March 2001
NSF 01/26/EPADW395

Environmental Technology Verification Report

Removal of Arsenic

Watermark Technologies, LLC
eVOX® Model 5

Prepared by

NSF International

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

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE: **CHEMICAL COAGULATION/FILTRATION SYSTEM USED IN PACKAGED DRINKING WATER TREATMENT SYSTEMS**

APPLICATION: **REMOVAL OF ARSENIC**

TECHNOLOGY NAME: **eVOX® MODEL 5**

COMPANY: **WATERMARK TECHNOLOGIES, LLC**

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

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

NSF International (NSF) in cooperation with the EPA operates the Drinking Water Treatment Systems (DWTS) pilot, one of 12 technology areas under ETV. The DWTS pilot recently evaluated the performance of a Chemical Coagulation/Filtration system used in package drinking water treatment system applications. This verification statement provides a summary of the test results for the Watermark Technologies, LLC eVox® Model 5 Coagulation/Filtration System. Cartwright, Olsen & Associates, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the Watermark Technologies, LLC eVox® Model 5 Coagulation/Filtration System (Watermark eVox® Model 5) was conducted at the Park City, Utah, Spiro Tunnel Water Filtration Plant from April 11 to April 26, 2000. The source water was groundwater from an abandoned silver mine, representing one of the sources of drinking water for the City of Park City, Utah. Verification testing was conducted at the operating conditions specified by the manufacturer. Ferric chloride ($FeCl_3$) and sodium hypochlorite (NaOCl) were metered into the feedwater supply at a rate of 0.094 gallons per hour (gph) of 0.7% $FeCl_3$ and 0.005 gph of 0.42% of NaOCl to effect coagulation. When operated under the designed conditions at this site, the Watermark eVox® Model 5, removed each arsenic (As) species [total As, dissolved As and As (V)], from the feedwater supply to an average concentration of less than 4.7 µg/L.

TECHNOLOGY DESCRIPTION

The Watermark eVox® Model 5 uses ferric hydroxide [$Fe(OH)_3$] (converted from $FeCl_3$) to react with the soluble As to produce an insoluble precipitate that can be removed with a backwashing media filter. The Watermark eVox® Model 5 consists of metering pumps to feed $FeCl_3$ and NaOCl into the feedwater stream, a retention tank to facilitate coagulation, and a repressurization pump to feed coagulated water to a multi-media filter to continuously remove the precipitated As. The multi-media filter consisted of a 6” diameter column with a 6” depth of ¼” pea gravel, a 6” layer of 8 – 12 mesh course garnet, and a 24” layer of 60 mesh fine garnet. At four-hour intervals, a timer initiated a five-minute backwashing sequence utilizing raw water and consisting of a four-minute backwash at 20 gpm per square foot of surface area, followed by one minute for media settling.

The Watermark eVox® Model 5 is designed for small system applications; this sized unit would serve 15 – 20 people. The test unit is self-contained, skid-mounted and easily transportable by truck. The only connections required are an inlet line for pressurized feedwater, outlet line for filtrate, drain line for backwash water, and an electrical connection. The footprint of the unit is approximately 12 ft^2 (l.1 m^2).

VERIFICATION TESTING DESCRIPTION

Test Site

The verification testing site was the Park City Spiro Tunnel Water Filtration Plant in Park City, Utah. The source water was the Spiro Tunnel Bulkhead water, which is considered a groundwater source under the State of Utah source water protection program. Water is developed from water bearing fissures in an abandoned silver mine tunnel. A five-foot bulkhead built approximately two miles into the tunnel holds back the water and creates a reservoir. Water is piped from this reservoir to the treatment plant through a 12-inch diameter pipe. The water is considered stable with respect to quality and quantity, and is known to contain As.

Methods and Procedures

Temperature, pH, turbidity (both on-line and bench-top), and dissolved oxygen analyses were conducted on both the feedwater and filtrate streams at least once per day at the test site in accordance to *Standard Methods for the Examination of Water and Wastewater*, 18th edition (APHA, et. al., 1992). The State of Utah, Department of Health, Division of Laboratory Services performed analyses daily for alkalinity, antimony and speciated As [total, dissolved, As (III) and As (V)] on both the feedwater and filtrate streams. The As speciation procedure (see Appendix C of the Final Report) involved filling containers as follows: bottle A – as collected; bottle B – filtered through a 0.45µ filter; and bottle C – portion of the solution from bottle B run through an ion exchange resin for As (V) removal.

The Division of Laboratory Services also analyzed hardness, total organic carbon (TOC), UV254 absorbency, aluminum, iron (Fe), manganese, sulfate, and algae (chlorophyll A) on a weekly basis. These parameters were also measured on a more frequent basis during the verification performance where eleven sets of samples were collected over a 48-hour period.

VERIFICATION OF PERFORMANCE

System Operation

Verification testing was conducted under manufacturer's specified operating conditions. The flow rate of the system ranged between 1.0 and 1.1 gpm with a total backwash volume of 16 gallons produced every four hours during the backwashing operation.

The system initially operated for 24 hours without coagulation chemicals ($FeCl_3$ and NaOCl). At the end of this initial operation period, the metering pumps were activated and the coagulant chemicals of $FeCl_3$ and NaOCl were fed into the system. This coagulant addition continued, with only one brief interruption, for another 328.5 hours.

Evaluation of the required concentration of $FeCl_3$ necessary for optimum As removal was carried out by means of a simple series of jar tests conducted at the end of March prior to the initiation of the ETV testing period. Water from the Park City Bulkhead supply source was introduced into the Watermark eVox® Model 5 treatment equipment with increasing amounts of $FeCl_3$ added. The samples were then analyzed during the incremental addition of $FeCl_3$. The results were used to determine the $FeCl_3$ injection concentration for the ETV testing period at approximately 3 mg/L (as Fe).

The Watermark eVox® Model 5 was set to automatically backwash every four hours (based on a timer setting). The on-line turbidimeter alarm was set to initiate when the filtrate turbidity reached 0.5 NTU. Based on data gathered during initial operations, it was determined that the backwashing frequency should be every four hours. Backwash cycles were automatically initiated and controlled with a timer/controller. This frequency was maintained throughout the duration of the test.

Arsenic Removal

During initial operations, without coagulation chemicals, the media filter removed approximately 49% of the total As in the feedwater stream and approximately 11.5% of dissolved As was removed. Because Fe is present in the tunnel water, and this supply is exposed to the air, it is suspected that the resulting $[Fe(OH)_3]$ reacted with a portion of the total As in the feedwater stream forming the insoluble $[Fe(OH)_3]$ / As complex, which was almost 93% removed by the media filter.

During the test period, while coagulant chemicals were being fed to the feedwater stream, approximately 95% of the average total As concentration was removed by this system, with all but two of the filtrate concentration readings at 2 μg/L or less. The Watermark eVox® Model 5 removed approximately 89% of the average dissolved As in the feed water and all of the filtrate samples were at or below 4 μg/L, except for two instances. Almost all of the dissolved As was found as the As (V) species and this species was removed to an average of 4 μg/L in the filtrate. The As (III) species was detected near the detection limit (quantitative at 2 μg/L) in the feed water and at the qualitative detection limit (0.5 μg/L) in the filtrate. A summary of the concentrations of As species in both the feedwater and filtrate streams is presented in the following table.

Arsenic Data Summary (April 12 – April 26, 2000)
based on 22 samples

	Feedwater (µg/L)	Filtrate (µg/L)
Total Arsenic		
Average	77.6	4.1
Minimum	60.9	1.2
Maximum	146.0	34.5
Standard Deviation	16.8	8.5
95% Confidence	70.6, 84.6	0.6, 7.6
Dissolved Arsenic		
Average	42.0	4.7
Minimum	37.4	1.4
Maximum	45.9	32.6
Standard Deviation	2.5	7.5
95% Confidence	41.0, 43.1	1.5, 7.8
Arsenic (III)		
Average	2.5	0.7
Minimum	2.1	<0.5*
Maximum	3.6	1.0
Standard Deviation	0.4	0.2
Confidence Interval	2.4, 2.7	0.6*, 0.8
Arsenic (V)		
Average	39.5	4.0
Minimum	35.2	0.9
Maximum	43.8	31.6
Standard Deviation	2.6	7.4
95% Confidence	38.4, 40.6	0.9, 7.1

*All readings at the MDL for As (III) (<0.5 µg/L) were used as that number in calculations.

Note: the reliability of the low-level data (MDL of 0.1 µg/L to approximately 2 µg/L) should be considered only qualitative (not quantitative).

Iron Removal

Fe in the feedwater stream was at an average concentration of 0.268 mg/L and was consistently removed to below detection limits (<0.02 mg/L) in all samples collected.

Turbidity

Turbidity measurements made both with on-line turbidimeters and the bench-top instrument showed significant turbidity reduction by the Watermark eVox® Model 5 (in excess of 90%). On-line feedwater turbidity readings during the testing period averaged 1.51 NTU, compared to the bench-top turbidity average of 1.66 NTU. The on-line filtrate turbidity readings for the testing period averaged 0.060 NTU, compared to the bench-top average of 0.13 NTU. Although there was a lack of complete agreement between the instruments in the measurement of filtrate turbidity, the trend was consistent.

Operation and Maintenance Results

Testing was initiated at 16:30 hours on April 11, 2000, and except for approximately one hour on April 14 (when a new feed pump was installed), the system ran continuously until 09:00 hours on April 26, 2000. On April 20, 2000, a pinhole leak occurred in the $FeCl_3$ discharge tubing line from the metering pump, which was quickly repaired. On six occasions, the on-line turbidimeter alarm was initiated, signaling a filtrate turbidity reading exceeding 0.5 NTU. This always occurred during or immediately following the automatic backwashing activity, and the alarm shut off automatically within five minutes. It was concluded that this was due to the generation of turbidity during backwashing with incomplete settling and no rinse prior to the system returning to operation. By adjusting the backwashing sequence to allow for complete settling, this problem can be eliminated.

The electrical power used was 110VAC, single phase, 20A service. The power was recorded on an Amprobe Kilowatt/Hour (kWh) Meter (non-demand). The total power consumed was 359 kWh. The total quantity of filtrate produced was 23,265 gallons. Total quantity of NaOCl consumed was 0.13 gallons of 5.25% bleach. Total quantity of $FeCl_3$consumed was 0.67 gallons of a 32.5% $FeCl_3$ solution.

All of the sludge from the backwashing operations was collected in a drum, and over the 352.5 hours of the test, a total of 18.9 liters of a 1% solids concentration was obtained. This is equivalent to 2.1×10^{-6} gallons of sludge produced (100% basis) per gallon of filtrate produced.

Original Signed by
E. Timothy Oppelt *04/18/01*

E. Timothy Oppelt Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original Signed by
Gordon Bellen *04/27/01*

Gordon Bellen Date
Vice President
Federal Programs
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 a 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 March 30, 2000, the Verification Statement, and the Verification Report (NSF Report #01/26/EPADW395) are available from the following sources:
(NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.)

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

March 2001

Environmental Technology Verification Report

Removal of Arsenic from Drinking Water

Watermark Technologies, LLC
eVox® Model 5
Coagulation/Filtration System

Prepared for
NSF International
Ann Arbor, MI 48105

Prepared by
Cartwright, Olsen and Associates, LLC
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Under a cooperative agreement with the U.S. Environmental Protection Agency

Jeffrey Q. Adams, Project Officer
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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. CR 824815. This verification effort was supported by the Drinking Water Treatment Systems Pilot operating under the Environmental Technology Verification (ETV) Program. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release.

Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for NSF International (NSF) and the United States Environmental Protection Agency (EPA) by Cartwright, Olsen & Associates, LLC (COA) in cooperation with Watermark Technologies, LLC. The test was conducted during March and April of 2000 at the Spiro Tunnel Water Filtration Plant, Park City, Utah.

Throughout its history, the EPA has evaluated the effectiveness of innovative technologies to protect human health and the environment. A new EPA program, the Environmental Technology Verification Program (ETV) was developed to verify the performance of innovative technical solutions to environmental pollution or human health threats. ETV was created to substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. Verifiable, high quality data on the performance of new technologies is made available to regulators, developers, consulting engineers, and those in the public health and environmental protection industries. This encourages more rapid availability of approaches to better protect the environment.

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

The ETV DWTS is being conducted by NSF with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division, Cincinnati, Ohio. It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the FTO.

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Abbreviations and Acronyms

APHA	American Public Health Association
AWWA	American Water Works Association
°C	Degrees Celsius
COA	Cartwright, Olsen and Associates, LLC
EPA	U.S. Environmental Protection Agency
ESWTR	Enhanced Surface Water Treatment Rule
ETV	Environmental Technology Verification
FOD	Field Operations Document
ft^2	Square foot (feet)
FTO	Field Testing Organization
gpm	Gallon(s) per minute
ICR	Information Collection Rule
L	Liters
µ	Micron(s)
µg/L	Microgram(s) per liter (ppb)
m^2	Square meter(s)
m^3/d	Cubic meter(s) per day
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MDL	Minimum Detection Limit
mg/L	Milligram(s) per liter
mL	Milliliter(s)
NIST	National Institute of Standards and Technology
NSF	NSF International, formerly known as the National Sanitation Foundation
NTU	Nephelometric turbidity unit(s)
PFW	Particle Free Water
ppb	Parts per billion (µg/L)
psi	Pound(s) per square inch
PVC	Polyvinyl chloride
QA	Quality assurance
QC	Quality control
SM	Standard Methods for the Examination of Water and Wastewater
SWTR	Surface Water Treatment Rule
TDS	Total dissolved solids
TOC	Total Organic Carbon
Ten State's Standards	Great Lakes-Upper Mississippi River Board of State Public Health and Environmental Managers, *Recommended Standards for Water Works.*
UV_{254}	Ultraviolet light absorbance at 254 nanometers
WEF	Water Environment Federation
WHO	World Health Organization

Acknowledgments

The Field Testing Organization, Cartwright, Olsen & Associates (COA), was responsible for all elements in the testing sequence, including collection of samples, calibration and verification of instruments, data collection and analysis, data management, data interpretation and the preparation of this report.

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Contact: Peter Cartwright, PE.

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

State of Utah
Department of Health
Division of Laboratory Services
46 Medical Drive
Salt Lake City, Utah 84113-1105
Phone: (801) 536-4204
Fax (801) 615-5311
Contact: Larry P. Scanlan, Environmental Scientist III

The Manufacturer of the Equipment was:

Watermark Technologies, LLC
12753 South 125 East
Draper, Utah 84020
Phone: (801) 816-1800
Fax (801) 816-0388
E-mail: info@watermarktechnologies.net
Contact: Mark Hashimoto

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

COA is especially indebted to the following individuals at the Spiro Tunnel Water Treatment Plant: John A. Lind, Assistant Public Works Director, Richard W. Hilbert, Assistant Public Superintendent, Leo

Williams for his invaluable assistance in monitoring and sample collection speciation, and Jay Glazier and Scott Clayburn for their assistance to Mr. Williams.

Mr. Larry Scanlan, Environmental Scientist, State of Utah, Department of Environmental Quality, Division of Drinking Water, deserves special recognition for obtaining and regenerating the anion resin used for arsenic speciation.

Dr. Zenon Pawlak, Chief of the Radiochem and Metals Lab, Division of Laboratory Services, was invaluable in his coordination of all laboratory analyses and processing of the resulting data. Wayne Pierce, Director of the Bureau of Environmental Chemistry and Toxicology, Division of Laboratory Services, is thanked for his able supervision of all analytical activities.

Chapter 1
Introduction

1.1 ETV Purpose and Program Operation

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

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NSF International (NSF) in cooperation with the EPA operates the Drinking Water Treatment Systems (DWTS) pilot, one of 12 technology areas under ETV. The DWTS pilot evaluated the performance of the Watermark Technologies, LLC, eVox® Model 5 Coagulation/Filtration System, which is a backwashable depth filtration system used in package drinking water treatment system applications. This document provides the verification test results for the Watermark filter system.

1.2 Testing Participants and Responsibilities

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

NSF International
Cartwright, Olsen & Associates, LLC
Watermark Technologies, LLC
State of Utah Division of Drinking Water Laboratory
U.S. Environmental Protection Agency
Park City Municipal Corporation, Spiro Tunnel Water Filtration Plant

The following is a brief description of each ETV participant and their roles and responsibilities.

1.2.1 NSF International

NSF is a not-for-profit standards and certification organization dedicated to public health safety and the protection of the environment. Founded in 1946 and located in Ann Arbor, Michigan, NSF has been instrumental in the development of consensus standards for the protection of public health and the environment. NSF also provides testing and certification services to ensure that products bearing the NSF Name, Logo and/or Mark meet those standards. The EPA partnered with NSF to verify the performance of drinking water treatment systems through the EPA's ETV Program.

NSF provided technical and primary quality oversight of the verification testing. NSF arranged an inspection of the field analytical and data gathering and recording procedures on April 17 and 18, 2000. NSF reviewed the Field Operations Document (FOD) to assure its conformance with the pertinent ETV generic protocol and test plan. NSF also conducted a review or this report and coordinated the EPA and technical reviews of this report.

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NSF International
789 N. Dixboro Rd.
Ann Arbor, MI 48105
Phone: 734-769-8010
Fax: 734-769-0109
Contact: Bruce Bartley, Project Manager
E-mail: bartley@nsf.org

1.2.2 Field Testing Organization

Cartwright, Olsen & Associates, (COA), a Limited Liability Company, conducted the verification testing of Watermark eVox® Model 5 Coagulation/Filtration System. COA is a NSF-qualified Field Testing Organization (FTO) for the Drinking Water Treatment System ETV pilot project.

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

COA conducted the onsite analyses and data recording during the testing. Oversight of the daily tests was provided by Peter Cartwright, of COA.

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1.2.3 Manufacturer

The treatment system is manufactured by Watermark Technologies, LLC, a water treatment company. Watermark Technologies, LLC is a small company based in Salt Lake City, Utah and is dedicated to the development and marketing of arsenic removal technologies.

Watermark was responsible for supplying a field-ready eVox® Model 5 Coagulation/Filtration System equipped with all necessary components including treatment equipment, instrumentation and controls and an operations and maintenance manual. Watermark was responsible for providing logistical and technical support as needed as well as providing technical assistance to COA during operation and monitoring of the equipment undergoing field verification testing.

Contact Information:
Watermark Technologies, LLC
12753 South 125 East
Draper, Utah 84020
Phone: (801) 816-1800 Fax (801) 816-0388
Contact: Mark Hashimoto, Chief Executive
E-mail: info@watermarktechnologies.net

1.2.4 Analytical Laboratory

All chemical analyses were performed by the State of Utah Division of Drinking Water Laboratory. These analyses were made under the direct supervision of Larry P. Scanlan, Environmental Scientist III.

Contact Information:
State of Utah Division of Drinking Water Laboratory
Phone: (801) 536-4204: Fax (801) 615-5311
Contact: Larry P. Scanlan, Environmental Scientist III
E-mail: lscanlan@dep.state.ut.us

The QA/QC manual for this laboratory is located in Appendix A.

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. CR 824815. This verification effort was supported by the Drinking Water Treatment Systems Pilot operating under the ETV Program. This document was peer reviewed for technical and quality control content by the EPA.

1.2.6 Park City Municipal Corporation, Spiro Tunnel Water Filtration Plant

Park City Municipal Corporation personnel performed non-supervisory labor associated with the operation and monitoring of equipment under direct supervision of Peter Cartwright. These activities included collecting operating data and collection of analytical samples and speciation of arsenic samples.

Contact Information:

Park City Municipal Corporation
445 Marsac Avenue
P.O. Box 1480
Park City, Utah 84060
Contact: Jerry Gibbs, Public Works Director
Phone: (435) 615-5310: Fax (435) 615-4904

The address of the testing site is:

Spiro Tunnel Water Filtration Plant
1884 Three Kings Drive
Park City, Utah 84060
Contact: Rich Hilbert
Phone: (435) 615-5321: Fax (435) 658-9022

1.3 Verification Testing Site

The site selected for challenge testing of the Watermark eVox® Model 5 Coagulation/Filtration System was the Park City Spiro Tunnel Water Filtration Plant, 1884 Three Kings Drive, Park City, Utah 84060.

The Park City Municipal Corporation has direct access to Spiro Tunnel Bulkhead water. This water source was used for verification testing. Historical (non-ETV verified water) data at the intake location are summarized in Table 1–1. A schematic of the Spiro Tunnel Water Filtration Plant is attached as Figure 1-1.

Table 1-1. Historical Spiro Tunnel Bulkhead Water Quality Parameters

Parameter	Minimum	Maximum
pH	7.3	8.2
Total dissolved solids (TDS) (mg/L)	520	660
Arsenic (Total As) (µg/L)	4	225
Turbidity (NTU)	1	4
Total alkalinity (mg/L as HCO_3^-)	17.4	152
Total hardness (mg/L)	420	680
Iron (mg/L)	0.07	2.7
Calcium (mg/L as Ca)	106	160
Chloride (mg/L)	1	10
Sulfate (mg/L)	259	450
Manganese (mg/L)	5	30
Antimony (µg/L)	6	12
Beryllium (µg/L)	<1	5
Cadmium (µg/L)	<1	5
Cyanide (µg/L)	<2	5
Nitrite (NO_2^-) (µg/L)	<0.01	<0.02
Nitrate (NO_3^-) (µg/L)	<0.02	8.15
Selenium (µg/L)	<1	<5
Thallium (µg/L)	<2	<500
Mercury (µg/L)	<0.02	<1.1

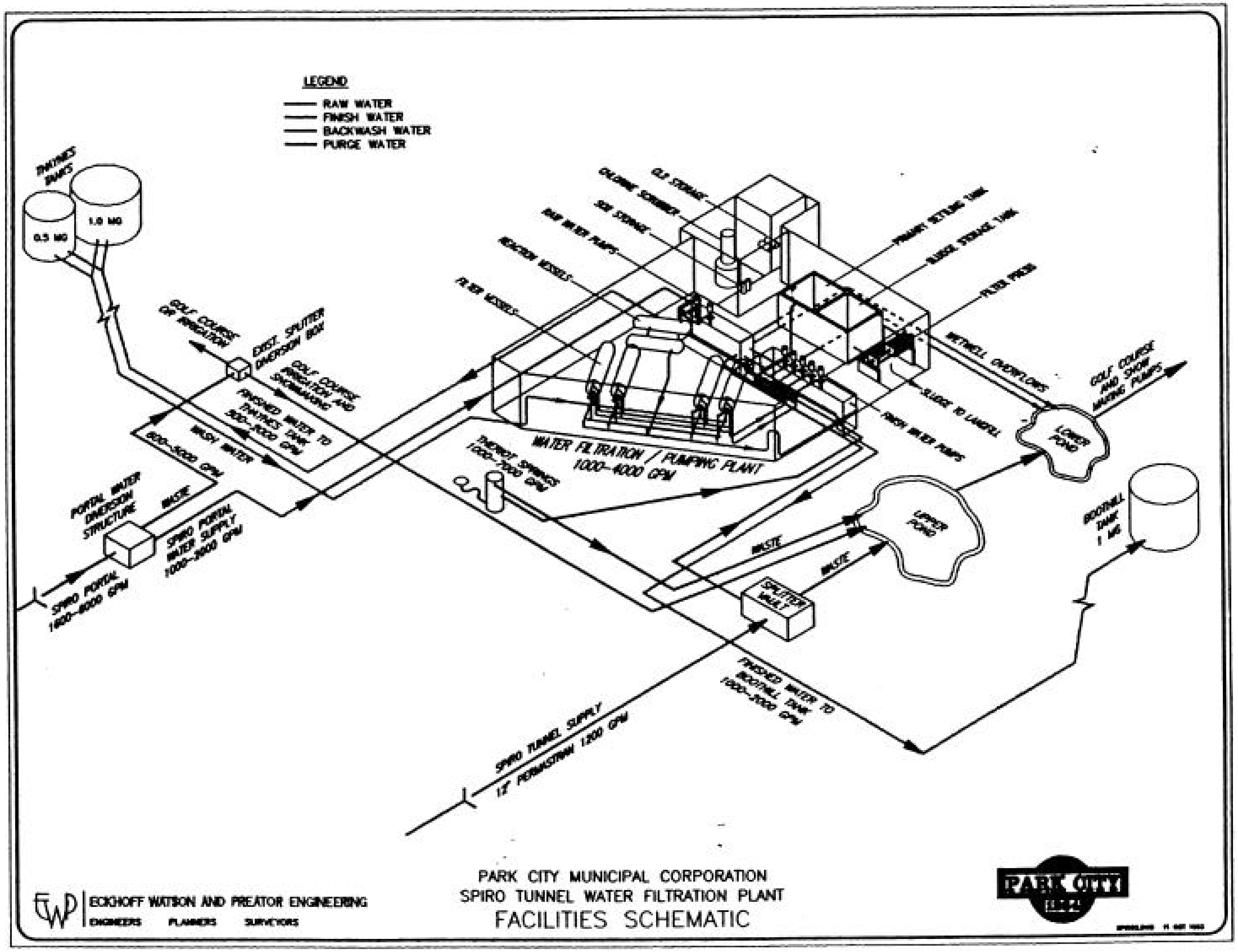


Figure 1-1. Schematic of Spiro Tunnel Water Filtration Plant

Influent water quality to the Watermark eVox® Model 5 Coagulation/Filtration System was verified and documented as a function of the Initial Operations tasks and are detailed in Chapter 4, Results and Discussions.

