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Environmental Technology Verification Report

Removal of Arsenic in Drinking Water

Pall Corporation
Microza® Microfiltration System

Prepared by

NSF International

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

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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

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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

BGL	Below Ground Level
CIP	Clean In Place
°C	Degree(s) Celsius
CAWET	California Waste Extraction Test
DWS	Drinking Water Systems
DWTS	NSF International Drinking Water Treatment Systems Laboratory
DQO	Data Quality Objectives
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
Ft^2	square feet or square foot
FTO	Field Testing Organization
g	Gram(s)
gfd	Gallon(s) per day per square foot
gfd/psi	Gallon(s) per day per square foot per pounds per square inch
gpd	Gallon(s) per day
gpm	Gallon(s) per minute
gpm/ft^2	Gallon(s) per minute per square foot
hr	Hour(s)
hp	Horsepower
I.D.	Inside Diameter
L	Liter
LCS	Laboratory Control Sample
m	Meter(s)
MCL	Maximum Contaminant Level
MDEQ	Michigan Department of Environmental Quality
Microza System	Pall Corporation Microza® Microfiltration System
ml	Milliliter(s)
mg	Milligram(s)
mg/L	Milligram(s) per liter
mm	Millimeter(s)
NBR	Nitrile Butadiene Rubber
NIST	National Institute of Standards and Technology
NRMRL	National Risk Management Research Laboratory
NSF	NSF International
NTU	Nephelometric turbidity unit(s)
OCDC	Oakland County Drain Commissioner
O&M	Operation and Maintenance
Pall	Pall Corporation
PLC/PC	Programmable Logic Controller/Personal Computer
psi	Pounds per square inch
PSTP	Product Specific Test Plan
PVC	Polyvinyl chloride
PVDF	Polyvinylideneflouride
QA/QC	Quality Assurance/Quality Control

QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RSD	Relative Standard Deviation
SCADA	Supervisory control and data acquisition
SCFH	Standard cubic feet per hour
SCFM	Standard cubic feet per minute
TCLP	Toxicity Characteristics Leaching Procedure
TMP	Transmembrane Pressure
TOC	Total organic carbon
TSS	Total suspended solids
µg/L	Microgram(s) per liter

Acknowledgements

The Field Testing Organization (FTO), NSF International 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 NSF International DWTS wishes to thank the following participants:

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

Oakland County Drain Commissioner Office, especially Ms. Connie Sims, for help in selecting the test site, managing the public contact, and supplying requested information on water quality. Mr. Lloyd Lewis and his staff provided invaluable field support to Pall and NSF by arranging all site installation requirements and checking on the test system throughout the installation, startup, and testing program.

Pall Corporation for supplying the verification test unit and support services during the startup period. Mr. William Sellerberg, P.E. and Mr. Carlos Lopez 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 Pall Corporation Microza® Microfiltration System (Microza System), which is a microfiltration system used in drinking water treatment system applications. The statement of performance objective evaluated during field-testing of the system was that the system is capable of removing arsenic to less than 5 micrograms per liter (µg/L) in drinking water. This document provides the verification test results for the Microza System.

1.2 Testing Participants and Responsibilities

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

NSF International

NSF International Drinking Water Treatment Systems Laboratory (DWTS) and its consultant, Scherger Associates
Pall Corporation
Oakland County Drain Commissioner (OCDC)
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 Microza System. The DWTS is an NSF-qualified FTO for the ETV DWS Center.

The FTO was responsible for conducting the verification testing for 30 calendar days. The FTO provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. The FTO was responsible for ensuring 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.

FTO employees conducted the on-site analyses and data recording during the testing. 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 Pall Corporation Microza® Microfiltration System for the treatment of drinking water.

The manufacturer was responsible for supplying a field-ready microfiltration 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

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1.2.5 U.S. Environmental Protection Agency

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1.3 Verification Testing Site

1.3.1 Site Background Information

Two production wells are installed at the Plum Creek Development in Oakland Township, Oakland County, Michigan. The well house address is 2714 Long Winter Lane, Oakland, Michigan 48363. These wells supply potable water to approximately thirty-six homes (maximum design for fifty-one homes). The Plum Creek Development is a suburban residential development northeast of Detroit, Michigan, located in the Paint Creek Watershed, which discharges into the Clinton River. The area is a mix of suburban residential developments with some agriculture.

Basic well information was obtained from the OCDC office and the well installation records. The wells are installed in the same aquifer, with both wells being drilled to a depth of 99 feet below ground level (BGL). One well is cased with an 8-inch inside diameter (I.D.) well casing and the other is cased with a 12-inch I.D. well casing, and both have 20 feet of stainless steel well screen. The well screens are located between 79 and 99 feet BGL. The geology at the site consists of glacial tills, and sand and gravel outwash lithologies from the ground surface to approximately 250 feet (BGL). Productive water bearing sand and gravel lithologies are encountered between 25 and 97 feet BGL. The well screens are placed just below this contact point. Approximately 16 feet of gray clay barrier protection is present above the defined aquifer.

After installation, pump tests were performed to indicate how 100 days of continuous pumping would affect safe yield. The estimated safe yield for an 8-inch production well was 1,472 gallons per minute (gpm). This safe aquifer yield is well in excess of the 500-gpm design basis for each well. The well with an 8-inch well casing has a maximum well screen intake of 500 gpm and the well with a 12-inch well casing has a maximum well screen intake of 1,000 gpm.

The water supply system uses both wells and a single pressurized water supply tank to deliver water to the development. The water supply tank is a fixed wall tank and does not have a bladder insert in the tank. When the water level in the supply tank drops to a preset level, one well is activated and refills the tank. Once the tank is filled, the pump shuts off. When the tank level drops again, the second pump turns on and refills 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 will be a blend of the two wells. Since the wells are within a few feet of each other and screened at the same depth, the water quality of both wells is expected to be similar. There are no chemicals added to the well water delivered by the wells to the supply tank or to the water delivered to the homes.

The average daily water use for the community is 29,700 gallons per day (gpd) based on weekly meter readings from June 2003 through June 2004. The average maximum water use based on the weekly readings is 93,000 gpd. Well #1 typically reaches a maximum pumping rate of approximately 500 gpm when it is operating, whereas Well #2 typically reaches a maximum pumping rate of approximately 1,000 gpm during its cycle. Records are maintained of the time each pump operates and the flow rates during each cycle. A review of the pump records for May 22-30, 2004 shows that Well #1 normally pumps for four to five minutes and Well #2 normally pumps for two to three minutes to refill the supply tank. The supply tank is replenished based on level control and the time between pump activation will depend on the demand for water. The records for May 22-30, 2003 indicate that the "normal" time between well activation is two to four hours (alternating between wells #1 and #2), with some cycles as short as once per hour at high demand and as long as once in six hours at low demand over night. It appears that on an overall average basis, a well pump is actively pumping (either #1 or #2) for approximately three to four minutes every two to three hours (this will vary widely depending on demand). The supervisory control and data acquisition (SCADA) system monitors the pumping times and flow rates on a minute-by-minute basis. These data are available for the verification test period.

Table 1-1 presents raw water quality for samples taken from the water supply tank. These data were collected by OCDC as part of their regular monitoring program for this public drinking water supply site. The water has moderate total hardness of 250-290 milligrams per liter (mg/L) and the pH is normally about 7.4. Water quality data for total arsenic are available for the period between August 2002 and May 2004. In May 2004, the raw water was also analyzed for volatile organic compounds, semivolatile organics and pesticides/herbicides. The results showed no detectable concentrations of any of these organics.

Table 1-1. Raw Water Quality Data

Parameter	Units	August 2002	November 2002	February 2003	June 2003	January 2004	May 2004
Hardness	mg/L as $CaCO_3$	---	---	---	288	---	247
Sodium	mg/L	---	---	---	13	---	13
Chloride	mg/L	---	---	---	12	---	13
Sulfate	mg/L	---	---	---	17	---	16
Fluoride	mg/L	---	---	---	0.6	---	0.6
Iron	mg/L	---	---	---	0.9	---	1.0
Total Arsenic	mg/L	0.014	0.011	0.011	---	---	0.009
Turbidity	nephelometric turbidity units (NTU)	---	---	---	---	<1	---
Manganese	mg/L	---	---	---	---	0.021	---

1.3.2 Test Site Description

Structural

The entire water supply system, two wells, supply tank, controls, and piping, are located inside a secure building. There was room in the building to add the needed piping to supply the Microza System, house the chemical addition pumps and tanks (sodium hypochlorite, sulfuric acid, ferric chloride), and store basic supplies and equipment needed by the FTO. The building was not large enough to house the Microza System, but there was a large paved area immediately adjacent to the building. The Microza System was housed under a tent outside of the building on the paved area. The water supply was piped through the wall of the building, where it flowed into the mixing/coagulation tank, which supplied the chemically treated feed water to the microfiltration membrane. This test site provided the following advantages:

- Full electrical supply;
- Building enclosing 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 either ground water or to the sanitary sewer system.

Handling of Filtrate and Residuals

All treated water (filtrate) was discharged to a drainpipe that then discharged onto the land at the side of the building. The water flowed over the land and either entered the soil or reached a small tributary to Paint Creek. Backwash water was discharged through a separate drainpipe that was parallel to the filtrate discharge pipe and also discharged directly to the soil.

Discharge Permits

According the State of Michigan regulations and discussion with the Michigan Department of Environmental Quality (MDEQ), no special discharge permits were required for the discharge of the filtrate and backwash water from the Microza System test unit.

Chapter 2
Equipment Description and Operating Process

2.1 Description of Equipment

The Microza System used during the verification test was a skid mounted test rig supplied by Pall Corporation for testing the application of its microfiltration system. The test equipment was the Microza System Single Station test rig, which was designed to demonstrate the efficiency and performance of the Microza System. The test rig was designed to test one microfiltration module. Full-scale installations use multiple modules to attain the design flow rates needed by public drinking water supply systems. The single-module test unit holds a pilot-scale module to reduce the quantity of water required for testing.

The test rig is a self-contained, complete system that connects to a pressurized water supply. The unit delivers filtered product to either a site supplied collection tank or other drainage location. At Plum Creek, the filtrate from the Microza System discharged over the land, where it seeped into the soil. Any excess water entered a nearby surface water tributary of Paint Creek. The test rig is designed to treat flows up to 10 gpm using the microfiltration module selected for this verification test. A flow schematic is presented in Appendix A along with additional information on the test rig.

Similar to the Pall full-scale systems, the test system is automated and programmed to control all aspects of the filter operation. Clean In Place (CIP) maintenance is operator initiated with computer aided cleaning functions. The control system automatically initiates backwash cycles based on the time set by the operator. The backwash cycle time is dependent on the water quality conditions and the amount of solids generated in the coagulation process. The test rig controls provide the same full functionality and operator interface as Pall provides with full-scale public water supply systems. The control system is a programmable logic controller/personal computer (PLC/PC) based controller with data logging, trend display graphs, and a remote monitoring modem connection for off-site technical support.

The computer monitors and records transmembrane pressure (TMP), flow rates, temperature, air scrub parameters, and turbidity. All this 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 sulfate or 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 then be removed by various forms of particle removal (settling, filtration etc.). Some equipment trains 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 Pall process is based on chemical coagulation, mixing, and microfiltration 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 effective for arsenic removal, while arsenic (III) is not removed as easily to the low concentrations required to meet drinking water regulations. Therefore, water that contains arsenic (III) is often pre-treated with an oxidization step to convert the arsenic (III) to arsenic (V). The Pall system uses chlorine (fed as sodium hypochlorite) as a pretreatment step to convert any arsenic (III) to arsenic (V). The Pall system is compatible with several different oxidants in addition to chlorine.

2.3 Description of Treatment Train and Unit Processes

The Microza System includes pretreatment with sodium hypochlorite to oxidize any arsenic (III) to arsenic (V), and iron present in the water supply. Ferric chloride is then added to augment any natural occurring iron and optimize the iron dose. Sulfuric acid is added to adjust the pH to an optimal level, as determined during shakedown testing at the site. This chemically treated water (feed water) enters the feed tank supplied as part of test rig.

The coagulated water in the feed tank is mixed with an installed mixer and then is pumped directly to the microfiltration module. Flow enters the module on the outside of the membrane, passes through the membrane, and flows on the inside of the membrane to the outlet of the module. The microfiltration membrane filters the water, removing the precipitate, including arsenic, iron, and any other precipitated constituents. A portion of the filtrate is collected in a tank (reverse filtration tank) for use during the backwash process. The microfiltration system is designed to filter all of the water under normal operating conditions, [i.e., there is no reject (concentrate) water from the system]. In certain applications, small amounts of reject water may occur in a microfiltration system. No reject water was generated at the Plum Creek Site.

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 to 90 pounds per square inch (psi). A flow control valve was installed downstream of a back flow preventer to control the flow rate of raw water. A flow meter was used to monitor the flow rate and total flow of raw water to the chemical treatment portion of the process.

The piping installed to carry the raw water to the test unit feed tank incorporated the chemical feed part of the process. Chemical feed ports along the pipe provided for injection of sodium hypochlorite, ferric chloride, and acid. Each chemical was stored in a five-gallon container at the site. Chemical metering pumps were used to inject the chemicals into the water. Sampling ports were located before any chemical addition (raw water), and after the chemical addition points and the mixing tank. These sampling ports were manual valves placed in the line. Small diameter tubing was attached to the valves so that samples of the raw water and the feed water could be collected directly into the sample bottles.

The chemically treated water flowed into the 30-gallon feedwater holding tank. The water in this tank was continuously mixed with an installed mixer. The water was pumped to the microfiltration module at flow rate of approximately 6.3 gpm. The raw water flow rate to the feed tank was set slightly higher than the feed to the microfiltration module to ensure water was always present for continuous feed to the module. At the established flow of 6.3 gpm, the mixing time in the feed water holding tank was less than five minutes.

A variable speed pump controls the flow rate to the filter module. The flow meter measures the flow in both directions so that both filtrate flow and backwash flow are monitored. Pressure gauges are mounted on both the feed water line and the filtrate line to monitor pressure in the system and to monitor the pressure differential across the membrane. A full schematic of the system is presented in Appendix A.

The Microza System uses a combination of air and water to backwash the microfiltration membrane. Water is supplied from the reverse filtration tank (30 gallon tank), which holds filtrate from the system. A compressor with a fully automated control system supplies air for the air scrub. When a backwash is initiated, the air system is activated and supplies air to the feed side of the module. The reverse filtration pump pumps filtrate in a reverse flow through the membrane as well. The combination of air scrubbing and reverse water flow removes the particles that have been trapped by the microfiltration module. Backwash water from the test system is discharged either directly to a wastewater collection system or to another appropriate disposal outlet. For the verification test, the backwash water was discharged through a drainpipe to the soil behind the well house. Airflow and water flow are monitored during the backwash cycles.

Occasionally, microfiltration membranes require chemical cleaning to remove materials that are not removed during the backwash process. Chemical CIP is typically required on a two or three month basis. A CIP was not required during the 30-day verification test. Therefore, the CIP demonstration was done at the end of the test, manually. When the CIP was performed, the feed water tank was used to hold water that contained sodium hydroxide (caustic) and sodium hypochlorite. The mixture was recirculated through the system for approximately two hours. The system was then flushed with raw water to remove any residual chemicals. A citric acid cycle followed the caustic/chlorine cycle. The entire process was monitored once at the end to the verification test. The chemical CIP water was collected and discharged to the sanitary sewer system. Appendix B presents the Pall procedure for chemical cleaning of the module.

The Microza System had two inline turbidimeters to monitor turbidity on a continuous basis. Turbidity was monitored and recorded for the feed water and the filtrate.

A summary of typical operating conditions is provided in Table 2-1.

Table 2-1. Test System Typical Operating Conditions

Parameter	Specification
Flux	120 gallons per day per square foot (gfd)
Filtrate Flow Rate	6.3 gpm
Air Scrub Filtrate Rate	0.5 gpm
Air Scrub Air Rate	1.1 SCFM (66 SCFH)
Air Scrub Duration	60 seconds
Forward Flush Rate	3 gpm
Forward Flush Duration	30 seconds
Filtration Duration	28 minutes(1)
Waste per Air Scrub and Forward Flush	2.0 gallons
Excess Recirculation	None
Source Water Pressure	55-90 psi

(1) Actual filtrate production time was approximately 28 minutes out of every 30 minutes, with two minutes needed to complete the backwash cycle.

The microfiltration membrane used for the verification test was a Pall polyvinylideneflouride (PVDF) hollow fiber Microza® microfilter. The nominal pore size was 0.1 micron. Specifications for the membrane are given in Table 2-2.

Table 2-2. Microfilter Membrane Specifications

Name	Pall PVDF Hollow Fiber Microza® Microfilter
Model	USV-3003
Diameter	7.62 cm (3 inches)
Length	1126 millimeters (mm) (44.3 inches)
Number of filters	1800
Nominal pore size	0.1 microns
Operational pH	1 - 10
Filter Area	7 m^2 (75 ft^2)

2.4 Description of Physical Construction/Components

The Microza System test rig was a skid mounted, self-contained unit. The membrane was housed in a polyvinyl chloride (PVC) module with nitrile butadiene rubber (NBR) gasket and epoxy resin potting. Maximum operating pressure was approximately 3 bar. The test rig was 96" (L) x 34" (D) x 125" (H). The air compressor was a separate unit that was 30" (L) x 36" (W) x 70" (H). The main components of the Microza System were:

- 2 horsepower (hp) feed centrifugal pump;
- 2 hp reverse filtration pump;
- Feed water tank (30 gallons);
- Reverse filtration tank (30 gallons);
- Schedule 80 PVC piping for water, stainless steel tubing for air;
- One module holder for the membrane;

- Air compressor;
- Pressure, level, temperature transmitters;
- Flow meters (two);
- Inline turbidimeters (two); and
- Automated PLC/PC based control system.

A detailed set of specifications is provided in Appendix A. Figure 2-1 is a photograph of the Microza System used in this verification test.

Figure 2-1. Photograph of the Microza® System

2.5 Chemical Consumption and Production of Waste Material

2.5.1 Chemical Consumption

Three chemicals were used during normal operation of the testing equipment. Sodium hypochlorite was fed to oxidize any arsenic (III) to arsenic (V) and any iron in the raw water. The target dose for chlorine was approximately 1 mg/L. Ferric chloride was added for arsenic removal by coagulation. The final feed rate for ferric chloride was approximately 3 mg/L as ferric chloride. Sulfuric acid was added to adjust pH as needed. All chemical use was recorded during the verification test.

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 produced at the rate of approximately 96 gpd during continuous operation. This backwash volume represented approximately 1.2% of the filtrate volume produced each day. This water in a full-scale system may need to be disposed of to a sanitary sewer system or may need a liquid-solids separation process to clean the backwash water prior to discharge. If solids are settled or filtered, they will contain higher levels of iron and arsenic, and may require special handling for disposal. For the test system, the backwash water was discharged to the ground at the same location as the filtrate.

