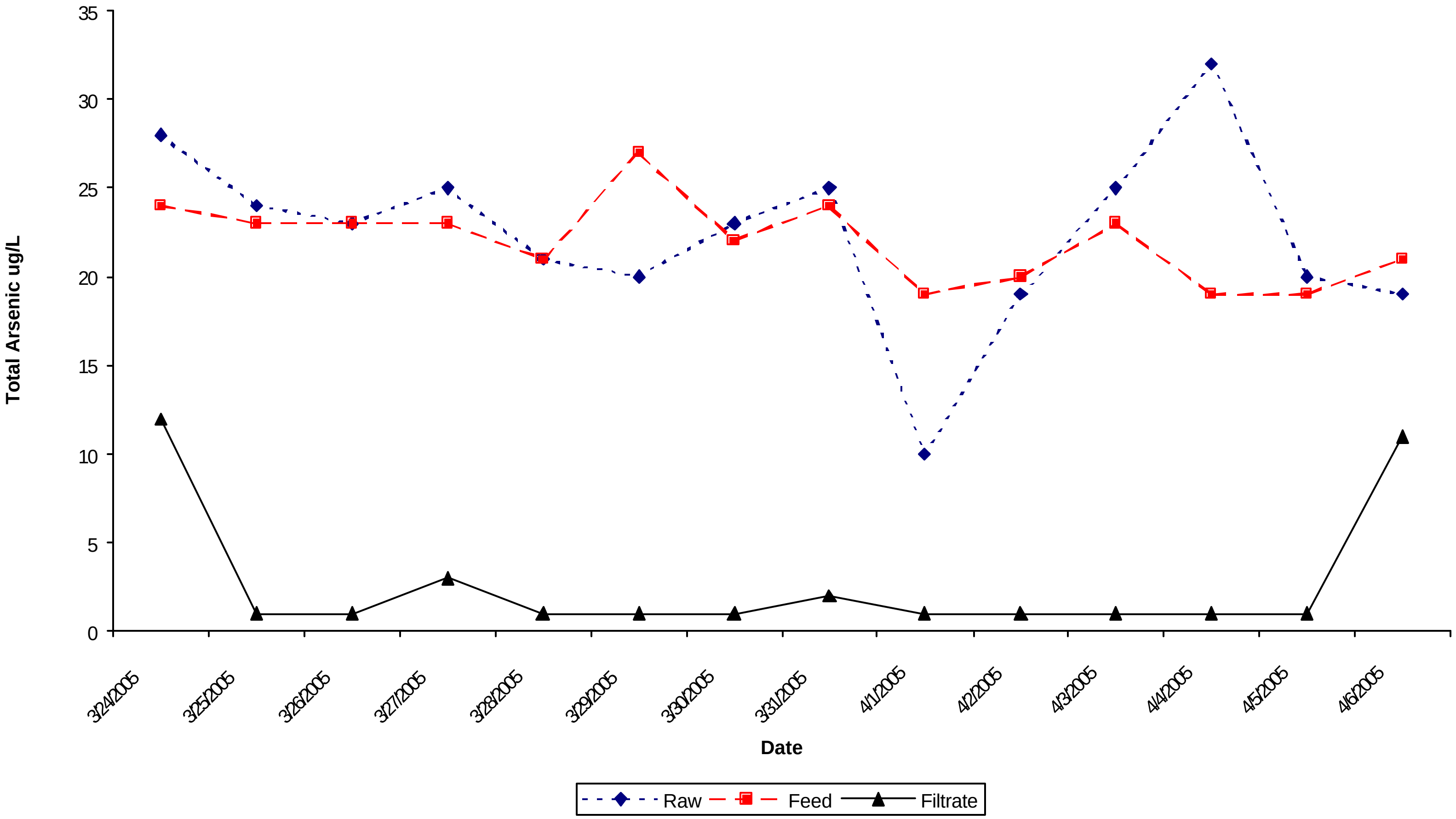

Figure 4-1. Verification test daily arsenic results.

4.5.3 Raw, Feed, and Filtrate Water Quality Results

Water quality data were collected each day for pH, temperature, turbidity, and chlorine (total and free residual). Samples for iron and alkalinity analyses were also collected daily. These parameters were key water quality indicators and important to this technology, which uses chlorine oxidation and iron coagulation as part of the process. Dissolved oxygen was monitored daily in the raw water, as it can affect the oxidation of iron and arsenic (III). Other water quality parameters were monitored on a weekly basis, including calcium, magnesium, total hardness, manganese, sulfate, chloride, fluoride, TOC, and color. All of the field data log sheets and laboratory reports are included in Appendices B and C.

Tables 4-9 and 4-10 present the individual pH measurements for the daily samples and for the 48-hour intensive survey. Figure 4-2 shows the pH for the raw, feed, and filtrate water from the daily samples. The raw water pH was steady in the range of 7.20-7.48 during the verification test period. The addition of chlorine and ferric chloride had very little impact on the feed water pH. Feed pH ranged from 7.10-7.49, which was similar to the raw water results. The negligible impact of the chemical addition on feed water pH was most likely due to the high alkalinity of the raw water and the small amount of chemical required at this site. Other locations with lower alkalinity or sites requiring higher chemical doses may exhibit a larger change in pH in the feed water. The filtrate pH was very similar to the feed water pH, as expected. The filtrate pH ranged from 7.22-7.46, with a median value of 7.30. The pH during the 48-hour intensive survey was monitored frequently and showed similar results to the daily pH levels found over the 14-day verification test.

Table 4-9. pH Results (S.U.)

Date	Raw	Feed	Filtrate
3/23/05	7.38	7.10	7.30
3/24/05	7.32	7.34	7.28
3/25/05	7.48	7.35	7.26
3/26/05	7.26	7.24	7.26
3/27/05	7.28	7.45	7.46
3/28/05	7.47	7.49	7.40
3/29/05	7.39	7.35	7.44
3/30/05	7.27	7.31	7.38
3/31/05	7.30	7.28	7.30
4/1/05	7.30	7.22	7.22
4/2/05	7.32	7.32	7.34
4/3/05	7.47	7.40	7.37
4/4/05	7.29	7.22	7.28
4/5/05	7.20	7.19	7.23
4/6/05	7.24	7.27	7.26
Number of samples	15	15	15
Median	7.30	7.31	7.30
Maximum	7.48	7.49	7.46
Minimum	7.20	7.10	7.22

Table 4-10. pH Results (Bench Top) for the 48-Hour Intensive Survey (S.U.)

Date	Time	Raw	Feed	Filtrate
3/30/05	11:15	7.27	7.31	7.38
3/30/05	12:30	7.59	7.50	7.49
3/30/05	14:30	7.50	7.48	7.41
3/30/05	17:25	7.47	7.37	7.36
3/30/05	23:30	7.25	7.22	7.26
3/31/05	05:30	7.37	7.46	7.42
3/31/05	11:30	7.30	7.28	7.30
3/31/05	11:45	7.34	7.33	7.37
3/31/05	12:30	7.31	7.18	7.23
3/31/05	14:30	7.30	7.15	7.20
3/31/05	17:15	7.17	7.18	7.24
3/31/05	23:22	7.04	7.01	7.19
4/1/05	05:40	7.37	7.34	7.18
4/1/05	11:10	7.25	7.28	7.26
Number of samples		14	14	14
Median		7.31	7.30	7.28
Maximum		7.59	7.50	7.49
Minimum		7.04	7.01	7.18

