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Environmental Technology Verification Report

Removal of Arsenic in Drinking Water

ADI International Inc.
ADI Pilot Test Unit No. 2002-09
with MEDIA G2®

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: **ARSENIC ADSORPTION MEDIA FILTER USED IN DRINKING WATER TREATMENT SYSTEMS**

APPLICATION: **REMOVAL OF ARSENIC IN DRINKING WATER**

TECHNOLOGY NAME: **ADI PILOT TEST UNIT NO. 2002-09 WITH MEDIA G2®**

COMPANY: **ADI INTERNATIONAL INC.**

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

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

NSF International (NSF), in cooperation with the EPA, operates the Drinking Water Systems (DWS) Center, one of seven technology areas under the ETV Program. The DWS Center recently evaluated the performance of an adsorption media filter system for the reduction of arsenic in drinking water. This verification statement provides a summary of the test results for the ADI Pilot Test Unit No. 2002-09 with MEDIA G2® system. Gannett Fleming, Inc., an NSF-qualified field testing organization (FTO), performed the verification testing. The verification report contains a comprehensive summary of the verification test.

ABSTRACT

Verification testing of the ADI International Inc. Pilot Test Unit No. 2002-09 with MEDIA G2® arsenic adsorption media filter system was conducted at the Hilltown Township Water and Sewer Authority (HTWSA) Well Station No. 1 in Sellersville, Pennsylvania from October 8, 2003 through May 28, 2004. The source water was groundwater from Well No. 1, one of HTWSA's three groundwater supply wells. The treatment unit feed water for the verification test was withdrawn from an on-site chlorine detention tank, which contained groundwater that had been disinfected with sodium hypochlorite. Verification testing was conducted under manufacturer-specified operating conditions. The feed water, with an average total arsenic concentration of 21 μg/L and a pH of 7.6, was treated with sulfuric acid to lower the pH to 6.4 prior to the treatment unit. When operated under the manufacturer's specified conditions for this site and at the design flow rate of 1.7 gpm, the ADI International Inc. Pilot Test Unit No. 2002-09 with MEDIA G2® system reduced the total arsenic concentration from an average of 21 μg/L in the feed water to an average of 7 μg/L in the treated water.

TECHNOLOGY DESCRIPTION

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

MEDIA G2® is an iron-based adsorption treatment technology for removing arsenic from drinking water supplies, specifically groundwater. MEDIA G2® arsenic adsorption media consists of an inorganic, natural substrate to which iron (ferric hydroxide) has been chemically bonded. The iron attracts metallic ions in water and binds them to the substrate by chemisorption. The arsenic adsorption filter pilot unit used in this test consisted of one vessel containing MEDIA G2® adsorption media which was operated in a downflow mode. Arsenic is removed by the technology by adsorption onto the filter media as water passes through the media. Over time, as the media becomes saturated with arsenic, the concentration of arsenic in the treated water begins to increase. Before the treated water arsenic concentration reaches the pre-determined maximum allowable contaminant level (breakthrough), the media is either replaced or regenerated on-site. ADI has stated that MEDIA G2® can be regenerated four to five times, with a loss in capacity of approximately 10% following each regeneration.

MEDIA G2® is a registered trade mark of ADI International Inc. and is protected by US Patent No. 6,200,482. MEDIA G2® adsorption media is certified under NSF/ANSI Standard 61 for water treatment plant applications. MEDIA G2® treatment units can be used for groundwater supplies of any size and require limited manpower and operating skills. The filter system can operate continuously or intermittently. The filter tank is freestanding, and filter components, which are modular in nature, can be installed by a qualified plumber. The filter system requires only a level surface capable of supporting its weight, sustained ambient temperature above 35°F, a feed water pressure between 20 and 125 psi, and flow rate control.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification testing site was the HTWSA Well No. 1 in Sellersville, Pennsylvania. The source water was groundwater from Well No. 1, which was first disinfected with sodium hypochlorite. Well No. 1 is one of three wells currently used to supply the HTWSA water distribution system. The feed water quality was particularly variable for a groundwater supply. During the verification test, the turbidity ranged from 0.15 NTU to 7.6 NTU and averaged 0.70 NTU. The feed water iron concentration ranged from 47 µg/L to 1,120 µg/L and averaged 180 µg/L. The feed water manganese concentration ranged from 77 µg/L to 1,070 µg/L and averaged 140 µg/L. The feed water was characterized as having a high level of hardness, 270 mg/L as $CaCO_3$, and a high degree of buffering as indicated by an alkalinity of 120 mg/L as $CaCO_3$. The raw water pH was relatively stable at 7.6, but the feed water pH varied due to the operation of the acid feed pump. It ranged from 5.7 to 7.1, with an average of 6.4. The feed water total arsenic concentration ranged from 12 µg/L to 63 µg/L and averaged 21 µg/L.

Methods and Procedures

Operations, sampling, and analytical procedures were performed in a manner that ensured the quality of the data collected and provided an accurate evaluation of the treatment system under field conditions. The verification test consisted of three main phases. The first phase, the Integrity Test, evaluated the reliability of equipment operation under the environmental and hydraulic conditions at the well station site during the initial two weeks of testing. The second phase, the Capacity Test, evaluated the capacity of the arsenic adsorption system with respect to arsenic. The third phase of the test monitored the performance of the system for one month following regeneration.

The Integrity Test ran for 13 full days plus eight hours, during which the field test operator was on-site twice per day to monitor the test equipment, collect data, and collect water samples for analysis. The Capacity Test began in conjunction with the Integrity Test on October 8, 2003 and continued through the media regeneration on April 30, 2004. One month of post-regeneration operation began on April 30, 2004 and continued through May 28, 2004. The treatment system was operated continuously, independent of the well operations, using water supplied from the well station's pressurized chlorine detention tank. Flow rate, production volume, and pressure were monitored and recorded twice per day. Raw, feed (before and after addition of sulfuric acid), and treated water samples were analyzed for pH, temperature, turbidity, alkalinity, calcium, magnesium, hardness, free available chlorine, and fluoride by the field test operator. Samples were collected and delivered to the Pennsylvania Department of Environmental Protection Laboratory to be analyzed for silica, sodium, aluminum, iron, manganese, chloride, sulfate, and total phosphorus. Arsenic samples were collected and sent to NSF's laboratories for analysis. A total of 14 sets of arsenic samples were speciated during the test to determine the relative concentration of soluble arsenic compared to total arsenic, and, with respect to the soluble arsenic, the relative amounts of arsenic III and arsenic V.

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

VERIFICATION OF PERFORMANCE

System Operation

The verification test was conducted under the manufacturer's specified operating conditions. Contact time is a critical parameter for arsenic adsorption efficiency and is dependent upon maintaining the flow rate within the design range of 1.7 gpm ± 0.1 gpm. A pressure-reducing valve was used to reduce the pressure from the chlorine detention tank from 110 psi to 50 psi to make throttling the flow rate easier for the operator. A relatively constant flow rate was maintained, with minimal flow rate adjustments required. The system was operated continuously, 24 hours each day, for the entire test. The filter unit was manually backwashed and rinsed 15 times throughout the test, based on the accumulation of filter bed headloss.

Water Quality Results

The results of total arsenic analyses are shown in Figure VS-1. During the Capacity Test, the feed water total arsenic concentration averaged 21 µg/L, with 13 µg/L in the soluble state. Pretreatment with hypochlorite completely converted the feed water soluble arsenic to the arsenic V species. The treated water total arsenic concentration averaged 7 µg/L during the Capacity Test, all of which was in the soluble state. For calculation of the media capacity to remove arsenic from the feed water, 430,000 gallons were treated from October 8, 2003 through April 22, 2004 during the Capacity Test. The treated water volume represents 25,000 media bed volumes, based on the calculated bed volume of 2.3 cubic feet and an empty bed contact time of ten minutes. Based on the feed and treated water total arsenic concentrations during the Capacity Test, the capacity of the media for this system, through April 22, 2004, was 470 µg arsenic per gram of media.

One media regeneration was performed during the verification test. As shown in Figure VS-1, treated water arsenic concentrations were elevated for several hours following the media regeneration. However, the post-regeneration treated water arsenic concentration (April 30, 2004 through May 28, 2004) returned to a level similar to that observed at the beginning of the Capacity Test, averaging 4 µg/L, which indicates that the media regeneration was successful.

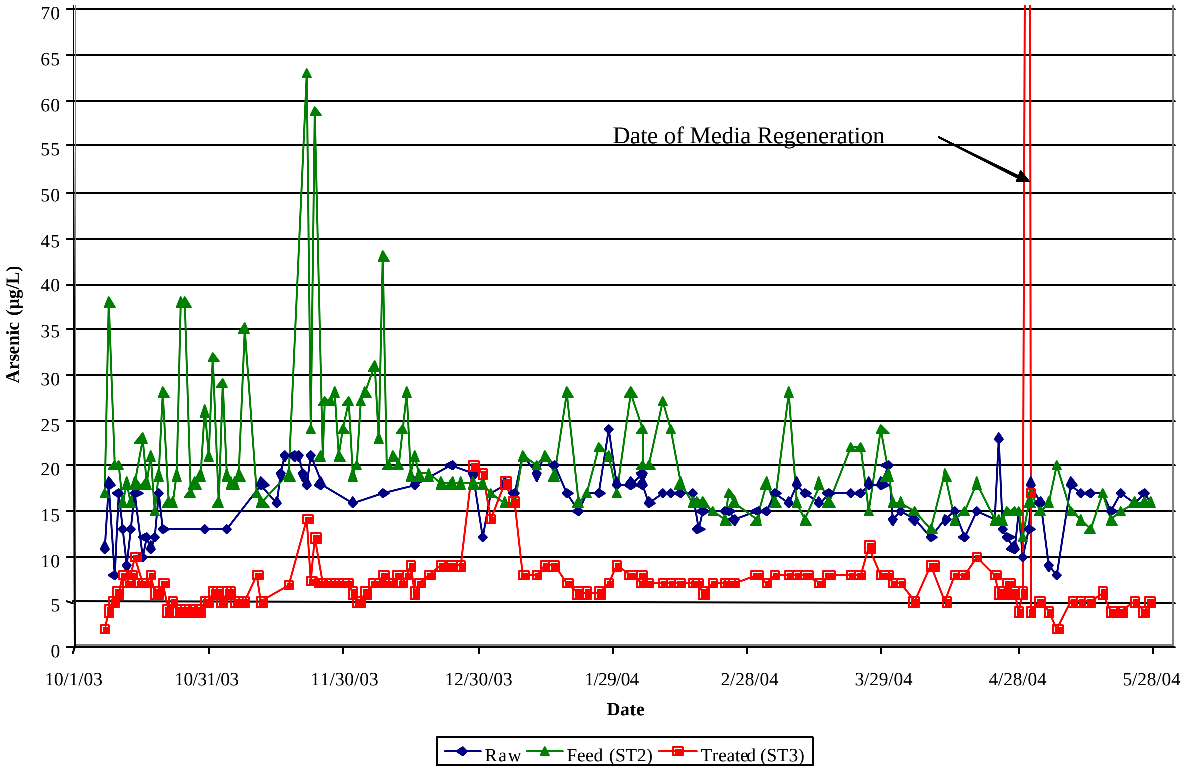

Figure VS-1. Capacity Test Arsenic Concentration.

The addition of sulfuric acid prior to the treatment unit reduced the pH of the raw water from an average of 7.6 to 6.4 in the feed water. The pH reduction corresponded with a 21% reduction in alkalinity. The sulfate concentration increased from an average of 100 mg/L in the raw water to 160 mg/L in the feed water, following the addition of sulfuric acid. The feed water pH appeared to have a significant impact on the treatment unit's ability to remove arsenic. The highest treated water arsenic concentrations occurred when the feed water pH was highest. The manufacturer indicated that the feed water pH should be maintained between 6.5 and 6.8 for optimum arsenic removal, but difficulties encountered with the acid feed pump operation resulted in several periods during the verification test when the pH was above this range. As an example of the correlation, a decrease in feed water pH from 7.1 to 6.2 on the ninth day of the test resulted in a 70% decrease in the treated water arsenic concentration. Thereafter, correlations in treated water arsenic with the feed water pH were not as significant but continued to occur. At the request

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

of the manufacturer, testing was carried out at reduced pH from April 23, 2004 through April 30, 2004. During the reduced pH operation, the treated water arsenic concentration averaged 6 µg/L.

Feed water calcium and hardness concentrations were reduced only slightly through the adsorption filter. The average feed water iron and manganese concentrations during the Capacity Test, 180 µg/L and 140 µg/L, respectively, were significantly reduced by the adsorption filter. The treated water iron concentration averaged 68 µg/L and the treated water manganese concentration averaged 16 µg/L. Turbidity was also reduced by the adsorption filter during the Capacity Test, from an average of 0.70 NTU in the feed water to 0.30 NTU in the treated water. The silica concentration increased by an average of 15%, from a feed concentration of 28 mg/L to a treated water concentration of 33 mg/L. Sodium, fluoride, chloride, aluminum, and sulfate concentrations were generally unaffected by the adsorption filter.

Operation and Maintenance Results

The verification test began on October 8, 2003 and ended on May 28, 2004. The treatment unit operated manually, including backwash cycles, throughout the test. The majority of operator time and attention was spent on water quality and equipment testing. Equipment operation required minimal operator attention overall, with the exception of the sulfuric acid metering pump, which required frequent re-priming and feed rate adjustment to maintain the feed water pH within the manufacturer's stated operating range. Periodic manual filter backwashes each required 1.5 to 2 hours of operator time, and media regeneration required approximately five hours. Fifteen manual filter backwashes and one media regeneration were performed during the verification test. The backwash water was relatively turbid and contained elevated concentrations of iron, manganese, aluminum, and arsenic. Arsenic in the backwash water was primarily in particulate form, which indicates the removal of particulate material from the filter, not desorption of arsenic from the media. The treated water arsenic concentration returned to approximately that of the new media following the media regeneration, which indicates a successful regeneration. However, a spike in the treated water arsenic concentration occurred when the unit was returned to service following the media regeneration. Modification of the media regeneration procedures and increased on-site monitoring of the treated water arsenic concentration may be required to prevent returning a unit to service with an elevated treated water arsenic concentration immediately following regeneration. Other than monitoring the metering pump and performing filter backwashes, regular operator attention was primarily required to verify, adjust, and maintain a constant flow rate.

Consumables and Waste Generation

Electrical power was required only for the metering pump and a solenoid valve. The solenoid valve was provided to automatically shut off the feed water supply in the event of a power outage to prevent water from entering the treatment unit without pH adjustments. Wastewater from each filter backwash and rinse was discharged to a sanitary sewer adjacent to the well station. The total water usage for each backwash and rinse was approximately 200 gallons, for a total backwash and rinse water usage of 2,800 gallons. The backwash and rinse water usage represents 0.5% of the total throughput of 520,000 gallons during the test, including the Integrity, Capacity, and post-regeneration phases.

The media regeneration, which was performed once during the verification test following seven months of operation, required three bed volumes (50 gallons) of 1% caustic soda, 20 gallons of 0.5% sulfuric acid solution, and rinse water.

Quality Assurance/Quality Control

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

Original Signed by
Sally Gutierrez *8/19/05*

Sally Gutierrez Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original Signed by
Robert Ferguson *8/30/05*

Robert Ferguson Date
Vice President
Water Systems
NSF International

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

Availability of Supporting Documents
Copies of the *ETV Protocol for Equipment Verification Testing for Arsenic Removal* dated April 2002, the verification statement, and the verification report (NSF Report #05/10/EPADWCTR) are available from the following sources:
(NOTE: Appendices are not included in the verification report. Appendices are available from NSF upon request.)

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

June 2005

Environmental Technology Verification Report

Removal of Arsenic in Drinking Water

ADI International Inc.
ADI Pilot Test Unit No. 2002-09 with MEDIA G2®

Prepared for:

NSF International
Ann Arbor, Michigan 48105

Prepared by:

Gannett Fleming, Inc.
Harrisburg, Pennsylvania 17106-7100

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

Foreword

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

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

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

Sally Gutierrez, Director
National Risk Management Research Laboratory

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Acronyms and Abbreviations

ANSI	American National Standards Institute
AWWA	American Water Works Association
CA WET	California Waste Extraction Tests
°C	Degrees Celsius
EBCT	Empty Bed Contact Time
EPA	U. S. Environmental Protection Agency
ETV	Environmental Technology Verification
°F	Degrees Fahrenheit
ft	Feet
FTO	Field Testing Organization
g	Gram
gpm	Gallons per Minute
HDPE	High Density Polyethylene
HTWSA	Hilltown Township Water and Sewer Authority
ISE	Ion Selective Electrode
ITS	Industrial Test Systems, Inc.
L	Liter
lb	Pound
m	Meter
MCL	Maximum Contaminant Level
mgd	Million Gallons per Day
mg/L	Milligram per Liter
mL	Milliliter
MDL	Method Detection Level
MSDS	Material Safety Data Sheets
N/A	Not Applicable
ND	Non-Detect
NEMA	National Electrical Manufacturers Association
NIST	National Institute of Standards and Technology
NRMRL	National Risk Management Research Laboratory
NSF	NSF International
NTIS	National Technical Information Service
NTU	Nephelometric Turbidity Unit
O&M	Operation and Maintenance
PADEP	PA Department of Environmental Protection
PE	Performance Evaluation
PRV	Pressure Reducing Valve
psi	Pounds per Square Inch
PSTP	Product Specific Test Plan
PVC	Poly Vinyl Chloride
QA	Quality Assurance
QC	Quality Control
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan

Acronyms and Abbreviations (continued)

SAC	Standard Analysis Code
SCADA	Supervisory Control and Data Acquisition
SMCL	Secondary Maximum Contaminant Level
SM	*Standard Methods for the Examination of Water and Wastewater*
SOP	Standard Operating Procedure
TCLP	Toxicity Characteristic Leaching Procedure
TSTP	Technology Specific Test Plan
µg/L	Microgram per Liter

Acknowledgements

The Field Testing Organization (FTO), Gannett Fleming, Inc., 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.

Gannett Fleming, Inc.
P.O. Box 67100
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Phone: (717) 763-7212, Ext. 2109
Fax: (717) 763-1808
Contact: William Allis, Project Manager
E-mail: wallis@gfnet.com

The laboratory selected for analysis of the water quality parameters, with the exception of arsenic, a U.S. Environmental Protection Agency (EPA) accredited and Pennsylvania Department of Environmental Protection (PADEP) certified laboratory, was:

PADEP Laboratories
Inorganic Services Division

Mailing Address:
P.O. Box 1467
Harrisburg, PA 17105-1467

Express Mail Address:
1500 North 3rd Street
Harrisburg, PA 17102

Phone: (717) 705-2197
Fax: (717) 783-1502
Contact: Ted Lyter, Inorganic Services Division Chief
E-mail: plyter@state.pa.us

Regeneration wastewater toxicity analyses were performed by:

TriMatrix Laboratories, Inc.
5555 Glenwood Hills Parkway, SE
Grand Rapids, MI 49588
Phone: (616) 975-4500
Fax: (810) 220-2803
Contact: Michael W. Movinski, Vice President, Sales and Marketing
Email: mmtrimatrix@comcast.net

Arsenic analyses were performed by the NSF laboratory.

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

The manufacturer of the equipment was:

ADI International Inc.
Suite 300
1133 Regent Street
Fredericton, NB E3B 3Z2 Canada
Phone: (506) 452-9000
Fax: (506) 459-3954
Contact: Michael McMullin, P. Eng.
E-mail: mjm@adi.ca

Gannett Fleming wishes to thank the following participants:

NSF, especially Bruce Bartley, Angela Beach and Dale Scherger, for providing guidance and program management.

PADEP, especially Ted Lyter and Dennis Neuin, for providing laboratory services.

David “Butch” Erwin, Operations Manager, Hilltown Township Water and Sewer Authority (HTWSA).

Chapter 1
Introduction

1.1 ETV Purpose and Program Operation

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

ETV works in partnership with recognized standards and testing organizations; with stakeholder groups consisting of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans responsive to the needs of stakeholders, conducting field 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.

EPA has partnered with NSF International (NSF) under the ETV Drinking Water Systems (DWS) Center to verify performance of small drinking water systems that serve small communities. A goal of verification testing is to enhance and facilitate the acceptance of small drinking water treatment equipment by state drinking water regulatory officials and consulting engineers, while reducing the need for testing of equipment at each location where the equipment's use is contemplated. NSF meets this goal by working with manufacturers and NSF-qualified Field Testing Organizations (FTOs) to conduct verification testing under the approved protocols. It is important to note that verification of the equipment does not mean the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the FTO.

The DWS Center evaluated the performance of the ADI International Inc. (ADI) Pilot Test Unit No. 2002-09 with MEDIA G2® system, which is an adsorption media filter for the reduction of arsenic in drinking water. The verification test evaluated the ability of the adsorptive media to remove arsenic from drinking water. This document provides the verification test results for the ADI Pilot Test Unit No. 2002-09 with MEDIA G2® system.

1.2 Testing Participants and Responsibilities

The ETV testing of the ADI International Inc. Pilot Test Unit No. 2002-09 with MEDIA G2® was a cooperative effort among the following participants:

NSF International
Gannett Fleming, Inc.

ADI International Inc.
Pennsylvania Department of Environmental Protection (PADEP)
U.S. Environmental Protection Agency
Hilltown Township Water and Sewer Authority

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

1.2.1 *NSF International*

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

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

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Fax: (734) 769-0109
Contact: Bruce Bartley, Project Manager
Email: bartley@nsf.org

1.2.2 *Field Testing Organization*

Gannett Fleming, Inc., a consulting engineering firm located in Harrisburg, Pennsylvania, conducted the verification testing of the ADI International Inc. arsenic removal system. Gannett Fleming is an NSF-qualified FTO for the ETV DWS Center.

Gannett Fleming was responsible for conducting the Integrity Test for 14 calendar days (13 full days plus 8 hours) and for conducting the Capacity Test. The Integrity Test evaluated the reliability of the equipment under field conditions, while the Capacity Test produced operational and water quality data for the system through the pre-defined arsenic breakthrough concentration. The test also included one media regeneration and one month of post-regeneration monitoring. Gannett Fleming provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. Gannett Fleming was responsible for ensuring that the testing location and feed water conditions were such that the verification testing could meet its stated objectives. Gannett Fleming prepared the

PSTP; oversaw the pilot testing; managed, evaluated, interpreted, and reported on the data generated by the test; and evaluated and reported on the performance of the technology.

The Gannett Fleming field technician conducted the on-site analyses and data recording activities during the test. Gannett Fleming's Project Manager provided oversight of the daily tests.

Contact Information:
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P.O. Box 67100
Harrisburg, PA 17106-7100
Phone: (717) 763-7212, Ext. 2109
Fax: (717) 763-1808
Contact: William Allis, Project Manager
E-mail: wallis@gfnet.com

1.2.3 Manufacturer

The treatment system is the ADI Pilot Test Unit No. 2002-09 with MEDIA G2® manufactured by ADI International Inc. The manufacturer was responsible for supplying a field-ready arsenic adsorption media filter system equipped with all necessary components, including treatment equipment, instrumentation and controls, and an operations and maintenance (O&M) manual. The manufacturer was responsible for providing logistical and technical support, as needed, as well as providing technical assistance to the FTO during operation and monitoring of the equipment undergoing field verification testing.

Contact Information:
ADI International Inc.
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1133 Regent Street
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Phone: (506) 452-9000
Fax: (506) 459-3954
Contact: Michael McMullin, P.Eng.
E-mail: mjm@adi.ca

1.2.4 Analytical Laboratories

The PADEP Laboratories performed all of the laboratory water quality analyses, excluding arsenic.

Contact Information:
PADEP Laboratories
Inorganic Services Division
Mailing Address:
P.O. Box 1467
Harrisburg, PA 17105-1467

Express Mail Address:
1500 North 3rd Street
Harrisburg, PA 17102
Phone: (717) 705-2197
Fax: (717) 783-1502
Contact: Ted Lyter, Inorganic Services Division Chief
E-mail: plyter@state.pa.us

Regeneration wastewater toxicity analyses were performed by:

Contact Information:
TriMatrix Laboratories, Inc.
5555 Glenwood Hills Parkway, SE
Grand Rapids, MI 49588
Phone: (616) 975-4500
Fax: (810) 220-2803
Contact: Michael W. Movinski, Vice President, Sales and Marketing
Email: mmtrimatrix@comcast.net

NSF laboratories performed all laboratory arsenic water quality analyses.

1.2.5 Pennsylvania Department of Environmental Protection

PADEP's mission is to protect Pennsylvania's air, land, and water from pollution and to provide for the health and safety of its citizens through a cleaner environment. PADEP is the state agency largely responsible for administering Pennsylvania's environmental laws and regulations. Its responsibilities include: reducing air pollution; making sure Pennsylvania's drinking water is safe; protecting water quality in Pennsylvania's rivers and streams; making sure waste is handled properly; managing the Commonwealth's recycling programs; and helping citizens prevent pollution and comply with the Commonwealth's environmental regulations. PADEP is committed to general environmental education and encouraging effective public involvement in setting environmental policy.

PADEP provided laboratory water quality analyses, excluding arsenic, and review of the test plan and final report.

1.2.6 U.S. Environmental Protection Agency

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

1.3 Verification Testing Site

The verification test site was the Hilltown Township Water and Sewer Authority (HTWSA) Well Station No. 1 located off Brookside Drive in Hilltown Township, Bucks County, PA. Well Station No. 1 has a permitted capacity of 145 gallons per minute (gpm) and supplies a portion of HTWSA's 1,065 connections, with a population served of 3,200. The frequency and duration of Well Station No. 1 pump operation depends on the distribution system demand. HTWSA indicates that the Well Station No. 1 cumulative daily well pump run time ranges from 8 to 20 hours per day at a flow rate of 145 gpm.

HTWSA also has two other sources of supply, Well Nos. 2 and 5. Chlorine in the form of sodium hypochlorite and Calciquest, a brand of polyphosphate sequestrant, are normally fed at all three well stations.

The MEDIA G2® arsenic adsorption media filter was installed inside the Well Station No. 1 building, a masonry block building located off Brookside Drive in the Pleasant View housing development. The building is heated to a minimum temperature of 60ºF. During this test, a continuous flow of chlorinated water from the sample tap located on the chlorine detention tank of Well No. 1 was diverted to the MEDIA G2® arsenic adsorption media filter. Normally, water from this sample tap would also contain two chemicals fed at the well station: sodium hypochlorite for disinfection, and polyphosphate for sequestration and corrosion control. However, HTWSA agreed to terminate the addition of polyphosphate for the duration of the ETV test because sequestrants could possibly interfere with the arsenic adsorption removal process. In addition, HTWSA has indicated that it has not observed a significant improvement in water quality since the sequestrant feed program was initiated. The treated water from the arsenic adsorption media filter was discharged (via the station floor drain) to an existing storm water culvert. At the request of the PADEP, the backwash, rinse, and regenerant wastewaters were discharged to an existing sanitary sewer adjacent to the building.

Well No. 1 operates intermittently and is controlled through the HTWSA Supervisory Control and Data Acquisition (SCADA) system, which is interconnected with Well Station Nos. 2 and 5, and the system's one million gallon finished water, ground-level storage tank. High and low water level sensors in the finished water storage tank, set at 78 feet (ft) and 71 ft, respectively, activate/deactivate the well pumps located at each well station. Booster pumps, located in the distribution system, increase the pressure to a constant 115 pounds per square inch (psi). Prior to the installation of the SCADA system, Well No. 1 operated off high and low pressure settings on the hydropneumatic tank located within Station No. 1. The hydropneumatic tank has since been converted to a chlorine detention tank; this tank no longer has any control features associated with the well pump.

1.3.1 Feed Water

The source water for the verification test was chlorinated ground water from HTWSA's Well Station No. 1 chlorine detention tank. The Well No. 1 source water and the treatment system feed water were generally of poor quality, with a highly variable turbidity that averaged 0.70 Nephelometric Turbidity Units (NTU) and a very high level of hardness. The feed [sample tap

#2 (ST2)] water's average manganese concentration of 140 micrograms per liter (µg/L) is more than two times the Secondary Standard for drinking water. The feed (ST2) water's total arsenic concentration averaged 21 µg/L. The source water's total arsenic concentration was less than the current maximum contaminant level (MCL) of 50 µg/L, but exceeds the future limit of 10 µg/L, which will become effective in January 2006. According to the manufacturer's performance objectives, a pH adjustment of the source water was required to achieve the manufacturer's equipment operation specifications. A summary of the feed (ST2) water quality information is presented in Table 1-1. Additional feed water quality data are presented in Chapter 4. The source water quality appears to degrade in the on-site chlorine contact tank, as indicated by higher concentrations of arsenic, iron, and manganese in the feed water than in the raw water. This is discussed further in Chapter 4, Section 4.3.2.

Under normal operations, there were four sample locations during the test:

- Raw water, sampled from a tap on the well discharge pipe prior to any chemical addition and prior to the chlorine detention tank;
- Feed water (ST1), a sample tap located immediately downstream of the chlorine injection point and chlorine detention tank;
- Feed (ST2) water, a sample tap located downstream of the chlorine injection point, chlorine detention tank, and sulfuric acid feed point (immediately before entering the arsenic adsorption filter); and
- Treated water (ST3), a sample tap located immediately downstream of the arsenic adsorption filter.

1.3.2 Pilot Filter Discharges

An existing floor drain served to collect treated water from the arsenic adsorption media filter to avoid having to re-pump the water into the distribution system. The floor drain was piped outside to an existing storm water culvert. The arsenic adsorption media filter backwash and regeneration wastewaters were discharged to a sewer manhole via a garden hose that was routed through a louvered vent in the building.

Spent media was properly disposed of in a municipal landfill. The disposal of the media for manifesting purposes was the responsibility of the manufacturer.

Backwash and regeneration wastewater flow rate, volume, and duration were monitored for each manually initiated backwash during the test. Backwash and rinse wastewater quality parameters were sampled to evaluate the quantity and quality of water discharged to the sanitary sewer. These data are presented in detail in Chapter 4.