The Pall CIP chemical process was performed three times during this verification test; once after initial startup and shakedown before the arsenic loss test, once at the start of the 30-day verification test, and once at the conclusion of the 30-day verification test. The water from this caustic/sodium hypochlorite (bleach) cleaning had a high pH and chlorine content. It was neutralized before disposal to the sanitary sewer system. The second part of the cleaning waste had a low pH, which was also neutralized and discharged to the sanitary sewer.

2.6 Licensing Requirements

Based on conversations with the MDEQ, there were no special licensing requirements to operate the Pall equipment during the test. Larger systems may require licensed water treatment operators and wastewater permits for disposal of backwash water or cleaning chemicals.

2.7 Statement of Performance Objectives

The Microza System is a chemical coagulation and microfiltration system used in drinking water treatment system applications for reduction of arsenic. This document provides the verification test results for the Microza System.

2.8 Advantages of the Pall Microza System Process

According to the Pall Corporation, the main advantages of the Microza System microfiltration process for removing arsenic from water are as follows:

- The process is simple, compact, and can be operated on-demand;
- The hollow fiber filter membranes have a long service life;
- Each module provides a high filtration surface area;
- Fully automated control system allows operation with only periodic operator attention;
- Unique air scrub and flush system maintains long membrane runs between chemical cleaning;
- System is compatible with chlorine and other common treatment chemicals; and,
- Modular construction on skids provides for ease of installation and expansion.

2.9 Limitations of Equipment

Potential limitations of the microfiltration process for the treatment of raw drinking water with respect to source water quality are:

- Poor source water quality can cause high backpressure and plugging of the filters, increasing backwash frequency and chemical cleaning requirements.
- A disposal location, such as a sanitary sewer system, is needed to handle the low volume of 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. If the water quality of the source water varies it may require adjustment of the chemical feeds in order to maintain optimal removal efficiency.
- A heated structure is recommended when freezing temperatures are encountered. A roof may be needed in other areas to protect the equipment from sunlight and high temperature.
- Routine maintenance includes checking hoses, fittings and valves for leaks by a brief visual inspection. Chemicals need replenishment to ensure adequate supplies are available for injection to the system.

Chapter 3
Methods and Procedures

3.1 Quantitative and Qualitative Evaluation Criteria

The objectives of the verification test were to evaluate equipment in the following areas:

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

In order to address these objectives, the verification employed the quantitative and qualitative factors listed in Table 3-1 in evaluating the microfiltration equipment performance.

Table 3-1. Quantitative and Qualitative Evaluation Criteria

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

The primary application of the coagulation and microfiltration system is the removal of dissolved inorganic chemicals. In the case of this verification, the primary application was total arsenic removal. The microfiltration system can also be used for the removal of bacteria and cysts and oocysts, which was not part of this verification test.

3.2 Key Filtrate Water Quality Parameters

3.2.1 Key Groundwater Quality Parameters the Equipment is Designed to Address

The operating range of the Microza System, as stated by Pall Corporation is summarized in Table 3-2.

Table 3-2. Operating Range of the Microza System

Parameter	Range
Total Arsenic[(1)]	Less than 200 µg/L
pH	2 to 10 S.U.
Turbidity	0 - 1000 NTU

(1) During verification testing, the range of total arsenic in the feed water was <20 µg/L.

3.2.2 Key Filtrate Water Quality Parameters for Evaluating Equipment Performance

Key filtrate water quality parameters employed for evaluation of the Microza System are listed in Table 3-3. The Water Quality and Inorganic Parameter columns were the key parameters for evaluating the treatment process and water quality. The Other Parameters were not expected to have immediate impact on the treatment process, but were considered important parameters in drinking water supplies.

Table 3-3. Key Filtrate Water Quality Parameters

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

3.3 Calculations

3.3.1 Calculation of Statistical Uncertainty

The count, average, minimum, and maximum values were tabulated for all data sets. For the water quality parameters described in Table 3-3, 95% confidence intervals were calculated for parameters with more than eight data points (total arsenic, iron, turbidity, chlorine, and alkalinity). Equation 3-1 was used for confidence interval calculation:

$$\text{Confidence Interval} = \overline{X} \pm t_{n-1,1-\frac{\alpha}{2}}\left(\frac{S}{\sqrt{n}}\right) \qquad (3\text{-}1)$$

where: X = sample mean;

S = sample standard deviation;
n = number of independent measurements included in the data set;
t = Student's t distribution value with n-1 degrees of freedom; and
α = significance level, defined for 95% confidence as: 1 - 0.95 = 0.05.

According to the 95% confidence interval approach, the α term is defined to have the value of 0.05, thus simplifying the equation for the 95% confidence interval in the following manner:

$$95\%\ \text{Confidence Interval} = \overline{X} \pm t_{n-1,0.975}\left(\frac{S}{\sqrt{n}}\right) \qquad (3\text{-}2)$$

With input of the analytical results for pertinent water quality parameters into Equation 3-2, the output is reported as the sample mean value plus or minus the second term. The results of this statistical calculation are presented as a range of values falling within the 95% confidence interval. For example, the results of the confidence interval calculation provide the following information: 520 +/- 38.4 mg/L, with a 95% confidence interval range described as (481.6, 558.4).

3.3.2 Definition of Operational Parameters

The following are definitions used for the verification report and designation of sampling locations:

Filtrate is defined as the water produced by the microfiltration membrane process, the treated water.

Feed water is defined as the water introduced to the membrane element after all chemical additions.

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

Membrane flux is the average flux across the microfiltration membrane surface calculated by dividing the flow rate of filtrate by the surface area of the membrane.

Membrane flux is calculated according to Equation 3-3:

$$J_t = \frac{Q_p}{S} \qquad (3\text{-}3)$$

where: J_t = filtrate flux at time t (gfd or L/(h-m^2))
Q_p = filtrate flow (gpd or L/h)
S = membrane surface area (ft^2 or m^2)

Temperature Adjustment for Flux Calculation: Temperature corrections to 20°C for filtrate flux and specific flux will be made to correct for the variation of water viscosity with temperature. The following empirically derived equation will be used to provide temperature corrections for specific flux calculations:

$$J_t \text{ (at } 20^\circ\text{C)} = \frac{Q_p \times e^{-0.0239\,(T-20)}}{S} \qquad (3.4)$$

where: J_t = filtrate flux at time t (gfd, L/(h-m^2))
Q_p = filtrate flow (gpd, L/h)
S = membrane surface area (ft^2, m^2)
T = temperature of the feed water (°C)

Transmembrane Pressure is the pressure across the membrane, equal to the average feed water pressure on the membrane (average of inlet pressure and outlet pressure) minus the filtrate (permeate) pressure:

$$TMP = \left[\frac{(P_f + P_c)}{2}\right] - P_p \qquad (3.5)$$

where: TMP = transmembrane pressure (psi, bar)
P_f = inlet pressure to the feed side of the membrane (psi, bar)
P_c = outlet pressure on the concentrate side of the membrane (psi, bar)
P_p = filtrate pressure on the treated water side of the membrane (psi, bar)

Specific flux is used to refer to filtrate flux that has been normalized for the TMP. The equation used for calculation of specific flux is given by the formula provided below. Specific flux is usually discussed with use of flux values that have been temperature-adjusted to 20 or 25°C per equation 3.4 above:

$$J_{tm} = \frac{J_t}{TMP} \qquad (3.6)$$

where: TMP = Transmembrane pressure across the membrane (psi, bar)
J_t = filtrate flux at time t (gfd, L/(h-m^2)). Temperature-corrected flux values will be employed. Temperature correction is to 20°C.
J_{tm} = specific flux at time t (gfd/psi, (L/(h-m^2))/bar)

3.4 Operation and Maintenance

The manufacturer’s O&M documentation for a typical full-scale system was reviewed. NSF, as part of the verification testing, performed this review and the results of this review are included in this report. In addition, the following aspects of operability were evaluated:

- Fluctuation of flow rates and pressures through unit – the time interval at which resetting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?)
- Presence of devices to aid the operator with flow control adjustment.
- Is pressure measurement provided?
- Is rate of flow of raw water measured?
- Is chemical feed paced with raw water flow?
- Adequacy and ease of use of the PLC/PC control system.

The test unit used a pilot-size module, which allowed observation of the design and operation of this part of the system. The control system was also the same system used in larger applications. The backwash and chemical cleaning cycles were identical to larger multiple module 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 membrane over time;
- Frequency and ease of backwash;
- Chemical cleaning cycle requirements;
- 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

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

The following sections describe the tasks completed for the verification. The Microza System was operated 24 hours a day, seven days a week with staff on-site each day to operate the system and collect water quality data.

3.6 Environmental Technology Verificaition Testing Plan

A PSTP was prepared for the Microza System verification test in accordance with ETV Protocols. The PSTP divided the work into three main tasks (A, B, C) with Task C, the verification test itself, divided into six (6) tasks. These tasks were:

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 (Treated) Water Quality
    Task 3: Operating Conditions and Performance
    Task 4: Arsenic Removal

Task 5: Data Management
Task 6: Quality Assurance/Quality Control

The PSTP, which included a Quality Assurance Project Plan (QAPP), specified the procedures that were 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 the testing procedures presented in the following sections.

3.6.1 Task A: Raw Water Characterization

The objective of Task A, an initial operations task, was to obtain a chemical and physical characterization of the feed water. Information on the groundwater supply that provided the raw water was obtained from the OCDC to aid in interpretation of feedwater characterization.

3.6.2 Task B: Initial Test Runs

During Task B, initial test runs, Pall Corporation evaluated the equipment operation to determine the optimal chemical dosages and other pretreatment conditions that were needed to provide effective treatment of the feed water. Pall Corporation performed all startup and shakedown testing.

3.6.3 Task C: Verification Test Procedures

Task 1: Verification Testing Run

The Microza System was operated for 30 days to collect data on equipment performance and water quality for the verification test. The 30-day test period was selected based the microfiltration process being used by the Microza System and the ETV Protocol requirement for testing such filtration processes.

Task 2: Raw Water, Feed Water, and Filtrate (Finished) Water Quality

During verification testing, raw, feed, and filtrate water samples were collected, and appropriate analyses were performed. For example, iron analyses were performed to monitor the coagulation process, in addition to arsenic analyses for the evaluation of arsenic removal.

Task 3: Operating Conditions and Performance

During verification testing, operating conditions and performance of the water treatment equipment were documented. Operating conditions include pretreatment chemistry for coagulation, a listing of treatment processes used, and their operating conditions. Equipment performance information included data on rate of filter head loss change, duration of filter runs, and the frequency and duration of backwash and filter cleaning. The operating conditions included plant flow rates and chemical dosages.

Task 4: Total Arsenic Removal

The objective of this task was to evaluate total arsenic removal during verification testing by measuring total arsenic in the raw, feed and filtrate water. In addition, detailed data on coagulant dosages and pre-oxidants were collected.

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. Prepared master field logs and field data sheets were used to ensure all scheduled activities were performed. These logs were delivered to the ETV DWS Center project coordinator on a weekly basis.

Task 6: Quality Assurance/Quality Control

An important aspect of verification testing was the development of specific quality assurance and quality control (QA/QC) procedures and measures. The objective of this task was to assure accurate measurement of operational and water quality parameters during the verification test. A project specific QAPP was prepared with the PSTP to identify data quality objectives (DQO) for the test. Appropriate QA/QC measures for both field and laboratory data were used by the NSF staff and reported as part of the field logs and laboratory reports.

3.7 Task A: Raw Water Characterization

3.7.1 Site Background Information

Section 1.3 provided a description of the area and basic information on the wells. This information was obtained from OCDC and the well installation records. In the past, the site operator (OCDC) collected samples periodically, which were used for general characterization of the water quality. The historical data were presented in Table 1-1.

3.7.2 Additional Analytical Data

During Task A, grab samples of the raw water were collected for characterization purposes. These samples were collected and analyzed to confirm the historical data. The analyses included arsenic speciation to determine the distribution of arsenic (III) and arsenic (V) in the raw water. These analyses also included parameters that were part of verification test as described in Task C. Table 3-4 shows the parameters that were analyzed on these initial samples. Information on sampling and analysis methods and procedures is provided in later sections. These data, along with historical data for the groundwater source, provided characterization of the untreated water source.

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

pH	Manganese
Temperature	Barium
Turbidity	Chloride
Alkalinity	Sulfate
Residual Chlorine	TOC
Dissolved Oxygen	Fluoride
Total Arsenic	Calcium(1)
Arsenic (speciation)	Magnesium(1)
Iron	

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

3.7.3 Evaluation Criteria

The raw water characteristics were evaluated in context of the Pall 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, iron addition, and pH adjustment to properly co-precipitate arsenic present in the raw water. The Microza System was set up and operated to check system integrity and ensure the unit was properly installed for the verification test.

3.8.2 Work Plan

Pall technical support staff worked with OCDC site staff to install the equipment and ready the Microza System for operation. Pall staff was on-site to direct final connections and the startup for the equipment. Once ready for operation, Pall Corporation ran the initial startup and shakedown tests.

Pall Corporation provided a basic outline of the testing that was planned to determine the optimal iron dose and optimal pH for the coagulation process. This outline was presented in the PSTP, Appendix C. These tests included varying the chlorine and iron concentrations, and the pH. Samples for total and soluble iron and total arsenic were collected. Pall also monitored pH on the samples. The testing plan followed the basic outline provided, and the startup proceeded smoothly. Pall arranged with a local laboratory to perform the analyses of samples collected during the shakedown testing.

Once Pall had confirmed the operating conditions and chemical feed rates recommended for the verification test, they informed NSF that the Microza System was ready for the verification test. These operating conditions defined by Pall were used for the verification test.

Pall has a standard integrity test procedure that is used to check the microfiltration membrane after installation. The integrity test procedure, based on pressurizing the system, is presented in Appendix D. Pall performed this test to ensure that the membrane was free of major defects. The integrity test also functioned as a leak check on the test system to ensure that all connections were tight and that the seals on the module did not leak.

3.8.3 Arsenic Loss Test

Prior to starting the verification test, the unit was flushed for two hours using raw water with no chemical feed. It should be noted that the raw water contained naturally occurring iron at a concentration of approximately 1 mg/L. Normal backwash cycles were performed and all operating conditions (flow rate, pressure, etc.) were monitored and confirmed by the NSF field staff. Following the flushing of the system, an initial test run was performed to determine if there is any total arsenic loss in the system when coagulants were not being used. This test run lasted for 24 hours with samples of raw water, feed water, and filtrate being collected after 6, 12, 18, and 24 hours of continuous operation. Once this testing was completed and all operating parameters confirmed, the verification test began.

3.8.4 Analytical Schedule

The samples collected during the arsenic loss test were grab samples collected at the times specified. The four sets of samples (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) had arsenic speciation tests run 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
Temperature	4/24 hours	Raw, feed, filtrate
Turbidity	4/24 hours	Raw, feed, filtrate
Alkalinity	4/24 hours	Raw, feed, filtrate
Residual Chlorine	4/24 hours	Raw, feed, filtrate
True Color	1/24 hours	Raw, feed, filtrate
Calcium[2]	4/24 hours	Raw, feed, filtrate
Magnesium[2]	4/24 hours	Raw, feed, filtrate
Total Arsenic	4/24 hours	Raw, feed, filtrate
Arsenic (speciation)	2/24 hours	Raw, feed, filtrate
Iron	4/24 hours	Raw, feed, filtrate
Manganese	1/24 hours	Raw, feed, filtrate
Barium	1/24 hours	Raw, feed, filtrate
Chloride	1/24 hours	Raw, feed, filtrate
Sulfate	1/24 hours	Raw, feed, filtrate
Fluoride	1/24 hours	Raw, feed, filtrate
TOC	1/24 hours	Raw, feed, filtrate
Dissolved Oxygen	4/24 hours	Raw, filtrate

(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

During startup and shakedown testing, Pall determined the optimal chemical doses (chlorine and ferric chloride) and the system operating conditions to achieve arsenic removal. NSF reviewed this information and determined that the data indicated that the total arsenic removal performance and operating conditions met the stated performance objective. Therefore, the recommended chemical feed rates and system operating conditions were used for the verification test.

3.9 Task C: Verification Test

3.9.1 Introduction

The verification test was run for a 30-day period from September 9, 2004 through October 8, 2004. The Microza System was operated continuously, 24 hours a day, seven days per week, except for a power outage that occurred overnight on September 27-28. Water quality data for the raw, feed and the filtrate were collected in accordance with the PSTP, as described in the following sections. All samples were grab samples collected from the sampling ports installed on the test rig.

The PSTP described six tasks to be performed to achieve a successful verification test. Each of these tasks was performed in accordance with the approved PSTP as outlined below.

3.9.2 Experimental Objectives

The objective of Task C was to assess the ability of the Microza System to demonstrate the treatment capability of reducing 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 in order to achieve the objective. Statistical analyses (standard deviation and confidence intervals) were performed on all analytes with eight or more discrete samples collected over the 30-day verification period.

3.9.3 Task 1: Verification Testing Runs

Introduction

The verification test was designed to use the optimal configuration and filtration operating conditions determined by the shakedown testing. The 30-day test was designed to measure the performance of the 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 did not vary significantly over the test period.

The filtrate produced during the verification was not used for public supply purposes. The filtrate was discharged to the ground.

Operating Schedule

The Microza System was operated continuously during the verification test. Flow was maintained to the system 24 hours a day, seven days per week, except during the short routine backwash cycles that are part of the normal system operating procedure. Two CIP cleanings were performed during the Task C verification. One chemical CIP procedure was performed at the start of the verification test and the procedure was repeated at the end of the 30-day period to demonstrate the effectiveness of the chemical CIP procedure.

During the 30-day 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 was also collecting and recording operating data for the system. Sampling and analysis included one intensive 58-hour sample collection period.

Table 3-6. On-site Equipment Operation Parameter Monitoring and Data Collection Schedule

Parameter	Monitoring Frequency	Monitoring Method
Raw water flow rate	Check and record once per day.	Raw water flow meter.
Feed/filtrate water production	Check and record once per day.	Raw water totalizer meter.
Feed/filtrate water flow rate	Check and record once per day (adjust when 5% above or below target; record before and after adjustment).	Feed/filtrate water flow meters.
Feed water pressure	Check and record once per day.	Feed water pressure gauge.
Filtrate water pressure	Check and record once per day.	Filtrate water pressure gauge.
Concentrate water pressure	Check and record once per day	Concentrate water pressure gauge.
Backwash volume per cycle	Check and record once per day.	Bucket and stop watch.
Total backwash volume	Check and record once per day.	Number backwashes per day multiplied by the backwash volume.
Chemical feeds: tank volume and pump metering rate of the three chemicals: acid, chlorine, ferric chloride	Check and record once per day.	Measure with measuring tape depth of chemical remaining and, as required, quantity of chemical refill.
Chemicals used	As needed.	Record name of chemical, supplier, commercial strength, and dilution used for making batch solution.
Rapid Mixer	Check once per day.	Visual observation that mixer is properly working.
Operating hours	Record the total hours of operation since last site visit once per day.	Based on PLC/PC and total volume meters, determine total hours.
In Line Turbidimeters	Verify these meters are operating and data are recorded.	Compare to bench-top meter; calibrate as needed.