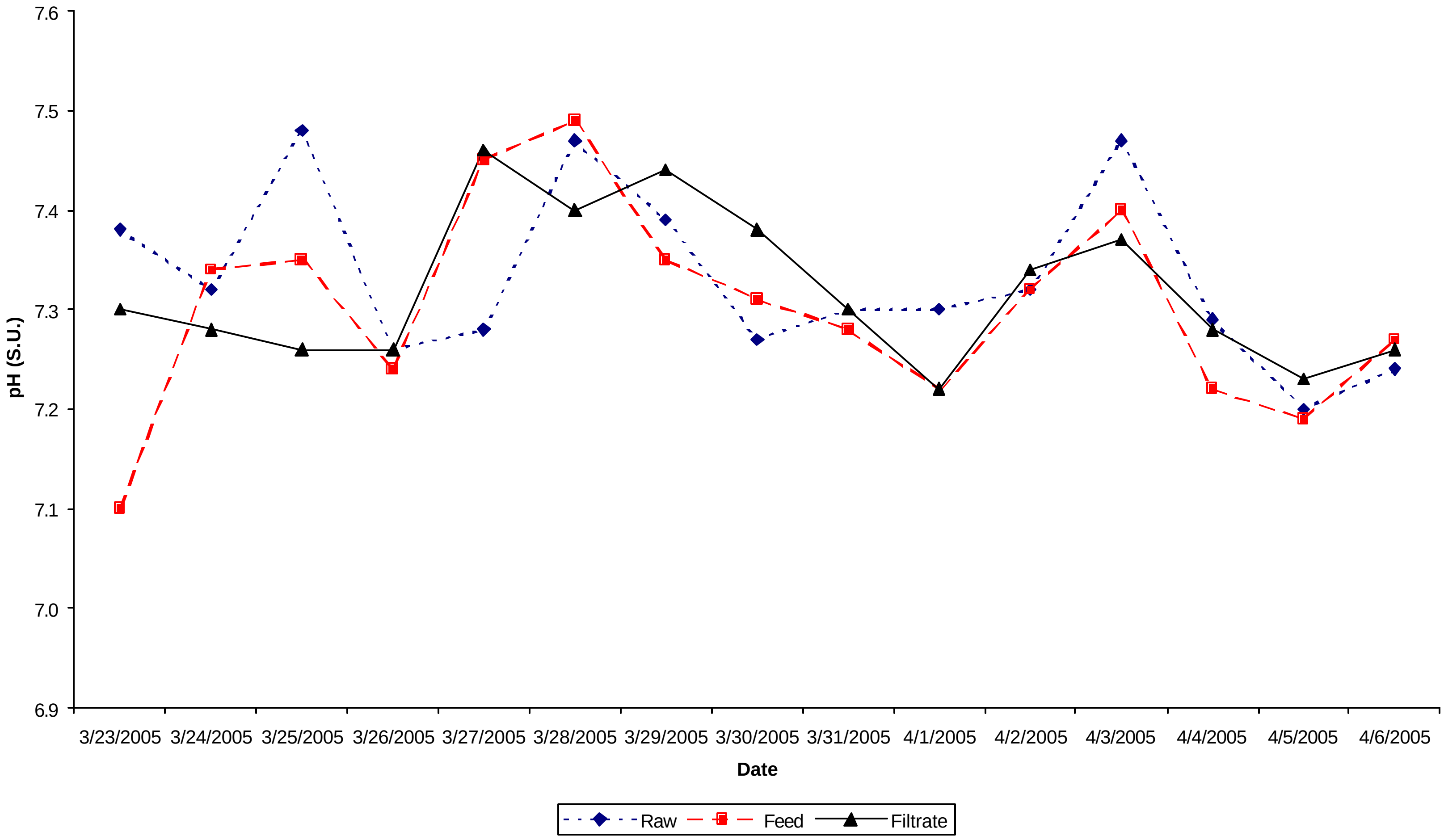

Figure 4-2.. Verification test pH results.

Tables 4-11 and 4-12 present the individual turbidity measurements for the daily turbidity levels and for the 48-hour intensive survey. Figure 4-3 shows the turbidity for the raw, feed, and filtrate water from the daily samples. The filtrate turbidity was low, averaging 0.30 NTU based on the bench top turbidimeter used by the field personnel. In addition to the bench top turbidity meter, the KemLoop System had inline turbidity meters on the raw and filtrate water lines. The inline turbidimeter showed the filtrate averaged 0.179 NTU.

The bench top turbidity meter always gave higher turbidity readings compared to the inline units. As an example, the raw water turbidity based on the bench top unit averaged 2.4 NTU, whereas the average turbidity based on the inline unit was 0.578 NTU. The inline unit was calibrated using appropriate standards, as was the bench top unit. It is believed that the bench top unit data may have been biased high due to temperature and slight fogging issues that can be problematic when collecting cold samples and transferring them to the bench top vials. Based on the bench top meter measurements, the filtrate was below 0.5 NTU in 93% of samples. There were no values between 0.5 and 1 NTU, and 7% of the readings (1 reading) were between 1 and 2 NTU. No turbidity levels were measured above 2 NTU. The inline turbidimeter gave the same distribution of turbidity readings in the filtrate.

During the 48-hour intensive survey, the turbidity readings were taken from the inline turbidity unit. Results during the 48-hour intensive survey were very similar to the daily results over the 14-day verification test. The turbidity levels in the filtrate did tend to increase slightly near the end of each filter run. Turbidity appeared to increase slightly and then decrease after the active filter was taken off line for backwashing and the standby filter was brought on line. However, all turbidity measurements for the filtrate were below 0.2 NTU, even at the end of a 24-hour run.

Table 4-11. Turbidity Results (NTU)

	Turbidity (bench top)[1]			Turbidity (inline)	
Date	Raw	Feed	Bench top Filtrate	Raw	Inline meter Filtrate
3/23/05	3.15	4.04	1.85	NR	1.36
3/24/05	0.67	2.45	0.37	0.96[2]	0.232
3/25/05	1.58	2.10	0.13	0.347	0.034
3/26/05	0.96	1.53	0.32	0.513	0.260
3/27/05	5.62	4.70	0.19	0.680	0.039
3/28/05	4.81	1.38	0.17	0.554	0.089
3/29/05	1.54	1.62	0.21	0.670	0.127
3/30/05	1.04	2.18	0.30	0.495	0.185
3/31/05	2.54	2.28	0.21	0.407	0.096
4/1/05	1.74	1.83	0.10	0.570	0.032
4/2/05	1.16	2.00	0.10	0.750	0.051
4/3/05	6.84	1.64	0.04	0.441	0.037
4/4/05	1.92	1.76	0.33	0.544	0.035
4/5/05	1.74	3.14	0.21	0.650	0.077
4/6/05	1.20	0.96	0.32	0.505	0.036
Number of samples	15	15	15	14	15
Average	2.4	2.2	0.30	0.578	0.179
Maximum	6.8	4.7	1.9	0.96	1.36
Minimum	0.65	0.95	<0.05	0.347	0.032
Std. Deviation	1.9	1.0	0.45	0.157	0.335
95% Conf. Interval	(1.4, 3.5)	(1.7, 2.8)	(0.1, 0.55)	(0.487, 0.668)	(0.000, 0.365)

(1) Bench top statistics have been rounded according to the *Standard Method* guidelines.

(2) The field log recorded this result as 0.096 NTU, but review of the PLC records indicates the value should be reported as 0.96 NTU.

NR = Not Recorded.

Table 4-12. Inline Turbidity Results for the 48-Hour Intensive Survey (NTU)

Date	Time	Raw	Filtrate
3/30/05	11:15	0.495	0.185
3/30/05	12:30	0.531	0.046
3/30/05	14:30	0.568	0.031
3/30/05	17:25	0.715	0.047
3/30/05	23:30	0.680	0.030
3/31/05	05:30	0.679	0.045
3/31/05	11:30	0.407	0.096
3/31/05	11:45	0.605	0.034
3/31/05	12:30	0.491	0.035
3/31/05	14:30	0.490	0.035
3/31/05	17:15	0.860	0.065
3/31/05	23:22	0.731	0.036
4/1/05	05:40	0.654	0.036
4/1/05	11:10	0.569	0.070
Number of samples		14	14
Average(1)		0.605	0.057
Maximum		0.860	0.185
Minimum		0.407	0.030
Std. Deviation		0.122	0.041
95% Conf. Interval		(0.535, 0.676)	(0.033, 0.080)

(1) Statistics have been rounded according to the *Standard Method* guidelines.