Table 1-1. Feed (ST2) Water Quality During Verification Testing

Parameter	Units	Number of Samples	Mean/ Median(1)	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Arsenic	µg/L	121	21	12	63	8	19 – 23
pH	units	218	6.43	5.70	7.09	N/A	N/A
FAC	mg/L	218	0.85	0.05	2.17	0.24	0.81 – 0.89
Temperature	°C	201	13.2	12.0	14.3	0.22	13.1 – 13.2
Turbidity	NTU	203	0.70	0.15	7.6	0.65	0.60 – 0.80
Alkalinity	mg/L as $CaCO_3$	98	121	62	148	14	117 – 124
Calcium	mg/L as $CaCO_3$	29	254	218	296	20.7	245 – 264
Magnesium	mg/L as $CaCO_3$	27	22	4	40	11	17 – 27
Hardness	mg/L as $CaCO_3$	29	272	238	320	23.1	262 – 282
Fluoride	mg/L	43	0.30	0.13	0.65	0. 08	0.27 – 0.33
Sodium	mg/L	41	25.1	22.7	29.0	1.41	24.5 – 25.6
Silica	mg/L	41	28.5	25.7	40.2	2.28	27.7 – 29.4
Aluminum	µg/L	41	208	<200	539	53	<200 – 228
Iron	µg/L	96	180	47	1120	158	143 – 217
Manganese	µg/L	96	140	77	1070	133	109 – 171
Chloride	mg/L	29	36.9	36.1	37.6	0.37	36.8 – 37.1
Sulfate	mg/L	29	155	111	202	17.4	147 – 163
Total Phosphorus	mg/L	29	0.011	<0.010	0.016	0.002	0.011 – 0.012

(1) The median is reported for the pH data, not the mean.
N/A = Not applicable (statistics not calculated for pH).
FAC = Free available chlorine.

Chapter 2
Equipment Description and Operating Processes

2.1 Equipment Description

The equipment tested was ADI International Inc.'s arsenic adsorption media filter system. The model tested was the ADI Pilot Test Unit No. 2002-09 with MEDIA G2®. The major system components included: a pressure filter tank, filter media, feed water pipe, treated water pipe, raw water sample tap, two feed water sample taps, treated water sample tap, and chemical feed pumps. The system configuration and components are described in more detail in the following sections.

2.1.1 Basic Scientific and Engineering Concepts of Treatment

The conceptual treatment process for the arsenic adsorption media filter is based on passing arsenic-contaminated feed water through a bed of media that has a strong affinity for arsenic.

2.1.2 Generic Arsenic Adsorption Media Description(1)

Arsenic occurs in water in two valence states (arsenic III and arsenic V). The toxicity of arsenic varies, depending upon its concentration and valence. The arsenic valence state can change while in aqueous solution, depending upon the oxidation-reduction potential of the water and/or its pH. Consequently, the objective of arsenic removal treatment is to remove all of the arsenic — regardless of its valence.

Adsorption is the attachment of the adsorbate (arsenic) to the surface of a porous adsorbent, such as media grains. The adsorption capacity and effectiveness of the arsenic removal media depends on a number of factors, such as pH, competing anions, and available sites for adsorption on the media. An adsorptive media's surface area is a function of its available porosity. An adsorptive treatment media contains an extensive network of fine (small diameter) pores that extend throughout the body of a grain of media.

The arsenic ion requires time to migrate into a pore within the grain of the adsorbent. As the surface area of each adsorbent grain becomes saturated with arsenic ions, the time required for additional adsorption becomes longer. Other factors that determine the capacity and effectiveness of adsorbent media are accessibility of the pore sites for arsenic ions, competing ions for pore sites, concentration of arsenic in the feed water, pH of the feed water, and flow characteristics of the feed water that convey the arsenic into the bed of adsorbent media.

The adsorptive media is normally in a packed bed contained in a pressure vessel. The water to be treated typically flows in the downflow mode through the treatment bed. Gravity flow is feasible, but if pH adjustment is employed, gravity flow is not as effective because the pressure required to retain the carbon dioxide in solution does not occur under gravity flow conditions. Therefore, the free carbon dioxide is released, which results in the pH rising to higher than the

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(1) From Chapter 6 – *Adsorptive Media Processes for the Removal of Arsenic of the EPA/NSF ETV Protocol for Equipment Verification Testing for Arsenic Removal*

desired level. As the feed water flows through the adsorptive media, the arsenic ions are adsorbed onto the available adsorption sites. As the water flows through the bed, the arsenic concentration decreases until it is no longer detectable.

As the feed water continues to flow through the treatment bed, the media that first comes in contact with the feed water becomes saturated with arsenic ions. A treatment band then progresses through the treatment bed until breakthrough occurs. At that point, traces of arsenic appear in the treated water. As flow continues, the treatment band progresses through the media until the bed is saturated; the arsenic concentration in the treated water is then the same as that in the feed water. Since the arsenic concentration in the treated water is the contaminant of concern, it must be controlled to the desired level.

There are various methods of sequencing multiple treatment beds (parallel and/or series arrangements), which allow use of the entire (or almost the entire) adsorptive media capacity. When the adsorptive media becomes saturated with arsenic ions, it is removed from service for regeneration or disposal.

Normally, the economic feasibility of the adsorptive process requires reuse of the treatment media. This is accomplished by means of chemical regeneration, which requires adjustment of pH (or other methods) to a level at which adsorptive conditions no longer exist. At these pH levels, the adsorptive treatment media desorbs the adsorbate. The arsenic is released and flushed from the adsorptive media as a high concentration arsenic wastewater.

When regeneration is complete, the pH of the media is adjusted to the desired treatment pH, at which point the media is reused for a subsequent treatment cycle. During regeneration, some adsorptive media may be consumed (through attrition); if that occurs, replacement adsorptive media should be added to the treatment bed. In small treatment systems and/or in treatment systems in which the arsenic concentration in the feed water is not excessively high, economic feasibility might dictate replacement of spent media in lieu of regeneration.

Historically, the adsorptive media that has demonstrated the most cost-effective, reliable performance has been granular activated alumina. Other adsorptive media, such as bone char and synthetic bone char (tri-calcium phosphate), have also been used, but have not performed as effectively as activated alumina.

2.1.3 Capacity

The capacities and performance of different adsorptive media vary. Some types of adsorptive media may be capable of regeneration, while others may not. Adsorptive media that have regeneration capability may also vary in performance during subsequent treatment runs. The arsenic removal capacity diminishes until it is determined that adsorptive media replacement is required. Other types of adsorptive media experience attrition during each regeneration, requiring the addition of makeup adsorptive media prior to commencement of the next arsenic removal treatment run. The latter type of adsorptive media may not experience reduction of arsenic removal capacity during subsequent treatment runs.

2.1.4 Intermittent Operation

In full-scale arsenic adsorptive media water treatment systems, operation may be intermittent. The smaller the system, the higher the probability that the operation of the treatment system will experience more frequent starts and stops.

The performance of adsorptive media is not degraded when operated on an intermittent basis. In fact, after a shutdown of the process, the arsenic adsorption media generally exhibits a short period of improved performance during the time immediately after the restart of treatment. Performance then returns to the level occurring at the time of the treatment process shutdown.

2.1.5 MEDIA G2® Description

MEDIA G2® arsenic adsorption media consists of an inorganic, natural substrate (calcined diatomite) upon which iron (ferric hydroxide) is chemically bonded. It is the iron that attracts the metallic ions in water and binds them to the substrate by chemisorption. Although it was developed specifically for adsorbing arsenic, ADI claims that MEDIA G2® will also adsorb iron, manganese, zinc, cadmium, lead, copper, and uranium. The adsorption capacity for arsenic is 800 µg to 2,400 µg of arsenic per gram of media, depending on the operating pH and initial arsenic concentration in the raw water.

The arsenic adsorption pilot unit used in this test consists of one vessel containing MEDIA G2® adsorption media that was operated in a downflow mode. As the media becomes saturated with arsenic, the concentration of arsenic in the treated water begins to increase. Before this concentration reaches the pre-determined maximum allowable contaminant level (breakthrough), the media is either replaced or regenerated on-site.

ADI has stated that MEDIA G2® can be regenerated four to five times, with a loss in capacity of approximately 10% following each regeneration. Eventually it becomes more economical to replace the media rather than continue to regenerate it, due to the cumulative loss in arsenic adsorption capacity.

Previous research and pilot tests conducted by ADI have shown that MEDIA G2® systems work well within the pH range of 5.0 to 7.5. However, the lower the pH, the better the chance for extending the life of the media because its adsorption capacity increases with decreasing pH. However, for most applications it is desirable to operate the system in the pH range of 6.5 to 6.8, as indicated in the ADI Operations Manual in Appendix A.

After pH, the most critical parameter is the contact time in the adsorption vessels. The MEDIA G2® arsenic adsorption filter is sized for a ten-minute empty bed contact time (EBCT).

MEDIA G2® is a registered trademark of ADI International Inc. and is protected by U.S. Patent No. 6,200,482. MEDIA G2® adsorption media is certified to NSF/American National Standards Institute (ANSI) Standard 61 for water treatment plant applications, as indicated in Appendix B. The performance of MEDIA G2® was also verified under ETV Canada's Environmental Technology Verification Program in March 2001.

Table 2-1 presents information about manufacturing and procedures specific to the MEDIA G2® arsenic adsorption media. Table 2-2 presents the specifications of the MEDIA G2®.

Table 2-1. Manufacturing and Procedures Specific to the MEDIA G2® Adsorptive Media

Item	Manufacturing/Procedures
Raw material used to make the adsorptive media	Calcined diatomite substrate and iron (ferric hydroxide)
Method of Manufacture	• Chemical processes: ferric hydroxide is chemically bonded to the calcined diatomite media (proprietary process) • Thermal processes: proprietary • Sizing/Screening methods: proprietary • Packaging methods: proprietary
Preconditioning Procedure (Pilot Test Unit No. 2002-09)	• Wetting requirements: a) Place media in filter vessel and backwash at a rate of 3.2 gpm for 30 to 60 minutes to remove fines. b) Rinse with acidified water (pH 4.0-5.0) at a filtration rate of 1.7 gpm until pH of the filter effluent water is reduced to 6.5. See ADI Operations Manual in Appendix A for further details. • Waste: discharged to nearby sewer easement
Regeneration Procedure (Pilot Test Unit No. 2002-09)	• Backwash: see ADI Operations Manual, pages 3 and 4, in Appendix A. • Chemical process: meter ~50 gallons of 1% caustic soda to the filter to regenerate the media, followed by neutralization of the media by feeding 0.5% sulfuric acid solution until a filter effluent pH of less than 7.0 occurs (but not less than 5.0). See ADI Operations Manual, pages 6 and 7, in Appendix A, for additional details. • Return to treatment mode: rinse following acid neutralization until the pH of the effluent water is within one pH unit of the pilot feed water (ADI's target pH in the effluent water is 6.5 to 6.8). Media is ready for normal operation following rinse. • Waste: see ADI Operations Manual, Appendix A, for treatment and disposal of wastewater.
Regeneration Results	• Adsorption media capacity: reduced by 10% with each regeneration. • Number of regenerations: MEDIA G2® reportedly can be regenerated 4 to 5 times in place. After this, it is more economical and practical to replace the media. • Waste: see ADI Operations Manual in Appendix A for discussion on disposal of regenerants and spent media.

Table 2-2. MEDIA G2â Adsorptive Media Specifications

Chemical Constituents	
Base material	Mined calcined diatomite graded
Processed	and coated with ferric hydroxide
Iron, % by weight	5 to 30
Physical Properties	
Bulk density	47 pounds (lbs)/cubic feet (ft^3)
Hardness	210 lbs/sq in
Attrition	No data available
Voids	No data available
Pore size	No data available
Pore volume	No data available
Abrasion loss	No data available
Moisture (weight)	No data available
Sieve sizes, US sieve series	No data available
Particle size	No data available
Effective size	0.32 mm
Uniformity coefficient	1.8 to 2.0
Arsenic adsorption capacity	800 – 2,400 µg arsenic per gram of media
Ionic preference series	no data available
Approvals	Certified to NSF/ANSI 61 (See Appendix B) Toxicity Characteristic Leaching Procedure (TCLP)
MEDIA G2® Material Safety Data Sheets (MSDS)	See Appendix B

2.2 ADI's Arsenic Adsorption Media Test Unit Installation

ADI's filter installation at Hilltown in Well Station No. 1 was a pilot test unit, with a footprint of less than one square foot. The pilot unit has a capacity of only 1.7 gpm, although it is hydraulically configured and operated to simulate any size system that employs pressure filter vessels.

The depth of media in the pilot filter is about 3 ft and the diameter of the filter is 12 inches, which results in a hydraulic loading rate of 2.16 gpm/sf and an EBCT of 10.3 minutes. The hydraulic capacity of a full-scale system is determined by the size and number of vessels. Smaller systems generally use vertical pressure vessels, while larger systems [over 5 million gallons per day (mgd)] use horizontal vessels.

The feed water was obtained from an existing tap on the well station chlorine detention tank, located in the building. The pressure at this location was a constant 115 psi. ADI installed a pressure-reducing valve (PRV) on the feed line to reduce pressure to the pilot filter unit to 50 psi. An electric solenoid valve was installed on the line feeding the pilot filter unit to positively shut off the water flow to the unit in the event of a power outage at the station. The solenoid valve and chemical metering pumps received power from a constant 120-volt circuit. In response to a loss of power, the solenoid valve would have closed, to prevent the passage of water through the pilot filter unit without pH adjustment by the addition of sulfuric acid.

An electronic, battery-operated flow meter measured the rate of flow to the test unit. Its stated accuracy is ±1% of full scale, or ±0.05 gpm. A Neptune Trident mechanical totalizer meter measured both the feed water supply and backwash water supply to the test unit. Because backwash water for the test unit was supplied by the well, which contained arsenic, sampling for arsenic in the treated water for verification purposes was done at least one hour after forward flow was re-initiated.

HTWSA feeds sodium hypochlorite for disinfection to the raw water just upstream of the chlorine detention tank at a dose sufficient to produce a free chlorine residual of approximately 0.8 milligrams per liter (mg/L) in the water entering the distribution system. ADI stated that the target chlorine residual in the pilot unit effluent should be 0.7 to 1.0 mg/L. Therefore, additional chlorine was not supplied to the feed water as part of the arsenic adsorption treatment process. The portion of chlorinated water that was diverted to the pilot filter unit was dosed with sulfuric acid to decrease the pH to less than 7.0 (preferably within the range of 6.5 to 6.8 specified by ADI). Two sample taps (ST1 and ST2) were located immediately upstream and downstream, respectively, of the acid feed point.

The test unit was supplied with two graduated chemical batch tanks and two metering pumps for feeding sulfuric acid, and either sodium hypochlorite or caustic soda into the water. Since the well water was already chlorinated prior to being diverted to the pilot filter unit, ADI's sodium hypochlorite feed system served as a spare and was available for use in the event that HTWSA's chlorine feed system was out of service; it also served to meter caustic soda during the regeneration. The metering pumps operated at a fixed rate. They were plugged into electrical outlets that provide continuous power to operate in conjunction with the continuous arsenic adsorption treatment unit.

A sulfuric acid solution was added to lower the pH from the approximate raw water pH of 7.6 to a target range of 6.5 to 6.8. Periodic adjustments of the pump speed were required to keep the pH within the target range. The sulfuric acid usage was calculated daily from the volume changes in the batch tank. All chemicals were metered into the pilot filter unit from diluted solutions. (See ADI's Operations Manual in Appendix A for an example preparation of sulfuric acid solution.)

The filter unit was fitted with inlet and outlet pressure gauges for measuring pressure drop through the media bed. The filter was to be backwashed when the pressure drop reached 10 psi or following four weeks of continuous operation, whichever occurred first.

Analysis of backwash water is discussed in detail in Chapter 4. ADI noted that backwash water will always exhibit a reddish-orange color, even after hours of backwashing. ADI indicated that this was normal and that the backwash period should not exceed the time given in the Operations Manual. After each backwash, the filter was rinsed at the service flow rate for 15 minutes. During the filter rinse, the reddish-orange color disappeared in the rinse water within a few minutes.

Treated water from the test unit was discharged to the well station floor drain, which conveys the treated water to a stream culvert adjacent to the building. PADEP gave permission for this discharge. Treated water samples were collected at Sample Tap 3 (ST3), as shown in Figures 2-1 and 2-2.

2.2.1 Filter System Components

The following equipment was provided by ADI, specifically for the verification test; they are not normally included with the arsenic adsorption media filter:

- Two chemical metering pumps for metering sulfuric acid and caustic soda (for regeneration only);
- One solenoid valve to automatically isolate the filter unit in the event of a power outage (Well Station No. 1 does not have a back-up power supply);
- One electronic flow meter for monitoring flow rate;
- One mechanical totalizer meter for monitoring accumulative production through the filter unit;
- Two chemical batch and feed tanks (sulfuric acid and caustic soda);
- One pressure reducing valve to lower the chlorine detention tank discharge pressure from 115 psi to 50 psi for ease in regulating the flow through the test unit;
- Two pressure gauges for measuring filter influent pressure and filter effluent pressure, and calculating pressure drop across the filter unit; and
- Eight ball valves for manual operation of the filter unit flows, including service, backwash, rinse, regeneration, and sampling.

2.2.2 Physical Construction of the Test Unit

The filter vessel is constructed of fiberglass, with a pressure rating of 125 psi. Rigid piping is Schedule 80 polyvinyl chloride (PVC). Flexible piping is reinforced, clear plastic tubing. Manually operated valves are all PVC ball valves.

2.2.3 Equipment Performance Range and Known Limitations of Equipment

ADI has stated that their MEDIA G2® ADI Pilot Test Unit No. 2002-09 requires specific water quality conditions to minimize interference from other ions and to maximize arsenic removal. Based on previous lab and pilot-scale tests by ADI, as well as experience with ten, full-scale installations, ADI has made the following statements regarding interferences to MEDIA G2®:

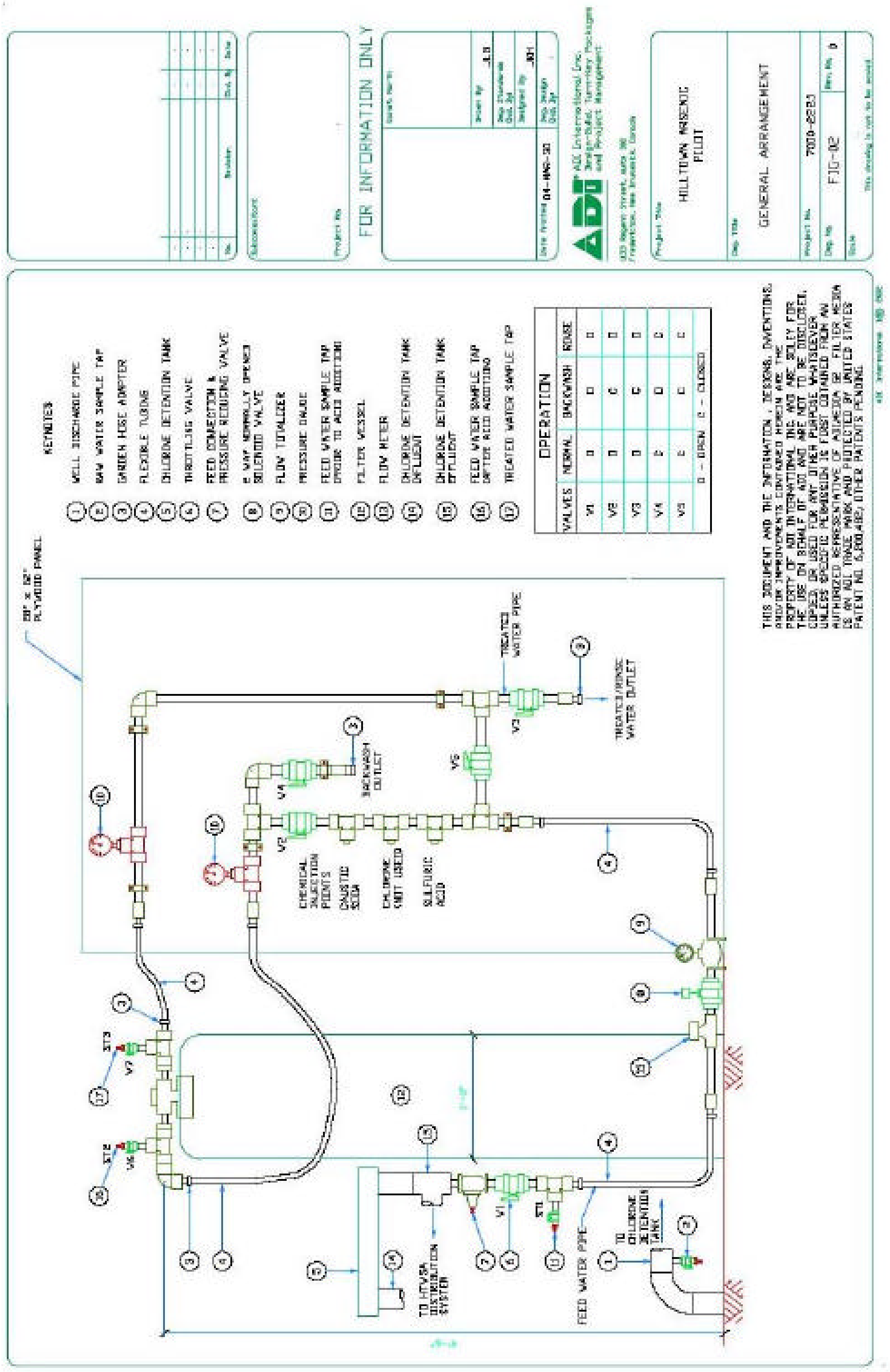
- Adsorption capacity is not affected by chloride and sulfate ions at concentrations up to 250 mg/L. Chloride and sulfate ions in excess of 250 mg/L may reduce the MEDIA G2® capacity for arsenic;
- MEDIA G2® does not adsorb silica when the operating pH is at or below 7.2;
- The presence of naturally-occurring iron and manganese concentrations up to 2.0 mg/L and 0.8 mg/L, respectively, may enhance performance of MEDIA G2® for arsenic removal, but more frequent backwashing may be required due to increased pressure drop. Both iron and manganese will be reduced to well below the MCLs;

- MEDIA G2® does not remove fluoride by any measure;
- Chlorine and ozone, when used as oxidants or for disinfection, reportedly have no effect on the integrity of MEDIA G2®. Preoxidation is necessary where a portion of the arsenic exists as arsenic III; oxidation converts arsenic III to arsenic V, which is more easily removed by MEDIA G2®. (ADI prefers chlorine residual within the filter bed.) As to whether an oxidant will improve the performance of MEDIA G2® directly, there are no available data;
- MEDIA G2® will remove arsenic III and arsenic V with preoxidation of arsenic III to arsenic V;
- Adsorption media is appropriate for groundwater not under the influence of surface water;
- Although MEDIA G2® has performed effectively over a pH range of 5.0 to 7.5 in previous applications, the optimal pH range for most applications is 6.5 to 6.8; and
- The manufacturer states that the process is appropriate for "smaller" systems. It is also appropriate for "larger" systems up to 5.0 mgd.

The equipment flow range and maximum system pressure are presented in Table 2-3. The filter tank material rating is 125 psi.

2.2.4 Drawings of Equipment

Figures 2-1 and 2-2 present two schematics of the MEDIA G2® Arsenic Removal Pilot Unit.



VALVES	OPERATION NORMAL	BACKWASH	RINSE
V1	O	O	O
V2	O	C	O
V3	O	C	O
V4	C	O	C
V5	C	C	C

O – OPEN C – CLOSED

Figure 2-1. Schematic of MEDIA G2® Arsenic Removal Pilot Unit.

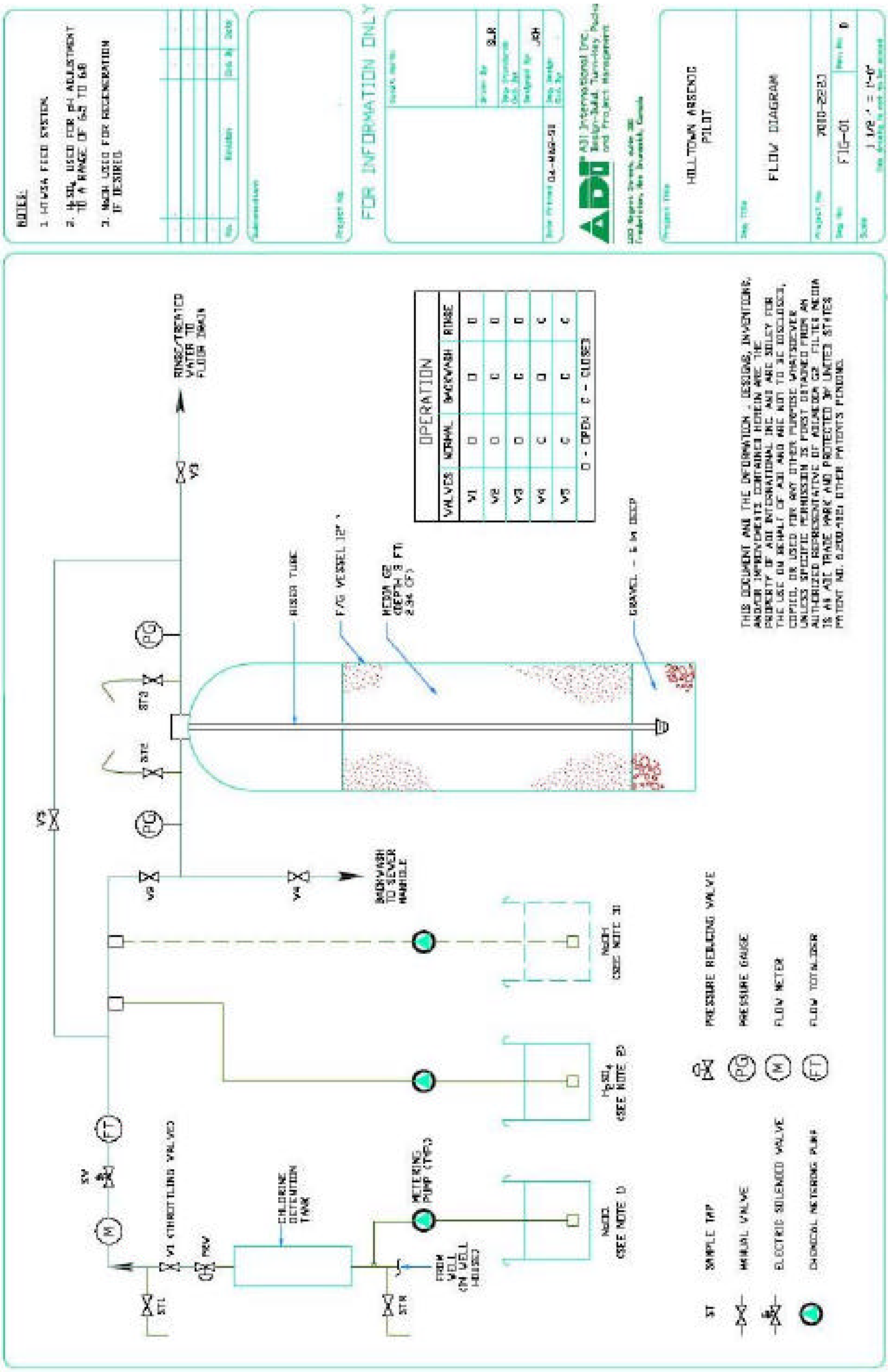


Figure 2-2. Schematic of MEDIA G2® Arsenic Removal Pilot Unit.

2.2.5 Design Criteria

Table 2-3 presents design criteria for the arsenic adsorption process and appurtenances.

Table 2-3. Equipment Design Criteria

Model No. 2002 Pilot Unit MEDIA G2®	
No. of Filter Units	1
Filter Tank Dimensions	
Diameter (ID)	12 in
Height (vessel only)	54 in
Mode of Operation	downflow
Operating Capacity and Service Flow Rate	1.7 gpm
Hydraulic Loading Rate	2.16 gpm/sf
EBCT at 1.7 gpm	10.3 minutes
Initial pressure drop (clean media bed)	2 psi
Filter Media	
Depth	35.4 in
Freeboard above media	12.6 in
Volume	~2.3 ft^3, or ~17 gal (uncompacted)
Weight	109 lbs (based on 47 lbs/ft^3) Note: 109 lbs of media was weighed on-site by ADI prior to installation in the filter vessel
Support gravel layer	6 in
Media expansion during backwash	See backwash expansion curve in Appendix A, Operations Manual.
Filter Tank Material	Fiberglass rated at 125 psi
Control	Manual
Backwash	
Frequency criteria	Pressure drop of 10 psi, or every four weeks, whichever occurs first
Flow Rate	3.2 gpm during initial startup 3.9 gpm after initial startup
Duration	15 minutes
Rinse	
Duration	~15 minutes (until rinse water is clear)
Regeneration	
Flow Rate	1.2 gpm (forward flow)
Caustic Soda Feed Rate	Rate that will allow a 1% solution to enter the pilot unit
Caustic Soda Feed Duration	Time required to feed 3 bed volumes of 1% solution

Table 2-3. Equipment Design Criteria (Continued)

Regeneration (continued)	
Neutralization	
Sulfuric Acid Feed Rate	Rate that will allow a 0.5% solution to enter the pilot unit
Sulfuric Acid Feed Duration	Time required to reduce the pH of the effluent below 7.0 (ENSURE THAT THE pH DOES NOT DROP BELOW 5.0)
Rinse	
Flow Rate	1.7 gpm
Duration	Time required for pH of effluent water to be within one unit of the pH of influent water
Pressure Gauges	
Manufacturer	Lyn Car
Pressure Range	0-100 psi
Accuracy	±0.5%
Totalizer Meter	
Manufacturer	Neptune Trident
Type	Positive displacement
Series	T10
Flow Meter	
Manufacturer	Blue-White Industries, Ltd.
Type	Electronic-impeller
Model	F2000/RTSB-50P2-GM2
Range	0.5 to 5.0 gpm
Accuracy and repeatedly	± 1% of full scale
Power supply	4 AA batteries or AC transformer
Size	0.5 in
Enclosure	National Electrical Manufacturers Association (NEMA) 4X
Feed Water Throttling Valve	
Manufacturer	Hayward Industrial Products, Inc.
Type	Ball valve
Material of Construction	PVC
Size	0.75 in
Control	Manual
Pressure Reducing Valve	
Manufacturer	Conbraco Industries Inc
Model No.	36C
Series	200
Static set pressure	50 psig
Adjustable pressure range	25 to 75 psig
Size	0.75 in
Solenoid Valve	
Manufacturer	Hayward Industrial Products Inc.
Type	PVC True Union
Maximum Service Pressure	120 psig
Size	0.75 in
Power requirement	1.6 amps; 20V/AC; 50/60 Hz; 19 watts

Table 2-3. Equipment Design Criteria (Continued)

Chemical Feed Tanks	
Number	2
Manufacturer	ACO Container Systems
Type	Graduated - poly
Volume	100 L
Dimensions	
Diameter	20 in
Height	30 in
Chemical Metering Pumps	
Sulfuric Acid	
Manufacturer	Prominent Fluid Controls
Series	beta/4
Series No.	7-BT4A1601PPE200BDO
Type	Electronic solenoid diaphragm pump
Capacity at Max Pressure	1.1 L/hr
Max Pressure	253 psig
Capacity at ½ Max Pressure	1.4 L/hr
½ Max Pressure	126 psig
Capacity at Static Set Pressure	~1.7 L/hr
Power Requirement	0.7 amps/115 V/50–60 Hz
Caustic soda	
Manufacturer	Prominent Fluid Controls
Series	gamma/L
Series No.	GALa 1602NPB900UD
Type	Electronic solenoid diaphragm pump
Capacity at Max Pressure	1.4 L/hr
Max Pressure	253 psig
Capacity at ½ Max Pressure	1.7 L/hr
1/2 Max Pressure	126 psig
Capacity at Static Set Pressure	~2.6 L/hr
Power Requirement	0.7 amps/100-230 V/50-60 Hz

2.2.6 *Photographs of Equipment*

A photograph of the equipment installed at the water treatment plant is shown in Figure 2-3. Additional photographs are included in Appendix C.

