September 2004
NSF 04/09/EPADWCTR
EPA/600/R-04/188

Environmental Technology Verification Report

Removal of Arsenic in Drinking Water

Delta Industrial Services, Inc.
CampWater Porta-5 System

Prepared by

NSF International

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

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**OZONATION-FILTRATION USED IN DRINKING WATER TREATMENT SYSTEMS**
APPLICATION:	**REMOVAL OF ARSENIC VIA OZONATION-FILTRATION FROM DRINKING WATER**
TECHNOLOGY NAME:	**CAMPWATER PORTA-5 SYSTEM**
COMPANY:	**DELTA INDUSTRIAL SERVICES, INC.**
ADDRESS:	**P.O. BOX 1109** **DELTA JUNCTION, AK 99737**
PHONE:	**(907) 895-5053**
FAX:	**(907) 895-6205**
WEB SITE:	**http://www.deltaindustrial.com**
EMAIL:	**jwd@deltaindustrial.com**

The U.S. Environmental Protection Agency (EPA) supports the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

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

NSF International (NSF) in cooperation with the EPA operates the Drinking Water Systems (DWS) Center, one of seven technology areas under the ETV Program. The DWS Center recently evaluated the performance of a Delta Industrial Services, Inc. (DISI) CampWater Porta-5 (CampWater) system for the reduction of arsenic in drinking water. This verification statement provides a summary of the test results for the CampWater system. University of Alaska Anchorage (UAA) Small Public Water System Training and Technical Assistance Center (ATTAC), an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

The CampWater system uses ozonation followed by cartridge filtration to remove arsenic via co-precipitation. The system utilizes ozone to oxidize iron and arsenic (III) to arsenic (V). The arsenic bound to the iron precipitates is then removed by cartridge filtration. No additional flocculation, solids separation or clarification is required. The CampWater system was tested on a ground water source with 27 µg/L arsenic and 0.62 mg/L iron. Operating the system at 550 mV oxidation-reduction potential (ORP) and the natural water pH of 7.9 reduced the arsenic by 33%. Subsequent tests at 550 mV ORP showed that decreasing pH to 7.5 improved arsenic removal.

TECHNOLOGY DESCRIPTION

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

The CampWater system uses ozone to oxidize the naturally occurring iron in the feed water to form a ferric hydroxide solid and convert any arsenic (III) to arsenic (V). The CampWater system relies on the reduction of arsenic by filtration of the ferric hydroxide solid suspended in water upon which arsenic (V) is adsorbed. The CampWater system directly filters the ferric hydroxide solid without any additional flocculation, solid separation or clarification. The system consists of a raw water pump, an ozone generator and contact chamber, and a series of 20 µm, 5 µm, and 1 µm-absolute cartridge filters. The system is easily transportable and is designed to fit into a standard pickup truck or small aircraft.

VERIFICATION TESTING DESCRIPTION

Test Site

Verification testing occurred at Southwood Manor, a residential community located at 9499 Brayton Road, Anchorage, Alaska. The source water for the verification testing was ground water. The well is considered a back-up water source and was not used by local residents during the verification test. The test site was equipped with a 200-gpm submersible well pump. Because the existing well pump capacity exceeded the rated capacity of the CampWater system, two 300-gallon storage tanks were installed to feed the test unit. These tanks were periodically filled by the well pump resulting in a storage period of up to 3 hours when the CampWater system was continuously operating and significantly longer storage periods (up to several days) under start/stop operations. During the storage period, iron present in the well water could have been oxidized more readily than reduced arsenic. The unknown extent of oxidation during storage prior to treatment could have affected the feed water quality to the treatment system.

Methods and Procedures

ETV testing on the CampWater system occurred in three phases:

Phase A

Phase A was initiated on August 28, 2003. Start/stop operations were performed on the CampWater system for the first 48 hours and then the system was run continuously, except for filter change-outs, until September 13, 2003 for a total of 327 hours over the 17-day period. The system was operated at the natural pH of the feed water (approximately 7.9) and an ORP set point of 550mV. The average flow rate during this phase of testing was 3.85 gpm. During Phase A, 72 feed water samples and 73 treated water samples were collected for total arsenic analysis. During the 48 hours of start/stop operation in Phase A, feed and treated water samples for arsenic, iron, manganese, turbidity, ORP and pH analysis were collected within the first 15 minutes of operation and after 1 hour, 5 hours, and 9 hours of operation after each start-up. Water quality parameters including alkalinity and hardness were measured daily. Weekly samples for sulfate, arsenic speciation, total organic carbon, total suspended solids, total dissolved solids, and ultraviolet light absorbance analysis were collected. Similar collection procedures and frequencies were used for Phases B and C. Ozone production, off-gas ozone concentration, and the dissolved ozone in the water were measured once per day during Phase A.

Phase B

Phase B was a series of five tests conducted between October 11, 2003 and December 12, 2003 to understand the influence of pH and ORP on system performance. Six pairs of pH and ORP operating conditions were tested: pH 7.9/ORP 550 mV, pH 7.5/ORP 550 mV, pH 7.0/ORP 550 mV, pH 7.9/ORP 650 mV, pH 7.5/ORP 650 mV, and pH 7.0/ORP 650 mV. Since the system ran at pH 7.9 (natural pH) and ORP 550 mV during Phase A, the data from Phase A was used for that pair of conditions. A chemical metering pump with an integrated pH controller was used to dose muriatic acid (HCl) to the raw water prior to entry to the CampWater system. The controller was calibrated and used to maintain the desired pH within an error of ±0.1. Tests were conducted using a pH range of 7.0–7.9. The ORP controller was adjusted to set the target ORP point, either 550mV or 650mV. On-site measurements of pH, ORP, and turbidity were taken concurrently with water samples. Flow rate was monitored to maintain constant flow. Instrument calibration, sample handling and storage, and system monitoring procedures outlined in the verification test plan were followed. A total of 31 feed and treated water sample pairs were analyzed for arsenic, iron and manganese concentrations. All samples were sent to NSF for laboratory analysis. No measurements of ozone were performed during Phase B.

Phase C

The intent of Phase C was to verify the improved removal efficiency at a lower feed water pH shown in Phase B under start/stop operating conditions. Phase C was a 48-hour verification test of the CampWater system, operated with an adjusted pH of 7.5 and an ORP set point of 550mV. This phase was conducted over eight days, between February 17, 2004 and March 18, 2004. Phase C followed the same testing procedures, sampling times, and quality control/quality assurance requirements followed during Phase A. The average flow rate during this phase of testing was 3.93 gpm. A total of 29 feed water and 29 treated water samples were collected to test arsenic, iron and manganese concentrations over the course of Phase C. Two sets of arsenic speciation and other weekly water analyses were collected. All samples were sent to NSF for laboratory analysis. Site conditions only allowed for three to nine hours of operation at one time. Ozone production and ozone off-gas concentration were measured once per day during Phase C.

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

VERIFICATION OF PERFORMANCE

System Operation

The CampWater system is designed to use ozone to oxidize the naturally occurring iron in the feed water to form a ferric hydroxide solid and convert any arsenic III to arsenic V. The CampWater system uses filtration of the ferric hydroxide solid suspended in water upon which arsenic V is adsorbed, to reduce arsenic in the treated water.

Raw water is first passed through an Amiad 1 ½” y-strainer and then through a 20 mm FlowMax pleated cartridge filter in a stainless steel Shelco Model 4FOS4 filter housing. Ozone is injected into the pre-filtered water by a Mazzei Model 584K venturi-type injector. Ozone is supplied to the injector by a Clearwater Tech Model CD2000 ozone generator. Contact time is provided in a 54-gallon (approximately) cylindrical stainless steel reaction chamber equipped with an air release valve and a 1” vent that was piped outside the building during the verification test. After the contact chamber, ozonated water passes through 5mm and 1mm absolute FlowMax pleated cartridge filters in Shelco Model 4FOS4 filter housings.

Water Quality Results

Phase A

The average feed water total and soluble arsenic concentrations during Phase A were 27 µg/L and 18 µg/L, respectively. Speciation of feed water soluble arsenic samples resulted in an average of 4 µg/L arsenic (III) and 14 µg/L arsenic (V). The feed water contained approximately 0.62 mg/L of iron which corresponds to iron-to-arsenic weight ratio of 23:1, and a molar iron-to-arsenic ratio of 31:1.

The treated water during Phase A had an average concentration of 18 µg/L total arsenic and an average concentration of soluble arsenic of 15 µg/L, with an average removal efficiency of arsenic of 33%. Treated water turbidity averaged 1.3 NTU. However, a noticeable improvement in the treated water turbidity occurred in the last third of the testing period. During the first two-thirds of the test, the nut used to seal the plate against the filter elements was inadequately tightened thus allowing untreated water to occasionally bypass the filter elements. When additional force was systematically applied to the nut to properly seat the top filter plate, the average turbidity of the treated water was 0.25 NTU, compared to an average turbidity of 1.5 NTU in the treated water before the vessel was properly tightened. The iron concentration of the treated water also showed improved removal after the vessel was properly tightened. The iron concentration prior to this procedure was 0.20 mg/L, whereas the concentration after was 0.03 mg/L. No significant improvement in arsenic removal was recorded as a result of the change in operating procedure.

Phase B

The arsenic concentrations in the feed and treated water during Phase B are presented in Table VS-1. Reducing the pH to 7.5 improved the arsenic removal efficiency in all operation conditions. Maintaining the ORP at 550mV and reducing the pH of the feed water stream to pH 7.5 produced the best removal efficiency of 77%. These conditions were selected as the conditions for the 48-hour start/stop verification test in Phase C.

Table VS-1. Phase B Test Series Results

	Number of Samples	Units	Average	Minimum	Maximum	Removal Efficiency
pH 7.9/ORP 550mV (Phase A data)						
Feed Arsenic	72	(µg/l)	27	19	33	
Treated Arsenic	73	(mg/l)	18	8	27	33%
pH 7.5/ORP 550mV						
Feed Arsenic	5	(µg/l)	26	22	29	
Treated Arsenic	5	(mg/l)	6	4	9	77%
pH 7.0/ORP 550mV						
Feed Arsenic	5	(µg/l)	24	23	27	
Treated Arsenic	5	(µg/l)	11	8	16	54%
pH 7.9/ORP 650mV						
Feed Arsenic	6	(µg/l)	23	21	24	
Treated Arsenic	6	(µg/l)	7	6	8	70%
pH 7.5/ORP 650mV						
Feed Arsenic	5	(µg/l)	22	14	35	
Treated Arsenic	5	(µg/l)	9	6	11	59%
pH 7.0/ORP 650mV						
Feed Arsenic	6	(µg/l)	23	17	28	
Treated Arsenic	6	(µg/l)	9	7	13	61%

Phase C

Phase C was operated with an adjusted feed water pH of 7.5 and an ORP set point of 550 mV. Laboratory analyses of the feed water samples summarized in Table VS-2 show average total and soluble arsenic concentrations of 18 µg/L and 10 µg/L, respectively. No detectable (<2 µg/L) arsenic (III) and 8 µg/L arsenic (V) were present, on average, in the feed water samples. The feed water contained 0.51 mg/L iron and 540 µg/L manganese during Phase C. The treated water contained an average of 9 µg/L arsenic, which corresponds to a 50% reduction in feed water arsenic concentration. Improvements in iron and turbidity removal were also observed.

Table VS-2 Phase C Water Quality

	Number of Samples	Units	Average	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Feed Water							
Arsenic	29	(µg/L)	18	13	25	3.1	17 – 20
Soluble As	3	(µg/L)	10	9	10	N/A	N/A
As (III)[1]	3	(µg/L)	<2	<2	<2	N/A	N/A
As (V)[2]	3	(µg/L)	8	7	8	N/A	N/A
Iron	29	(mg/L)	0.51	0.04	1.0	0.25	0.40 – 0.62
Manganese	29	(µg/L)	540	260	780	147	480 – 600
Total Alkalinity	8	(mg/L)	180	155	240	29.1	151 – 209
Total Hardness	8	(mg/L)	244	228	280	17.2	227 – 262
TDS	2	(mg/L)	300	270	320	N/A	N/A
TSS	2	(mg/L)	4	3	4	N/A	N/A
TOC	2	(mg/L)	1.7	1.6	1.7	N/A	N/A
UVA	2	(cm^{-1})	0.0619	0.0510	0.0728	N/A	N/A
Sulfate	3	(mg/L)	13	13	14	N/A	N/A
Turbidity	36	(NTU)	7.7	4.9	15.5	2.2	6.8 – 8.6
pH[3]	29	--	7.44	7.21	7.62	N/A	N/A
Treated Water							
Arsenic	29	(µg/L)	9	5	15	3.0	8 – 10
Soluble As	3	(µg/L)	9	6	12	N/A	N/A
As (III) [1]	3	(µg/L)	<2	<2	<2	N/A	N/A
As (V)[1]	3	(µg/L)	7	4	10	N/A	N/A
Iron[1]	29	(mg/L)	0.04	< 0.02	0.19	0.04	0.03 – 0.06
Manganese	29	(µg/L)	51	2	130	36	35 – 67
Total Alkalinity	8	(mg/L)	174	145	190	15.1	158 – 189
Total Hardness	8	(mg/L)	229	213	248	11.3	218 – 240
TDS	2	(mg/L)	280	260	300	N/A	N/A
TSS[1]	2	(mg/L)	<2	<2	<2	N/A	N/A
TOC	3	(mg/L)	1.6	1.5	1.7	N/A	N/A
UVA	2	(cm^{-1})	0.0261	0.0225	0.0296	N/A	N/A
Sulfate	3	(mg/L)	15	13	20	N/A	N/A
ORP	42	(mV)	559	399	782	83.9	529 – 590
Turbidity	36	(NTU)	0.60	0.15	1.8	0.45	0.40 – 0.80
pH[3]	29	--	7.41	7.20	7.59	N/A	N/A

N/A = Standard Deviation and 95% Confidence Interval calculated on data sets of eight value or more.

[1] The value of lab analysis' LOD was used to calculate statistical information when a value was non-detect.

[2] No direct measurement. Calculated by subtracting arsenic (III) values from soluble values.

[3] The median is reported for the pH data, not the mean.

Operation and Maintenance Results

During the verification test, there were no operational problems with the system operation, system equipment, or monitoring equipment. Several operating conditions and equipment performance factors were monitored during the verification test, including power usage, volume of treated flow, flow rates, head loss across filters, ozone generation, and ambient parameters such as temperature, dew point, and atmospheric pressures.

Operators were needed to monitor treated water turbidity, flow rate and pressure loss to determine when a filter change was needed. During the ETV test, filters were changed at least once per day. The ORP probe needed to be cleaned regularly and the ORP controller needed to be monitored to make sure the system operates at the set ORP point. The system was small and easily installed to provide easy access to all components for routine maintenance. The level of skill required for efficient operation was low, and the system had a low-flow switch that would shut the pump down under unfavorable operating conditions.