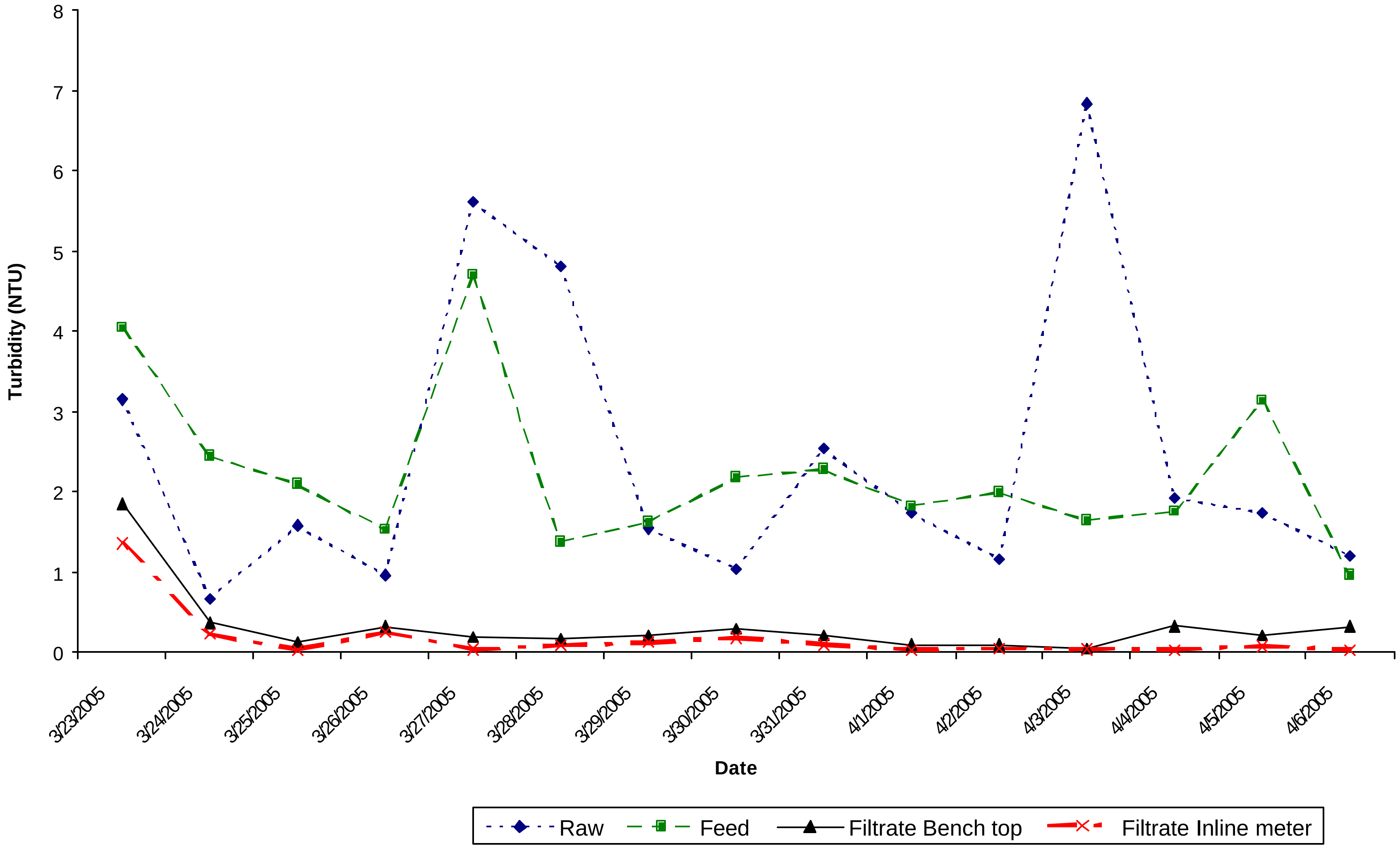

Figure 4-3. Verification test turbidity results.

Figure 4-4 presents the alkalinity results for the raw, feed, and filtrate water. The raw water averaged 260 mg/L as $CaCO_3$ and was stable throughout the test. The maximum concentration was 270 mg/L and the minimum was 220 mg/L. The alkalinity in the feed water also averaged 260 mg/L, with a maximum of 270 mg/L and a minimum of 220 mg/L. There was no change in alkalinity through the filter. The filtrate alkalinity averaged 260 mg/L, with a maximum of 270 mg/L and a minimum of 220 mg/L. The alkalinity concentration during the 48-hour intensive survey was similar to the levels found during the entire verification test, as shown in Table 4-13.

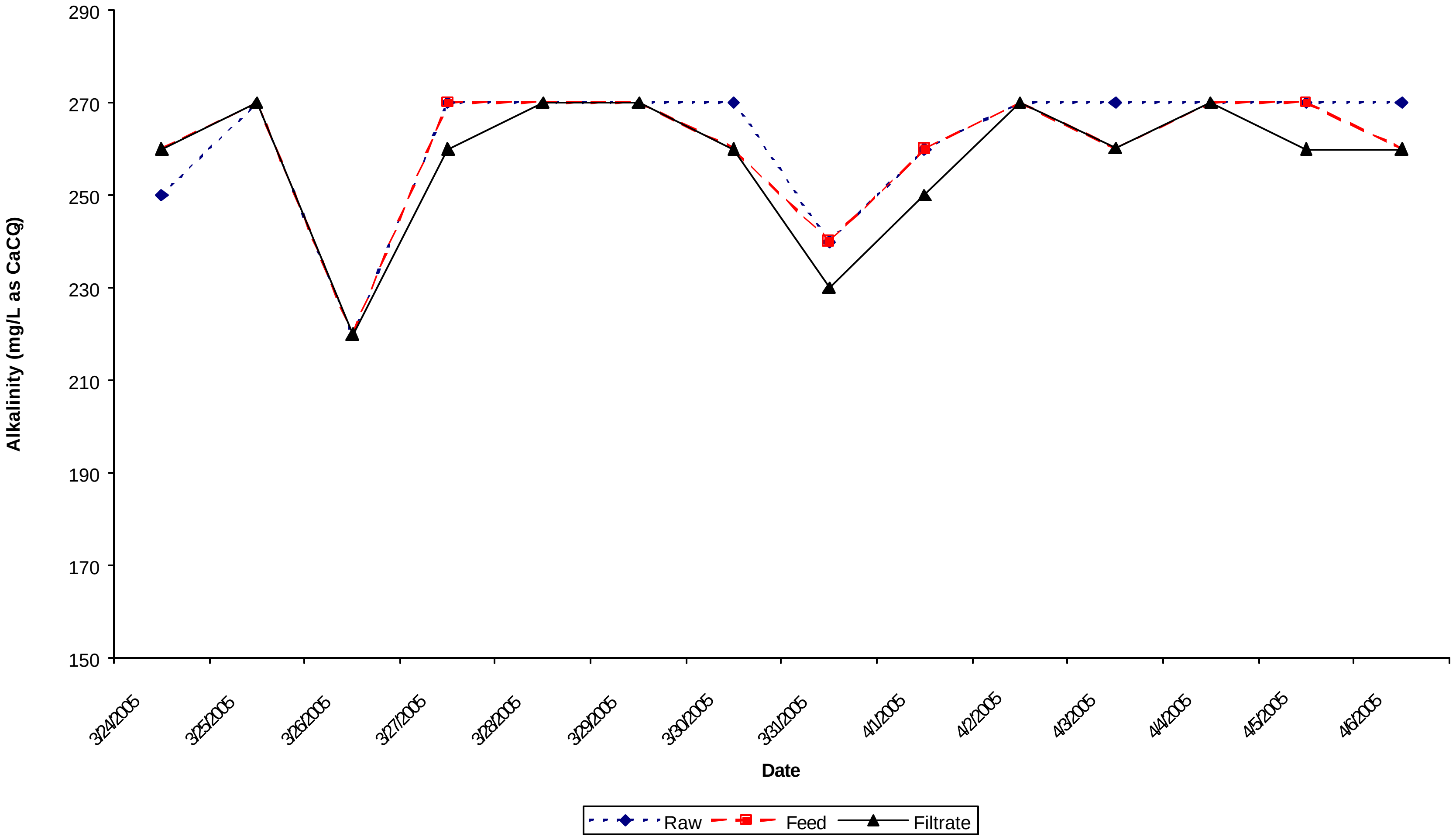

Figure 4-4. Verification test alkalinity results.

Table 4-13. Alkalinity Results for the 48-Hour Intensive Survey (mg/L as $CaCO_3$)

Date	Time	Raw	Feed	Filtrate
3/30/05	11:15	270	260	260
3/31/05	11:30	240	240	230
3/31/05	11:45	240	240	240
4/01/05	11:10	260	260	250

Figure 4-5 shows the total iron concentrations measured in the raw, feed, and filtrate water. The raw water contained naturally occurring iron, averaging 0.47 mg/L with a maximum of 1.0 mg/L and minimum of 0.34 mg/L. The pre-testing by ORCA showed that this amount of iron was not sufficient to provide the desired arsenic removal performance, so additional iron was added to the system to achieve the needed iron concentrations for coagulation of the arsenic. The feed water averaged 1.9 mg/L as Fe with a median concentration of 1.8 mg/L. The maximum iron concentration in the feed water was 4.5 mg/L on March 24, the first day of the test. The iron dose was decreased on March 24 and remained close to the targeted 2.0 mg/L for the remaining days of the test. On March 28 and 29 the iron level in the feed water decreased to 0.37 and 0.96 mg/L, respectively. There was no apparent reason for this decrease. Arsenic removal remained consistent on these days.