Figure 2-3. ADI International Inc. Pilot Test Unit. No. 2002-09 with Media G2$^{®}$ as installed at the HTWSA Well Station No. 1.

2.2.7 *Data Plate*

A data plate was installed on the arsenic adsorption media filter tank that provided the following information:

Equipment name: MEDIA G2$^{®}$ Arsenic Removal Unit
Model No.: 2002-09
Electrical Requirements: 120V, 60Hz for powering chemical metering pumps and solenoid valve
Maximum pressure: 125 psi

Manufacturer's Name and Address:
ADI International
1133 Regent Street
Suite 300
Fredericton, NB E3B 3Z2
Canada

Additional Information:
Serial Number: N/A
Service flow: 1.7 gpm, continuous or start/stop
Unit installed for NSF and EPA Environmental Technology Verification Program.
Call 506-452-9000 for more information.

Warning and Caution Statements:
Testing in progress, please do not disturb.
This unit is designed to operate with minimum and maximum inlet pressures of 30 and 125 psi, respectively.

2.3 Operating Process

This modular filter system consists of one pressurized filter vessel designed for operation in the downflow mode. The filter does not require electricity to operate, although appurtenances require electricity. The filter system can operate either intermittently or continuously at the service flow rate of 1.7 gpm. Specific operating criteria are used to determine when a backwash should be conducted. A backwash is manually initiated and operated after either four weeks of operation or when there is a pressure drop of 10 psi across the filter, whichever comes first.

The cumulative flow and the flow rate through the filter unit were monitored with one accessory electronic flow meter and one mechanical totalizer meter, each located on the feed side of the unit prior to the sulfuric acid injection point. The flow meter also monitored backwash, rinse, and regeneration water flow rates. The flow rate was throttled with a non-integral PVC ball valve located on the treated water side of the filter unit. The collection of backwash and rinse wastewaters for volume determination and water quality analyses occurred once per month during the Capacity Test. The collection of regeneration wastewater for volume determination and water quality analyses occurred once at the end of the Capacity Test. The difference in feed water and treated water pressure readings provided loss of head across the filter unit.

Grab samples for on-site and laboratory analyses were collected from a raw water sample tap on the well discharge pipe prior to chlorine addition (not shown on Figure 2.1), at a sample tap prior to sulfuric acid addition (ST1), at the feed water sample tap (ST2) located immediately upstream of the pilot filter unit, and from the treated water sample tap (ST3), located downstream of the pilot filter unit. Samples from these taps were collected following the opening of their respective valves and a flush period of about five seconds.

2.3.1 Operator Requirements

The pilot filter unit operated continuously using the chlorinated well water bled from the chlorine detention tank. Operator attention during the verification test mainly consisted of monitoring the equipment, conducting process water quality analyses, refilling chemical tank(s), and confirming operation in accordance with the test plan. Frequent adjustment of the sulfuric acid feed rate was required to maintain the required feed water pH.

The system must be backwashed manually following four weeks of operation or a pressure drop of 10 psi, whichever comes first. Operator initiation is required. The operator also manually re-initiates service operation of the filter following a backwash period. For the purpose of the Integrity Test, the filter was manually backwashed at the end of the two-week Integrity Test.

Each manually initiated backwash required one to two hours of operator time. Operator time included setup, 30 minutes of backwash time, 30 minutes of rinse time, on-site water quality analyses, sample collection for laboratory water quality analyses, documentation, and equipment cleanup. The manually initiated backwash, monitoring, and data collection was requested by PADEP as a special condition of the test plan and is not a general equipment operation requirement.

Spent MEDIA G2$^{®}$ media must be regenerated by the operator by feeding an alkaline caustic soda solution to the media. An increase in pH above 10 with the addition of the alkaline solution causes the previously adsorbed arsenic to solubilize and release from the media. Following this step, the operator is required to feed sulfuric acid to the filter to neutralize the high pH caused by the caustic solution. Media regeneration was performed once during the Capacity Test. The combination of filter backwash and regeneration required more than five hours of operator time, including setup and sample collection.

2.3.2 Required Consumables

Due to the water quality chemistry of the Well No. 1 supply, the system requires chemicals during normal treatment operations, as well as additional chemicals during regeneration. Raw or treated water is also required for each filter backwash. The required consumables are:

- MEDIA G2$^{®}$ media: 2.3 ft^3, or 109 lbs (uncompacted), replaced following four regenerations;
- Sulfuric Acid: 15 gallon carboy of 94% H_2SO_4. Frequency of replacement is site-specific. At HTWSA's Well Station No. 1, the rate of acid usage was 1 gallon for about every 25,000 gallons of treated water. At this rate, the frequency of replacement for a 15-gallon carboy of 94% H_2SO_4 acid is about six months;
- Sodium Hypochlorite: based on a required chlorine dose of 1.2 mg/L to achieve ADI's target free chlorine residual of 0.7 mg/L to 1.0 mg/L, approximately 0.75 lbs of chlorine (0.75 gallons of 12.5% sodium hypochlorite) is required for every 75,000 gallons of treated water;
- Caustic Soda: 50 gallons of 1% caustic soda were used during the media regeneration; and

- Electricity: power consumption for the metering pumps and solenoid valve.

2.3.3 Rates of Waste Production

2.3.3.1 Backwash. Approximately 103 gallons of backwash wastewater and 90 gallons of rinse wastewater were generated from each backwash. Filter backwashes are required following every four weeks of continuous operation or following a 10 psi filter bed pressure drop, whichever comes first. The backwash and rinse wastewater was discharged to the sanitary sewer adjacent to the building. Backwash water quantity and water quality characteristics are described in more detail in Chapter 4.

2.3.3.2 Regeneration. Regeneration of the spent media produced approximately 50 gallons of regenerant wastewater. A portion of this regenerant wastewater was collected for TCLP analysis. In addition, wastewater is generated following regeneration due to rinsing of the filter bed until the treated water is within one pH unit of the feed water. Both of these wastewaters were discharged to the sanitary sewer during the media regeneration performed during the Capacity Test.

Spent MEDIA G2® media must be disposed in a manner that complies with all state and federal regulations for ultimate waste disposal. ADI has stated that spent MEDIA G2® media is suitable for disposal in a landfill.

2.3.4 Licensing Requirements Associated with Equipment Operation

States usually require a specific grade of waterworks operator permit in order to operate a filter process on a public water supply. However, this requirement did not apply for the ETV since all of the treated water was discharged to waste.

In Pennsylvania, a C9 license is required to operate a full-scale version of this treatment technology for the Hilltown Water and Sewer Authority. "C" refers to a capacity of 1.0 mgd or less, and "9" refers to inorganics removal.

Chapter 3
Methods and Procedures

3.1 Experimental Design

This verification test was developed to provide verifiable information related to the performance of the ADI International Inc. ADI Pilot Test Unit No. 2002-09. Field operations, sampling, and analytical methodologies were performed in a manner which assured the quality of the data collected provided an accurate evaluation of the treatment system under the field conditions.

The results of the verification test were reported in two phases. The Phase 1 Report included the results of testing designed to evaluate the reliability of the equipment operation under the environmental and hydraulic conditions at the Well Station No. 1 site during the initial two weeks of testing. In addition to the Phase 1 results, this Phase 2 report includes the results of testing designed to evaluate the capacity of the arsenic adsorption system to remove arsenic from the feed water.

3.1.1 Objectives

The objectives of this phase of the verification testing were to:

- Produce data to meet the Data Quality Objectives shaped by the manufacturer's performance objectives;
- Present data on the impact of variations in feed water quality such as turbidity, arsenic, pH, silica, fluoride, iron, and manganese on equipment performance;
- Evaluate the logistical, human, and economic resources necessary to operate the equipment;
- Evaluate the reliability, ruggedness, cost factors, range of usefulness, and ease of operation of the equipment; and
- Evaluate the arsenic adsorption capacity of the equipment under field conditions.

3.1.2 Equipment Characteristics

3.1.2.1 Qualitative Factors. The equipment was operated in such a way as to maintain its operating parameters within the manufacturer’s recommendations. The operating range for pH is a critical parameter for arsenic adsorption efficiency. Contact time is also a critical parameter for arsenic adsorption efficiency and is dependent on maintaining the flow rate within the design range. The nature and frequency of the changes required to maintain the operating conditions are used in the qualitative evaluation of the equipment.

Frequent and significant adjustments would indicate relatively lower reliability and higher susceptibility to environmental conditions, and also the degree of operator experience that may be required. Note that the system appurtenances that required adjusting, such as valves and metering pumps, are likely to be of higher quality and automatically controlled on a full-scale installation. The effect of operator experience on the treatment results was also evaluated.

The modular nature of the filter components, similar to a residential ion exchange water softener, makes equipment installation easy and straightforward. The equipment can be installed by a qualified plumber. This also makes the equipment easy to move and reinstall at another location, if necessary. The filter unit is freestanding, requiring only a level surface capable of supporting 135 lbs and maintenance of an ambient temperature above 40ºF.

3.1.2.2 Quantitative Factors. The following factors were quantified for site-specific conditions, based on data collected during this testing program:

- Rate of media exhaustion;
- Quantity of sulfuric acid;
- Quantity of sodium hypochlorite;
- Quantity of caustic soda;
- Frequency of media replacement;
- Backwash and rinse water quantity and quality;
- Backwash and rinse duration and frequency;
- Regenerant water quantity and quality;
- Regeneration duration and frequency;
- Estimated labor hours for operation and maintenance; and
- Chemical tank batching frequency and volume.

These quantitative factors were evaluated for the purpose of assessing equipment performance and developing operation and maintenance cost factors.

3.1.2.3 Raw and Feed Water Quality. Well Station No. 1 finished water supplied the feed water for the adsorption media filter unit. Raw and finished water quality data (following the chlorine detention tank and all chemical additions) are presented in Chapter 4. The raw water is of relatively poor quality for a groundwater supply; the arsenic concentration exceeds the promulgated MCL and the manganese concentration exceeds the existing secondary maximum contaminant level (SMCL). The water is high in total and calcium hardness. Sulfate levels are moderately high in this supply, although less than the level stated by ADI as a potential limiting factor for MEDIA G2®'s capacity for arsenic removal. A relatively high conductivity level, due in part to the hardness and sulfate concentration, indicates a high level of dissolved ions.

The feed water (Well Station No. 1 finished water) quality was analyzed prior to testing when the sequestrant was being added to minimize manganese precipitation; the manganese concentration could create aesthetic problems for consumers if allowed to "plate out". HTWSA agreed to terminate the addition of the sequestrant for the duration of the verification test, stating that it has not provided significant improvement in water quality. The feed water had high levels of hardness and alkalinity, slightly alkaline pH, and an arsenic concentration double the promulgated MCL of 10 µg/L.

The feed water turbidity was relatively high for a groundwater supply. Since the raw water samples had generally lower turbidity, the higher feed water turbidity is likely due to the oxidation of iron and manganese in the chlorine detention tank.

3.2 Equipment Operations and Design

The test plan was developed based on the *ETV Protocol For Equipment Verification Testing For Arsenic Removal*. Chapter 5 in the protocol, the *Equipment Verification Testing Plan - Adsorptive Media Processes for the Removal of Arsenic,* includes information on the requirements for the verification test and other documents used in the preparation of this report. This chapter also specifies the procedures that were used to ensure the accurate documentation of both equipment performance and treated water quality. Strict adherence to these procedures resulted in verifiable performance of the equipment.

3.3 Field Test Equipment

Table 3-1 presents the analytical and calibration equipment that were used on-site.

Table 3-1. Field Analytical and Calibration Equipment

Equipment	Manufacturer/Model/Specs
Turbidimeter	Hach Model 2100P Portable Ratio™ Optical System (meets or exceeds EPA Method 180.1 criteria)
pH/Ion Selective Electrode (ISE) Meter	Orion Model 290A with Triode pH Electrode Model 91-578N (resolution 0.1/0.01/0.001, accuracy ± 0.005); and Fluoride Combination Electrode Model 96-09 (reproducibility ± 2%)
Thermometer	Miller & Weber [range 0-32º C; National Institute of Standards and Technology (NIST) traceable]
Arsenic Field Test Kit	Industrial Test Systems, Inc. (ITS) Model QUICK Low Range II (optimum accuracy below 6 µg/L)
Colorimeter	Hach Model DR/850; wavelength range 520, 610 nm; wavelength accuracy ±1 nm
Dead weight pressure gauge tester	Amthor Testing Instrument Co. Inc. (Type No. 460; range 0-6000 psi)
Burettes for analytical titrations	50 mL capacity with 0.1 mL subdivisions and 1000 mL reagent reservoir
Stopwatch and "bucket"	Digital stopwatch and 2.0 L graduated cylinder with 10 mL increments for rotameter, totalizer meters, and control module drive water calibration checks; fifty-gallon container for backwash wastewater flow calibration

3.4 Communications, Documentation, Logistics, and Equipment

Gannett Fleming was responsible for coordinating communication among all verification testing participants. All field activities were thoroughly documented in:

- Field Logbook;

- Field Data Sheets;
- Photographs;
- Laboratory Chain-of-Custody Forms, Submission Sheets, and Reports; and
- Laptop Computer.

Gannett Fleming was responsible for maintaining all field documentation. A bound field logbook was used to record all water treatment equipment operating data. Each page was sequentially numbered and labeled with the project name and number. Completed pages were signed and dated by the individual responsible for the entries. Errors have one line drawn through them and are initialed and dated.

Laboratory submission forms accompanied all samples shipped to the PADEP and NSF laboratories. Copies of laboratory submission forms or chain-of-custody forms for all samples were provided at the time of the quality assurance/quality control (QA/QC) inspection and are included in the verification report appendices.

3.5 Equipment Operation and Water Quality Sampling for Verification Testing

The field activities conformed to requirements included in the PSTP that was developed and approved for this verification testing. The sampling and sample analyses that occurred during this verification testing program were performed according to the procedures detailed by Gannett Fleming in the PSTP.

Any unanticipated or unusual situations that altered the plans for equipment operation, water quality sampling, or data quality were discussed with the NSF technical lead and PADEP. Any deviations from the approved final PSTP were documented.

During routine operation, the following were documented daily:

- Number of hours the arsenic adsorption media filter was operated;
- Number of hours the operator was working at tasks at the well station related to the operation of the arsenic adsorption media filter; and
- Description of tasks performed during arsenic adsorption media filter operation.

3.6 Recording Data

The following information was recorded on-site:

- Experimental run number;
- Water type (raw, feed—prior to and after sulfuric acid addition—and treated);
- Wastewater type (backwash, rinse, regenerant);
- Hours of operation (since previous monitoring period) and total hours;
- Feed water flow rate;
- Feed water total production;
- Feed water pressure;
- Treated water pressure;

- Feed water temperature;
- Treated water temperature;
- Raw, feed, and treated water turbidity;
- Raw, feed (prior to and after sulfuric acid addition), and treated water pH;
- Raw, feed (prior to and after sulfuric acid addition), and treated water chlorine residual;
- Raw, feed, and treated water arsenic concentration (qualitatively with field test kit);
- Raw, feed, and treated calcium, magnesium, and hardness;
- Raw, feed, and treated alkalinity;
- Raw, feed, and treated fluoride;
- Occurrence of a backwash;
- Backwash water flow rate;
- Backwash duration;
- Total volume of backwash wastewater;
- Rinse water flow rate;
- Rinse duration;
- Total volume of rinse water;
- Occurrence of a regeneration;
- Regeneration water flow rate;
- Regeneration duration;
- Total volume of regenerant water;
- Sulfuric acid metering pump rate;
- Sulfuric acid dose;
- Sulfuric acid tank level;
- Caustic soda metering pump rate during regeneration;
- Caustic soda dose during regeneration; and
- Caustic soda drum level during regeneration.

3.7 Recording Statistical Uncertainty for Assorted Water Quality Parameters

For the analytical data obtained during verification testing, 95% confidence intervals were calculated by Gannett Fleming for arsenic data and for all other water quality data where the sample set contained eight or more values, with the exception of pH.

The consistency and precision of water quality data were evaluated with the use of the confidence interval. A confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. The following formula was employed for confidence interval calculation:

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

where: $\overline{X}$ is the sample mean;
S is the sample standard deviation;
n is the number of independent measures included in the data set;
t is the t distribution value with n-1 degrees of freedom; and
α is the significance level, defined for 95% confidence as: 1 - 0.95 = 0.05.

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

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

Results of these calculations were expressed as the sample mean plus or minus the width of the confidence interval.

3.8 Verification Testing Schedule

Verification testing activities included equipment set up and shakedown, equipment integrity verification testing, and adsorptive capacity testing. The test schedule was developed to encompass all of these activities.

The Integrity Test began on October 8, 2003. The Integrity and Capacity Tests were initiated simultaneously. The Integrity Test ran for a two-week (13 full days plus 8 hours) period, ending October 21, 2003. The Capacity Test continued to run until May 28, 2004.

3.9 Task 1: System Integrity Verification Testing

3.9.1 Introduction

During Task 1, Gannett Fleming evaluated the reliability of the equipment operation under the environmental and hydraulic conditions at the HTWSA Well Station No. 1 site. The adsorption media filter was operated for Integrity Test purposes within the operational range presented in the equipment design criteria.

3.9.2 Experimental Objectives

The experimental objectives for the Integrity Test phase of the verification testing were to:

- Evaluate equipment operational reliability under field conditions;
- Document feed water quality and arsenic concentration; and
- Collect operational and water quality data under field conditions.

3.9.3 Work Plan

The vendor used a platform scale to weigh the media prior to installation into the filter vessel. ADI's procedure for media replacement is included in Appendix D. The installed weight of the media is specified in Table 2-3. The protocol for media conditioning includes placing media in the filter vessel and backwashing at a rate of 3.2 gpm for 30 to 60 minutes to remove fines, and rinsing with acidified water (pH 4.0 to 5.0) at the normal service flow rate (1.7 gpm) until the pH of the filter outlet water is reduced to less than 6.5 (See Appendix A, ADI Operations Manual, pages 1 to 4, for additional details).

The monitoring and on-site data collection schedules are presented in Tables 3-2 and 3-3. Grab samples for on-site and laboratory analyses were collected based on the sampling schedule presented in Table 3-3. The raw water, feed (ST1), feed (ST2), and treated (ST3) water sample taps were flushed for at least five seconds prior to sample collection. A sampling plan for arsenic that includes the Integrity Test is presented in Table 3-4. Seven days of the daily raw, feed, and treated water arsenic samples were speciated during the Integrity Test, as specified in Table 3-4. The protocol for arsenic speciation is presented in Appendix E. Daily and weekly samples collected for on-site analysis were analyzed immediately after collection. Sample collection and handling procedures followed *Standard Methods* 3010 B.

Daily and weekly samples were collected for laboratory analysis during the daily two-hour monitoring period. All of the samples were collected by the Gannett Fleming field technician in appropriate sample bottles prepared with preservatives, as required, specific to the analytical methods to be used. The samples were stored and shipped in accordance with appropriate procedures and holding times, as specified by the PADEP and NSF laboratories. The methods used for on-site and laboratory analytical procedures are presented in Table 3-3. The water quality sampling protocol is described in Section 3.13.5.

One backwash was manually initiated by the field engineer at the end of the system Integrity Test. Backwash water flow rate, duration, volume, and water quality were monitored following the methods and schedule presented in Table 3-5.

3.9.4 Analytical Schedule

The arsenic adsorption media filter system operational data was monitored following the procedures and at the frequencies prescribed in the test plan, as summarized below and in Table 3-2.

- Operational Data Collection
    - Feed water production was monitored twice per day at the mechanical totalizer meter, located on the feed water pipe;
    - Feed water flow rate was monitored twice per day and adjusted, as needed, with the flow meter and ball valve located on the treated water pipe. Flow rate was recorded twice per day, before and after adjustment. The flow rate was set at 1.7 gpm ±0.1 gpm;
    - Feed water pressure was monitored and recorded twice per day at the pressure gauge located on the feed water pipe. The specified minimum and maximum operating pressures for the filter vessel are 30 psi and 125 psi, respectively. A PRV maintained the feed water pressure at approximately 50 psi during the test;
    - Treated water pressure was monitored and recorded twice per day at the pressure gauge located on the treated water pipe. This was performed at the same time as the feed water pressure measurement. The difference between these measurements represents the pressure drop through the pilot filter unit;
    - The sulfuric acid chemical batch tank level was checked and recorded daily (see Table 3-2). The tank was refilled, as needed, with the time and quantity of refill noted; and

- The sulfuric acid metering pump feed rate was monitored and adjusted, based on the draw down in the batch tank, to maintain ADI's goal of sustaining the pH as close as possible to 6.5 in the feed (ST2) and treated (ST3) water.

Table 3-2. On-site Equipment Operating Parameter Monitoring and Data Collection Schedule

Parameter	Monitoring Frequency	Monitoring Method
Feed water production	Check and record twice per day	Feed water totalizer meter
Feed water flow rate	Check and record twice per day (adjust when 5% above or below target; record before and after adjustment)	Feed water flow meter
Feed water pressure	Check and record twice per day	Feed water pressure gauge
Treated water pressure	Check and record twice per day	Treated water pressure gauge
Chemical feed: tank volume and pump metering rate	Check and record once per day	Measure with measuring tape depth of chemical remaining and, as required, quantity of chemical refill
Chemicals used	As needed	Record name of chemical, supplier, commercial strength, dilution used for making batch solution

- Water Quality Data Collection
  - The water quality of the raw water, feed water (both prior to and after sulfuric acid addition), and treated water was characterized by analysis of the water quality parameters listed in Tables 3-3 and 3-4;
  - Samples were collected during the two-hour monitoring period;
  - All "on-site analyses" were analyzed on-site; and
  - The water quality analyses presented in Tables 3-3 and 3-4 were conducted to provide state drinking water regulatory agencies with background data on the quality of the raw water being treated and the quality of the feed and treated water.

Table 3-3. Water Quality Sampling Schedule - System Integrity Verification Testing

Parameter	Sampling Frequency	Test Streams Sampled	Standard Method(1)	EPA Method(2)	Hach Method(3)
On-site Analyses					
Arsenic	(4)	Raw Water, Adsorptive Media Feed and Treated Water	(See Appendix F)		
pH	Twice Daily	Raw Water, ST1(5), Adsorptive Media Feed and Treated Water	4500-H$^+$ B	--	--
Temperature	Daily	Adsorptive Media Feed and Treated Water	2550 B	--	--
Turbidity	Daily	Raw Water, ST1(5), Adsorptive Media Feed and Treated Water	2130 B	--	--
Alkalinity	Daily	Raw Water, Adsorptive Media Feed and Treated Water	--	--	8221
Calcium	Weekly	Raw Water, Adsorptive Media Feed and Treated Water	--	--	8222
Magnesium	Weekly	Raw Water, Adsorptive Media Feed and Treated Water	--	--	Calculated (8226-8222)
Hardness	Weekly	Raw Water, Adsorptive Media Feed and Treated Water	--	--	8226
Fluoride	Daily	Raw Water(6), Adsorptive Media Feed and Treated Water	4500-F$^-$ C	--	--
FAC	Twice Daily	Raw Water, ST1(5), Adsorptive Media Feed and Treated Water	--	--	8021
Laboratory Analyses					
Arsenic(7)	Daily	Raw Water, Adsorptive Media Feed and Treated Water	--	200.8	--
Silica	Daily	Raw Water(6), Adsorptive Media Feed and Treated Water	--	200.7	--
Aluminum	Daily	Raw Water(6), Adsorptive Media Feed and Treated Water	--	200.7	--
Iron	Daily	Raw Water(6), Adsorptive Media Feed(8) and Treated Water	--	200.7	--
Manganese	Daily	Raw Water(6), Adsorptive Media Feed(8) and Treated Water	--	200.7	--
Chloride	Weekly	Raw Water, Adsorptive Media Feed and Treated Water	--	300.0	--
Sulfate	Weekly	Raw Water, Adsorptive Media Feed and Treated Water	--	300.0	--
Sodium	Weekly	Raw Water, Adsorptive Media Feed and Treated Water	--	200.7	--
Total Phosphorus	Weekly	Raw Water, Adsorptive Media Feed and Treated Water	--	365.1	--

(1) APHA, AWWA and WPCF (1998). *Standard Methods for Examination of Water and Wastewater*. 20th ed. Washington, D.C. APHA.

(2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

(3) Hach Water Analysis Handbook (1992). Hach Company, Loveland, Colorado.

(4) See Table 3-4. An arsenic field test kit was used for periodic qualitative arsenic checks.

(5) A sample was collected once per day from ST1, the sample tap located on the chlorinated water, prior to sulfuric acid addition.

(6) The raw water was collected and analyzed weekly.

(7) The NSF laboratory performed laboratory arsenic analyses. The PADEP Laboratory analyzed all other laboratory analyses during the Integrity Test.

(8) The feed water was checked for the soluble fractions of iron and manganese, in addition to the total concentrations of these metals, requiring filtration through 0.22 µm filter paper.

Table 3-4. Arsenic Sampling Plan

Test Period	Sample Sources	Sample Frequency	Sampling Period	No. of Days Samples Speciated[(1)]	Hold Samples	Total No. Analyses
Laboratory Analyses						
Integrity Test	raw, feed, treated	daily	13 days 8 hours	7	none	84
Capacity Test	raw(2), feed, treated	weekly	first 6 months(1)	monthly(3)	none	84
Capacity Test	raw (2), feed, treated	daily	final 2 months(1)	monthly(3)	12 per week	72
Post-Regeneration Verification	raw(2), feed, treated	3x/week(4); weekly	one 4 week period	1x(3)	N/A	19
On-site Qualitative Analyses(5)						
Integrity Test	feed, treated	weekly	13 days 8 hours	N/A	N/A	4
Capacity Test	feed, treated	weekly	first 6 months(1)	N/A	N/A	48
Capacity Test	feed, treated	3x per week	final 2 months(1)	N/A	N/A	48
Post-Regeneration Verification	feed, treated	weekly	one 4 week period	N/A	N/A	8

(1) The sampling period was based on the manufacturer's performance objectives.

(2) Three samples per week, if after the results of daily sampling during the Integrity Test indicated that raw and feed total arsenic levels may vary significantly.

(3) This was considered the minimum number of samples speciated; if arsenic results not anticipated occurred, such as premature breakthrough or significant variation in feed arsenic level, more frequent arsenic speciation would have occurred.

(4) For the first week, weekly thereafter.

(5) Method procedure presented in Appendix F.

Table 3-5. Backwash Wastewater and Rinse Water Monitoring, Sampling, and Analyses

Parameter	Backwash and Rinse Wastewater Monitoring or Sample Type	Frequency	Method
Flow Rate	yes	every backwash	"bucket"(2) and stopwatch
Volume	yes	every backwash	graduated container(2)
Duration	yes	every backwash	stopwatch
Turbidity	grab(1)	monthly	SM 2130-B
pH	grab(1)	monthly	SM 4500-H^+
Arsenic	grab(1)	monthly	EPA 200.8
Manganese	grab(1)	monthly	EPA 200.7
Iron	grab(1)	monthly	EPA 200.7
Aluminum	grab(1)	monthly	EPA 200.7
Sodium	grab(1)	monthly	EPA 200.7
Alkalinity	grab(1)	monthly	Hach 8221
FAC	grab(1)	monthly	Hach 8021

(1) Grab samples were collected from a continuously mixed batch tank using a 2-liter beaker. All wastewaters were collected in a 50-gallon container.

(2) The "bucket" was a 50-gallon container for calibrating backwash and rinse flow rates. Increments in liters were marked on the sides of this container, based on incrementally filling the container beforehand with a 2-liter graduated cylinder.

3.9.5 Evaluation Criteria and Minimum Reporting Requirements

Tables and time series plots were produced to present all feed water and treated water quality data that varied over time during the Integrity Test. These plots are presented in Chapter 4. The Integrity Test was performed to demonstrate the initial ability of the adsorptive media to reduce the feed water arsenic concentration in the treated water. All water quality parameters, operational parameters, backwash flow rates, and quantities were also tabulated and/or plotted, as appropriate. A plot of feed and treated water pressure and system headloss is presented in Chapter 4. System headloss information may be used to infer power requirements for a system that pumps directly through the treatment unit. No direct measurement of power was possible, since the system does not directly require electricity.

3.10 Task 2: Adsorptive Capacity Verification Testing

3.10.1 Introduction

The objectives of the Capacity Test were to produce quality operational and water quality data until what ADI has defined as the breakthrough arsenic level for their arsenic adsorption system. The performance of the adsorptive media is a function of the feed water quality, contact time, rest time, and type of adsorptive media used. Arsenic breakthrough is highly dependent on the concentration and adsorptive characteristics (isotherm) of the arsenic to be treated by the adsorptive media. Design and EBCT helps define the performance of a given media for a given feed water quality.