Backwash water generated during the verification testing was quantified, sampled and discharged to the Snyderville Sewer Improvement District. A discharge permit was not required.

1.3.1 Arsenic Chemistry

Arsenic is the 20th most abundant element in the earth's crust and is a component of over 245 minerals. Because the physical appearance of arsenic resembles that of a metal, it is classified as a metalloid and is located in group Va of the Periodic Table. It readily forms both oxide and sulfide compounds in the environment.

Arsenic also enters the environment as the result of both manufacturing and natural processes. Arsenic trioxide (As_20_3) is formed during smelting operations and has created significant air and land pollution problems. Arsenic also is released through the burning of certain fossil fuels and volcanic eruptions.

In natural waters, soluble arsenic is virtually always present in the oxidation states of either of +3(III) or +5(V) valence. An organic species (methylated) has been detected; however, concentrations of this organic compound rarely exceed 1 part per billion (ppb) and it is considered of little or no significance as a drinking water contaminant.

In oxygenated waters, the As (V) valence is dominant, existing in the anionic forms of $H_2AsO_4^-$**,** $HAsO_4^=$ and AsO_4^{-3}. In waters containing little or no oxygen (anoxic), As (III) exists in the nonionic form, H_3AsO_3 below a pH of 9.22, and the anionic form, $H_2AsO_3^-$ at a pH above 9.22.

1.3.2 Health Concerns

Arsenic has significant notoriety as a poison, even featured in a stage play, "Arsenic and Old Lace". Recent studies have indicated that arsenic in drinking water is more dangerous than previously thought, with risks to exposure comparable to that of radon and second hand tobacco smoke. In humans, ingested arsenic can cause liver, lung, kidney, bladder and skin cancers. Arsenite [As (III)] is significantly more toxic than arsenate [As (V)].

1.3.3 Regulatory

The newly established USEPA Maximum Contaminant Level (MCL) for arsenic in drinking water is 10 ug/L, with a Maximum Contaminant Level Goal (MCLG) of 0. The World Health Organization (WHO) has established a provisional arsenic limit of 10 ppb.

The Table 1-2 lists the properties of selected inorganic arsenic compounds.

Table 1-2. Selected Inorganic Arsenic Compounds

Property	Arsenic	Arsenic Trioxide	Sodium Trioxide	Sodium Arsenate
Synonyms	Arsenic black, colloidal arsenic, gray arsenic	Arsenic oxide, arsenious acid, arsenious oxide, white arsenic	Disodium arsenate, sodium biarsenate, arsenic acid disodium salt	Arsenious acid sodium salt, sodium metaarsenite
Chemical formula	As	As_2O_3 (As_40_6)	Na_2HAs0_4	$NaAsO_4$
Molecular weight	74.92	197.84	185.91	129.91
Valence state	0	3	5	3
Water Solubility	Insoluble	Soluble 37 g/L at 20°C. 101 g/L at 100°C	Soluble	Very Soluble

1.3.4 Water Source

The Spiro Tunnel Bulkhead source is considered a groundwater source under the State of Utah source protection program. It is located at N40° 41' 20.8" and W111° 31' 25.0". Water is developed from water bearing fissures in an abandoned silver mine tunnel at approximately 13,6000 feet into the tunnel, a five-foot high bulkhead has been constructed to hold back a quantity of water. This water exits the tunnel through a 12" diameter pipe at a flow rate of 1,150 gpm, and enters the treatment plant, which is located about 300 yards away. The tunnel is located 1,000 feet or more under remote unoccupied forest in a mountainous region, and the tunnel entrance is approximately 50 feet below the bulkhead. There is no use of manmade chemicals on ground above this source.

The water source used for this test is known as the Spiro Tunnel Bulkhead source, is stable with respect to quality and quantity. Because this water source contains arsenic, for the municipal supply, it is currently diluted with the treatment plant finished water to form a blend that meets the present arsenic standard. For this test, only the untreated, unblended Spiro Tunnel Bulkhead supply was used.

The filtration plant was built in February, 1993, has nominal capacity of 1,000 gpm, and is designed to remove iron, manganese, and arsenic from the raw water. This source is one of five active sources serving the municipality: 2 tunnels, 2 deep wells, and a spring. The water system serves 6,500 residents, and as much as 20,000 people per day during the winter season.

Spiro Tunnel Bulkhead water quality before treatment is listed in Table 1-1. These data are historical and not ETV verified. This table is a summary of water quality data contained in Appendix B.

Chapter 2

Equipment Description and Operating Processes

2.1 Historical Background

The highly respected filtration scientist, Appiah Amirthqarajah, once wrote, "It is ironic that filtration fails when pretreatment fails, and theory also fails when pretreatment fails." At the same time he commented, "Chemical pretreatment with particle destabilization is the single most important factor for the production of the best quality filtered water" (Amirtharajah, 1988).

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

Large water treatment systems have long employed coagulation, flocculation, settling and filtration for the production of quality water. Small systems have been more reluctant to build treatment plants that use coagulation because of the higher level of operator training required and the need for continuous monitoring. With the soon to be implemented Interim Enhanced Surface Water Treatment Rules (IESWTR), and revised arsenic MCL, coagulation may be a suitable technology for smaller systems allowing them to meet tough new standards with a modest increase in cost.

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

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

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

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

Of the several treatment regimens that incorporate coagulation are those that include a settling basin, where the floc is allowed to settle by gravity and the supernatant decanted and filtered. This is a scheme common to municipal gravity filter systems. The Watermark Coagulation and Filtration System is a Direct Filtration System, where the coagulant is added to the raw water in a constant stream, mixed in a mixing chamber, and then the solids separated through backwashable granulated media filtration. Because the process stream is slow (approximately 1 gpm), filtration can be accomplished with an off-the-shelf pressure vessel. The process rate of 1.1 gpm allows for a daily total of 1,584 gallons; thus it is well suited to small system requirements where waters must be treated to reduce arsenic levels.

Watermark Technologies, LLC has successfully piloted several filtration systems that employ coagulation as pretreatment.

The primary issue here was whether the Watermark eVox® Model 5 Coagulation/Filtration System could effectively reduce the total concentration of arsenic to meet the revised arsenic MCL of 10 µg/L.

The operation of this equipment is more technically sophisticated than a filter alone, and required more extensive training in the proper dosing of coagulating chemistry; therefore, the state and municipal health authorities may have requirements for operation beyond those of a filter. Watermark Technologies, LLC, requires no special licensing, and will offer operator training upon equipment installation and start-up.

The wastewater produced by the Park City Municipal Corporation is directed to the raw water wet well.

2.2 Equipment Description

This environmental technology verification (ETV) test is designed to challenge the Watermark eVox® Model 5 Coagulation/Filtration System to convert soluble arsenic into an insoluble precipitate and to remove the precipitate at flow rates of 1 gpm (5 gpm/ft^2). Watermark expected that the filter system would achieve a total arsenic concentration of less than 5µg/L, from an influent stream containing up to 90 µg/L of arsenic.

The Watermark eVox® Model 5 System included the following components, described in order of process water flow: Sodium hypochlorite injection into feed water supply via metering pump → Ferric chloride injection into feedwater supply via metering pump → On-line static mixer → Flow control → Retention tank → Repressurization pump → Filtration → Flow control.

The coagulant chemicals are chlorine plus ferric chloride, injected separately into the feedwater stream by LMI metering pumps, followed by a reaction module and holding reservoir to facilitate coagulation. The eVox® Model 5 Coagulation/Filtration System utilizes chlorine and ferric chloride ($FeCl_3$) to convert the arsenate to an insoluble precipitate which is removed by the multimedia filter.

The chemicals are thoroughly mixed in a chemical reaction module of proprietary design, and the retention tank (holding reservoir) is a 3.7 gallon cylindrical container. In the Park City Spiro Tunnel Bulkhead Municipal Water Supply, almost all of the arsenic is in the soluble arsenate (V) form (see ChemTech-Ford letter in Appendix B).

The multimedia filter vessel is six inches in diameter with a six inch deep base of ¼” pea gravel, 6” layer of 8-12 mesh coarse garnet, and a 24” layer of 60 mesh (0.25 mm) fine garnet.

Figure 2-1 is a schematic of the Watermark System and Figure 2-2 provides additional detail of the complete Watermark eVox® Model 5 Coagulation/Filtration System. Photograph 1 is a view of the Watermark eVox® Model 5 Coagulation/Filtration System and Photograph 2 illustrates the coagulant chemicals and metering pumps.

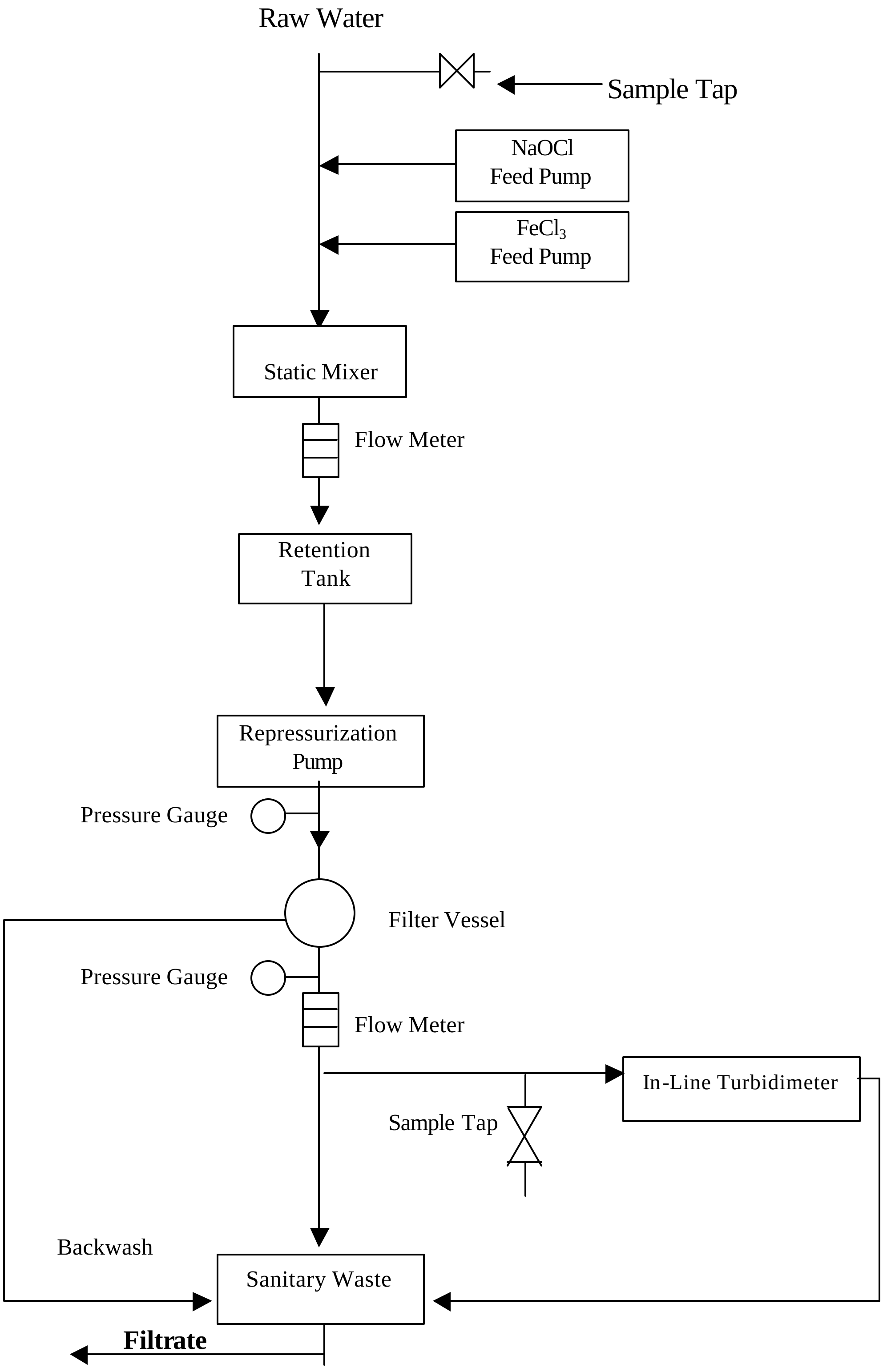


Figure 2-1. Watermark eVox® Coagulation/Filtration System Schematic

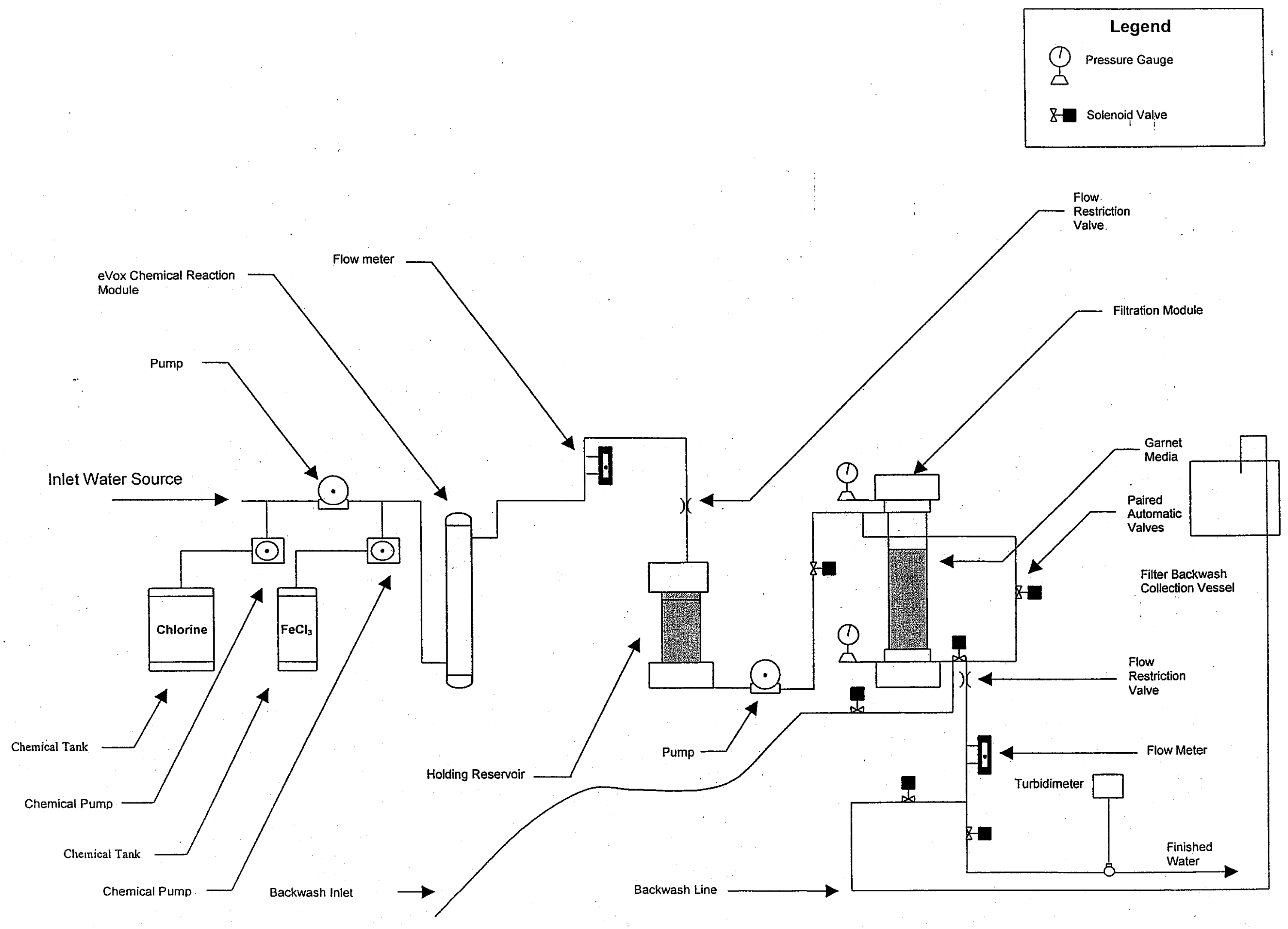
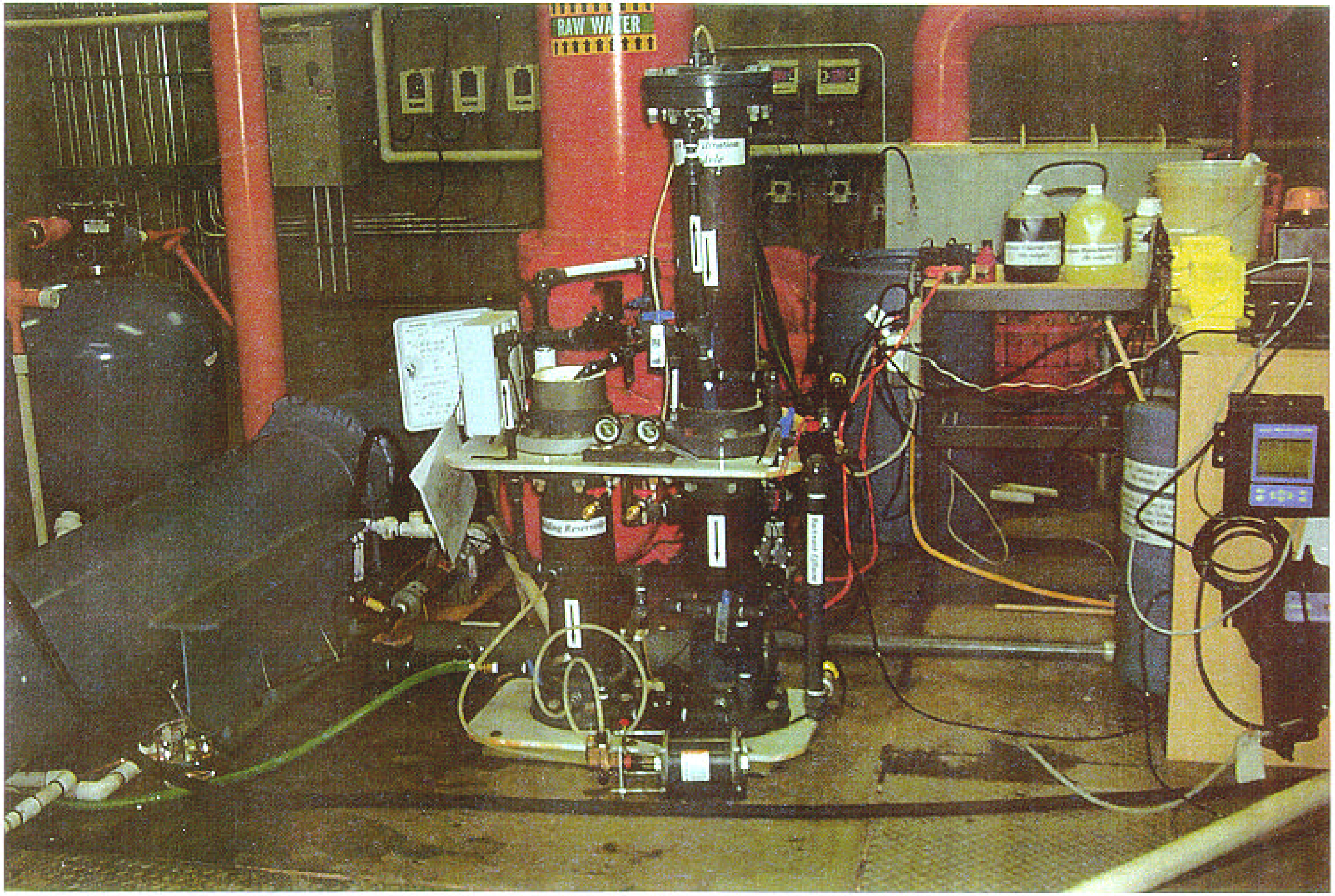


Figure 2-2. Illustration of the Watermark eVox® Coagulation/Filtration System



Photograph 1 – Front view of the Watermark eVox® Coagulation/Filtration System

Photograph 2 – View of the Watermark eVox® Coagulation/Filtration System

The Watermark eVox® Model 5 Coagulation/Filtration System is designed for small system applications. The tanks can be made of fiberglass or of steel. The piping is Schedule 80 PVC. Polyethylene or PVC tanks are used for the reaction tanks and to hold the coagulant chemicals.

Table 2-1 lists the maximum and minimum influent conditions.