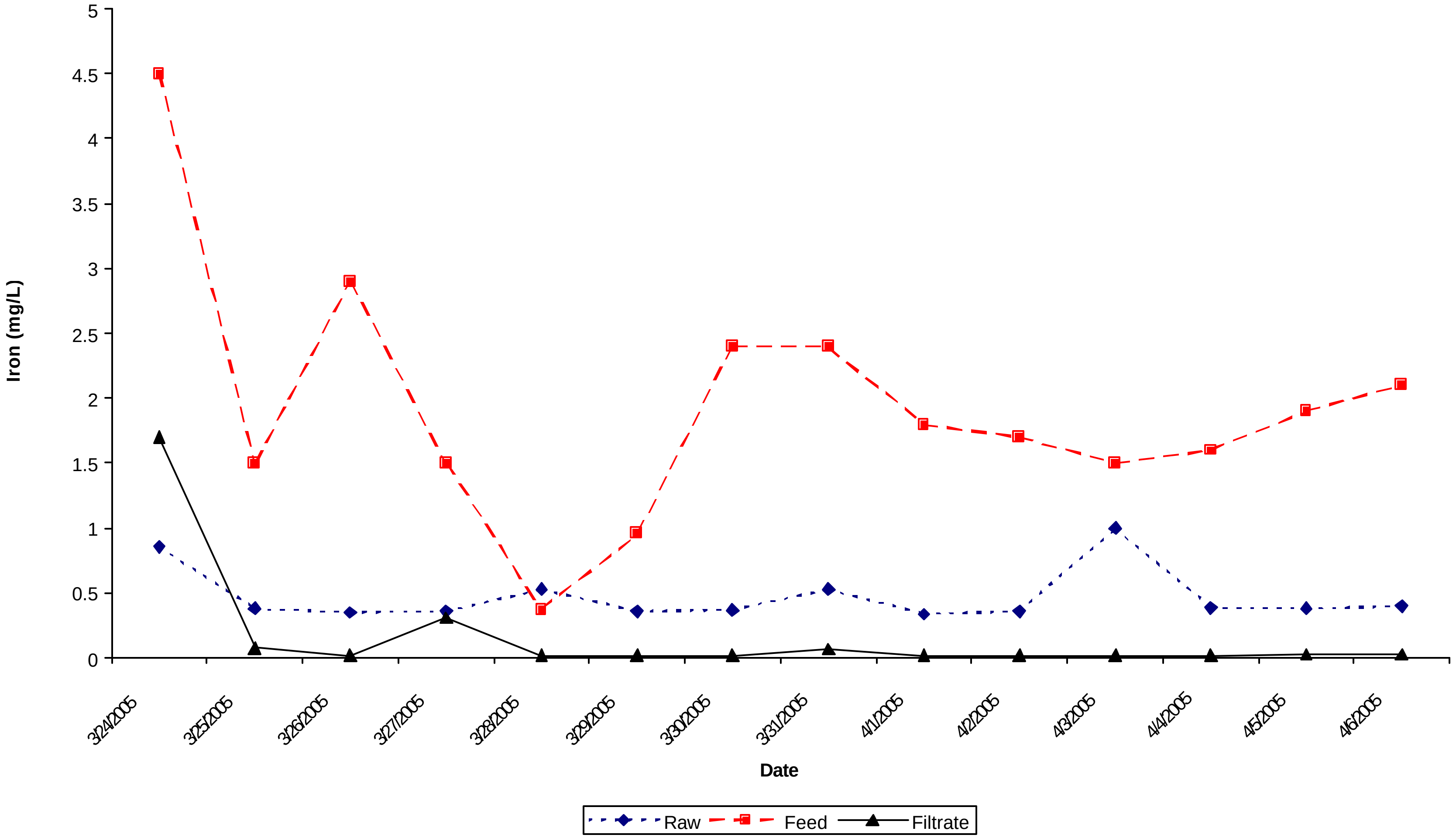

Figure 4-5. Verification test iron results.

The KemLoop System removed the iron present in the feed water, producing treated water that had 0.03 mg/L or less on all but three days. On March 24, the first day of the test, when the iron concentration in the feed was measured at a maximum concentration of 4.5 mg/L, the filtrate concentration was 1.7 mg/L. On March 27 the iron concentration was 0.31 mg/L, just above the MCL. Iron was detected at 0.07 mg/L on March 31. This sample was taken just before the filter backwash during the 48-hour intensive survey. Table 4-14 shows the iron results for the 48-hour survey. The data show that the KemLoop System can generally achieve the statement of performance objective of producing a filtrate with <0.30 mg/L of iron.

Table 4-14. Iron Results for the 48-Hour Intensive Survey (mg/L)

Date	Time	Raw	Feed	Filtrate
3/30/05	11:15	0.37	2.4	<0.02
3/30/05	12:30	0.49	2.0	<0.02
3/30/05	14:30	0.54	3.0	<0.02
3/30/05	17:25	0.41	2.8	<0.02
3/30/05	23:30	0.33	2.2	<0.02
3/31/05	05:30	0.38	0.39	<0.02
3/31/05	11:30	0.53	2.4	0.07
3/31/05	11:45	0.37	1.6	<0.02
3/31/05	12:30	0.35	2.9	<0.02
3/31/05	14:30	0.34	2.7	<0.02
3/31/05	17:15	<0.02(1)	0.42	<0.02
3/31/05	23:22	0.40	2.7	<0.02
4/1/05	05:40	0.38	0.54	<0.02
4/1/05	11:10	0.34	1.8	<0.02
Number of samples		13	14	14
Average		0.40	2.0	<0.02
Maximum		0.54	3.0	0.07
Minimum		0.33	0.39	<0.02
Std. Deviation		0.07	0.93	NC
95% Conf. Interval		(0.36, 0.45)	(1.5, 2.5)	NC

(1) Data considered an outlier; not used in calculating statistics.
NC = Not Calculated.

The field staff measured total and free residual chlorine daily. Table 4-15 shows the residual chlorine data for the raw, feed, and filtrate water. The raw water is a non-chlorinated source and should have no residual chlorine. The data show this was the case on most days, with total and free residual chlorine measuring below the detection limit. As shown in Table 4-16 during the 48-hour survey, one result indicated the presence of total residual chlorine at 0.10 mg/L. It is not known why an occasional sample showed chlorine present in the raw water samples. These data appear to be anomalous readings. There is no reason to believe that chlorine is present in the raw water source.

During the verification test, the feed water averaged 1.01 mg/L of total residual chlorine, and the filtrate water averaged 0.95 mg/L. Most of the data points were clustered in the range of 0.85-1.15 mg/L. The free residual chlorine results show that a large percentage of the total residual chlorine was combined chlorine. It is apparent that this groundwater source contained constituents that combined with the chlorine. The free residual chlorine in the feed water averaged 0.22 mg/L, and the filtrate averaged 0.18 mg/L. The bleach solution was fed at a target rate of 2.2 mg/L to maintain approximately 1.0 mg/L of total residual chlorine in the feed water, indicating the raw water had a chlorine demand of approximately 1.2 mg/L.

Table 4-15. Total and Free Residual Chlorine (mg/L)

	Free Chlorine			Total Chlorine			Dissolved Oxygen
Date	**Raw**	**Feed**	**Filtrate**	**Raw**	**Feed**	**Filtrate**	**Raw**
3/23/05	0.09(1)	0.11	0.05	<0.05	0.85	0.85	3.7
3/24/05	<0.05	0.43	0.24	<0.05	1.17	1.15	5.9
3/25/05	<0.05	0.09	<0.05	<0.05	1.10	1.04	3.6
3/26/05	<0.05	<0.05	<0.05	<0.05	1.10	1.11	4.4
3/27/05	<0.05	0.07	0.04	<0.05	1.05	1.00	5.3
3/28/05	<0.05	0.12	0.05	<0.05	1.13	0.96	4.0
3/29/05	<0.05	0.64	0.73	<0.05	1.04	1.07	5.0
3/30/05	<0.05	0.10	<0.05	<0.05	1.10	1.08	4.6
3/31/05	<0.05	0.06	<0.05	<0.05	1.05	1.00	3.6
4/1/05	<0.05	0.31	0.14	<0.05	1.07	0.85	2.5
4/2/05	<0.05	0.12	0.34	<0.05	1.10	0.97	3.0
4/3/05	<0.05	0.33	0.28	<0.05	0.75	1.01	3.8
4/4/05	<0.05	0.20	0.21	<0.05	0.80	0.69	3.7
4/5/05	<0.05	0.38	0.34	<0.05	0.97	0.98	4.3
4/6/05	<0.05	0.23	0.06	<0.05	0.80	0.46	3.5
Number of samples	14	15	15	15	15	15	15
Average	<0.05	0.22	0.18	<0.05	1.01	0.95	4.1
Maximum	0.09(1)	0.64	0.73	<0.05	1.17	1.15	5.9
Minimum	<0.05	0.05	0.04	<0.05	0.75	0.46	2.5
Std. Deviation	NC	0.17	0.19	NC	0.14	0.18	0.9
95% Conf. Interval	NC	(0.12, 0.31)	(0.07, 0.28)	NC	(0.93, 1.08)	(0.85, 1.05)	(3.6, 4.5)

(1) Value judged to be anomalous data based on total result chlorine result and not included in the statistical calculations.

Note: Concentrations reported as “less than values” set equal to the detection limit for calculating statistics.

NC = Not calculated.