The Capacity Test was performed once through arsenic breakthrough. Following breakthrough, MEDIA G2® was regenerated and returned to operation for four weeks of continuous operation. Regeneration was accomplished by first performing a backwash of the pilot unit, followed by chemical regeneration of MEDIA G2® by passing three bed volumes (approximately 50 gallons total) of 1% caustic soda through the filter bed. Subsequently, the filter bed was neutralized with a 0.5% sulfuric acid solution. Details of the regeneration procedure are provided in Section 6.0 of ADI's Operations Manual (see Appendix A).

3.10.2 Experimental Objectives

The experimental objective was to provide equipment operating and water quality data relative to the adsorptive media capacity to remove arsenic from the feed water.

3.10.3 Work Plan

Task 2 (Adsorption Capacity Verification Testing) began simultaneously with Task 1 (System Integrity Verification Testing). The operating conditions were as stated under the Work Plan for Task 1 (Section 3.9.3).

3.10.4 Analytical Schedule

- Operational Data Collection
    - Feed water production was monitored twice per day at the mechanical totalizer meter, located on the feed water pipe;
    - Feed water flow rate was monitored twice per day at the flow meter and adjusted, as needed, with the ball valve located on the treated water pipe. Flow rate, before and after adjustment, was recorded twice per day. The flow rate was set at 1.7 gpm ±0.1 gpm;
    - Feed water pressure was monitored and recorded twice per day at the pressure gauge located on the feed water pipe. Minimum and maximum operating pressures for the filter vessel are 30 psi and 125 psi, respectively. A PRV maintained the feed water pressure at approximately 50 psi;
    - Treated water pressure was monitored and recorded twice per day at the pressure gauge located on the treated water pipe. This was performed at the same time as the feed water pressure measurement. The difference between these measurements represents the pressure drop through the pilot filter unit;
    - The sulfuric acid chemical batch tank level was checked and recorded daily. The tank was refilled as needed, with the time and quantity of refill noted;
    - The sulfuric acid metering pump feed rate was monitored and adjusted based on the treated water pH to maintain ADI's goal of sustaining the pH within the range of 6.5 to 6.8 in the treated water; and
    - Fluoride, silica, and aluminum samples were collected weekly during Task 2. More frequent sampling of these parameters would have occurred if data collected daily during Task 1 showed that the concentration of the parameter fluctuated or was at a higher concentration than expected.

- Water Quality Data Collection
  - The water quality of the raw water; adsorptive media feed and treated water (pre- and post-regeneration); backwash wastewater; rinse wastewater; and regeneration wastewater were characterized by the analysis of the water quality parameters listed in Tables 3-2, 3-4, 3-5, 3-6, 3-7, and 3-8. The sampling frequency was intended to provide sufficient water quality data to effectively characterize the breakthrough profile of arsenic, to develop representative backwash and regenerant wastewater quality profiles, and to produce quality operational and water quality data for a minimum of four weeks of continuous operation following regeneration of the media.
  - Grab samples of backwash, rinse, and regenerant wastewaters were collected for the water quality analyses at the frequency presented on Table 3-5 and 3-8. The wastewaters were collected separately; each was mixed to maintain a relatively homogenous suspension during sample collection.

Table 3-6. Water Quality Sampling Schedule - Media Adsorption Capacity Verification Testing

Parameter	Sampling Frequency	Test Streams Sampled	Standard Method(1)	EPA Method(2)	Hach Method(3)
On-Site Analyses					
Arsenic	(4)	Adsorptive Media Feed and Treated Water	(See Appendix F)		
pH	Daily	Raw Water, ST1(5), Adsorptive Media Feed and Treated Water	4500-H$^+$ B	--	--
Temperature	Daily	Adsorptive Media Feed and Treated Water	2550 B	--	--
Turbidity	Daily	Raw Water, ST1(5), Adsorptive Media Feed and Treated Water	2130 B	--	--
Alkalinity	3/Week	Raw Water, Adsorptive Media Feed and Treated Water	--	--	8221
Calcium	Weekly	Adsorptive Media Feed and Treated Water	--	--	8222
Magnesium	Weekly	Adsorptive Media Feed and Treated Water	--	--	Calculated (8226-8222)
Hardness	Weekly	Adsorptive Media Feed and Treated Water	--	--	8226
Fluoride	Weekly	Adsorptive Media Feed and Treated Water	4500-F$^-$ C	--	--
FAC	Daily	ST1(5), Adsorptive Media Feed and Treated Water	--	--	8021
Laboratory Analyses					
Arsenic(6)	Weekly(7)	Raw Water, Adsorptive Media Feed and Treated Water	--	200.8	--
Silica	Weekly	Adsorptive Media Feed and Treated Water	--	200.7	--
Aluminum	Weekly	Adsorptive Media Feed and Treated Water	--	200.7	--
Iron	Weekly	Adsorptive Media Feed and Treated Water	--	200.7	--
Manganese	Weekly	Adsorptive Media Feed and Treated Water	--	200.7	--
Chloride	Weekly	Adsorptive Media Feed and Treated Water	--	300.0	--
Sulfate	Weekly	Adsorptive Media Feed and Treated Water	--	300.0	--
Sodium	Weekly	Adsorptive Media Feed and Treated Water	--	200.7	--
Total Phosphorus	Weekly	Adsorptive Media Feed and Treated Water	--	365.1	--

(1) APHA, AWWA and WPCF (1995). *Standard Methods for Examination of Water and Wastewater*. 19th ed. Washington, D.C. APHA.

(2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

(3) Hach Water Analysis Handbook (1992). Hach Company, Loveland, Colorado.

(4) See Table 3-4. An arsenic field test kit was used for periodic qualitative arsenic checks.

(5) A sample was collected three times per week from ST1, the sample tap located on the chlorinated water, prior to sulfuric acid addition.

(6) The NSF laboratory performed laboratory arsenic analyses.

(7) See arsenic sampling plan in Table 3-4.

3.10.5 Evaluation Criteria and Minimum Reporting Requirements

The results of the Capacity Test are presented in Chapter 4 and include the following:

- Record of Arsenic Removal
  - An arsenic breakthrough curve showing adsorptive media treated water concentrations versus bed volumes treated was plotted. Feed water arsenic concentrations were included on the same plot.
  - A spreadsheet table tabulating arsenic feed water concentrations and the average feed water arsenic concentration.
- Process Control
  - The adsorptive media feed water and treated water arsenic, pH, FAC, pressure, water production, and flow rate were tabulated and used to calculate incremental feed and treated water production, differential pressure, and cumulative arsenic removed. The average, standard deviation, and confidence interval were included for each parameter when appropriate.
- Record of Chemical Consumption
  - Gallon(s) of chemicals consumed per 1,000 gallons of treated water were calculated. The calculated data aids in generating operating cost factors for the treatment system.

Table 3-7. Water Quality Sampling Schedule – Post-Regeneration Media Verification Testing

Parameter	Sampling Frequency	Test Streams Sampled	Standard Method(1)	EPA Method(2)	Hach Method(3)
On-Site Analyses					
Arsenic	(4)	Adsorptive Media Feed and Treated Water		(See Appendix F)	
pH	Daily(5)	Raw Water, ST1(6), Adsorptive Media Feed and Treated Water	4500-H$^+$ B	--	--
Temperature	Daily	Adsorptive Media Feed and Treated Water	2550 B	--	--
Turbidity	Daily	Adsorptive Media Feed and Treated Water	2130 B	--	--
Alkalinity	3/Week	Raw Water, Adsorptive Media Feed and Treated Water	--	--	8221
Calcium	3/Week	Adsorptive Media Feed and Treated Water	--	--	8222
Magnesium	3/Week	Adsorptive Media Feed and Treated Water	--	--	Calculated (8226-8222)
Hardness	3/Week	Adsorptive Media Feed and Treated Water	--	--	8226
Fluoride	3/Week(5)	Adsorptive Media Feed and Treated Water	4500-F$^-$ C	--	--
FAC	Daily	ST1(6), Adsorptive Media Feed and Treated Water	--	--	8021
Laboratory Analyses					
Arsenic(7)	3/Week(8)(9)	Raw Water, Adsorptive Media Feed and Treated Water	--	200.8	--
Silica	3/Week(8)	Adsorptive Media Feed and Treated Water	--	200.7	--
Aluminum	3/Week(8)	Adsorptive Media Feed and Treated Water	--	200.7	--
Iron	3/Week(8)(5)	Adsorptive Media Feed and Treated Water	--	200.7	--
Manganese	3/Week(8)	Adsorptive Media Feed and Treated Water	--	200.7	--
Chloride	3/Week(8)	Adsorptive Media Feed and Treated Water	--	300.0	--
Sulfate	3/Week(8)	Adsorptive Media Feed and Treated Water	--	300.0	--
Sodium	3/Week(8)	Adsorptive Media Feed and Treated Water	--	200.7	--
Total Phosphorus	3/Week(8)	Adsorptive Media Feed and Treated Water	--	365.1	--

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(1) APHA, AWWA and WPCF (1995). *Standard Methods for Examination of Water and Wastewater*. 19th ed. Washington, D.C. APHA.

(2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

(3) Hach Water Analysis Handbook (1992). Hach Company, Loveland, Colorado.

(4) See Table 3-4. An arsenic field test kit was used for periodic qualitative arsenic checks.

(5) Samples were collected 3x during the first 12 hours following regeneration.

(6) A sample was collected three times per week from ST1, the sample tap located on the chlorinated water, prior to sulfuric acid addition.

(7) The NSF laboratory performed laboratory arsenic analyses. The PADEP Laboratory analyzed all other laboratory analyses during the post-regeneration Test.

(8) During the first week following regeneration, followed by weekly sampling thereafter.

(9) See arsenic sampling plan in Table 3-4.

Table 3-8. Regeneration Wastewater Monitoring, Sampling and Analyses

Parameter	Backwash, Rinse and Regeneration Wastewater Monitoring or Sample Type	Frequency	Method
Flow Rate	yes	1x	"bucket"(1) and stopwatch
Volume	yes	1x	Graduated container
Duration	yes	1x	Stopwatch
Volume of Caustic Soda	yes	1x	Graduated container
Volume of Sulfuric Acid	yes	1x	Graduated container
Turbidity	grab(2)	1x	SM 2130-B
pH	grab(3)	1x	SM 4500-H^+
Arsenic	grab(4)	1x	EPA 200.8
Manganese	grab(2)	1x	EPA 200.7
Iron	grab(2)(4)	1x	EPA 200.7
Aluminum	grab(2)(4)	1x	EPA 200.7
Sodium	grab(2)	1x	EPA 200.7
Alkalinity	grab(2)	1x	Hach 8221
FAC	grab(2)	1x	Hach 8021
TCLP(5)	grab(2)	1x	SW-846 EPA 1311

(1) The "bucket" was a 50-gallon container for calibrating backwash, rinse and regeneration flow rates, and the volume of caustic soda fed. Increments in liters were marked on the sides of this container based on incrementally filling the container beforehand with a 2-liter graduated cylinder.

(2) Grab samples were collected from a continuously mixed batch tank using a 2-liter beaker. All wastewaters were collected in a 50-gallon container.

(3) Samples for pH analysis were collected every 5 minutes during the regeneration rinse to evaluate the efficiency of media pH adjustment and to assure that the media is conditioned to within the pH “window” specified by ADI.

(4) Samples for laboratory analysis of arsenic, iron and aluminum were collected every 10 minutes during the regeneration and rinse to evaluate the efficiency of regeneration.

(5) TriMatrix Laboratories, Inc. performed the TCLP analyses.

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

3.11.1 Introduction

During each day of verification testing, arsenic adsorption media filter operating conditions were documented, including the rate of head loss gain. The volumetric flow rate through an adsorptive media vessel is a critical parameter, and must be thoroughly monitored and documented. Adsorptive media performance is affected by the EBCT, which varies directly with the volumetric flow rate through the vessel.

3.11.2 Experimental Objectives

The objective of this task was to accurately and fully document the operating conditions and performance of the equipment.

3.11.3 Work Plan

During each day of verification testing, treatment equipment operating parameters were monitored and recorded on a routine basis. This included documenting a complete description of all applicable data.

3.11.4 Schedule

Table 3-9 presents the schedule that was followed for observing and recording equipment operation and performance data.

Table 3-9. Schedule for Observing and Recording Equipment Operation and Performance Data

Operational Parameter	Action
Feed water flow rate	Check and record in logbook twice per day, adjust when >5% above or below target. Record before and after adjustment.
Filter system feed water and treated water pressures	Record in logbook initial clean bed feed water and treated water pressure at the start of the run, and thereafter record twice per day.
Tasks performed during equipment operation	Record in logbook tasks performed on a daily basis.
Number of hours per day operator attends to all tasks related to the treatment process	Record number of hours required by operator to accomplish all tasks.
Totalizer meter readings	Record totalizer meter readings twice daily.

3.11.5 Evaluation Criteria

The data developed from this verification test were used to evaluate the performance of the adsorption media filter. An objective evaluation of the difficulty of operations was based on the assessment of time required for process monitoring and hydraulic control.

3.12 Task 4: Data Management

3.12.1 Introduction

The data management system that was used in this verification involved computer spreadsheet software and manual recording of system operating parameters.

3.12.2 Experimental Objectives

The objective of this task was to establish a viable structure for the recording and transmission of field testing data by Gannett Fleming, such that sufficient and reliable data were produced for verification purposes.

3.12.3 Work Plan

The following procedures were implemented for data handling and data verification by Gannett Fleming. The field testing operator recorded operating and water quality data and calculations by hand in a laboratory logbook, using the following protocol:

- All daily measurements were recorded in the logbook;
- The logbook was permanently bound with consecutively numbered pages;
- The logbook indicated the starting and ending dates that apply to entries in the logbook;
- All pages had appropriate headings to avoid entry omissions;
- All logbook entries were made in black water-insoluble ink;
- All corrections in the logbook were made by drawing one line through the erroneous information and were initialed by the field testing operator; and
- Pilot operating logs included a description of the adsorptive media equipment, description of test run(s), names of visitors, and a description of any problems or issues, etc. Such descriptions were provided in addition to experimental calculations and other items.

The original logbook was stored on-site. The logbook was photocopied at least once per week and copies forwarded to the Gannett Fleming project engineer. This protocol not only eased referencing the original data, but offered protection of the original record of results.

The database for this verification testing program was set up in the form of custom-designed spreadsheets. The spreadsheets were capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets were entered into the appropriate spreadsheets. Data entry was conducted off-site by the designated data-entry technician. All recorded calculations were also checked at this time. Following data entry, the spreadsheet was printed out and the printout was checked against the handwritten data sheet by another individual. Any corrections were noted on the hard copies and corrected on the screen, and then a corrected version of the spreadsheet was printed out. Each step of the verification process was initialed by the field testing operator or supervisor performing the entry or verification step.

Each experiment (i.e. each test run) was assigned a run number that was then tied to the data from the experiment through each step of data entry and analysis. As samples were collected and sent to the PADEP and NSF laboratories, the data were tracked by use of a system of run numbers. Data from the PADEP and NSF laboratories was received and reviewed by the field testing operator. These data were entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

3.13 Task 5: Quality Assurance/Quality Control

3.13.1 Introduction

Quality assurance and quality control for the operation of the arsenic adsorption media filter and the measured water quality parameters was maintained during the verification testing program, as described in this section.

3.13.2 Experimental Objectives

The objective of this task was to maintain strict QA/QC methods and procedures during this verification. Maintenance of strict QA/QC procedures was important in that if a question arose when analyzing or interpreting data collected for the arsenic adsorption media filter, it would be possible to verify exact conditions at the time of testing.

3.13.3 Work Plan

Equipment flow rates were verified and equipment operation verification was recorded on a routine basis. A routine daily walk-through during testing was established to verify that each piece of equipment or instrumentation was operating properly. The items listed below are in addition to any specified checks outlined in the analytical methods.

It was extremely important that system flow rates were maintained at set values and monitored frequently. Doing so allowed a constant and known EBCT to be maintained in the adsorptive media. Adsorptive media performance is directly affected by the EBCT, which in turn is proportional to the volumetric flow rate through the media. Therefore, an important QA/QC objective was the maintenance of a constant volumetric flow rate through the adsorptive media by frequent monitoring and documentation. Documentation included calculating an average and standard deviation of recorded flow rates through the adsorptive media.

The following weekly QA/QC checks were performed by the field testing operator to assure representative data:

- In-line rotameter (cleaned any foulant buildup, as needed, and verified flow rate volumetrically);
- In-line totalizer meter (cleaned any foulant buildup, as needed, and verified the production rate volumetrically);
- Tubing (verified good condition of all tubing and connections, replaced as necessary); and
- Chemical tank volumes (calculated the change for weekly time of filter operation to confirm calibration of each metering pump).

3.13.4 Analytical Methods

The analytical methods utilized in this study for on-site and laboratory monitoring of raw water, and adsorptive media feed and treated water quality, are summarized in Tables 3-3 and 3-5.

Arsenic analyses were the most critical for the entire verification test. Minimum analytical turnaround time was required to achieve optimum process control. This method required that ultra-pure (optimum) grade nitric acid be used, not reagent grade acid, to avoid the trace amounts of arsenic that can be present in reagent grade nitric acid.

Arsenic analyses were also performed on-site for qualitative purposes using the Model QUICK Low Range II field test kit from ITS. The arsenic field test kit has an optimum accuracy below 6 µg/L and has a reaction time of less than 15 minutes. The complete method procedure is presented in Appendix F.

At the end of the Capacity Test, TCLP analyses were performed on the regenerant wastewater by TriMatrix Laboratories, Inc. using SW-846 and EPA Method 1311. TriMatrix Laboratories, Inc. used Method SW-846 6010B for As, Ba, Cd, Cr, Cu, Pb, Se, Ag, and Zn; and Method SW-846 7470A for Hg.

3.13.5 Samples Shipped Off-Site for Analysis

Samples for inorganic analysis by the PADEP Laboratory including chloride, sodium, sulfate, silica, aluminum, total phosphorus, iron, and manganese, were collected and preserved in accordance with *Standard Methods* procedure 3010 B, paying particular attention to the sources of contamination as outlined in *Standard Methods* procedure 3010 C. After collection and during shipment, the samples were maintained at a temperature of 2º to 8ºC. The samples collected for analysis by the PADEP Laboratory were dropped off at the Bucks County Department of Health located in the Neshaminy Manor Center in Doylestown. The Bucks County Department of Health ships water samples to the PADEP Laboratory on a daily basis, Monday through Thursday. Any samples collected Friday through Sunday were kept refrigerated until they could be shipped on Monday. The laboratory kept the samples between 2º to 8ºC until initiation of analysis. The samples collected for arsenic analysis by the NSF laboratory were shipped by Gannett Fleming at the determined frequencies, without being preserved or packed in ice, as per NSF instructions. The PADEP and NSF laboratories processed the samples for analysis (logged in the samples) within 24 hours of receiving the samples. Table 3-10 presents the sampling protocol that was followed during the verification test for samples analyzed by the PADEP Laboratory.

Table 3-10. Water Quality Sampling Protocol

					PADEP Sample ID Protocol – Sample Submission Sheet						NSF Test Tracking ID	
					Sequence Number(1)							
Parameter	Sample Bottle	Sample Volume	Sample Preservation	Sample Hold Time	Feed	Treated	SAC(1) No.(2)	Bottle Cap ID(2)	Collector No.:(2)	Date/Time Collected	Integrity	Capacity
Laboratory												
Aluminum, Silica, Sodium, Iron and Manganese	125 mL HDPE(3)	125 mL	Nitric acid to pH <2.0; iced	6 months	101	102	109	M	1749	✓	I	II
Arsenic	125 mL Trace Clean	100 mL	N/A(4)	6 months	N/A	N/A	N/A	N/A	N/A	✓	I	II
Sulfate and Chloride	500 mL HDPE	250 mL	Iced	28 days	201	202	109	N/A	1749	✓	I	II
Total Phosphorus	125 mL HDPE	100 mL	Sulfuric acid to pH <2.0; iced	28 days	201	202	109	P	1749	✓	I	II

(1) SAC: Standard Analysis Code.
(2) Information also required on sample bottle.
(3) High Density Polyethylene.
(4) Samples preserved with nitric acid (to pH <2.0) upon arrival to NSF laboratory.

3.13.6 Tests and Data Specific to Adsorptive Media Type Evaluated

ADI's MEDIA G2® adsorptive media used for this testing is described by data on the adsorptive media type, characteristics, and tests, listed in Tables 2-1, 2-2, and 2-3.

3.14 Operations and Maintenance

The following are recommendations for criteria to be included in the Operations Manual for adsorptive media removal of arsenic, as described in the Technology Specific Test Plan (TSTP) within the ETV Protocol.

3.14.1 Operations

ADI provided a customized O&M manual (which included installation instructions) that provided information needed to operate the equipment at the HTWSA Well No. 1 site. ADI's Operations Manual is included in Appendix A.

3.14.2 Maintenance

ADI International Inc. provided readily understood information on the required or recommended maintenance schedule for each piece of operating equipment including, but not limited to:

- manual valves;
- solenoid valve;
- pressure reducing valve;
- on-line measuring instruments;
- chemical metering pumps; and
- pressure gauges (Both pressure gauges required occasional removal for cleaning, which was not mentioned in the Operations Manual).

ADI International Inc. provided readily understood information on the required or recommended maintenance schedule for non-mechanical or non-electrical equipment including, but not limited to:

- adsorptive media vessel; and
- feed lines.

Chapter 4
Results and Discussion

4.1 Introduction

The verification test of the ADI International Inc. ADI Pilot Test Unit No. 2002-09 was conducted in two phases, which included an Integrity Test and a Capacity Test. The two-week (13 full days plus 8 hours) Integrity Test was conducted from October 8 through October 21, 2003. The Capacity Test was initiated in conjunction with the Integrity Test and continued until May 28, 2004. The test included on-site media regeneration and one month of post-regeneration operation. The verification test site was the HTWSA Well Station No. 1, located in Sellersville, Pennsylvania. The well station and arsenic adsorption media filter were described in detail in Chapter 2.

Due to unrepresentative feed water quality during the original Integrity Test, the Integrity Test that began on October 8, 2003 was a retest. It was determined that the well station chlorine detention tank had accumulated a significant amount of sediment, which would become suspended whenever well pump operation was initialized. On September 10, 2003, HTWSA staff removed the tank from service and flushed all sediment from the tank. Data collected during the first Integrity Test, which was performed from August 12 through August 25, 2003, is not presented in this report but is included in Appendix G for reference.

This chapter presents a summary of water quality and operational data, including preliminary arsenic analyses, water quality immediately following chlorine detention tank cleaning, equipment startup, results of the Integrity Test, results of the Capacity Test, and a discussion of the results. The results and discussion encompass the concentration and speciation of arsenic in the raw, feed (ST2), and treated (ST3) water; other water quality analyses of raw, feed (ST1), feed (ST2), and treated (ST3) water; the quantity and rate of treated water production; backwash and rinse wastewater quantity and quality; media regeneration summary; and equipment operation characteristics. QA/QC procedures are also presented.

4.2 Equipment Installation, Startup, and Shakedown

The equipment was installed by ADI International Inc. personnel in September 2002. Initial arsenic speciation tests on the feed (ST2) water and treated water (ST3) were performed in December 2002, prior to the development of the PSTP. These initial arsenic tests were used to make a preliminary assessment of the ability of the system to remove arsenic under the existing water quality conditions at the site, and to evaluate the speciation of arsenic in the feed and treated water. Preliminary arsenic speciation results are presented in Table 4-1. The analytical test reports and sample submission forms are included in Appendix H.

Preliminary arsenic speciation analyses indicated that 95% of the feed water total arsenic concentration was in the soluble state. Arsenic III was detected in one of the feed water samples at 55% of the total arsenic concentration; no arsenic III was detected in a second feed water sample. The detection of arsenic III in the first sample may have been due to an under-dose of chlorine. The treated water total arsenic concentration was equal to 50% of the total feed water arsenic concentration during each sampling event, with all of the detectable arsenic occurring as arsenic V in the treated water. The average treated water arsenic concentration of 11 µg/L during the preliminary testing exceeded the proposed MCL of 10 µg/L. Subsequent bench testing conducted by the manufacturer determined that more effective removal of arsenic by MEDIA G2® would occur if the existing feed water pH of 7.5 was depressed below 7.0, preferably in the range of 6.5 to 6.8.

Table 4-1. Preliminary Arsenic Speciation

	Feed (ST2)				Treated			
Sample Date	Total Arsenic (µg/L)	Soluble Arsenic (µg/L)	Arsenic III (µg/L)	Calculated Arsenic V (µg/L)	Total Arsenic (µg/L)	Soluble Arsenic (µg/L)	Arsenic III (µg/L)	Calculated Arsenic V (µg/L)
10-Dec-02	21.6	20.4	12.0	8.4	10.7	10.2	<4.0	>6.2
19-Dec-02	19.2	19.8	<4.0	>15.8	10.9	11.9	<4.0	>7.9

The arsenic speciation analytical method uses an anion exchange resin to separate arsenic III and arsenic V. The anion exchange resin used for arsenic speciation during these preliminary arsenic sampling events was subsequently determined from resin performance evaluation testing (using known concentrations of arsenic III and arsenic V) to be only approximately 70% accurate in the recovery of arsenic III. All subsequent arsenic speciations were performed using a new batch of anion exchange resin, prepared by NSF. Arsenic speciation using the NSF-prepared resin columns resulted in 100% recovery of known concentrations of arsenic III in performance evaluation testing.

The laboratory arsenic analyses for the preliminary samples were performed at the PADEP Laboratory, using the analytical method EPA 200.8, with a reporting limit of 4.0 µg/L. All arsenic analyses following the preliminary arsenic speciation were performed at the NSF Laboratory, using the analytical method EPA 200.8, with a reporting limit of 2 µg/L. Performance evaluation testing results for arsenic speciation and on-site water quality analyses are presented in Section 4.9.2.2.3.

Several physical modifications were made to the arsenic adsorption media filter system prior to the initiation of testing. The source of feed water was moved from just upstream of the chlorine detention tank to just downstream of the tank. For pH adjustment, a sulfuric acid feed system was installed to inject acid into the feedwater just upstream of the arsenic adsorption media filter. In addition, an electronic flow meter was installed just upstream of the electronic solenoid valve on the feed water side of the filter.

The manufacturer installed new MEDIA G2® media on September 23, 2003, following the chlorine detention tank cleaning. The media installation was witnessed by the Gannett Fleming field technician. Installation of the media and pilot unit startup notes are summarized below.

A platform scale, calibrated on-site, was used to weigh 109 lbs of MEDIA G2® prior to installation of the media into the pilot filter vessel. Two bags of media were weighed individually; each weighed 55.6 lbs. The weight of each empty bag was 0.6 lbs; therefore, the tare weight of the media was 110 lbs. One pound of media was weighed and removed prior to the media installation. Based on the reported media bulk density of 47 lbs per cubic foot, the 109 lbs of installed media should have resulted in an uncompacted bed volume of 2.3 ft^3. However, this could not be confirmed since the internal riser tube and flow distribution apparatus contribute an unknown volume to the bed depth. Based on the filter vessel having an internal tank diameter of 12 inches and a total tank height of 54 inches, the depth of media should be around 35 inches, without taking into account the displaced volume due to the internal flow distribution apparatus. According to the PSTP, "Data will be generated that will represent the actual volume of water treated by the 2.3 cubic feet of MEDIA G2® media…"

Equipment startup and media conditioning were performed by the manufacturer and witnessed by the Gannett Fleming field technician. The protocol for start-up is included in the ADI Operations Manual in Appendix A. Following media installation, the filter was backwashed at a rate of 3.2 gpm for a duration of 45 minutes. The manufacturer conditioned the new media by using feed water dosed with sulfuric acid so that the rinse water pH was depressed to 4.5. The media rinse and conditioning were combined in one step. The filter media was conditioned overnight at the depressed pH of 4.5. However, the ADI Operating Manual instructions indicate the rinse (treated) water pH need only be depressed to 6.5 during the conditioning period.

Prior to the installation of new MEDIA G2®, the totalizer meter reading was 120,181 gallons. The totalizer meter reading at the initiation of the Integrity Test, following media conditioning, was 124,874 gallons. This indicated that the manufacturer had used approximately 4,700 gallons during the media conditioning period. Based on a media bed volume of 2.3 ft^3, the volume of water used during startup was equal to 272 bed volumes. Water used during the media conditioning period was not included in the treated water volume used to assess the capacity of the media.

4.3 Task 1: System Integrity Verification Testing

During the Integrity Test, Gannett Fleming evaluated the reliability of the arsenic adsorption media filter equipment under the environmental and hydraulic conditions at the HTWSA Well Station No. 1 site, with the arsenic adsorption media filter feed water supplied from the chlorine detention tank.

4.3.1 Experimental Objectives

As established in the PSTP, the experimental objectives for the Integrity Test were as follows:

- Evaluate the equipment's operational reliability under field conditions;
- Document feed water quality and arsenic concentration; and
- Collect operational and water quality data under field conditions.

4.3.2 Preliminary Water Quality Analyses

Prior to initiation of the Integrity Test, several steps were taken to mitigate the degradation in well water quality that occurred during the original Integrity Test. Degradation in well water quality occurred due to the apparent resuspending of accumulated solids in the chlorine detention tank when the well pump operation was initiated and water from the well was discharged into the bottom of the chlorine detention tank.

The chlorine detention tank was temporarily removed from service and sediment build-up was removed from the tank by HTWSA. Following the tank cleaning, samples were collected for five consecutive days (September 15–19, 2003) from both the raw water sample tap and the chlorine detention tank sample tap (ST2), in order to evaluate the effectiveness of the tank cleaning. The treatment system was off-line during this period of monitoring.

The samples were analyzed on-site for turbidity, pH, and FAC. The samples were also analyzed both on-site and at the PADEP Laboratory for total and soluble fractions of iron, manganese, and arsenic, as presented in Tables 4-2 and 4-3. Logbook copies and analytical data reports for the preliminary water quality analyses are included in Appendix I. The results of the on-site analyses for iron, manganese and arsenic are qualitative only, having used methods for the analyses that are not EPA-approved. The Hach FerroVer and Periodate Oxidation methods, used for analyzing iron and manganese, respectively, each require a predigestion step, which was not performed. In addition, the Periodate Oxidation method is not considered accurate below 100 µg/L. Therefore, the on-site iron, manganese, and arsenic results were not considered sufficiently accurate for analysis of the effects of the tank cleaning and are not further discussed.