Table 2-1. Maximum and Minimum Operating Conditions

Parameter	Unit
Inlet flow rate – maximum	1.1 gpm
Inlet flow rate – minimum	0 gpm
Maximum static pressure	100 psi
Minimum inlet dynamic pressure	30 psi
Maximum temperature	90°F (32°C)
Minimum temperature	35°F (1.7°C)
Maximum inlet turbidity	8 NTU

The Watermark eVox® Model 5 Coagulation/Filtration System will produce the following filtrate characteristics, as listed in Table 2-2.

Table 2-2. Watermark eVox® Model 5 Coagulation/Filtration System Filtrate Characteristics

Parameter	Unit
Expected pressure drop	5 psi
Minimum outlet pressure	25 psi
High pH	pH 9
Low pH	pH 6
Maximum temperature	90°F (32°C)
Minimum temperature	35°F (1.7°C)
Normal outlet turbidity	0.10 NTU
Maximum allowable outlet turbidity	0.50 NTU

2.3 Operating Process

The Watermark eVox® Model 5 Coagulation/Filtration System is designed to automatically backwash (with raw water) under any of the following conditions:

Effluent Turbidity	0.5 or greater (adjustable)
Run Time	4 hours (adjustable)
	By Manual Initiation

The usual backwash sequence based on run time is as follows:

Duration	Activity
1. 3 hours, 55 minutes	filtration
2. 4 minutes	backwash at 20 gpm/sq/ft bed area
3. 1 minute	system off while media settles

The Watermark eVox® Model 5 Coagulation/Filtration System assumes a finished water storage tank and intermittent flows, which are common to small system requirements. Several of the control functions can be initiated by sensors in the storage tank. One such is the return to on-line filtration, initiated when a storage tank reaches a pre-established low level. The verification study did not employ a storage tank as the system ran continuously during the verification period.

The Watermark eVox® Model 5 Coagulation/Filtration System claims to achieve an effluent stream containing less than 5 µg/L total arsenic from an influent stream containing up to 225 µg/L of total arsenic at a flow rate of 1.1 gpm (5.5 gpm/ft^2 filter bed surface area).

Following are the Watermark eVox® Model 5 Coagulation/Filtration System installation requirements:

• Room temperature range	50-120°F
• Voltage/frequency/amperage	120/220/480 v/60 Hz/ 30 amps
• Ceiling Height	8 feet

Chapter 3
Methods and Procedures

3.1 Experimental Design

This verification study was designed to provide accurate information regarding the performance of the Watermark eVox® Model 5 drinking water treatment system. Due to the unpredictability of environmental conditions and mechanical equipment performance, this document should not be viewed in the same light as scientific research conducted in a controlled laboratory setting.

3.1.1 Objectives

The verification testing was undertaken to evaluate the performance of the Watermark eVox® Model 5 System for arsenic reduction. Specifically evaluated were Watermark's stated equipment capabilities and equipment performance relative to the removal of arsenic to help communities meet the new MCL.

3.1.1.1 Evaluation of Stated Equipment Capabilities

This ETV study was undertaken to demonstrate the manufacturer's claim that the Watermark eVox® Model 5 System is capable of producing a filtrate stream containing a maximum of 5 µg/L total arsenic at a flow rate of 5-6 gpm/ft^2 filter bed surface area from an influent stream containing a maximum of 90 µg/L total arsenic.

3.1.1.2 Evaluation of Equipment Performance Relative To Water Quality Regulations

With the revised arsenic MCL established at 10 µg/L, with an MCLG of 0 µg/L, it is expected that the search for alternative arsenic removal technologies will grow significantly.

3.1.1.3 Evaluation of Operational and Maintenance Requirements

An overall evaluation of the operational requirements for the treatment system was undertaken as part of this verification. This evaluation was qualitative in nature. The manufacturer's Operations and Maintenance (O&M) manual, experiences, and events that occurred during the verification period were used to develop a subjective judgment of the operational requirements of this system. The O&M manual is attached to this report as Appendix C.

Verification testing also evaluated the maintenance requirements of the treatment system. Not all of the system's maintenance requirements were necessary due to the short duration of the testing cycle. The O&M manual details various maintenance activities and their frequencies.

3.1.1.4 Evaluation of Equipment Characteristics

The qualitative, quantitative and cost factors of the tested equipment were identified, in so far as possible, during the verification testing. The relatively short duration of the testing cycle creates difficulty in reliably identifying some of the qualitative, quantitative operational and cost factors. The quantitative factors examined during the verification were operational aspects of the Watermark eVox® Model 5 System, for example, the measurement of head loss, as well as other factors that might impact performance. The qualitative factors examined during the verification testing process included the dosing requirement of the coagulant chemical. Power consumption, waste disposal, and operations and maintenance issues, and the effect of each on the length of the operating cycle are also addressed. The operating conditions were recorded to allow reasonable prediction of performance under other, similar conditions.

3.2 Verification Testing Schedule

After Initial Operations, the Watermark eVox® Model 5 drinking water treatment was operated continuously for a minimum of 320 hours (the equivalent of 13 full days plus one 8-hour work shift) from April 12, 2000 until April 26, 2000. During this time, the coagulation and filtration package treatment equipment operated continuously from start-up until turbidity breakthrough or terminal head loss was attained. Interruptions in filtration occurred only as needed for backwashing of the filter.

The duration of each filter run and the number of gallons of water produced per square foot of filter area were recorded in the operational results.

During routine equipment operation, the package water treatment equipment was operated to meet the system demands and water quality requirements.

3.3 Initial Operations

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

Initial operations allowed Watermark to refine the unit's operating procedures and to make operational adjustments as needed to successfully treat the source water. Coagulant chemistry and optimum dosages were determined as well as the relationship between filtrate turbidity and total arsenic concentration in the filtrate.

The major operating parameters examined during initial operations were coagulant chemistry, filter loading rate, pressures and flow rates.

3.3.1. Water Quality Characteristics

3.3.2.1 Feed Water Characteristics

Specifically, the water quality characteristics that were recorded and analyzed were:

- Turbidity
- Temperature
- pH
- Total Alkalinity
- Total Hardness
- Total Organic Carbon
- Ultraviolet light absorbance at 254 nanometers (UV_{254})
- True Color
- Arsenic (concentration by species)
- Algae
- Iron
- Manganese
- Aluminum
- Sulfate
- Antimony
- Dissolved Oxygen

3.3.2.2 Water Quality Data Collection and Analysis

Although not required by the Test Plan and not stated in the FOD, analytical samples were collected daily from the influent (feed) and effluent (filtrate) streams and speciated in order for the State Laboratory to measure total arsenic, dissolved arsenic, As III and As V, as well as antimony. The arsenic speciation procedure is detailed in Appendix D; and involved filling containers as follows: bottle A – as collected; bottle B – filtered through a 0.45 μ filter; bottle C – portion of the solution from bottle B run through an ion exchange resin for As (V) removal.

Daily samples were taken beginning on April 11, during Initial Operations and through April 23. On April 24, Task 4 activities commenced, wherein 11 analytical samples were collected during a 48-hour period. The entire test was completed on April 26, 2000.

The parameters, which were analyzed as part of this testing and the sampling frequency, are presented in Table 3-1, Section 3.4. Daily on-site analyses were recorded in the Operations Logbook; semi-weekly analyses were recorded in the Operations Logbook and also recorded on separate laboratory report sheets. These data are summarized in Chapter 4, Results and Discussions, and the data spreadsheets are attached to this report as Appendix E.

Both the feedwater and filtrate streams were sampled for each parameter.

3.3.2 Initial Test Runs

Before runs were made in which chlorine and coagulant were used, the package plant equipment was operated with uncoagulated feed water for one 24-hour run. The samples were collected from the feed water and the filter effluent at 0, 6, 12, 18 and 24 hours of operation to determine if arsenic losses occur through the system.

3.3.2.1 Coagulant Chemistry

Optimization of coagulant chemistry is dependent on chemical composition and temperature of the source water. Accordingly, it was of critical importance that coagulant chemistry be studied and tested prior to performance verification. This was first accomplished with testing to identify suitable coagulant chemicals, dosage and contact time. Once this testing was complete, initial test runs were performed to both terminal head loss and turbidity breakthrough. The manufacturer utilized ferric chloride as the coagulant and used their test unit to optimize the $FeCl_3$ dosage. Sodium hypochlorite (NaOCl) was selected as the oxidant and the dosage of that chemical was optimized at the same time. Information on these Initial Operations activities is detailed in Appendix B.

3.3.2.2 Filter Loading Rate

Initial filter runs were performed to both terminal headloss and turbidity breakthrough. Total filtered water volume was measured and the character of finished water was evaluated throughout each filter run. Terminal head loss was established at 12-psi delta P across the filter. Turbidity breakthrough was considered reached when the turbidity in the effluent water was 0.50 Nephelometric turbidity unit (NTU). Backwashing using raw water was initiated manually when turbidity breakthrough occurred. Filters were backwashed until the waste stream ran clear, as determined by turbidity of 5 NTU or less. Filters were run in a rinse-to-waste cycle for a minimum of two bed volumes before a filter was returned to service. Filter service flow rate was established at 5.5 gpm/ft^2. Backwash flow rate was established at 20 gpm/ft^2, all within original manufacturer operating specifications for the equipment under test. Upon return to service, the filter ripening period was monitored and timed. These data were used to better understand time requirements for backwash, rinse and especially the expected duration of service run cycles during the testing and verification period.

A four-hour time interval was established for automatic backwashing throughout the duration of the test.

3.4 Verification Task Procedures

The procedures for each task of verification testing were developed in accordance with the requirements of the EPA/NSF Protocol for Equipment Verification Testing For Arsenic Removal (EPA/NSF, 2000) and approved in the FOD (dated April, 2000). The Verification Tasks were as follows:

- Task 1 - Verification Testing Runs and Routine Equipment Operation

- Task 2 - Feed and Finished Water Quality Characterization
- Task 3 - Documentation of Operating Conditions and Treatment Equipment Performance
- Task 4 - Arsenic Contaminant Removal Testing

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

3.4.1 Task 1 - Verification Testing Runs And Routine Equipment Operation

The objective of this task was to operate the equipment provided by Watermark for the 13.33 day period and assess its ability to meet water quality goals and other performance characteristics specified the Manufacturer.

Verification testing consisted of continuous evaluation of the treatment system, using the most successful treatment parameters defined in Initial Operations. After the Initial Operations period, the total verification testing was conducted over a period of slightly more than the required 13.33 days (320 hours). During this period, the feed water quality was consistent with the Manufacturer's statement of performance capability of the equipment. Feed water quality (turbidity and temperature) during this period ranged from 1.1 to 7.22 NTU (based on on-line turbidimeter readings), and 8.9 to 10.6°C.

Temperature, turbidity, other feed water quality parameters such as algae, natural organic matter, pH, alkalinity and hardness can influence coagulant chemistry and filtration. In order to offer a "worst case" challenge to the equipment under test, no attempt was made to lower the turbidity or raise the temperature of the incoming feed water.

The ETV protocol required the equipment to be run continuously with coagulant chemistry for 13.33 days. This period began on April 12, 2000 at 17:30 and the testing was completed on April 26, 2000 at 0900. During a 24 hour period immediately prior to this run, the system was operated without coagulant chemistry and analytical samples collected at time 0, 6 hours, 12 hours, 18 hours and 24 hours of operation to determine arsenic and antimony losses (if any) within the system. On-line coagulation chemistry was monitored by comparing turbidity levels measured at feedwater and filter effluent. The Watermark eVox® Model 5 System control functions allowed for differing conditions to indicate the requirement for backwash. These conditions included turbidity breakthrough, filter headloss and time.

Standard operating parameters for filtration, backwash, and coagulant feed were established through the use of the manufacturer's O&M Manual and during initial operations of the treatment system. The unit was then operated under those conditions and operational data were collected according to the schedule presented in Table 3-1.

3.4.2 Task 2 - Feed And Finished Water Quality Characterization

This task identified the water quality matrices of the influent water and effluent water and the composition of the removed particulate material, with the relationships to the terminal headloss and/or turbidity breakthrough point. This information was used to evaluate performance of the water treatment equipment relative to stated performance goals. Feedwater and finished water parameters were analyzed and recorded during the verification period according to the schedule in Table 3-1.

Table 3-1. Analytical Data Collection Schedule

Parameter	Facility	*Standard Methods*[1] Number or other method reference	EPA Method[2]	Minimum Frequency
Temperature (ºC)	On-site	2550 B		Daily
pH	On-site	4500-H^+ B	150.1 / 150.2	[3]
Total Alkalinity (mg/L)	Lab	2320 B		Daily
Total Hardness (mg/L)	Lab		200.7[4]	Weekly
Total Organic Carbon (mg/L)	Lab	5310 B		Weekly
UV_{254} Absorbance (cm^{-1})	Lab	5910 B		Weekly
Turbidity (NTU)	On-site	2130 B / Method 2	180.1	Daily
Aluminum (mg/L)	Lab		200.7	Weekly
Iron (mg/L)	Lab		200.7	Weekly
Manganese (mg/L)	Lab		200.7	Weekly
Suspended Solids in Backwash Water (mg/L)	Lab		160.2	Task 4
Algae (µg/l)	Lab	10200H		Weekly[5]
Sulfate (mg/L)	Lab		375.2	Weekly
Dissolved Oxygen (mg/L)	On-site	4500		Daily
True Color (TCU)	On-site	2120 B (Hach Company modification of *SM* 2120 measured in spectrophotometer at 455 nm)		Weekly
Arsenic Concentration and Species (µm)	Lab		200.8	Task 4
Antimony (µm)	Lab		200.8	Task 4

Notes:

[1] Standard Methods source: 18th Edition of Standard Methods for the Examination of Water and Wastewater, 1992 American Water Works Association.

[2] EPA Methods source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Services (NTIS).

[3] Once per 8 hours during runs with (when test system was staffed) no arsenic sampling. Each time arsenic samples were taken, coagulant water pH was measured.

[4] Calculated by adding together calcium and magnesium

[5] Weekly or once during each set of treatment conditions for which arsenic sampling was done.

All data collecting and analytical testing was performed in accordance with the procedures and protocols established in *Standard Methods for the Examination of Water and Wastewater,* 18th Edition *(SM)* or EPA approved methods. Water sampling ports were located on the feedwater supply and on the filter effluent.

Turbidity monitors were both continuous and bench. The continuous (on-line) turbidity meter was checked daily against a bench turbidimeter that was checked against turbidity standards. The bench turbidimeter was checked against secondary standards with each use. The turbidity instruments for this study included a HACH Model 17200 (on-line) and a HACH P2100 (bench).

Evaluation of water quality in this task was related to manufacturer's claims of performance for the Watermark eVox® Model 5 Coagulation/Filtration System, as stated in Section 3.1.1.1, Evaluation of Stated Equipment Capabilities.

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

During each day of verification testing while the equipment was staffed, operating conditions were documented. This documentation included description of pretreatment chemistry for coagulation and such treatment equipment operating data, as flow rate, pressure drop (filter head loss) and backwash frequency and volume.

Treatment equipment operating parameters for both pretreatment and filtration were monitored and recorded on a routine basis. Data on filter head loss and backwashing were also collected, as well as electrical energy consumed by the treatment equipment. Operational data were read and recorded for each day of the testing cycle. The operational parameters and frequency of the readings are listed in Table 3-2 below.

Table 3-2. Operational Data Collection Schedule

Operating Data	Action
Chemicals Used	Record on a daily basis. Type: supplier, commercial and dilution for stock solution to be fed.
Chemical Type, Feed Volume and Dosage	Check every two hours. Refill as needed, note volumes and time of refill. Maintain all calculations on coagulant chemical solution preparation and all data on coagulant chemicals as purchased from supplier or chemical manufacturer. Calculate the chemical dosage for each filter run in which arsenic challenge testing was carried out.
Feedwater Flow and Filter Flow	Check and record every two hours. Adjust when flow >10% above or below goal. Record flows before and after adjustment.
Filter Head Loss	Record initial clean bed total head loss at start of filter run. Record total head loss every two hours. Record terminal head loss at end of filtration.
Filtered Water Production	Record gallons of water produced per square foot of filter bed area for each filter run. (This figure is the product of filtration rate (gpm/ft^2) and length of filter run in minutes performed at a constant rate).
Filter Backwash	Record time and durations of each filter backwashing. Record water volume used to backwash filter.
Suspended Solids in Washwater	This requirement is replaced by the process of running all backwash water though a filter press and measuring total solids in the filter cake at the completion of testing.
Electrical Power	Record meter reading once per day.
Hours Operated Per Day	Record in logbook at end of day or at beginning of first shift on each following workday.

Note: All Parameters were checked only during times when pilot plant was staffed.

Manufacturer operating performance criteria to which collected data were compared are presented in Table 3-3.

Table 3-3 below summarizes the operational objectives of this ETV test.

Table 3-3. Filtration Performance Capability Objectives

Characteristic	Definition	Criteria
Initial turbidity	Filtrate turbidity at 15 minutes into run	0.1 NTU or less
Operating turbidity	Turbidity from matured filter	0.2 NTU or less
All turbidity	All data taken at equal intervals	0.3 NTU or less in 95% of all samples, or in all data from continuous turbidimeters
Time to reach turbidity breakthrough	Time to reach 0.5 NTU	4 hours minimum
Water production	Volume of water during a filter run	1,292.5 gallons per sq. ft. (258.5 gallons)

3.4.4 Task 4 - Arsenic Removal

The objective of this task was to evaluate arsenic removal during verification testing by measuring arsenic concentration naturally present in the feedwater as well as arsenic concentration in the filtrate. This portion of the study was of central importance, as it measured the effectiveness of the Watermark eVox® Model 5 Coagulation/Filtration System for arsenic removal.

A task involving a total of 48 hours of operation with collection of 11 arsenic and antimony samples was conducted to provide statistically verifiable arsenic removal data. This task was initiated immediately at the conclusion of the 279.5-hour Task 1 activity.

Water quality samples were collected from the plant feed water supply and the filter effluent water sampling ports. Samples were collected after the treatment plant had been in operation for a total of three (3) theoretical detention times (the theoretical detention time is the volume of water held in the treatment equipment divided by the rate of flow) as measured through the pretreatment process up to the filter. The theoretical detention time ranged from 50 to 70 minutes. Arsenic samples were collected at time zero and at 1, 3 and 6 hours past time zero. Thereafter arsenic samples were collected once every 6 hours thereafter until the filter run had lasted 48 hours from time zero. This resulted in collection of 11 sets of arsenic samples in a 48-hour filter run. During the sampling event, one 250-mL sample was collected at each sampling location and speciated on-site to allow Laboratory determination of total arsenic, dissolved arsenic, As (III) and As (V). Total chlorine concentration of the treated water was also measured at the same time each sample was collected.

3.5 Recording Data

The water quality parameters and operating data were maintained in the Operations Logbook. All readings were manually logged.

Also recorded were the following:

- Type of chemical added and concentration
- Water type (feedwater, filtrate)

Documentation of study events was facilitated through the use of logbooks, notebooks, photographs, data sheets and chain of custody forms. Data handling is a critical component of any equipment evaluation testing. Care in handling data assures that the results are accurate and verifiable. Accurate sample analysis is meaningless without verifying that the numbers are being entered into spreadsheets and reports accurately and that the results are statistically valid.

The data management system used in the verification-testing program involved the use of computer spreadsheet software and manual recording methods for recording operational parameters. The following describes how data were managed for each parameter.

3.5.1 Objectives

The objective was to tabulate the collected data for completeness and accuracy, and to permit ready retrieval for analysis and reporting. In addition, the use of computer spreadsheets allowed manipulation of the data for arrangement into forms, useful for evaluation. A second objective was the statistical analysis of the data as described in the "NSF/EPA ETV Protocol for Equipment Verification Testing for Arsenic Removal" (EPA/NSF 2000).

3.5.2 Procedures

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

3.5.2.1 Log Books

Data were collected by COA in bound logbooks, a laboratory notebook and on computer generated charts from the appropriate testing instruments. There was a single field logbook containing all on-site operating data, which remained on site and contained instrument readings, on-site analyses and any comments concerning the test run with respect to either the nature of the feedwater or the operation of the equipment.

Each page of the notebook was sequentially numbered and identified as Watermark ETV Test. Each completed page was signed by the on-duty FTO staff. Errors were crossed out with a single line and initialed. Deviations from the FOD whether by error or by a change in the conditions of either the test equipment or the water conditions were noted in the notebook. The notebook included a carbon copy of each page. The original notebook was stored on-site, and the carbon copy sheets retained by the FTO. This not only eased referencing of the original data, but offered protection of the original record of results.

3.5.2.2 Photographs

Photographs were taken with a camera and were utilized by COA to select the most appropriate photographs for this report.

3.5.2.3 Chain of Custody

Original chain of custody forms traveled with the samples (copies of which are attached as Appendix E).

3.6 Calculation of Data Quality Indicators

3.6.1 Representativeness

Water quality parameter samples were taken as indicated in Table 3-1. Off-site samples were collected in accordance with *SM* 1060B, held and preserved according to *SM* 5010, and delivered to the laboratory for analysis. On-site samples were taken utilizing *SM* 1060B sampling techniques.

3.6.2 Statistical Uncertainty

Statistical 95% confidence calculations were performed for arsenic data, and confidence intervals determined by taking three discrete samples of arsenic at one operating set during the testing period. Sampling requirements are noted below in the work plan below. The formula used for confidence calculations follows:

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

S = standard deviation
n = number of measurements in data set
t = distribution value with n-1 degrees of freedom
α = the significance level defined for 95% confidence as: 1- 0.95 = 0.05.

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

Statistical 95% confidence calculations were also performed for critical water quality data. The above confidence calculations were used for these water quality data, and results are presented in Chapter 4, Task 2, Feed and Finished Water Quality Characterization.

3.6.3 Accuracy

For water quality parameters, the accuracy referred to the difference between the sample result and the true or reference value. Care in sampling, calibration and standardization of instrumentation and consistency in analytical technique ensured accuracy.

The pressure gauges used were NIST-traceable standard gauges. Performance evaluation was established by calibration of instruments used on-site and by conformance to *SM* and EPA protocols.

3.6.4 Precision

Precision was the measure of the degree of consistency from test to test, and was assured by replication. In the case of on-site testing for water quality, precision was ensured by multiple tests and averaging; for single reading parameters, such as pressure and flow rates, precision was ensured by redundant readings from operator to operator. Travel blanks were not required for this testing.

3.7 Equipment

In order to assure data validity, the EPA/NSF Verification Testing Plan procedures were followed. This ensured the accurate documentation of both water quality and equipment performance. Strict adherence to these procedures resulted in verifiable performance of equipment. A summary of how the Watermark system testing and analytical equipment was operated during the verification testing is presented in this section.

3.7.1 Equipment Operations

The operating process for the Watermark eVox® Model 5 System is described in the Operations Manual (Appendix B), which was maintained on site.

In summary, the system works by the injection of sodium hypochlorite into the water stream followed by the injection of ferric chloride. The ferric chloride is oxidized by the sodium hypochlorite to ferric hydroxide. Based on studies by Clifford, et al, the arsenic removal mechanism can be modeled as an adsorption phenomenon. A ligand exchange process dominates, and in the presence of ionic arsenic, an arsenate ion replaces an hydroxide ion in the structure of the ferric hydroxide and this arsenic compound precipitates with the insoluble ferric hydroxide.