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 of 30 days continuous operations were documented. Backwash cycles and times were recorded. All data are summarized in Chapter 4, Results and Discussion. The field logs and log sheets are presented in Appendix E.

3.9.4 Task 2: Feed Water and Filtrate Water Quality

Introduction

Water quality data were collected for raw water, feed water, and filtrate for a 30-day period from September 9 through October 8, 2004. One intensive 58-hour sampling period was performed from September 20 through 22, 2004. These data provided the basis for determining the total arsenic removal performance of the system and documenting the water quality achieved. The sampling and analysis also included data collection to monitor the changes or impacts of the coagulant addition (ferric chloride) on water quality.

Work Plan

Monitoring of water quality parameters in the feed water and filtrate water streams was performed on a regular basis as shown in Table 3-7. These data were used to calculate the change in the total arsenic concentration and changes in other inorganic chemicals. In addition to the regular sample collection schedule, there was one intensive sampling and analysis period, which focused on total arsenic removal, pH and turbidity variability, and the concentration of related process chemicals, such as iron, and residual chlorine. The intensive sampling period is described further in Section 3.9.6.

Table 3-7. Weekly Sampling Schedule

Parameter	Sampling Frequency	Test Streams Sampled
Temperature	Daily	Raw, Feed, and Filtrate Water
pH	Daily	Raw, Feed, and Filtrate Water
Alkalinity	3/week	Raw, Feed, and Filtrate Water
Turbidity	Daily	Raw, Feed, and Filtrate Water
Hardness(1)	Weekly	Raw, Feed, and Filtrate Water
Calcium	Weekly	Raw, Feed, and Filtrate Water
Magnesium	Weekly	Raw, Feed, and Filtrate Water
TOC	Weekly	Raw, Feed, and Filtrate Water
Total Iron	3/week	Raw, Feed, and Filtrate Water
Manganese	Weekly	Raw, Feed, and Filtrate Water
Total Arsenic(2)	3/week	Raw, Feed, and Filtrate Water
Sulfate	Weekly	Raw, Feed, and Filtrate Water
Chloride	Weekly	Raw, Feed, and Filtrate Water
True Color	Weekly	Raw, Feed, and Filtrate Water
Residual Chlorine	Daily	Raw, Feed, and Filtrate Water
Barium	Weekly	Raw, Feed, and Filtrate Water
Fluoride	Weekly	Raw, Feed, and Filtrate Water
Dissolved Oxygen	Daily	Raw Water
TSS(3)	Weekly	Backwash water
Total Arsenic(3)	Weekly	Backwash water
Total Iron(3)	Weekly	Backwash water
pH(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 during a backwash cycle.

The field staff analyzed samples on-site for pH, temperature, turbidity, total and free chlorine, dissolved oxygen, and true color. The NSF Chemistry Laboratory performed analyses of the remaining water quality parameters. The methods used for measurement of water quality parameters are identified in Table 3-8. Further discussion of analytical methods is presented in the PSTP and in the QAPP.

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	On-site	2120B		
Turbidity	On-site		180.1	
Temperature	On-site	2550		
Chlorine (total and free)	On-site	4500-Cl		8167 (total) 8021 (free)
Dissolved Oxygen	On-site	4500-G		
NSF Lab 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		
Barium	Laboratory		200.7	
Fluoride	Laboratory		300.0	
Alkalinity	Laboratory	2320B		
Hardness	Laboratory[4]	2340 B		

(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) Hardness was calculated from calcium and magnesium measurements.

Water samples submitted to the NSF Chemistry Laboratory were collected in appropriate containers (containing necessary preservatives as applicable) prepared by the NSF Chemistry Laboratory. The samples were stored in a cooler with ice, delivered to the laboratory (no commercial shipping used), and analyzed in accordance with appropriate procedures and holding times. Table 3-9 summarizes the preservation and holding times applicable to the various analyses.

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

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

Analytical Schedule

The analytical parameter list and frequency shown in Table 3-7 was designed to frequently monitor the parameters that are critical to the coagulation and filtration process. The parameters monitored on a less frequent basis are general water quality parameters to provide water quality characteristics. Dissolved oxygen concentration in the raw water was considered important, as the treatment system depends on the oxidation of iron to achieve the proper conditions for arsenic coagulation and removal.

It should be noted that pH was monitored on all three water types, raw, feed, and filtrate. The pH adjustment step was an important part of the process; therefore, monitoring the pH before adjustments, after adjustment, and after filtration was an important operating parameter. Turbidity measurements were made continuously within inline turbidimeters. The inline turbidimeters were checked daily using a bench-top turbidimeter. If the inline units required calibration, it was performed by the DWTS field staff and recorded in the logbook.

The backwash water was sampled once per week during a backwash cycle to obtain information on the TSS concentration in the backwash. Backwash samples were also analyzed for the concentration of total arsenic, total iron, and pH. The PSTP also called for residual chlorine analyses on the backwash water, but these analyses were not performed. The backwash water residual chlorine was approximately the same as the filtrate water, since filtrate water was collected in a tank for backwashes that occurred every 15 to 30 minutes.

The protocol and PSTP called for measuring the metals leached from any sludge produced from the system using the Toxicity Characteristics Leaching Procedure (TCLP) and California Waste Extraction Test (CAWET) leaching procedures. The Microza System would typically produce sludge only if the backwash water was stored in a tank and passed through a solids separator to remove suspended solids prior to discharge. This was not the method of handling backwash at the site. Backwash was directly discharged onto the ground. Therefore, no residues accumulated during the test and no solids testing was performed.

Water Quality Sample Collection

All raw water, feed water, and filtrate samples were grab samples collected from the sampling valves installed in the test system. The raw water sample tap was located prior to any chemical addition. The feed water sample port was located after all chemical additions and mixing just prior to the filtration unit. The filtrate (treated water) sample tap was located downstream of the microfiltration module. Prior to collecting the sample, each valve and sample tube (tubing attached the 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 sample were then poured into the required containers for laboratory analysis or on-site analysis. Samples from all three locations were collected within a short period of time (less than 30 minutes) so that data were representative of the current conditions. Backwash samples were grab samples collected from the backwash line as it discharged from the system during the backwash cycle.

Special sampling procedures were employed for bench-top turbidity samples. The method for collecting grab samples consisted of 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 (MCL) of 0.3 mg/L.

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

Other water quality data were summarized and are presented in the Chapter 4 in either graphical or tabular format. Daily analyses were plotted against time, while weekly parameters were summarized in a tabular format. Information includes:

- A graph plotting the daily turbidity, pH, alkalinity, and iron for the raw, feed and filtrate over the test period.
- A table summarizing the raw, feed, and filtrate concentrations of hardness, manganese, TOC, sulfate, chloride, and true color.
- A table summarizing the residual chlorine data.
- An appendix containing all data collected during the verification test.

3.9.5 Task 3: Operating Conditions and Treatment Equipment Performance

Introduction

Operating conditions were documented during each day of verification testing, including descriptions of chemicals used for coagulation and operating conditions. The performance of the water treatment equipment was documented, including flow rates through the microfilter, pressure drop across the filter, frequency and duration of filter backwash cycles, and any maintenance required.

The objective of this task was to accurately document the operating conditions during treatment and the equipment performance. This task was intended to result in operational data describing the operation of the equipment.

Work Plan

A description of the equipment, microfiltration membrane characteristics, and test system operating conditions was presented in Chapter 2. During verification testing, operating parameters such as those defined by Pall (Table 2-1) were monitored. 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,
  - Monitoring the chlorine pre-oxidation step,
  - Observing the operation of the mixing in the feed water tank, and
  - Calculating process detention time in the feed water tank based on system flow rate data.
- Filter pressure drop before and after backwash cycles, and backwashing data (frequency, flow rate, volume), cleaning data.
- Chemical dosages for all chemicals used, including oxidants. Sodium hypochlorite was used as an oxidant. Free and total residual chlorine were measured daily, including when total arsenic samples are collected. The feed rate of iron coagulant chemical, the strength of the solution, and the specific gravity for liquid coagulant, were documented. The quantity of sulfuric acid used for pH adjustments was monitored, and the strength of the solution, and the specific gravity were documented.
- Electrical energy consumed by the treatment equipment based on aggregate horsepower of all pumps in operation (based on operating time estimate), air compressor, and mixer was calculated and reported.
- Effectiveness of the chemical CIP procedure was monitored by comparing post cleaning membrane pressure drop to original clean membrane pressure drop at the start of the test. Chemical use, flow rates, and waste generated were recorded.

<u>Schedule for Operating Parameter Data Collection</u>

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

<u>Evaluation Criteria</u>

The data developed from this task were used to present operating data on system flow rate, membrane flux, pressure drop across the filter module, frequency and duration of filter backwash cycles, and information on the chemical CIP procedure at the end of the test.

The results of operating and performance data were tabulated and are included in Chapter 4. The results include:

- Average volume of flow treated, expressed as gpd;
- Average filtrate water flow rate, expressed as gpm;
- Average filtration rate, expressed as gallons per minute per square foot (gpm/ft^2);
- Flux as gfd, and specific flux as gallons per day per square foot per pounds per square inch (gfd/psi);

- Chemical usage over the duration of the test;
- Daily TMP across the module;
- Typical backwash water production;
- Typical suspended solids in the backwash; and
- Effectiveness of the chemical in place cleaning procedure.

3.9.6 Task 4: Arsenic Removal

Introduction

Total arsenic removal was the primary objective of coagulation and microfiltration process being evaluated in this verification. The effectiveness of the coagulation and filtration treatment processes for total arsenic removal was evaluated in this task. Assessment of treatment efficacy was made on the basis of total arsenic removal, by measuring total arsenic naturally present in the raw water**,** the feed water (after coagulation with iron), and in the filtrate (treated) water.

Work Plan

Task 4 was performed simultaneously with the verification testing runs described in Task 1. The treatment equipment was operated using the chemical treatment conditions and system operating conditions established by Pall during the shakedown test.

Evaluation of total arsenic removal was performed by analyzing total arsenic in the raw, feed and filtered waters. The total arsenic evaluation included monitoring total arsenic concentration on a frequency of three times per week, as shown in Table 3-7, and during one intensive sampling period over 58 hours. The intensive sampling period started on the 12th day of the verification test. Samples were collected at the start (time zero), 1, 3, 6, 10, 24, 29, 34, 48, 53, and 58 hours after time zero (11 sets of samples). The collection of total arsenic samples during this intensive program provided verifiable total arsenic removal data.

Chlorine dose and residual chlorine were monitored throughout the verification. During the intensive total arsenic test, residual chlorine was analyzed on every sample. The Pall process includes a pre-oxidation step with chlorine to convert any arsenic (III) to arsenic (V) and also 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, Pall has implemented the preferred approach and uses pre-oxidation to convert all arsenic to arsenic (V) to attain the most effective results. Pre-oxidation used sodium hypochlorite as the chlorine source and pre-oxidation operating conditions were documented.

Analytical Schedule

Turbidity in the feed water and filtered water was monitored using continuous flow turbidimeters equipped with recording capability, so data were available on a 24-hour-per-day basis during verification testing. Raw water, feed water and filtrate turbidity were also monitored once per day using a bench-top turbidimeter. The bench-top results were used to verify the calibration of the inline units.

The regular daily and weekly sample analyses for total arsenic and other water quality parameters are discussed in Section 3.9.4, Task 2. Total arsenic samples were collected three times per week and one sample each week was speciated. The sampling schedule was summarized in Table 3-7.

For the 58-hour intensive sampling period, samples were collected from the raw water (before chemical addition), from the feed water (after chemicals addition and mixing), and from the filtrate (the filter effluent). Total arsenic samples were collected at times, resulting in collection of 11 sets of total arsenic samples in a 58-hour period. The total concentration of iron, used as the coagulant to co-precipitate arsenic, was also determined in each raw water, feed water, and filtered water sample.

The complete list of parameters that were monitored during the 58-hour intensive sampling period is shown in Table 3-10.

Table 3-10. Parameter List for Arsenic Intensive Sampling Program

Parameter	Sampling Frequency	Test Streams Sampled
Total Arsenic	All samples(1)	Raw, Feed, and Filtrate Water
Arsenic Speciation	0, 10, 24, 48 hours	Raw, Feed, and Filtrate Water
Temperature	0, 10, 24, 48 hours	Raw, Feed, and Filtrate Water
pH	All samples	Raw, Feed, and Filtrate Water
Alkalinity	0, 24, 48 hours	Raw, Feed, and Filtrate Water
Turbidity	Daily	Raw, Feed, and Filtrate Water
Turbidity	For all arsenic samples by continuous meter	Feed and Filtrate Water
Hardness(2)	Once at 24 hrs	Raw, Feed, and Filtrate Water
Calcium	Once at 24 hrs	Raw, Feed, and Filtrate Water
Magnesium	Once at 24 hrs	Raw, Feed, and Filtrate Water
TOC	Once at 24 hrs	Raw, Feed, and Filtrate Water
Iron	All samples	Raw, Feed, and Filtrate Water
Manganese	Once at 24 hrs	Raw, Feed, and Filtrate Water
Barium	Once at 24 hrs	Raw, Feed, and Filtrate Water
Sulfate	Once at 24 hrs	Raw, Feed, and Filtrate Water
Chloride	Once at 24 hrs	Raw, Feed, and Filtrate Water
Fluoride	Once at 24 hrs	Raw, Feed, and Filtrate Water
True color	Once at 24 hrs	Raw, Feed, and Filtrate Water
Residual Chlorine	All samples	Raw, Feed, and Filtrate Water
Dissolved Oxygen	0, 24, 48 hours	Raw and Filtrate Water
TSS(3)	Once between 24-48 hrs	Backwash water
Total Arsenic(3)	Once between 24-48 hrs	Backwash water
Total Iron(3)	Once between 24-48 hrs	Backwash water
pH(3)	Once between 24-48 hrs	Backwash water

(1) All samples means time zero and 1, 3, 6, 10, 24, 29, 34, 48, 53, 58 hrs after time zero.

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

(3) Samples were collected during a backwash cycle.

Evaluation Criteria

Performance evaluation was conducted in the context of the manufacturer's statement of performance objectives with respect to total arsenic removal. The following information is provided in Chapter 4:

- 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 filtered water data were tabulated and the concentration of iron in filtered water was compared to the secondary MCL of 0.3 mg/L.

The following data are also presented in the Chapter 4:

- The total arsenic data plotted against sample time to show trends or variations performance.
- A graph plotting the turbidity, pH, and iron for the raw, feed and filtrate over the 58-hours test period.
- A table summarizing the raw, feed, and filtrate concentrations of hardness, manganese, TOC, sulfate, chloride, and true color.
- A table summarizing the residual chlorine data.
- An appendix containing all data collected during the verification test.

3.9.7 Task 5: Data Management

Introduction

The data management system used in the verification testing plan included the use of computer spreadsheets and manual recording of operational parameters for the microfiltration equipment on a daily or weekly basis. DWTS field staff, their consultant, and DWS Center staff collected the information and entered it into the appropriate spreadsheets and logbooks. All field activities were documented. Field documentation included field logbooks, field data sheets, and chain of custody forms. The procedures for logbook format and entries were as follows:

- Field notes were kept in a bound logbook;
- Field log sheets were used to record all water treatment equipment operating data;
- Each page in bound log books were sequentially numbered;
- Each data log sheet page was labeled with the date and time;
- Completed pages were initialed and dated by the individual responsible for the entries; and
- Errors were noted by drawing a line through them.

Original field sheets and chain of custody forms accompanied all samples delivered to the analytical laboratory. Copies of field sheets and chain of custody forms for all samples are included in Appendix F.

Experimental 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 NSF 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, and the PSTP.

Work Plan

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) by hand in field and laboratory logbooks. Daily measurements were recorded on specially prepared data log sheets. The original logbooks were stored on-site during the test; copies were delivered to the DWS Center project coordinator at NSF at least once per week 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, etc.), in addition to experimental calculations and other items.

A database for the project was setup in the form of custom-designed spreadsheets. The spreadsheets were capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the on-site laboratory logbooks and data log sheets were entered into the appropriate spreadsheet. Following data entry, the spreadsheets were printed out and the printouts were checked against the handwritten data sheet. All spreadsheets were then proof read by the DWS Center staff to provide a 100% check of the data.

Samples collected and sent to the NSF Chemistry Laboratory were tracked by use of chain of custody forms. Each sample had a location name, date, time of collection, and the parameters written on the label. Data from the NSF Chemistry Laboratory were received and reviewed by the NSF coordinator. These data were entered into the data spreadsheets, corrected, and verified in the same manner as the field data. Copies of the spreadsheets are presented in Appendix G.

3.9.8 Task 6: Quality Assurance

QA/QC of the operation of the Microza System equipment and the measured water quality parameters was maintained during verification testing by following the QAPP developed as part of the PSTP. The QAPP included accuracy and precision objectives for the analytical work. The need to meet representativeness and completeness criteria is also discussed in the QAPP. Calibration requirements for field meters and for analytical equipment/methods are detailed in the QAPP, Chapter 5 of the PSTP.

On-site Equipment Checks

Equipment flow rates were documented and recorded on a daily basis. A routine daily walk through during testing was established to verify that each piece of equipment or instrumentation was operating properly. Inline monitoring equipment such as flow meters, etc. were checked to confirm that the readout matches with the actual measurement.

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

Weekly QA/QC Verifications:

- Inline flow meters (cleaned any fouling buildup as needed, and verified flow rate volumetrically, bucket and stop watch or tank fill time);
- Inline totalizer meter (cleaned any material buildup as needed and verified production rate volumetrically, monitored volume recorded over time based on calibrated flow rate);
- Tubing/piping (verified good condition of all tubing and connections, replace as necessary); and,
- Confirmed calibration of each metering pump by using a graduated cylinder to determine the flow rate of each pump.

Daily QA/QC Verifications:

- Turbidity calibration of the inline meters were verified daily by comparison with bench-top turbidimeter results.

Sampling and Analytical Methods

The analytical methods utilized in this verification-testing plan 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 on-site 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 Section 5 of the PSTP.

3.10 Operation and Maintenance

NSF obtained the O&M manual from Pall to evaluate the instructions and procedures for their applicability during the verification test and for overall completeness. NSF reviewed the Pall O&M manual. Results of the O&M manual review are reported in Chapter 4.

3.10.1 Maintenance

Some of the items that were evaluated during the verification test and review of the O&M manual included:

Did the manufacturer provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment, such as:

- Pumps;
- Valves;
- Pressure gauges;
- Flow meters;
- Chemical feeders;
- Mixers;
- Motors;
- Membrane cleaning; and
- Continuous turbidimeters?

Did Pall Corporation provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment, such as:

- Tanks;
- Piping; and
- Filter vessels?

3.10.2 Operation

Among the operating aspects that were evaluated are:

Pre-oxidant generation/feed:

- Measurement of pre-oxidant concentration generated; and
- Measurement of pre-oxidant concentration fed into treatment equipment.

Chemical feeder pumps:

- Calibration check;
- Settings and adjustments – how they should be made; and
- Dilution of chemicals – proper procedures.

Microfiltration:

- Control of filtration flow and rate;
- Observation and measurement of pressure drop across the membrane during filter run; and
- Feed flow control in response to temperature changes.