Table 4-16. Free and Total Residual Chlorine Results for 48-Hour Survey (mg/L)

		Free Chlorine			Total Residual Chlorine		
Date	**Time**	**Raw**	**Feed**	**Filtrate**	**Raw**	**Feed**	**Filtrate**
3/30/05	11:15	<0.05	0.10	<0.05	<0.05	1.10	1.08
3/30/05	12:30	<0.05	0.07	<0.05	<0.05	1.06	1.10
3/30/05	14:30	<0.05	0.13	0.17	<0.05	1.15	1.11
3/30/05	17:25	<0.05	0.08	0.11	NA	NA	1.08
3/30/05	23:30	<0.05	0.12	0.06	0.10	1.13	1.06
3/31/05	5:30	<0.05	0.10	<0.05	<0.05	0.95	1.00
3/31/05	11:30	<0.05	0.06	<0.05	<0.05	1.05	1.00
3/31/05	11:45	<0.05	0.24	0.33	<0.05	0.83	0.82
3/31/05	12:30	<0.05	0.30	0.13	<0.05	1.23	0.94
3/31/05	14:30	<0.05	0.17	0.18	<0.05	1.14	0.92
3/31/05	17:15	<0.05	0.11	0.14	NA	NA	0.57
3/31/05	23:22	<0.05	0.07	0.05	<0.05	1.08	0.80
4/1/05	5:40	<0.05	0.22	0.20	<0.05	1.01	0.87
4/1/05	11:10	<0.05	0.15	0.12	<0.05	0.74	0.57
Number of samples		14	14	14	12	12	14
Average		<0.05	0.14	0.12	<0.05	1.04	0.92
Maximum		<0.05	0.30	0.33	0.10	1.23	1.11
Minimum		<0.05	0.06	0.05	<0.05	0.74	0.57
Std. Deviation		NC	0.07	0.08	NC	0.14	0.18
95% Conf. Interval		NC	(0.10, 0.18)	(0.07, 0.17)	NC	(0.95, 1.13)	(0.82, 1.03)

NA = Not analyzed.
NC = Not calculated.
Note: Concentrations reported as "less than values" set equal to the detection limit for calculating statistics.

The results for the other water quality parameters are shown in Table 4-17. The raw water concentrations were stable throughout the test. The feed and filtrate water showed similar average concentrations of sulfate, TOC, fluoride, calcium, magnesium, and manganese. The KemLoop System had little or no impact on these water quality parameters. The chloride concentration increased 4-7 mg/L in the feed and filtrate water due to the addition of ferric chloride. Manganese was present at an elevated level in the filtrate water on one day, March 24. The manganese was reported as 180 µg/L, ten times higher than the raw water. The laboratory data were checked for a calculation error or a matrix interference, but no errors or interferences were apparent. The cause of this increase on manganese for one day is not known.

Temperature was monitored daily in the raw, feed, and filtrate water. The mean temperature of the raw water was 12.0 °C. The feed water and filtrate temperatures were similar to the raw water, with mean values of 12.3 °C and 12.8 °C, respectively.

During the verification test, the true color in the raw water and the filtrate was higher than would be expected in deep groundwater and filtered water. (Note that true color was measured directly, and samples were not filtered prior to measurement.) Color in water typically occurs when organic matter degrades to form dissolved organic carbon. TOC concentrations did not change during the arsenic loss test (Table 4-4) or during the verification test (Table 4-17). Whatever the source of TOC in this water, the filtration process, with or without coagulation, did not remove the organic material. While the organic carbon might play a role in the color levels measured, the TOC results did not change, whereas the color results varied considerably. These data, and the fact that the wells drew from 125-150 feet below grade and were not influenced by surface water, suggest that the difference in the color of the raw water originated from colloidal formation of iron (US EPA. July 1976. Quality Criteria For Water.). This would cause a high color reading in a sample that was not filtered. Iron is naturally present in this water and may have oxidized in the pressure tank before withdrawal for treatment. The DO in the raw water was in the 2.5-5.9 mg/L range. This would indicate that some oxidation could occur. The possible cause of the color levels measured in the filtrate is not as clear. The filtrate was low in turbidity and iron, which would indicate that suspended solids were removed. The filtrate was clear when inspected visually. The color data may not be indicative of actual conditions, although there was no apparent problem in the analyses.

Table 4-17. Other Water Quality Parameters

	Chloride (mg/L)			Sulfate (mg/L)			TOC (mg/L)	
Date	**Raw**	**Feed**	**Filtrate**	**Raw**	**Feed**	**Filtrate**	**Raw**	**Filtrate**
3/24/05	12	19	19	17	17	18	0.6	0.6
3/31/05	14	19	18	18	18	17	0.5	0.5
4/1/05	15	19	20	19	19	19	0.5	0.6
Number of samples	3	3	3	3	3	3	3	3
Average	14	19	19	18	18	18	0.5	0.6
Maximum	15	19	20	19	19	19	0.6	0.6
Minimum	12	19	18	17	17	17	0.5	0.5

	Fluoride (mg/L)		Calcium (mg/L)		Magnesium (mg/L)		Hardness (mg/L as $CaCO_3$)	
Date	**Raw**	**Filtrate**	**Raw**	**Filtrate**	**Raw**	**Filtrate**	**Raw**	**Filtrate**
3/24/05	0.4	0.5	76	75	23	23	280	280
3/31/05	0.6	0.6	73	73	23	23	280	280
4/1/05	0.5	0.6	73	72	24	23	280	270
Number of samples	3	3	3	3	3	3	3	3
Average	0.5	0.6	74	73	23	23	280	280
Maximum	0.6	0.6	76	75	24	23	280	280
Minimum	0.4	0.5	73	72	23	23	280	270

Table 4-17. Other Water Quality Parameters (continued)

	Manganese (µg/L)		True Color[1] (C.U.)		
Date	Raw	Filtrate	Raw	Feed	Filtrate
3/23/05	--	--	19	46	24
3/24/05	18	180	--	--	--
3/31/05	14	9	14	29	3
4/1/05	<10	<10	10	34	17
Number of samples	3	3	3	3	3
Average	14	66	14	36	15
Maximum	18	180	19	46	24
Minimum	<10	<10	10	29	3

(1) The true color test was performed without filtering the sample that is required by the method.

4.5.4 Backwash Water Frequency and Quality

As described in Chapter 2, the KemLoop System backwash cycle can be automatically initiated by pressure differential, turbidity differential, time, or filtrate volume produced. During the verification test, all of the backwash cycles were initiated based on time, because the pressure differential and turbidity differential set points were not reached during any 24-hour filter run. The backwash water was discharged through a separate backwash line that was sampled during the verification test.

The backwash water was sampled and analyzed during the verification test. A composite sample was collected from the backwash discharge line before the water entered the holding tank. Table 4-18 shows the results for total arsenic, total iron, TSS, and pH. Free and total residual chlorine were also analyzed on the samples, but results were not considered accurate, due to the presence of background color in the samples, and are not reported. All of the free and total residual chlorine results were much higher than concentrations measured in the feed and filtrate water, indicating a strong positive bias in the sample results. The color in the backwash samples clearly interfered with these analyses.

The backwash water was enriched in arsenic, iron, and TSS, as would be expected, given the removal of arsenic and iron as measured in the filtrate. The KemLoop System produced an average daily filtrate volume of 14,600 gallons and generated an average backwash volume of 220 gpd. Thus, on a mass balance basis, the concentration of arsenic and iron would be projected to increase by a factor of approximately 66. The average iron concentration in the feed water was 1.9 mg/L. Therefore, the projected iron concentration in the backwash water would be 130 mg/L. The results are very close to the projected concentrations, indicating most or all of the iron precipitate was being removed from the filter during the backwash cycle. The arsenic mass balance shows a projected backwash concentration of 1250 µg/L versus a measured average of 990 µg/L, calculated without the apparent outlier on April 1. The balance is reasonably good, considering the backwash water samples only represented three or four days of operation.

Table 4-18. Backwash Water – Water Quality Results

Date	Total Arsenic (µg/L)	Total Iron (mg/L)	TSS (mg/L)	pH (S.U.)
3/27/05	1000	130	280	7.50
3/30/05	1100	150	300	7.13
4/1/25	870	100	230	7.11
4/6/05	64(1)	100	200	7.32
Number of samples	4	4	4	4
Average(2)	760	120	253	7.13
Maximum	1100	150	300	7.50
Minimum	64	100	200	7.11

(1) Result appears to be an outlier based on iron data and previous results.
(2) Median reported for pH, not the average.
NC = Not Calculated.

Local disposal requirements determine whether a water is acceptable for discharge to a sanitary sewer system or another discharge location, or if it requires further treatment prior to discharge. The suspended solids present in the backwash water can be expected to contain most of the arsenic and iron, because the basis of the technology is to precipitate arsenic with iron in the mixing loop. If solid separation were required before the backwash water could be discharged, the solids would need to be sent to a landfill for disposal. A sample of the solids accumulated over the 14-day test, which settled to the bottom of the holding tank, was collected and analyzed by the TCLP and the CAWET. This sample represented a composite of all solids generated during the verification test, not from just a single day or single backwash cycle. The backwash solids were not considered a hazardous waste based on the arsenic concentrations, which were below the 5 mg/L limit under the Resource Conservation and Recovery Act (RCRA). Table 4-19 presents the results of the TCLP and CAWET analyses. The laboratory test report received from TriMatrix Laboratories is included in Appendix E.