Consumables and Waste Generation

The only waste the CampWater system generated was spent filter cartridges. A total of 144 filter cartridges were used during Phase A. TCLP analyses of spent filters of each size were performed and satisfactorily passed the regulatory limits. California WET procedures on each filter size failed for arsenic. Waste disposal procedures would be dependent on the standards required by each state.

Quality Assurance/Quality Control

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

Original Signed by
Sally Gutierrez for
Lawrence W. Reiter *09/30/04*

Lawrence W. Reiter Date
Acting Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original Signed by
Gordon Bellen *09/30/04*

Gordon Bellen Date
Vice President
Research
NSF International

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

Availability of Supporting Documents
Copies of the *ETV Protocol for Equipment Verification Testing for Arsenic Removal* dated September 2003, the verification statement, and the verification report (NSF Report #04/09/EPADWCTR) are available from the following sources:
(NOTE: Appendices are not included in the verification report. Appendices are available from NSF upon request.)

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

September 2004

Environmental Technology Verification Report

Removal of Arsenic in Drinking Water

Delta Industrial Services, Inc.
CampWater Porta-5 System

Prepared for:

NSF International
Ann Arbor, Michigan 48105

Prepared by:

University of Alaska Small Public Water System Training and Technical Assistance Center
Anchorage, Alaska 99508

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

Jeffrey Q. Adams, Project Officer
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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 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.

Lawrence W. Reiter, Acting Director
National Risk Management Research Laboratory

Table of Contents

Section Page

Table of Contents (continued)

Tables

Table of Contents (continued)

<u>Figures</u>

<u>Appendices</u>

Abbreviations and Acronyms

API	Advanced Pollution Instrumentation Inc.
ASET	Applied Science, Engineering and Technology Laboratory
ATTAC	University of Alaska Small Public Water System Training and Technical Assistance Center
cm	Centimeter
DISI	Delta Industrial Services, Inc.
DQO	Date Quality Objectives
DWS	Drinking Water Systems Center
°C	Degrees Centigrade
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
FTO	Field Testing Organization
GPM	Gallons per Minute
LOD	Limit of Detection
µg/L	Microgram per liter (10^{-6}g/L)
mg/L	Milligram per liter (10^{-3}g/L)
mV	Millivolts
ND	Non Detectable at Reporting Limit
NIST	National Institute of Standards and Technology
NRMRL	National Risk Management Research Laboratory
NSF	NSF International (formerly known as the National Sanitation Foundation)
NTU	Nephelometric Turbidity Unit
O&M	Operations and Maintenance Manual
ORP	Oxidation – Reduction Potential
PE	Performance Evaluation
PSI	Pounds per Square Inch
PSTP	Product Specific Test Plan
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
SCFH	Standard Cubic Feet per Hour
SWM	Southwood Manor
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UAA	University of Alaska Anchorage
UVA	Ultraviolet Absorbance
WET	California Waste Extraction Test

Acknowledgements

The Field Testing Organization (FTO), University of Alaska Anchorage (UAA), was responsible for all elements in the testing sequence, including collection of samples, calibration and verification of instruments, data collection and analysis, data management, data interpretation, and the preparation of this report.

University of Alaska Anchorage
School of Engineering
3211 Providence Drive
Anchorage, AK 99508
Contact Person: Craig Woolard, Ph.D., P.E.

The laboratory selected for the majority of off-site analytical work for this study was:

NSF International
789 Dixboro Road
Ann Arbor, MI 48105
Contact People: Kristie Wilhelm, P.E. and Angela Beach

The laboratory that conducted the Toxicity Characteristic Leaching Procedure and California Waste Extraction Test was:

TriMatrix Laboratories, Inc.
5555 Glenwood Hills Parkway, SE
Grand Rapids, MI 49588
Phone: (616) 975-4500
Fax: (616) 942-7463
E-mail: mmtrimatrix@comcast.net
Contact Person: Michael W. Movinski, Vice President, Sales and Marketing

The manufacturer of the equipment was:

Delta Industrial Services, Inc.
P.O. Box 1109
Delta Junction, AK 99737
Contact Person: Jon Dufendach

UAA wishes to thank Southwood Manor and Water System Services of Anchorage, Alaska for their assistance and use of their site for testing.

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 Delta Industrial Services, Inc. (DISI) CampWater Porta-5 (CampWater) system, which is an oxidation/filtration system used in drinking water treatment system applications to remove arsenic. The performance capabilities stated by the manufacturer were used to shape the data quality objectives (DQOs) and testing plan used for this ETV test. This document provides the verification test results for the CampWater system.

1.2 Testing Participants and Responsibilities

The ETV testing of the CampWater system was a cooperative effort among the following participants:

NSF International

University of Alaska Anchorage (UAA), a member of the Alaska Training and Technical Assistance Center (ATTAC)
DISI
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.

Contact Information:
NSF International
789 N. Dixboro Road
Ann Arbor, MI 48105
Phone: (734) 769-8010
Fax: (734) 769-0109
Contact: Bruce Bartley, Project Manager
Email: bartley@nsf.org

1.2.2 Field Testing Organization

UAA, a member of the ATTAC, is a non-profit institution of higher education. UAA conducted the verification testing of the CampWater system. UAA is an NSF-qualified FTO for the ETV DWS Center.

The FTO was responsible for conducting the verification test. 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 prepared the PSTP; oversaw the demonstration 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 provided oversight of the daily test process, schedule, and logs.

Contact Information:

University of Alaska Anchorage, School of Engineering
3211 Providence Drive
Anchorage, AK 99508
Phone: (907) 786-1863
Fax: (907) 786-1079
Contact Person: Craig Woolard, PhD, P.E.
Email: afcrw@uaa.alaska.edu

1.2.3 Manufacturer

The treatment system is manufactured by DISI. DISI was responsible for supplying a field-ready treatment system equipped with all necessary components, including treatment equipment, instrumentation and controls, and an operations and maintenance (O&M) manual (Appendix A). DISI 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.

Contact Information:

Delta Industrial Services, Inc.
P.O. Box 1109
Delta Junction, AK 99737
Phone: (907) 895-5053
Fax: (907) 895-6205
Contact Person: Jon Dufendach, President
Email: jwd@deltaindustrial.com

1.2.4 Analytical Laboratory

All metals analysis and water quality laboratory analyses were performed by NSF's certified laboratory in Ann Arbor, Michigan. The FTO was responsible for appropriate collection, labeling, storage, and shipping of all samples sent to NSF. The Toxicity Characteristic Leaching Procedure (TCLP) and California Waste Extraction Test (WET) laboratory analyses were performed by TriMatrix Laboratories, Inc., coordinated by NSF.

Contact Information:

NSF International
789 Dixboro Road
Ann Arbor, MI 48105
Phone: (734) 769-8010
Fax: (734) 769-0109
Contact People: Kristie Wilhelm, P.E. and Angela Beach

TriMatrix Laboratories, Inc.
5555 Glenwood Hills Parkway, SE
Grand Rapids, MI 49588

Phone: (616) 975-4500
Fax: (616) 942-7463
E-mail: mmtrimatrix@comcast.net
Contact Person: Michael W. Movinski, Vice President, Sales and Marketing

1.2.5 U.S. Environmental Protection Agency

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

1.3 Verification Testing Site

Verification Testing occurred at Southwood Manor (SWM), a residential community located at 9499 Brayton Road, Anchorage, Alaska.

1.3.1 Source Water

The source water for the verification testing was ground water. The SWM well is considered a back-up water source and was not used by local residents during verification testing. During testing, the ground water was pumped into two 300-gallon storage tanks equipped with float switches to control the well pump. Water from the storage tanks was used to supply the CampWater system.

The SWM test site was equipped with a 200-gallon per minute (gpm) submersible well pump. Because the existing well pump capacity exceeded the rated capacity of the CampWater system, two 300-gallon storage tanks were installed to feed the test unit. These tanks were periodically filled by the well pump resulting in a storage period of up to three hours when the CampWater system was continuously operating and significantly longer storage periods (up to several days) under start/stop operations. During the storage period, iron present in the well water may have been oxidized more readily than reduced arsenic. The unknown extent of oxidation during storage prior to treatment could have affected the feed water quality to the treatment system.

The verification test consisted of three phases. Phase A included a 327 hour test, which included start/stop events in the first 48 hours of operation. Water was supplied to the CampWater system at the naturally occurring pH of 7.9 and an oxidation reduction potential (ORP) set point of 550 millivolts (mV). Phase A was the only time during the verification test when water was treated without pH adjustment. Phase B included a series of five test runs with varying pH and ORP values to optimize system performance. Phase C consisted of a 48-hour start/stop test using the optimum pH (7.5) and ORP (550 mV) values established in Phase B. The ground water quality was characterized by the collection of samples in Phase A, which occurred between August 28 and September 13, 2003. Seventy-two feed water samples were taken over the course of Phase A. The average arsenic concentration in the feed water during Phase A was 27 micrograms per liter (µg/L). The average feed water iron and manganese concentrations were 0.62 mg/L and 670 µg/L, respectively. A summary of the feed water quality collected during Phase A is presented in Table 1-1.

Table 1-1. Source Water Quality (Phase A)

Parameter	Number of Samples	Analysis Location	Units	Average	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Arsenic	72	NSF	(µg/l)	27	19	33	2.8	26 – 28
Soluble As	2	NSF	(µg/l)	18	16	19	N/A	N/A
As (III)[1]	2	NSF	(µg/l)	4	< 2	5	N/A	N/A
As (V)[2]	-	--	(µg/l)	14	14	14	N/A	N/A
Iron	72	NSF	(mg/l)	0.62	0.37	1.2	0.15	0.58 – 0.66
Manganese	72	NSF	(µg/l)	670	270	860	110	640 – 700
Total Alkalinity	17	On-site	(mg/l)	205	195	225	7.35	201 – 209
Total Hardness	16	On-site	(mg/l)	248	232	265	9.38	242 – 254
Total Dissolved Solids (TDS)	2	NSF	(mg/l)	300[3]	290	300	N/A	N/A
Total Suspended Solids (TSS)	2	NSF	(mg/l)	4	3	4	N/A	N/A
Total Organic Carbon (TOC)	3	NSF	(mg/l)	2.2	2.0	2.4	N/A	N/A
Ultraviolet Absorbance (UVA)	2	NSF	(cm^{-1})	0.085	0.066	0.104	N/A	N/A
Sulfate	2	NSF	(mg/L)	16	14	17	N/A	N/A
Turbidity	68	On-Site	(NTU)	3.6	1.6	13	1.7	3.1 – 4.0
pH[4]	59	On-Site	--	7.88	7.15	8.16	N/A	N/A

NTU = Nephelometric Turbidity Unit

N/A = Standard Deviation and 95% Confidence Interval calculated on data sets of eight or more.

[1] The value of analysis' Limit of Detection (LOD) was used to calculate statistical information when a value was non-detect.

[2] No direct measurement. Calculated by subtracting arsenic (III) values from soluble arsenic values.

[3] Average value reflects 2 significant figures.

[4] The median is reported for the pH data, not the mean.

1.3.2 Pilot Effluent Discharge

The effluent of the pilot treatment unit was discharged into the local storm drain system. No discharge permits were required.

Chapter 2
Equipment Description and Operating Processes

2.1 Equipment Description

The CampWater system uses ozone to oxidize the naturally occurring iron in the feed water to form a ferric hydroxide solid and convert any arsenic (III) to arsenic (V). The CampWater system relies on the reduction of arsenic by filtration of the ferric hydroxide solid suspended in water upon which arsenic (V) is adsorbed. The CampWater system directly filters the ferric hydroxide solid without any additional flocculation, solid separation, or clarification. The system is easily transportable and is contained in square plastic shipping containers that fit into a standard pickup truck or small aircraft. The CampWater system weighs approximately 550 pounds and is composed of three modules (two shipping containers and the ozone contact chamber). Each module can be moved by one-two individuals. The system, shown schematically in Figure 2-1, consists of a raw water pump, an ozone generator and contact chamber, and a series of cartridge filters.

Raw water is first passed through an Amiad 1.5" y-strainer and then through a 20 µm FlowMax pleated cartridge filter in a stainless steel Shelco Model 4FOS4 filter housing. Ozone is injected into the pre-filtered water by a Mazzei Model 584K venturi-type injector. Ozone is supplied to the injector by a Clearwater Tech Model CD2000 ozone generator. Contact time is provided in a 54-gallon (approximately) cylindrical stainless steel reaction chamber equipped with an air release valve and a 1" vent that was piped outside the building during the verification test. The ozone generator has a rated capacity of 9 grams per hour at approximately 20 standard cubic feet per hour (SCFH) when ambient air is drawn in and fed to the generator via the built-in air drier. When fed either with bottled oxygen or from an oxygen concentrator, the production rises to 20 grams per hour at approximately 14 SCFH.

Ozone is drawn into the system by means of a venturi-type injector which creates a negative pressure that draws ozone gas into the water stream. Ozone flow rate is controlled by adjustment of bypass valve V-4, which controls the vacuum produced by the venturi. System design allows regulated recirculation of ozonated (by adjusting valve V-3) water from the outlet of the ozone tank back through the first two filter housings. Flow rate is controlled by adjustment of valve V-3 and V-5 (see Figure 2-1). (During the ETV test, measurement of flow rate occurred at the system outlet.)

After the contact chamber, ozonated water passes through 5µm and 1µm absolute FlowMax pleated cartridge filters in Shelco Model 4FOS4 filter housings. Filter porosity and type can be adapted to meet the water-quality conditions at a particular source. The test system specifications are summarized in Table 2-1. Photos of the test system are provided in Figure 2-2 and Figure 2-3.