The insoluble ferric hydroxide is filtered out of the water stream by the multimedia filter, which is automatically backwashed, based on a timer interval or initiated by either turbidity breakthrough or terminal headloss.

Residence time to ensure a complete chemical reaction between the ferric chloride, sodium hypochlorite and arsenic ion was accomplished by a retention tank located between the chemical injection pumps and the filter unit. At the operating rate of 1.1 gpm, the residence time in the retention tank (holding reservoir) was 3.3 minutes.

3.7.2 Analytical Equipment

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

- A Hach 2100P portable turbidimeter (serial number 000100024023) was used for benchtop turbidity analyses. A Certificate of Conformance for this meter is located in Appendix F.
- Pressure gauge was a National Institute of Standards and Technology (NIST) traceable pressure gauge (Ametek Model number 1980L, Certification number 0084-6). There were two pressure gauge quick-connect fittings on the system, located on the inlet and outlet of the filter vessel. The Certificate of Calibration for this gauge is located in Appendix F.
- RadioShack Model No: 63-1009A indoor-outdoor thermometer was used for the measurement of temperature. This RadioShack thermometer was calibrated against a NIST-traceable Thermometer (Tel-Tru model 0054-5).
- A rotometer [(Blue and White model F40750-LN16 (0 to 10 gpm)] was used to measure flow rates.
- On-line turbidity measurements were taken with a HACH 17200 turbidimeter.
- Chlorine measurements were taken with a HACH 2010 spectrophotometer.
- Dissolved oxygen measurements were taken with a Hach "sension 8" dissolved oxygen meter, serial no. 990900000112.
- pH measurements were taken with an Oakton pH/mV/°C meter, part no. 35615-00.

3.8 QA/QC Procedures

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

3.8.1 QA/QC Verifications

Daily QA/QC Verifications included:

On-line turbidimeter readings standardized against a calibrated bench turbidimeter, which was calibrated against secondary standards with each use.
pH meter calibration was verified at pH 4, 7 and 10 with NIST-traceable pH buffers

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

Cleaning and re-calibration of on-line turbidimeters;
Pressure gauges with NIST-traceable gauge;
Inspection of turbidimeter tubing for unimpeded flow and integrity.

Calibration of test unit flow meter using "bucket and stopwatch" method. Although this activity was performed on April 26, 2000, in error, it was not recorded in the Laboratory Notebook.

Further descriptions of these verification procedures are provided below.

3.8.2 On-Site Analytical Method

Specific Instrumentation methods for on-site QA/QC accuracy were as follows:

3.8.2.1 pH

Analyses were made by *SM* 4500-H^+. A three-point calibration with NIST-traceable pH buffers was performed daily. Between tests, the pH probe was kept wet in KCl solution. For on-site determination of pH, field procedures were used to limit absorbance of carbon dioxide to avoid skewing results by poorly buffered water.

pH measurements do not lend themselves to "blank" analyses. Duplicates were run once a day. Performance evaluation samples were analyzed during the testing period. Results of the duplicates and performance evaluation were recorded. The unit was also calibrated against a standardized pH instrument in the State of Utah Laboratory and found to be within 5% accuracy.

3.8.2.2 Temperature

Temperatures were measured in accordance with *SM* 2550, at least once per day. The thermometer read in 0.1° C increments and calibrated by the State of Utah Laboratory as well as against a NIST-traceable thermometer.

3.8.2.3 Turbidity

The turbidimeters remained on during the duration of the testing period. On-line and bench top turbidimeters were used, and the bench top turbidimeter was the calibration standard for the test. Manufacturer's procedures for maintenance were followed and the schedules for maintenance and cleaning noted in the logbook. All glassware was dedicated and cleaned with lint free tissues to prevent scouring or deposits on the cells. The calibration of the bench-top turbidimeter (Hach 2100P) was verified on March 15, 2000, using Hach StablCal® Standards (Stabilized Formizin Turbidity Standards) of 800, 100, 20 and <0.1 NTU. On a weekly basis, the instrument calibration was verified using secondary standards of Hach Gelex measuring 526, 52.2 and 4.87 NTU. Another secondary standard, measuring 0.4 NTU was used to verify calibration before every use. *SM* 2130 was employed for measurement of turbidity.

3.8.2.4 True Color

True color was measured in accordance with *SM* 2120 at 455nm wavelength with a Hach DR2010 spectrophotometer.

3.8.2.5 Total Chlorine

Total chlorine measurements were made in accordance with *SM* 4500 on a Hach DR2000 spectrophotometer which was standardized with each set of measurements in accordance with the method.

3.8.2.6 Particle Free Water (PFW)

The State of Utah, Department of Health, Division of Laboratory Services, provided water for our use at the site. The ultra-pure water was brought from the Laboratory in new, transparent, polyethylene one-gallon bottles marked and dedicated for this purpose.

This water was prepared by treating with reverse osmosis, followed by exchange deionization resins.

3.8.2.7 Pressure Gauges

The pressure gauge for this study was a glycerin-filled, NIST-traceable and calibrated against an Ametek Model 1980L Gauge (0- 60 psig).

3.8.3 Off-Site Analysis for Chemical and Biological Samples

3.8.3.1 Organic Parameters, Total Organic Carbon and UV_{254} Absorbance

Samples for these analyses were collected in glass bottles supplied by the State of Utah Laboratory and delivered to the Laboratory by COA at least twice a week. Metals samples were collected in acidified bottles and all samples held for no more than three days at 4°C prior to delivery to the Laboratory in accordance with *SM* 5010B and *SM* 1060. This processing procedure is reflected in the chain of custody forms located in Appendix E. Table 3-1 lists the *SM* number used for these tests.

3.8.3.2 Algae (Chlorophyll) Samples

Samples were collected in opaque containers supplied by the State Laboratory and kept at 0°C in the on-site refrigerator prior to delivery to the laboratory. Table 3-1 lists the sampling frequency and *SM* number used.

3.8.3.3 Inorganic Samples

Inorganic samples were collected, held in the refrigerator at 4°C, and shipped in accordance with *SM* 3010B and C and 1060 and EPA §136.3, 40 CFR Ch.1. Proper bottles and preservatives, where required (iron and manganese for example) were used. Although the travel time was brief, samples were shipped in coolers at 4° C. The appropriate *SM* and EPA test methods and minimum testing frequencies are listed in Table 3-1.

Chapter 4

Results and Discussion

4.1 Introduction

Complete verification testing of the Watermark eVox® Model 5 Coagulation/Filtration System, which occurred at the Park City Spiro Tunnel Water Filtration Plant, commenced on April 11, 2000, and concluded on April 26, 2000.

This section of the verification report presents the results of the Initial Operations period as well as the Verification Testing period and a discussion of the results. Results and discussions of the following are included: initial operations, verification tasks, and QA/QC.

4.2 Initial Operations Results

An Initial Operations period allowed COA and Watermark to refine the unit's operating procedures and to make operational adjustments as needed to successfully treat the source water. The primary goals of the Initial Operations period were to establish an optimum process of coagulant chemistry, coagulant dosage, filter run times and backwashing frequency.

4.2.1 Characterization of Influent Water

Historical untreated surface water quality data that were obtained from Park City Municipal Corporation showed that the Spiro Tunnel Bulkhead water exhibited the following characteristics as shown in Table 1-1. Review of these historical data indicated that the technology should be suitable for this site.

4.2.2 Initial Test Runs

The Test Plan required that an initial test run be performed with uncoagulated feed water, and that samples be collected after 6, 12, 18 and 24 hours of operation. This activity was intended to determine if arsenic is removed from the system in the absence of coagulant chemicals. Tables 4-1 through 4-5 and Figures 4-1 through 4-3 provide the analytical results of this Initial Operations activity for a number of parameters.

Table 4-1. Initial Testing without Coagulant Chemicals (April 11, 2000)

Parameter	Hour 0	Hour 6	Hour 12	Hour 18	Hour 24
As (total) (µg/L)					
Feedwater	78.1	70.6	71.3	68.9	75.2
Filtrate	37.3	36.2	35.3	37.7	38.7
As (dissolved) (µg/L)					
Feedwater	38.8	38.3	39.5	38.5	40.4
Filtrate	30.2	35.5	34.2	35.9	37.3
As (insoluble) (µg/L)					
[1] Feedwater	39.3	32.3	31.8	30.4	34.8
[2] Filtrate	7.1	0.7	1.1	1.8	1.4
As (III) (µg/L)					
Feedwater	2.5	2.7	2.7	2.7	2.4
Filtrate	<0.5*	2.5	2	2.6	1.9
As (V) (µg/L)					
Feedwater	36.3	35.6	36.8	35.8	38
Filtrate	29.7	33	32.2	33.3	35.4
Antimony (µg/L)					
Feedwater	9.2	9.0	9.1	8.7	9.1
Filtrate	10.4	8.9	8.9	9.0	9.0
In-Line Continuous Turbidity (NTU)					
Feedwater	1.64	-	1.82	1.73	1.77
Filtrate	0.107	-	0.07	0.059	0.057
Bench Turbidity (NTU)					
Feedwater	2.43	1.67	1.68	1.63	1.69
Filtrate	0.23	0.10	0.13	0.13	0.15
Alkalinity (mg/L)					
Feedwater	144	142	146	144	146
Filtrate	145	145	146	145	146
Temperature (°C)					
Feedwater	8.9	9.7	10.9	8.9	8.9
Filtrate	9.9	9.9	9.9	10.0	10.0
pH					
Feedwater	7.39	7.36	7.30	7.30	7.30
Filtrate	7.42	7.43	7.37	7.39	7.40
Dissolved Oxygen (mg/L)					
Feedwater	6.09	6.26	5.59	5.91	6.28
Filtrate	6.16	6.47	5.83	5.75	5.78

*All readings at the MDL were used as that number in calculations.

[1] Feedwater Insoluble As = Total Feedwater As - Dissolved Feedwater As

[2] Filtrate Insoluble As = Total Filtrate As - Dissolved Filtrate As

Table 4-2 summarizes the arsenic species from Table 4-1.

Table 4-2. Arsenic Data Summaries (no coagulation chemicals) (April 11, 2000)

	As (total) (µg/L)		As (dissolved) (µg/L)		As (insoluble) (µg/L)		As III (µg/L)		As V (µg/L)	
	Feedwater	Filtrate	Feedwater	Filtrate	Feedwater	Filtrate	Feedwater	Filtrate	Feedwater	Filtrate
Average	72.8	37.0	39.1	34.6	33.7	2.4	2.6	1.9	36.5	32.7
Min.	68.9	35.3	38.3	30.2	30.4	0.7	2.4	<0.5*	35.6	29.7
Max.	78.1	38.7	40.4	37.3	39.3	7.1	2.7	2.6	38	35.4
Std. Dev	3.7	1.3	0.9	2.7	3.5	2.6	0.1	0.8	1.0	2.1
95% CI	69.5, 76.1	35.9, 38.2	38.3, 39.9	32.2, 37.0	30.7, 36.8	0.1, 4.7	2.5, 2.7	1.2, 2.6	35.7, 37.3	30.9, 34.5

* All readings at the Minimum Detection Limit (MDL) for Arsenic III of (<0.5 µg/L) were used as that number in calculations.

Note: The reliability of the low level (MDL of 0.1 µg/L to approximately 2 µg/L) should be considered as only qualitative (not quantitative).

Figure 4-1 demonstrates reduction in total arsenic concentrations during the 24-hour Initial Operations period.

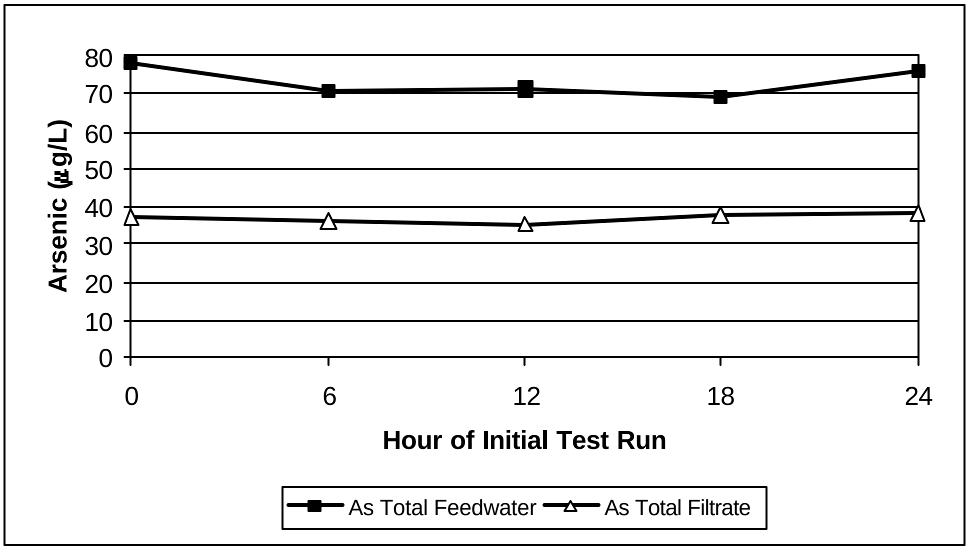


Figure 4-1. Total Arsenic Concentrations For Initial Testing Period (no coagulation chemicals) (April 11, 2000)

Average removal for Total As for the 24-hour Initial Operations period are provided in Table 4-3:

Table 4-3. Total Arsenic Removal Summary (no coagulation chemicals) (April 11, 2000)

	Total As in Feedwater (µg/L)	Total As in Filtrate (µg/L)
Average	72.8	37.0
Minimum	68.9	35.3
Maximum	78.1	38.7
Standard Deviation	3.7	1.3
95% Confidence Interval	69.5, 76.1	35.9, 38.2

Figure 4-2 illustrates the dissolved arsenic concentrations during the Initial Operations period. As shown in this figure, the data suggest that there is very little removal of dissolved arsenic by the filter alone without the addition of coagulation chemicals.

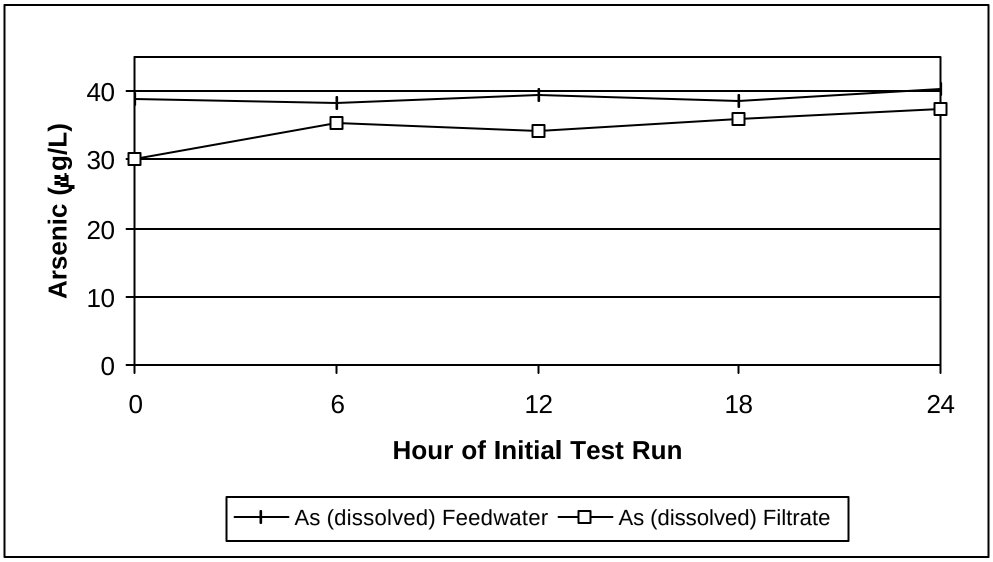


Figure 4-2. Dissolved Arsenic Concentrations For Initial Testing Period (no coagulation chemicals) (April 11, 2000)

Average removal for dissolved arsenic for the 24-hour Initial Operations period are provided in table 4-4:

Table 4-4. Dissolved Arsenic Removal Summary (no coagulation chemicals) (April 11, 2000)

	Dissolved As in Feedwater (µg/L)	Dissolved As in Filtrate (µg/L)
Average	39.1	34.6
Minimum	38.3	30.2
Maximum	40.4	37.3
Standard Deviation	0.9	2.7
95 % Confidence Interval	38.3, 39.9	32.2, 37.0

The average dissolved As concentration in the filtrate stream is somewhat lower than that in the feedwater stream. While this reduction is minimal, it is greater than expected.

Figure 4-3 illustrates the insoluble arsenic concentrations during the Initial Operations period. As shown in this figure, the data suggest significant removal of insoluble arsenic by the filter alone without the addition of coagulation chemicals.

It is postulated that the iron present in the feedwater supply oxidizes in the presence of air and forms an insoluble complex with a portion of the arsenic in the feedwater supply. This accounts for the average reduction in insoluble arsenic from an average of 33.7 µg/L in the feedwater to an average of 2.4 µg/L in the filtrate (Table 4-5).

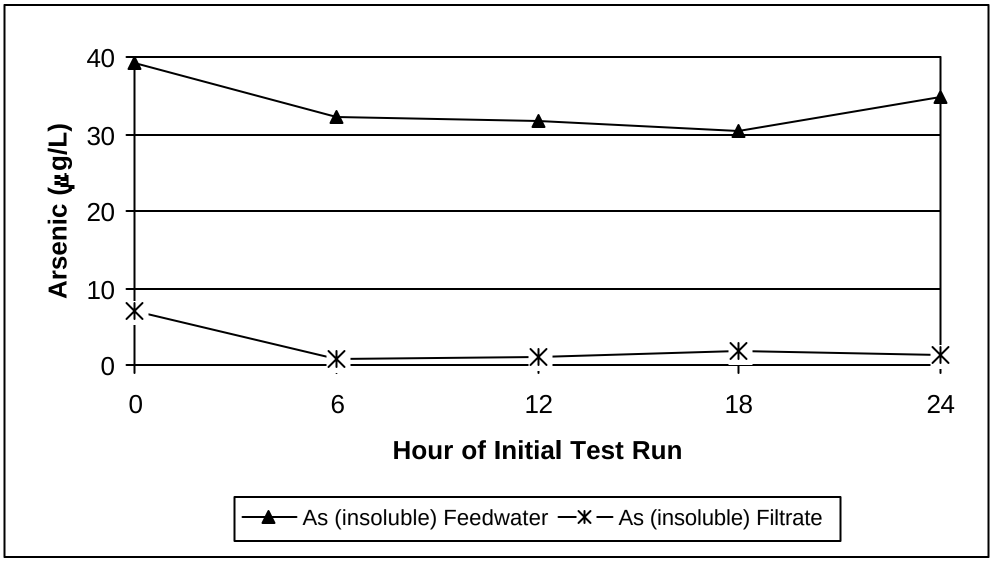


Figure 4-3. Insoluble Arsenic Concentrations For Initial Testing Period (no coagulation chemicals) (April 11, 2000)

Table 4-5. Insoluble Arsenic Removal Summary (no coagulation chemicals) (April 11, 2000)

	Insoluble As in Feedwater (µg/L)	Insoluble As in Filtrate (µg/L)
Average	33.7	2.4
Minimum	30.4	0.7
Maximum	39.3	7.1
Standard Deviation	3.5	2.6
95 % Confidence Interval	30.7, 36.8	0.1, 4.7

Figure 4-4 illustrates the antimony concentrations in both feedwater and filtrate streams during the initial run when no coagulant chemicals were added. Review of this figure suggests very little removal of antimony by the Watermark unit.

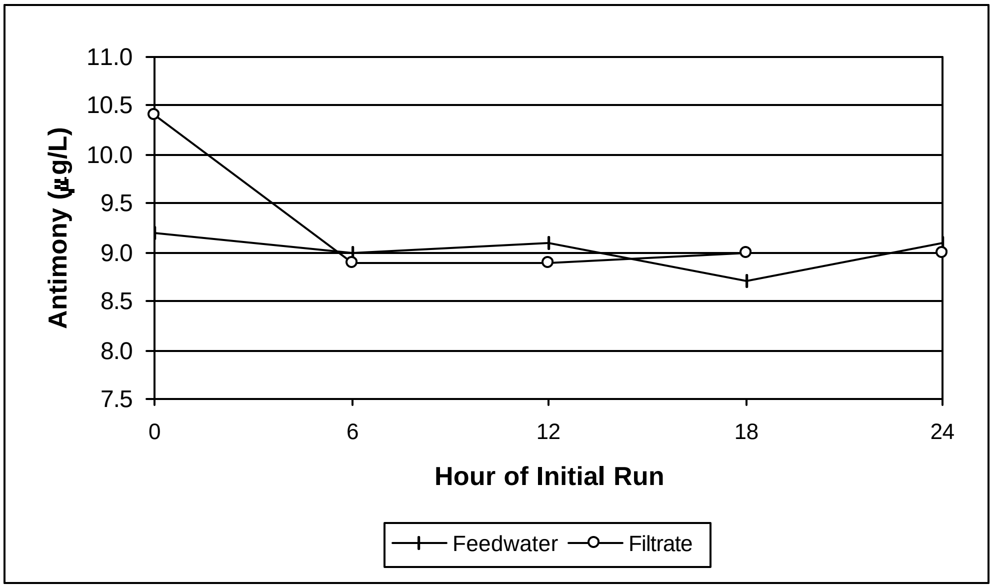


Figure 4-4. Antimony Concentration vs. Time (no coagulant chemicals) (April 11, 2000)

4.2.2.1 Coagulant Chemistry

Evaluation of the required concentration of $FeCl_3$ necessary for optimum arsenic removal was carried out by means of a simple series of jar tests conducted on February 22, 2000, prior to the initiation of the ETV testing period. Water from the Park City Bulkhead supply source containing an average of 80 µg/L total As was introduced into the eVox® treatment equipment with increasing amounts of ferric chloride added. This average total As was verified by Mr. Ron Fuller (Consultant to Watermark Technologies LLC). The samples were then analyzed and the results were used to fix the ferric chloride injection concentration for the ETV testing period at approximately 3 mg/L (as Fe).

Table 4-6. Chemical Injection Concentrations

Concentration of Iron Added (mg/L as Fe)	Residual Chlorine (mg/L as Cl_2)	Filtrate Total Arsenic (µg/L)
1	1	6.6
1.5	1	4.5
2	1	2
2.3	1.25	2
3	0.37	1.3
3.6	1.18	0.5
4	1.37	1.1

It had already been determined that the major component necessary for arsenic reduction in the Bulkhead water supply was iron, and that little additional oxidation enhancement was required. However, the Park City water sources had experienced historical fluctuations in the concentration of arsenic as well as other elements; it was therefore decided by the manufacturer to maintain a residual chlorine concentration of 1 mg/L as an insurance measure against the need for unforeseen oxidation requirements.