Table 4-19. Backwash Solids – TCLP and CAWET Analyses

Parameter	Units	TCLP	CAWET
Arsenic	mg/L	0.32	3.1
Barium	mg/L	2.6	1.3
Cadmium	mg/L	<0.010	<0.010
Chromium	mg/L	<0.050	<0.050
Copper	mg/L	0.015	0.041
Lead	mg/L	<0.050	0.11
Mercury	mg/L	<0.0002	<0.010
Nickel	mg/L	0.011	<0.25
Selenium	mg/L	<0.10	0.19
Silver	mg/L	<0.010	0.020
Zinc	mg/L	2.1	1.2

4.5.5 Chemical Consumption

The KemLoop System used a 6% sodium hypochlorite (bleach) as the stock chemical for adding chlorine to the system. The stock feed was made by diluting 12% bleach at a ratio of one to one with water. The targeted total residual chlorine concentration in the feed water was 1 mg/L. Based on preliminary test data, the chemical metering pump was set to feed approximately 1.3 mL/min (1.9 L/day) from the five-gallon container of bleach solution. Approximately 28 liters of 6% bleach solution were used to treat 204,870 gallons of raw water over the 14-day verification test. In the absence of any chlorine demand in the raw water, the calculated chlorine concentration at this feed rate was approximately 2.2 mg/L. The theoretical amount of bleach solution needed to achieve the measured average total residual chlorine concentration (0.95 mg/L) was calculated to be 12.3 L. These data indicate a chlorine demand in this water of approximately 1.2 mg/L.

Iron was added to the raw water using a 4.8% ferric chloride solution. The ferric chloride was fed with a chemical metering pump that was set to deliver approximately 2.2 mL/min (3.2 L/day), which would yield an iron addition of 2.8 mg/L as Fe. The pump calibration checks showed the average fed rate was closer 1.8 mL/min (2.6 L/day). A total of 23.9 liters (6.3 gallons) of ferric chloride solution was used over the 14-day test to treat 204,870 gallons of raw water. Based on the total amount of solution fed, the average concentration of ferric chloride added to the raw water was calculated to be 1.5 mg/L. The measured feed water concentration averaged 1.9 mg/L, and the raw water concentration averaged 0.47 mg/L. These data indicated approximately 1.43 mg/L of iron addition, which was close to the calculated 1.5 mg/L fed based on chemical use. It should be noted that the daily calibration average of 1.8 ml/min is higher than the average iron feed rate based on the total volume of ferric chloride used over the duration of the test. The reason for the higher rate reading on the pump calibration graduated tube is not known, but may be due to the difference between pumping against the water supply pressure and the atmospheric pressure used for calibration. The actual total volume measured for the entire test is considered the most accurate data, because it balances with the measured iron concentrations in the feed water and represents the entire pumping period rather than a five-minute daily calibration period.

4.6 Other Operating Information

The KemLoop System was operated by the DWTS field staff during the 14-day verification period. The system was found to be easy to operate and required little time for daily maintenance. The field staff was on site for two to three hours per day. Most of the time on site was spent performing ETV-related activities, including daily chemical analyses, flow checks, calibrations, and so forth. In a normal operation, the inline pH meters and turbidimeters would be used for system checks. The PLC records all of the flow data, pressure information, backwash cycles, and so forth. Therefore, it would be anticipated that the time to check the system on site would be minimal, possibly less than 30 minutes, except when chemical feedstocks needed to be replenished or inline instruments calibrated. The PLC can be set up for remote access, allowing main system parameters to be monitored without a site visit.

The chemical feed system used two chemical metering pumps, a 5-gallon plastic container for the bleach solution, and a 15-gallon plastic container for the ferric chloride solution. The bleach solution was made by diluting the purchased bleach solution with water at a ratio of one part bleach to one part water. The purchased ferric chloride solution was also diluted prior to use at one part ferric chloride to two parts water. An operator needs to periodically make the bleach and ferric chloride solutions and pour both feed solutions into the feed containers. Larger feed containers could be used to reduce the frequency of chemical additions. For larger systems, the containers could be larger and possibly used as the actual feed containers (totes, etc.).

The chemical meter pumps held the same stroke per minute settings throughout the test. However, the calibration data and the measured concentration data for iron did seem to indicate that the ferric chloride feed rate varied more than might be expected. The 95% confidence interval for the feed water iron concentration was in the 1.1-2.1 mg/L range, after adjustment for the raw water iron content. The chemical metering pumps were not paced based on flow rate. In the ORCA system the flow rate is set to a constant rate, so a constant chemical pump feed rate should give consistent feed water concentration.

The KemLoop System has an interface for connecting a computer to the PLC, which allows reading and checking of current and historical data for all key operating parameters. The unit also has manual readouts on the feed and filtrate flow rate; the pressures for feed, filtrate and concentrate; and the inline pH meters and turbidimeters. The PLC readings were easy to see, but did require an understanding of the PLC operating keys to display the readings. The laptop computer supplied for the test was easier to use for checking systems flows, pressures, and so forth.

Backwash for this system is based on a preset time and backwash cycle. The backwash is also set to initiate based on pressure differential across the filter (head loss) or turbidity differential between the raw water and the filtrate. The entire backwash cycle is fully automated and requires no operator intervention. The backwash source can either be raw (untreated) or treated water. It is important that the source have sufficient capacity to deliver the required backwash flow rate. ORCA specifications call for 75-100 gpm and a total volume of 500 gallons. The measured flow rate for the test system was 45-62 gpm, and the volume averaged 220 gallons per backwash. At the test site, the raw water intake line from the pressure tank was not large enough to supply the needed flow rate. Therefore, a treated water holding tank was used to supply water for the backwash pump.

The KemLoop System operated continuously during the verification test. There were no unexpected shutdowns or equipment maintenance issues during the test, except for failure of the inline pH meters. The feed water pH meter electrode broke at the beginning of the test. It would have taken several days to obtain an electrode, and the unit would have to be shut down to replace the electrode. Since there was no acid addition required for this test and daily pH measurements were being made at the on-site laboratory set up by the DWTS field staff, it was decided to continue the verification test without repairing the inline pH meters. This situation demonstrates the importance of having critical spare parts available for common items, such as pH electrodes, turbidity sensors, and so forth, in addition to the chemicals needed to treat the raw water.

The verification test originally started on March 21, but was postponed to March 23 due to a leak in the ferric chloride feed system. During the first night of testing, the chemical metering pump fell off its base, and the inlet pipe broke. Ferric chloride spilled from the chemical feed tank. The chemical feed pump was not inside of secondary containment, and the ferric chloride spilled out of the shipping container housing the unit and onto the concrete pad. It was noted that the entire chemical feed system for both ferric chloride and bleach should be built within secondary containment to avoid this problem. The pump mounting system used for the test system was not the standard ORCA mounting, because this unit was built inside a shipping container to accommodate the site conditions. ORCA indicated future systems would have secondary containment. The ferric chloride was cleaned up and the test restarted on March 23.

Overall, the KemLoop System appears well suited to small- or medium-scale installations where an operator is not present at all times. The system is automated, and all equipment appeared sturdy and properly selected for the process. The PLC/PC system tied to an Internet connection is recommended to allow operator monitoring from a remote location.

ORCA provides an O&M manual for each system installed at a site. The draft O&M manual for a KemLoop System, presented in Appendix A, provides a good description of the system, appropriate safety precautions, and detailed descriptions of operating procedures, capability and operation of the computer control system, and specific instructions for utility operators. The maintenance section of the manual includes some descriptions of required maintenance, but refers the reader to the individual equipment literature supplied by the various pump and instrument manufacturers. These manuals were provided in a notebook. The draft O&M manual did not contain specific checklists for routine site visits. The manual is well organized and easy to read. However, the draft needs to be revised and updated to incorporate missing items noted in the draft. The addition of a troubleshooting section and operator routine checklists would be helpful.

The O&M manual provides detailed information on the various modes that can be used for operating the equipment. The modes are preprogrammed operating conditions that include filter backwash triggers and the manner in which the PLC responds to various signals and alarms. The PLC discussion is thorough, and the programming provides good flexibility for the operator.

The O&M manual also describes the tanks, piping, and filter units, with information on the connections for each vessel. Instructions for items to check prior to start-up are included in the descriptions.

As stated in the PSTP, the KemLoop System was evaluated for overall operability based on the actual conditions observed during the verification test and on the capabilities of the system equipment and control system. The KemLoop System was found to be easy to operate. It provided all needed information and controls to operate the system, and flexibility for multiple chemical feeds and adjustment of operating and backwash cycles.

The system design provides for multiple feed ports in the raw water feed line to add several chemicals, including acid/caustic for pH control (not used in this application), coagulant (in this case iron), and oxidants (bleach). In the test unit, the chemical feed pumps were not paced to raw water flow. However, the raw feed rate was manually set by the operator, so unless there was a wide variation in pressure at the raw water source, flow rate should be steady and matched to the chemical feed rate. It would be helpful in a regular installation if the chemical feed pumps were set up to be flow paced and automatically shut down if flow were interrupted. ORCA has indicated that the control of chemical feeds based on raw water flow can be provided. The bleach chemical feed pump was stable throughout the test and did not need adjustment to maintain the selected feed rate. The ferric chloride feed pump varied based on the calibration checks performed, and the iron dose fluctuated between 1.1-2.1 mg/L based on the calculated 95% confidence interval of the iron concentrations. This part of the system may need close attention during the first few weeks of operation to be sure the targeted dose is being delivered consistently. The variation did not appear to affect arsenic removal in this application.