Membrane backwashing:

- Programming automated frequency;
- Proper backwash venting and disposal;
- Appropriate backwash rate; and
- Monitoring during return of filter to service.

Chemical cleaning:

- Selection of proper chemical washing sequence;
- Proper procedures for dilution of chemicals;
- Monitoring of pH through chemical cleaning cycle;
- Rinsing of membrane system following chemical clean; and
- Return of filter to service.

Monitoring and observing operation:

- Observation of floc;
- Filtered and feedwater water turbidity;
- Filter pressure differential;
- Measuring the iron coagulant dose; and
- Measuring and controlling pH of coagulated water.

The ETV Protocol recommends that a manufacturer should provide a troubleshooting guide, a simple checklist of what to do for a variety of problems, in the O&M manual including:

- No raw water (feed water) flow to plant;
- Cannot 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;
- Mixer will not operate (will not rotate);
- Filter cannot be backwashed or backwash rate of flow cannot change;
- No reading on turbidimeter;
- Automatic operation (if provided) not functioning;
- Filtered water turbidity too high;
- Filter head loss builds up excessively rapid;

- Valve stuck or will not operate;
- Low feed pump pressure;
- Reduced filtrate flux;
- Pump cavitation; and
- No electric power.

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

3.10.3 Operability Evaluation

The following were the basis of the review and evaluation for operability aspects of the equipment.

During verification testing attention was given to equipment operability aspects. The following are some of the factors considered:

- Fluctuation of chemical feed rate from desired value – the time interval at which re-setting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?).
- 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?
- Can automatic backwash be initiated by reaching a set value for head loss?
- Does plant have multiple feed points for chemicals:
  - for pH adjustment?
  - for coagulant chemical feed?
  - for oxidants?
- Is membrane 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, can the equipment be automatically shut down?
- Upon automatic shutdown, can a means of operator notification be provided, if the operator is not present on the site where the equipment is located?

Chapter 4
Results and Discussion

4.1 Introduction

The verification test program for the Microza System was conducted from June 22 through October 13, 2004. The equipment was installed the week of June 22 and Pall conducted startup and shakedown testing through July 1, 2004. Raw water characterization tests and an arsenic loss test were performed in August 2004. The 30-day verification test, including a 58-hour intensive arsenic sampling period, was performed from September 9 through October 8, 2004. The membranes were chemically cleaned in place at the beginning and end of the 30-day verification test. The verification test site was located at the OCDC Plum Creek Development in Oakland Township, Oakland County, Michigan, which has two production wells supplying a residential neighborhood. The test site was described in Section 1.3. The Microza System was described in detail in Chapter 2 of this report.

Chapter 4 presents a summary of the water quality and operating data collected during the verification test. Activities and data collected during the startup and shakedown of the equipment, raw water characterization, and the arsenic loss test are presented to describe activities performed prior to the actual 30-day verification test. The results for the 30-day verification test are presented including data on raw water, feed water, and treated water arsenic concentrations and for 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 membranes and related operating information. Information describing the chemical CIP procedure performed at the beginning and end of the test is also presented. 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, Startup, and Shakedown

Pall personnel installed the equipment at the Plum Creek site with assistance from OCDC staff the week of June 21, 2004. The unit was shipped as a complete skid mounted unit with all components in one package except for the air compressor needed for the air scrub backwash. Piping was installed to route raw water from the pressure supply tank inside the building to the Microza System, which was placed outside the building. The raw water line included inline locations to inject sodium hypochlorite (source of chlorine), ferric chloride (coagulant), and sulfuric acid (pH adjustment) using chemical metering pumps supplied by Pall. The raw water piping also included a water meter to provide both raw water flow rate and total volume. The air compressor was housed next to the membrane system and also outside the OCDC building. The compressor was initially in the open, but after noise complaints from nearby homes, a temporary wooden structure was erected around the compressor to suppress the noise. The system installation was completed in a two to three day period.

Pall has developed a startup and shakedown procedure, which includes an integrity test for the unit and a series of operating tests to optimize chemical feeds and flow rates for the system. These procedures were included as appendices to the PSTP and are also included in Appendix D.

The integrity test was conducted at the end of the equipment installation. This test is an air pressure test where the unit is subjected to air pressure of 20 to 30 psi and then the pressure decay is monitored. A pressure decay rate less than 0.2 psi/min demonstrates that the membranes do not have significant flaws and that the system piping connections are leak free. The unit was tested by Pall on June 24, 2004 and found to meet the specifications on the first test.

Over a two-day period from June 30 through July 1, 2004, Pall ran a series of tests that included operating at varying doses of ferric chloride and residual chlorine (in the feed water to the unit), and at different pH levels in the feed water. 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 treated water. Samples of raw water, feedwater (after chemical addition), and filtrate water were collected for laboratory analysis for iron, arsenic, and turbidity. The data obtained by Pall was summarized and shown in Appendix D. This shakedown period data are provided for informational purposes only and were not verified. The shakedown tests required only two days because of the rapid response of this type of technology to changes in operating conditions. Thirteen sets of test run combinations were completed in this two-day period. Based on the data, Pall set the basic operating conditions that were used for the verification test.

Results of the shakedown tests showed that arsenic could be removed using the naturally occurring iron in the raw water (approximately 1.0 mg/L), a residual chlorine dose concentration of 1.0 mg/L, and without pH adjustment. However, there was still a detectable level of arsenic in the filtrate at 2-3 µg/L. The addition of ferric chloride at 3-5 mg/L (1.0-1.7 mg/L as Fe) and lowering the pH to 6.8 resulted in a non-detectable (<2 µg/L) level of arsenic in the filtrate. The data also suggested that lower dosages of ferric chloride could achieve similar results, Pall determined that the best operating condition for this water was to use 3 mg/L of ferric chloride, 1.0 mg/L residual chlorine, and a pH of 6.8 (range of 6.6 – 7.0). These were the target chemical concentrations used for the 30-day verification test.

The Microza System was operated from July 2 until August 23, 2003, when the unit was chemically cleaned prior to the arsenic loss test. During this time, Pall monitored the system from their office using the PLC and phone line connection. The OCDC staff checked on the unit on a regular basis and filled the chemical feed tanks as needed. Operator attention required during this time was minimal (<15 minutes/day). Pall monitored the flow rate and TMP change during this seven-week period to confirm the final operating conditions for the verification test. The flow rate was steady at 6.3 gpm and the TMP increased from approximately 8.8 psi to 12.5 psi. Based on these results, Pall confirmed the final operating conditions for the 30-day verification test. Flow rate was targeted to be 6.3 gpm (120 gfd), with the backwash set to occur every 30 minutes for 90 seconds (60 second air scrub, 30 second forward flush).

4.3 Raw Water Characterization

Historical water quality data for the combined water from the two production wells at the Plum Creek Development site were obtained from the OCDC in the initial planning stage for this verification test. As shown in Table 1-1, the total arsenic concentrations was in the range of 9 to 14 µg/L and total iron ranged from 0.9 to 1.0 mg/L. An additional set of water quality samples were collected on August 19, 2004 and included samples for the individual wells and the combined well water, which was the raw water source for this verification test. 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. These data confirm that the raw water quality is similar to the historical water quality that was used to plan the verification test with the exception that turbidity data were higher in the combined well sample from the pressure tank. Dissolved oxygen present in the water from the tank, most likely oxidized the some of the naturally occurring iron, causing the iron to form a precipitate and increase the turbidity. Most of the arsenic is present as arsenic (III). The water quality of the individual wells is similar as was expected.

Table 4-1. Raw Water Characterization Data – August 19, 2004

Parameter	**Units**	**Well #1**	**Well #2**	**Combined Wells**
pH	S.U.	7.17	7.17	7.18
Temperature	^{o}C	11.5	10.5	11.0
Turbidity	NTU	0.20	0.20	5.5
Free Chlorine	mg/L	<0.05	0.05	<0.05
Total Chlorine	mg/L	<0.05	<0.05	<0.05
Dissolved Oxygen	mg/L	1.74	1.63	7.05
Apparent Color	C.U.	<5	<5	<5
Alkalinity	mg/L as $CaCO_3$	240	240	240
Total Arsenic	µg/L	10	10	9
Dissolved Arsenic	µg/L	10	9	8
Arsenic (III)	µg/L	8	7	7
Arsenic (V)	µg/L	2	2	<2
Iron	mg/L	0.94	0.95	1.0
Manganese	µg/L	20	22	19
Barium	µg/L	160	150	150
Chloride	mg/L	16	15	16
Sulfate	mg/L	14	14	14
TOC	mg/L	0.6	0.6	0.7
Fluoride	mg/L	0.5	0.5	0.6
Calcium	mg/L	72	72	74
Magnesium	mg/L	24	24	25
Hardness	mg/L as $CaCO_3$	280	280	290

4.4 Arsenic Loss Test

The arsenic loss test, a test to determine if arsenic is removed and retained by the system without chemical addition, was performed over a 24-hour period beginning on August 24, 2004. The Microza System had been operating since late June 2004, and the arsenic loss test requires that the system be clean prior to starting the test. Therefore, the system was cleaned using the chemical CIP procedure. The TMP had increased from the typical clean system startup TMP of 8 to 9 psi at 6.3 gpm to over 12.0 psi during this pretest, operating period.

The Pall CIP is a cleaning procedure that uses warm water in the range of 90-104^{o}F. Sodium hydroxide is added to the water to produce a concentration of 1.0% NaOH and sodium hypochlorite is added to produce a concentration of 1,000 mg/L total residual chlorine. The water is recirculated through the system for about two hours. After a rinse step to remove the caustic and bleach solution, an acid cleaning is performed with a 2% citric acid solution for one to two hours. A final rinse step is performed and the unit TMP checked to determine that the cleaning was effective. The standard operating procedure for the Pall CIP is in Appendix B. Pall personnel performed this procedure on August 23, 2004. The TMP after cleaning was 8.9 psi, similar to clean startup condition.

The operating data and results from the 24-hour arsenic loss test are shown in Table 4-2. This test was run with no chemical addition to the system. It should be noted that the raw water contained naturally occurring iron at a concentration of approximately 1 mg/L. The flow rate was steady during the test run at 6.3 gpm. The total volume processed during the 24-hour period was 8,619 gallons, giving a flux of 118 gfd. The TMP only increased from 8.3 psi to 8.8 psi.

Table 4-2. Operating Data Arsenic Loss Test

Date	Time	Feed Pressure psi	Filtrate Pressure psi	TMP psi	Flow Rate gpm	Total Volume Treated gal	Total Backwash Volume gal
8/24/2004	9:25	13.9	4.9	8.3	6.3	225	0
	14:57	15.7	6.5	8.4	6.3	372	23.5
	21:00	15.8	6.4	8.6	6.3	4149	51.4
8/25/2004	3:00	16.0	6.5	8.7	6.3	6123	65.3
	8:44	17.0	7.1	8.8	6.3	8619	110.1

Tables 4-3 and 4-4 show the water quality for the arsenic loss test. There was no significant loss of arsenic through the system over the 24-hour test with feed water total arsenic averaging 11 µg/L and the filtrate averaged 9 µg/L. Arsenic (III) is the predominant arsenic species in the raw water and only a slight oxidation of the arsenic was observed as the water came in contact with oxygen and passed through the system. Turbidity, iron, and color were removed by filtration system as expected. All other water quality indicators remained steady and passed through the membranes.

Table 4-3. Arsenic Loss Test Water Quality Results

		Raw Water				Feed Water				Filtrate			
		8/24/2004		8/25/2004		8/24/2004		8/25/2004		8/24/2004		8/25/2004	
Parameter	Units	14:57	21:00	3:00	8:44	14:57	21:00	3:00	8:44	14:57	21:00	3:00	8:44
pH	S.U.	6.90	7.31	7.18	7.30	6.89	7.20	7.08	7.15	6.93	7.20	7.05	7.12
Temperature	°C	12.4	12.6	12.3	11.7	13.6	13.3	11.4	12.1	15.6	13.8	12.0	12.6
Bench-top Turbidity(1)	NTU	9.8	5.8	7.4	3.5	9.1	5.0	7.8	5.2	0.55	0.25	0.40	0.35
Alkalinity	mg/L as $CaCO_3$	250	260	240	250	250	250	250	250	250	250	250	250
Free Residual Chlorine	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	0.07	<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	3.3	4.8	5.4	5.3	NA	NA	NA	NA	3.3	4.2	4.1	4.4
Calcium	mg/L	70	69	70	70	69	72	69	70	70	69	72	69
Magnesium	mg/L	24	24	24	24	24	24	24	25	24	25	24	24
Hardness	mg/L as $CaCO_3$	260	260	260	260	260	260	260	260	260	260	260	260
Total Arsenic	µg/L	11	11	11	10	11	10	11	10	9	9	8	10
Dissolved Arsenic	µg/L	9	NA	NA	11	9	NA	NA	11	10	NA	NA	10
Arsenic (III)	µg/L	9	NA	NA	8	7	NA	NA	8	7	NA	NA	7
Arsenic (V)	µg/L	<2	NA	NA	<2	2	NA	NA	3	3	NA	NA	3
Iron	mg/L	1.0	0.97	1.0	0.96	0.95	0.97	1.0	0.93	0.38	0.47	0.31	0.55

(1) Turbidity monitored at start of test (9:25 AM) – Raw water 3.9 NTU; Feed Water 3.7 NTU; Filtrate 0.20 NTU.

NA = Not analyzed.

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

		August 25, 2004 9:00 AM		
Parameter	**Units**	**Raw Water**	**Feed Water**	**Filtrate**
Manganese	µg/L	19	20	22
Barium	µg/L	150	150	150
Chloride	mg/L	15	15	15
Sulfate	mg/L	13	13	13
Fluoride	mg/L	0.5	0.6	0.6
TOC	mg/L	0.6	0.9	0.6
True Color	C.U.	30	20	<5

During the arsenic loss test of August 24 and 25, color in the raw water was higher than in the feed water (note that color was measured directly and samples were not filtered because the raw water was groundwater). Color in water typically occurs when organic matter degrades forming dissolved organic carbon. The TOC results did not decline throughout the arsenic loss test whereas the color was reduced after the filtration. There is some amount of carbon in the water that is not removed and may not have affected the color of the water. The fact that the wells drew from 97 to 99 feet below grade and are not under the influence of surface water suggests that the difference in color originates from colloidal formation of iron and manganese (US EPA. July 1976. Quality Criteria For Water). Table 4-4 shows that the manganese levels were similar in the raw, feed and filtrate indicating that the manganese was in the dissolved and not colloidal form, otherwise the membrane filter would have removed the colloidal manganese. However, iron may have been in a colloidal form as indicated by the lower concentrations of iron in the filtrate (see Table 4-3). Only total, and not dissolved iron, was measured in the raw and feed water (Table 4-3) which does not allow confirmation of whether the differences seen in color were due to colloidal iron.

4.5 Verification Test

4.5.1 Operating Results

The Microza System was cleaned using the Pall CIP procedure on September 7, 2004 just before the start of the 30-day verification test. The test began on September 9 and ended on October 8, 2004. During this period, the Microza System operated continuously 24-hours per day, seven days per week, except for a 10.5-hour period during a power outage. Basic operating parameters were monitored on a daily basis by the DWTS field team in accordance with the PSTP.

The Microza System was set to the operating criteria established by Pall during the shakedown testing. Chemical feeds were established to feed 1.0 mg/L of total chlorine in order to maintain total residual chlorine in the feed water of approximately 0.5 to 1.0 mg/L. The ferric chloride feed rate was set to deliver 3 mg/L of ferric chloride to raw water. The sulfuric acid feed system was set to maintain a pH of 6.8 in the feed water. Based on the previous operating data, the flow rate for filtrate was set at 6.3 gpm to give a targeted flux rate of 120 gfd. The backwash system was set to backwash the membranes every 30 minutes. The backwash included a one minute air scrub period, followed by a 30 second forward flush period.

Table 4-5 shows the daily operating data for the verification test. The filtrate flow rate remained steady throughout the test at an average of 6.3 gpm. The total filtrate volume produced each day was also consistent, except for September 28, 2004. The system shut down at 23:45 on September 27 and remained off until 10:30 on September 28 when the operator reset the system. The cause of the shut down is uncertain, but it appears there was a temporary power outage at the site.

Table 4-5. Verification Test Operating Data

Date	Feed Flow Rate gpm	Filtrate Flow Rate gpm	Total Filtrate Volume gal	Feed Pressure psi	Filtrate Pressure psi	Concentrate Pressure(1) psi	Operating Hours hours
9/9/2004	6.3	6.3	8142	11.0	4.8	14.8	24
9/10/2004	6.2	6.3	7993	16.8	6.6	14.9	24
9/11/2004	6.2	6.2	8141	17.2	6.7	15.6	24
9/12/2004	6.2	6.3	8156	17.5	7.0	15.9	24
9/13/2004	6.3	6.3	8061	18.0	6.5	16.2	24
9/14/2004	6.3	6.3	8160	21.3	9.4	19.5	24
9/15/2004	6.2	6.3	8156	20.5	8.1	18.9	24
9/16/2004	6.2	6.3	8143	21.2	8.1	19.2	24
9/17/2004	6.3	6.3	8135	20.9	8.2	19.2	24
9/18/2004	6.3	6.3	8135	21.2	8.1	19.6	24
9/19/2004	6.3	6.3	8133	21.5	8.1	19.9	24
9/20/2004	6.3	6.3	8015	21.8	8.0	20.2	24
9/21/2004	6.3	6.3	8135	22.0	8.2	20.4	24
9/22/2004	6.2	6.3	8132	22.4	8.1	20.8	24
9/23/2004	6.3	6.3	8121	22.5	8.1	21.0	24
9/24/2004	6.2	6.3	8135	22.5	8.2	20.7	24
9/25/2004	6.2	6.3	8130	22.8	8.2	21.2	24
9/26/2004	6.3	6.3	8134	23.2	8.3	21.5	24
9/27/2004	6.2	6.3	7978	23.1	8.2	21.3	23.75
9/28/2004	6.3	6.3	4738	23.0	8.4	21.4	13.5
9/29/2004	6.2	6.3	8119	23.1	8.4	21.6	24
9/30/2004	6.2	6.3	8128	23.3	8.5	21.8	24
10/1/2004	6.3	6.3	8128	23.7	8.3	22.0	24
10/2/2004	6.3	6.3	8133	23.7	8.4	22.0	24
10/3/2004	6.3	6.3	8133	24.1	8.4	22.3	24
10/4/2004	6.3	6.3	7967	23.4	8.3	22.3	24
10/5/2004	6.3	6.3	8130	25.2	8.7	23.5	24
10/6/2004	6.2	6.3	8125	25.1	8.7	23.5	24
10/7/2004	6.2	6.3	8127	24.8	8.7	23.0	24
10/8/2004	6.3	6.3	3647	25.0	8.7	23.4	10.5
Number of Samples	30	30	30	N/A	N/A	N/A	30
Average	6.3	6.3	7850(2)	N/A	N/A	N/A	23.6
Minimum	6.2	6.2	3647	N/A	N/A	N/A	13.5
Maximum	6.3	6.3	8160	N/A	N/A	N/A	24
Std. Dev.	0.05	0.02	1006	N/A	N/A	N/A	N/A
95% Conf. Int.	(6.3, 6.2)	(6.3, 6.3)	(7475, 8226)	N/A	N/A	N/A	N/A

N/A – Not Applicable.