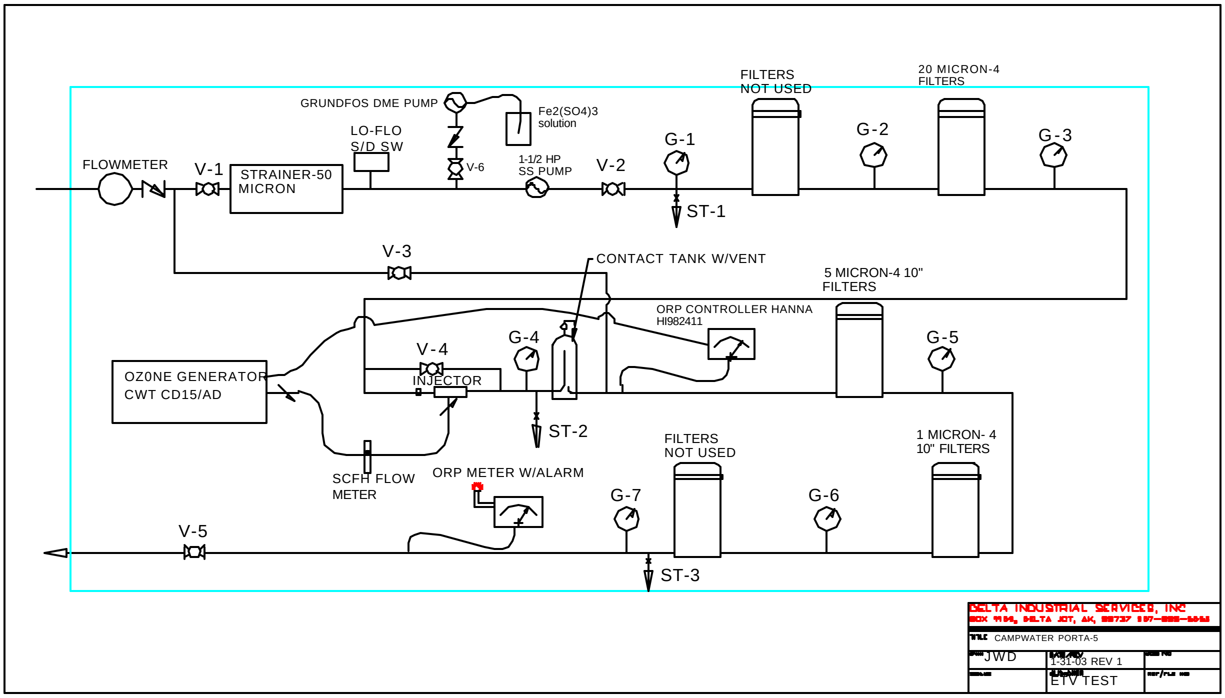

Figure 2-1. Schematic of the CampWater System.

Table 2-1. CampWater System Specifications

Model: FOA10-01

Serial Number: 100500-01

Electrical Requirements: 220 V single phase, 50 or 60 Hz. Power is supplied to a main junction box. Power is provided to the ozone generator and raw water pump from the junction box.

Raw Water Pump: Goulds Model NPE, Number 1ST1F1B4, 5.75" impeller

Construction: Construction is primarily welded and threaded stainless steel piping that connects stainless steel pressure vessels and an ozone contactor. Ozone contact chamber (manufactured by Swift Company) has diameter of 15" and a height of 72" with a total volume of 54 gallons. The approximate weight of this unit is 100 lbs. Base unit (which contains the pump, filter housings, and piping is 4' square and weighs approximately 300 lbs.). A second 4' square container houses the main power switch, the ozone generator, and storage space for spare filters and parts.

Ozone Generator: Cleanwater Tech Inc. Model CD2000 Ozone Generator, with a Clearwater AD40 Air Dryer that removed moisture in the air prior to feeding it into the ozone generator.

Filter Vessels: All cartridge filter vessels are Shelco Model 4FOS4. Y-strainer is an Amiad 1.5" unit.

Cartridge Filters: Flow-Max Pleated Cartridge Filter (series of four identical individual 20µm cartridge filters act as pre-filters and are installed upstream of the ozone injection venture; 5µm and 1µm absolute cartridge filters are installed in series after the ozone contact chamber). All pleated cartridge filters are 9.75" length, 2.5" outer diameter, and either 20µm, 5µm or 1µm pore size. The filters are manufactured by Flowmatic Systems, Inc., Dunnellon, FL, (352) 465-2000 and can be ordered using part numbers FM-20-975 (20µm), FM-5-975 (5µm), and FM-1A-975 (1µm absolute).

Process Flow Rates: The system is designed to produce treated water at a rate of up to approximately 10 gpm. Actual production rate is a function of the amount of recycled flow used during operation. A flow rate of 4 gpm was targeted for the ETV test.

Flow Meter: ABB Water Meter Model C700

Flow Switch: ITT McDonnell and Miller Model Number FS4-3

Expected Operating Pressure: Inlet operating pressure (after the raw water pump) was a maximum of 50 pounds per square inch (psi). Typical head loss across the system is 10-40 psi. Pressure gauges are installed to indicate pre- and post-filtration pressures.

Waste Water Volumes: No wastewater is generated from the system. Spent cartridge filters are the only waste product.

On-Skid Instrumentation: Cole Parmer ORP probe is installed after the contact tank and relays data to a Hanna 982411 ORP controller.

Figure 2-2. Photo of CampWater System.

Figure 2-3: Close-up Photo of CampWater System.

2.2 Operating Process

2.2.1 Startup Procedure

Operation of the CampWater system was initiated by first filling the system with water to purge air from the vessels. Each time the system was started during start/stop operations, the following procedure was used:

1. The master and pump switches were turned on, and it was confirmed that the indicator light for the ozone generator and air drier were on. At least 30 minutes was allowed for the air drier to warm up if it had been off prior to the startup event.

2. Valve positions were then set as follows:
   - Filter housing vent valves: open;
   - Valves V-1, V-2, and V-4: open;
   - Valve V-3: not adjusted;
   - Valve V-5: closed;
   - Filter drains: closed;
   - Strainer drain: closed; and
   - Contact chamber drain: closed.

3. The bypass switch was activated, allowing the pump to operate. The CampWater system has a low-flow switch that normally stops the pump under low flow (<2 gpm) conditions. The bypass switch overrides this function until sufficient flow is achieved.

4. Filter housing valves were closed sequentially as the system filled.

5. After the final filter housing was filled and pressure gauges G-4 though G-6 showed positive pressure readings, the effluent valve (V-5) was opened.

6. The system was then allowed to run for a few minutes to ensure the contact chamber tank and all housings were filled.

The system was checked for air build-up by occasionally opening each filter housing vent to release any trapped air.

2.2.2 Installing or Changing Filters

Filters were replaced at least once per day during operation. Filters were always changed when flow rate dropped below 2.5 gpm. All 12 filters were replaced (four each of 20µm, 5µm, and 1µm absolute filter cartridges) during each filter change.

Filters were changed according to the following procedure:

1. The unit was shut down by switching the main pump off.

2. The filter housings were drained using the filter drain valves
3. The ring clamp securing the top of the filter housing to the filter base was loosened and removed.
4. The spent filters were removed and the housing was cleaned of debris, if necessary.
5. Four new filter cartridges were inserted into the housing by sliding them over posts located at the base of the filter housing.
6. The top plate was replaced and screwed tightly into place to obtain a firm seal between the top plate and the filter cartridge.
7. The filter housing top was replaced and secured with the ring clamp. Tapping the ring clamp with a small hammer while tightening helped to assure a good seal.
8. The system was started again, following the steps listed in Section 2.2.1, Startup Procedure.

Chapter 3
Methods and Procedures

The verification test of the CampWater system consisted of three phases. Phase A was a 327-hour test with start/stop operation conducted during the first 48 hours of operation. SWM ground water was supplied at the naturally occurring pH of 7.9 and the ORP set point of 550 mV. Phase B included a series of five test runs with varying pH and ORP values to identify the conditions giving optimum system performance. Phase C consisted of 48 hours of start/stop operation using the optimum pH and ORP values established in Phase B (pH 7.5 and ORP set point of 550 mV).

Prior to the start of the verification test phases, the following two tasks were performed: Task A – Characterization of the Feed Water and Task B – Initial Test Runs. Details of these two tasks are provided in this chapter.

During Phases A, B and C of the verification test, the following tasks were performed:
- Task 1 – Verification Testing Runs
- Task 2 – Feed Water and Finished Water Quality
- Task 3 – Operating Conditions and Treatment Equipment Performance
- Task 4 – Arsenic Removal
- Task 5 – Data Management
- Task 6 – Quality Assurance/Quality Control (QA/QC)

The methods and procedures for each of the above tasks are described in this chapter.

3.1 Task A: Characterization of Feed Water

SWM source water was initially characterized by collecting two sets of samples to determine the water quality parameters summarized in Table 3-1. Two separate sampling events were performed before ETV testing began, providing sufficient data to adequately characterize the untreated water source. The performance objective evaluated was the capability of the system to reduce total arsenic levels in ground water when sufficient iron was present and ozone was applied to attain an ORP after the ozone contact chamber of between 500 mV and 900 mV.

All analyses performed during the feed water characterization were conducted at the Applied Science, Engineering and Technology (ASET) laboratory at UAA or in the field using field test kits. To reduce the time and expense of the ETV testing effort, these data were not subjected to rigorous QA and were thus not included in the final verification report.

Table 3-1. Water Quality Parameters for Feed Water Characterization

Feed Water Parameter
Temperature
pH
Total Alkalinity
Hardness
TOC
UVA
Turbidity
Sulfate
Iron
Manganese
Arsenic (total and speciation)
TDS

3.2 Task B: Initial Test Runs

Based on the raw water quality, initial test runs were conducted to assure that the selected ozone dose and cartridge filters were appropriate to obtain arsenic removal via co-precipitation and filtration. The testing performed during this task provided a basis to determine the proper frequency of filter changes and sampling schedule for monitoring arsenic removal and whether an iron coagulant must be added to the raw water to facilitate arsenic co-precipitation.

All arsenic and iron analyses performed during the initial test runs were conducted at the ASET laboratory at UAA or in the field using field test kits. To reduce the time and expense of the ETV testing effort, these data were not subjected to rigorous QA and were thus not included in the final verification report.

During the initial testing, total arsenic concentration, turbidity, pH, iron, ORP, manganese, and alkalinity were monitored at a sufficient frequency to evaluate system performance and select the appropriate ozone dose for testing. DISI evaluated the data from the initial testing phase to select the appropriate ozone dose, cartridge filter specifications, and whether an iron coagulant dose was needed to meet the criteria specified in their performance objectives. It was determined during the initial test runs that sufficient iron concentrations were present in the ground water and an iron coagulant was not warranted during the verification test.

3.3 Task 1: Verification Testing Runs

The CampWater system was tested to evaluate the system's capability to reduce total arsenic levels in the groundwater when sufficient iron was present and ozone was applied to attain an ORP of between 500 mV and 900 mV after the ozone contact chamber. The CampWater system was operated at a target flow rate of 4 gpm. The performance capabilities stated by the manufacturer were used to shape the DQOs and testing plan used for this ETV test.

The verification testing of the CampWater system consisted of three phases. Phase A was designed as a test run of a minimum duration of 320 hours and a maximum of 30 days. Treated water samples were collected at regular intervals throughout each day and sent to NSF for analysis. A series of short runs in Phase B tested arsenic removal capabilities under different pH and ORP operating conditions. Phase C was a 48-hour start/stop verification test under one selected pH/ORP condition.

In Phase A, the CampWater system was operated for 327 hours over 17 days. Because start/stop periods are common in small systems that are candidates for this treatment technology, the first 48 hours of run time was accumulated from a 12-hour-on/12-hour-off schedule for a total of 48 hours of operation. The system was then operated continuously (except during filter changes) for the remaining 279 hours.

During the 48 hours of start/stop operation, feed and treated water samples were collected after 15 minutes, one hour, four hours, and eight hours of operation in Phases A and C. Sample collection was initiated after a total of three theoretical detention times (defined as the volume of water held in the treatment equipment, divided by the rate of flow) had passed after the start of system operation during all phases. The remainder of the sampling frequency is described in Task 2.

The system was operated from startup until head loss decreased to 12 psi across the system or the flow rate dropped below 2.5 gpm. Samples were collected at time of terminal head loss or filter change.

Sampling procedures for Phases B and C were the same as those under start/stop operations.

3.4 Task 2: Feed Water and Finished Water Quality

Water quality data were collected on the feed and system effluent using a combination of on-site measurements and off-site analytical laboratory tests. All samples were analyzed using EPA approved methods or *Standard Methods for the Examination of Water and Wastewater* (APHA, 1998). All samples for off-site analysis were collected in appropriate sample containers and shipped to comply with specified holding times.

Table 3-2 summarizes the analytical schedule for the CampWater verification study. Samples for iron, manganese, pH, ozone, and ORP were collected at the same time arsenic samples were collected and at any time terminal head loss was recorded.

Table 3-2. Summary Analytical Testing Schedule for CampWater ETV Testing

Parameter (facility)	Minimum Frequency
Temperature (on-site)	Daily
ORP (on-site)	Once every four hours during staffed operation[1]
pH (on-site)	Once every four hours during staffed operation
Total Alkalinity (on-site)	Daily
Hardness (on-site)	Daily
TOC (NSF)	Weekly
UVA (NSF)	Weekly
Turbidity (on-site)	Every two hours during staffed operation with calibrated bench-top turbidimeter.
Sulfate (NSF)	Weekly
Iron (NSF)	Once every four hours during staffed operation
Manganese (NSF)	Once every four hours during staffed operation
Dissolved Ozone (on-site)	Once each day at a sampling point located immediately after the contact chamber
Total Arsenic (NSF)	Once every four hours during staffed operation
Arsenic Speciation (on-site, NSF)	Once per week (Battelle method used on-site, samples sent to NSF for analysis)
TSS (NSF)	Weekly
TDS (NSF)	Weekly

[1] The system was staffed a minimum of 12 hours per day during the first 48 hours of operation for frequent sample collection and 8-12 hours per day during the remainder of ETV testing.

3.5 Task 3: Operating Conditions and Treatment Equipment Performance

Operating conditions during treatment and equipment performance were documented to develop operation and maintenance cost factors, such as power used and number of cartridge filters used. Operating conditions and treatment equipment performance were evaluated using a combination of quantitative and qualitative parameters. Quantitative parameters that were measured included:

- Feed and treated water quality - see Task 2;
- Power usage - estimated by measuring daily the current drawn by the entire system at the breaker with a portable ammeter;
- System flow rates - measured each day during staffed operation using both the flow meter and a stopwatch and volumetric container;
- Head loss across each filter unit - recorded every four hours during staffed operation and before each filter replacement;
- Total treated flow (gallons of water processed) - recorded using a totalizing meter located at the system discharge location;
- Filter replacement frequency – recorded occurrences in logbook;
- Air flow rate to ozone generator and dissolved ozone concentration after the contact chamber - monitored once each day;
- Ozone production rate for the generator - verified daily;
- Ozone off-gas concentration - measured daily; and

- Ozone temperature, ozone gas pressure, atmospheric pressure, and dew point - measured and recorded daily.

The qualitative factors used to evaluate the system's reliability and ease of operation included:

- The frequency that operating parameters must be adjusted to achieve efficient operation;
- The ease of making adjustments to the operating parameters;
- The overall quality of the constructed units;
- The ability to access system components that require routine maintenance;
- The level of skill required for efficient operation; and
- Frequency of equipment failure and redundancy of system components.

Daily log sheets were completed by UAA to quantify the amount of time required to operate the system.