To achieve the desired outlet pressure from the feedwater pump, the flow rate was 2 gpm. This is the flow into which the coagulant chemicals were metered. The feedwater flow rate that was directed into the Watermark eVox® Model 5 Coagulation/Filtration System was 1.1 gpm, with the reminder of the feedwater flow, containing ferric chloride and sodium hypochlorite, directed to the Snyderville Sewer Improvement District.

4.2.2.2 Coagulant Dosage

The sources, strengths, dilution and flow rates of the coagulant chemicals were established as follows:

Table 4-7. Sources, Strengths, Dilution And Flow Rates Of The Coagulant Chemicals

Parameter	Sodium Hypochlorite	Ferric Chloride
Source	**Whirl Brand (Grocery Store)**	**Thatcher Chemical**
Strength (as supplied)	5.25%	32.5%
Dilution* (as fed)	0.42%	0.7%
Metering Rate	0.005 gph	0.094 gph
Feedwater Concentration (at 1.1 gpm)	0.175 mg/L (as NaOCl)	5.48 mg/L (as $FeCl_3$)

*Plant Tap Water

The above parameters were maintained throughout the duration of the test.

4.2.3 Filter Run Times

The Watermark eVox® Model 5 Coagulation/Filtration System was set to automatically backwash every four hours (based on a timer setting). The on-line turbidimeter alarm was set to initiate when the filtrate turbidity reached 0.5 NTU. On six occasions, the alarm was activated, but it automatically shut off in less than five minutes on each occasion. Based on observations made by the equipment operator, and recorded in the laboratory notebook, filtrate turbidity exceeded 0.5 NTU on April 16, 18, 21 and 22 for a short period. In each case this occurred immediately after timer activated backwashing, and recovered in less than five minutes. No adjustments were made to the filter run schedule; however, the control system can be adjusted to allow for a longer settling time, thereby eliminating this problem.

4.2.4 Backwashing Frequency

Based on data gathered during Initial Operations, it was determined that the backwashing frequency should be every four hours. Backwash cycles were automatically initiated and controlled with a timer/controller. This frequency was maintained throughout the duration of the test. Raw feedwater was used as the source of the backwash water.

4.3 Verification Testing Results

4.3.1 Task 1 - Verification Testing Runs And Routine Equipment Operation

Automatic coagulant feeding was initiated at 1730 on April 12, 2000, immediately at the conclusion of the 24-hour Initial Testing period.

On April 14, it was noticed that the feedwater pump was emitting extraneous sounds that suggested the potential of eventual pump failure. It was suspected that the bearings on this pump were beginning to fail, therefore from 0750 to 0840, the unit was shut down and a replacement pump (a Teel multistage centrifugal pump) was installed.

At 0130 on April 20, 2000, a leak in the tubing from the $FeCl_3$ metering pump into the static mixer was observed. It was repaired with tape, but at approximately 0940, a leak around the tape was observed. The tubing was cut off at that point and reinserted into the pump discharge.

At least once per day, the following parameters were measured on-site on both the feedwater and filtrate streams:

- Temperature
- pH
- Bench-Top Turbidity
- Dissolved Oxygen
- Total Chlorine

Daily temperature readings for the verification testing period are listed in Table 4-8.

Table 4-8. Daily Temperature Data (April 12 – April 26, 2000)

Date	Time	Temperature (°C) Feedwater	Temperature (°C) Filtrate
4/12/00	1900	9.0	10.0
4/13/00	1135	9.3	10.1
4/14/00	0900	8.9	10.0
4/14/00	1445	8.9	8.5
4/15/00	1345	8.9	10.0
4/15/00	1630	8.9	10.0
4/16/00	0830	8.9	10.0
4/17/00	0800	8.9	10.0
4/17/00	0845	8.9	10.0
4/18/00	1345	9.4	10.8
4/19/00	1245	9.3	10.4
4/20/00	0830	9.2	10.2
4/21/00	1030	9.2	10.2
4/22/00	0930	9.3	10.3
4/23/00	1000	10.6	9.7
4/24/00	900	9.7	10.7
4/24/00	1000	9.6	10.7
4/24/00	1200	9.3	9.8
4/24/00	1500	9.6	10.6
4/24/00	2100	9.9	10.1
4/25/00	300	9.6	10.5
4/25/00	900	9.7	10.5
4/25/00	1500	9.7	10.7
4/25/00	2100	9.7	10.7
4/26/00	300	9.7	10.6
4/26/00	900	9.6	10.5

These data are summarized and plotted in the following tables and figures. Note that the multiple readings for temperature as required for Task 4 for the period of April 24 through 26 are included in the graphs as additional data points.

Table 4-9. Temperature Data Summary (April 12 – April 26, 2000)

	Feed (°C)	Filtrate (°C)
Average	9.4	10.2
Minimum	8.9	8.5
Maximum	10.6	10.8
Standard Deviation	0.4	0.5
95% Confidence Interval	9.2, 9.5	10.0, 10.4

Note that there is approximately a 1°C increase in temperature from the feed to the filtrate stream as shown in Figure 4-5. This increase is likely due to the residence time in the equipment, which was installed in an area where the ambient temperature was maintained by the facility at approximately 70°F (21° C).

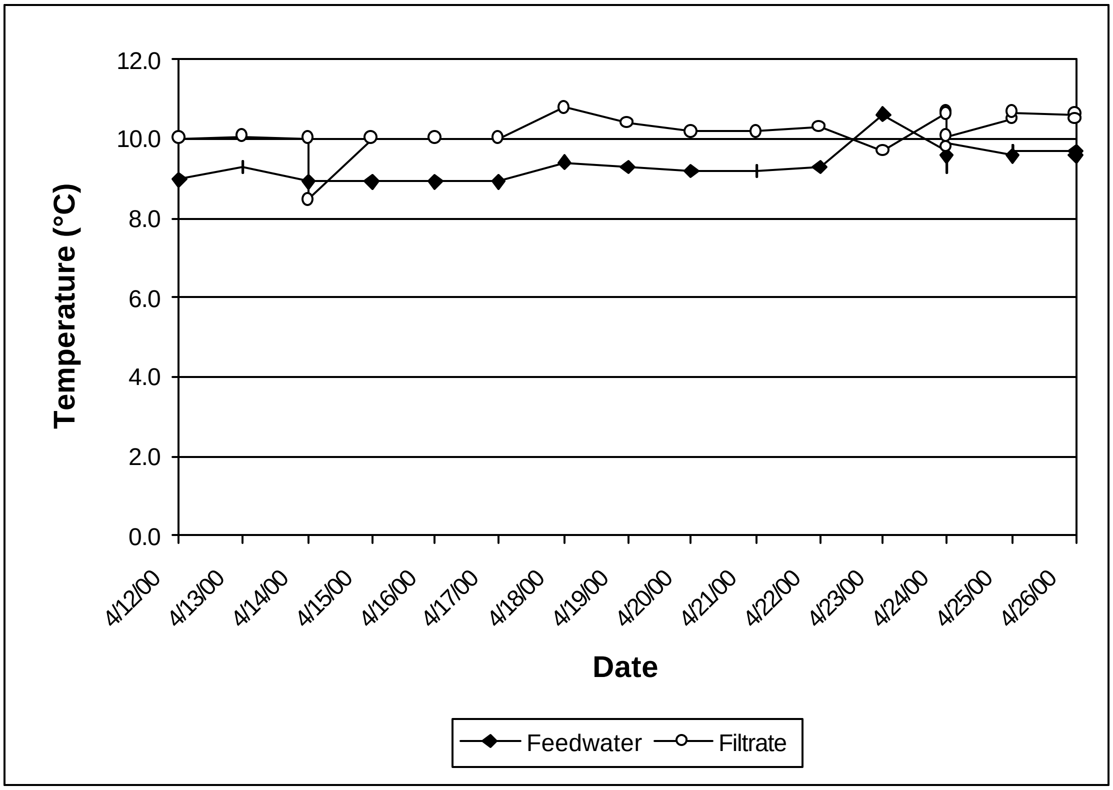


Figure 4-5. Daily Temperature Data vs. Time (April 12 – April 26, 2000)

Daily pH measurements taken during the verification testing period are shown in Table 4-10.

Table 4-10. Daily pH Data (April 12 – April 26, 2000)

Date	Time	Feedwater	Filtrate	Coagulated Feedwater
4/12/00	1900	7.31	7.19	-
4/13/00	1135	7.32	7.23	-
4/14/00	0900	7.33	7.22	7.14
4/14/00	1445	7.38	7.22	7.10
4/15/00	1345	7.27	7.07	-
4/15/00	1630	7.26	7.15	7.09
4/15/00	1900	7.21	7.12	7.08
4/16/00	0800	7.23	7.15	7.10
4/16/00	1600	7.27	7.17	7.14
4/17/00	0845	7.24	7.16	7.18
4/18/00	0920	7.21	7.09	7.14
4/18/00	2000	7.22	7.10	7.06
4/19/00	1700	7.27	7.17	-
4/20/00	0830	7.33	7.43	-
4/21/00	1030	7.31	7.22	-
4/21/00	1845	7.25	7.15	-
4/22/00	0930	7.32	7.27	-
4/22/00	2200	7.24	7.19	-
4/23/00	1000	7.31	7.18	-
4/23/00	1920	7.29	7.18	-
4/24/00	900	7.33	7.23	-
4/24/00	1000	7.33	7.37	-
4/24/00	1200	7.29	7.17	-
4/24/00	1500	7.38	7.26	-
4/24/00	2100	7.34	7.22	-
4/25/00	300	7.33	7.17	-
4/25/00	900	7.33	7.25	-
4/25/00	1500	7.35	7.22	-
4/25/00	2100	7.34	7.20	-
4/26/00	300	7.31	7.18	-
4/26/00	900	7.29	7.19	-

- No measurement taken

The filtrate pH is virtually always lower than the feedwater pH. This is likely due to the addition of acidic ferric chloride to effect coagulation. This is underscored by the pH data in Table 4-1 that show that without ferric chloride, the average filtrate pH was higher than that of the feedwater.

Table 4-11. Daily pH Data Summary (April 11 – April 26, 2000)

	Feed	Filtrate	Coagulated Feedwater
Average	7.30	7.20	7.11
Minimum	7.21	7.07	7.06
Maximum	7.38	7.43	7.18
Standard Deviation	0.05	0.07	0.04
95% Confidence Interval	7.28, 7.31	7.17, 7.22	7.09, 7.14

The multiple readings for pH as required for Task 4 for the period of April 24 through 26 are included in Figure 4-6 as additional data points.

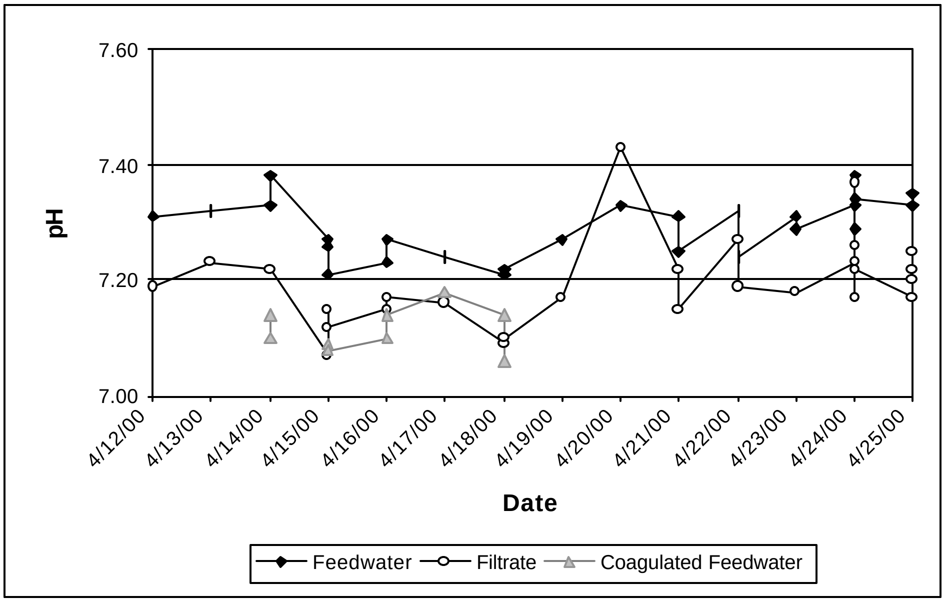


Figure 4-6. Daily pH Data vs. Time (April 12 – April 26, 2000)

Table 4-12 lists the Bench-Top turbidity readings for the testing period.

Table 4-12. Daily Bench-Top Turbidity Data (NTU) (April 12 – April 26, 2000)

Date	Time	Feedwater (NTU)	Filtrate (NTU)
4/12/00	1900	1.69	0.12
4/13/00	1135	1.73	0.29
4/14/00	900	1.71	0.21
4/14/00	1445	1.52	0.19
4/15/00	1630	1.38	0.09
4/16/00	830	1.71	0.13
4/17/00	845	1.67	0.09
4/18/00	1345	1.4	-
4/19/00	1245	1.64	0.09
4/20/00	830	1.65	0.09
4/21/00	1030	4.27	0.09
4/22/00	930	1.41	0.08
4/23/00	1000	1.50	0.11
4/24/00	900	1.53	0.12
4/24/00	1000	1.52	0.60
4/24/00	1200	1.44	0.06
4/24/00	1500	1.56	0.09
4/24/00	2100	1.76	0.09
4/25/00	300	1.42	0.07
4/25/00	900	1.45	0.09
4/25/00	1500	1.48	0.06
4/25/00	2100	1.47	0.08
4/26/00	300	1.47	0.07
4/26/00	900	1.49	0.11

From the Table 4-12 data, it is obvious that the multimedia filter in the test unit substantially reduced particulate material in the feedwater.

Table 4-13. Bench-Top Turbidity Data Summary (April 12 – April 26, 2000)

	Feed (NTU)	Filtrate (NTU)
Average	1.66	0.13
Minimum	1.38	0.06
Maximum	4.27	0.60
Standard Deviation	0.57	0.12
95% Confidence Interval	1.43, 1.89	0.08, 0.18

Note that multiple readings for the bench-top turbidity data as required for Task 4 for the period of April 24 through 26 are included in the graphs as additional data points

On April 21, 2000 the bench-top turbidity reading on the feedwater stream was very high (4.27 NTU verses an average concentration of 1.66 NTU). On the same date the plant continuous turbidimeter readings peaked at 2.24 NTU (as compared to an average of 1.51 NTU). Also on April 21, 2000, the total arsenic concentration in the feedwater stream peaked at 146 µg/L (verses an average concentration of 77.6 µg/L). The insoluble arsenic in this stream is approximately 106 µg/L (146-40.1). From the above, it is apparent that a disturbance in the tunnel created the turbidity spike which carried out additional arsenic, probably complexed with ferric hydroxide in the insoluble complex.

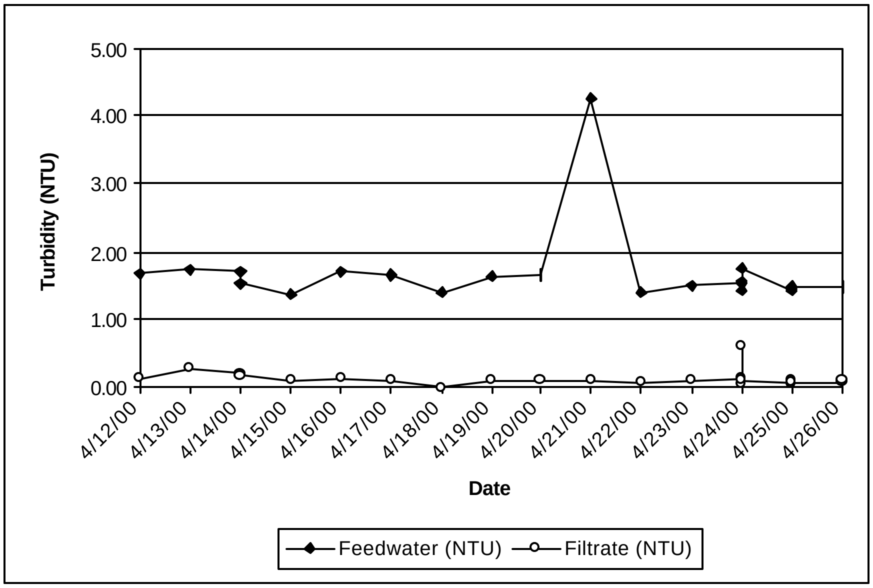


Figure 4-7. Daily Bench-Top Turbidity Data vs. Time (April 12 – April 26, 2000)

Turbidity as shown in Figure 4-7 was substantially reduced by the multimedia filter in the Watermark eVox® Model 5 Coagulation/Filtration System. The April 21, 2000, turbidity spike had no effect on the filtrate turbidity reading for that day.

Table 4-14 shows the daily measurements for dissolved oxygen.

Table 4-14. Daily Dissolved Oxygen Data (mg/L) (April 12 – April 26, 2000)

Date	Time	Feedwater (mg/L)	Filtrate (mg/L)
4/12/00	1900	6.71	6.28
4/13/00	1135	6.42	5.72
4/14/00	900	5.66	6.14
4/14/00	1445	5.53	5.59
4/15/00	1630	6.19	6.12
4/16/00	830	5.26	5.81
4/17/00	845	5.54	5.77
4/18/00	1345	5.07	5.32
4/19/00	1245	5.29	5.76
4/20/00	830	5.51	5.37
4/21/00	1030	5.75	6.23
4/22/00	930	5.66	5.77
4/23/00	1000	5.31	6.16
4/24/00	900	6.02	6.02
4/24/00	1000	5.63	6.21
4/24/00	1200	5.84	5.67
4/24/00	1500	6.35	6.75
4/24/00	2100	5.90	6.37
4/25/00	300	5.66	5.72
4/25/00	900	6.48	5.91
4/25/00	1500	6.54	6.68
4/25/00	2100	5.80	5.65
4/26/00	300	6.48	7.02
4/26/00	900	6.27	6.42

Table 4-15. Daily Dissolved Oxygen Data Summary (April 12 – April 26, 2000)

	Feed (mg/L)	Filtrate (mg/L)
Average	5.87	6.02
Minimum	5.07	5.32
Maximum	6.71	7.02
Standard Deviation	0.46	0.43
95% Confidence Interval	5.68, 6.06	5.84, 6.19

Note that multiple readings for the dissolved oxygen data as required for Task 4 for the period of April 24 through 26 are included in the graphs as additional data points.

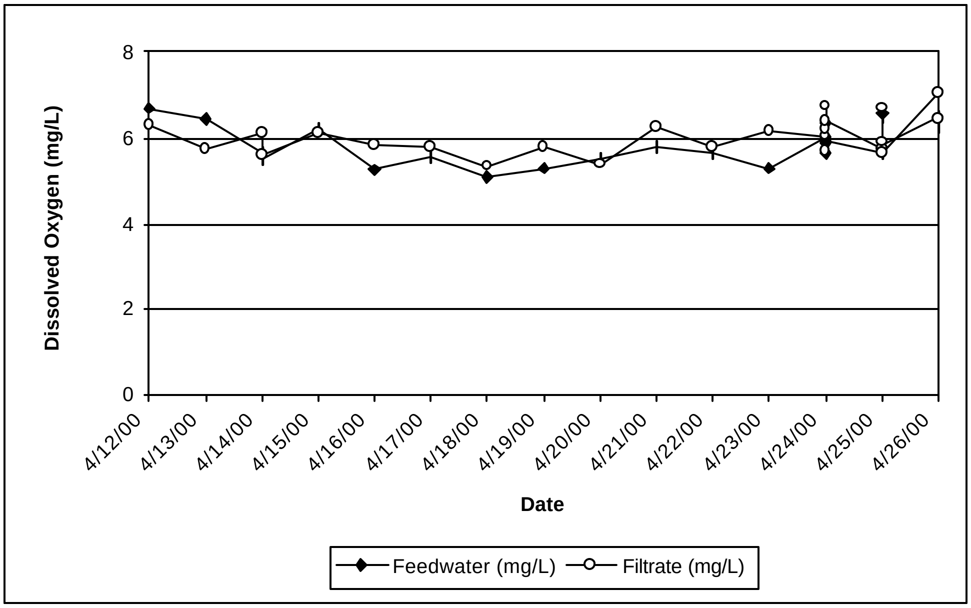


Figure 4-8. Daily Dissolved Oxygen Data vs. Time (April 12 – April 26, 2000)

There does not appear to be substantial differences in dissolved oxygen concentration between feedwater and filtrate streams.

4.3.2 Task 2 - Feed and Finished Water Quality Characterization

Continuous turbidity data from the wall-mounted plant turbidimeter on the feedwater stream, and from the Watermark turbidimeter on the filtrate stream (Appendix E) are summarized in Table 4-16 and plotted in Figure 4-9. On-line feedwater turbidity readings during the testing period averaged 1.51 NTU, compared to the bench-top turbidity average of 1.66 NTU. The on-line filtrate turbidity readings for the testing period averaged 0.060 NTU, compared to the bench-top average of 0.13 NTU. The Watermark filtrate turbidimeter was shut down for repair parts of each of the days of April 18, 19 and 24.