(1) System operated with no concentrate flow. Water was processed through the membranes and there was no recycle stream. The concentrate pressure was measured on the closed concentrate line to allow for the calculation of TMP.

(2) If the average volume of filtrate produced is calculated for all days except September 28 and October 8, then the average is 8110 gpd.

It should be noted that the flow rate readings (gpm) in Table 4-5 are once per day instantaneous readings from the flowmeters. The filtrate volume data are the actual volume of filtrate produced for each twenty-hour period (no filtrate produced during the total of four minutes of backwashing per hour). The average volume of filtrate produced for all days except September 28 and October 8 is 8110 gpd. Accounting for the backwash cycle of four minutes each hour, the average flow rate is calculated to be 6.03 gpm. This rate is within 4% of the instantaneous rate recorded of 6.3 gpm. The volumetric data are within 1% of the flow rate based on the calibration data shown in Table 4-17 in Section 4.7 (QA/QC), which shows the flow rate averaged 6.05 gpm. All hydraulic calculations are performed based on the daily volume of filtrate produced, as the daily volume data account for fluctuations in flow over the 24 hour period whereas the flow rate measurements represent one time each day.

The pressure on the system was monitored at three locations, feed water (inlet to the membranes), filtrate (exit of the membranes), and on the concentrate side of the membrane unit. It should be noted that this system operated with no concentrate flow, all water was processed through the membranes and there was no recycle stream. The concentrate pressure was measured on the closed concentrate line to allow for the calculation of TMP. The pressure on the feed water line slowly, steadily increased over the 30-day period, while the filtrate pressure remained steady, as expected. The TMP steadily increased indicating the membranes were accumulating materials in the pores that were not removed by the backwash. Figure 4-1 shows a graph of TMP for the 30-day period and Table 4-6 shows the daily, calculated TMP. Pall recommends that the Microza System be cleaned using the CIP procedure when TMP exceeds 35 psi (filter maximum TMP specification is 43.5 psi). After 30 days of operation, the TMP was 15.5 psi, indicating that cleaning was not yet required. However, in accordance with PSTP, the membranes were chemically cleaned at the end of the test, as described later in Section 4.5.4.

The hydraulic flow conditions for membrane systems, such as the Microza System, are typically described by calculating the flux, the temperature corrected flux, and the specific flux. All of these measures of flow are based on daily volume produced as function of membrane surface area. The equations used for the calculation of these hydraulic characteristics were presented in Section 3.3.2. Table 4-6 shows the daily flux, temperature corrected flux (corrected to 20^{o}C), and specific flux at 20^{o}C. The daily volumes are based on the volume data collected by the PLC, which was for the period midnight to midnight of each operating day. Since flux values are reported on a per day basis, the volumes used in the calculations for September 27, 28, and October 8 were normalized to a 24-hour period by calculating the volume that would have been produced in a full 24-hour period. The data were also adjusted for the approximately four minutes in each hour when the unit was in backwash mode and not producing filtrate.

The flux remained constant throughout the test as would be expected given the steady total volumes of filtrate produced. The specific flux decreased as the TMP increased. While the increase in TMP may not follow a liner relationship as the pressure increases, the steady rise in TMP can be used to project when the TMP would reach 35 psi. It is projected that the TMP would approach 35 psi at between 90 and 120 days. Thus, it could be expected that the membranes would require chemical cleaning in this site application about once every 12 to 17 weeks.

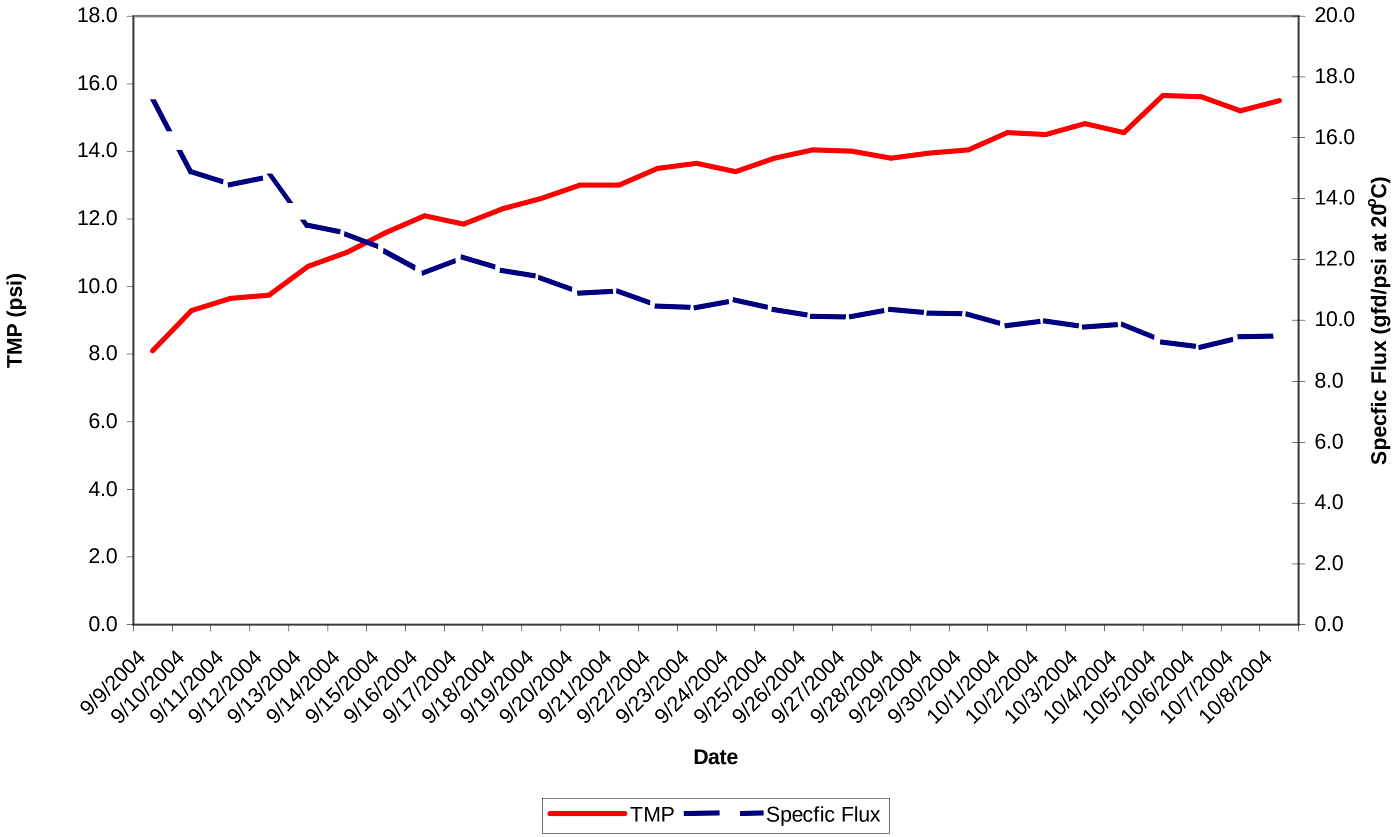

Figure 4-1. Transmembrane Pressure and Specific Flux at 20^{o}C

Table 4-6. Flux, TMP, and Specific Flux Data

Date	Flux (gfd)	Feed Temperature (°C)	Temp Corrected Flux(1) (gfd)	TMP (psi)	Specific Flux(1) (gfd/psi)
9/9/2004	114.0	11.7	139.0	8.1	17.2
9/10/2004	111.9	11.1	138.4	9.3	14.9
9/11/2004	114.0	11.5	139.6	9.7	14.5
9/12/2004	114.2	10.5	143.3	9.7	14.7
9/13/2004	112.9	11.2	139.3	10.6	13.1
9/14/2004	114.2	11.0	141.7	11.0	12.9
9/15/2004	114.2	10.7	142.6	11.6	12.3
9/16/2004	114.0	11.5	139.7	12.1	11.5
9/17/2004	113.9	10.4	143.3	11.9	12.1
9/18/2004	113.9	10.4	143.3	12.3	11.6
9/19/2004	113.9	10.2	143.9	12.6	11.4
9/20/2004	112.2	10.3	141.5	13.0	10.9
9/21/2004	113.9	10.6	142.6	13.0	11.0
9/22/2004	113.8	10.9	141.5	13.5	10.5
9/23/2004	113.7	10.7	142.0	13.7	10.4
9/24/2004	113.9	10.4	143.3	13.4	10.7
9/25/2004	113.8	10.4	143.2	13.8	10.4
9/26/2004	113.9	10.6	142.6	14.1	10.1
9/27/2004	111.7	10.1	141.5	14.0	10.1
9/28/2004	113.7	10.4	143.0	13.8	10.4
9/29/2004	113.7	10.4	143.0	14.0	10.2
9/30/2004	113.8	10.3	143.5	14.1	10.2
10/1/2004	113.8	10.5	142.8	14.6	9.8
10/2/2004	113.9	9.9	144.9	14.5	10.0
10/3/2004	113.9	9.9	144.9	14.8	9.8
10/4/2004	111.5	9.4	143.7	14.6	9.9
10/5/2004	113.8	9.7	145.6	15.7	9.3
10/6/2004	113.8	10.7	142.1	15.6	9.1
10/7/2004	113.8	10.2	143.8	15.2	9.5
10/8/2004	116.7	10.3	147.2	15.5	9.5
Number of Samples	30	30	30	30	30
Average	113.7	10.5	142.6	13.0	11.3
Minimum	111.5	9.4	138.4	8.1	9.1
Maximum	116.7	11.7	147.2	15.7	17.2
Std. Dev.	0.9	0.52	2.0	2.0	1.9
95% Conf. Int.	(113.3, 114.0)	(10.3, 10.7)	(141.8, 143.3)	N/A	N/A

(1) Temperature corrected flux and specific flux at 20°C.

N/A – Not applicable

4.5.2 Verification Test Arsenic Results

The determination of arsenic removal using the Microza System was the primary objective of the verification test. This section presents the results for the raw, feed, and filtrate water from analysis of arsenic samples performed three times per week. Also included are the results from the 58-hour intensive sampling period, when samples for arsenic analysis were collected on a more frequent basis. Arsenic speciation data are also included with the data presented in Table 4-7. Figure 4-2 shows the arsenic results plotted for the entire 30-day test.

The Microza System removed total arsenic to less than the detection limit (2 µg/L) for all filtrate samples collected during the 30-day verification test. The total arsenic in the raw water and feed water averaged 11 µg/L and 13 µg/L, respectively, during the test with little variation. The arsenic speciation data for the raw water showed that all of the arsenic was present as arsenic (III), with no detectable concentrations of arsenic (V) in any sample collected.

With pH adjustment to 6.6 to 7.0, the chemical addition of sodium hypochlorite (target feed of 1 mg/L) and ferric chloride (target feed of 3 mg/L in addition to the naturally occurring iron, which average 0.95 mg/L) was effective in precipitating and coagulating the arsenic in the raw water. As shown in Table 4-7, 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 no detectable levels of soluble arsenic in the feed water. The effectiveness of this oxidation and coagulation process was key to the results obtained by the Microza System. With all or most of the arsenic in the particulate form after chemical treatment, and the membrane filtration system removing the particulate, the result was a filtrate with no detectable arsenic in any sample.

The data collected during the intensive 58-hour sampling period were consistent with the data collected during the regular three times per week sampling program. There was no indication of any transient or short time changes in the arsenic concentration or in any other monitored parameter. The frequent short duration backwashes provided a stable membrane condition. TMP increased over the 30-day period, as discussed in Section 4.5.1, but chemical cleaning was not needed during the 30-day test period. The Microza System produced consistent results throughout the verification test.

Table 4-7. Arsenic Results

		Raw				Feed				Filtrate			
Date		Total Arsenic (µg/L)	Soluble Arsenic (µg/L)	As (III) (µg/L)	As (V) (calculated) (µg/L)	Total Arsenic (µg/L)	Soluble Arsenic (µg/L)	As (III) (µg/L)	As (V) (calculated) (µg/L)	Total Arsenic (µg/L)	Soluble Arsenic (µg/L)	As (III) (µg/L)	As (V) (calculated) (µg/L)
9/9/04		10	10	10	<2	11	<2	<2	<2	<2	<2	<2	<2
9/13/04		12	10	9	<2	12	<2	<2	<2	<2	<2	<2	<2
9/15/04		12	---	---	---	12	---	---	---	<2	---	---	---
9/17/04		12	---	---	---	13	---	---	---	<2	---	---	---
9/20/04	Hour 0	12	11	10	<2	12	<2	<2	<2	<2	<2	<2	<2
	Hour 1	11	---	---	---	16	---	---	---	<2	---	---	---
	Hour 3	12	---	---	---	12	---	---	---	<2	---	---	---
	Hour 6	11	---	---	---	15	---	---	---	<2	---	---	---
	Hour 10	11	10	8	2	16	<2	<2	<2	<2	<2	<2	<2
9/21/04	Hour 24	10	10	8	2	10	<2	<2	<2	<2	<2	<2	<2
	Hour 29	9	---	---	---	12	---	---	---	<2	---	---	---
	Hour 34	10	---	---	---	12	---	---	---	<2	---	---	---
9/22/04	Hour 48	10	11	9	2	10	<2	<2	<2	<2	<2	<2	<2
	Hour 53	10	---	---	---	10	---	---	---	<2	---	---	---
	Hour 58	10	---	---	---	11	---	---	---	<2	---	---	---
9/24/04		10	---	---	---	10	---	---	---	<2	---	---	---
9/27/04		11	11	13	<2	13	<2	<2	<2	<2	<2	<2	<2
9/29/04		12	---	---	---	16	---	---	---	<2	---	---	---
10/1/04		12	---	---	---	12	---	---	---	<2	---	---	---
10/4/04		12	---	---	---	12	---	---	---	<2	---	---	---
10/5/04		12	12	9	3	14	<2	<2	<2	<2	<2	<2	<2
10/6/04		12	---	---	---	16	---	---	---	<2	---	---	---
10/8/04		12	---	---	---	13	---	---	---	<2	---	---	---
Number of Samples		23	8	8	8	23	8	8	8	23	8	8	8
Average		11	11	10	<2	13	<2	<2	<2	<2	<2	<2	<2
Minimum		9	10	8	<2	10	<2	<2	<2	<2	<2	<2	<2
Maximum		12	12	13	3	16	<2	<2	<2	<2	<2	<2	<2
Std. Dev.		1.0	0.74	1.6	N/C	2.0	N/C	N/C	N/C	N/C	N/C	N/C	N/C
95% Conf. Int.		(11,12)	(10, 11)	(8, 11)	N/C	(12, 13)	N/C	N/C	N/C	N/C	N/C	N/C	N/C

N/C – Not calculated

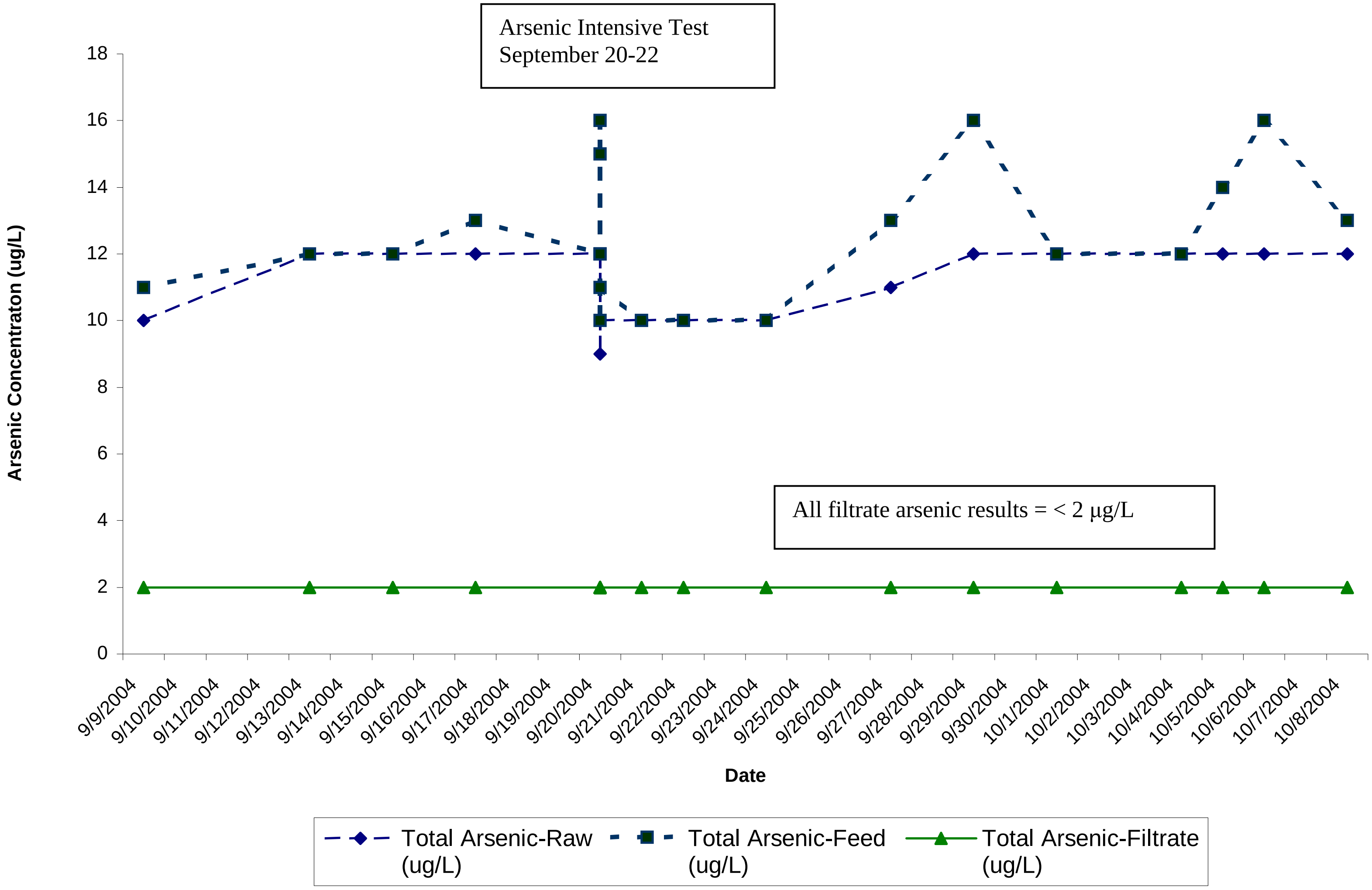

Figure 4-2. Verification Test Arsenic Results

4.5.3 Raw, Feed, and Filtrate Water Quality Results

Water quality data were collected on a daily basis for pH, temperature, turbidity, and chlorine (total and free residual). Samples for iron and alkalinity analyses were collected three times per week. These parameters are key water quality indicators and important to this technology, which used chlorine oxidation, iron coagulation, and pH adjustment as part of the technology process. Dissolved oxygen was monitored daily in the raw water because it can impact the oxidation of iron and arsenic (III). Other water quality parameters were also monitored on a weekly basis, including calcium, magnesium, total hardness, manganese, barium, sulfate, chloride, fluoride, TOC, and true color. All of the laboratory and field data reports are included in Appendices E and F.