3.6 Task 4: Arsenic Removal

Arsenic removal during verification testing was evaluated by measuring the arsenic naturally present in the feed water and the amount of arsenic remaining after treatment. Intensive arsenic sampling conducted during the start/stop schedule was detailed in Task 1. Based on historical data and sample results obtained from Tasks A and B, the SWM well contained approximately 25-30 μg/L of total arsenic. Samples to evaluate arsenic removal were collected every four hours during staffed operation during Phases A, B and C. Sample frequency increased during the start/stop operation. Nineteen pairs of feed water and treated water samples were collected during the 48-hour start/stop period at the following frequencies: 15 minutes after start-up, after one hour of operation, after four hours of operation, and after eight hours of operation. This same sample frequency was performed during Phases B and C, or sampling was more frequent depending on run duration.

3.7 Task 5: Data Management

UAA established a structure for collecting, verifying, reducing, and reporting data collected during the verification test. These objectives were accomplished using checklists, schedules, site visits, and interim reports. To facilitate data collection, a daily log sheet (as shown in Appendix B) was developed for evaluating the CampWater system. The log sheet listed the required samples and sample frequency as well as an operations checklist. Each day the log sheet was copied. Originals were stored in a project notebook in the project manager's office and the copies were kept on-site.

Once completed, the daily log sheets were reviewed by a member of UAA and checked for completeness. Any questions about the data were resolved with the individual who collected the data. The verified data were then entered into a Microsoft Excel spreadsheet designed for this project. The entered data were spot-checked for accuracy by a second member of the UAA staff.

Laboratory data reports were checked by UAA staff for completeness and for any violations of the laboratory's written QA/QC parameters. Each chain of custody was also evaluated for completeness. If for some reason samples were present that did not meet the QA/QC criteria, a second set of samples was immediately collected by the UAA staff. All verified laboratory data were entered into the Excel database. The entered data were spot-checked for accuracy against the original laboratory reports by a second member of the UAA staff.

3.8 Task 6: Quality Assurance and Quality Control

UAA maintained strict QA/QC standards to facilitate accurate data interpretation for each parameter specified in the PSTP.

3.8.1 QA/QC Verification Prior to Testing Period

Before starting the verification test, the skid instruments were cleaned and calibrated and their accuracy verified. Pressure gauge readings were verified by comparing the readings with a certified, factory-calibrated pressure gauge. Calibration records can be found in Appendix C. The pumps and valves were tested to verify that they were in good working order before initiating the verification test. In addition, all on-skid and off-skid piping were inspected and any defects immediately repaired.

3.8.2 Daily QA/QC Verification

Daily QA/QC procedures were conducted by UAA to ensure that the equipment being verified remained in good working order throughout the test period. Each day, the operators visually verified that all piping and connections were in good condition. All pumps, pressure gauges, and skid instrumentation were checked for integrity. The condition of each element was noted on the daily logs. Any problems identified were immediately relayed to DISI for corrective action or repaired by UAA staff.

Daily verifications of the flow rate instrumentation using a stopwatch and volumetric container confirmed the inline flow meter performance throughout the duration of the tests.

3.8.3 On-Site Analytical Methods

All on-site parameters were analyzed using the procedures specified in *Standard Methods* or by an accepted EPA method.

> **3.8.3.1 pH.** The pH was monitored using *Standard Method* 4500-H^+ B. The Myron L Ultrameter 6P pH meter was calibrated and verified daily using pH=4, pH=7, and pH=10 certified buffer solutions. When not in use, the meter's probe was stored in the manner outlined by the manufacturer.
>
> **3.8.3.2 Turbidity.** All turbidity measurements were analyzed using a bench-top HACH 2100P portable turbidimeter. The turbidimeter was calibrated to the expected turbidity range of 0-10 NTU. The meter was calibrated according to the manufacturer’s instruction using <1, 20, 100, and 800 NTU standards at the beginning of the verification test and on a weekly basis. After calibration, the values of three secondary standards (ranges 0-10, 0-100, 0-1000) were initially recorded. The recorded values were then used

to check the meter calibration daily. A StabilCal standard of 1.0 NTU was used to check calibration of the meter at the lower turbidity range. All glassware was properly cleaned using a lint-free cloth supplied by the manufacturer.

Grab samples were analyzed daily for turbidity using *Standard Method* 2130. Samples were collected from a designated sampling site on the feed and effluent lines. Prior to sample collection, each sample tap was allowed to run slowly and the beaker was rinsed three times with the sample water. Samples for analysis were collected carefully to minimize air entrainment. Each turbidity sample was allowed to warm to a temperature that eliminated fogging of the sample cell. If feed water samples showed a difference of 5 NTU from prior sampling event, the cell was cleaned and the test repeated. If treated water samples showed a gain of 1 NTU above prior sample results, the cell was cleaned and retested. If the second test showed the same result, another grab sample was taken and tested.

3.8.3.3 Temperature. Water temperature was measured daily using an on-line thermometer positioned just prior to the first filter housing. The thermometer was graduated in 1 degrees centigrade (°C), and ranged from 0° to + 50°C. It was not discovered until after the test was completed that the thermometer was not the National Institute of Standards and Technology (NIST)-precision thermometer described in the PSTP.

3.8.3.4 ORP. The response of the ORP probe was checked against Ricca Chemical Company's Zobell's Solution for APHA-Redox Standard Solution for Oxidation Reduction Potential once each week. The test plan had specified calibration twice per week; however the probe was only tested once per week during Phase A. Probe readings were recorded on the data sheets. If the probe had not provided an acceptable output, it would have been replaced. This was not necessary during Phase A. A new probe was installed prior to Phase C. At this time, the calibration solution was replaced with Cole Parmer Company's ORP Solution.

The Hanna 982411 ORP controller failed midway through conducting the Phase B series of pH and ORP tests. The controller was replaced by a newer Hanna model, HI 8720 for the remainder of Phase B and Phase C.

3.8.3.5 Ozone. Dissolved ozone in the effluent from the ozone contact chamber was measured on-site daily. HACH Indigo Accu-Vac method was used to take the dissolved ozone measurements using a HACH DR/2400 Spectrophotometer.

An Advanced Pollution Instrumentation Inc (API) 450M NEMA UV ozone monitor measured the generator ozone production rate and the rate of ozone off-gas from the contact chamber. Once each day, flow from the ozone generator was directed through the monitor and the ozone production rate recorded. Once each day, gas flow from the off-gas line of the ozone contact chamber was directed through the monitor and ozone off-gas rate recorded. Gas pressure and temperature were also recorded. Prior to the ETV test, API verified the monitor reading and provided a calibration certificate documenting monitor performance (see Appendix C).

3.8.3.6 TCLP and California WET. The waste filters with arsenic-iron precipitate that were generated during Phase A testing were analyzed according to EPA TCLP Method 1311 and the California WET procedure. Three (20 µm, 5µm, and 1µm) filter cartridges were shipped directly to TriMatrix Laboratories, a certified laboratory selected by NSF. TriMatrix used Method SW 846 6010 for Ag, As, Ba, Cd, Cr, Cu, Pb, Ni, Se, Zn and Method SW 846 7470a for Hg to test the waste filter cartridges.

3.8.4 Chemical Samples Shipped Off-Site for Analyses

All samples were collected for laboratory analysis according to the procedures specified in the appropriate *Standard Methods* or EPA methods. Samples were collected and stored on ice during staffed operation. At the end of staffed operation, the samples were transferred to a UAA laboratory refrigerator, where the refrigerator temperature was monitored and maintained at 2-4°C. Temperatures were monitored whenever new samples were added to the storage. The temperature log is found in Appendix B. Once a week, samples were shipped on ice to NSF using priority overnight shipping services. Chain of custody sheets were stored with samples at all times. The methods used to analyze the samples are summarized in Table 3-3.

Table 3-3. Methods Used to Analyze Laboratory Samples

Parameter	Method Number	
	Standard Method	EPA Method
Total Alkalinity	2320 B	
Total Hardness	2340 C	
UVA	5910 B	
TOC	5310 C	
Iron		200.7
Manganese		200.8
Ozone[1]		
TDS	2540 C	
TSS	2540 D	
Arsenic[2]		200.8
TCLP/California WET	SW846-6010, SW846-7470a	
Sulfate		300.0

[1] Ozone was analyzed in the field using the HACH Indigo Accu-Vac method.

[2] Arsenic speciation was conducted as per the Battelle field ion exchange method included as Appendix D. Note that each lot of the arsenic speciation columns was checked against a standard sample with known concentrations of arsenic (III) and arsenic (V). A certified laboratory under contract with NSF prepared the standards. This laboratory shipped standard samples directly to UAA for resin column testing. NSF subsequently approved the use of UAA resin columns for the ETV test.

3.9 Corrective Action Plan

Table 3-4 summarizes the corrective actions that were performed during verification testing.

Table 3-4. Corrective Action Plan

Parameter	Acceptance Criteria	Corrective Action
Any duplicate analysis	≤10% difference	Resample duplicates, check instrument calibration, and recalibrate, if necessary.
Any method blank	Criteria set in EPA or *Standard Method* used for analysis (see Table 3-3).	Perform procedures specific to each analysis as per EPA or *Standard Method* shown in Table 3-3.
Any performance evaluation (PE) sample	Criteria set in EPA or *Standard Method* used for analysis (see Table 3-3).	Perform procedures specific to each analysis as per EPA or *Standard Method* shown in Table 3-3.
pH	≤10% difference	Check for feed water supply source change, resample duplicates, check instrument calibration, and recalibrate, if necessary.
Turbidity	< 5 NTU difference recorded from previous measurement for feed water < 1 NTU gain from previous measurement for treated water sample	Verify turbidity meter performance and status of sampling tap, verify fogging of sample cell had not occurred, recalibrate, and resample.
Temperature	> 20% change from previous reading	Check for change in feed water source.
Alkalinity, hardness, TOC, UVA, Iron, Manganese, TDS, TSS	Criteria set in EPA or *Standard Method* used for analysis (see Table 3-3).	Perform procedures specific to each analysis as per EPA or *Standard Method* shown in Table 3-3.

3.10 Operations and Maintenance

UAA reviewed the O&M manual provided by DISI (Appendix A) and evaluated its applicability during the verification test. This review included an assessment of the appropriateness of the material for the pumps, filters, ozone generator, and instrumentation on the treatment system, as well as the tanks, piping, and filter vessels. UAA also evaluated the manual to determine if the instructions for proper operation of the CampWater system are appropriate. The elements evaluated included:

- Starting and shutting down the system;
- Settings and adjustment on the ozone generator;
- Control of filtration rate;
- Control of recycle;
- Changing filters and returning the unit to service; and
- Filter selection.

3.11 Quality Assurance Project Plan (QAPP)

The Quality Assurance Project Plan (QAPP) for the verification project specified procedures that were used to ensure data quality and integrity. The data quality parameters that were established for the verification test included:

- *Representativeness*: degree to which the data accurately and precisely represent the conditions being evaluated;
- *Accuracy*: difference between the experimentally determined sample result and the accepted reference (or standard) value;
- *Precision*: measure of the random error associated with individual measurements;
- *Statistical uncertainty*: amount of variation around the mean; and
- *Completeness*: amount of data collected from a measurement process compared to the amount that was expected to be obtained.

The policies and procedures that were used to ensure that these data quality parameters were evaluated appropriately are presented in the following sections.

3.11.1 Data Representativeness

The following procedures ensured representativeness of the data collected during the verification project.

- A single location for sampling the feed water and one for sampling the effluent were identified after setup, and all water quality samples were drawn from these locations throughout the project. Sample collection times were noted on the daily log sheets.
- NSF supplied all of the containers for water quality samples analyzed at their laboratory. These sample containers were transported to SWM in a cooler complete with ice pack and chain of custody forms.
- The operators noted the time of sampling for any on-site analysis on the daily data sheets as well as on the chain of custody forms that accompanied the samples for off-site analysis.
- The sampling schedule in Table 3-2 was strictly adhered to so that sufficient data for evaluating process performance were collected.
- The operators checked the operating condition of the test skid daily and recorded their observations on the daily checklist.

3.11.2 Data Accuracy

Data accuracy was ensured by adopting the following combination of verification and calibration procedures.

- Instrumentation used in daily water quality analyses was calibrated at least once every week. Before analyzing a sample on-site, a check standard was analyzed to determine if the instrument was calibrated (i.e., if the standard value was within +/- 10% of the calibrated value). If not, the instrument was recalibrated before analyzing the water quality sample. The results of all check standards and calibrations were recorded by the UAA staff and included in Appendices B and C.
- Flow rates indicated by the system instrumentation were verified once every day using a stopwatch and a volumetric container.
- The pressure gauges used on the test skid were verified prior to initiation of verification testing by comparing gauge readings with factory-calibrated pressure gauges.
- The NSF laboratory prepared, labeled, and shipped all required sample bottles in a sealed cooler to UAA for each sampling event. Chain of custody forms were completed for each set of samples and included in Appendix E.
- Accuracy for spiked samples and recovery for laboratory control analyses were performed by the NSF laboratory as part of their own QA/QC protocol. All samples performed within a satisfactory range.

3.11.3 Data Precision

Data precision was evaluated by calculating the standard deviation and percent relative standard deviation for replicate samples. All of the off-site water quality analyses had one set of samples collected in triplicate during Phase A (see analytical schedule in Table 3-2). No duplicates or triplicates were collected during Phase C. The results of these triplicate samples were used to calculate a mean, a standard deviation, and a percent relative standard deviation.

$$\% \text{ Relative Standard Deviation} = S(100)/X_{avg}$$

Where: S is the standard deviation;
n is the number of samples;
X is the recovery value;
X_{avg} is the arithmetic mean of the recovery values; and

Standard deviation is defined as:

$$S = [(X_i - X)^2/(n-1)]^{0.5}$$

3.11.4 Statistical Uncertainty

The statistical uncertainty of the water quality analyses was evaluated by calculating the 95% confidence interval for samples collected eight or more times during the verification test period.

This included the following parameters: alkalinity, temperature, iron, manganese, hardness, total arsenic, ozone, ORP, and turbidity.

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

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

For a 95% confidence level, the equation becomes:

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

3.11.5 Completeness

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.

Completeness was defined as follows for all measurements:

$$\%C = (V/T) \times 100$$

Where: %C = percent completeness;
V = number of measurements judged valid; and
T = total number of measurements.

3.12 Health and Safety

The following health and safety procedures adhered to during the verification study ensured the safety of the operators and consumers served by SWM.

- The test skid was isolated from SWM’s normal water treatment process. As such, the performance of the verification study did not affect the treated water quality provided to the residents.
- Power to the CampWater system was provided by installing a dedicated breaker in the existing panel in accordance with current electrical codes.
- Excess ozone was vented to the atmosphere through a 1” vent hose that penetrated the building wall. This vent hose was checked each day to verify that it was free of ice or obstructions. In the event that the vent hose were to clog during unstaffed operation, backpressure would be created in the ozone contact chamber that would eventually stop flow through the system. Under no-flow conditions, the flow switch shown in Figure 2-1 would shut down the system.