The data indicate that there was a reduction in turbidity, iron, manganese and arsenic between the raw water tap and ST2. Turbidity and iron reduction was probably due to particulates settling in the chlorine detention tank. The average reductions in turbidity, total iron (laboratory) and total manganese (laboratory) were 33%, 44% and 43%, respectively. No total arsenic reduction occurred. The average reductions in soluble fractions of raw water iron (laboratory), manganese (laboratory), and arsenic (laboratory) were nearly 100%, 42% and 7%, respectively. Oxidation of the soluble fraction of iron to a particulate apparently enabled significant removal to occur through settling prior to the feed (ST2) sample location. Removal of soluble manganese can possibly be accounted for by adsorption to the inside walls of the piping and tank, which appeared to have developed a thin layer of manganese dioxide.

Table 4-2. Preliminary On-site Water Quality Analyses (9/15/03 to 9/19/03) – After Tank Cleaning

Parameter	Units	Number of Samples	Mean(1)	Minimum	Maximum
Raw					
pH	units	5	7.5	7.4	7.6
Turbidity	NTU	5	0.50	0.35	0.90
FAC	mg/L	5	0.07	0.02	0.17
Iron - Tot	µg/L	5	340	90	990
Iron - Sol	µg/L	5	90	10	230
Manganese - Tot	µg/L	5	100	<10	200
Manganese - Sol	µg/L	5	140	<10	200
Arsenic - Tot	µg/L	5	13	12	15
Feed (ST2)					
pH	units	5	7.5	7.5	7.6
Turbidity	NTU	5	0.35	0.25	0.45
FAC	mg/L	5	1.00	0.81	1.15
Iron - Tot	µg/L	5	80	70	90
Iron - Sol	µg/L	5	30	10	40
Manganese - Tot	µg/L	5	160	100	200
Manganese - Sol	µg/L	5	100	<10	200
Arsenic - Tot	µg/L	5	7	7	7

(1) The median is reported for the pH data, not the mean.

Table 4-3. Preliminary Laboratory Water Quality Analyses (9/15/03 to 9/19/03) – After Tank Cleaning

Parameter	Units	Number of Samples	Mean	Minimum	Maximum
Raw					
Iron - Tot	µg/L	5	90	80	120
Iron - Sol	µg/L	5	64	<10	100
Manganese - Tot	µg/L	5	76	36	91
Manganese - Sol	µg/L	5	81	49	93
Arsenic - Tot	µg/L	5	16	14	17
Arsenic - Sol	µg/L	5	14	12	16
Feed (ST2)					
Iron - Tot	µg/L	5	50	50	50
Iron - Sol	µg/L	5	<10	<10	<10
Manganese - Tot	µg/L	5	43	36	49
Manganese - Sol	µg/L	5	47	36	51
Arsenic - Tot	µg/L	5	16	16	16
Arsenic - Sol	µg/L	5	13	13	14

The water quality from the feed (ST2) sample tap following tank cleaning indicated that analyte concentrations had either remained the same or decreased between the raw and feed (ST2) locations. Therefore, the Integrity Test was initiated on October 8, 2003.

4.3.3 Integrity Test Operational Data

The arsenic adsorption media filter operated continuously, with feed water supplied from the chlorine detention tank. Well No. 1 operated on demand, based on the water level in the storage tank. Approximately 30,500 gallons were treated during the Integrity Test. A pressure reducing valve installed on the chlorine detention tank sample tap was set to reduce system pressure from 115 psi to 50 psi prior to the treatment unit. Monitoring and on-site data collection were performed, as scheduled, to verify the equipment performance.

Table 4-4 summarizes the operational data from the arsenic adsorption media filter during the Integrity Test. Copies of the original logbook data sheets and compiled Integrity Test operational data are included in Appendix J. The ball valve located on the treatment unit discharge hose was throttled to control the flow rate through the arsenic adsorption media filter in order to maintain the flow rate within the manufacturer's stated operational range.

The feed water pressure averaged 51 psi during the Integrity Test, within a range of 4 psi, which is within the filter vessel's specified pressure range. The manufacturer indicated that the loss of head across a clean filter bed at 1.7 gpm would be about 2 psi. However, the computed loss of head across the treatment unit, based on the difference between the feed water and treated water pressure gauges, was less than or equal to zero for the first six days of operation. However, the feed water pressure gauge was found to read low by 2 psi, based on calibrations performed on each gauge by Gannett Fleming using a dead-weight pressure tester. An additional loss of head of 6 psi developed between days six and seven of the testing, apparently due to the degradation in groundwater quality as the result of a significant rainfall event. Filter bed loss of head remained in the range of 4 psi to 6 psi for the remaining six days of the Integrity Test. The loss of head, feed pressure, and treated pressure during the Integrity Test are presented in Figure 4-1.

Table 4-4. Integrity Test Operational Data

	Before Flow Rate Adjustment (gpm)	**After Flow Rate Adjustment (gpm)**	**Feed Pressure (psi)**	**Treated Pressure (psi)**	**Pressure Differential (psi)**
Number of Samples	28	28	28	28	28
Mean	1.67	1.70	51	49	3
Minimum	1.25	1.65	50	44	-2
Maximum	1.75	1.75	54	56	6
Standard Deviation	0.09	0.03	N/A	N/A	N/A
95% Confidence Interval	1.63 1.71	1.69 1.71	N/A	N/A	N/A

N/A = Statistics not appropriate for these parameters.

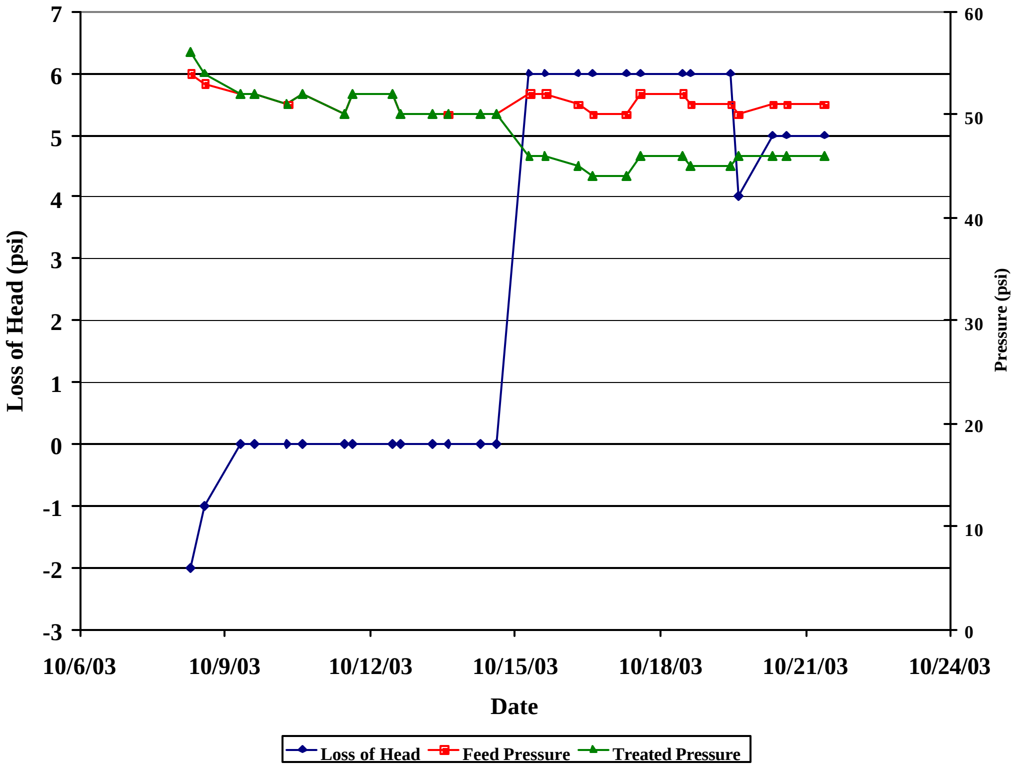

Figure 4-1. Integrity Test Filter Loss of Head, Feed, and Treated Pressure.

4.3.4 Integrity Test On-site Water Quality Analyses

The results of on-site water quality analyses performed during the Integrity Test are summarized in Table 4-5. The feed and treated water temperatures were nearly identical throughout the test. The feed water temperature varied less than 1ºC during the two-week Integrity Test, as shown in Figure 4-2. As shown in Figure 4-3, the raw water pH of 7.5 was generally depressed to within the range of 6.5 to 7.0, as initially specified by the manufacturer. The average raw and feed (ST1) water pH levels were relatively stable at 7.5. The addition of sodium hypochlorite had minimal impact on pH, despite a slight increase in the alkalinity from the raw to the feed (ST1) sample locations. Following the addition of sulfuric acid, the mean pH of 6.7 at the feed (ST2) and treated water sample locations was within the range originally specified by the manufacturer for optimal arsenic removal.

The raw and feed water turbidities were relatively high and variable for a groundwater supply, as indicated on Figure 4-4. The average turbidity levels at the feed water sample taps (ST1 and ST2) were 47% and 150% higher, respectively, than at the raw water sample tap. Several factors likely account for this increase in turbidity. Based on the weather events recorded in the logbook, there appeared to be a correlation between rainfall events and degradation in well water quality, which would appear at different times at the raw and feed water sample taps. The lag times between these sample locations could vary from 70 minutes to 17 hours depending on the frequency of well pump operations. The combination of these factors results in turbidity (including iron and manganese) spikes occurring at different times for these sampling locations. Also, oxidation of raw water dissolved iron and manganese likely contributed to an increase in the turbidity level due to the precipitation of particulates. Another factor that could have contributed to the variation in water quality between sample locations was the on/off status of well pump operations during sample collection.

Turbidity in the feed (ST2) was reduced by an average of 66% through the adsorption media filter; however, the filter effluent turbidity averaged only 15% less than the raw water turbidity. The highest treated water turbidity, of 3.8 NTU, occurred with the highest treated water iron and manganese concentrations during the Integrity Test.

As shown in Figure 4-5, the alkalinity increased slightly from the raw water to the feed water sample location (ST1), due to the addition of the alkaline chemical sodium hypochlorite. Alkalinity at the feed water sample location (ST2) averaged 12% less than the raw water alkalinity due to the addition of sulfuric acid. The feed (ST2) and treated water sample locations had essentially the same level of alkalinity, indicating that MEDIA G2® had minimal impact on alkalinity during the Integrity Test.

There was minimal variability between raw, feed (ST1 and ST2), and treated water fluoride concentrations for any set of samples. As shown in Figure 4-6, recorded fluoride concentrations were relatively variable from day to day. It is believed that some of this variation was due to either malfunction or miscalibration of the fluoride analytical equipment. Three out of 14 fluoride data points were discarded due to suspected analytical problems and were not included in the computed results presented in Table 4-5 or in Figure 4-6. MEDIA G2® had little, if any, impact on the level of fluoride in the feed water. The manufacturer indicated that fluoride would not be removed by MEDIA G2®.

The results of analyses for calcium, magnesium, and total hardness indicate that the water is very hard. A slight reduction in the total hardness and calcium levels appears to have occurred through the treatment process. Only two samples were collected for calcium, magnesium, and hardness analyses during the Integrity Test. Additional data was collected during the Capacity Test and these water quality parameters are evaluated in more detail with the Capacity Test data in Section 4.4.

A trace concentration of FAC was detected in the raw water, likely due to diffusion of chlorine back from the chlorine detention tank when the well pump was off line. The two feed water sample locations, ST1 and ST2, had similar levels of chlorine, although the chlorine concentration level at ST2 was typically slightly lower due to the oxidant demand in the raw water exerted during the travel time between the two locations (see Figure 4-7). Additional chlorine depletion, averaging 0.32 mg/L, occurred between ST2 and the treated water, possibly as a result of both further satisfying the oxidant demand of the raw water and the exertion of oxidant demand by the media.

A complete summary of on-site water quality data and copies of the original logbook are included in Appendix J.

Table 4-5. Integrity Test On-site Water Quality Analyses

Parameter	Units	Number of Samples	Mean/ Median[(1)]	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Raw							
pH	units	28	7.5	7.4	7.6	N/A	N/A
Turbidity	NTU	14	0.65	0.15	2.0	0.50	0.30 – 1.0
Alkalinity	mg/L as $CaCO_3$	14	147	130	160	7.04	143 - 152
Fluoride	mg/L	12	0.35	0.13	0.62	0.12	0.26 - 0.44
FAC	mg/L	28	0.06	0.02	0.31	0.07	0.03 - 0.09
Feed (ST1)							
pH	units	14	7.4	7.4	7.5	N/A	N/A
Turbidity	NTU	14	0.95	0.35	2.7	0.60	0.55 - 1.4
Alkalinity	mg/L as $CaCO_3$	14	156	146	160	3.41	153 - 158
Fluoride	mg/L	12	0.36	0.13	0.64	0.13	0.26 - 0.46
FAC	mg/L	14	1.25	0.91	1.60	0.18	1.13 - 1.37
Feed (ST2)							
pH	units	28	6.7	5.9	7.1	N/A	N/A
Temperature	°C	14	13.2	12.9	13.4	0.17	13.1 - 13.3
Turbidity	NTU	14	1.6	0.35	7.6	2.0	0.25 - 3.0
Alkalinity	mg/L as $CaCO_3$	14	130	120	148	11.0	123 - 138
Calcium	mg/L as $CaCO_3$	2	260	258	262	N/A	N/A
Magnesium	mg/L as $CaCO_3$	2	18	18	18	N/A	N/A
Hardness	mg/L as $CaCO_3$	2	278	276	280	N/A	N/A
Fluoride	mg/L	12	0.35	0.13	0.65	0.13	0.26 - 0.45
FAC	mg/L	28	1.13	0.82	1.61	0.19	1.04 - 1.21
Treated							
pH	units	28	6.7	5.9	7.0	N/A	N/A
Temperature	°C	14	13.4	13.0	13.8	0.20	13.2 - 13.5
Turbidity	NTU	14	0.55	0.15	3.8	0.95	0 -1.2
Alkalinity	mg/L as $CaCO_3$	14	130	116	146	10.6	122 - 137
Calcium	mg/L as $CaCO_3$	2	247	246	248	N/A	N/A
Magnesium	mg/L as $CaCO_3$	2	19	18	20	N/A	N/A
Hardness	mg/L as $CaCO_3$	2	266	264	268	N/A	N/A
Fluoride	mg/L	11	0.35	0.13	0.62	0.14	0.24 - 0.45
FAC	mg/L	28	0.80	0.29	1.05	0.25	0.69 - 0.91

(1) The median of the pH data is reported, not the mean.

N/A = Standard Deviation and 95% confidence intervals were not calculated for pH. Statistics not calculated for sample sets of less than 8.

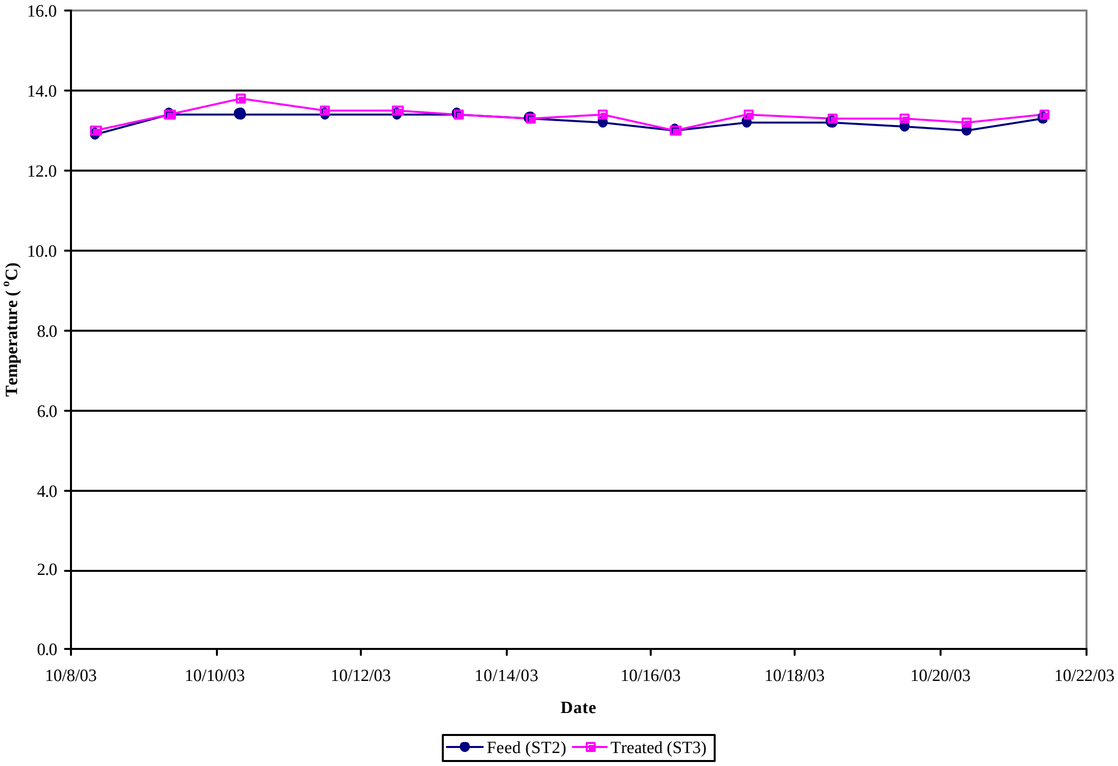

Figure 4-2. Integrity Test Temperature.

Figure 4-3. Integrity Test pH.

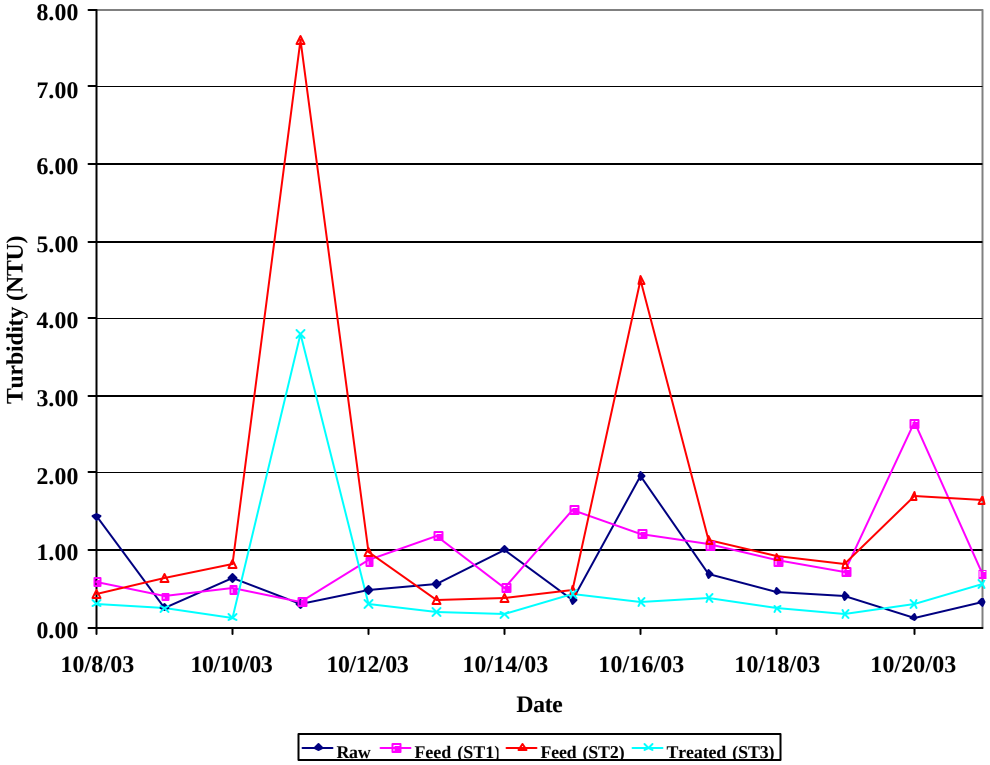

Figure 4-4. Integrity Test Turbidity.

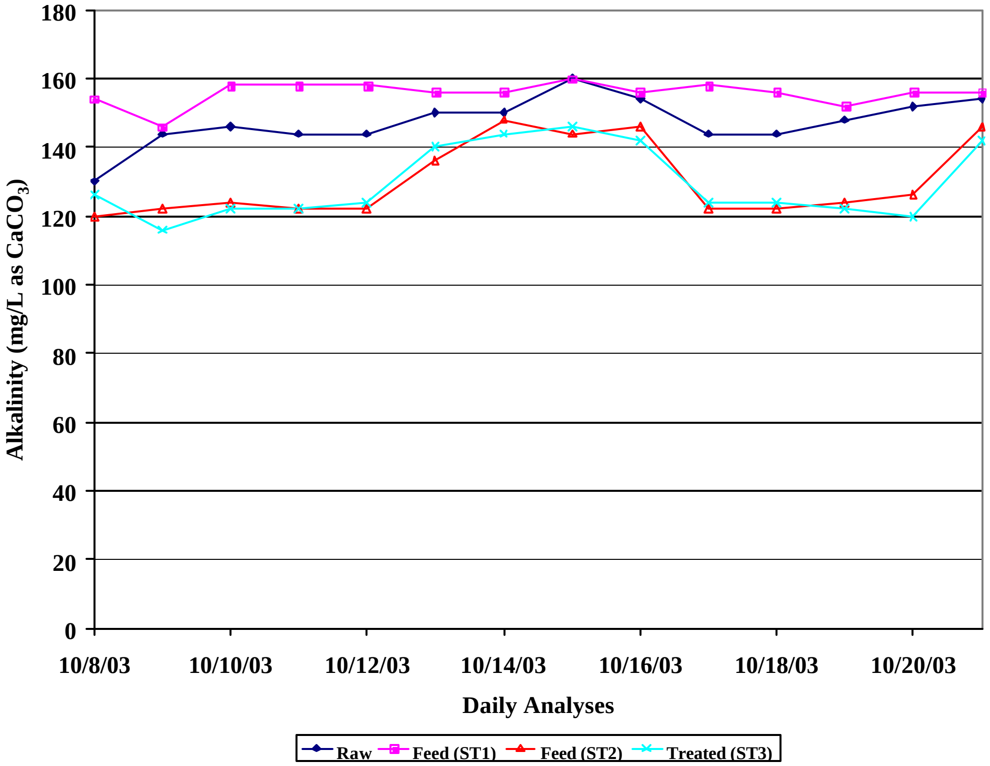

Figure 4-5. Integrity Test Alkalinity.

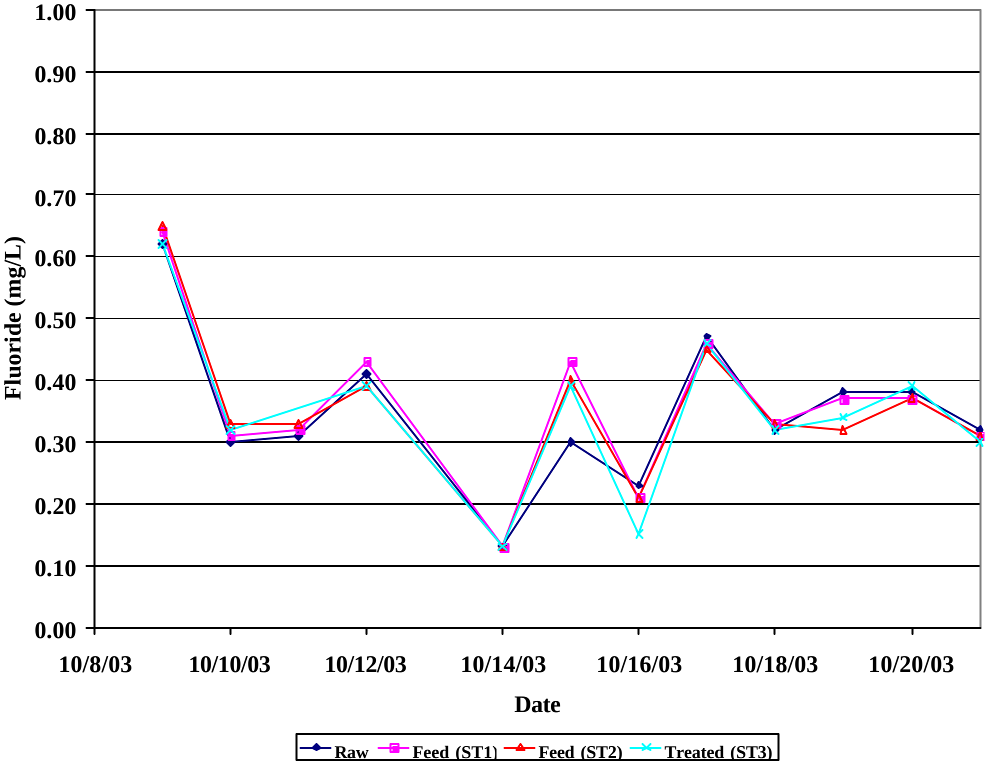

Figure 4-6. Integrity Test Fluoride.

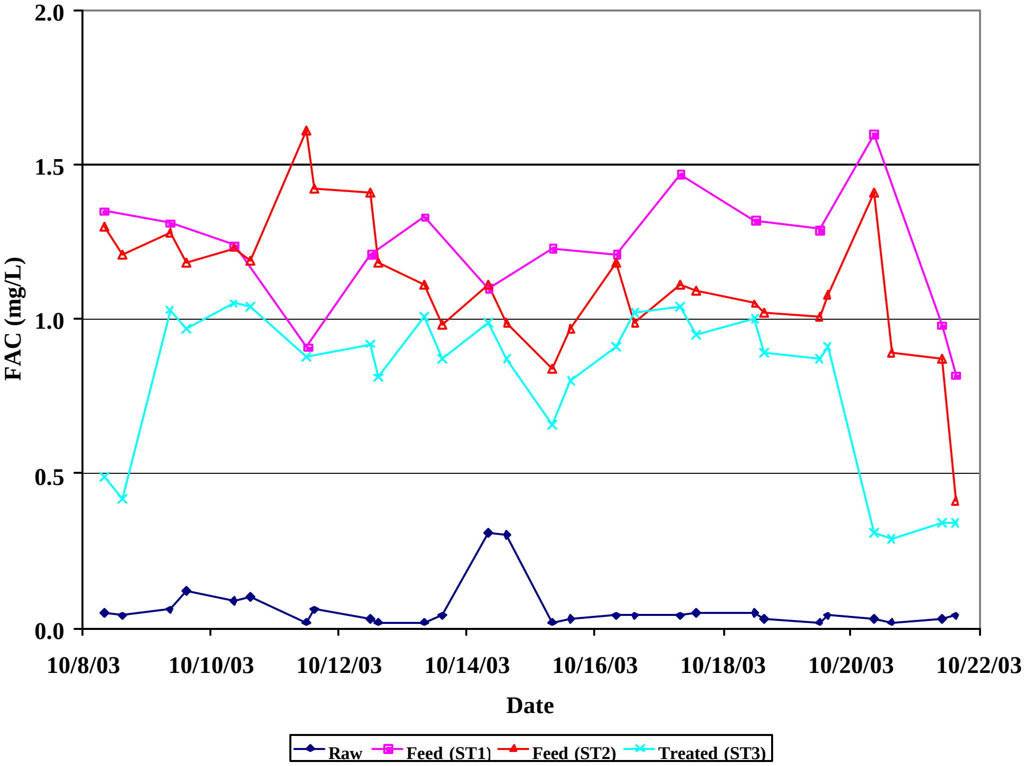

Figure 4-7. Integrity Test FAC.

4.3.5 Integrity Test Laboratory Water Quality Analyses

The results of water quality analyses performed at the PADEP Laboratory are summarized in Table 4-6. Compiled data, copies of the original laboratory data reports, and sample submission forms are included in Appendix K.

As shown in Figure 4-8, the sodium concentration at the four sample locations varied in unison during the Integrity Test, within a range of 15%. There was no apparent sodium removal by, or displacement from, the media. The overall variation in sodium concentrations was likely a result of groundwater dilution from rainfall and variations in the sodium hypochlorite feed rate.

The filter media was apparently contributing silica to the treated water. The silica concentration was initially 70% higher in the treated water than in the feed water at the beginning of the Integrity Test. The silica concentration in the treated water decreased during the Integrity Test, as indicated in Figure 4-9, so that by the end of the 14-day period the treated water silica concentration was only 30% higher than in the feed water. By the end of the verification test, the treated water silica concentration was approximately equal to the feed water silica concentration.

Concentrations of sulfate and chloride, analyzed twice during the Integrity Test, were not significantly altered by the treatment process. Sulfate increased by 10% in the feed (ST2) water relative to the raw water. This increase was most likely a result of the formation of sulfate by-products following the addition of sulfuric acid for pH adjustment. Feed (ST2) and treated water sulfate concentrations were essentially equal in the two samples. The raw water chloride level remained the same through the treatment process. Both the chloride and sulfate feed levels were considerably below the 250 mg/L levels that the manufacturer states may reduce the arsenic adsorption capacity of MEDIA G2®.

The raw, feed (ST2), and treated water were analyzed twice during the Integrity Test for total phosphorus. The analyses indicated a significant variation in concentration between sample locations, particularly for the raw and feed water locations. This may represent a variation in feed water quality, although it is also conceivable that the phosphorus reduction may be due to sodium reacting with phosphorus, producing a by-product that precipitates in the detention tank. No phosphorus was detected in the treated water, probably due to the media's affinity for phosphorus. The effects of the phosphorus concentration by the media were further evaluated following the Capacity Test.

There was a relative correlation in trends between the feed water turbidity, iron concentration, and manganese concentration, presented in Figures 4-4, 4-10, and 4-11, respectively. The correlation was particularly evident in regards to the spikes of these constituents, which peaked on the fourth and ninth days of the Integrity Test. The peak levels of feed water iron and manganese were greater than their secondary maximum contaminant levels (SMCLs) of 300 µg/L and 50 µg/L, respectively. Although the cause of the first spike is unknown, it is very likely that the second spike in the water quality of the well supply was due to the impact of a significant rainfall event. The treatment unit generally removed both iron and manganese below their SMCLs, despite the variation in feed water concentrations. One treated water sample during the Integrity Test, however, did exceed the SMCL for manganese, at 60 µg/L. Aluminum concentrations at all sample locations were below the detection limit of 200 µg/L.