Figure 4-3 shows the pH for the raw, feed, and filtrate water. The raw water pH was steady in the range of 7.0 to 7.4 for most of the test period. Sulfuric acid was added in small quantities to adjust the pH in the feed water in the range of 6.6 to 7.0. The pH in the feed water was controlled on most days within the target range. On October 3, 2004, the manually collected filtrate water pH was reported as 7.42, which is out of the normal range. There is no indication of any changes in the system on or near this date, so it is believed that this datum point is an outlier. The feed pH was in the normal range on that day and the inline pH meter was reading pH 6.75.

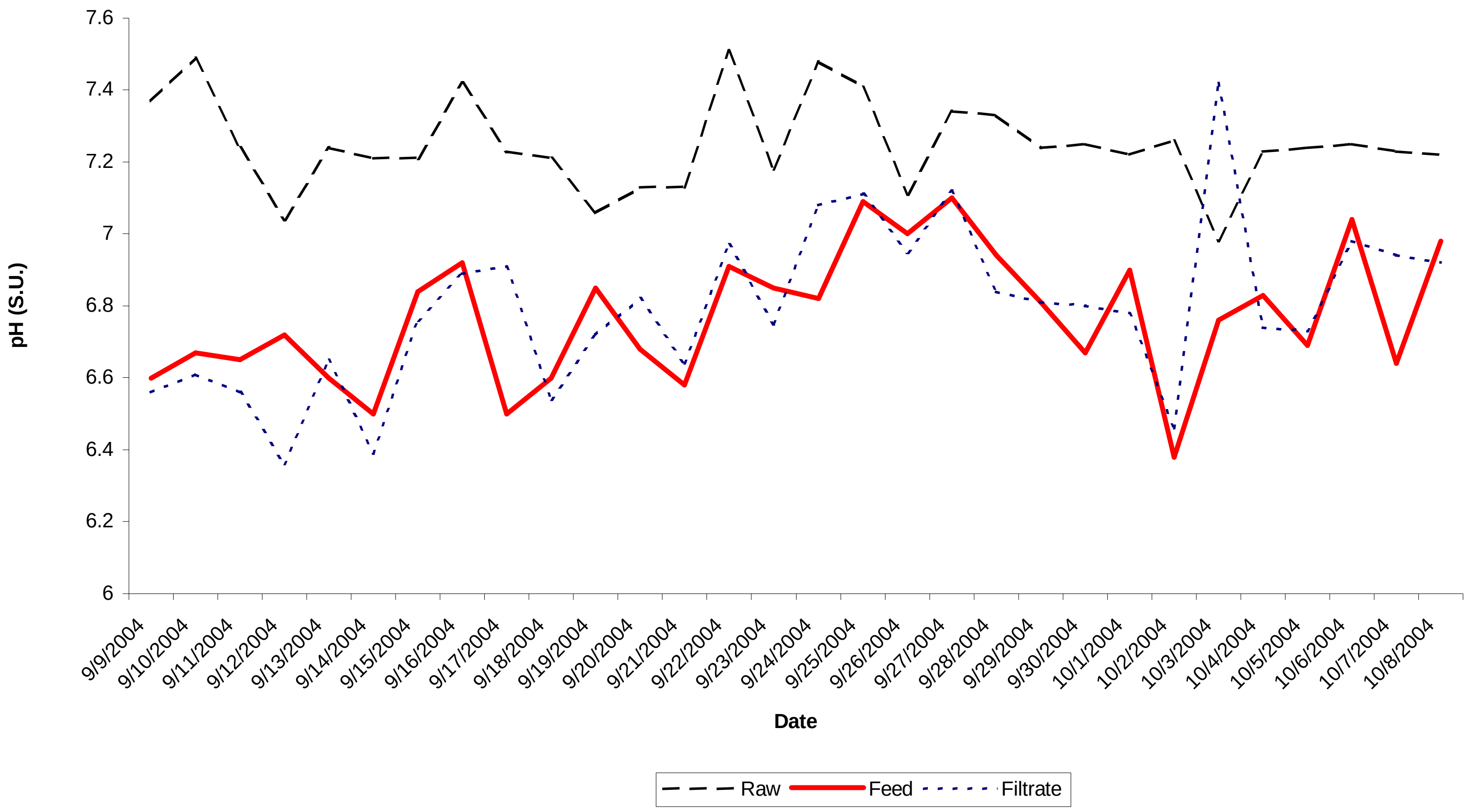

Figure 4-3. Verification Test pH Results

Figure 4-4 shows the turbidity for the raw, feed, and filtrate water. The raw water turbidity averaged 4.9 NTU and was higher than the historical data indicated. Dissolved oxygen concentrations in the raw water ranged from 6.5 to 9.3 mg/L. It is likely that the elevated dissolved oxygen levels caused the naturally occurring iron to oxidize and precipitate, thus increasing turbidity in the raw water. Feed water turbidity only increased slightly after the addition of the oxidation and coagulation chemicals. The filtrate turbidity was low, averaging 0.25 NTU based on the bench-top turbidimeter. In addition to the bench-top turbidity meter used by the field personnel, the Microza System had inline turbidity meters on the raw and filtrate water lines. The filtrate meter was a Hach laser unit that could measure turbidity at a lower level than the bench-top meter. This inline turbidimeter showed the filtrate averaged 0.021 NTU. Table 4-8 shows the daily turbidity levels. 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 were between 1 and 2 NTU. There were no turbidity levels above 2 NTU. The inline turbidimeter indicated the filtrate water never exceeded 0.10 NTU.

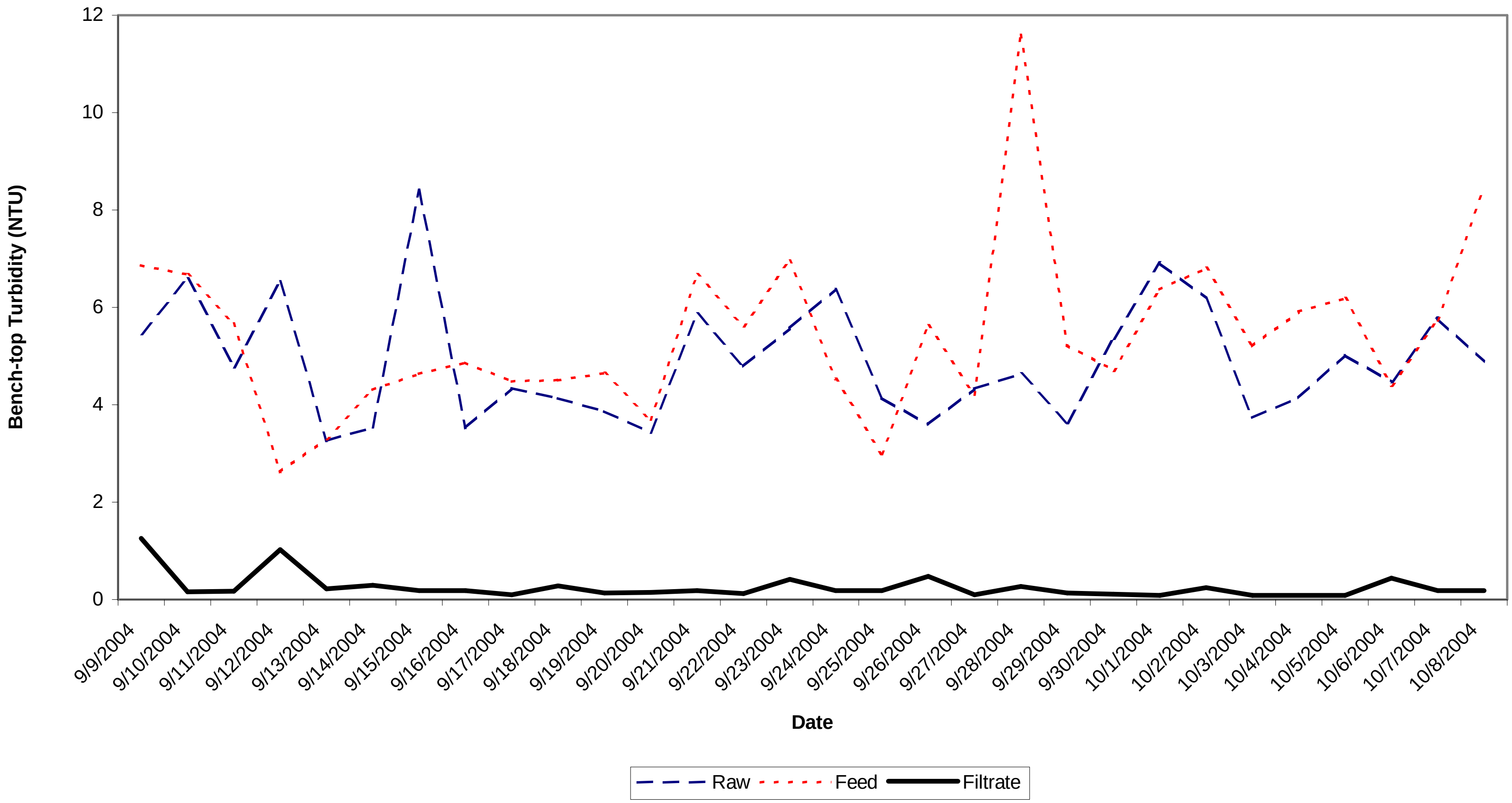

Figure 4-4. Verification Test Bench-top Turbidity Results

Table 4-8. Turbidity Results (NTU)

Date	Raw	Feed	Filtrate	Filtrate In Line Meter(1)
9/09/2004	5.46	6.87	1.26	0.021
9/10/2004	6.59	6.67	0.16	0.023
9/11/2004	4.78	5.67	0.17	0.022
9/12/2004	6.54	2.62	1.03	0.031
9/13/2004	3.26	3.31	0.22	0.021
9/14/2004	3.54	4.31	0.29	0.024
9/15/2004	8.41	4.64	0.18	0.021
9/16/2004	3.53	4.87	0.18	0.022
9/17/2004	4.34	4.47	0.10	0.022
9/18/2004	4.13	4.50	0.28	0.020
9/19/2004	3.86	4.65	0.14	0.053
9/20/2004	3.43	3.70	0.15	0.026
9/21/2004	5.87	6.67	0.18	0.020
9/22/2004	4.79	5.62	0.12	0.020
9/23/2004	5.57	6.96	0.41	0.021
9/24/2004	6.38	4.53	0.18	0.021
9/25/2004	4.15	2.99	0.18	0.020
9/26/2004	3.60	5.62	0.48	0.019
9/27/2004	4.33	4.21	0.10	0.019
9/28/2004	4.64	11.6	0.27	0.018
9/29/2004	3.63	5.23	0.14	0.017
9/30/2004	5.36	4.71	0.11	0.017
10/1/2004	6.92	6.37	0.09	0.016
10/2/2004	6.19	6.81	0.24	0.016
10/3/2004	3.73	5.21	0.08	0.018
10/4/2004	4.15	5.92	0.08	0.016
10/5/2004	5.02	6.18	0.08	0.018
10/6/2004	4.47	4.40	0.44	0.016
10/7/2004	5.78	5.73	0.18	0.019
10/8/2004	4.89	8.46	0.18	0.020
Number of Samples	30	30	30	30
Average	4.9 (2)	5.5	0.25	0.021
Minimum	3.3	2.6	0.10	0.016
Maximum	8.4	11.6	1.3	0.053
Std. Dev.	1.3	1.7	0.25	0.007
95% Conf. Int.	(4.4, 5.4)	(4.8, 6.1)	(0.15, 0.35)	(0.019, 0.024)

(1) Instantaneous readings taken when samples were collected for bench-top turbidity analysis.

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

Figure 4-5 presents the alkalinity for the raw, feed, and filtrate water. The raw water averaged 250 mg/L as $CaCO_3$ and was stable throughout the test with a maximum concentration of 270 mg/L and minimum of 230 mg/L. Sulfuric acid was added to the feed water to lower the pH, which lowered the alkalinity. The alkalinity in the feed water averaged 230 mg/L with a maximum of 250 mg/L and minimum of 200 mg/L. There was no change in alkalinity through the membranes with the filtrate alkalinity averaging 230 mg/L with a maximum of 250 mg/L and minimum of 200 mg/L.

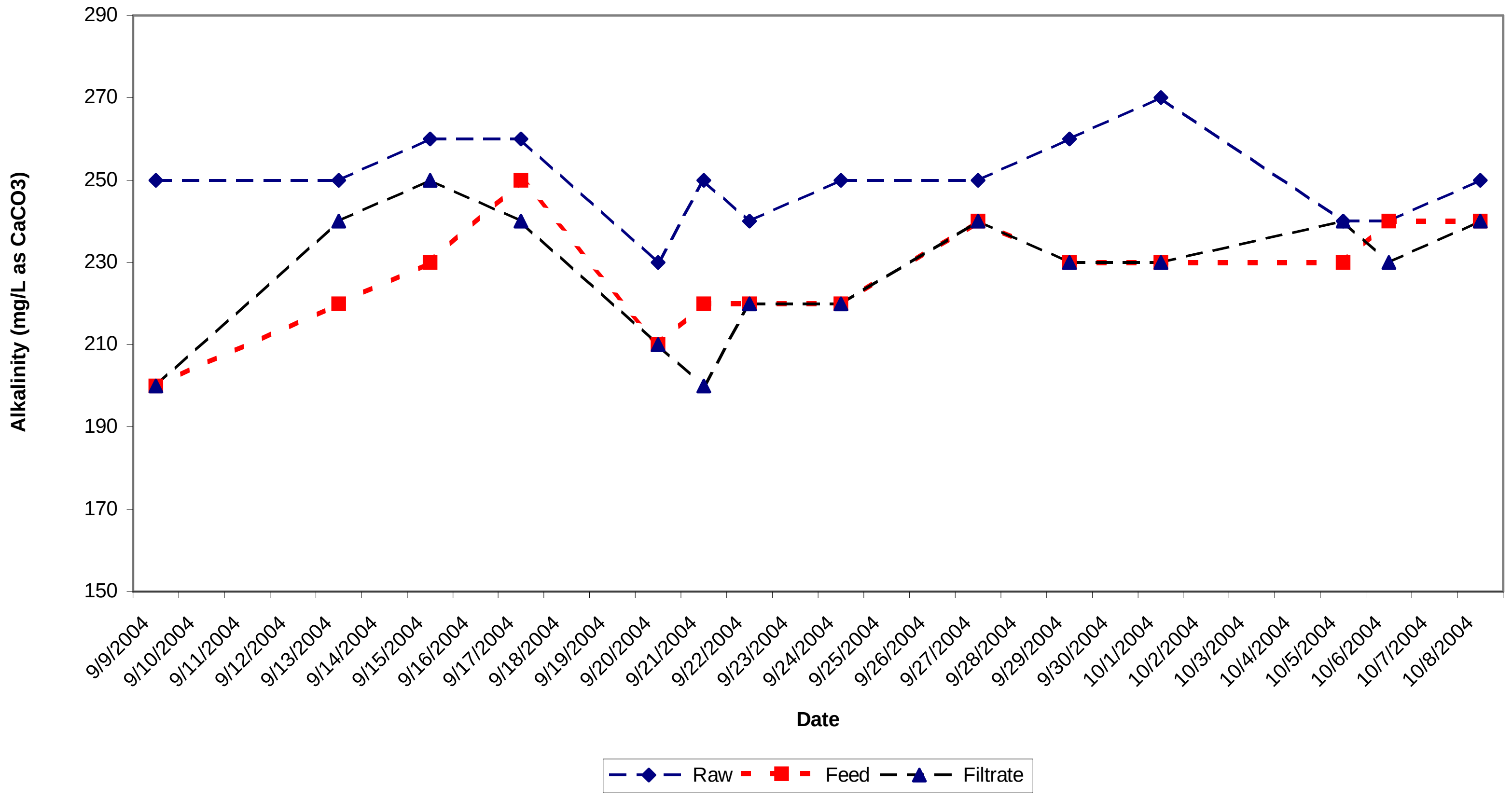

Figure 4-5. Alkalinity Results

Figure 4-6 shows the total iron concentrations measured in the raw, feed, and filtrate water. The raw water contained natural occurring iron, averaging 0.99 mg/L with a maximum of 1.9 mg/L and minimum of 0.81 mg/L. The pre-testing by Pall 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 achieved the needed iron concentrations for coagulation of the arsenic. The feed water averaged 2.3 mg/L as Fe with a median concentration of 2.1 mg/L. The maximum iron concentration in the feed water was 4.2 mg/L. The iron concentrations were typically in the 1.8 to 2.9 mg/L range.

The Microza System removed the iron present in the feed water, producing treated water that had less than 0.02 mg/L for all but two samples. On October 6, when the iron concentration in the feed was measured at a maximum concentration of 3.5 mg/L, the filtrate concentration was 0.1 mg/L. There was also one sample during the intensive arsenic sample test that showed iron in the filtrate at 3.6 mg/L, which was higher than both the feed and raw water concentrations. This datum point appears to be an outlier, as the samples collected 12 hours before and five hours after this sample showed filtrate iron concentrations of <0.02 mg/L. These data show that the Microza System can achieve the statement of performance objective of producing a filtrate with <0.02 mg/L of iron.