The system included inline pH and turbidimeters to monitor the raw and filtrate water, which provided data to show that effective chemical feed rates were being delivered to the system. The PLC/PC provided both real-time display of the pH and turbidity and historical data that could be displayed in a trend plot for any time interval selected. The turbidity meters worked well during the test. As stated earlier, the inline pH meters were not functioning during the verification test. They appear to be standard units that should work in this application, if properly calibrated.

The KemLoop System includes a flow totalizer and flow rate meter for the filtrate water. The system has pressure gauges on the feed and filtrate lines that provide pressure data for monitoring pressure differential (head loss) across the filters. All of this information is recorded and monitored by the PLC/PC and is available to the operator for review. Both real-time readings and trend plots can be displayed on a PC. The system also monitors hours of operation and can activate an alarm if any operating parameter is outside of preset “normal” operating limits. The PLC/PC can be programmed to shut down the unit if turbidity, pH, or any other operating parameter exceeds the preset acceptable limits.

The electrical use by the KemLoop System is primarily for the raw water pump (if required), the backwash pump, the chemical feed pumps, and the PLC and instrumentation. The test system used a 230 VAC, 1 Phase, 30-ampere electrical supply. The test system had two 1.5 hp centrifugal pumps, one to provide raw water flow (not used in this application) and one for backwash. The two chemical feed pumps were small units using approximately 150 watts each. The PLC/PC power consumption was considered small. Based on one of the 1.5 hp pumps running during backwash cycles for approximately 4 minutes, it is estimated that approximately 0.1 hp-hour of electrical power was used by this equipment. Unadjusted horsepower (not adjusted for efficiency factor) is equal to 746 watts per hp. Therefore, it is estimated that approximately 0.75 kilowatt-hr was used for the pump. The other equipment (chemical pumps and PLC/PC) used an estimated 0.4 kilowatt-hr, bringing the total estimated electrical power use to 0.5 kilowatt-hr. This use was only during the daily backwash cycle. The chemical feed system and PLC were in operation continuously 24 hours per day.

For a system that requires a dedicated raw water pump, the 1.5 hp pump would run continuously, assuming continuous system operation. In this case, a 1.5 hp pump would use approximately 1.1 kilowatt-hr. A system with a dedicated raw water pump, two chemical feed pumps, and a PLC would use approximately 1.5 kilowatt-hr.

4.7 Quality Assurance/Quality Control

As described in Task 6, Section 3.9.8, a structured QA/QC program was implemented as part of this verification to ensure the quality of the data being collected. A QAPP was developed as part of the PSTP and followed by the field staff and laboratory during the testing period. Careful adherence to the established procedures ensured that the data presented in this report are sound, defensible, and representative of the equipment performance.

4.7.1 Documentation

DWTS site operators recorded on-site data and calculations (e.g., calculating calibration flow rates using the bucket and stop watch, and other similar routine calculations) in a field logbook and prepared field log sheets. Daily measurements were recorded on specially prepared data log sheets. The original logbook was stored on site, and copies were forwarded to the project coordinator at NSF offices once per week during the verification test. The operating logbook included calibration records for the field equipment used for on-site analyses. Copies of the logbook, the daily data log sheets, and calibration log sheets are in Appendix B.

Data from the on-site laboratory and data log sheets were entered into Excel spreadsheets. These spreadsheets were used to calculate various statistics (average, mean, standard deviation, etc.). The data in the spreadsheets were proofread by the initial data entry person. NSF DWS Center staff then checked 100% of the data entered into the spreadsheets to confirm the information was correct. The spreadsheets are presented in Appendix D.

Samples collected and delivered to the NSF Chemistry Laboratory for analyses were tracked using chain-of-custody forms. Each sample was assigned a location name, date, and time of collection, and the parameters were written on the label. The laboratory reported the analytical results using the NSF Chemistry Laboratory management system reports. These reports were received and reviewed by the NSF DWS Center coordinator. These laboratory data were entered into the data spreadsheets, corrected, and verified in the same manner as the field data. Lab reports and chain-of-custody records are included in Appendix C.

4.7.2 Quality Audits

The NSF QA department performed on-site audits on March 24 (Day 1) and March 28, 2005 (Day 5) to review the field procedures, including the collection of operating data and performance of on-site analytical methods. The PSTP requirements and QAPP were used as the basis for the audit. The NSF QA auditor prepared an audit report. All deficiencies were corrected immediately.

The NSF QA Department reviewed the Chemistry Laboratory analytical results for adherence to the QA requirements for calibration, precision, and accuracy detailed in the project QAPP and for compliance with the laboratory quality assurance requirements. The laboratory raw data records (run logs, bench sheets, calibrations records, etc.) are maintained at NSF and are available for review.

4.7.3 Data Quality Indicators

The data quality indictors established for the ETV project and described in the QAPP included:

- Representativeness
- Accuracy
- Precision
- Completeness

4.7.3.1 Representativeness

Representativeness refers to the degree to which the data accurately and precisely represent the conditions or characteristics of the parameter represented by the data. In this verification testing, representativeness was ensured by executing consistent sample collection procedures in accordance with established approved procedures, and following specific sample preservation, packaging, and delivery procedures. Approved analytical methods were used to provide results that represent the accurate and precise measurements of drinking water. For equipment operating data, representativeness entailed collecting and documenting a sufficient quantity of data during operation to be able to detect a change in operations. For most water treatment processes involving total arsenic removal, detecting a +/- 10% change in an operating parameter was sufficient. The primary operating parameters for this verification test were filtrate volume treated per day and the related parameter raw water pressure. On two days, April 3 and 4, 2005, the filtrate water volume was more than 10% below the target volume of 14,400 gallons, and the raw water pressure dropped to 34-35 psi, slightly more than 10% below the 40 psi target. The drop in pressure from the Center's pressure tank caused the lower pressure and the resultant drop in raw water flow rate (equal to filtrate flow rate). There were no adjustments made, because this pressure was dependent on the Center's pressure tank. The slightly lower filtrate volume for these two days did not appear to affect treatment performance. Thus, these data were judged to be representative and were included in the data set for the verification test.

4.7.3.2 Accuracy

On-Site Equipment Accuracy and Calibration

On-site equipment, including KemLoop System flow meters and DWTS on-site analytical equipment, was tested for accuracy through regular calibration checks. Meters and gauges were checked at the frequencies presented in Table 4-20. The calibration records for pH, turbidity, total and free residual chlorine, and DO were recorded in the field calibration log (Appendix B). All calibrations were performed at the frequency required. All calibration data were within the specified QC objectives on all days analyses were performed.

The KemLoop System had a filtrate water flow rate and totalizer meter. The "bucket and stopwatch" technique was used to determine the accuracy of the flow meters. Table 4-21 shows the calibration data. All calibrations were within the defined objective of ± 10%.

Table 4-20. Field Instrument Calibration Schedule

Instrument	Calibration Method	Frequency	Acceptable Accuracy
Flow Meters	Volumetric "bucket & stop watch"	Weekly	± 10%
Portable Turbidimeter	Secondary turbidity standards Primary turbidity standards	Daily Weekly	N/A
Portable pH/ISE Meter with Combination pH/ Temperature Electrode	Three-point calibration using 4.0, 7.0 and 10.0 buffers	Daily	± 5%
DO Meter	Based on known air saturation concentrations of DO at the measured air temperature	Daily	N/A
Thermometer (National Institute of Standards and Technology [NIST]-traceable)	Calibration against NIST traceable	Monthly	± 5%
Spectrophotometer	Chlorine check standard	Daily	± 25%

N/A = Not Applicable.

Table 4-21. Filtrate Flow Meter Calibration Data

Date	Calibration Result (gpm)	Flow Meter Reading (gpm)
3/31/05	10.2	10.0
4/06/05	10.4	10.3

One of the original objectives was to use the bench top turbidity readings to check the inline turbidity meters for the raw and filtrate water. However, it became apparent that the inline readings were always lower than the bench top readings. Both units were calibrated with primary and secondary standards, but the inline unit always read lower. The explanation may be that the cool samples tended to slightly fog the bench vials used to hold the sample, which would give a higher turbidity readings. It is believed that the inline unit may provide the more accurate data in this situation. Both the bench top and inline unit showed filtrate water was below 0.5 NTU on 13 out of 14 days, and both units showed high turbidity on one day, March 24. Therefore, both units showed the filtrate had a low turbidity. In the case of the raw water, the bench top unit showed a mean turbidity of 2.4 NTU, whereas the inline unit showed a mean value of 0.60 NTU. This is a groundwater source and would be expected to have a low turbidity. It is possible that, in addition to the effect of fogging in the bench top unit, iron present in the raw water started to oxidize during the bench top test, thus increasing the turbidity of the sample.