Table 4-16. Continuous Turbidity Data Summary (April 12 – April 26, 2000)

	Feed (NTU)	Filtrate (NTU)
Average	1.51	0.059
Minimum	0.99	0.018
Maximum	2.55	0.455
Standard Deviation	0.37	0.097
95% Confidence Interval	1.44, 1.57	0.042, 0.077

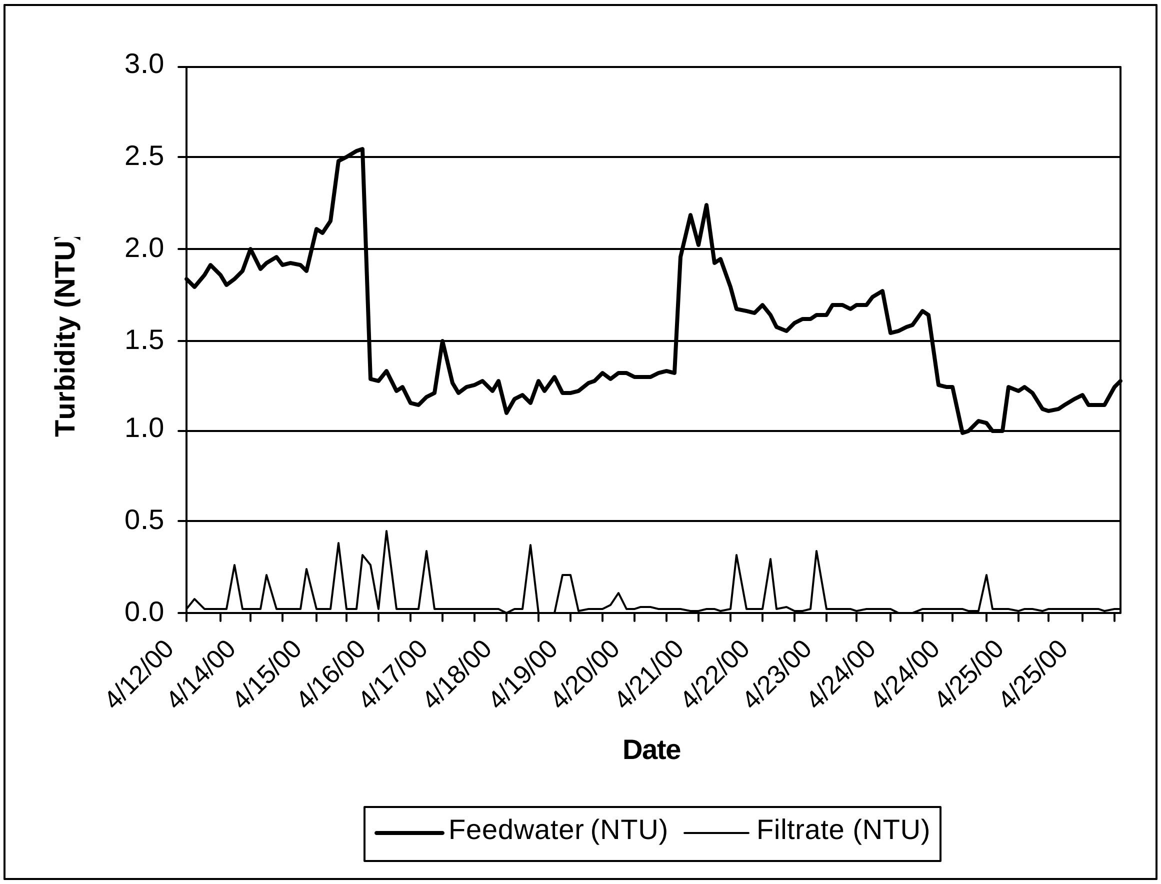


Figure 4-9. Continuous Turbidity vs. Time (April 12 – April 26, 2000)

Based on the average turbidity data from Table 4-16, feedwater turbidity was reduced by 96% by the Watermark eVox® Model 5 Coagulation/Filtration System. Although aberrations in turbidity measurements in the filtrate stream are expected to be minimal, the accuracy of the on-line turbidimeter data on the low readings in the filtrate stream is called into question and addressed in Section 4.5.3.3.

Table 4-17. Iron Concentrations (April 21 - April 26, 2000)

Date	Time	Feedwater Iron (mg/L)	Filtrate Iron (mg/L)
4/21/00	1030	0.756	0.0216
4/22/00	0930	0.244	0.0233
4/23/00	0910	0.225	<0.02
4/24/00	0900	0.231	<0.02
4/24/00	1000	0.235	<0.02
4/24/00	1200	0.343	<0.02
4/24/00	1500	0.25	<0.02
4/24/00	2100	0.286	<0.02
4/25/00	0300	0.236	<0.02
4/25/00	0900	0.238	<0.02
4/25/00	1500	0.358	<0.02
4/25/00	2100	0.234	<0.02
4/26/00	0300	0.275	<0.02
4/26/00	0900	0.26	<0.021

Table 4-18. Iron Data Summary (April 21 – April 26, 2000)

	Feedwater (mg/L)	Filtrate (mg/L)
Average	0.298	0.020
Minimum	0.225	0.02
Maximum	0.756	0.0233
Standard Deviation	0.138	0.001
95% Confidence Interval	0.226, 0.370	0.020, 0.021

*All readings at the MDL for Arsenic III (0.02 mg/L) were used as that number in calculations.

It is apparent from Table 4-18 that the Watermark System has removed almost all of the iron in the feedwater, even though $FeCl_3$ was injected as a coagulant.

On a daily basis, samples were taken and the laboratory measured the concentrations of the alkalinity and antimony. Tables 4-19 and 4-20 list the raw data and provide a summary of the alkalinity, and Figure 4-10 is a plot of alkalinity data over the test period.

Table 4-19. Alkalinity Daily Measurements (April 12 – April 26, 2000)

Date	Time	Feedwater (mg/L)	Filtrate (mg/L)
4/13/00	1135	146	137
4/14/00	1445	142	137
4/15/00	1345	144	137
4/16/00	1000	145	137
4/17/00	1400	144	135
4/18/00	900	141	138
4/19/00	1130	146	137
4/20/00	830	142	148
4/21/00	1030	146	140
4/22/00	930	144	137
4/23/00	900	144	137
4/24/00	900	145	136
4/24/00	1000	143	144
4/24/00	1200	144	138
4/24/00	1500	144	139
4/24/00	2100	144	136
4/25/00	300	147	139
4/25/00	900	145	137
4/25/00	1500	146	137
4/25/00	2100	144	136
4/26/00	300	145	138
4/26/00	900	144	139

Table 4-20. Alkalinity Data Summary (April 12 – April 26, 2000)

	Feedwater (mg/L)	Filtrate (mg/L)
Average	144	138
Minimum	141	135
Maximum	147	148
Standard Deviation	1.5	2.9
95% Confidence Interval	144, 145	137, 139

The multiple readings for the alkalinity data as required for Task 4 for the period of April 24 through 26 are included in the tables and graph as additional data points.

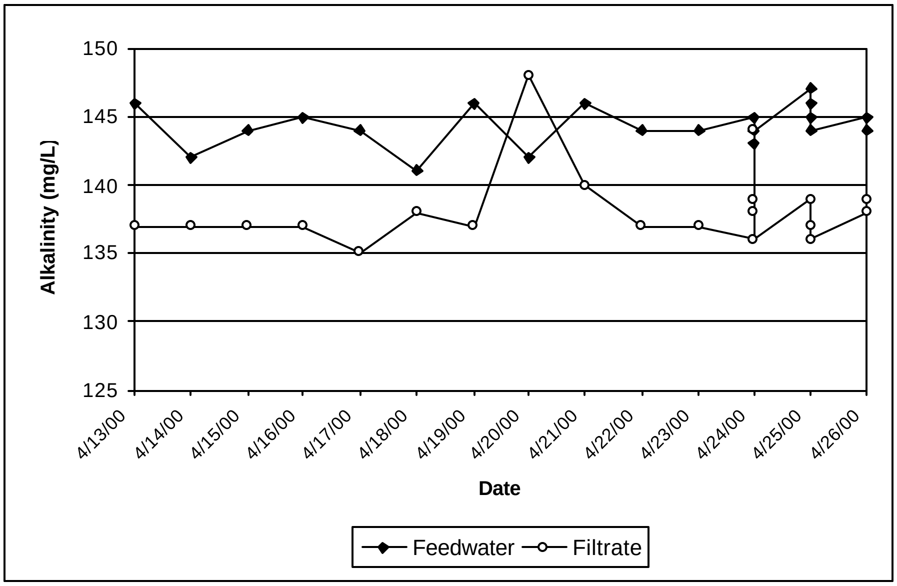


Figure 4-10. Alkalinity vs. Time (April 12 – April 26, 2000)

Although the average alkalinity measurement of the filtrate stream is approximately 4% less than the feedwater stream, it is apparent that alkalinity is not effectively removed by this technology.

Antimony data generated during the testing are listed in the following tables and graph. Table 4-21 lists the daily measurements for antimony for the verification testing period.

Table 4-21. Antimony Daily Measurements (April 12 – April 26, 2000)

Date	Time	Feedwater (µg/L)	Filtrate (µg/L)
4/13/00	1135	9.2	9.0
4/14/00	1445	8.9	8.4
4/15/00	1345	8.9	8.5
4/16/00	1000	9.4	8.4
4/17/00	1400	9.4	9.1
4/18/00	900	9.3	8.9
4/19/00	1130	9.4	8.7
4/20/00	830	9.4	9.1
4/21/00	1030	9.2	8.7
4/22/00	930	9.1	9.0
4/23/00	900	9.4	8.9
4/24/00	900	8.9	8.5
4/24/00	1000	8.9	8.8
4/24/00	1200	9.3	8.7
4/24/00	1500	9.0	8.5
4/24/00	2100	8.9	8.5
4/25/00	300	8.8	8.4
4/25/00	900	8.8	8.5
4/25/00	1500	8.7	8.5
4/25/00	2100	9.0	8.6
4/26/00	300	9.0	8.6
4/26/00	900	9.1	8.7

Table 4-22. Antimony Data Summary (April 12 – April 26, 2000)

	Feedwater (µg/L)	Filtrate (µg/L)
Average	9.1	8.7
Minimum	8.7	8.4
Maximum	9.4	9.1
Standard Deviation	0.2	0.2
95% Confidence Interval	9.0, 9.2	8.6, 8.8

The multiple readings for the antimony data as required for Task 4 for the period of April 24 through 26 are included in the tables and graph as the additional data points.

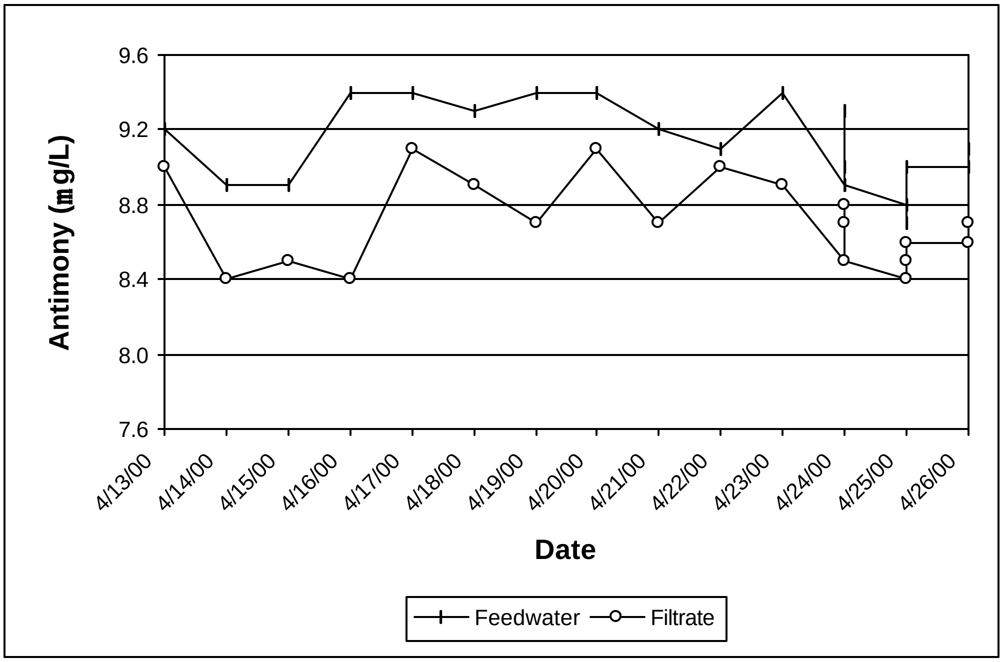


Figure 4-11. Antimony vs. Time (April 12 – April 26, 2000)

From the above data, it is evident that, although there is a slight reduction, antimony is not effectively removed by this process.

Sample measurements for Arsenic (Total, Dissolved, III, and V) for the testing period are listed below in Table 4-23.

Table 4-23. Arsenic Data Measurements (April 12 – April 26, 2000)

		Total As (µg/L)		Dissolved As (µg/L)		As (III) (µg/L)		As (V) (µg/L)	
Date	Time	Feedwater	Filtrate	Feedwater	Filtrate	Feedwater	Filtrate	Feedwater	Filtrate
4/13/00	1135	73.8	1.8	40.4	1.8	2.5	<0.5*	37.9	1.3
4/14/00	1445	60.9	1.2	37.4	1.7	2.2	<0.5*	35.2	1.2
4/15/00	1345	66.8	1.3	40.1	1.7	2.2	<0.5*	37.9	1.2
4/16/00	1000	74.8	1.3	42	1.6	2.4	<0.5*	39.6	1.1
4/17/00	1400	82.7	1.4	40.1	2	2.4	<0.5*	37.7	1.5
4/18/00	900	65.3	1.2	37.8	1.4	2.3	<0.5*	35.5	0.9
4/19/00	1130	87.2	1.3	40	1.7	2.1	<0.5*	37.9	1.2
4/20/00	950	80	34.5	40.8	32.6	2.8	1	38	31.6
4/21/00	1030	146	1.7	40.1	2.1	2.7	0.9	37.4	1.2
4/22/00	930	73.7	25.2	40.3	21.9	3.2	0.9	37.1	21
4/23/00	910	75.1	1.7	41.8	2.2	2.7	0.9	39.1	1.3
4/24/00	900	69.8	1.8	40.6	2.2	2.5	0.8	38.1	1.4
4/24/00	1000	71.8	1.9	43	2.3	3	0.9	40	1.4
4/24/00	1200	89.4	1.6	42.6	2.1	3.6	0.9	39	1.2
4/24/00	1500	72.7	1.5	42.9	1.9	3	0.9	39.9	1
4/24/00	2100	76.6	2	43.5	2.6	2.6	0.8	40.9	1.8
4/25/00	300	70.2	1.4	45.4	3.2	2.4	1	43	2.2
4/25/00	900	70.6	1.4	45.8	3.4	2.2	<0.5*	43.6	2.9
4/25/00	1500	84.7	1.3	43	3.5	2.4	<0.5*	40.6	3
4/25/00	2100	69.6	1.8	45.9	3.7	2.1	<0.5*	43.8	3.2
4/26/00	300	71.4	1.3	45.3	3.5	2.1	<0.5*	43.2	3
4/26/00	900	74.1	1.8	45.7	4	2.4	<0.5*	43.3	3.5

* MDL for Arsenic III (<0.5 µg/L).

Note: the reliability of the low-level data (MDL of 0.5 µg/L to approximately 2µg/L) should be considered only qualitative (not quantitative).

Samples tested for Arsenic (Total, Dissolved, III, and V) in the coagulated feedwater (sample taken immediately prior to the retention tank) on April 18, 2000 at 0900 are not shown in corresponding Table 4-24 summary, or graphed in corresponding arsenic Figures 4-12 through 4-15. Data were collected as an indicator of the process operations and are in addition to the ETV Protocol. These data are available in Appendix G.

A closer inspection of the dissolved arsenic data in Table 4-23 shows that there is an inconsistency between the dissolved arsenic results and the total arsenic results shown for the filtrate. The total arsenic results are all lower than the dissolved arsenic concentrations. This obviously cannot be an accurate result. The feedwater and concentrate data show in all cases that the total arsenic is higher than the dissolved arsenic. The concentration in these streams is much higher suggesting that the problem only occurs at concentrations near the detection limit. This data would suggest that the problem is related to interference in the analysis at very low concentrations.

Given this inconsistency, the State of Utah laboratory was asked to review the data and attempt to explain the possible cause of the discrepancy. Their findings are presented in their entirety in Appendix H. The basic cause of the problem, in their opinion, appears to be that the use of sulfuric acid in the preservation process for the dissolved arsenic samples causes a positive interference in the ICP-MS analysis. This positive interference is relatively small (a few tenths of a µg/l; typically 0.4-0.6 µg/l), but at the low concentrations being measured in the permeate this positive interference is significant. Therefore, the dissolved arsenic results appear to be biased high. This positive bias results in an understating of the removal percentage for the dissolved arsenic in the feed water.

The NSF quality control review of the data suggested that a higher quantitation limit maybe more appropriate for the arsenic analysis. For more information, see Section 4.5.1 of this report.

A slight break in the FeCL3 metering pump discharge line, discovered very early in the morning of April 20, 2000, resulted in some leakage of the $FeCl_3$ solution. Although repaired by 0945, the arsenic samples collected at approximately 0950 show extremely high readings for Total As, Dissolved As and As(V) in the filtrate stream. These high readings are suspected to be the result of insufficient $FeCl_3$ coagulant chemical injection.

Table 4-24. Arsenic Data Summary (April 12 – April 26, 2000)

	Feedwater (µg/L)	Filtrate (µg/L)
Total Arsenic		
Average	77.6	4.1
Minimum	60.9	1.2
Maximum	146.0	34.5
Standard Deviation	16.8	8.5
95% Confidence Interval	70.6, 84.6	0.6, 7.6
Dissolved Arsenic		
Average	42.0	4.7
Minimum	37.4	1.4
Maximum	45.9	32.6
Standard Deviation	2.5	7.5
95% Confidence Interval	41.0, 43.1	1.5, 7.8
Arsenic (III)		
Average	2.5	0.7
Minimum	2.1	<0.5*
Maximum	3.6	1.0
Standard Deviation	0.4	0.2
95% Confidence Interval	2.4, 2.7	0.6*, 0.8
Arsenic (V)		
Average	39.5	4.0
Minimum	35.2	0.9
Maximum	43.8	31.6
Standard Deviation	2.6	7.4
95% Confidence Interval	38.4, 40.6	0.9, 7.1

*All readings at the MDL for Arsenic III (<0.5 µg/L) were used as that number in calculations.

Note: the reliability of the low-level data (MDL of 0.1 µg/L to approximately 2 µg/L) should be considered only qualitative (not quantitative).

Total arsenic readings as required for Task 4 for the period of April 24 through 26 are included in Figure 4-12 as additional data points.

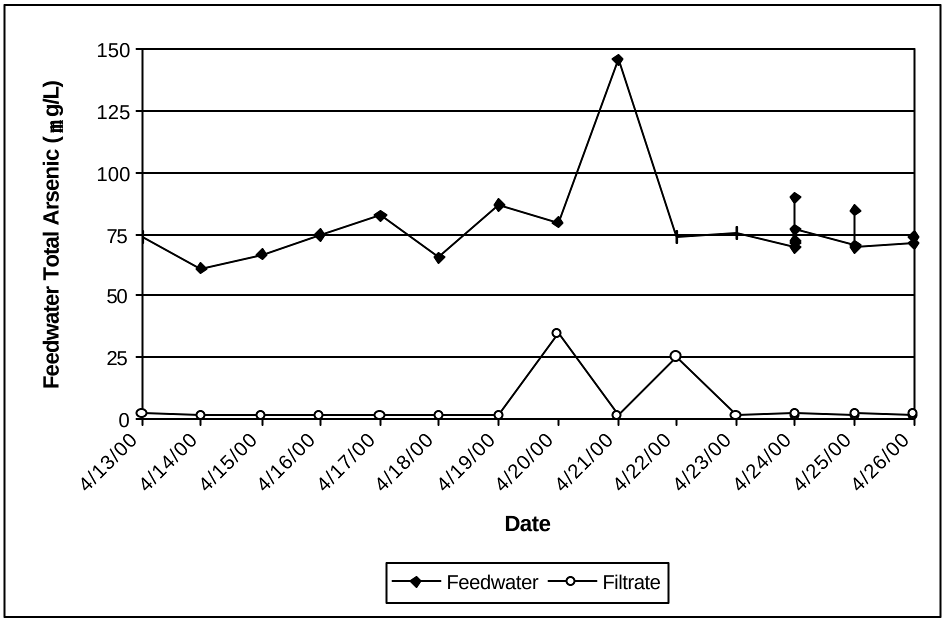


Figure 4-12. Total Arsenic vs. Time (April 12 – April 26, 2000)

Based on average total arsenic data in Table 4-24, almost 95% of this contaminant was removed. In addition, with the exception of 2 readings, all filtrate concentrations of total arsenic were at 2 µg/L or below.

The multiple readings for the dissolved arsenic data as required for Task 4 for the period of April 24 through 26 are included in Figure 4-13 as additional data points

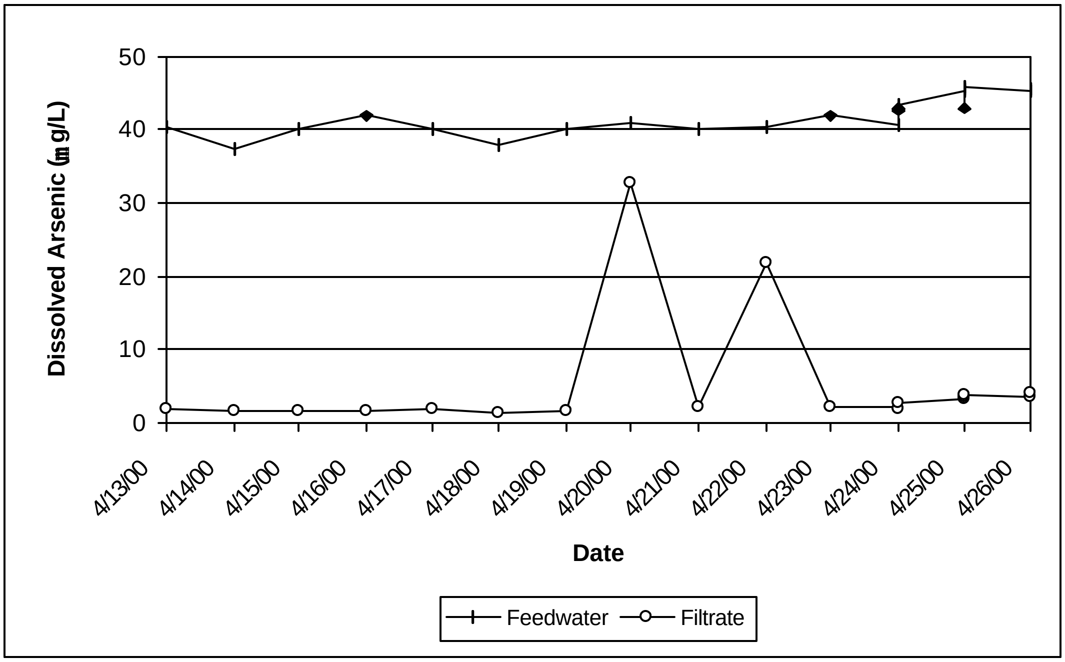


Figure 4-13. Dissolved Arsenic vs. Time (April 12 – April 26, 2000)

Based on average dissolved arsenic values in Table 4-24, almost 89% of this species was removed by the Watermark eVox® Model 5 Coagulation/Filtration System. With the exception of 2 data points[1], all of the filtrate readings are at or below 4 µg/L.

Sample collections for Arsenic III as required for Task 4 during the period of April 24 through 26 are included in Figure 4-14 as additional data points.