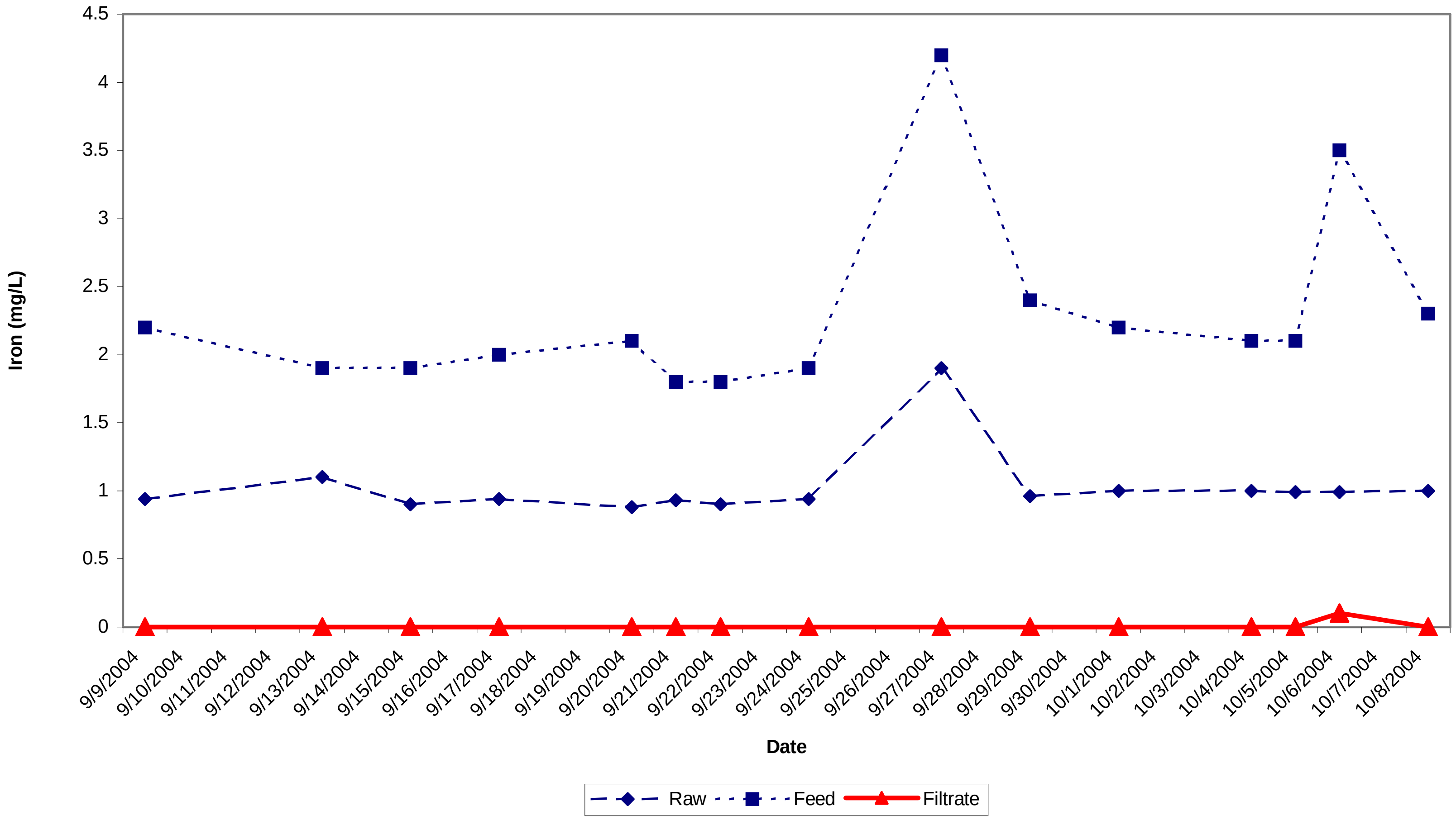

Figure 4-6. Iron Results

The field staff measured total and free residual chlorine daily. Table 4-9 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. These data show this was the case on most days with total and free residual chlorine being below the detection limits. On four days, however, the data indicated the presence of free residual chlorine, even though on two of those days the total residual chlorine was below the detection limit. It is not known why these data show chlorine present in the raw water samples, but the data appear to be anomalous readings. There is no known reason to believe that chlorine is present in the raw water source.

The feed water averaged 0.60 mg/L of total residual chlorine and the filtrate water averaged 0.58 mg/L. Most of the data points were clustered in the range of 0.5 to 0.7 mg/L. The free residual chlorine results show that 20 to 30% of the residual chlorine was free chlorine with the feed averaging 0.13 mg/L and the filtrate 0.16 mg/L. The bleach solution was fed at a target rate of 1.0 mg/L, which indicates the raw water had a chlorine demand of approximately 0.4 mg/L.

Table 4-9. Total and Free Residual Chlorine (mg/L)

	Free Chlorine			Total Chlorine			Dissolved Oxygen
Date	**Raw**	**Feed**	**Filtrate**	**Raw**	**Feed**	**Filtrate**	**Raw**
9/9/2004	<0.05	0.12	0.05	<0.05	0.63	0.73	3.85
9/10/2004	0.21	0.35	0.25	<0.05	0.79	0.66	9.23
9/11/2004	<0.05	0.17	0.28	<0.05	0.73	0.67	6.52
9/12/2004	<0.05	0.22	0.09	<0.05	0.66	0.58	4.78
9/13/2004	<0.05	<0.05	0.40	<0.05	0.40	0.55	6.88
9/14/2004	<0.05	0.23	0.23	<0.05	0.79	0.81	6.22
9/15/2004	0.20	0.26	0.46	0.13	0.55	1.16	8.67
9/16/2004	0.26	0.23	0.49	<0.05	0.63	0.64	8.50
9/17/2004	<0.05	0.08	0.10	<0.05	0.72	0.81	6.16
9/18/2004	<0.05	0.14	0.12	0.05	0.68	0.54	6.80
9/19/2004	0.05	0.16	0.12	0.06	0.65	0.60	4.65
9/20/2004	<0.05	0.17	0.45	<0.05	0.68	0.64	8.86
9/21/2004	<0.05	0.15	0.42	<0.05	0.60	0.66	5.65
9/22/2004	0.29	0.33	0.35	0.16	0.79	0.71	9.22
9/23/2004	<0.05	0.11	0.16	<0.05	0.66	0.68	6.53
9/24/2004	<0.05	<0.05	<0.05	0.05	0.47	0.46	8.98
9/25/2004	<0.05	<0.05	<0.05	<0.05	0.53	0.47	9.04
9/26/2004	<0.05	0.08	<0.05	<0.05	0.62	0.54	3.82
9/27/2004	<0.05	0.06	<0.05	<0.05	0.34	0.46	9.28
9/28/2004	<0.05	0.31	0.15	<0.05	0.74	0.76	7.16
9/29/2004	<0.05	0.06	<0.05	<0.05	0.50	0.49	6.45
9/30/2004	<0.05	<0.05	<0.05	<0.05	0.48	0.53	6.20
10/1/2004	<0.05	0.10	0.34	0.05	0.55	0.52	7.34
10/2/2004	<0.05	0.17	0.07	<0.05	0.57	0.44	7.45
10/3/2004	<0.05	0.12	<0.05	<0.05	0.56	0.45	4.47
10/4/2004	<0.05	0.11	0.19	0.05	0.42	0.37	6.35
10/5/2004	<0.05	0.14	0.09	<0.05	0.53	0.47	7.50
10/6/2004	<0.05	0.05	<0.05	<0.05	0.81	0.39	8.60
10/7/2004	<0.05	<0.05	<0.05	<0.05	0.49	0.32	7.30
10/8/2004	<0.05	0.12	0.05	0.05	0.47	0.36	6.86
Number of Samples	30	30	30	30	30	30	30
Average	<0.05	0.13	0.16	<0.05	0.60	0.58	6.98
Minimum	<0.05	<0.05	<0.05	<0.05	0.34	0.32	3.82
Maximum	0.29	0.35	0.49	0.16	0.81	1.16	9.28
Std. Dev.	0.08	0.10	0.16	0.04	0.13	0.17	1.63
95% Conf. Int.	N/C	(0.10, 0.17)	(0.10,0.22)	N/C	(0.55, 0.65)	(0.52, 0.65)	(6.37, 7.59)

N/C – Not calculated.

The results for the other water quality parameters are shown in Table 4-10 and Table 4-11. The raw concentrations were stable throughout the test. The hardness did appear to increase on September 27 primarily due to an increase in magnesium concentration. The next data set obtained on October 5 showed hardness and magnesium levels back to the typical concentrations found earlier in the test run and are similar to the data collected prior to the verification test. The feed and filtrate water showed similar average concentrations of chloride, sulfate, TOC, fluoride, calcium, magnesium, and barium. The Microza System had little or no impact on these water quality parameters. Sulfate in the feed and filtrate was increased by an average of 20 to 22 mg/L due to the addition of sulfuric acid for pH control for this treatment system. Sulfate was not removed by the membrane filtration system. The Microza System did appear to reduce the manganese concentration. The raw and feed waters averaged 23 µg/L and 29 µg/L, respectively. The filtrate average concentration was 15 µg/L indicating a removal of 35 to 48 percent of the manganese in the water. Manganese was present at an elevated level in the filtrate water on one day, September 21. The manganese was reported as 100 µg/L, much higher than the raw or feed water. The cause of this increase on manganese for one day is not known. The TOC results in Table 4-10 did not decline throughout the verification test. TOC apparently is not removed by the treatment process. The nature of the source of TOC is unknown.

Table 4-10. Other Water Quality Parameters

	Chloride (mg/L)			**(Sulfate mg/L)**		
Date	**Raw**	**Feed**	**Filtrate**	**Raw**	**Feed**	**Filtrate**
9/9/2004	18	22	22	13	61	59
9/13/2004	19	22	22	15	39	24
9/21/2004	19	21	22	14	40	57
9/27/2004	19	21	22	14	17	17
10/5/2004	21	20	24	14	21	14
Number of Samples	5	5	5	5	5	5
Average	19	21	22	14	36	34
Minimum	18	20	22	13	17	14
Maximum	21	22	24	15	61	59

	TOC (mg/L)			**Fluoride (mg/L)**		
Date	**Raw**	**Feed**	**Filtrate**	**Raw**	**Feed**	**Filtrate**
9/9/2004	0.7	0.7	1.0	0.6	0.6	0.6
9/13/2004	0.6	0.6	0.6	0.6	0.6	0.6
9/21/2004	0.8	0.7	0.7	0.6	0.6	0.6
9/27/2004	0.6	0.6	0.6	0.5	0.5	0.6
10/5/2004	0.7	0.6	0.6	0.6	0.6	0.5
Number of Samples	5	5	5	5	5	5
Average	0.7	0.6	0.7	0.6	0.6	0.6
Minimum	0.6	0.6	0.6	0.5	0.5	0.5
Maximum	0.8	0.7	1.0	0.6	0.6	0.6

Table 4-11. Other Water Quality Parameters

	Calcium (mg/L)			Magnesium (mg/L)			Hardness (mg/L as $CaCO_3$)		
Date	**Raw**	**Feed**	**Filtrate**	**Raw**	**Feed**	**Filtrate**	**Raw**	**Feed**	**Filtrate**
9/9/2004	69	90	71	22	24	24	260	320	280
9/13/2004	72	64	70	22	22	22	270	250	270
9/21/2004	69	69	72	19	21	21	250	260	270
9/27/2004	67	69	71	42	43	42	340	350	350
10/5/2004	69	69	68	20	21	21	260	260	260
Number of Samples	5	5	5	5	5	5	5	5	5
Average	69	72	70	25	26	26	280	290	280
Minimum	67	64	68	19	21	21	250	250	260
Maximum	72	90	72	42	43	42	340	350	350

	Barium (µg/L)			Manganese (µg/L)			True Color (C.U.)		
Date	**Raw**	**Feed**	**Filtrate**	**Raw**	**Feed**	**Filtrate**	**Raw**	**Feed**	**Filtrate**
9/9/2004	160	160	150	19	27	12	5	5	<0.1
9/13/2004	170	160	160	22	27	10	<0.1	12	5
9/21/2004	140	130	130	23	30	100	18	22	5
9/27/2004	160	170	140	23	28	17	<0.1	<0.1	<0.1
10/5/2004	160	160	170	26	32	21	15	20	7
Number of Samples	5	5	5	5	5	5	5	5	5
Average	160	160	150	23	29	15(1)	N/C	N/C	N/C
Minimum	140	130	130	19	27	10	<0.1	<0.1	<0.1
Maximum	170	170	170	26	32	100	18	22	7

(1) Average does not include 9/21/04 outlier.

N/C – Not calculated.

4.5.4 Chemical Use, Backwash Quality, and Chemical Cleaning

As described in Chapter 2, the Microza System uses a short duration (90 seconds) backwash cycle to remove solids that accumulate on the membranes. The backwash water generated from the air scrub and a forward flush cycle is discharged from the unit to an appropriate disposal location. The backwash water is discharged through a separate backwash line that was sampled during the verification test.

The backwash water quantity was preset by setting the flow rate of the water used for the air scrub and forward flush (0.5 and 3 gpm, respectively), and setting the duration of the air scrub and forward flush in the PLC (60 and 30 seconds, respectively). This resultant backwash volume was approximately 2 gallons per backwash cycle. The backwash volume was checked each day during the verification test by collecting the backwash water in a tared container and weighing the filled container. The weight was then converted to gallons of backwash water produced for a cycle. While the actual volume measured on a given day varied from 1.2 to 2.9 gallons, the average of the 30 measurements was 2.0 gallons with a median of 2.0 gallons. The variation in some measurements may be a more function of the difficulty of using a “bucket” collection method with an open discharge pipe, than any real variation in the backwash volume per cycle. The average and mean data show the volume of 2.0 gallons is identical to the target backwash volume. This backwash volume represented approximately 1.2% of the filtrate volume produced each day during the verification test.

The backwash water was sampled and analyzed on weekly basis during the verification test. Table 4-12 shows the results for total arsenic, total iron, and TSS. 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 water is not considered a hazardous waste based on the arsenic concentrations, which is below the 5,000 µg/L limit under the Resource Conservation and Recovery Act (RCRA).

Table 4-12. Backwash Water – Water Quality Results

Date	Total Arsenic (µg/L)	Total Iron (mg/L)	TSS (mg/L)
9/9/2004	340	78	140
9/13/2004	420	79	240
9/21/2004	420	87	190
9/27/2004	370	93	120
10/4/2004	220	37	NA
10/5/2004	1,700	310	760
Average	580	114	290
Median	390	83	190
Minimum	220	37	120
Maximum	1,700	310	760

NA = Not analyzed.

The Microza System used a 6% sodium hypochlorite (bleach) as the stock chemical for adding chlorine to the system. The targeted chlorine feed was 1 mg/L. The chemical metering pump was set to feed approximately 0.38 milliliters/minute (ml/min) from the five-gallon container [8.5 inches (W) by 11.5 inches (D) by 12 inches (H)] of bleach solution. The metering pump stroke rate was checked daily and the calibration was checked four times during the verification test. The volume of bleach solution used from the container was estimated based on the change in liquid depth in the container. A total of 3.9 gallons of 6% bleach solution was used over the 30-day test to treat 252,600 gallons of raw water. This equates to an average water concentration added to the raw water of 0.92 mg/L.

Iron was added to the raw water using a 40% ferric chloride solution stored in a five-gallon container [8.5 inches (W) by 11.5 inches (D) by 12 inches (H)]. The ferric chloride was fed with a chemical metering pump that was set to deliver approximately 0.125 ml/min. The pump calibration checks showed the average was closer to 0.106 ml/min. The volume of ferric chloride solution used from the container was estimated based on the change in liquid depth in the container. A total of 1.3 gallons (15.2 pounds) of ferric chloride solution was used over the 30-day test to treat 252,600 gallons of raw water. Based on the total amount of solution fed, the average concentration of ferric chloride in the feed water was calculated to be 2.89 mg/L, close to the target of 3 mg/L of ferric chloride (1.0 mg/L as Fe). The iron added was in addition to the 0.95 mg/L (as Fe) of natural occurring iron in the raw water.

Sulfuric acid solution was also stored in a five-gallon container [8.5 inches (W) by 11.5 inches (D) by 12 inches (H)] at the site and feed with a chemical metering pump. The feed rate was monitored in the same manner as for the iron and chlorine feeds. Acid addition was based on the need to lower pH to an operating range of 6.6 to 7.0. Approximately 5.4 gallons of sulfuric acid was used over the 30-day test to treat 252,600 gallons of raw water.

The chemical CIP procedure used by Pall to clean membranes is described in Appendix B. The process uses a sodium hydroxide and bleach solution that is recirculated through the system for two hours. After a rinse, a citric acid solution used to further clean the membranes with low pH water, followed by a rinse. Pall performed a CIP before the start of the verification test and again at the end of the test. DWTS field staff observed both cleaning procedures and recorded the chemical use and TMPs before and after the final cleaning. The CIP procedure took approximately five hours to complete. This time includes the time to drain the feed water tank, make the chemicals used for cleaning, perform the entire procedure, and reset the unit for operation.

The chemicals used for the post verification test CIP procedure on the filter membrane (surface area 75 ft^2) included:

- Sodium Hydroxide: 1.25 lbs;
- Bleach (6% solution): 942 ml;
- Sodium Hydroxide and Bleach were diluted into 15 gallons of water; and
- Citric Acid: 1.668 lbs dilute into 10 gallons of water.

The recirculation and air scrub cycle for the caustic/bleach solution was run for two hours and ten minutes, followed by a rinse with raw water for approximately 30 minutes. The citric acid scrub was run for one hour and was followed by a 20-minute rinse with raw water. During the rinse cycle between the caustic and acid cleaning, the TMP was checked at various flow rates, and then checked again during the acid rinse. Table 4-13 shows the TMP data. At the end of the CIP, the TMP had returned to the original TMP for the unit at the beginning of the verification test. These data indicated that the unit was cleaned and restored to original operating condition. The final check was an integrity test to demonstrate that the membranes were still in good condition. The integrity test data are presented in Table 4-14. These data demonstrate the membrane was in good condition after cleaning and met the same integrity specifications measured during installation of the equipment.

Table 4-13. TMPs Before and After the CIP

Flow Rate (gpm)	TMP Before Cleaning (psi)	TMP After High pH Cleaning (psi)	TMP After Low pH Cleaning – Final (psi)
1.0	3.2	2.6	2.0
2.0	5.5	4.3	3.0
3.0	7.8	6.0	4.2
4.0	10.4	7.7	5.4
5.0	12.7	9.4	6.5
6.0	15.1	11.1	7.7
6.3	15.7	11.6	8.0

Table 4-14. Integrity Test Pressure Drop Data

Time (seconds)	Pressure (psi)
0	25.8
30	25.7
60	25.6
90	25.5
120	25.4
150	25.3
180	25.3
210	25.2
240	25.1
270	25.0
300	24.9

After completion of the CIP, the Microza System was placed back in operation to verify that the system was producing similar results to the clean system at the beginning of the verification test. Flow rate, turbidity, and TMP were recorded before and after the CIP. These data are presented in Table 4-15. As can be seen, the turbidity results for the filtrate were good and the results similar to clean system at the beginning of the verification test.

Table 4-15. Operating Data Before and After the CIP

Time	Flow Rate (gpm)	TMP (psi)	Feed Inline Turbidity (NTU)	Filtrate Inline Turbidity (NTU)
Before CIP	6.3	15.9	4.83	0.016
After CIP	6.3	8.4	10.5	0.077
One hour and 20 min after normal operation	6.3	9.0	4.78	0.016

4.6 Other Operating Information

The Microza System was operated for the 30-day verification period by the DWTS staff. The system was found to be easy to operate and required little time for daily maintenance. The field staff was on-site for approximately 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, etc. 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, etc. 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 feed stocks needed to be replenished or inline instruments calibrated. The PLC can be set up for remote access; so main system parameters can be monitored without a site visit.

The chemical feed system used well-designed chemical metering pumps and five-gallon containers for the acid, bleach, and ferric chloride solutions. The chemicals were fed in the concentration purchased, so it was not necessary to make dilutions or perform other potentially dangerous handling activities. An operator does need to pour the solutions into the feed containers. For larger systems, the size of the containers can be expected to be larger and possibly used as the actual feed containers (totes, etc.). The chemical feed rates were steady over the duration of the test. As can be seen by the data presented earlier, the concentrations of chlorine, iron, and the pH stayed within the anticipated ranges during the test. The chemical meter pumps held the same stroke per minute settings throughout the test.