- The cartridge filters were stored on-site until the waste disposal requirements were determined. The TCLP results, as presented in Table 4-6, showed that the spent cartridge filters could be disposed legally in the local landfill. Had the TCLP results shown differently, the spent cartridges would have been disposed through the ASET Laboratory process for hazardous waste.

Chapter 4
Results and Discussion

4.1 Introduction

ETV testing on the CampWater system occurred in three phases:

- Phase A was initiated on August 28, 2003. Start/stop operations were performed on the CampWater system for the first four days, and then the system was run continuously except for filter change-outs until September 13, 2003. The 48-hour start/stop period consisted of a 12-hour-on/12-hour-off schedule. The system was run for a total of 327 hours over the 17-day period. The system was operated using the natural feed water pH value of 7.9 and an ORP set point of 550mV.

- Phase B represents a series of runs conducted between October 11, 2003 and December 12, 2003 to understand the influence of pH and ORP on system performance. Six pairs of pH and ORP operating conditions were tested: pH 7.9/ORP 550 mV, pH 7.5/ORP 550 mV, pH 7.0/ORP 550 mV, pH 7.9/ORP 650 mV, pH 7.5/ORP 650 mV, and pH 7.0/ORP 650 mV. Since the system ran at pH 7.9 (natural pH) and ORP 550 mV during Phase A, the data from Phase A were used for that pair of conditions.

- Phase C was a 48-hour verification test of the CampWater system operated with an adjusted pH of 7.5 and an ORP set point of 550mV, which was the optimum pair of operating conditions established in Phase B. This phase was conducted over eight days, between February 17, 2004, and March 18, 2004.

The results of all three phases are summarized in this chapter according to the tasks developed for the verification test. Each task reports the relevant information from Phases A, B, and C:

- Task 1 - Verification Testing Phases
- Task 2 - Feed Water and Finished Water Quality
- Task 3 - Operating Conditions and Treatment Equipment Performance
- Task 4 - Arsenic Removal
- Task 5 - Data Management
- Task 6 - Quality Assurance/Quality Control

Copies of the data collected during the verifications test and supporting documentation are provided in the appendices. On-site daily log sheets and logbook pages are found in Appendix B. Laboratory analytical test reports, laboratory QA/QC documentation, and chain of custody forms are found in Appendix E.

4.2 Task 1 – Verification Testing Phases

Phase A

During the verification test Phase A, 72 feed water samples and 73 treated water samples were collected for total arsenic analysis. Six pairs of samples comprised of four triplicate analyses (two for feed, two for treated), of which the first data point of each triplicate was included in the summary statistical analysis. All samples were sent to NSF for analyses. System conditions during the tests were the following:

- Ozone was injected to maintain an ORP after the ozone contact chamber of 550mV;
- Target flow rate of treated water was 5gpm; and
- The pH of the water was not adjusted.

Phase B

Of the six possible pH/ORP pairs, five sets of pH/ORP conditions were each evaluated using a 6-hour test run in Phase B (the sixth set of conditions [pH 7.9/ORP 550 mV] is represented by data from Phase A). Because the original ORP controller had to be replaced in November, the results for the initial test under 650mV/pH 7.5 operating conditions were discarded and the test procedure was repeated.

A total of 31 sample pairs of feed and treated water were collected and analyzed for arsenic, iron, and manganese at all five operating conditions. Each of the five tests lasted approximately six hours. New filters were installed prior to the start of each test, and a minimum of five sample pairs were collected at each operating condition. On-site measurements of pH, ORP, and turbidity were taken concurrently with water samples. Flow rate was monitored to maintain constant flow. Instrument calibration, sample handling and storage, and system monitoring procedures outlined in the verification test plan were followed. All off-site analyses were conducted by NSF.

A ProMinent Dulcometer PHD pH controller was used to add muriatic acid (HCl) prior to the influent entry to the CampWater system. The controller was calibrated according to manufacturer's specifications and used to maintain the desired pH within an error of ±0.1. Tests were conducted using a pH range of 7.0–8 (natural feed water pH was assumed to be pH = 7.9). The ORP controller was adjusted to set the target ORP point, either 550mV or 650mV.

Phase C

A 48-hour verification run was conducted using the same testing procedures, sampling times, and QA/QC requirements used in Phase A. The intent was to conduct four, 12-hour start/stop cycles to verify the improved removal efficiency resulting from lower feed water pH (7.5) paired with an ORP set point of 550mV, which were the optimum conditions established in Phase B testing. However, due to the cold temperatures and the inability to discharge the treated water into the local storm sewer, UAA was forced to use a floor drain located within the well house. The capacity of the floor drain varied over the course of the test, accommodating anywhere from thee to nine hours of effluent disposal. A total of 29 feed water and 29 treated water samples were collected and analyzed for arsenic, iron, and manganese concentrations during Phase C. Two sets of arsenic speciation and other weekly water analyses were collected. All off-site analyses were conducted by NSF.

4.3 Task 2 – Feed Water and Finished Water Quality

Phase A

Table 4-1 contains the statistical summaries of measured feed water quality parameters for Phase A. Laboratory analyses of the feed water samples show an average concentration of 27 µg/L total arsenic and a soluble arsenic concentration of 18 µg/L. Speciation of soluble arsenic feed water samples resulted in an average of 4 µg/L arsenic (III) and 14 µg/L arsenic (V). The feed water contained an average of 0.62 mg/L iron and 670 µg/L manganese. Based on the data collected in Phase A, the source water contained an iron-to-arsenic weight ratio of 23:1 and a molar iron-to-arsenic ratio of 31:1.

Table 4-1. Phase A Feed Water Quality

Parameter	Number of Samples	Analysis Location	Units	Average	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Arsenic	72	NSF	(µg/l)	27	19	33	2.8	26 – 28
Soluble As	2	NSF	(µg/l)	18	16	19	N/A	N/A
As (III)[1]	2	NSF	(µg/l)	4	< 2	5	N/A	N/A
As (V)[2]	2	NSF	(µg/l)	14	14	14	N/A	N/A
Iron	72	NSF	(mg/l)	0.62	0.37	1.2	0.15	0.58 – 0.66
Manganese	72	NSF	(µg/l)	670	270	860	110	640 – 700
Total Alkalinity	17	On-site	(mg/l)	205	195	225	7.35	201 – 209
Total Hardness	16	On-site	(mg/l)	248	232	265	9.38	242 – 254
TDS	2	NSF	(mg/l)	300[3]	290	300	N/A	N/A
TSS	2	NSF	(mg/l)	4	3	4	N/A	N/A
TOC	3	NSF	(mg/l)	2.2	2.0	2.4	N/A	N/A
UVA	2	NSF	(cm^{-1})	0.085	0.066	0.104	N/A	N/A
Sulfate	2	NSF	(mg/L)	16	14	17	N/A	N/A
Turbidity	68	On-Site	(NTU)	3.6	1.6	13	1.7	3.1 – 4.0
Turbidity Days 1-12	53	On-Site	(NTU)	3.6	1.8	13	1.9	3.0 – 4.2
Turbidity Days 13-17	15	On-Site	(NTU)	3.2	1.6	4.8	0.90	2.7 – 3.8
pH[4]	59	On-Site	--	7.88	7.15	8.16	N/A	N/A

N/A = Standard Deviation and 95% Confidence Interval calculated on data sets of eight value or more.

[1] The value of analysis' LOD was used to calculate statistical information when a value was non-detect.

[2] No direct measurement. Calculated by subtracting arsenic (III) values from soluble arsenic values.

[3] Average value reflects 2 significant figures.

[4] The median is reported for the pH data, not the mean.

Table 4-2 contains the statistical summaries of measured treated water quality parameters for Phase A. Laboratory analyses show an average concentration of 18 µg/L total arsenic remaining in the treated water samples.

Table 4-2. Phase A Treated Water Quality

	Number of Samples	Analysis Location	Units	Average	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Arsenic	73	NSF	(µg/L)	18	8	27	4.3	17 – 19
Soluble As	2	NSF	(µg/L)	15[2]	14	15	N/A	N/A
As (III)[1]	2	NSF	(µg/L)	< 2	< 2	< 2	N/A	N/A
As (V)[2]	2	NSF	(µg/L)	13[2]	12	13	N/A	N/A
Iron[1]	73	NSF	(mg/L)	0.16	< 0.02	0.41	0.15	0.11 – 0.20
Manganese	73	NSF	(µg/L)	200	23	540	160	160 – 250
Total Alkalinity	17	On-site	(mg/L)	205	195	215	6.48	201 – 209
Total Hardness	17	On-site	(mg/L)	247	230	264	9.98	241 – 253
TDS	2	NSF	(mg/L)	310[3]	300	310	N/A	N/A
TSS[1]	2	NSF	(mg/L)	< 2	< 2	< 2	N/A	N/A
TOC	3	NSF	(mg/L)	2.2	2.0	2.4	N/A	N/A
UVA	2	NSF	(cm^{-1})	0.025	0.023	0.028	N/A	N/A
Sulfate	2	NSF	(mg/L)	16	14	17	N/A	N/A
Dissolved Ozone[1]	17	On-site	(mg/L)	0.06	<0.01	0.24	0.06	0.02 – 0.09
ORP	123	On-Site	(mV)	542	375	592	31	536 – 548
Turbidity	75	On-Site	(NTU)	1.3	0.10	3.9	1.0	1.0 – 1.5
Turbidity Days 1-12	60	On-Site	(NTU)	1.5	0.20	3.9	0.90	1.3 – 1.8
Turbidity Days 13-17	15	On-Site	(NTU)	0.25	0.10	0.45	0.10	0.15 – 0.30
pH[4]	59	On-Site	--	7.86	7.67	7.98	N/A	N/A

N/A = Standard Deviation and 95% Confidence Interval calculated on data sets of eight value or more.

[1] The value of analysis' LOD was used to calculate statistical information when a value was non-detect.

[2] No direct measurement. Calculated by subtracting arsenic (III) values from soluble arsenic values.

[3] Average value reflects 2 significant figures.

[4] The median is reported for the pH data, not the mean.

Figure 4-1 plots the turbidity measurements of both the feed and treated water during Phase A. Average turbidity for the feed water was 3.6 NTU, with a peak value of 13 NTU measured on the first day of start/stop operation.

Treated water turbidity averaged 1.3 NTU. However, a noticeable improvement in the treated water turbidity occurred in the last third of the testing period (e.g., from September 9-13, 2003). Prior to September 9, the nut used to seal the plate against the filter elements was inadequately tightened thus allowing untreated water to occasionally bypass the filter elements. After September 9, additional force was systematically applied to the nut to properly seat the top filter plate. The average turbidity of the treated water after the filter vessel was properly tightened (between September 9-13) was 0.25 NTU, compared to an average turbidity of 1.5 NTU in the treated water before the filter vessel was properly tightened (between August 28 and September 8). The iron concentration of the treated water also showed improved removal after September 9. The iron concentration prior to September 9 was 0.20 mg/L whereas the concentration after September 9 was 0.03 mg/L. No significant improvement in arsenic removal was recorded as a result of the change in operating procedure.

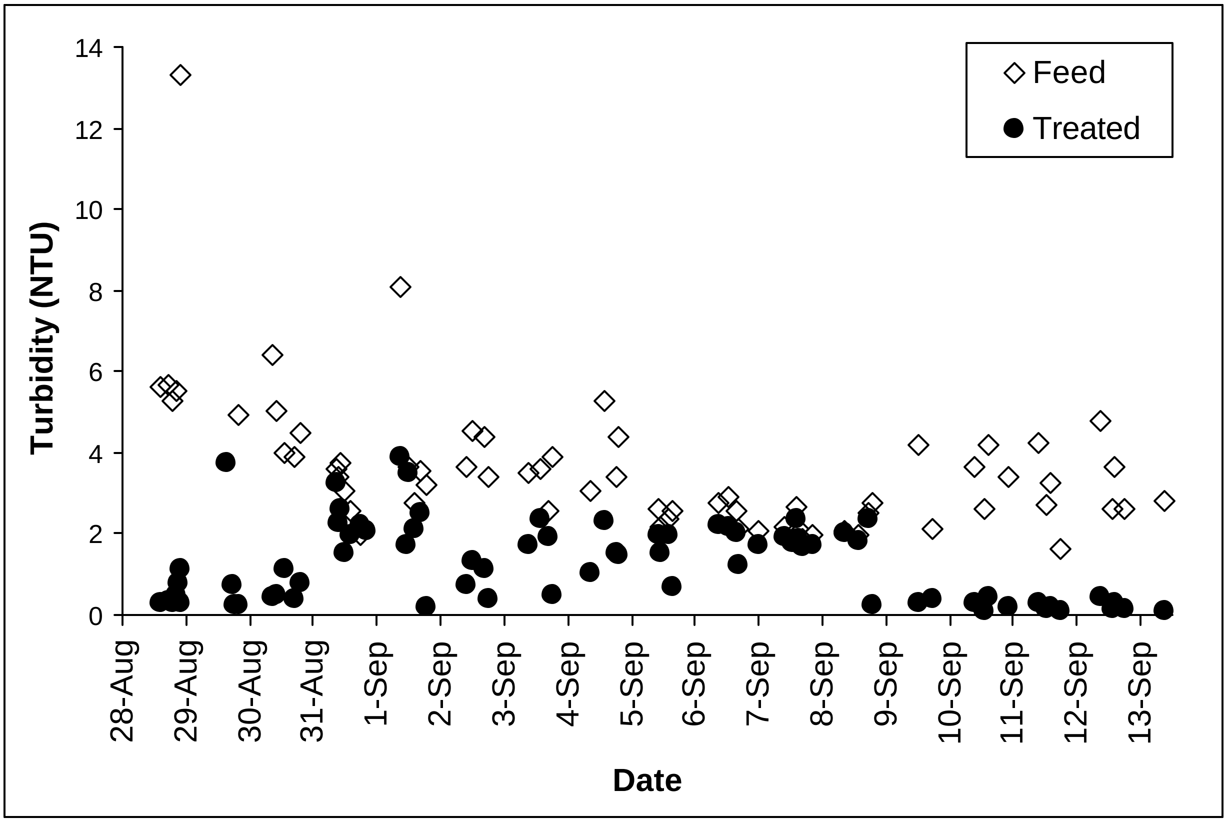

Figure 4-1 Phase A Turbidity of Feed and Treated Water.

Phase B

The arsenic concentrations in the feed and treated waters during Phase B are presented in Table 4-3. Reducing the pH to 7.5 (from pH 7.9) improved the arsenic removal efficiency in all operation conditions. Maintaining the ORP at 550mV but reducing the pH of the feed water stream to pH 7.5 produced the best removal efficiency of 77%. These conditions were selected to conduct the 48-hour start/stop verification run (Phase C).