Table 4-6. Integrity Test Laboratory Water Quality Analyses

Parameter	Units	Number of Samples	Mean	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Raw							
Sodium	mg/L	2	24.0	22.8	25.1	N/A	N/A
Silica	mg/L	2	27.8	27.2	28.5	N/A	N/A
Aluminum	µg/L	2	<200	<200	<200	N/A	N/A
Iron	µg/L	2	147	144	149	N/A	N/A
Manganese	µg/L	2	102	99	104	N/A	N/A
Chloride	mg/L	2	35.2	34.2	36.1	N/A	N/A
Sulfate	mg/L	2	101	99.9	103	N/A	N/A
Total Phosphorus	mg/L	2	0.063	<0.010	0.115	N/A	N/A
Feed (ST2 Total)							
Sodium	mg/L	14	25.1	22.8	27.1	1.56	24.1 – 26.0
Silica	mg/L	14	27.8	27.2	28.5	0.40	27.6 - 28.1
Aluminum	µg/L	14	<200	<200	<200	0	<200 - <200
Iron	µg/L	14	354	71	1120	342	122 - 585
Manganese	µg/L	14	298	88	1070	305	92 - 505
Chloride	mg/L	2	36.9	36.7	37.0	N/A	N/A
Sulfate	mg/L	2	117	111	123	N/A	N/A
Total Phosphorus	mg/L	2	0.012	<0.010	0.013	N/A	N/A
Feed (ST2 Soluble)							
Sodium	mg/L	14	25.1	23.0	26.8	1.43	24.1 - 26.0
Silica	mg/L	14	27.6	27.0	28.0	0.27	27.4 - 27.7
Aluminum	µg/L	14	<200	<200	<200	0	<200 - <200
Iron	µg/L	14	75	<20	202	55	38 - 113
Manganese	µg/L	14	45	28	68	9	39 - 51
Treated							
Sodium	mg/L	14	25.3	23.3	26.8	1.31	24.4 - 26.1
Silica	mg/L	14	38.9	34.2	47.3	3.86	36.3 - 41.5
Aluminum	µg/L	14	<200	<200	<200	0	<200 - <200
Iron	µg/L	14	82	32	209	61	41 - 123
Manganese	µg/L	14	27	<10	60	15	17 - 38
Chloride	mg/L	2	36.9	36.6	37.1	N/A	N/A
Sulfate	mg/L	2	119	113	124	N/A	N/A
Total Phosphorus	mg/L	2	<0.010	<0.010	<0.010	N/A	N/A

N/A = Statistics not calculated for sample sets of less than 8.

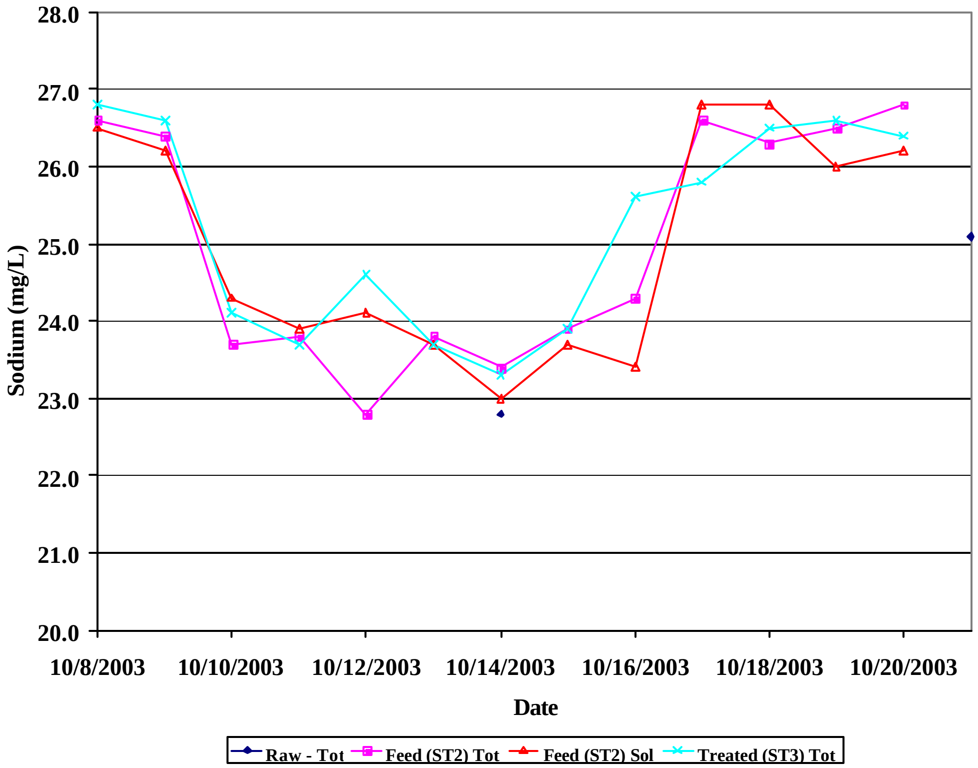

Figure 4-8. Integrity Test Sodium.

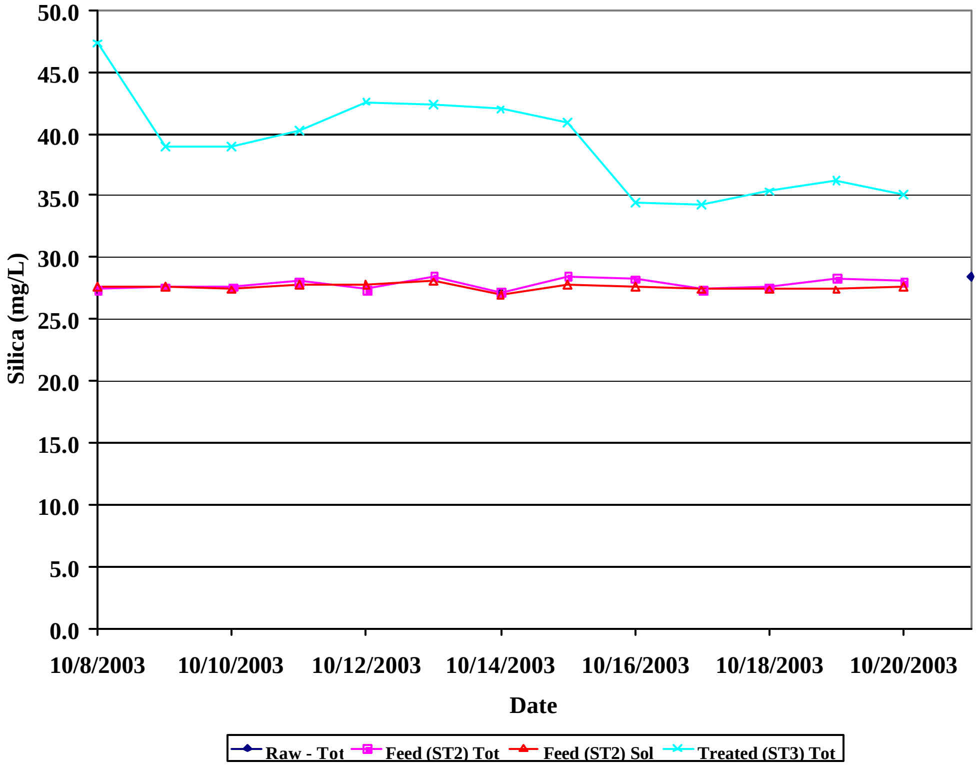

Figure 4-9. Integrity Test Silica.

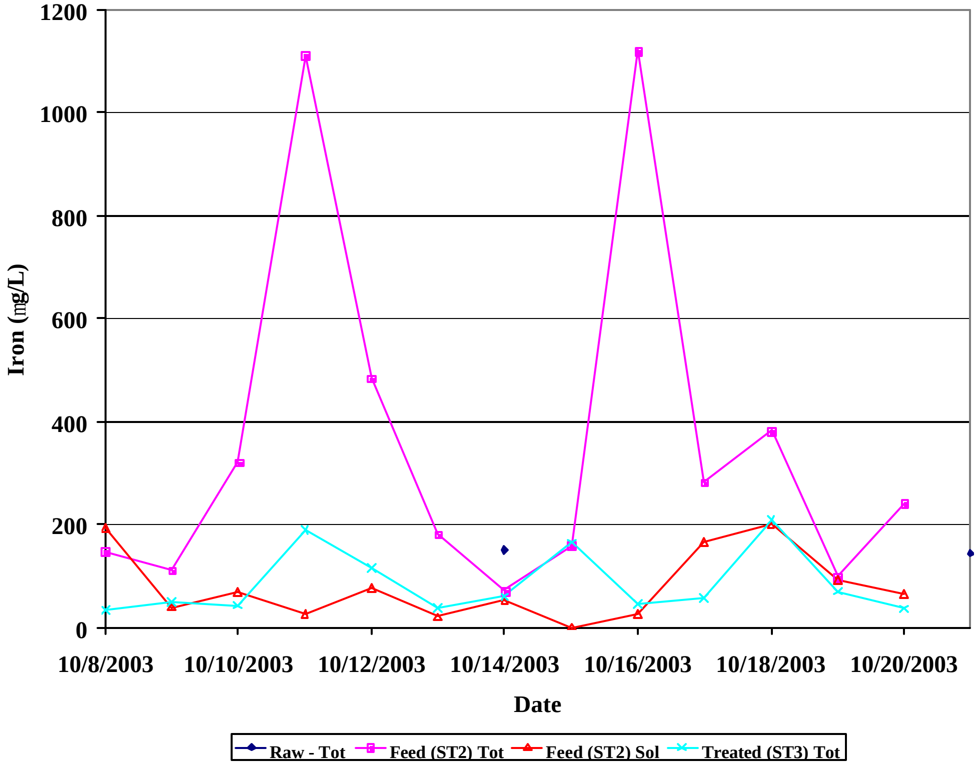

Figure 4-10. Integrity Test Iron.

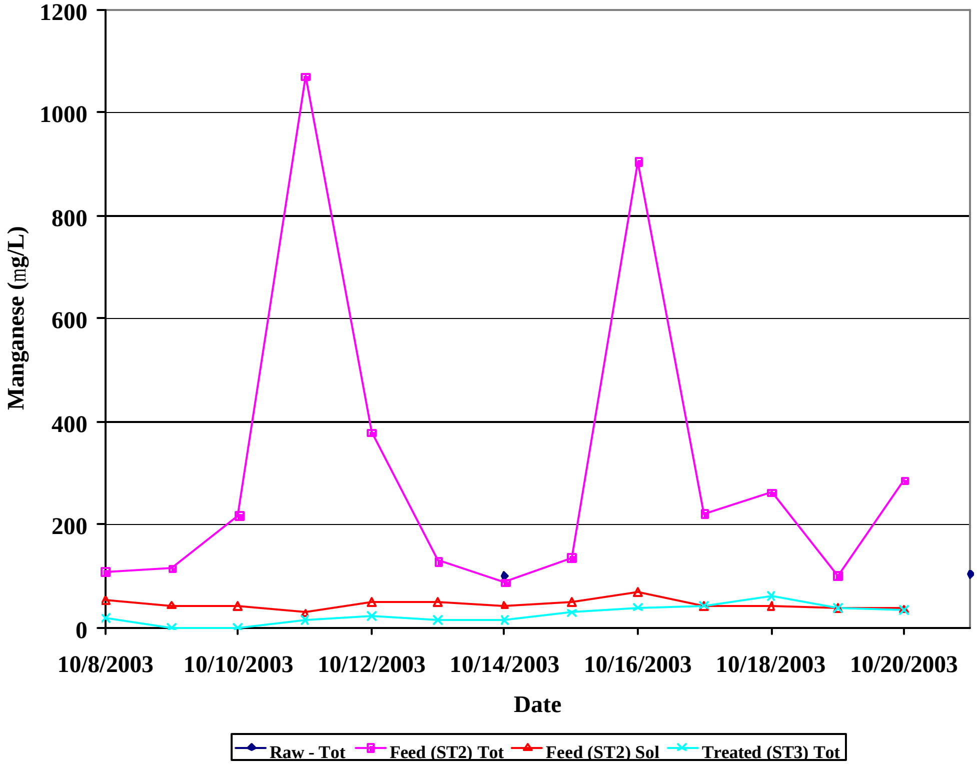

Figure 4-11. Integrity Test Manganese.

4.3.6 Integrity Test Laboratory Arsenic Analyses

Raw water, feed water, and treated water samples were collected daily for arsenic analysis during the Integrity Test. Seven of the sample sets were speciated to determine the fraction of soluble arsenic in the arsenic III valence state relative to arsenic V. The results of the NSF laboratory arsenic analyses are summarized in Table 4-7. Complete results of the arsenic analyses including a summary table, analytical test reports, and chain of custody forms are included in Appendix L. The raw data is on file at NSF.

The raw water total arsenic concentration averaged 13 µg/L during the Integrity Test, of which 5 µg/L was arsenic III. The average feed water arsenic concentration was 62% higher than the raw water arsenic concentration, possibly due to resuspension of previously settled solids in the detention tank. Arsenic III was not detected in the feed water following oxidation with sodium hypochlorite. The average feed water total arsenic concentration was 21 µg/L. Both the raw and feed water arsenic concentrations, presented in Figures 4-12 and 4-13, varied widely. The impact of the rainfall events on the well water quality may have contributed to the variations in raw and feed water arsenic concentrations.

On average, 67% of the feed water total arsenic was removed by the MEDIA G2® filter during the two-week Integrity Test. Total arsenic was detected in all of the treated water samples at levels above 2 µg/L, as presented in Figure 4-14. As indicated in Table 4-7, the treated water arsenic concentrations during the Integrity Test averaged 7 µg/L, with a maximum concentration of 10 µg/L. The lowest arsenic concentration in the treated water occurred on the first day of operations, prior to the system reaching equilibrium, and was apparently due to the virgin condition of the media. Interestingly, this occurred at the time of maximum displacement of silica from the media. Average feed water-soluble arsenic and arsenic V were reduced by 45% and 56%, respectively, in the treated water. The peak levels of total arsenic in the feed water, 38 µg/L and 28 µg/L, did not result in any significant increase in the treated water arsenic concentration.

The feed water pH appeared to have a far greater impact on the removal of arsenic than the feed water arsenic concentration. The highest treated water arsenic concentrations occurred when the feed water pH was highest. The correlation between increasing feed water pH and increasing treated water arsenic concentration is shown in Figure 4-15. The manufacturer indicated that the feed water pH should be maintained between 6.5 and 6.8 for optimum arsenic removal, but difficulties encountered with the acid feed pump operation resulted in several periods when the pH was above this range. A decrease in feed water pH from 7.1 to 6.2 on the ninth day of the test resulted in a 70% decrease in the treated water arsenic concentration. Thereafter, correlations in treated water arsenic with variations in feed water pH were not as significant but continued to occur.

Figure 4-16 shows that the majority of the treated water total arsenic concentration was in the form of soluble arsenic, composed primarily of the arsenic V species.

FAC concentration did not appear to significantly impact the treated water arsenic concentrations, as shown in Figure 4-17. However, the feed water FAC concentration was relatively stable during the Integrity Test.

Field arsenic analyses, performed using the ITS QUICK Low Range II test kit, were used to monitor the feed and treated water arsenic concentrations on-site for operations control and for quick qualitative results. However, the test kits are not an EPA-approved method, so the data are not presented here. On-site arsenic analyses results are included in the logbook copies in Appendix J.

Table 4-7. Integrity Test Laboratory Arsenic Analyses

	Raw				**Feed (ST2)**			
	Total Arsenic (µg/L)	**Soluble Arsenic (µg/L)**	**Arsenic III (µg/L)**	**Calculated Arsenic V (µg/L)**	**Total Arsenic (µg/L)**	**Soluble Arsenic (µg/L)**	**Arsenic III (µg/L)**	**Calculated Arsenic V (µg/L)**
Number of Samples	14	7	7	7	14	7	7	7
Mean	13	12	5	6	21	11	<2	9
Minimum	8	7	<2	2	15	8	<2	6
Maximum	18	16	12	12	38	13	<2	11
Standard Deviation	3	N/A	N/A	N/A	6.0	N/A	N/A	N/A
95% Confidence Interval	11 - 15	N/A	N/A	N/A	16 - 25	N/A	N/A	N/A

	Treated			
	Total Arsenic (µg/L)	**Soluble Arsenic (µg/L)**	**Arsenic III (µg/L)**	**Calculated Arsenic V (µg/L)**
Number of Samples	14	7	7	7
Mean	7	6	<2	4
Minimum	2	3	<2	1
Maximum	10	12	<2	10
Standard Deviation	N/A	N/A	N/A	N/A
95% Confidence Interval	N/A	N/A	N/A	N/A

N/A = Statistics not calculated for sample sets of less than 8. Statistics not appropriate for treated water arsenic.

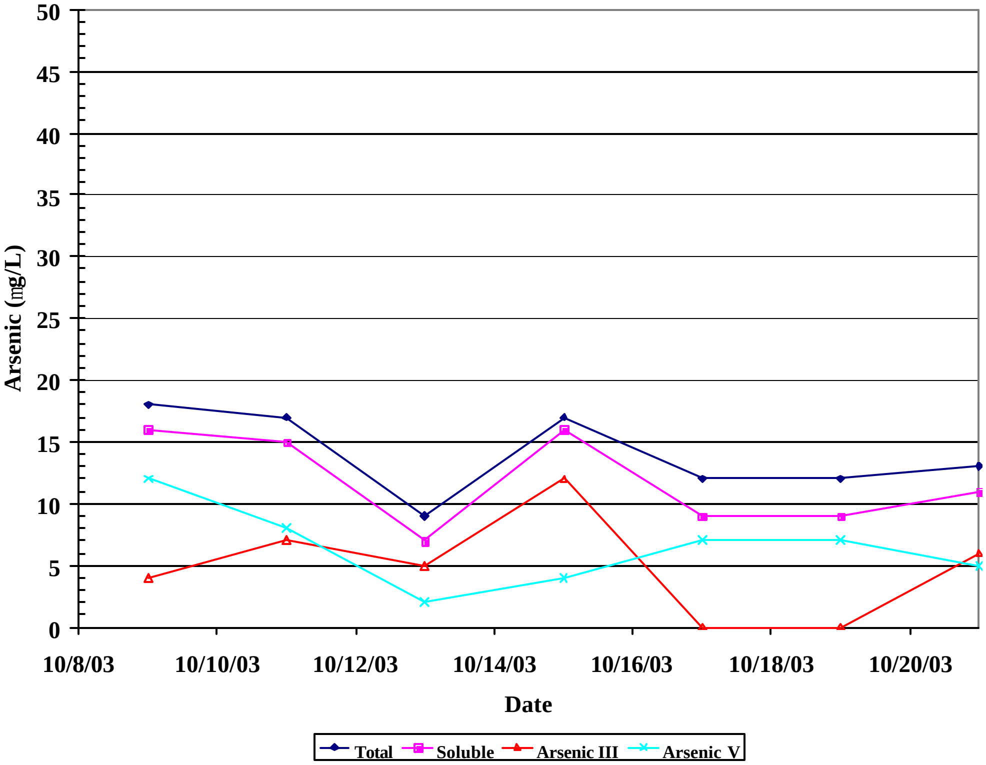

Figure 4-12. Integrity Test Raw Total, Soluble and Speciated Arsenic.

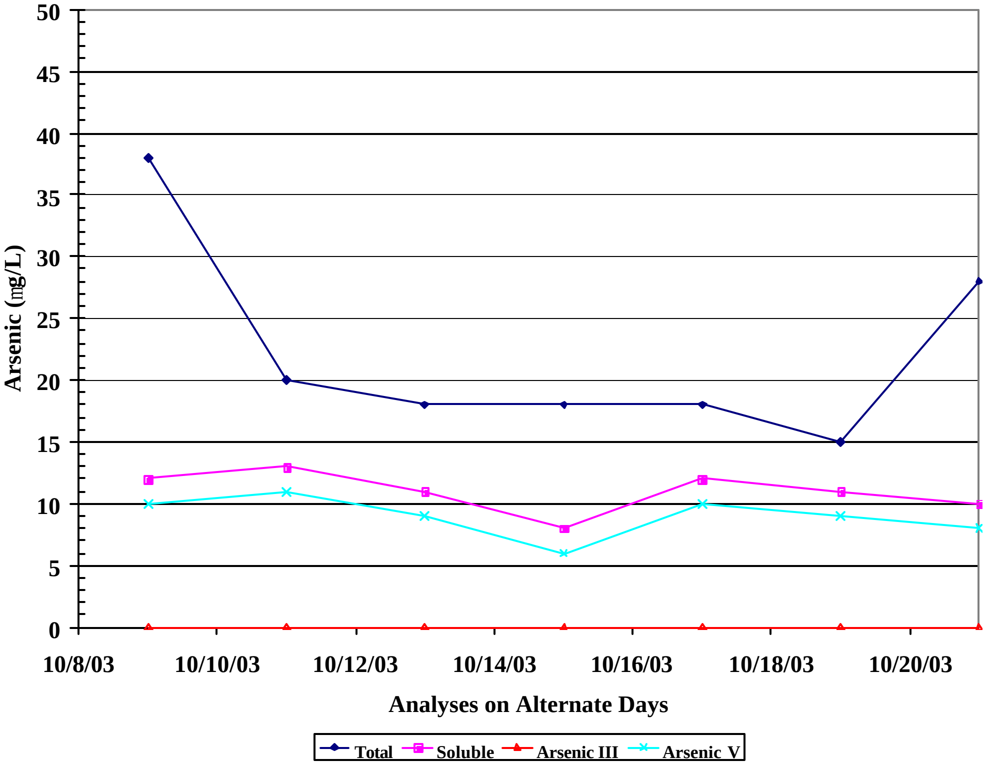

Figure 4-13. Integrity Test Feed (ST2) Total, Soluble and Speciated Arsenic.

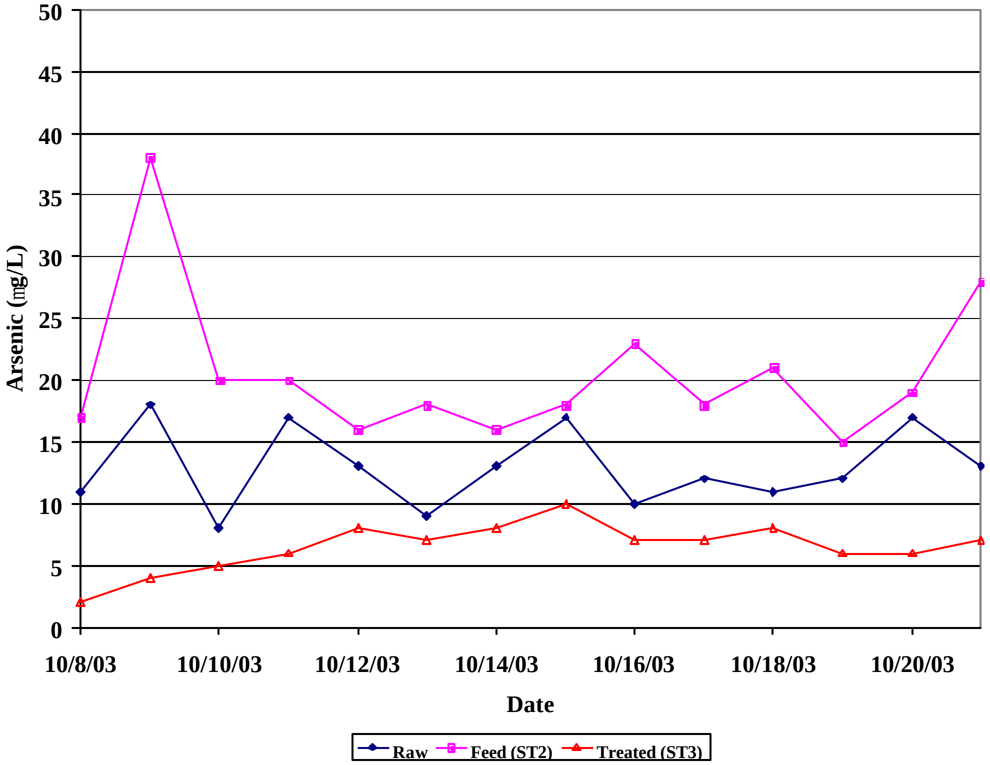

Figure 4-14. Integrity Test Total Arsenic.

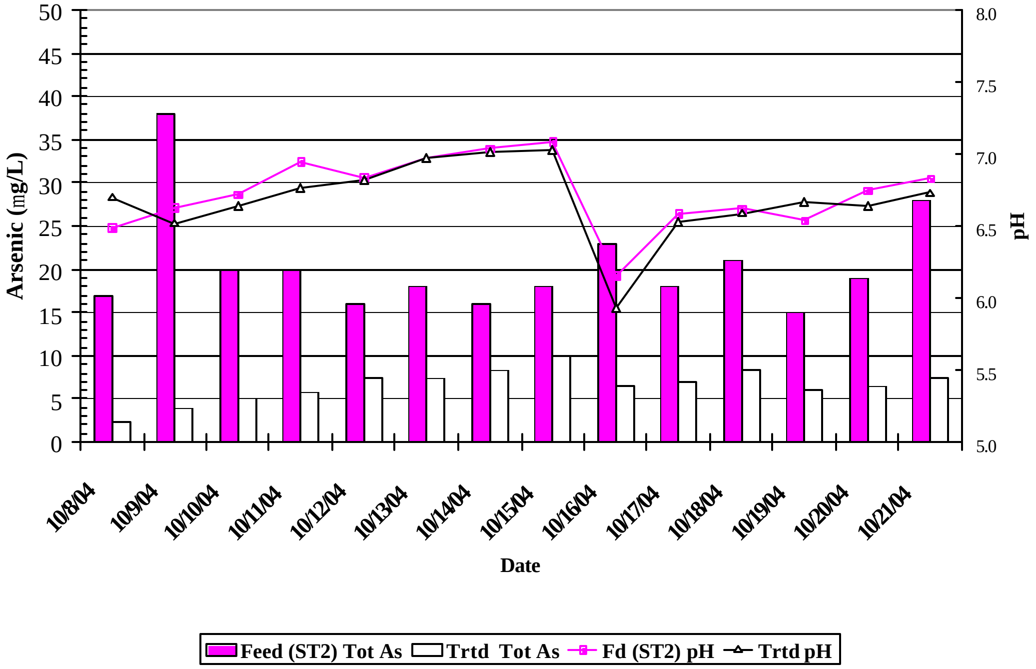

Figure 4-15. Integrity Test - Effect of pH on Arsenic Removal.

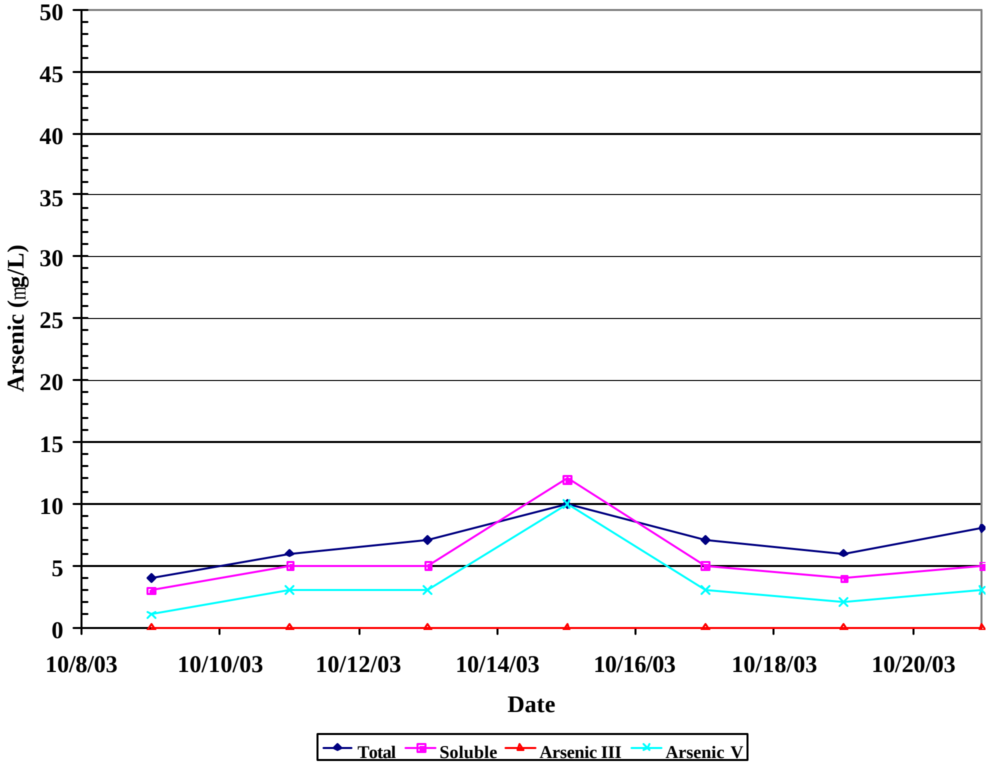

Figure 4-16. Integrity Test Treated Total, Soluble and Speciated Arsenic.

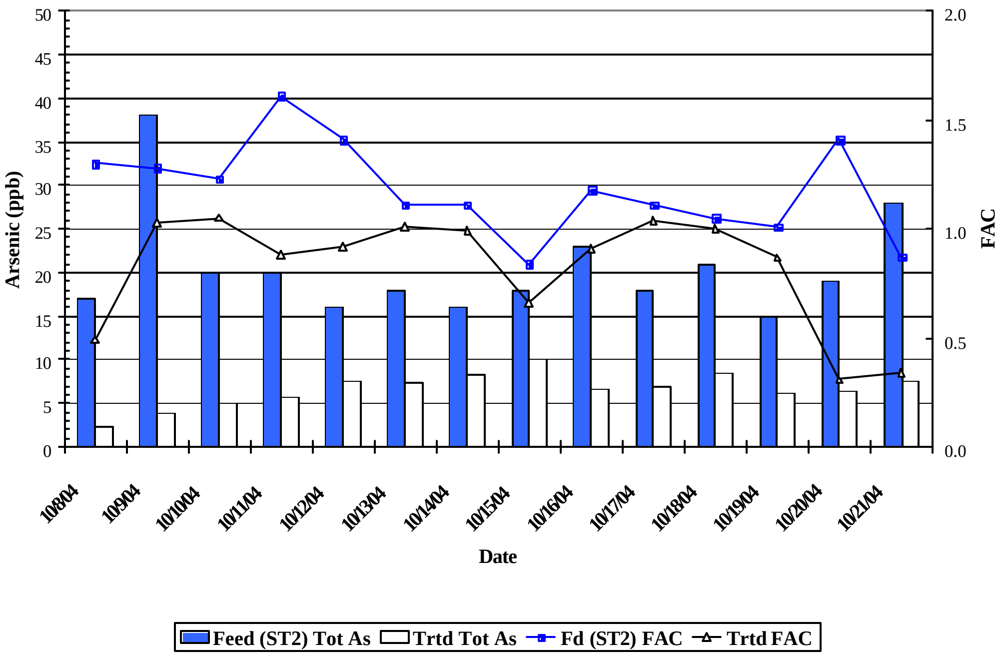

Figure 4-17. Integrity Test FAC and Arsenic Removal.