The Microza System has a computer for reading and checking 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 on the inline pH meters and turbidimeters. The readings were easy to see and were used during this test for the manually recorded verification data.

Backwash for this system is based on a preset time and backwash cycle. As compared to other filtration devices, the membrane system backwashes regularly and is not designed to backwash based on a pressure differential. The TMP is monitored by the PLC and when TMP reaches 35 psi, a CIP is scheduled to clean the unit. Based on the data for this site, the CIP would be expected to occur about every 90 to 120 days. The CIP would be initiated by an operator and require an operator to be on-site.

The Microza System operated continuously during the verification test expect for one day, September 28, 2004. When the site operator arrived on-site the unit was shut down and the computer indicated it needed to be reset. Based on the PLC record the unit had shut down at 23:45 the night before. The operator reset the system, a simple series of steps using the PLC, and the unit came back on line with all flows, pressure, and feeds at the same setting as the day before. The reason for this shut down is not known, but it is suspected that there was a short power outage that caused the system to shut down. In a full-scale system, a shutdown of this type could signal an alarm or notify an operator through standard PLC or security systems. The system can also be set up to shut down based on loss of flow, high filtrate turbidity or pH, or other PLC monitored parameters. If the system were shut down, the PLC monitoring system can be setup to send an alarm to an operator. Assuming power is on, the operator could review the PLC data from a remote location and determine if a site visit was needed.

The only maintenance performed on the Microza System was the replacement of one pH meter cable that failed on September 25, after being inadvertently damaged during a calibration procedure. The cable was shipped to the site and the DWTS field staff was able to install the cable and recalibrate the pH meter.

Overall, the Microza System appears well suited to small or medium scale installations where an operator is not present at all times, or even infrequently. The system is automated and all equipment appeared sturdy and properly selected for the process.

Pall provides an O&M manual for each system that is installed at a site. The generic O&M manual for a full-scale system is presented in Appendix A. The O&M manual 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 descriptions of components that require maintenance. Maintenance checklists including example forms for daily and periodic maintenance activities are included along with a troubleshooting section in a tabular format. The review of the O&M manual shows that the manual is well organized and easy to read.

The O&M manual provides instruction for membrane cleaning (CIP) using a bleach, caustic, and acid. The actual process is automated and controlled by the PLC/PC system with the system prompting the operator when chemicals need to be changed or added to the system. The control system also monitors flow rates, TMP, backwash cycles, and related operating parameters. If any of these parameters is outside of the “normal” range an alarm will be noted for operator attention. The troubleshooting guide provides information on how to correct the problem. Pall also provides phone numbers for technical support, if the operator needs assistance in troubleshooting the system or general information on the unit operation.

Maintenance guidelines and instructions are also provided for checking and cleaning various filters on the feed water tank and the reverse filtration tanks. These filters, the strainer on the feed water tank and the vent filter on the reverse filtration tank, need to be checked on a regular basis to protect the membranes from large particles and to ensure proper operation. The O&M manual also describes the tanks, piping, and membrane housing with information on the connections for each vessel.

As stated in Section 4.6.3 of the PSTP, the 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 Microza System was found to be easy to operate, provided all needed information and controls to operate the system, and provided 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, coagulant (in this case iron), and oxidants (bleach). Each chemical feed pump is controlled through the PLC/PC. In the test unit, the chemical feed pumps were not paced to raw water flow, but were set up to shut down if raw water flow was interrupted or stopped. In a utility application the capability to control chemical feeds based on raw water flow can be provided. The chemical feed pumps were very stable throughout the test and did not need adjustment to maintain the selected feed rate. The system included inline pH and turbidimeters to monitor the raw and filtrate water, thus providing 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 also provided historical data that could be displayed in a trend plot for any time interval selected.

The Microza System includes flow totalizers and flow rate meters for the raw, feed, and filtrate water. The system has pressure gauges on the feed, filtrate, and concentrate/recycle lines that provide pressure data for monitoring TMP. All of this information is recorded and monitored by the PLC/PC and is available to the operator for review. Both instantaneous current readings and trend plots can be displayed on the operator console. The system also monitors hours of operation and will 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 backwash cycle including air scrub time, backwash water flow and time, and the use of either feed forward or reverse filtration flow can be adjusted by the operator, if needed. The PLC/PC activates and controls the backwash cycle based on the time set by the operator and performs each set of the backwash cycle based on the preset flows and times.

The Microza System used for the verification test was a smaller unit (single module) than a typical multiple module unit used in utility applications. Therefore, the actual power consumption for the test unit may be slightly higher than the standard systems described in the O&M manual. The test system used a 230 VAC, 1 Phase, 30-ampere electrical supply. The test system had two 2 hp centrifugal pumps, one for feed water flow to the membrane and one for backwash (reverse filtration). The test system had one small ¼ hp mixer. The air compressor was a 3 hp unit similar to a multiple module unit. The chemical feed pumps (3 pumps) were all small units using 150 watts each. The PLC/PC power consumption was considered small. Based on one of the two hp pumps always being in operation (feed pump producing filtrate or forward backwash water, or the reverse filtration pump in operation during backwash), the mixer running continuously, and estimating that the air compressor runs approximately ten minutes per hour, it is estimated that approximately 2.75 hp-hr 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 2.05 kilowatt-hr was used for the pumps, air compressor and mixer. The other equipment (chemical pumps and PLC/PC) used an estimated 0.5 kilowatt-hr; bring the total estimated electrical power use to 2.55 kilowatt-hr.

A full-scale system with multiple modules, as described in the O&M manual (Appendix A), uses a 460 VAC, 60 hertz, 3 Phase electrical supply with larger pumps than the test system. A typical system with two 5 hp pumps, a 3 hp air compressor, and accessories would be expected to use approximately 8 to 10 hp or 6 to 8 kilowatt-hr of electrical power.

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 was 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 is of sound quality, 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. 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 E.

Data from the on-site laboratory and data log sheets were entered into Excel spreadsheets. These spreadsheets were used to calculate various statistics (average, median, standard deviation, etc.) and to calculate operating parameters such as flux, temperature corrected specific flux, and TMP. The data in the spreadsheets were proof read by the initial data entry person. NSF DWS Center staff then checked nearly 100% of the data entered into the spreadsheets to confirm the information was correct. The spreadsheets are presented in Appendix G.

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, 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 data were entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

4.7.2 Quality Audits

The NSF QA department performed an on-site audit on September 13, 2004 to review the field procedures, including the collection of operating data and performance of on-site analytical methods. The audit was based on observing the actual collection of operating data on Day 5 of the test and the collection and analysis of samples. 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 NSF 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. Representativeness was ensured by using approved analytical methods 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 (i.e., pressure drop, pressure) was sufficient. None of the primary operating parameters including feed water and filtrate flow rate, pressure or pressure drop across the membrane (on a daily basis) or backwash flow rate or times varied by more than 10% at any time during the verification test.

4.7.3.2 Accuracy

<u>On-Site Equipment Accuracy and Calibration</u>

On-site equipment, including Microza System flow meters and on-site analytical equipment, was checked for accuracy through regular calibration checks. Meters and gauges were checked at the frequencies presented in Table 4-16.

Table 4-16. Field Instrument Calibration Schedule

Instrument	Calibration Method	Frequency	Acceptable Accuracy
Flow Meters	Volumetric "bucket and stop watch"	Weekly	± 10%
Portable Turbidimeter	Secondary turbidity standards Primary turbidity standards	Daily Weekly	± 25%
Portable pH/ISE Meter with Combination pH/ Temperature Electrode	Three-point calibration using 4.0, 7.0 and 10.0 buffers	Daily	± 5%
Dissolved Oxygen Meter	Based on known air saturation concentrations of dissolved oxygen 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

The Microza System had a raw water flow rate and totalizer meter, and a feed water and filtrate flow rate meter. The "bucket and stopwatch" technique was used to determine the accuracy of the flow meters. Table 4-17 shows the calibration data. All calibrations were within the defined objective of ± 10%.

Table 4-17. Flow Meter Calibration Data

	Feed and Filtrate Flow Meter		Raw Water Flow Meter	
Date	Calibration Result (gpm)	Flow Meter Reading (gpm)	Calibration Result (gpm)	Flow Meter Reading (gpm)
8/24/04	6.2	6.3	6.1	6.4
9/10/04	6.0	6.3	6.0	6.3
9/13/04	6.0	6.3	6.0	6.2
9/20/04	6.0	6.3	6.1	6.3
9/27/04	6.0	6.3	6.0	5.9
10/04/04	6.1	6.3	6.1	6.2

The calibrations records for pH, turbidity, total and free residual chlorine, and dissolved oxygen were recorded in the field calibration log (Appendix E). All calibrations were performed at the frequency required. The only calibration data that were outside of the established requirements was for turbidity on September 26, 2004 when the secondary standard check fell below 75% of the true value. The turbidimeter was recalibrated the next day with primary standards and all subsequent calibrations were within the established QC objective.

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 to 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 arsenic (III) and arsenic (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 as follows:

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

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

Acceptable analytical precision under the verification testing program was set at a percent relative standard deviation 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 were collected at a frequency of 10% of samples collected for each parameter. The field duplicates included samples for all three sample locations: raw, feed, and filtrate water.

Tables 4-18 and 4-19 summarize the results for the field duplicate samples. The overall precision as measured by these field duplicates was excellent. All results were within the overall QC objective of 30% relative standard deviation (RSD), except for one turbidity set of replicates at 34% and one free chlorine duplicate at 37%. There was some scatter in the free and total residual chlorine data near the detection limit, which is typical of results near the detection limit. The raw water samples that showed elevated free or total chlorine were flagged as anomalous data, as mentioned earlier in the report.

Laboratory precision was also monitored during the verification test in accordance with QAPP and the NSF QA 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. No laboratory data were flagged or qualified.

Table 4-18. Precision Data – Field Duplicates for Field Analytical Tests

pH (S.U.)

Date	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
9/16/04	7.42	7.22	1.9	6.92	6.95	0.3	6.89	6.89	0.0
9/22/04	7.51	7.46	0.5	6.91	6.91	0.0	6.97	6.98	0.1
9/24/04	7.48	7.47	0.1	6.82	6.77	0.5	7.08	6.88	2.0
10/05/04	7.24	7.24	0.0	6.69	6.61	0.9	6.73	6.74	0.1

Turbidity (NTU)

Date	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
9/16/04	3.5	4.1	11	4.9	4.9	0.0	0.20	0.20	0.0
9/22/04	4.8	4.8	0.0	5.6	5.7	1.3	0.10	0.15	28
9/24/04	6.4	3.9	34	4.5	4.8	4.6	0.20	0.20	0.0
10/05/04	5.0	5.1	1.4	6.2	6.2	0.0	0.10	0.10	0.0

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
9/16/04	0.26	<0.05	N/C	0.23	0.16	25	0.49	0.35	24
9/22/04	0.29	0.17	37	0.33	0.23	25	0.35	0.25	24
9/24/04	<0.05	0.05	N/C	<0.05	0.06	N/C	<0.05	<0.05	0.0
10/05/04	<0.05	<0.05	0.0	0.14	0.15	4.9	0.09	0.12	20

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
9/16/04	<0.05	0.05	N/C	0.63	0.61	2.3	0.64	0.70	11
9/22/04	0.16	0.12	20	0.79	0.83	3.5	0.71	0.84	12
9/24/04	0.05	<0.05	N/C	0.47	0.47	0.0	0.46	0.48	3.0
10/05/04	<0.05	<0.05	0.0	0.53	0.55	2.6	0.47	0.48	1.5

Temperature (^{o}C)

Date	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
9/16/04	12.1	10.7	8.7	11.5	11.4	0.6	10.9	11.0	0.6
9/22/04	10.8	10.9	0.7	10.9	11.0	0.6	11.2	11.2	0.0
9/24/04	10.8	10.5	2.0	10.4	10.9	3.3	10.9	10.8	0.7
10/05/04	9.7	9.7	0.0	9.7	9.7	0.0	9.7	9.7	0.0

N/C – Not Calculated.

Table 4-19. 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
9/13/04	12	12	0.0	12	17	24	<2	<2	0.0
9/22/04	10	10	0.0	10	10	0.0	<2	<2	0.0
10/05/04	12	12	0.0	14	14	0.0	<2	<2	0.0

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
9/13/04	10	11	6.7	<2	<2	0	<2	<2	0.0
9/22/04	11	10	6.7	<2	<2	0	<2	<2	0.0
10/05/04	12	11	6.1	<2	<2	0	<2	<2	0.0

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
9/13/04	9	9	0	<2	<2	0	<2	<2	0
9/22/04	9	9	0	<2	<2	0	<2	<2	0
10/5/04	9	8	8.3	<2	<2	0	<2	<2	0

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
9/22/04	240	250	2.9	220	220	0.0	220	220	0.0
10/05/04	240	240	0.0	230	230	0.0	240	240	0.0

Iron (mg/L)

Date	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
9/13/04	1.1	0.91	13	1.9	2.6	22	<0.02	<0.02	0.0
9/22/04	0.90	0.84	4.9	1.8	1.8	0.0	<0.02	<0.02	0.0
10/05/04	0.99	0.99	0.0	2.1	2.2	3.3	<0.02	<0.02	0.0

Other Parameters (10/05/04)

Parameter	Raw Water			Feed Water			Filtrate		
	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD	Rep 1	Rep 2	%RSD
Chloride (mg/L)	21	18	11	20	24	13	24	20	13
Sulfate (mg/L)	14	14	0.0	21	22	3.3	14	15	4.9
Barium (μg/L)	160	160	0.0	160	160	0.0	170	150	8.8
Calcium (mg/L)	69	69	0.0	69	69	0.0	68	70	2.0
Magnesium (mg/L)	20	20	0.0	21	21	0.0	21	20	3.4
Manganese (μg/L)	26	26	0.0	32	32	0.0	21	21	0.0
Fluoride (mg/L)	0.6	0.6	0.0	0.6	0.6	0.0	0.5	0.6	13
TOC (mg/L)	0.7	0.7	0.0	0.6	0.6	0.0	0.6	0.6	0.0

4.7.3.4 Field Blanks and Method Blanks

Field blanks were collected once per week for water quality parameters collected daily or three times per week, and were collected twice during the verification test for water quality parameters being tested on a weekly basis. The field blanks were prepared in the field using distilled water.

The blank samples used the same bottles and preservatives as the regular samples. These field blanks provide data to show that the contamination was not being introduced during the sample collection, handling, and transportation or in the laboratory analysis.

Results for the field blank analyses are shown in Table 4-20. These results show that for most parameters the results were below the laboratory reporting limits. The TOC blanks showed positive results near the detection limit of 0.1 mg/L and the turbidity blanks showed steady readings at 0.1 NTU, again near the lowest limit that can be detected with the bench-top turbidimeter. The field blank results demonstrated that the sampling, handling, and analyses procedures were in control and did not introduce any contaminants to the samples.

Table 4-20. Field Blank Results

		Date				
Parameter	**Units**	**9/10/04**	**9/13/04**	**9/20/04**	**9/27/04**	**10/02/04**
Chloride	mg/L	<0.5	---	<0.5	---	---
Sulfate	mg/L	<0.5	---	<0.5	---	---
Total Arsenic	µg/L	<2	<2	<2	<2	<2
Soluble Arsenic	µg/L	<2	---	<2	---	---
Arsenic (III)	µg/L	<2	---	<2	---	---
Barium	µg/L	<1	---	<10	<1	---
Calcium	mg/L	<0.02	---	<0.02	<0.02	---
Iron	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02
Magnesium	mg/L	<0.02	---	<0.02	<0.02	---
Manganese	µg/L	<1	---	<1	<1	---
Alkalinity	mg/L	<5.0	5.9	<5.0	<5.0	<5.0
TOC	mg/L	0.1	---	0.1	---	---
Fluoride	mg/L	<0.1	---	<0.1	---	---
Turbidity	NTU	0.10	0.10	0.10	0.10	0.10
Free Chlorine	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05
Total Chlorine	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05
Color	C.U.	5	0	0	0	0
TSS	mg/L	<2	---	---	---	---

The laboratory analyses, and where appropriate, the field analyses, included method blanks as part of the standard analysis procedures. Methods 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 impacted by method blank results.

4.7.3.5 Completeness

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

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

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 membrane, amount of chemicals added to the water, 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, one total residual chlorine value, and four free residual chlorine values. Table 4-21 provides a summary of the completeness results for the verification test.

Table 4-21. Completeness Results

Parameter	**Percent Completeness**	**Comment**
Filtrate Flow Rate	100	All required daily measurements recorded.
TMP	100	All required daily measurements recorded.
Chemicals Added	100	Total amount of chemicals used recorded.
Volume and Rate of Backwash	100	All required daily measurements recorded.
Total Arsenic	100	All scheduled samples and analyses completed.
Iron	100	All scheduled samples and analyses completed.
pH	100	All required daily measurements recorded.
Bench-top Turbidity	100	All required daily measurements recorded.
Total Residual Chlorine	99	All required daily measurements recorded. One value out of 90 samples flagged.
Free Residual Chlorine	96	All required daily measurements recorded. Four values out of 90 samples flagged.
Backwash TSS	100	All scheduled samples and analyses completed.

Chapter 5
References

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Chapter 6
Vendor Comments

Pall Corporation submitted the following comments concerning the ETV test and report; supporting documentation from Pall Corporation can be found in Appendix H. These statements were not validated in the verification test and are the opinion of Pall Corporation:

“The U.S. EPA’s new Arsenic Rule became effective on February 22, 2002 and reduced the Maximum Contaminant Level (MCL) for arsenic in drinking water from 50 μg/ L to 10 μg/ L. The date by which systems must comply with this new MCL is January 23, 2006.

Pall Corporation conducted a NSF/EPA Environmental Technology Verification (ETV) pilot study to verify the coagulation/microfiltration (C/MF) process for arsenic removal. The C/MF process effectively removed naturally occurring arsenic in ground water to undetectable levels. Based upon the results of the pilot trials, the Pall C/MF system can be designed with the following parameters:

1. Flux of 120 GFD (ambient temperature) with a recovery of 98.0%,
2. Undetectable levels of arsenic in filtrate, and
3. Greater than 30-day Clean In Place (CIP) interval.

The process consists of adding an iron-based coagulant, such as ferric chloride, to water contaminated with arsenic followed by microfiltration. The ferric chloride will hydrolyze in water to form ferric hydroxide particles, which have a net positive surface charge at pH values less than 8. Arsenate ions are negatively charged and will absorb onto the positively charged ferric hydroxide particles. The particles are then removed with microfiltration. Naturally occurring dissolved iron in the water can be oxidized to form ferric hydroxide particles as well.

Pall is a *$1.8 billion* corporation with manufacturing, sales, marketing, engineering, and technical support located throughout the world. We have over 50 years of experience in thousands of successful installations using state-of-the-art filters to remove contaminants from liquid and gas streams. As the world’s largest supplier of filters, filter systems and fluid purification equipment we focus our strengths on advancing the state of the art in separation technology in thousands of diverse applications. We owe our success to developing products that offer our customers optimal value and economy of use.”