Table 4-3. Phase B Test Series Results

	Number of Samples	Analysis Location	Units	Average	Minimum	Maximum	Removal Efficiency
pH 7.9/ORP 550mV (Phase A data)							
Feed Arsenic	72	NSF	(µg/l)	27	19	33	
Treated Arsenic	73	NSF	(µg/l)	18	8	27	33%
pH 7.5/ORP 550mV							
Feed Arsenic	5	NSF	(µg/l)	26	22	29	
Treated Arsenic	5	NSF	(µg/l)	6	4	9	77%
pH 7.0/ORP 550mV							
Feed Arsenic	5	NSF	(µg/l)	24	23	27	
Treated Arsenic	5	NSF	(µg/l)	11	8	16	54%
pH 7.9/ORP 650mV							
Feed Arsenic	6	NSF	(µg/l)	23	21	24	
Treated Arsenic	6	NSF	(µg/l)	7	6	8	70%
pH 7.5/ORP 650mV							
Feed Arsenic	5	NSF	(µg/l)	22	14	35	
Treated Arsenic	5	NSF	(µg/l)	9	6	11	59%
pH 7.0/ORP 650mV							
Feed Arsenic	6	NSF	(µg/l)	23	17	28	
Treated Arsenic	6	NSF	(µg/l)	9	7	13	61%

Phase C

Phase C testing was conducted at a feed water pH of 7.5 and an ORP set point of 550 mV. Table 4-4 and Table 4-5 contain the statistical summaries of measured feed and treated water quality parameters for the 48-hour verification run. Laboratory analyses of the feed water samples show an average total and soluble arsenic concentration of 18 µg/L and 10 µg/L, respectively. The average arsenic (III) concentration was <2 µg/L, and the average arsenic (V) concentration was 9 µg/L. Treated water produced during Phase C contained an average total and soluble arsenic concentration of 9 µg/L each. Arsenic speciation indicated that no detectable (<2 µg/L) arsenic (III) and 7 µg/L arsenic (V) were present in the treated water. The feed water contained an average of 0.51 mg/L iron and 540 µg/L manganese.

Table 4-4. Phase C Feed Water Quality

	Number of Samples	Analysis Location	Units	Average	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Arsenic	29	NSF	(µg/L)	18	13	25	3.1	17 – 20
Soluble As	3	NSF	(µg/L)	10	9	10	N/A	N/A
As (III)[1]	3	NSF	(µg/L)	< 2	< 2	< 2	N/A	N/A
As (V)[2]	3	NSF	(µg/L)	8	7	8	N/A	N/A
Iron	29	NSF	(mg/L)	0.51	0.04	1.0	0.25	0.40 – 0.62
Manganese	29	NSF	(µg/L)	540	260	780	147	480 – 600
Total Alkalinity	8	On-site	(mg/L)	180	155	240	29.1	151 – 209
Total Hardness	8	On-site	(mg/L)	244	228	280	17.2	227 – 262
TDS	2	NSF	(mg/L)	300	270	320	N/A	N/A
TSS	2	NSF	(mg/L)	4	3	4	N/A	N/A
TOC	2	NSF	(mg/L)	1.7	1.6	1.7	N/A	N/A
UVA	2	NSF	(cm^{-1})	0.0619	0.0510	0.0728	N/A	N/A
Sulfate	3	NSF	(mg/L)	13	13	14	N/A	N/A
Turbidity	36	On-Site	(NTU)	7.7	4.9	15.5	2.2	6.8 – 8.6
pH[3]	29	On-Site	--	7.44	7.21	7.62	N/A	N/A

N/A = Standard Deviation and 95% Confidence Interval calculated on data sets of eight value or more.

[1] The value of lab analysis' LOD was used to calculate statistical information when a value was non-detect.

[2] No direct measurement. Calculated by subtracting arsenic (III) values from soluble arsenic values.

[3] The median is reported for the pH data, not the mean.

Table 4-5. Phase C Treated Water Quality

	Number of Samples	Analysis Location	Units	Average	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Arsenic	29	NSF	(µg/L)	9	5	15	3.0	8 – 10
Soluble As	3	NSF	(µg/L)	9	6	12	N/A	N/A
As (III)[1]	3	NSF	(µg/L)	< 2	< 2	< 2	N/A	N/A
As (V)[2]	3	NSF	(µg/L)	7	4	10	N/A	N/A
Iron[1]	29	NSF	(mg/L)	0.04	< 0.02	0.19	0.04	0.03 – 0.06
Manganese	29	NSF	(µg/L)	51	2	130	36	35 – 67
Total Alkalinity	8	On-site	(mg/L)	174	145	190	15.1	158 – 189
Total Hardness	8	On-site	(mg/L)	229	213	248	11.3	218 – 240
TDS	2	NSF	(mg/L)	280	260	300	N/A	N/A
TSS	2	NSF	(mg/L)	< 2	< 2	< 2	N/A	N/A
TOC	2	NSF	(mg/L)	1.6	1.5	1.7	N/A	N/A
UVA	2	NSF	(cm^{-1})	0.0261	0.0225	0.0296	N/A	N/A
Sulfate	3	NSF	(mg/L)	15	13	20	N/A	N/A
ORP	42	On-Site	(mV)	559	399	782	83.9	529 – 590
Turbidity	36	On-Site	(NTU)	0.60	0.15	1.8	0.45	0.40 – 0.80
pH[3]	29	On-Site	--	7.41	7.20	7.59	N/A	N/A

N/A = Standard Deviation and 95% Confidence Interval calculated on data sets of eight value or more.

[1] The value of lab analysis' LOD was used to calculate statistical information when a value was non-detect.

[2] No direct measurement. Calculated by subtracting arsenic (III) values from soluble arsenic values.

[3] The median is reported for the pH data, not the mean.

Figure 4-2 plots the turbidity measurements of both the feed and treated waters over each of the eight days of start/stop operations during Phase C. Average turbidity for the feed water was 7.7 NTU, over twice the average turbidity of the feed water in Phase A. Treated water turbidity was consistently less than 1 NTU.

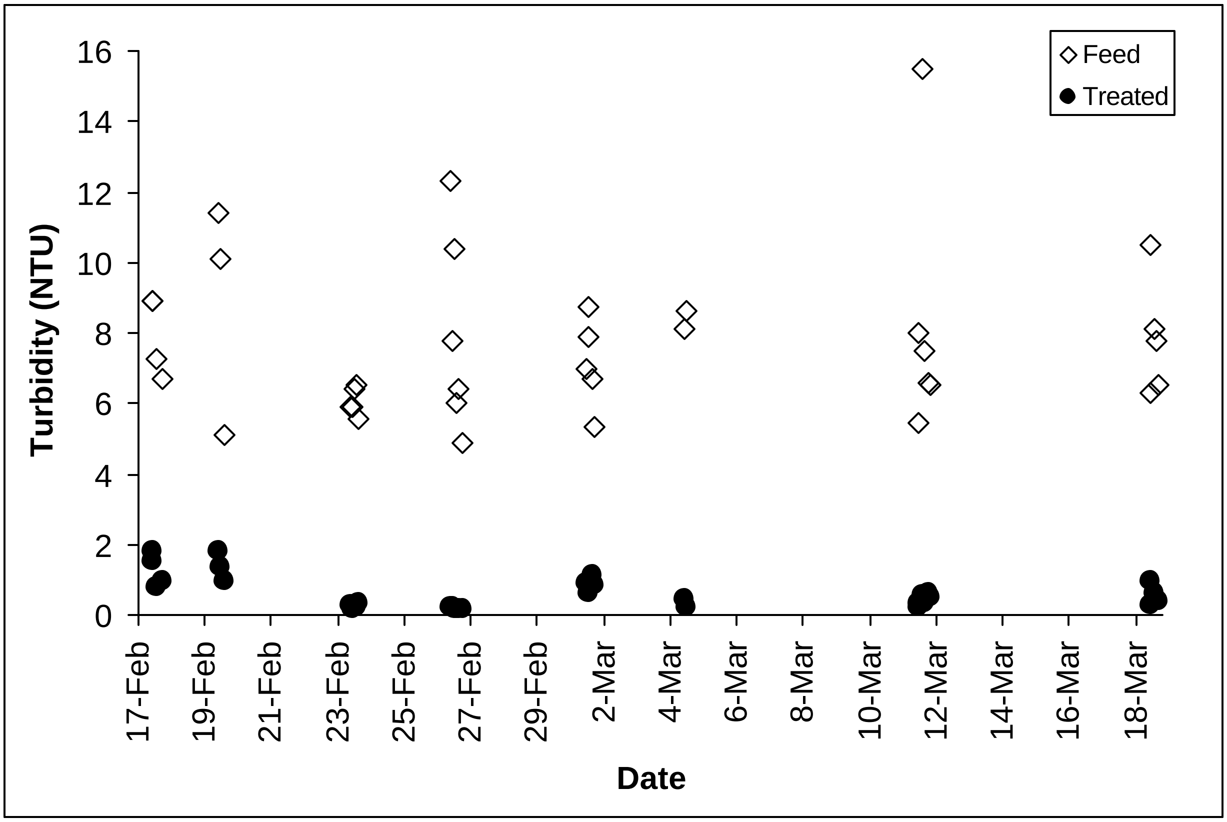

Figure 4-2 Phase C Turbidity of Feed and Treated Water.

4.4 Task 3 – Operating Conditions and Treatment Equipment Performance

During Phases A and C, there were no problems with the system operation, system equipment, or monitoring equipment. On the first day of Phase A, the main 480 volt 3 phase power supplying the well house was lost. The test start was delayed for several hours, but there was no damage or impact on any equipment. During an operational run of Phase B, the ORP controller failed. The equipment was replaced, and the data collected during the failed run was discarded.

Several operating conditions and equipment performance factors were monitored during the verification run. The results can be found in the daily log sheets in Appendix B and are summarized below.

4.4.1 Power Usage

A portable ammeter was used to measure the current drawn by the entire system at the 220-volt single phase 50Hz breaker. Separate measurements of both legs were collected and averaged on a daily basis. During Phase A, the average current draw was 6.64 amps with a standard deviation of +/- 0.36 amps.

At 220 volts and 6.64 average amps, 477 kWh were consumed over the 327 hours of Phase A, resulting in an overall energy consumption for the CampWater system of 6.3 kWh/1000 gallons treated.

4.4.2 Total Treated Flow

The total volume of water treated over the course of each phase was measured using a totalizing flow meter. The meter reading was recorded at the start and finish of each phase of testing. This reading was recorded on the daily log sheets. The total volume of water treated for Phase A was 75,525 gallons, calculated by subtracting the final meter value on September 13, 2003, from the initial reading on August 28, 2003. The total volume of water treated for Phase C was 12,430 gallons, which the sum of the volume of water treated during each day of start/stop operation.

4.4.3 System Flow Rates

The flow meter, which measured the treated water volume and flow rate, was verified once per day using a stopwatch and 2.5 gallon volumetric container. The verifications showed that the flow meter was accurately measuring flow rates over the duration of the test. Using the total treated volume and the total time of Phase A, the average flow rate was 3.85 gallons per minute. The average flow rate during Phase C was 4.25 gallons per minute. Because sample collection was initiated after a total of three detention periods had passed after the start of the start/stop periods, the actual duration of running the CampWater system was longer by at least four hours. Incorporating this time into the average flow rate calculation yields a more realistic flow rate of 3.93 gallons per minute.

4.4.4 Head Loss

The head loss was recorded across each of the filter canisters. The data cannot be summarized statistically since the values are dependent on flow rate, filter type, and filter run time. The measurements are recorded on the daily log sheets presented in Appendix B.

4.4.5 Ozone

Ozone production, off-gas ozone concentration, and the dissolved ozone in the water were measured once per day during Phase A. Ozone production and ozone off-gas concentration were measured once per day during Phase C. No measurements of ozone were performed during Phase B. To measure the ozone production, the system was stopped and the tubing connected to the venturi injector was redirected to the ozone monitor to measure the concentration, gas pressure, and gas temperature. To measure the off-gas ozone concentration, the off-gas vent was streamed through the monitor. Table 4-6 summarizes the average concentration of the ozone gas measurements during Phase A. All of the readings were collected and recorded on the daily log sheets presented in Appendix B.

Table 4-6. Ozone Measurements (Phase A)

	Number of Samples	Analysis Location	Units	Average	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Ozone Production	17	On-site	(% wt)	0.80	0.453	1.7	0.32	0.61 – 0.99
Air Flow Rate	15	On-Site	SCFH	6	3.5	8	1	6 – 7
Ozone Off-Gas	17	On-site	(% wt)	0.027	0.015	0.054	0.010	0.021 – 0.033
Dissolved Ozone[1]	17	On-site	(% wt)	0.06	< 0.01	0.24	0.06	0.02 – 0.09

[1] The value of lab analysis' LOD was used to calculate statistical information when a value was non-detect.

4.4.6 Ambient Parameters

The average feed water temperature during Phases A and C was 4ºC. However, the average air temperatures were lower during Phase C, which ran during February and March 2004, compared to Phase A, which ran during August and September 2003. The atmospheric pressure, dew point, and temperatures readings can all be found in the daily log sheets in Appendix B.

4.4.7 Qualitative Factors Evaluating System Reliability and Ease of Operation

There were few moving parts on the CampWater system that required monitoring or maintenance. Operators monitored effluent turbidity and canister pressure gauges to know when a filter change was needed. The ORP probe needed to be cleaned regularly, and the ORP controller should be monitored to make sure the system operates at the set ORP range. The system is small and can be set up to provide easy access to all components for routine maintenance. The level of skill required for efficient operation was low, and the system had a low-flow switch that would shut the pump down under unfavorable operating conditions.

Filters were replaced 12 times during Phase A, representing an average treated volume of 6294 gallons per filter set. The flow rate of the system decreased as the capacity of the filter cartridges was approached. All 12 filter cartridges were changed when the flow rate dropped (four of each 20µm, 5µm, and 1µm-absolute filter sizes) below 2.5 gpm in this test. A total of 144 filter cartridges were used during Phase A. The filter manufacturer claims that the filters can be washed and reused, which may reduce operating costs. However, this performance claim was not evaluated during the course of the verification test. The 20-µm filters and/or 5µm filters may have greater flow volume capacity and can be used longer than the 1µm-absolute filters prior to replacement. No tests were performed to evaluate this option.

Operators needed to tighten the top plate tightly against the filter elements to create a positive seal. Failure to achieve a tight seal showed an increase in turbidity and iron concentrations in the treated water, and could potentially impact the removal rates of other particulates.

4.5 Task 4 – Arsenic Removal

Phase A

Figure 4-3 plots the percent removal of total arsenic over the course of verification Phase A. The percent removal of total arsenic ranges from 10% to 63%, with an average removal efficiency of 33%.