4.3.7 Integrity Test Equipment Operation

During the Integrity Test, minimal time and/or attention was required to operate the equipment, although significant time was spent conducting on-site analyses. The pilot adsorption media filter is manually operated and uses electricity only for powering the feed water solenoid valve and the chemical feed pumps for metering sulfuric acid, sodium hypochlorite, and caustic soda. The time required for daily operation of the treatment unit included about ten minutes to monitor the flow rate, acid tank level, totalizer, and loss of head, and to verify that there were no leaks in the system. Permanent installation of the equipment would also require daily pH and FAC analyses, as well as periodic on-site arsenic analyses and/or collection of samples for laboratory analyses. FAC and pH analyses require approximately 15 to 20 minutes. On those days in which on-site arsenic analyses with a field test kit are also performed, the total analytical time is 45 minutes.

A filter backwash was performed to fulfill the PSTP requirement of conducting a minimum of one backwash during the Integrity Test, regardless of whether or not the criteria for backwash had occurred. Backwash data from the Capacity Test are summarized and discussed in more detail in Section 4.7.

4.4 Task 2: Adsorption Capacity Verification Testing

The Capacity Test began on October 8, 2003, coinciding with the initiation of the Integrity Test. Water quality sampling and analysis, system monitoring, and data collection were performed as scheduled in the test plan and described in Chapter 3. The filter media was regenerated following the manufacturer's specified procedures on April 30, 2004. The test concluded on May 28, 2004, following four weeks of post-regeneration operation. The results of the Capacity Test, which includes data collected during the Integrity Test, are detailed in the following sections.

4.4.1 Experimental Objectives

The experimental objective of the Capacity Test was to provide operating and water quality data relative to the ability of the arsenic adsorption media filter system to remove arsenic from the feed water under field conditions.

4.4.2 Capacity Test Operational Data

The treatment unit operated continuously during the Capacity Test, with feed water supplied from the storage tank. Well No. 1 operated on demand, based on the water level in the storage tank. Monitoring and on-site data collection were performed as scheduled to verify the equipment performance. Table 4-8 summarizes the arsenic adsorption media filter unit operational data during the Capacity Test, through the date of media regeneration. Table 4-9 summarizes the operational data during the four-week post-regeneration period. Copies of the original logbook data sheets and compiled operational data are included in Appendix J. The non-integral flow control system, consisting of a pressure regulating valve on the chlorine detention tank sample tap and a ball valve on the filter unit discharge, maintained a relatively constant flow rate of 1.69 gpm through the filter unit. The design flow rate was 1.7 gpm.

Table 4-8. Capacity Test Operational Data

	Before Flow Rate Adjustment (gpm)	After Flow Rate Adjustment (gpm)	Feed Pressure (psi)	Treated Pressure (psi)	Pressure Differential (psi)
Number of Samples	398	398	398	398	398
Mean	1.68	1.69	54	48	5
Minimum	1.25	1.57	50	42	-2
Maximum	1.77	1.77	58	56	11
Standard Deviation	0.04	0.03	N/A	N/A	N/A
95% Confidence Interval	1.68 – 1.69	1.69 – 1.69	N/A	N/A	N/A

N/A = Statistics not appropriate for these parameters.

Table 4-9. Post-Regeneration Operational Data

	Before Flow Rate Adjustment (gpm)	After Flow Rate Adjustment (gpm)	Feed Pressure (psi)	Treated Pressure (psi)	Pressure Differential (psi)
Number of Samples	58	58	58	58	58
Mean	1.70	1.70	55	49	6
Minimum	1.60	1.66	54	45	2
Maximum	1.75	1.75	56	52	10
Standard Deviation	0.02	0.02	N/A	N/A	N/A
95% Confidence Interval	1.69 – 1.71	1.69 – 1.71	N/A	N/A	N/A

N/A = Statistics not appropriate for these parameters.

The equipment operated continuously 24 hours per day. The feed water pressure was maintained by the pressure-regulating valve to within the manufacturer's recommended pressure limits of 30 to 125 psi and averaged 54 psi. The filter bed headloss accumulated significantly as a function of run time, as shown in Figure 4-18. A pattern of accumulating head loss between backwashes and a reduction in filter bed headloss following each filter backwash is apparent in the figure. Particulate iron and manganese likely contributed significantly to the accumulating headloss. The headloss across the treatment unit averaged 5 psi. The clean-bed headloss, observed during the first week of testing was 2 psi, when the pressure gauge inaccuracy is accounted for. The feed water pressure gauge was found to read low by about 2 psi, based on calibration checks performed on each gauge by Gannett Fleming using a dead-weight pressure tester.

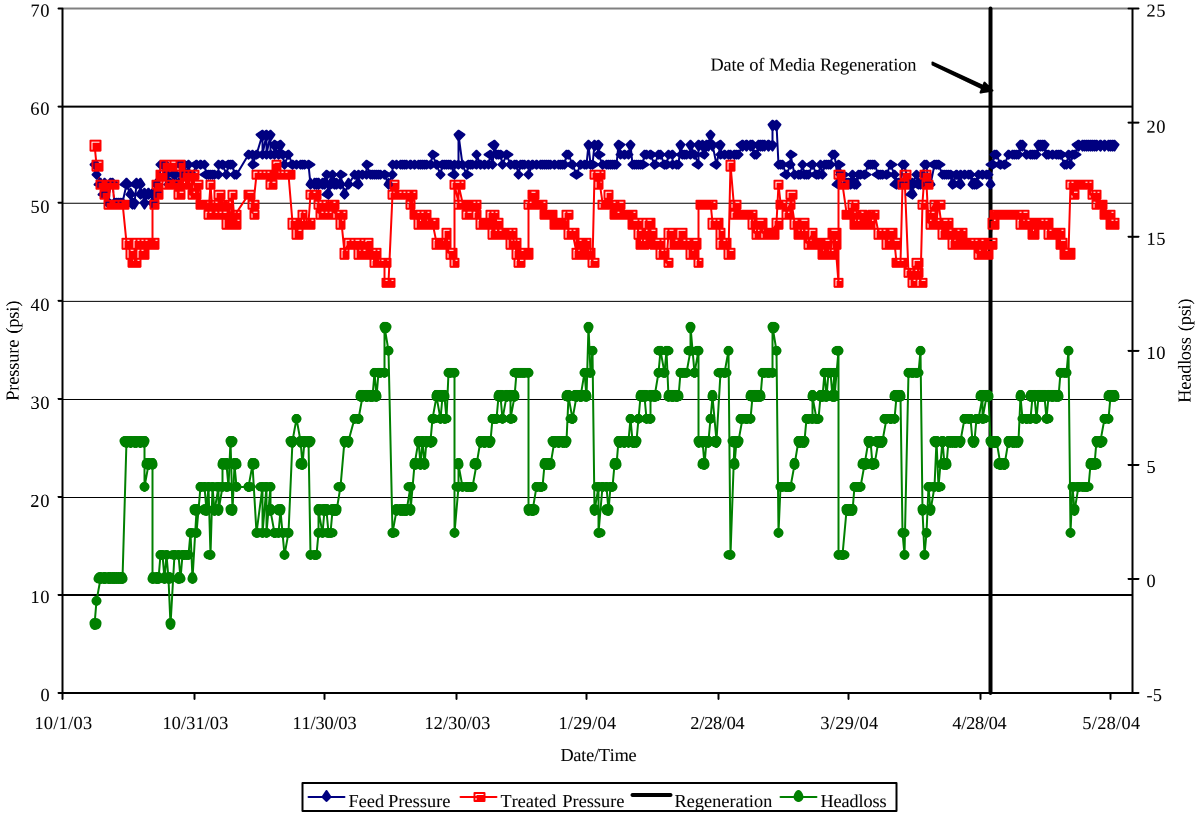

Figure 4-18. Capacity Test Feed Pressure, Treated Pressure, and Filter Bed Headloss.

4.4.3 Capacity Test On-site Water Quality Analyses

The results of Capacity Test on-site water quality analyses are summarized in Table 4-10. Post-regeneration on-site water quality data are summarized in Table 4-11. The media regeneration apparently had no effect on the treated water on-site water quality parameters including pH, turbidity, alkalinity, fluoride, FAC, calcium, magnesium, and hardness, as shown in Tables 4-10 and 4-11 and Figures 4-19 through 4-25. Copies of the original logbook data sheets and compiled on-site water quality data are included in Appendix J.

Table 4-10. Capacity Test On-site Water Quality Analyses

Parameter	Units	Number of Samples	Mean/ Median(1)	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Raw							
pH	units	217	7.57	6.89	7.83	N/A	N/A
Turbidity	NTU	201	0.95	0.10	7.5	1.1	0.80 – 1.1
Alkalinity	mg/L as $CaCO_3$	96	152	126	188	10.2	149 – 154
Calcium	mg/L as $CaCO_3$	2	221	218	224	N/A	N/A
Magnesium	mg/L as $CaCO_3$	2	25	24	26	N/A	N/A
Hardness	mg/L as $CaCO_3$	2	246	242	250	N/A	N/A
Fluoride	mg/L	21	0.32	0.13	0.62	0.10	0.26 – 0.37
FAC	mg/L	38	0.06	0.02	0.31	0.06	0.04 – 0.08
Feed (ST1)							
pH	units	107	7.55	7.24	7.86	N/A	N/A
Turbidity	NTU	203	0.75	0.25	2.7	0.30	0.70 – 0.80
Alkalinity	mg/L as $CaCO_3$	28	155	132	174	7.43	151 – 158
Fluoride	mg/L	21	0.32	0.13	0.64	0.11	0.27 – 0.38
FAC	mg/L	98	0.94	0.05	2.80	0.32	0.86 – 1.01
Feed (ST2)							
pH	units	218	6.43	5.70	7.09	N/A	N/A
Temperature	°C	201	13.2	12.0	14.3	0.22	13.1 – 13.2
Turbidity	NTU	203	0.70	0.15	7.6	0.65	0.60 – 0.80
Alkalinity	mg/L as $CaCO_3$	98	121	62	148	14	117 – 124
Calcium	mg/L as $CaCO_3$	29	254	218	296	20.7	245 – 264
Magnesium	mg/L as $CaCO_3$	27	22	4	40	11	17 - 27
Hardness	mg/L as $CaCO_3$	29	272	238	320	23.1	262 - 282
Fluoride	mg/L	43	0.30	0.13	0.65	0.08	0.27 – 0.33
FAC	mg/L	218	0.85	0.05	2.17	0.24	0.81 – 0.89
Treated							
pH	units	218	6.39	5.51	7.25	N/A	N/A
Temperature	°C	201	13.2	12.2	14.4	0.23	13.2 – 13.3
Turbidity	NTU	203	0.30	0.05	3.8	0.30	0.25 – 0.35
Alkalinity	mg/L as $CaCO_3$	98	117	54	162	16	113 – 120
Calcium	mg/L as $CaCO_3$	29	254	228	298	15.7	247 – 261
Magnesium	mg/L as $CaCO_3$	27	22	2	82	16	15 – 29
Hardness	mg/L as $CaCO_3$	28	271	242	322	22.6	261 - 281
Fluoride	mg/L	42	0.30	0.13	0.62	0.08	0.27 – 0.33
FAC	mg/L	218	0.69	0.04	2.42	0.25	0.65 – 0.72

(1) Median is reported for pH only.

N/A = Standard Deviation and 95% confidence intervals were not calculated for pH. Statistics not calculated for sample sets of less than 8.

Table 4-11. Post-Regeneration On-site Water Quality Analyses

Parameter	Units	Number of Samples	Mean/ Median[(1)]	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Raw							
pH	units	29	7.71	7.56	7.79	N/A	N/A
Turbidity	NTU	28	0.85	0.25	3.8	0.90	0.45 – 1.2
Alkalinity	mg/L as $CaCO_3$	11	158	148	188	13.4	147 – 168
Feed (ST1)							
pH	units	13	7.72	7.59	7.76	N/A	N/A
Turbidity	NTU	28	0.75	0.40	2.0	0.45	0.55 – 0.95
FAC	mg/L	11	0.82	0.04	1.08	0.38	0.52 – 1.12
Feed (ST2)							
pH	units	29	6.53	6.08	6.82	N/A	N/A
Temperature	°C	28	13.3	13.2	13.4	0.08	13.2 – 13.3
Turbidity	NTU	28	0.60	0.25	1.2	0.25	0.50 – 0.70
Alkalinity	mg/L as $CaCO_3$	11	123	102	134	8.50	117 – 130
Calcium	mg/L as $CaCO_3$	4	276	256	288	N/A	N/A
Magnesium	mg/L as $CaCO_3$	4	46	14	86	N/A	N/A
Hardness	mg/L as $CaCO_3$	4	322	290	374	N/A	N/A
Fluoride	mg/L	4	0.29	0.22	0.34	N/A	N/A
FAC	mg/L	28	0.75	0.04	1.25	0.45	0.54 – 0.95
Treated							
pH	units	29	6.51	6.05	6.71	N/A	N/A
Temperature	°C	28	13.3	13.1	13.4	0.08	13.2 – 13.3
Turbidity	NTU	28	0.35	0.10	0.75	0.15	0.25 – 0.40
Alkalinity	mg/L as $CaCO_3$	11	114	82	128	11.7	104 – 123
Calcium	mg/L as $CaCO_3$	4	262	242	278	N/A	N/A
Magnesium	mg/L as $CaCO_3$	4	43	22	56	N/A	N/A
Hardness	mg/L as $CaCO_3$	4	305	292	314	N/A	N/A
Fluoride	mg/L	4	0.29	0.23	0.32	N/A	N/A
FAC	mg/L	28	0.69	0.02	1.18	0.43	0.50 – 0.88

(1) Median is reported for pH only.

N/A = Standard Deviation and 95% confidence intervals were not calculated for pH. Statistics not calculated for sample sets of less than 8.

The raw and feed (ST1) pH values were nearly equal with median values of 7.57 and 7.55, respectively, and were relatively stable throughout the Capacity Test as shown in Figure 4-19. The feed (ST2) and treated (ST3) water pH values were significantly lower due to the addition of sulfuric acid to lower pH and improve the arsenic removal capacity of the media. The feed (ST2) median pH was 6.43 and the treated (ST3) median pH was 6.39. The variability in the feed (ST2) and treated (ST3) water pH values was due primarily to chemical feed pump operations. Also, as shown in Figure 4-19, the target pH was reduced in early November, at the manufacturer’s request, to improve arsenic removal. As shown in Figure 4-19, at the request of the manufacturer, a one-week period of operation with a reduced feed (ST2) pH with a target range of 6.0 to 6.2 was conducted prior to the media regeneration. In response to the reduction in feed (ST2) pH, the treated water arsenic concentration was reduced during this period, as shown later in this section. However, the period of reduced pH operation immediately prior to regeneration was not included in the calculation of the media capacity. The target pH was adjusted back to 6.5 after media regeneration.

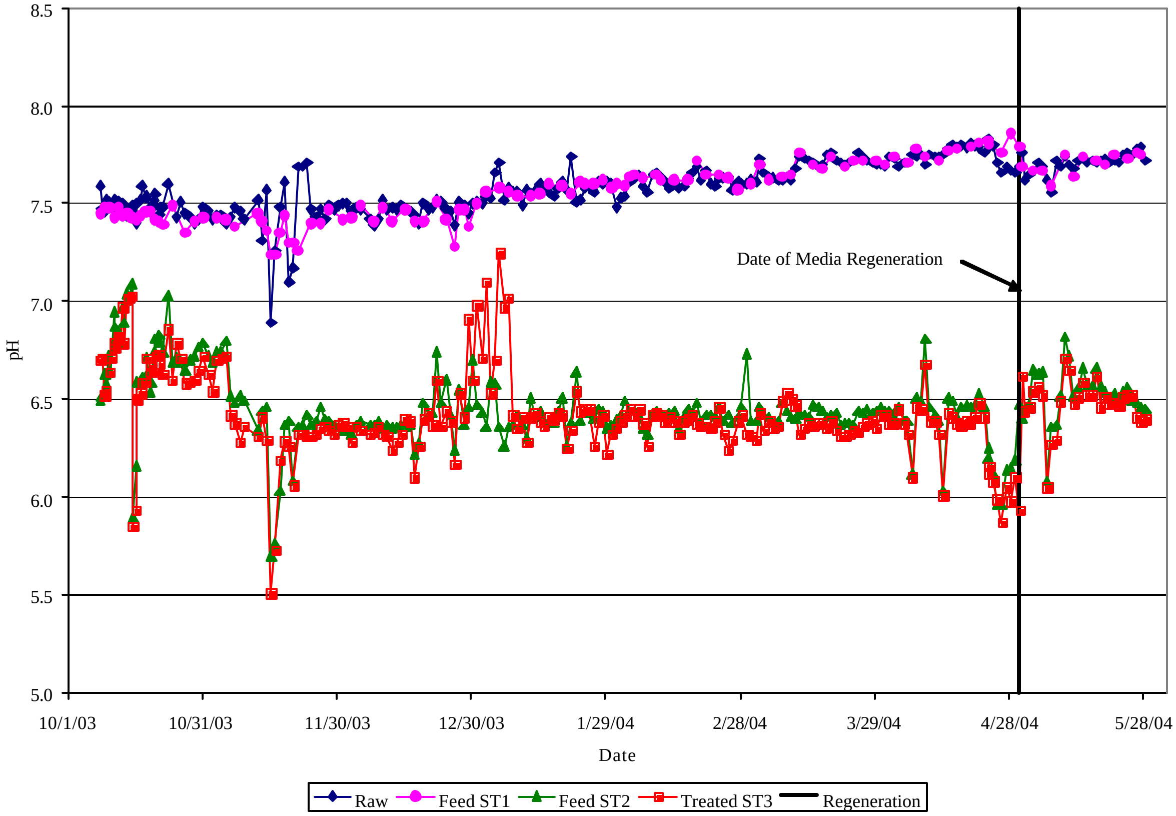

Figure 4-19. Capacity Test pH.

Due to the relatively short hydraulic detention time, the feed (ST2) and treated (ST3) water temperatures were nearly equal throughout the test, both averaging 13.2°C. Capacity Test and post-regeneration feed (ST2) and treated water temperatures are shown in Figure 4-20. The water temperatures were relatively stable, with minimum and maximum temperatures separated by approximately 2°C during the Capacity Test.

Figure 4-20. Capacity Test Temperature.

For a groundwater supply, the raw and feed water turbidities were relatively high and variable, as shown in Figure 4-21. The Capacity Test raw water turbidity averaged 0.95 NTU and was variable, ranging from 0.10 NTU to 7.5 NTU. The raw water turbidity was apparently impacted by precipitation events. The feed water turbidity averaged 0.75 NTU (ST1) and 0.70 NTU (ST2) but at times exceeded the raw water turbidity. This indicates that additional water quality deterioration, possibly resulting from the oxidation of dissolved iron and manganese and/or the disturbance of sediment in the chlorine contact tank, occurred prior to the filter unit. In addition, as discussed with the Integrity Test data in Section 4.3.4, variable demands and the frequency of well pump operations could result in a lag time between raw and feed water turbidity spikes. The treated water turbidity averaged 0.30 NTU, with minimum and maximum recorded values of 0.05 NTU and 3.8 NTU, respectively. The reduction in turbidity from the feed to the treated water indicates that filtration of particles was occurring within the treatment unit.

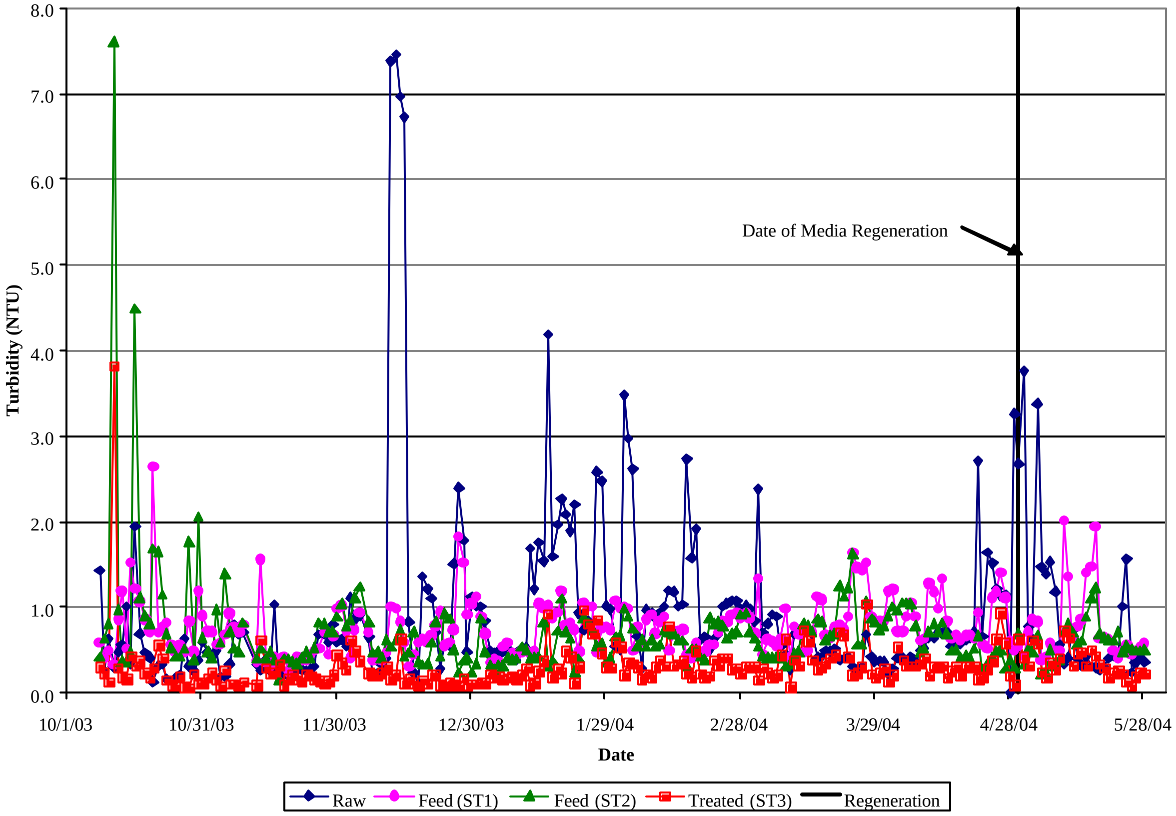

Figure 4-21. Capacity Test Turbidity.

The Capacity Test alkalinity concentrations are shown in Figure 4-22. The average raw and feed (ST1) alkalinity concentrations were nearly equal, averaging 152 and 155 mg/L as $CaCO_3$ respectively, as shown in Table 4-10. The feed (ST2) alkalinity averaged 121 mg/L as $CaCO_3$ and the treated water alkalinity averaged 117 mg/L as $CaCO_3$. These feed (ST2) and treated water alkalinities were 20% and 23% less than the raw water alkalinity, respectively. This alkalinity reduction was a direct result of the addition of sulfuric acid for pH adjustment. In addition, the treated water alkalinity was approximately 3% less than the feed (ST2) alkalinity, which indicates that some alkalinity may have been consumed in the filter unit. As shown in Figure 4-22, at the request of the manufacturer, a one-week period of operation with a reduced feed (ST2) pH was conducted prior to the media regeneration. As a result of the reduction in feed (ST2) pH, the feed (ST2) and treated water alkalinity was reduced during the period of reduced pH.

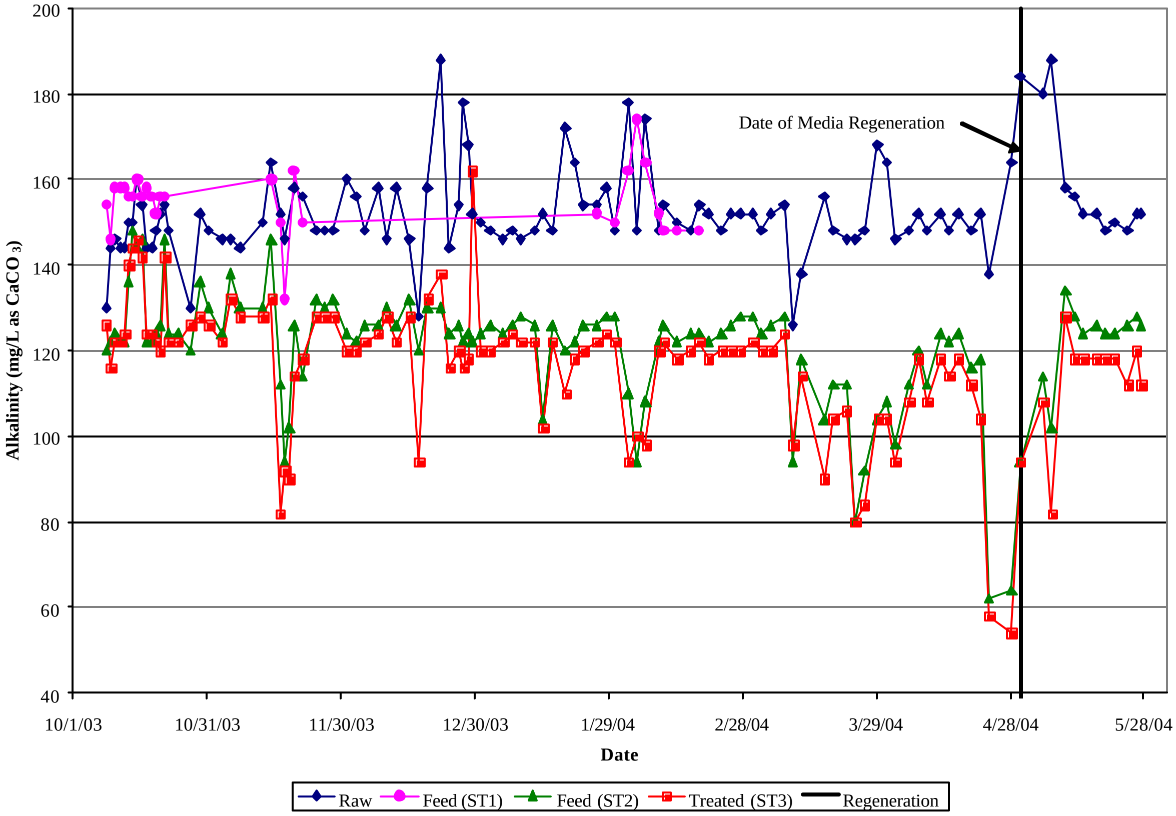

Figure 4-22. Capacity Test Alkalinity Concentration.

Figure 4-23 shows that raw, feed (ST1 and ST2), and treated water fluoride concentrations were unaffected by the treatment process, which supports the manufacturer's claim that the media does not remove fluoride. The fluoride concentration averaged 0.3 mg/L in the raw, feed, and treated water. The feed (ST2) and treated water fluoride concentrations both averaged 0.30 mg/L. Variable fluoride concentrations at the beginning of the Integrity Test were suspected to be a result of either malfunction or miscalibration of the fluoride analytical equipment and were not included in the statistical calculations or in Figure 4-23.

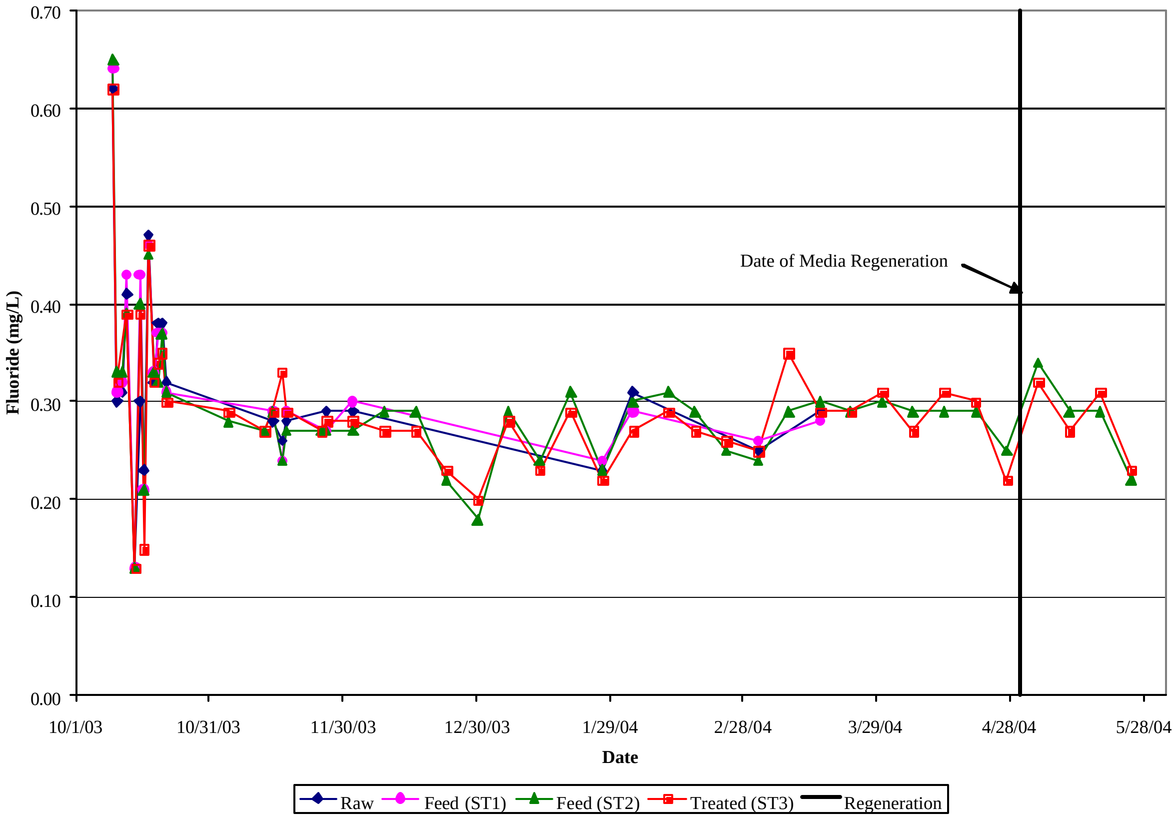

Figure 4-23. Capacity Test Fluoride Concentration.