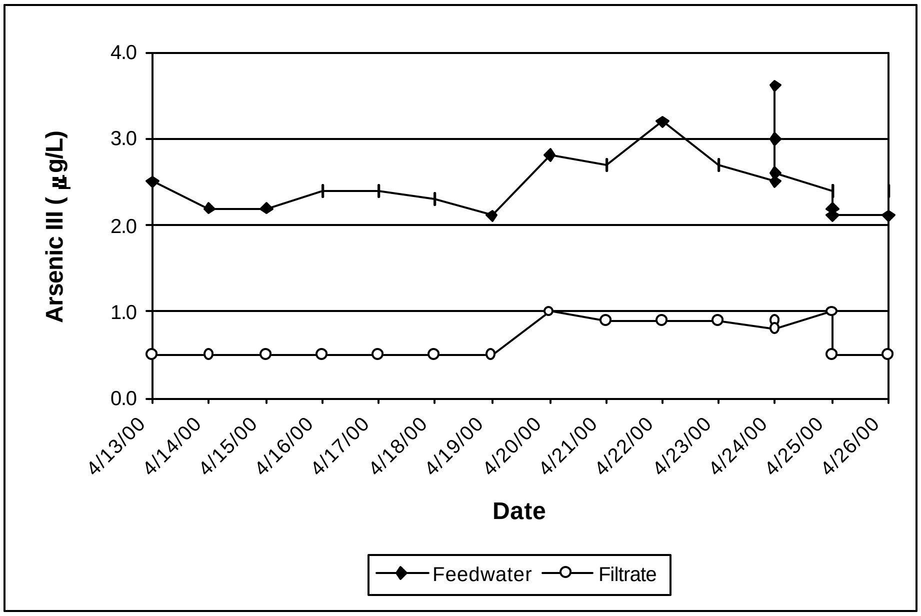


Figure 4-14. Arsenic (III) vs. Time (April 12 – April 26, 2000)

Although calculations indicate that 72% removal of As III occurred in this test, the uncertainty associated with the analytical measurements of concentrations at or below the quantitative detection limit calls into question the accuracy of this removal percentage.

Sample collection and measurement of Arsenic V as required for Task 4 during the period of April 24 through 26 are included in Figure 4-15.

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[1] A slight break in the FeCL3 metering pump discharge line, discovered very early in the morning of April 20, 2000, resulted in some leakage of the FeCl$_3$ solution. Although repaired by 0945, the arsenic samples collected at approximately 0950 show extremely high readings for Total As, Dissolved As and As(V) in the filtrate stream. These high readings are suspected to be the result of insufficient FeCl$_3$ coagulant chemical injection.

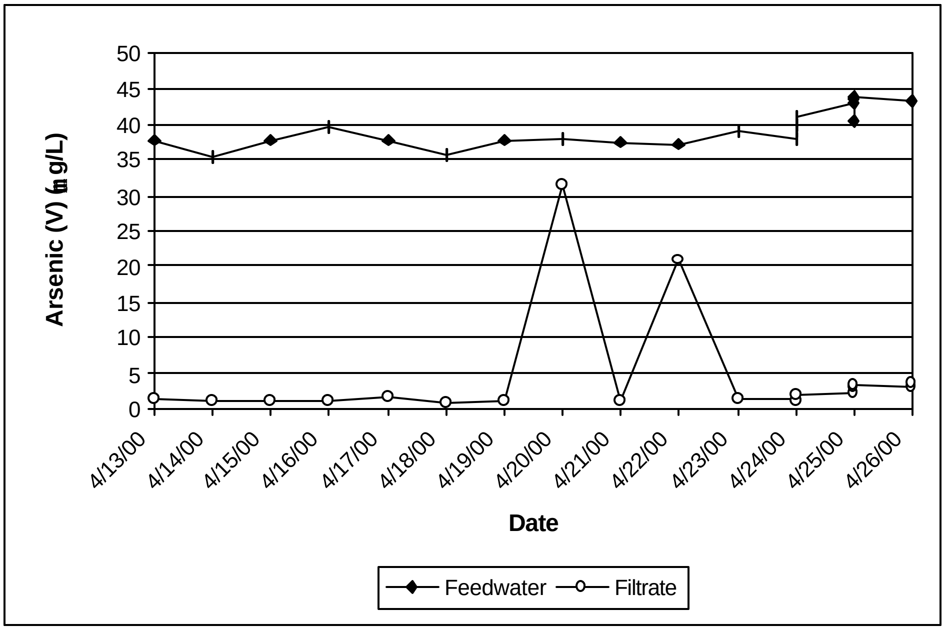

Figure 4-15. Arsenic (V) vs. Time (April 12 – April 26, 2000)

With the exception of 2 data points[2] and based on the average data from Table 4-24, the filtrate concentration of As V exhibited substantial removal (89.9%). Although it is evident that removal of As V occurred in this test, the uncertainty associated with the analytical measurements of concentrations, at or below the quantitative detection limit, such as what was experienced in this test, precludes calculation of accurate removal percentages.

4.3.3 Task 3: Documentation of Operating Conditions and Treatment Equipment Performance

The Watermark eVox® Model 5 Coagulation/Filtration System is designed to automatically backwash based on a preset time interval. For this test, the manufacturer chose a four-hour interval with backwashing to be initiated at five minutes before the hours of midnight, 4 AM, 8 AM, Noon, 4 PM and 8 PM every day throughout the duration of the test period.

The actual backwashing sequence involved four minutes of media backwash followed by one minute of media settling during which no water was flowing.

An audio/visual alarm was connected to the filtrate on-line turbidimeter to be activated when the reading reached 0.5 NTU. On April 13 at 0746, the alarm went off and the unit was backwashed by push button initiation. The alarm was reset to activate when the turbidimeter read 0.20 NTU, but was

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[2] A slight break in the FeCL3 metering pump discharge line, discovered very early in the morning of April 20, 2000, resulted in some leakage of the FeCl$_3$ solution. Although repaired by 0945, the arsenic samples collected at approximately 0950 show extremely high readings for Total As, Dissolved As and As(V) in the filtrate stream. These high readings are suspected to be the result of insufficient FeCl$_3$ coagulant chemical injection.

quickly reset to 0.50 NTU upon observation that it went off too frequently; on five or more occasions, the alarm went off just after the media settling period as service flow was initiated, but never for more than a five minute duration. It was determined that there was a small quantity of suspended solids left in the bottom of the filter vessel which passed out with the filtrate upon initiation of service flow after the backwash cycle. Programming the system to allow media setting prior to initiation of the service cycle can eliminate this problem.

The service flow rate of the filter was maintained at an almost constant 1.1 gpm with an operating time of 235 minutes between backwashing; the total quantity of water processed between backwashing episodes was 258.5 gallons. As expected, the pressure drop across the media filter increased during the interval between backwashing episodes, but never exceeded 5.0 psig, except for one reading of 9.5 psig. Table 4-25 is a summary of the pressure drop data over the duration of the test, and Figure 4-16 is a graphical representation. The time of each backwashing episode is also indicated.

The April 20 and 22 data for total arsenic, dissolved arsenic and arsenic (V) in the filtrate stream indicate unusually high concentrations. The following items were noted from the laboratory (field) notebook: 1). On April 20 at 0130 a leak in the $FeCl_3$ metering pump discharge was noticed and the hole was covered by tape. At 0940, the $FeCl_3$ solution was observed to be leaking slightly around the tape, so the tubing was cut at that point and reinserted into the discharge side of the pump. Analytical samples were taken at 0950. It is possible that an insufficient concentration of $FeCl_3$ solution was fed into the system during that time. 2). On April 22, 2 batches of $FeCl_3$ solution and 1 batch of Cl_2 solution were added to the feed tanks at 0830, however, there was no evidence that either solution had run out prior to this activity.

When total arsenic is compared to dissolved arsenic in table 4-24 an average of 54% of the total arsenic in the feedwater was dissolved. Additionally, from the same table, it can be calculated that an average of 94% of the dissolved arsenic in the feedwater was in the arsenic (V) form. Because of the relative ease of oxidation of arsenic (III) to arsenic (V) and the presence of chlorine (an oxidizer) in the coagulation process, it is expected that most of the arsenic (III) was oxidized to arsenic (V) prior to the filtration step.

Table 4-25. Pressure Drop Data Summary (April 12 – April 26, 2000)

	ΔP (psig)
Average	2.7
Minimum	0.5
Maximum	9.5
Standard Deviation	1.1
95% Confidence Interval	2.5, 2.9

Figure 4-16 shows the hours of operation, starting with the initiation of coagulation feed, and noting instantaneous pressure drop and backwash episodes.

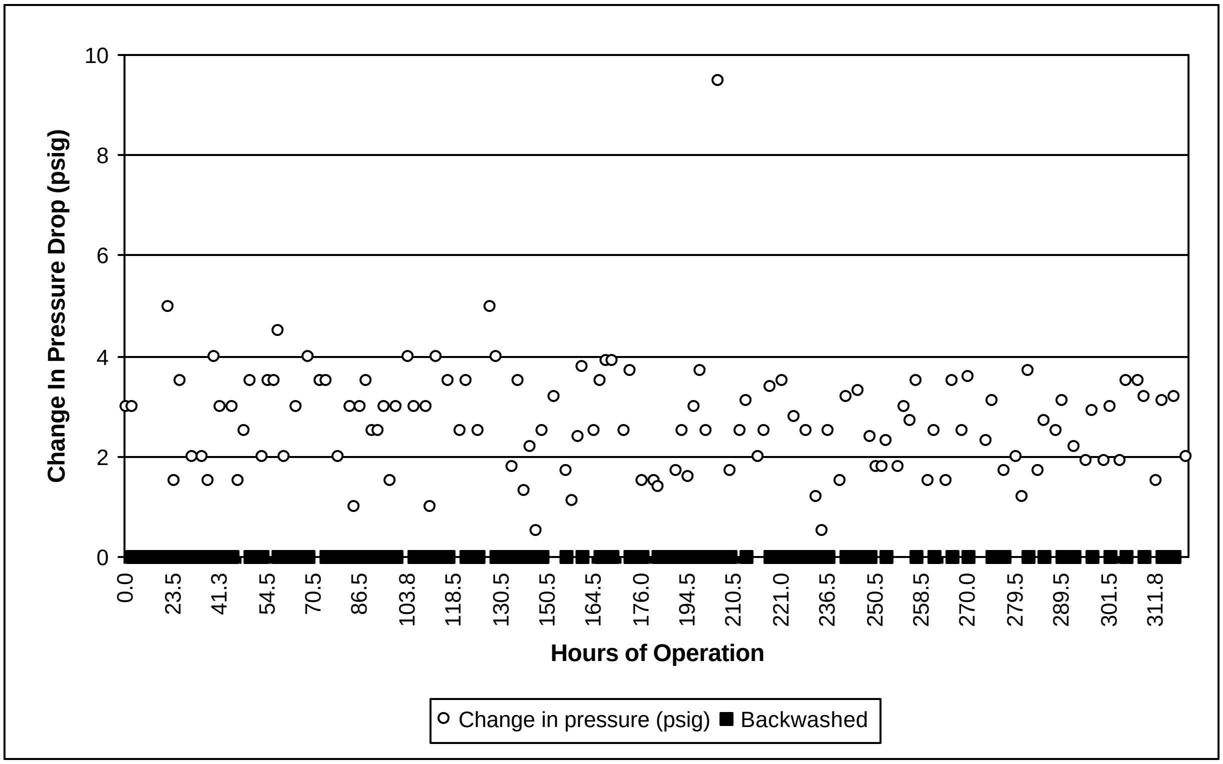

Figure 4-16. Pressure Drop vs. Run Time (April 12 – April 26, 2000)

With one exception (205.5 hours into the run), the pressure drop across the filter bed was maintained at 5 psig or less.

Backwashing with raw water was performed at a rate of 20 gpm/ft^2 of bed surface area for four minutes every four hours. Based on the fact that 258.5 gallons of water were processed between backwashing episodes, each of which utilized 16 gallons of backwash water, water recovery can be calculated by the following formula:

$$\%\ \text{recovery} = \frac{258.5 - 16}{258.5} \times 100 = 93.8\%\ \text{recovery}$$

4.3.4 Task 4: Arsenic Removal Results

The Test Plan required that samples be collected from both the feedwater and filtrate streams for analyses of speciated arsenic in particular. Samples were collected at time zero and at 1, 3, 6 hours and every six hours thereafter for a total of 48 hours. In addition to arsenic, the samples were analyzed by the Laboratory for the following parameters: Alkalinity; Algae (Chlorophyll A); Iron and Antimony. Results are presented in table 4-26.

Table 4-26. Task 4 Arsenic Data Summary (April 24 – April 26, 2000)

	Total As (μg/L)		Dissolved As (μg/L)		As (III)* (μg/L)		As (V) (μg/L)	
	Feedwater	Filtrate	Feedwater	Filtrate	Feedwater	Filtrate	Feedwater	Filtrate
Average	74.6	1.6	44.0	2.9	2.6	0.7	41.4	2.2
Minimum	69.6	1.3	40.6	1.9	2.1	<0.5*	38.1	1
Maximum	89.4	2.0	45.9	4	3.6	1.0	43.8	3.5
Std. Dev.	6.6	0.3	1.7	0.7	0.5	0.2	2.0	0.9
95% CI	70.8, 78.5	1.5, 1.8	42.9, 45.0	2.5, 3.4	2.3, 2.8	0.6, 0.8	40.2, 42.6	1.7, 2.8

*All readings at the MDL for Arsenic III (<0.5 μg/L) were used as that number in calculations.
Note: the reliability of the low-level data (MDL of 0.1 μg/L to approximately 2 μg/L) should be considered only qualitative (not quantitative).

Because the Watermark eVox® Model 5 Coagulation/Filtration System ran continuously and the Task 4 activity involved only more frequent sampling than during the previous portion of the testing, it is not surprising that most of the analytical results are very close to those obtained over the whole testing period, during the Task 2 activity (Section 4.3.2) and summarized in Table 4-24. The filtrate stream readings of total arsenic and dissolved arsenic in Table 4-26 would show much closer agreement to those in Table 4-24 if the readings for the data of 4/20/00 and 4/22/00 are not included. These data are suspected to be the result of either a leak in the $FeCl_3$ feedline or mislabeled sample containers. In addition, the reliability of all filtrate readings near the MDL is called into question, as explained in Section 4.3.2.

Figures 4-17 through 4-20 are plots of each arsenic species for Task 4 activities.

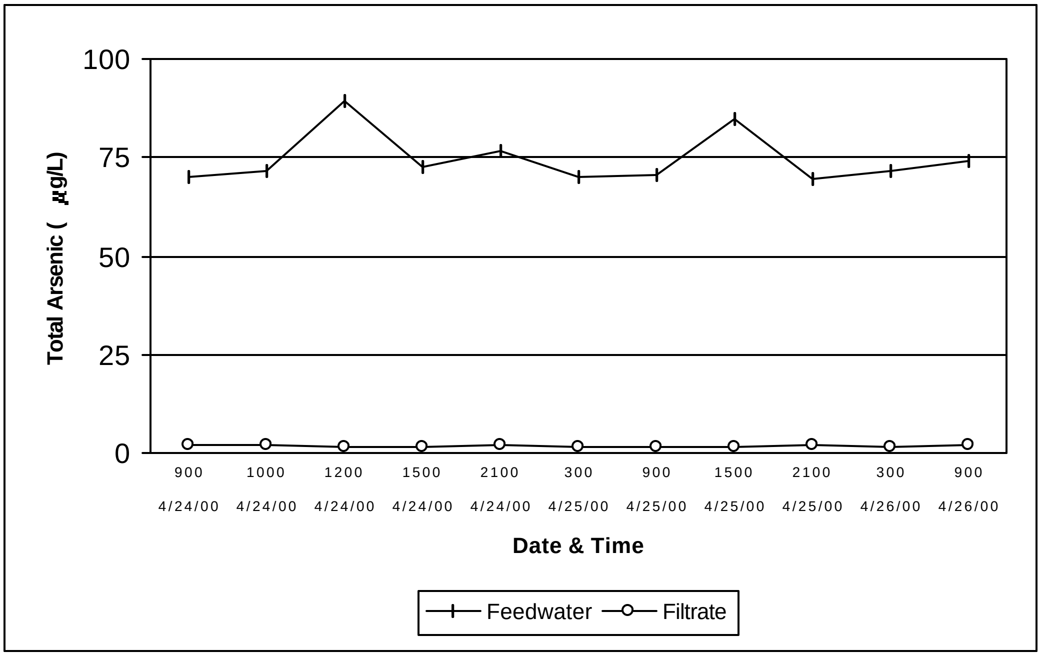

Figure 4-17. Task 4 Total Arsenic vs. Time (April 24 – April 26, 2000)

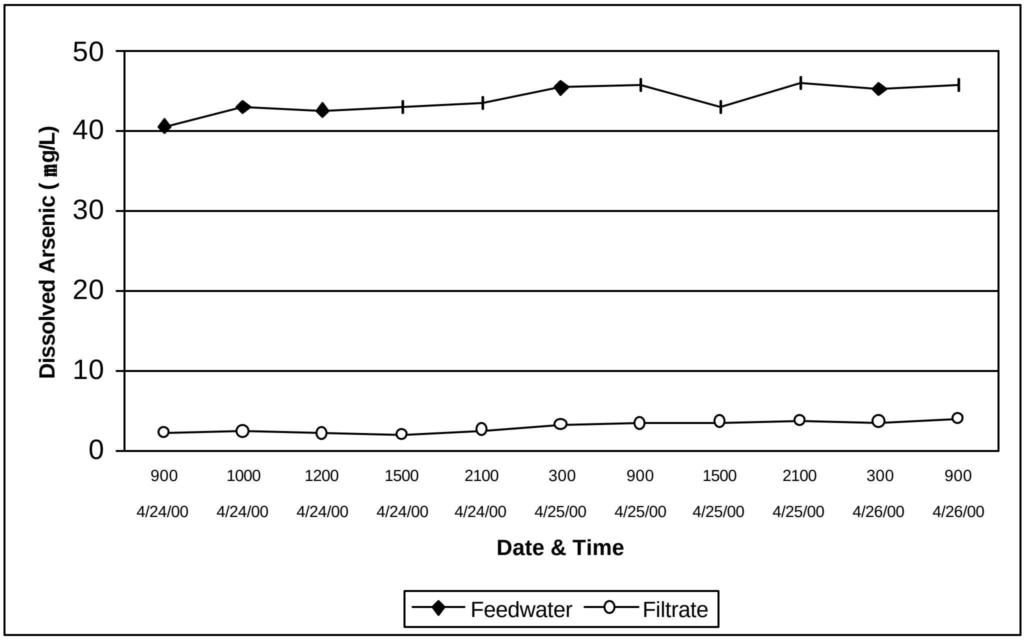

Figure 4-18. Task 4 Dissolved Arsenic vs. Time (April 24 – April 26, 2000)

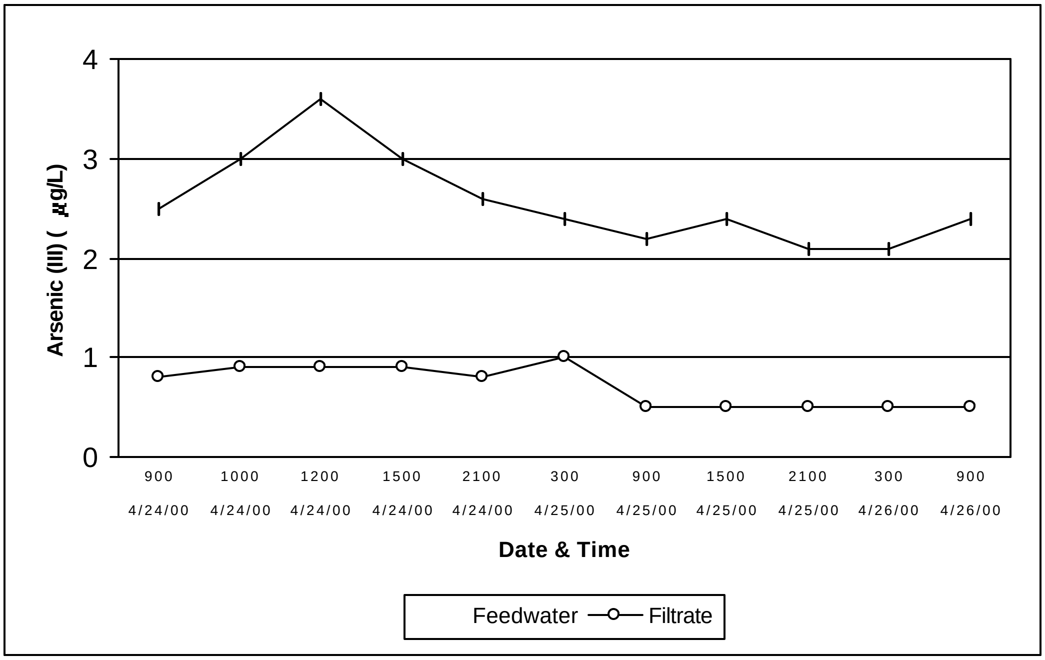

Figure 4-19. Task 4 Arsenic (III) vs. Time (April 24 – April 26, 2000)

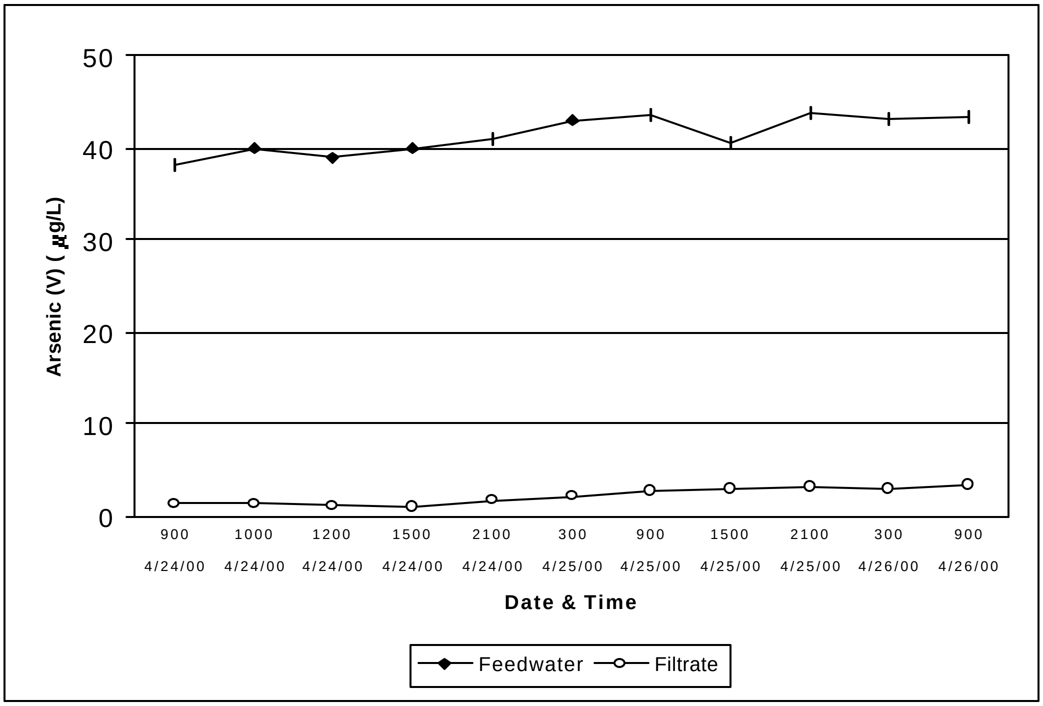

Figure 4-20. Task 4 Arsenic (V) vs. Time (April 24 – April 26, 2000)

Results for samples analyzed by the Laboratory for the Alkalinity, Algae (Chlorophyll A); Iron and Antimony are shown in Table 4-27.