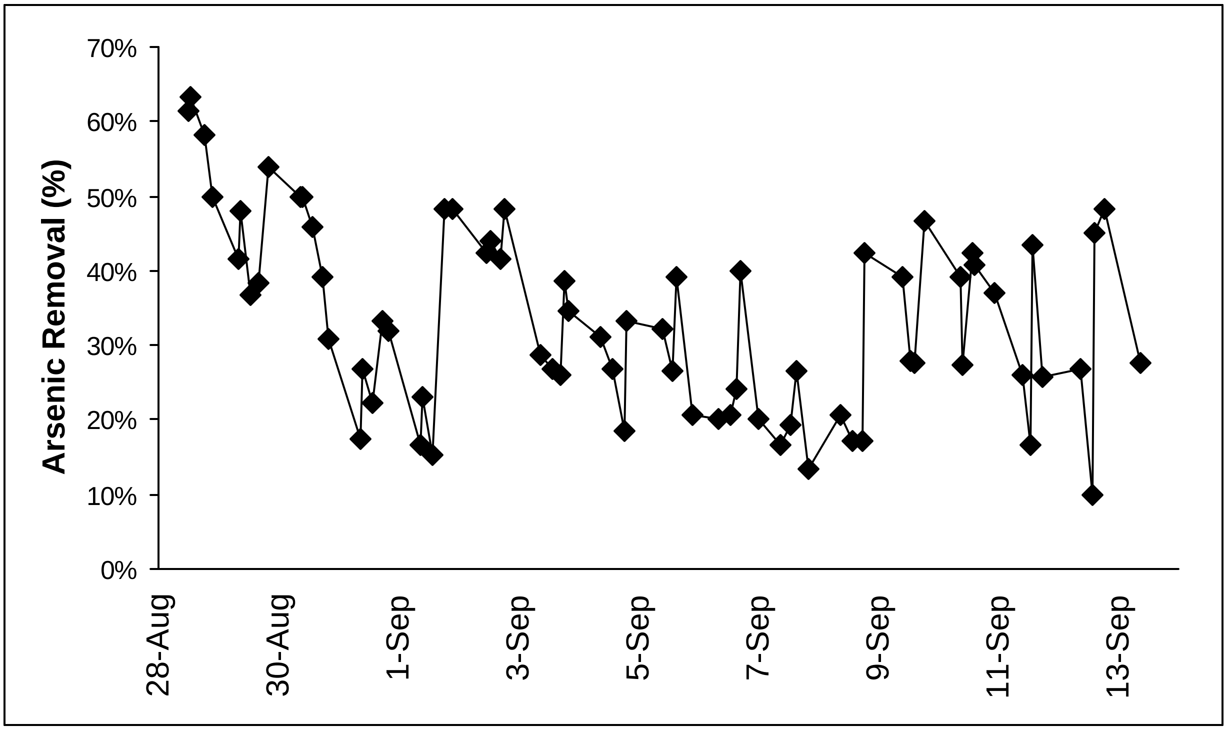

Figure 4-3: Phase A Total Arsenic Removal (%).

Figure 4-4 shows the feed and treated water total arsenic concentrations during Phase A. The feed water arsenic concentrations range from 19 to 33 µg/L, while the treated water arsenic concentration ranges from 8 to 27 µg/L.

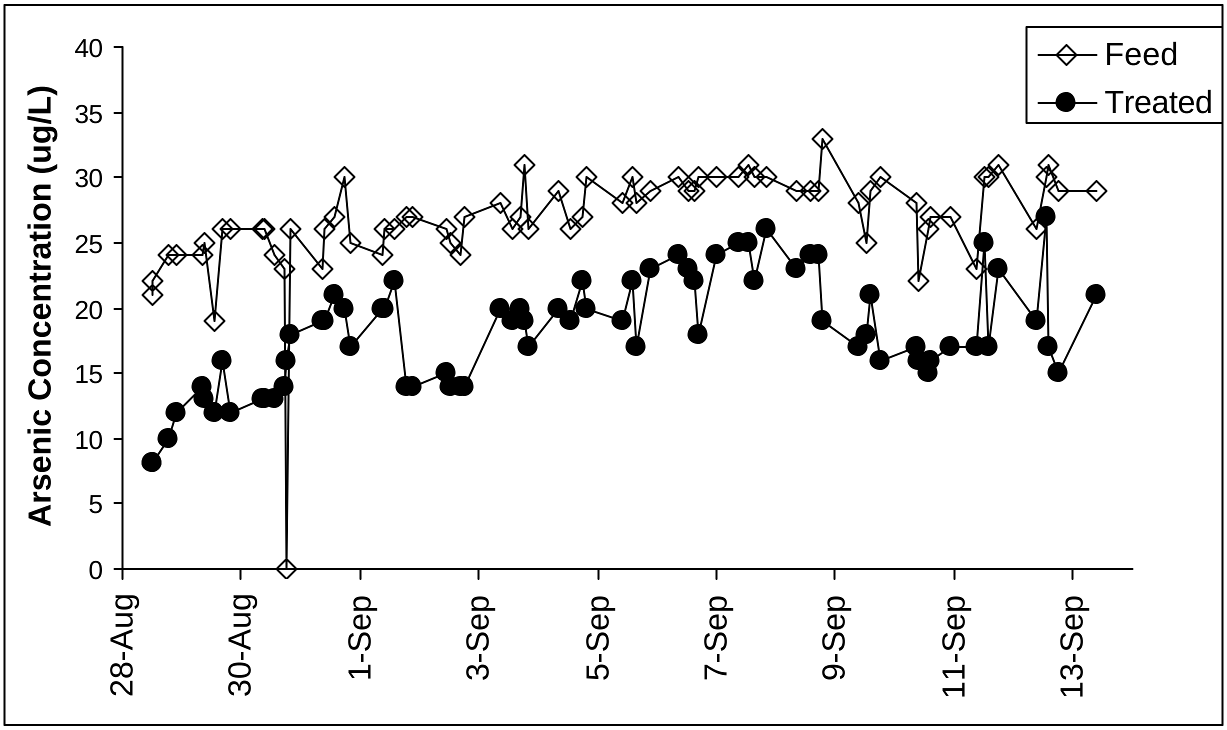

Figure 4-4: Phase A Total Arsenic Concentrations in Feed and Treated Waters.

Phase C

The average concentration of arsenic in the treated water during Phase C was 9 µg/L. Nine of the 29 treated water samples exceeded 10 µg/L arsenic. For three of the samples over 10 µg/L, low iron concentrations (0.04 and 0.08 mg/L) were measured in the feed water. Of the nine samples that exceeded 10 µg/L, six instances occurred when the iron-to-arsenic weight ratio of the feed water was under 20:1 (recommended weight ratio for co-precipitation of iron to treat arsenic, Sorg 2002).

Figure 4-5 shows the arsenic removal over the course of Phase C. The average removal efficiency of the CampWater system in operating conditions of pH 7.5 and ORP 550 mV was 50%. Figure 4-6 graphically displays the arsenic concentrations in both the feed and treated water samples during Phase C.

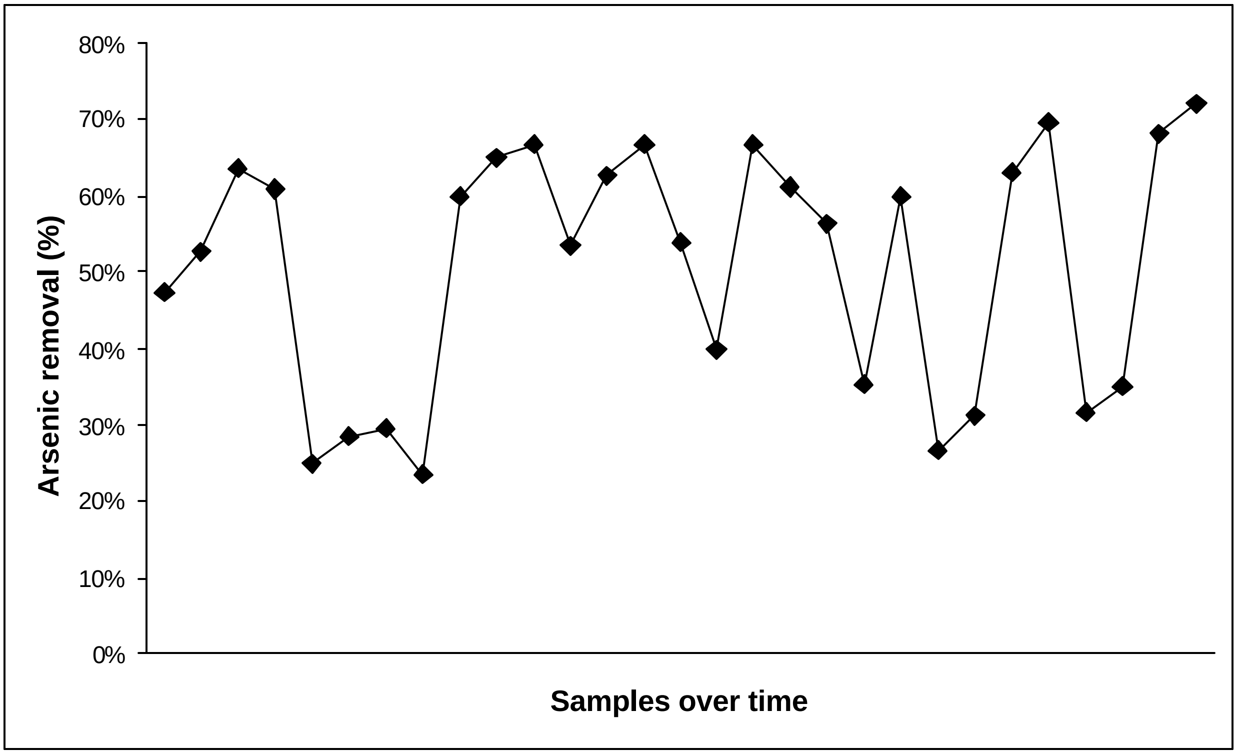

Figure 4-5: Phase C Total Arsenic Removal (%).

As previously described, the two 300-gallon storage tanks installed to feed the test unit were periodically filled by the well pump resulting in a storage period of up to three hours when the CampWater system was continuously operating and significantly longer storage periods (up to several days) under start/stop operations. Untreated water samples were collected after the storage tank and before entering the first filtration unit. During the storage period, iron present in the well water may have been oxidized more readily than reduced arsenic. The unknown extent of oxidation during storage prior to treatment could have affected the feed water quality to the treatment system.

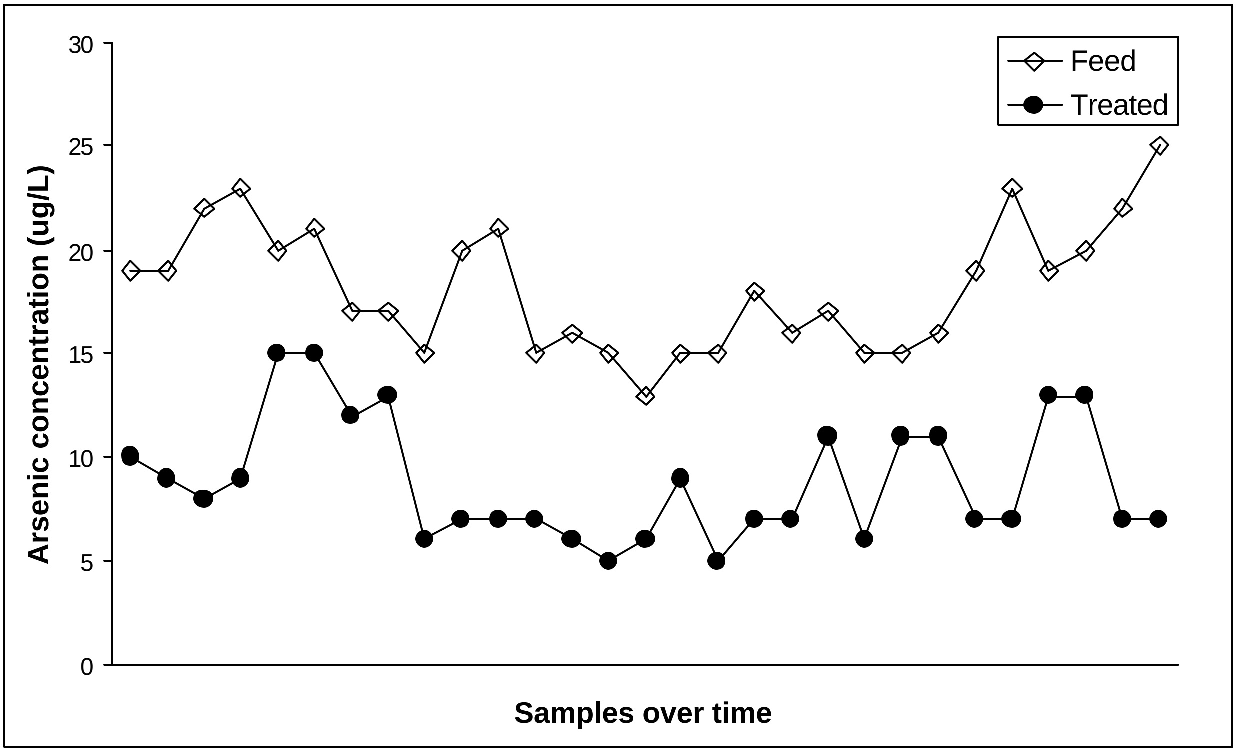

Figure 4-6: Phase C Total Arsenic Concentrations in Feed and Treated Waters.

4.6 Task 5 – Data Management

Data management for the verification test was accomplished using the procedures described in Section 3.7, including the use of daily log sheets and a site visit. UAA staff completed the daily log sheets provided in Appendix B each day of the ETV test. The data sheets were reviewed by the project manager and originals held in the UAA office.

4.7 Task 6 – Quality Assurance/Quality Control

Acceptable QA/QC of the verification test was accomplished using the procedures described in Section 3.8. Meter verifications, quantification of data precision and statistical uncertainty, and a summary of relevant notes that qualify study data are provided below.

4.7.1 pH meter Verification

The pH meter was calibrated daily with pH=4, 7, and 10 buffers. The calibration was then checked using the same pH=4, 7, and 10 buffers. All of the manually checked readings were within 3% of the calibrated value. On day 12 of Phase A, the pH was calibrated but only checked using the pH=7 buffer and on day 17 (final day), the pH meter calibration was not performed. During Phase B, the pH meter was calibrated but not checked during the run with no pH adjustment of the feed water and ORP at 650 mV.

4.7.2 Turbidity Calibration

The turbidimeter was calibrated using Primary StabilCal standards four times during the 17-day test period (Phase A), four times during Phase B tests, and five times during Phase C. Following calibration, secondary gelex standards of 0-10, 0-100, and 0-1000 NTU ranges were measured, recorded, and used to check the readings for subsequent calibration verifications. A StabilCal standard of NTU=1.0 was used to verify the lower turbidity range. The calibration verification readings (of the secondary standards of 0-10, 0-100, and 0-1000) never differed more than 2.2% from the set value for the gelex standards. The calibration verification of the 1.0 NTU standard showed more variance with the set value, but at most varied approximately 13%.