Laboratory Analyses

Accuracy for the laboratory analyses is quantified as the percent recovery of a parameter in a sample to which a known quantity of that parameter was added. Equation 4-1 is used to calculate accuracy:

$$\text{Accuracy} = \text{Percent Recovery} = 100 \times [(X_{known} - X_{measured}) \div X_{known}] \qquad (4\text{-}1)$$

where X_{known} = known concentration of measured parameter
$X_{measured}$ = measured concentration of parameter

Accuracy also incorporates calibration procedures and use of certified standards to ensure the calibration curves and references for analysis are near the "true value." Accuracy of analytical readings is measured through the use of spiked samples and lab control samples. The percent recovery is calculated as a measure of the accuracy.

The QAPP and the NSF Chemistry Laboratory QA/QC requirements established the frequency of spike sample analyses at 10% of the samples analyzed. Laboratory control samples (LCS) are also run at a frequency of 10%. The recovery limits specified for the parameters in this verification were 70-130% for laboratory-fortified samples and 85-115% for LCS. The NSF QA department reviewed the laboratory records and found all analyses for all sample groups were within the QC requirements for recovery. Calibration requirements were also achieved for all analyses.

The arsenic speciation resin columns were tested to ensure proper separation and recovery of the arsenic species. Each lot of the arsenic speciation resin was checked once against samples with known concentrations of As (III) and As (V). This QC check assured that the resin was properly prepared. The NSF Chemistry Laboratory maintained the documentation for the column checks.

4.7.3.3 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. Analytical precision is a measure of how far an individual measurement may be from the mean of replicate measurements. The relative standard deviation recorded from sample analyses was used to quantify sample precision. The percent relative standard deviation was calculated using the equation presented as Equation 4-2:

$$\text{Percent Relative Standard Deviation} = S(100) / X_{average} \qquad (4\text{-}2)$$

where: S = standard deviation
$X_{average}$ = the arithmetic mean of the recovery values

Standard Deviation is calculated in Equation 4-3:

$$\text{Standard Deviation} = \sqrt{\sum_{i=1}^{n} \frac{(Xi - X)^2}{n-1}} \qquad (4\text{-}3)$$

where: X_i = the individual measured values
X = the arithmetic mean of the measured values
n = the number of determinations

Acceptable analytical precision for the verification test was set at a percent relative standard deviation (RSD) for drinking water samples of 30%. Field duplicates were collected to incorporate both sampling and analytical variation to measure overall precision against this objective. The laboratory precision for the methods selected was tighter than the 30% overall requirement, generally set at 20% based on the standard NSF Chemistry Laboratory method performance.

Field Duplicates

Field duplicates were collected for all analyses (field lab and analytical laboratory) to monitor overall precision. The field duplicates included samples for all three sample locations: raw, feed, and filtrate water.

Tables 4-22 and 4-23 summarize the results for the field duplicate samples. The precision for analyses performed in the laboratory, as measured by these field duplicates, met the overall QC objective of 30% RSD, except for one manganese sample. The filtrate sample for March 24 was flagged as having an analysis problem. The results of 180 and 33 µg/L had very poor precision and were not typical of the manganese in this water (10-20 µg/L). The lab records were checked, but no apparent reasons for the poor precision and high concentration were determined. These data were flagged as outliers in the data set.

The field analyses data for field duplicates were good for pH and one set of free and total residual chlorine data. However, the second set of duplicates on April 5 showed poor precision for both free and total residual chlorine in the feed and filtrate samples. The actual sample results (replicate 1) were similar to previous analyses and within the expected concentrations based on chemical feed to the system. However, the field duplicate samples showed a low concentration of free and total residual chlorine. It is not known why the second field sample was low for both sampling locations. A switch could have occurred between samples or sample labels. Turbidity precision was poor for the one set of replicates collected. As noted previously in this report, the bench top turbidity readings were high compared to the inline analyzers. The problems with water temperature, fogging, and iron oxidation were the most likely cause of the poor precision and possible bias in the data.

Laboratory Analytical Duplicates

The NSF Chemistry Laboratory precision was monitored during the verifications test in accordance with QAPP and the NSF quality assurance program. Laboratory duplicates were analyzed at 10% frequency of samples analyzed. The NSF QA department reviewed the precision information and determined that the laboratory data met QC precision requirements.

4.7.3.4 Method Blanks

The laboratory included method blanks as part of the standard analysis procedures. Method blanks were analyzed in accordance with the approved methods. The NSF QA department reviewed the laboratory data and found the method blanks to be acceptable. No data were flagged as having been affected by method blank results.

Table 4-22. Precision Data – Field Duplicates for Laboratory Parameters

Total Arsenic (µg/L)

Date	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
3/24/05	28	28	0	24	23	3.0	12	12	0
4/02/05	19	19	0	20	20	0	<10	<1	NC
4/05/05	20	20	0	19	20	3.6	<10	1	NC

Dissolved Arsenic (µg/L)

Date	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
3/24/05	23	22	3.1	<1	<1	NC	<1	<1	NC

Arsenic III (µg/L)

Date	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
3/24/05	21	21	0	<1	<1	NC	<1	<1	NC

Alkalinity (mg/L as $CaCO_3$)

Date	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
3/24/05	250	260	2.77	260	240	5.66	260	250	2.77

Iron (mg/L)

Date	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
3/24/05	0.86	0.84	1.7	4.5	4.4	1.6	1.7	1.8	4.0
4/02/05	0.36	0.36	0	1.7	1.7	0	<0.02	<0.02	NC

Other Parameters (3/24/05)

Parameter	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
Chloride (mg/L)	12	12	0	19	20	3.6	19	19	0.0
Sulfate (mg/L)	17	18	4.0	17	18	4.0	18	18	0
Calcium (mg/L)	76	75	0.94	---	---	---	75	74	0.95
Magnesium (mg/L)	23	23	0	---	---	---	23	23	0
Manganese (µg/L)	18	18	0	---	---	---	180	33	98
Fluoride (mg/L)	0.4	0.5	16	---	---	---	0.5	0.5	0
TOC (mg/L	0.6	0.6	0	---	---	---	0.6	0.6	0

NC = Not Calculated.

“---” = Not required or scheduled for analysis.

Table 4-23. Precision Data – Field Duplicates for Field Parameters

pH (S.U.)

Date	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
3/30/05	7.27	7.40	1.25	7.31	7.34	0.29	7.38	7.40	0.19
4/05/05	7.20	7.20	0	7.19	7.25	0.59	7.23	7.24	0.10

Turbidity Bench Top (NTU)

Date	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
4/05/05	1.7	2.5	27	3.1	1.8	38	0.20	0.55	66

Free Residual Chlorine (mg/L)

Date	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
3/30/05	<0.05	<0.05	NC	0.10	0.12	13	<0.05	<0.05	NC
4/05/05	<0.05	<0.05	NC	0.38	0.07	97	0.34	0.06	99

Total Residual Chlorine (mg/L)

Date	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
3/30/05	<0.05	<0.05	NC	1.10	1.07	1.96	1.08	1.11	1.94
4/05/05	<0.05	<0.05	NC	0.97	0.13	108	0.98	0.38	62.4

NC = Not Calculated.

4.7.3.5 Completeness

Completeness is defined as the following (Equation 4-4) for all measurements:

$$\%C = (V/T) \text{ X } 100 \qquad (4\text{-}4)$$

where: %C = percent completeness
V = number of measurements judged valid
T = total number of measurements

Completeness refers to the amount of valid, acceptable data collected from a measurement process compared to the amount expected to be obtained.

The completeness objective for data generated during this verification test was based on the number of samples collected and analyzed for each parameter and/or method. A completeness objective of 90% applied to: total arsenic, iron, pH, daily bench top turbidity, residual chlorine, and TSS. Completeness criteria also applied to the following operating parameters: filtrate flow rate, pressure differential across the filter, and volume and flow rate measurements for backwash water. Samples for all of the critical parameters (total arsenic, iron, pH, daily bench top turbidity, residual chlorine for raw, feed, and filtrate water, and backwash water TSS) were collected and analyzed at the frequency specified for the verification test. All data were usable except for one suspect iron result and free residual chlorine value. Table 4-24 provides a summary of the completeness results for the verification test.

Table 4-24. Completeness Results

Parameter	Percent Completeness	Comment
Filtrate Flow Rate	100	All required daily measurements recorded.
Pressure Feed and Filtrate	100	All required daily measurements recorded.
Chemicals Added	100	Total amount of chemicals used recorded.
Volume and Rate of Backwash	79	All required volume and time measurements recorded. A few tank depth measurements missed, but not critical to monitoring backwash frequency because it was set to once per day by the PLC.
Total Arsenic	100	All scheduled samples and analyses completed. One raw water sample flagged as possible outlier. One set of speciation data was flagged, but there were a total of four sets of speciation data versus the two required. Several samples had matrix interferences.
Iron	100	All scheduled samples and analyses completed.
pH	100	All required daily measurements recorded.
Bench top Turbidity	100	All required daily measurements recorded. Problems with raw turbidity measurements noted in the report discussion.
Total Residual Chlorine	100	All required daily measurements recorded.
Free Residual Chlorine	99	All required daily measurements recorded. One sample out of 87 was flagged as an outlier.
Backwash TSS	100	All scheduled samples and analyses completed.

Chapter 5
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