Table 4-27. Task 4 Analytical Data Summary for Antimony, Alkalinity, Chlorophyll A and Total Iron (April 24 – April 26, 2000)

	Antimony (µg/L)		Alkalinity (mg/L)		Chlorophyll A (µg/L)		Total Iron (mg/L)*	
	Feedwater	Filtrate	Feedwater	Filtrate	Feedwater	Filtrate	Feedwater	Filtrate (prior to $FeCl_3$ addition)
Average	8.9	8.6	145	138	0.6	0.3	0.268	0.02
Minimum	8.7	8.4	143	136	0.3	0.3	0.231	<0.02
Maximum	9.3	8.8	147	144	0.8	0.3	0.358	0.021
Std. Dev.	0.2	0.1	1	2	0.4	0.0	0.045	0.00
95% Confidence Interval	8.8, 9.0	8.5, 8.6	144, 145	137, 140	0.1, 1.0	NA	0.241, 0.294	NA

*All readings for Total Iron at the MDL (0.02 mg/L) were used at that number in calculations.
NA because Standard Deviation = 0

The test indicated that antimony is not removed by the system.

Alkalinity was slightly removed (4.8% reduction from feedwater to filtrate on average), which may be attributed to the slight reduction in pH from feedwater to filtrate, as well as the addition of sodium hypochlorite to the feedwater.

Chlorophyll A concentrations were expected to be minimal in the feedwater because it is groundwater. Chlorophyll concentrations in the feedwater and filtrate streams were identical over the entire test, with one exception, a reading of 0.8 µg/L on 4/26/00.

Total iron concentrations in the feedwater streams were removed to the MDL in the filtrate stream.

Table 4-28 provides a summary of Task 4 testing results for temperature, pH and total chlorine.

Table 4-28. Task 4 Analytical Data for Temperature, pH and Chlorine (April 24- April 26, 2000)

	Temperature (°C)		pH		Total Chlorine (mg/L)	
	Feedwater	Filtrate	Feedwater	Filtrate	Feedwater	Filtrate
Average	9.6	10.5	7.33	7.22	-	1.61
Minimum	9.3	9.8	7.29	7.17	-	1.42
Maximum	9.9	10.7	7.38	7.37	-	1.82
Std. Dev.	0.1	0.3	0.03	0.06		0.12
95% Confidence Interval	9.6, 9.7	10.3, 10.7	7.31, 7.34	7.19, 7.26	-	1.54, 1.68

- = No reading was taken

The filtrate temperature averages less than 0.1 C higher than the feedwater temperature. This increase apparently the result of the residence time of the water in the treatment system located inside a heated building.

The pH of the filtrate stream averaged slightly more than 0.01 unit less than that of the feedwater stream. This slight reduction is probably due to the addition of ferric chloride coagulant, which is acidic.

Chlorine, in the form of sodium hypochlorite, was added to the feedwater to oxidize all As (III) to As (V). Table 4-28 is a summary of the residual chlorine in the filtrate stream after oxidization.

Table 4-29 summarizes all of the turbidity readings for the feedwater and filtrate streams.

Table 4-29. Task 4 Analytical Data Summary for On-line Turbidity and Bench-Top Turbidity (April 24 – April 26, 2000)

	On-line (Continuous) Turbidity (NTU)		Bench-Top Turbidity (NTU)	
	Feedwater	Filtrate	Feedwater	Filtrate
Average	1.18	0.021	1.51	0.13
Minimum	0.99	0.019	1.42	0.06
Maximum	1.66	0.025	1.76	0.60
Std. Dev.	0.16	0.002	0.09	0.16
95% Confidence Interval	1.12, 1.25	0.020, 0.021	1.45, 1.56	0.04, 0.22

Turbidity readings were made with both on-line (continuous) turbidimeters and a manual bench-top turbidimeter. There was fairly close agreement between the on-line and bench-top instruments on the feedwater turbidity data; however, a substantial difference between the two on the filtrate stream data. An explanation for this is offered in QA/QC Results, Section 4.5.3.3. Table 4-29 does illustrate that turbidity is significantly reduced by this system.

Table 4-30 shows the Dissolved Oxygen measured during Task 4 activities.

Table 4-30. Task 4 Dissolved Oxygen Data (April 24 – April 26, 2000)

	Feedwater (mg/L)	Filtrate (mg/L)
Average	6.09	6.22
Minimum	5.63	5.65
Maximum	6.54	7.02
Std. Dev.	0.35	0.47
95% Confidence Interval	5.88, 6.29	5.94, 6.50

Table 4-30 indicates that this system had no significant effect on the dissolved oxygen concentration in the feedwater stream.

Table 4-31 shows the miscellaneous parameters that were measured by the State of Utah Laboratory as part of Task 4 activities.

Table 4-31. Task 4 Analytical Data – Miscellaneous Parameters (April 24 – April 26, 2000)

Date	Time	Parameter	Units	Feedwater	Filtrate
4/24/00	0900	TOC	mg/L	<0.5*	<0.5
4/26/00	0900	TOC	mg/L	<0.5*	<0.5
4/24/00	0900	UV_{254} Absorbance	cm^{-1}	0.007	0.006
4/26/00	0900	UV_{254} Absorbance	cm^{-1}	0.005	0.007
4/24/00	0900	Hardness*	mg/L	443	439
4/26/00	0900	Hardness	mg/L	441	446
4/24/00	0900	Aluminum	mg/L	<0.030**	<0.030**
4/26/00	0900	Aluminum	mg/L	<0.030**	<0.030**
4/24/00	0900	Manganese	mg/L	0.0134	<0.0050**
4/26/00	0900	Manganese	mg/L	0.0163	<0.0050**
4/24/00	0900	Sulfate	mg/L	277.0	272
4/26/00	0900	Sulfate	mg/L	281.0	273.0
4/26/00	0900	Silica (total)	mg/L	19.6	19.7
4/26/00	0900	Silica (dissolved)	mg/L	19.3	19.1

* Hardness calculated from laboratory readings of calcium and magnesium using *SM* for the Analysis of Water and Wastewater (18th Ed, Method 2340B)

** Sample reported below the MDL.

As an indication of the extremely low organic content of this water, Total Organic Carbon (TOC) measurements were below the detection limit and UV_{254} Absorbance data were very low.

Hardness and sulfate parameters appeared to be unaffected by the coagulation/filtration process; aluminum levels were below the detection limit in both the feedwater and filtrate streams, and manganese appears to have precipitated out, more than likely as manganese hydroxide.

Since the concentration of manganese in the feedwater was less than 10% of the iron concentration, manganese probably had little or no effect on arsenic removal. The iron present in the feedwater was of sufficient concentration to react with the arsenic, particularly in the presence of chlorine, which oxidized the iron to the ferric form. The addition of ferric chloride ensured that there would be an excess of iron to complete the coagulation process.

From Table 4-31, it is evident that neither total or dissolved silica concentrations were affected by the Watermark system.

4.4 Results of Equipment Characterization

During the verification testing, the factors associated with the qualitative, quantitative and cost characteristics of the Watermark eVox® Model 5 Coagulation/Filtration System were identified, within the limits of the short duration of the test.

4.4.1 Qualitative Factors

The qualitative factors examined were the susceptibility of the equipment to environmental condition changes, operational reliability and equipment safety.

4.4.1.1 Susceptibility to Changes in Environmental Conditions

Changes in environmental conditions that cause changes in feedwater quality can affect the performance of coagulation/filtration systems.

The optimum performance of any coagulant chemistry is a function of many chemical and environmental variables such as pH, temperature, ORP level and any chemical constituents which might interfere with the formation of the ferric hydroxide/arsenic complex. This has resulted in the requirement for the Initial Operations period of the verification testing program wherein the coagulant chemistries and dosages were optimized.

Since the source was groundwater, even though ambient conditions were changing, the feedwater temperature remained relatively unchanged throughout the test. Also, the equipment was located indoors, so it was unaffected by weather changes.

4.4.1.2 Operational Reliability

The equipment ran continuously throughout the duration of the test, with only a 50-minute interruption for feed pump replacement on April 14, 2000. On April 20, 2000, a pinhole leak occurred in the $FeCl_3$ discharge tubing line from the metering pump. This was quickly repaired (refer to Section 4.3.2 for more detail).

Once flows, pressures and backwash conditions were established during the Initial Operations period, no adjustments were made throughout the duration of the test.

4.4.1.3 Equipment Safety

Evaluation of the safety of the treatment system was done by examination of the components of the system and identification of hazards associated with these components. A judgment as to the safety of the treatment system was made from these evaluations.

There are safety hazards associated with electrical service and pressurized water. The electrical service was connected by a qualified electrical contractor according to local code requirements and did not present an unusual safety risk. Based on the pressure data recorded during the test, the water pressure inside the treatment system was relatively low (<40 psi) and did not present an unusual safety risk. (See Appendix G).

The coagulation chemicals, sodium hypochlorite and ferric chloride, are considered hazardous; however, safe handling procedures (as outlined in the MSDS) were followed when replenishing the feed tanks and no problems were encountered.

No injuries or accidents occurred during the testing.

4.4.2 Quantitative Factors

Quantitative Factors examined during the verification testing were power, consumables, waste disposal and length of operating cycle.

4.4.2.1 Electrical Power

The electrical power used was 110VAC, single phase, 20A service. The power was recorded on an Amprobe Kilowatt/Hour Meter (non-demand). The total power consumed was 359 kWh.

4.4.2.2 Consumables

- Total quantity of filtrate produced:
  1.1 gpm x 60 min/hr x 352.5 hr = 23, 265 gallons.
- Total quantity of sodium hypochlorite consumed:
  0.005 gph x 328.5 hr = 1.64 gallons of 0.42% bleach = 0.13 gallons of 5.25% bleach.
  1.64 x 0.0042 = 0.0069 gallons (100% NaOCl basis) ÷ 23,265 gallons of filtrate = 3×10^{-7} gallons of 100% sodium hypochlorite per gallon of filtrate produced.
- Total quantity of ferric chloride consumed:
  0.094 gph x 328.5 = 30.879 gallons of 0.7% $FeCl_3$ = 0.67 gallons of 32.5% $FeCl_3$.
  30.879 x 0.007 = 0.22 gallons (100% $FeCl_3$ basis) ÷ 21,681 gallons of filtrate = 1×10^{-5} gallons of 100% $FeCl_3$ per gallon of filtrate produced.

The above data do not include the water, ferric chloride and sodium hypochlorite directed to the drain in order to maintain the optimum feed pump pressure.

4.4.2.3 Waste Disposal

The waste generated during the verification testing period was the backwash stream at approximately 16 gallons per episode. Since the system backwash was activated by a timer set for four (4) hour intervals and the total test period was 352.5 hours, a total of 88 backwashes occurred, producing a total volume of 1408 gallons. Because it is not representative of the operating characteristics of a treatment system used in an actual drinking water application, the excess feedwater flow discussed above is not included in the above calculation.

The backwash effluent collection tank was equipped with a level control and timer that allowed the precipitate to settle into an approximate 1,500-gallon reservoir at the bottom of the tank prior to automatically pumping the supernatant liquid out and to the Snyderville Sewer Improvement District for discharge. The settling time allowed for each backwashing episode was two hours. Over the total test period (352.5 hours), a total of 18.9 L of a 1% sludge was collected, equivalent to 2.1×10^{-6} gallons of sludge (100% basis) per gallon of filtrate.

4.4.2.4 Length of Operating Cycle

The four-hour automatic backwash cycle was the primary determinant of operating run length. With one exception, at the beginning of the test, all backwashing episodes were initiated by the four-hour timer.

4.5 QA/QC Results

The objective of this task is to assure the high quality and integrity of all measurements of operational and water quality parameters during the ETV project. QA/QC verifications were recorded in the laboratory logbooks. The results of QA/QC verification performed on on-line instrumentation, hand-held instruments and the analytical Laboratory are presented below, and a detailed discussion of the QA/QC procedures and apparent discrepancies is in Appendix H.

4.5.1 Arsenic Speciation and Analysis

On a daily basis, feed, concentrate and permeate samples were collected and speciated on-site. All samples were then delivered to the State Laboratory for analysis. The laboratory analyzed for total arsenic, dissolved arsenic and As(III). As(V) data were obtained by subtracting As(III) readings from the dissolved arsenic figure.

In almost all permeate samples, the dissolved arsenic figures were higher than the total arsenic figures. The State Laboratory investigated this anomaly in detail and postulates that the presence of the H_2SO_4 preservative in bottle b (bottles a and c had HNO_3 preservative) affected the accuracy of the ICP-MS analytical equipment. This explanation, arsenic speciation protocol and Laboratory QA/QC procedures are detailed in Appendix H.

The Quality Control review by NSF raised the question of whether or not the laboratory could actually document a reporting limit of 0.5 mg/L for total arsenic, dissolved arsenic and the arsenic species. The reviewer indicated that in the review comments that sulfate interference had not been proven in his opinion. It was also stated that a reporting limit (actual quantitation limit) is typically 10 - 30 times the MDL. Therefore, a reporting of limit of 3 - 5 mg/L maybe more appropriate. At this level, all of the data would be reported as "less than values" for the filtrate and the difference between the total and dissolved arsenic would be eliminated.

4.5.2 Data Correctness

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

- Representativeness
- Statistical Uncertainty
- Accuracy
- Precision

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

4.5.2.1 Representativeness

Operational parameters graphs and discussions are included under Task 3 – Documentation of Operations Conditions and Treatment Equipment Performance. Testing equipment verification is presented below in discussions in Daily QA/QC Results and Results of QA/QC Verification At The Start Of Each Testing Period.

4.5.2.2 Statistical Uncertainty

Ninety-five percent confidence intervals were calculated for the water quality parameters of the Watermark eVox® Model 5 Coagulation/Filtration System as presented in the water sample summary tables in the discussion of Task 2 – Feed and Finished Water Quality Characterization.

4.5.2.3 Accuracy

For this ETV study, accuracy refers to the difference between the sample result and the true or reference value. Calculations of data accuracy were made to ensure the accuracy of the testing equipment in this study. Accuracy of testing equipment verification is presented below in discussions on Daily QA/QC Results and Results of QA/QC Verification At The Start Of Each Testing Period.

4.5.2.4 Precision

Precision is a measure of the degree of consistency from test to test, and can be measured by replication. For single reading parameters, such as pressure and flow rates, precision was ensured by redundant readings from operator to operator. Calibration procedures for those on-site parameters consequential to the testing (bench-top turbidity and pH) are presented in discussions on Daily QA/QC Results and Results of QA/QC Verification At The Start Of Each Testing Period.

4.5.3 Daily QA/QC Results

The on-line feedwater turbidity readings were checked daily against the bench-top turbidimeter. The readout from the HF Scientific, Inc., Micro 200 on-line influent turbidity averaged 1.51 NTU during the verification period of April 12 through April 26, 2000; the average from the Hach 2100P benchtop turbidimeter was 1.66 NTU. The discrepancy between the two turbidimeters (on-line and benchtop) of 1.51 NTU and 1.66 NTU is acceptable and within limits (further discussions in Section 4.5.3.3).

The on-line filtrate turbidity readings were checked daily against the bench-top turbidimeter. The readout from the Hach Model 1720D on-line influent turbidity averaged 0.060 NTU during the verification period of April 12 through April 26, 2000; the average from the Hach 2100P benchtop turbidimeter was 0.13 NTU. This discrepancy is further explained in Section 4.5.3.3.

The pH meter was calibrated daily against NIST-traceable pH buffers at 7.00 and 10.00 daily. The pH meter was a Cole Palmer Oaktron® WD-35615 Series. The pH calibration buffers were Oakton pH Singles 7.00 (model #35653-02), and pH Singles 10.00 (model #35653-03). pH was measured from filtrate and feedwater water sample tap.

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

4.5.4.1 Tubing

The tubing and all water lines used on the treatment system were inspected before verification testing began (April 11, 2000). The tubing and lines were good condition and replacements were not necessary. Documentation of this activity was inadvertently omitted from the Laboratory Notebook. The tubing associated with the in-line plant turbidimeters were inspected with every calibration by the personnel of the water treatment plant.

4.5.4.2 Thermometer

Temperatures were measured in accordance with *SM* 2550, on the feed and filtrate streams, with a Radio Shack model No. 63-1009A digital indoor-outdoor thermometer. This instrument read in 0.1°C increments and was calibrated by the State of Utah Laboratory as well as in an ice bath and against a NIST-traceable Thermometer (Tel-Tru model 0054-5).

4.5.4.3 Turbidimeters

Both on-line and bench top turbidimeters were used during the Watermark eVox® Model 5 Coagulation/Filtration System ETV test.

Two on-line turbidimeters were utilized:

1) A wall mounted HF Scientific, Inc., Micro 200 turbidimeter was used to continuously measure turbidity of the feedwater. This instrument was cleaned and calibrated at the beginning of the verification testing period by Spiro Water Tunnel Filtration Plant personnel with standards of 0.01, 0.10, 10.0 and 100.0 NTU, and then cleaned and calibrated weekly, or after a significant turbidity spike.
2) A Hach Model 1720D turbidimeter purchased new for this test, mounted on the filtrate stream, and calibrated initially and weekly with standard solutions of 0.04, 0.40 and 4.0 NTU.

A new Hach 2100P turbidimeter was utilized to measure grab samples of both feedwater and filtrate at least once per day. The instrument calibration was verified on March 15, 2000, with primary standards of 800, 100, 20 and <0.1 NTU, weekly with secondary standards measuring 526, 52.2, 4.87 NTU, and with another secondary standard of 0.4 NTU with every use.

Discrepancies between the on-line and bench-top instruments were noted, particularly in the filtrate samples, as indicated in Table 4-29. Several explanations for these are offered which include:

1) Difference in the analytical techniques between the on-line and bench-top turbidimeters:
   The bench-top turbidimeter uses a glass cuvette to hold the sample; this cuvette can present some optical difficulties for this instrument. The on-line turbidimeter has no cuvette to present a possible interference with the optics of the instrument. The low level of turbidity can create analytical difficulties, particularly for the bench-top/ Manufacturer's specifications state that stray light interference is less than 0.02 NTU. Stray light interference approaching this level at the low turbidity levels tested could account for the differences in the readings.
2) Geologic activity in the Spiro Tunnel caused short-term turbidity spikes in the feedwater, which may have affected the accuracy of the on-line plant turbidimeter between routine cleanings. For example, a turbidity spike occurred at 0300 on April 2, 2000, which shut the filtration plant down (the alarm/shutdown turbidity level was set at 5.0 NTU). The turbidimeter was cleaned and returned to service.
3) Although attempts were made to collect bench-top turbidity samples at the same time that on-line turbidimeter readings were made, the logistics of the sampling locations resulting in small time differences may have resulted in slight changes in water quality between these events.
4) During Task 4 activities, when a total of 11 readings were taken in a 48-hour period, the calibration verification data were recorded with every bench-top turbidimeter reading. In addition, some calibration verification readings were taken by filling the same cuvette twice and comparing the two

readings of the same standard solution (0.4 NTU). These data are listed in Table 4-32 and summarized in Table 4-33.

Table 4-32. Bench-Top Turbidimeter Calibration Verification Data (using 0.4 NTU standard)

Date	Time	Reading (NTU)
4/24/00	0900	0.37
	1000	0.36
	1200	0.36
	1500	0.34
	2100	0.35
4/25/00	0300	0.35
	0900	0.34
	1500	0.30, 0.36 (same cuvette)
	2100	0.34, 0.33 (same cuvette)
4/26/00	0300	0.33, 0.30 (same cuvette)
	0900	0.31, 0.30 (same cuvette)

Table 4-33. Bench-Top Turbidimeter Calibration Verification Data Summary

	Reading (NTU)
Average	0.34
Minimum	0.30
Maximum	0.37
Standard Deviation	0.02
95% Confidence Interval	0.32, 0.35

4.5.4.4 True Color

True color was measured in accordance with *SM* 2120 at 455nm wavelength with a Hach DR2010 spectrophotometer. Altogether 17 samples were measured; the reading varied from –4 to +3 PtCo color units and seven were negative numbers. The Hach standard solution (500 PtCo color units) was diluted with ultrapure water to produce a solution that should read 1.0 PtCo color units; however, readings on this aliquot varied from –2 to 1.0. The same results were obtained when both ultrapure water and distilled water were tested alone. The conclusions drawn from the above were:

1) The Hach DR2010 unit cannot accurately measure color below a level of 2 PtCo color units.
2) Since the water source is groundwater and low in organics, the true color is expected to be very low, and in this case, below the accuracy of the instrument.

Further evidence of the low organics concentration is supplied by the fact that all TOC analyses were below the minimum detection limit of 0.5 mg/L and all UV_{254} absorbance readings were below 0.024 units.

4.5.4.5 Total Chlorine

Total chlorine measurements were made in accordance with *SM* 4500 on a Hach DR2000 spectrophotometer which was standardized with each set of measurements in accordance with the Method. The Test Plan required that the total chlorine be measured during Task 4 activities when samples were collected and other parameters measured. Since the feedwater was unchlorinated, and chlorine was added during the coagulation process, only the filtrate contained chlorine which was measured on-site and listed in Table 4-28.

4.5.4.6 Pressure Gauges

The pressure gauge used for this study was a glycerin-filled, NIST-traceable Ametek Model 1980L Gauge (0-60 psig). The inlet and outlet pressure gauge fittings were equipped with quick-connect fittings and the above gauge was inserted into these fittings for each reading. The certificate of calibration for this gauge is located in Appendix F.

4.5.4.7 Metering Pump

On April 26, 2000, at the completion of the testing, the chemical feed pump flow and stroke settings were verified and documented in the Laboratory Notebook. Flow rates were verified volumetrically with a graduated cylinder and stopwatch. A 1,000 mL graduated cylinder was used for the pump injecting coagulant (Ferric Chloride) and the sodium hypochlorite metering pump.

4.5.4.8Flow Rates

The “bucket and stopwatch” method for calibrating the flow meters was utilized. Unfortunately, this activity was not recorded in the Laboratory Notebook.

4.5.5 Off-Site Analysis for Chemical and Biological Samples

QA/QC procedures for laboratory analysis were based on *SM*, 18th Ed., (APHA, 1992) and EPA Methods for Chemical Analysis of Water and Wastes, (EPA, 1995).

4.5.5.1 Organic Parameters, Total Organic Carbon and UV_{254} Absorbance

Samples for these analyses were collected in glass bottles supplied by the State of Utah Laboratory and delivered to the Laboratory by COA. Although the Test Plan required only one analysis of these parameters, two analyses were made of each during the Task 4 activities and are listed in Table 4-27.

4.5.5.2 Algae (Chlorophyll) Samples

Samples were collected in opaque containers supplied by the State Laboratory and kept at 0°C in the on-site refrigerator prior to delivery to the laboratory.

4.5.5.3 Inorganic Samples

Inorganic samples were collected, held in the refrigerator at 4°C, and shipped in accordance with *SM* 3010B and C and 1060 and EPA §136.3, 40 CFR Chapter 1. Proper bottles and preservatives, where required (iron and manganese for example) were used. Although the travel time was brief, samples were shipped in coolers at 4°C.

Chapter 5
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