4.7.3 Thermometer

The in-line thermometer was not NIST-certified, nor was it calibrated or verified weekly against a NIST-certified thermometer during the verification testing. However, it was an industrial-grade thermometer that provided consistent readings between 3 and 5ºC during all phases of the ETV test.

4.7.4 ORP Probe

A new Cole-Parmer ORP probe was installed prior to the start of verification Phase A. The ORP probe was removed and calibrated against Ricca Chemical Company’s Zobell’s Solution at the start of the each phase and once each week. Each calibration was within 10% of the ORP value specified by the manufacturer of the ORP calibration solution. Therefore, the same probe remained in place for the duration of Phases A and B. The probe was replaced before the start of verification Phase C.

4.7.5 Ozone Monitor

An API 450M NEMA UV ozone monitor measured the generator ozone production rate and the rate of ozone off-gas from the contact chamber. Prior to the start of the ETV testing, API verified the monitor reading and provided a calibration certificate documenting monitor performance. Due to the historical stability of similar instruments, API suggested that calibration after the testing to certify readings was only necessary if the instrument failed or was under continual use for more than one year. Since the monitor provided stable readings over the course of the verification testing, UAA did not seek calibration confirmation after the testing was completed.

4.7.6 TCLP and California WET

Spent cartridge filters were sent to TriMatrix Laboratories, which conducted the TCLP and California WET tests on the material. Tables 4-7, 4-8, and list the laboratory findings for each filter type. In all cases, the filter waste passed the current TCLP regulatory limits for all tested metals. Therefore, the waste can be disposed legally in regular landfills in Alaska. The results show that all filter sizes failed the current California WET regulatory limit for arsenic waste. For states that use the WET test results for waste disposal, the filters would need to be processed as hazardous waste. Full laboratory results for the TCLP and California WET are found in Appendix E.

Table 4-7. TCLP and California WET Results for 1 micron Filters

1 micron	Analysis Type	Analytical Result (mg/L)	Reporting Limit (mg/L)	Regulatory Limit[1,2] (mg/L)
Arsenic	TCLP	ND[3]	0.20	5.0
Arsenic	WET	6.68	0.20	5.0
Barium	TCLP	1.08	0.20	100.0
Barium	WET	11.7	0.20	100.0
Cadmium	TCLP	ND	0.010	1.0
Cadmium	WET	0.026	0.010	1.0
Chromium	TCLP	ND	0.050	5.0
Chromium	WET	ND	0.050	5.0
Copper	TCLP	0.082	0.020	NA
Copper	WET	0.96	0.020	25
Nickel	TCLP	0.021	0.010	NA
Nickel	WET	0.10	0.010	20
Lead	TCLP	ND	0.10	5.0
Lead	WET	ND	0.10	5.0
Selenium	TCLP	ND	0.20	1.0
Selenium	WET	0.21	0.20	1.0
Silver	TCLP	ND	0.010	5.0
Silver	WET	ND	0.010	5.0
Zinc	TCLP	0.83	0.20	NA
Zinc	WET	2.48	0.20	250
Mercury	TCLP	ND	0.0002	0.2
Mercury	WET	ND	0.0020	0.2

[1] 40CFR261.24 Toxicity Characteristics.

[2] California regulations 66261.24.

[3] ND=Non-detect.

Table 4-8. TCLP and California WET Results for 5 micron Filters

5 micron	Analysis Type	Analytical Result (mg/L)	Reporting Limit (mg/L)	Regulatory Limit[1,2] (mg/L)
Arsenic	TCLP	ND[3]	0.20	5.0
Arsenic	WET	8.23	0.20	5.0
Barium	TCLP	1.19	0.20	100.0
Barium	WET	14.2	0.20	100.0
Cadmium	TCLP	0.013	0.010	1.0
Cadmium	WET	0.032	0.010	1.0
Chromium	TCLP	ND	0.050	5.0
Chromium	WET	0.051	0.050	5.0
Copper	TCLP	0.10	0.020	NA
Copper	WET	1.12	0.020	25
Nickel	TCLP	0.021	0.010	NA
Nickel	WET	0.12	0.010	20
Lead	TCLP	ND	0.10	5.0
Lead	WET	ND	0.10	5.0
Selenium	TCLP	ND	0.20	1.0
Selenium	WET	0.29	0.20	1.0
Silver	TCLP	ND	0.010	5.0
Silver	WET	ND	0.010	5.0
Zinc	TCLP	0.99	0.20	NA
Zinc	WET	3.77	0.20	250
Mercury	TCLP	ND	0.0002	0.2
Mercury	WET	ND	0.0020	0.2

[1] 40CFR261.24 Toxicity Characteristics.

[2] California regulations 66261.24.

[3] ND=Non-detect.

Table 4-9. TCLP and California WET Results for 20 micron Filters

20 micron	Analysis Type	Analytical Result (mg/L)	Reporting Limit (mg/L)	Regulatory Limit[1,2] (mg/L)
Arsenic	TCLP	ND[3]	0.20	5.0
Arsenic	WET	10.4	0.20	5.0
Barium	TCLP	1.12	0.20	100.0
Barium	WET	14.3	0.20	100.0
Cadmium	TCLP	0.013	0.010	1.0
Cadmium	WET	0.041	0.010	1.0
Chromium	TCLP	ND	0.050	5.0
Chromium	WET	0.053	0.050	5.0
Copper	TCLP	0.44	0.020	NA
Copper	WET	5.46	0.020	25
Nickel	TCLP	0.024	0.010	NA
Nickel	WET	0.17	0.010	20
Lead	TCLP	ND	0.10	5.0
Lead	WET	0.26	0.10	5.0
Selenium	TCLP	ND	0.20	1.0
Selenium	WET	0.38	0.20	1.0
Silver	TCLP	ND	0.010	5.0
Silver	WET	ND	0.010	5.0
Zinc	TCLP	0.69	0.20	NA
Zinc	WET	1.92	0.20	250
Mercury	TCLP	ND	0.0002	0.2
Mercury	WET	ND	0.0020	0.2

[1] 40CFR261.24 Toxicity Characteristics.

[2] California regulations 66261.24.

[3] ND=Non-detect.

4.7.7 Operations and Maintenance

The DISI O&M manual (Appendix A) adequately described the start-up and shutdown procedures for the CampWater system (summarized in Chapter 2 of this document). The operation of the ozone generator, the selection and replacement procedures for the filters, and control of the recycle and filtration flow rate were all covered and explained adequately to familiarize operators with the system functions. The procedure to determine appropriate filter replacement rates was also adequately described.

4.7.8 Data Precision

The results of the triplicate analyses conducted during Phase A to determine data precision and statistical uncertainty are summarized in Table 4-10 and 4-11. The tables are divided to reflect analysis of feed water and treated water separately. Each measurement contains the average, standard deviation, and relative standard deviation values obtained from the off-site water quality parameters during the verification study. One result for arsenic (III) from triplicate arsenic speciation of the feed water samples was under the LOD. Results for iron, arsenic (III), and TSS for treated water samples were all under the LOD. In these cases, the LOD was used as the value when performing calculations on these results.

The relative standard deviation of one set of feed arsenic (III) triplicate analyses was 46%. The concentrations of the samples were all under 5 µg/L, thereby resulting in a large relative standard deviation percentage when samples differed by only 1-2 µg/L.

Table 4-10. Statistical Analysis of Phase A Feed Water Triplicate Samples[1]

	Number of Samples	Analysis Location	Units	Average	Standard Deviation	Relative Standard Deviation (%)
Arsenic	3	NSF	(µg/l)	28	0.6	2%
Arsenic	3	NSF	(µg/l)	27	1.2	4%
Soluble As	3	NSF	(µg/l)	18	1.0	6%
As (III)	3	NSF	(µg/l)	3	1.5	46%
Iron	3	NSF	(mg/l)	0.54	0.02	3%
Iron	3	NSF	(mg/l)	0.48	0	0%
Manganese	3	NSF	(µg/l)	663	12	2%
Manganese	3	NSF	(µg/l)	650	26	4%
Aluminum[2]	3	NSF	(µg/l)	< 10	0	0%
TDS	3	NSF	(mg/l)	290	0	0%
TSS	3	NSF	(mg/l)	3	0	0%
TOC	3	NSF	(mg/l)	2.3	0	0%
UVA	3	NSF	(cm^{-1})	0.104	0.002	2%
Sulfate	3	NSF	(mg/L)	14	0	0%

[1] Two sets of triplicate analyses were collected for total arsenic, iron and manganese. Each statistical analysis was presented individually in the table.

[2] The value of lab analysis' LOD was used to calculate statistical information when a value was non-detect.

Table 4-11. Statistical Analysis of Phase A Treated Water Triplicate Samples[1]

	Number of Samples	Analysis Location	Units	Average	Standard Deviation	Relative Standard Deviation (%)
Arsenic	3	NSF	(μg/l)	17	0.6	3%
Arsenic	3	NSF	(μg/l)	17	1.0	6%
Soluble As	3	NSF	(μg/l)	16	0.6	4%
As (III)[2]	3	NSF	(μg/l)	< 2	0	0%
Iron[2]	3	NSF	(mg/l)	< 0.02	0	0%
Iron	3	NSF	(mg/l)	0.02	0	0%
Manganese	3	NSF	(μg/l)	40	1.5	4%
Manganese	3	NSF	(μg/l)	78	2.1	3%
Aluminum[2]	3	NSF	(μg/l)	< 10	0	0%
TDS	3	NSF	(mg/l)	300	0	0%
TSS[2]	3	NSF	(mg/l)	< 2	0	0%
TOC	3	NSF	(mg/l)	2.0	0.4	19%
UVA	3	NSF	(cm^{-1})	0.029	0.002	6%
Sulfate	3	NSF	(mg/L)	14	0	0%

[1] Two sets of triplicate analyses were collected for total arsenic, iron and manganese. Each statistical analysis was presented individually in the table.
[2] The value of lab analysis' LOD was used to calculate statistical information when a value was non-detect.

4.7.9 Completeness

Calculation of data completeness was made for on-site and laboratory water quality measurements. Tables of completeness data can be found in Appendix B.

Completeness of 82% was achieved for the feed and treated water pH measurements during the Phase A, which was below the 95% completeness objective outlined in the ETV protocol. The level of completeness for all other parameters either met or exceeded the completeness objectives. A few exceptions that occurred on specific days are discussed in 4.7.10.

4.7.10 Additional Data Qualifiers and Notes

Over the course of the verification study, there were a few issues to note. These included:

- NSF requested ORP and pH measurements to be taken at the same time as water samples, but the communication was not received until after verification testing had started. Correlated sampling time started on Day 4.
- The sample labels on a feed and treated water sample testing arsenic, iron, and manganese concentrations were switched on Day 13 of Phase A. The data were properly reported in the data tables in Appendix E.
- A review of the daily data sheets indicates that a full pH check was not completed on one day and a full pH calibration/check was not conducted on the final day of testing.
- During the site visit on Day 9 of the verification test, NSF noted that UAA staff members were not properly recording errors written on the daily data sheets or logbook notes. NSF

suggested using a single strike mark with operator initials to indicate data errors and corrections.

- During the Phase B series, the Hanna ORP controller failed and had to be replaced before testing could continue. A Hanna ORP model HI8720 was installed and utilized for the remainder of Phase B and Phase C.

Chapter 5
References

The following references were used in the preparation of this report:

Sorg, Thomas, *Iron Treatment for Arsenic Removal Neglected, Opflow: Reader Feedback*, November 2002.

*Standard Methods for the Examination of Water and Wastewate*r, 20th Ed. Washington, D.C., APHA, 1998.

U.S. EPA/NSF International. EPA/NSF ETV Protocol for Equipment Verification Testing for Arsenic Removal, April 2002.

Chapter 6
Vendor Comments

Delta Industrial Services, Inc. submitted the following comments concerning the ETV test and report. These statements were not validated in the verification test and are the opinion of Delta Industrial Services, Inc.:

"I believe this report significantly contributes to the understanding of the science of arsenic removal. The coprecipitation technology it evaluated has the stated advantages of economy and simplicity, and, as seen in the report, is effective when the ratio of iron-to-arsenic and the pH of the feedwater, and the process variables (e.g., ORP) are within certain limits. The specific benefit of this project that I see is that it helps quantify these limits. This in turn will assist in the proper application of this technology by engineers and regulators.

It is strongly suggested that further research be conducted to more precisely define the relationship between arsenic removal effectiveness and both pH and iron-arsenic ratio. This should include investigation of the various species of iron and arsenic, and the addition of iron if naturally - occurring iron is insufficient. Although TCLP results regarding the leachate were favorable, more research is needed to provide a method of meeting the California WET test. If Delta Industrial Services can assist in these efforts (such as the loan of a pilot plant), please contact us.

I wish to express my heartfelt thanks to all who made this project possible, including NSF, USEPA, the State of Alaska Dept of Environmental Conservation, Southwood Estates of Anchorage AK (the location of the trial runs), and the excellent staff at the University of Alaska Anchorage.

Delta Industrial does have filter-change data from earlier arsenic-reduction tests of the CampWater Porta-5. Following these tests, a design change was made which replaced the original cotton string-wound cartridges with a pleated inorganic design. Some data were subsequently obtained to prove the change, but the extent is very limited. Therefore, because a different style of filter cartridge was used in the [ETV] tests, the former data are not considered applicable and the results from the [ETV] program are the only significant recorded filter-change data on the unit in the present configuration. Reiterating the data from the [ETV] test, all the filters were changed when one or more sets were ready for replacement. This occurred at an average production of 6,294 gallons and cost approximately $82.40 (list price) for the complete change, resulting in a per gallon cost of 1.3 cents.

The CampWater Porta-5, as the name implies, was designed for remote camps, temporary remediation scenarios and emergencies. Therefore the design emphasis was more on portability and fast response and less on cost per gallon from factors such as filter changes. It follows that another design change would be in order for permanent installations where portability is no longer an issue, to decrease the cost of filter changes. In fact, Delta Industrial did design and produce a 40 gpm ozonation system utilizing 30-inch multi-media post-ozonation filters followed by 5 micron bag filters, for a permanent installation. Although arsenic was not a specific target in this application, iron was being effectively removed. In addition to backflushing the multimedia filters periodically, one of the bag filters was changed during tests, after one week's operation, at about 70,000 gallons. This bag lists for about $75, resulting in a per-gallon cost of about 0.1 cents. This indicates that coprecipitation of arsenic with the iron, if it were a contaminant in this application, could be effected at a much lower cost per gallon by going to the multi-media, followed by bag, filtration.

Very Sincerely, Jon Dufendach”