As shown in Figure 4-24, FAC concentrations generally decreased from feed (ST1), to feed (ST2), to the treated water, likely due to the oxidant demand of the raw water and possibly an oxidant demand of the media. During the Capacity Test, the raw water FAC, prior to the hypochlorite feed point, averaged 0.06 mg/L. Low concentrations of FAC detected in the raw water were likely a result of diffusion of chlorine back from the chlorine detention tank when the well pump was off line. The feed (ST1) and feed (ST2) FAC concentrations during the Capacity Test averaged 0.94 mg/L and 0.85 mg/L, respectively, and the treated water had an average FAC concentration of 0.69 mg/L. The significant variation in FAC that occurred between April 22, 2004 and May 8, 2004 was the result of an HTWSA hypochlorite feed pump malfunction.

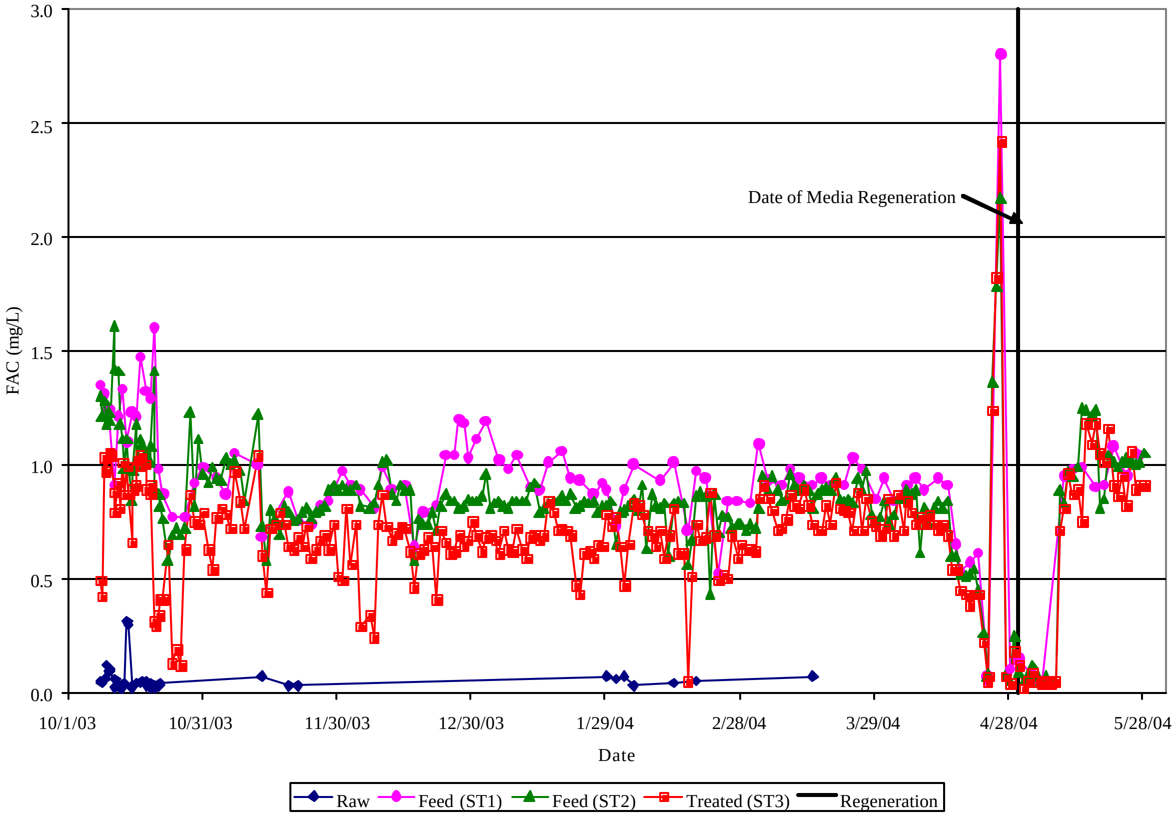

Figure 4-24. Capacity Test FAC.

Capacity Test water quality analyses indicate that calcium, magnesium, and total hardness concentrations in the feed water were relatively consistent during the test period and were apparently unaffected by the treatment process, as shown in Figure 4-25. Feed (ST2) and treated water calcium concentrations both averaged 254 mg/L as $CaCO_3$. The average feed and treated water magnesium concentrations were equal at 22 mg/L as $CaCO_3$. The total hardness concentrations of the feed (ST2) and treated water were 272 mg/L as $CaCO_3$ and 271 mg/L as $CaCO_3$, respectively.

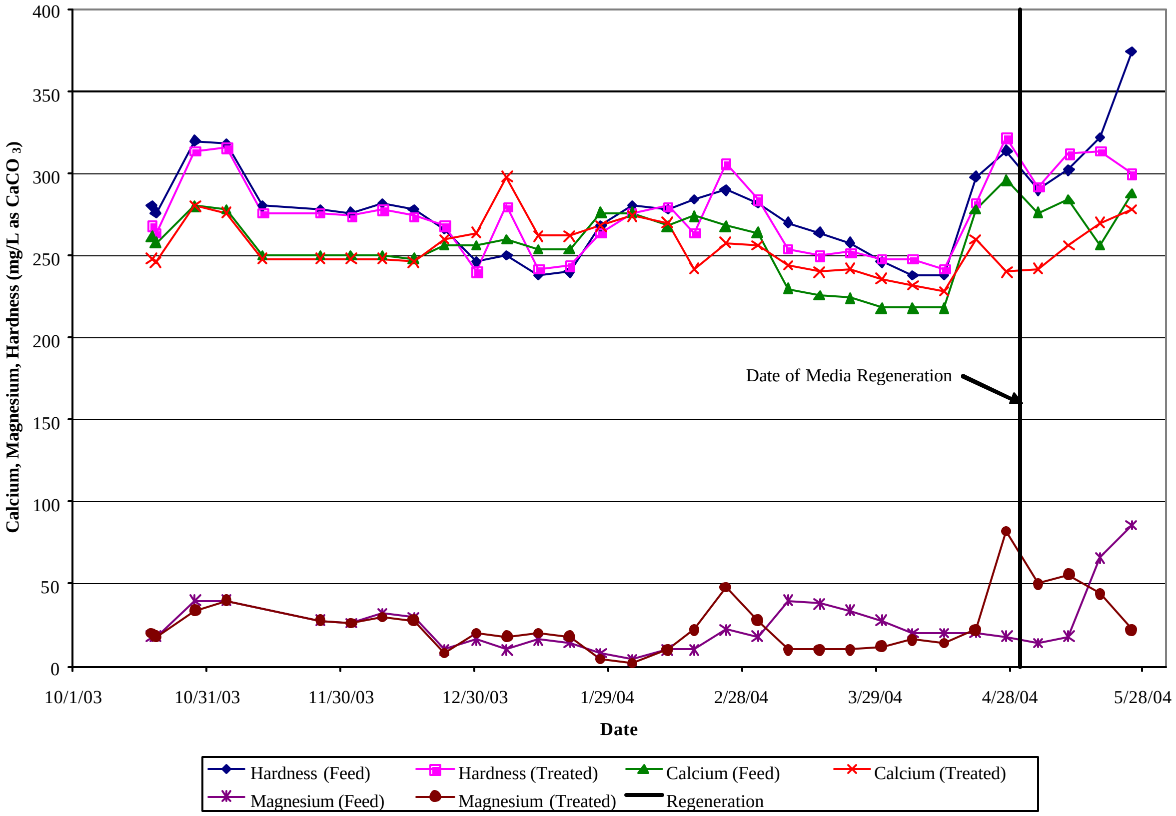

Figure 4-25. Capacity Test Calcium, Magnesium, and Hardness.

4.4.4 Capacity Test Laboratory Water Quality Analyses

The results of water quality analyses performed at the PADEP Laboratory are summarized for the Capacity Test in Table 4-12. Laboratory water quality analyses performed following media regeneration are summarized in Table 4-13. The media regeneration had no effect on the feed (ST2) and treated water quality parameters analyzed at the PADEP Laboratory, as shown in Tables 4-12 and 4-13 and in Figures 4-26 through 4-39. Laboratory water quality data and the analytical test reports and sample submission forms are included in Appendix K. The raw data are on file at NSF.

Table 4-12. Capacity Test Laboratory Water Quality Analyses

Parameter	Units	Number of Samples	Mean	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Raw							
Sodium	mg/L	28	23.8	21.4	26.9	1.38	23.2 – 24.5
Silica	mg/L	28	28.3	24.0	33.4	1.96	27.5 – 29.2
Aluminum	µg/L	28	<200	<200	<200	0	<200 - <200
Iron (Total)	µg/L	90	295	81	2370	316	220 – 371
Iron (Soluble)	µg/L	62	153	<20	733	101	123 – 182
Manganese (Total)	µg/L	90	105	90	219	18	101 – 110
Manganese (Soluble)	µg/L	62	98	<10	128	17	93 – 103
Chloride	mg/L	2	35.2	34.2	36.1	N/A	N/A
Sulfate	mg/L	2	101	100	103	N/A	N/A
Total Phosphorus	mg/L	2	0.063	<0.010	0.115	N/A	N/A
Feed (ST1)							
Sodium	mg/L	26	25.0	22.6	27.5	1.36	24.4 – 25.7
Silica	mg/L	26	28.5	25.5	32.1	1.47	27.9 – 29.2
Aluminum	µg/L	26	<200	<200	<200	0	<200 - <200
Iron	µg/L	26	268	73	2390	443	61 – 475
Manganese	µg/L	26	324	93	2390	466	106 – 542
Feed (ST2)							
Sodium (Total)	mg/L	41	25.1	22.7	29.0	1.41	24.5 – 25.6
Sodium (Soluble)	mg/L	14	25.1	23.0	26.8	1.43	24.1 – 26.0
Silica (Total)	mg/L	41	28.5	25.7	40.2	2.28	27.7 – 29.4
Silica (Soluble)	mg/L	14	27.6	27.0	28.0	0.27	27.4 – 27.7
Aluminum (Total)	µg/L	41	208(1)	<200	539	53	<200 - 228
Aluminum (Soluble)	µg/L	14	<200	<200	<200	0	<200 - <200
Iron (Total)	µg/L	96	180	47	1120	158	143 – 217
Iron (Soluble)	µg/L	69	38	<20	202	34	28 – 47
Manganese (Total)	µg/L	96	140	77	1070	133	109 – 171
Manganese (Soluble)	µg/L	69	52	28	94	9	49 – 54
Chloride	mg/L	29	36.9	36.1	37.6	0.37	36.8 – 37.1
Sulfate	mg/L	29	155	111	202	17.4	147 – 163
Total Phosphorus	mg/L	29	0.011	<0.010	0.016	0.002	0.011 – 0.012

Table 4-12. Capacity Test Laboratory Water Quality Analyses (Continued)

Parameter	Units	Number of Samples	Mean	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Treated							
Sodium	mg/L	41	25.3	22.8	32.0	1.56	24.7 – 25.8
Silica	mg/L	41	32.7	26.8	47.3	5.20	30.8 – 34.6
Aluminum	µg/L	41	<200	<200	<200	0	<200 - <200
Iron (Total)	µg/L	96	68	<20	956	117	41 – 96
Iron (Soluble)	µg/L	55	50	<20	556	83	24 – 76
Manganese (Total)	µg/L	96	16	<10	79	13	13 – 20
Manganese (Soluble)	µg/L	55	<10	<10	<10	0	<10 – <10
Chloride	mg/L	29	37.0	36.2	37.7	0.40	36.8 – 37.1
Sulfate	mg/L	29	160	113	205	19.0	152 – 169
Total Phosphorus	mg/L	29	0.010	<0.010	0.011	0.000	<0.010 – 0.010

(1) One feed (ST2) aluminum result of 539 µg/L, which is suspected to be an analytical error, skewed both the average and upper limit of the 95% confidence interval. If the suspected analytical error is discarded, the average feed (ST2) aluminum concentration would be <200 µg/L and the upper limit of the 95% confidence interval would be <200 µg/L.

N/A = Statistics not calculated for sample sets of less than 8.

Table 4-13. Post-Regeneration Laboratory Water Quality Analyses

Parameter	Units	Number of Samples	Mean	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Raw							
Sodium	mg/L	4	25.1	24.1	25.9	N/A	N/A
Silica	mg/L	4	29.9	28.5	31.2	N/A	N/A
Aluminum	µg/L	4	<200	<200	<200	N/A	N/A
Iron (Total)	µg/L	19	372	46	1080	314	196 – 548
Iron (Soluble)	µg/L	15	135	<20	423	120	57 – 213
Manganese (Total)	µg/L	19	101	91	110	4	99 – 103
Manganese (Soluble)	µg/L	15	98	77	107	7	93 – 102
Feed (ST1)							
Sodium	mg/L	4	27.0	26.0	28.7	N/A	N/A
Silica	mg/L	4	30.3	29.1	31.5	N/A	N/A
Aluminum	µg/L	4	<200	<200	<200	N/A	N/A
Iron	µg/L	4	169	111	302	N/A	N/A
Manganese	µg/L	4	168	118	252	N/A	N/A

Table 4-13. Post-Regeneration Laboratory Water Quality Analyses (Continued)

Parameter	Units	Number of Samples	Mean	Minimum	Maximum	Standard Deviation	95% Confidence Interval
Feed (ST2)							
Sodium	mg/L	4	26.4	26.0	27.1	N/A	N/A
Silica	mg/L	4	30.1	28.9	30.6	N/A	N/A
Aluminum	µg/L	4	<200	<200	<200	N/A	N/A
Iron (Total)	µg/L	19	125	62	306	61	91 – 160
Iron (Soluble)	µg/L	15	36	<20	65	16	26 – 47
Manganese (Total)	µg/L	19	112	34	213	41	90 – 135
Manganese (Soluble)	µg/L	15	58	<10	99	28	39 – 76
Chloride	mg/L	4	37.7	36.4	38.6	N/A	N/A
Sulfate	mg/L	4	152	146	162	N/A	N/A
Total Phosphorus	mg/L	4	0.028	<0.010	0.043	N/A	N/A
Treated							
Sodium	mg/L	4	26.8	26.0	27.8	N/A	N/A
Silica	mg/L	4	32.1	31.5	33.0	N/A	N/A
Aluminum	µg/L	4	<200	<200	<200	N/A	N/A
Iron (Total)	µg/L	19	74	<20	339	89	24 – 124
Iron (Soluble)	µg/L	15	44	<20	228	54	9 – 79
Manganese (Total)	µg/L	19	13	<10	39	8	9 – 18
Manganese (Soluble)	µg/L	16	10	<10	15	1	10 – 11
Chloride	mg/L	4	37.7	36.3	38.6	N/A	N/A
Sulfate	mg/L	4	161	148	169	N/A	N/A
Total Phosphorus	mg/L	4	0.015	<0.010	0.025	N/A	N/A

N/A = Statistics not calculated for sample sets of less than 8.

Sodium concentrations varied at the four sample points throughout the Capacity Test period, as shown in Figure 4-26, likely due to rainfall events and minor variations in the sodium hypochlorite feed rate. Although the total sodium concentration varied from a minimum of 21.4 mg/L in the raw water to a maximum of 32.0 mg/L in the treated water over the Capacity Test period, the average increase in sodium concentration from the raw water to the treated water was 1 mg/L, which indicates that the sodium hypochlorite contributes a continuous, but small portion of the treated water sodium concentration. The average raw water sodium concentration was 23.8 mg/L and the feed (ST1), feed (ST2), and treated water sodium concentrations averaged 25.0 mg/L, 25.1 mg/L, and 25.3 mg/L, respectively.

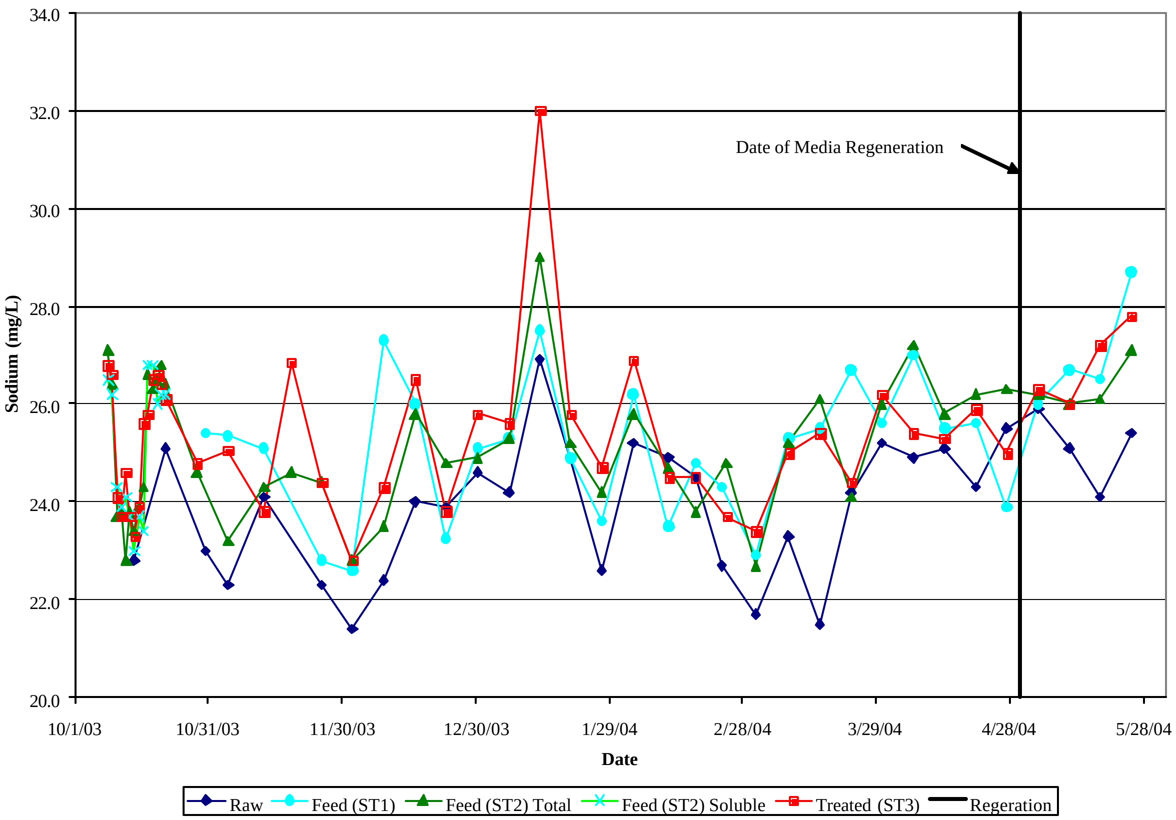

Figure 4-26. Capacity Test Sodium Concentration.

As discussed with the Integrity Test data, Figure 4-27 shows that silica concentrations in the treated water were initially much greater than silica concentrations in the raw and feed water, indicating that the media contributed silica to the treated water. After the initial one to two months of the test, the treated water silica concentration did not appear to be significantly affected by the media. During the Capacity Test, the average treated water silica concentration was 32.7 mg/L, while the raw, feed (ST1), and feed (ST2) silica concentrations averaged 28.5 mg/L.

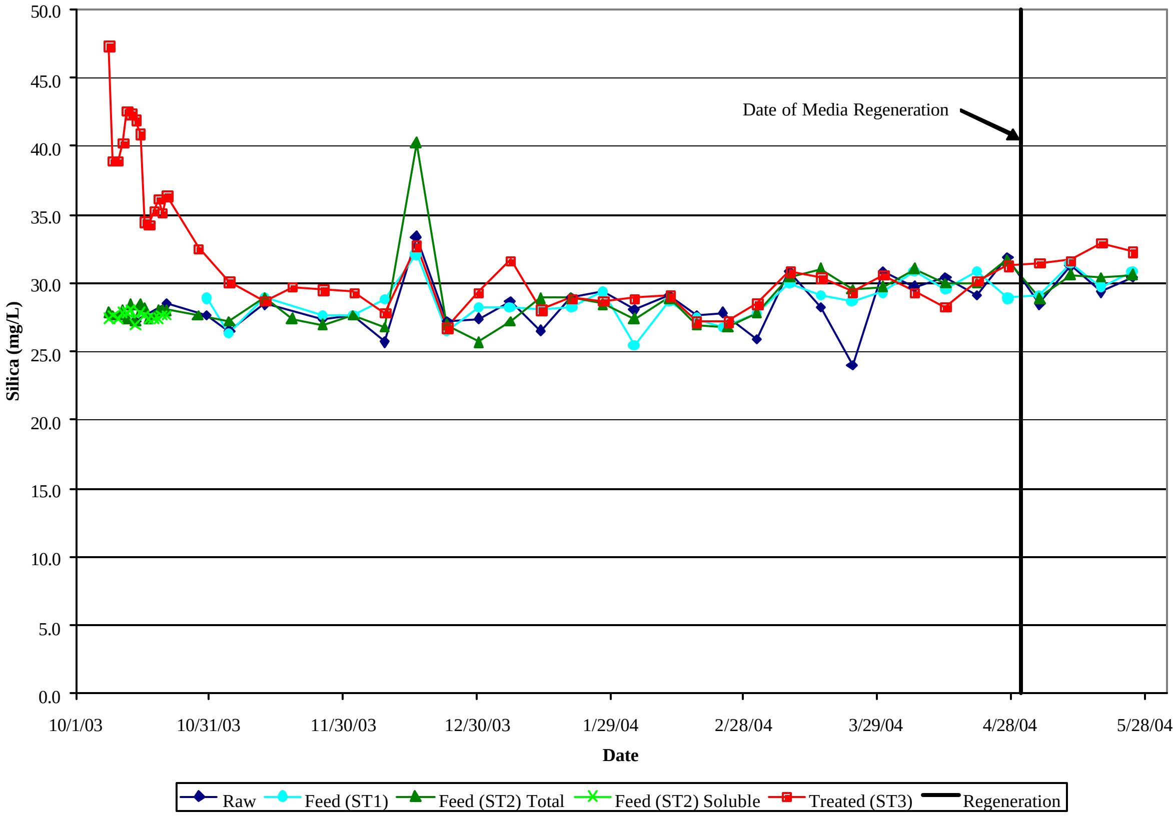

Figure 4-27. Capacity Test Silica Concentration.

Raw and feed water aluminum concentrations were generally less than the method detection limit (MDL) of 200 µg/L and were unaffected by the treatment process, as indicated in Tables 4-12 and 4-13. Only one feed water sample result was greater than the MDL of 200 µg/L. This feed (ST2) result of 539 µg/L is likely erroneous because the raw, feed (ST1), and treated water samples on that date all had aluminum concentrations of less than the MDL. No aluminum was detected in the treated water during the test. This data indicates that the media was not releasing aluminum to the treated water above detectable levels. The feed and treated water aluminum concentrations are shown in Figure 4-28.

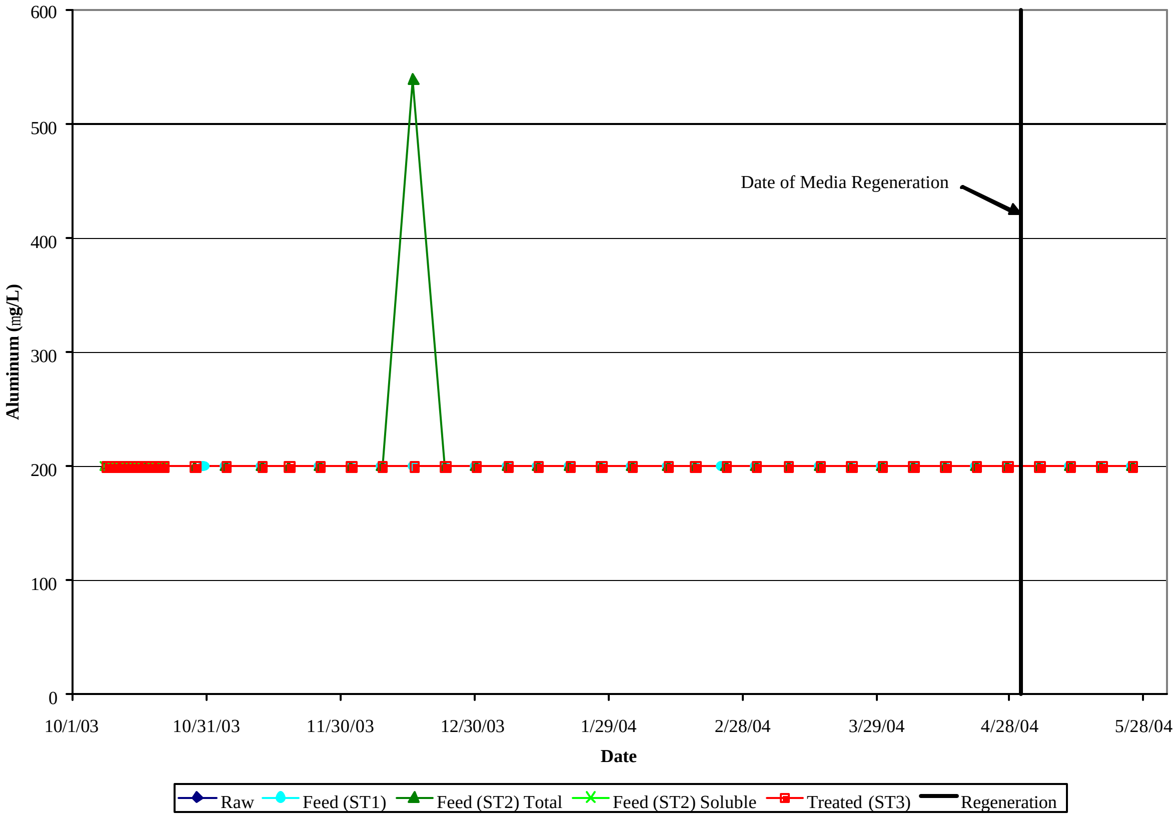

Figure 4-28. Capacity Test Aluminum Concentration.

As shown in Figure 4-29, the raw water total iron concentration was high, averaging 295 µg/L during the Capacity Test, which is near the iron SMCL of 300 µg/L. Raw water total iron concentrations were also highly variable, ranging from 81 to 2370 µg/L. The impact of precipitation events may have contributed to the variability of the raw water iron concentration.

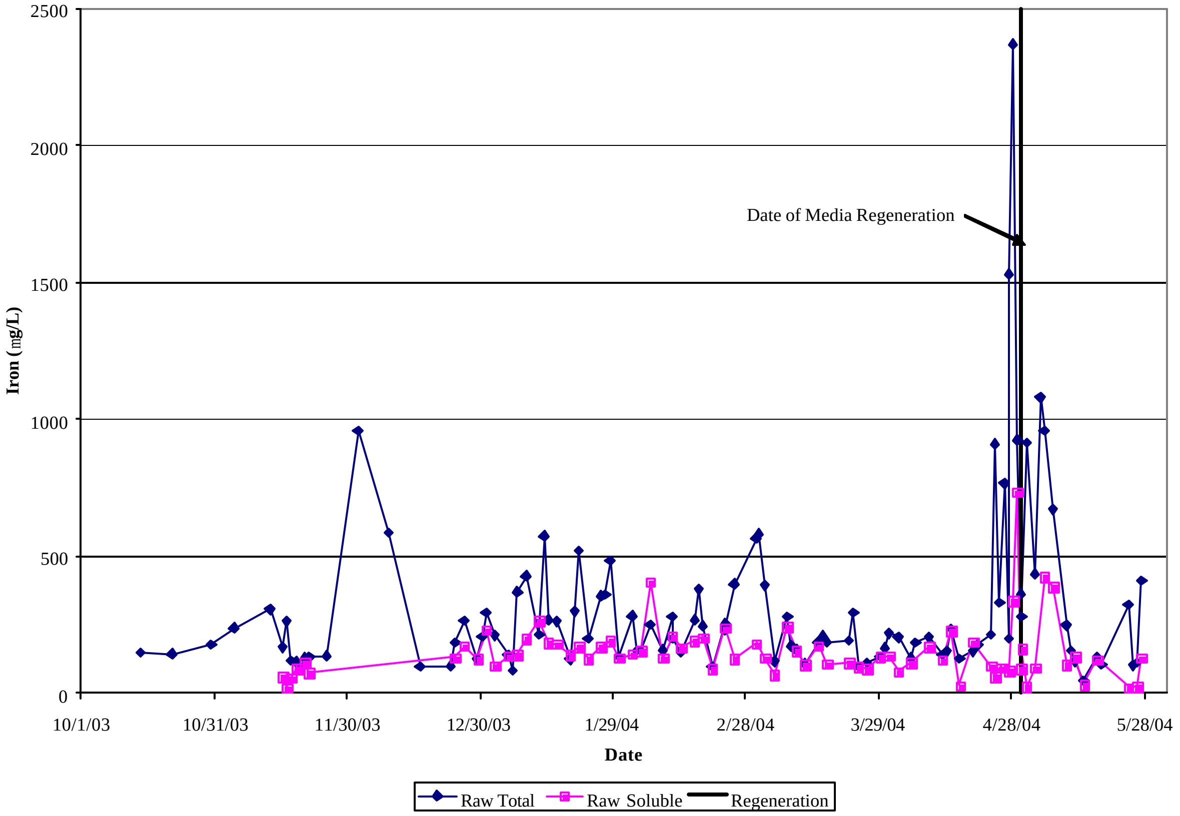

Figure 4-29. Capacity Test Raw Water Iron Concentration.

As shown in Figure 4-30, similar to the raw water, feed water iron concentrations were highly variable. However, all feed water iron spikes do not necessarily correspond to raw water iron concentration spikes. This indicates that the chlorine detention tank may have had significant effects on the iron concentration, possibly allowing particulate iron to settle when the well pump was off and having iron resuspended during well pump operation.

The treated water total iron concentration averaged 68 µg/L, which is much less than the raw water total iron concentration of 295 µg/L and the feed (ST2) concentration of 180 µg/L, indicating significant removal of iron by the treatment unit. However, the average treated water soluble iron concentration of 50 µg/L was actually greater than the average feed (ST2) soluble iron concentration of 38 µg/L. This is likely a result of the acid addition for pH reduction resulting in an increase in the metal solubility.

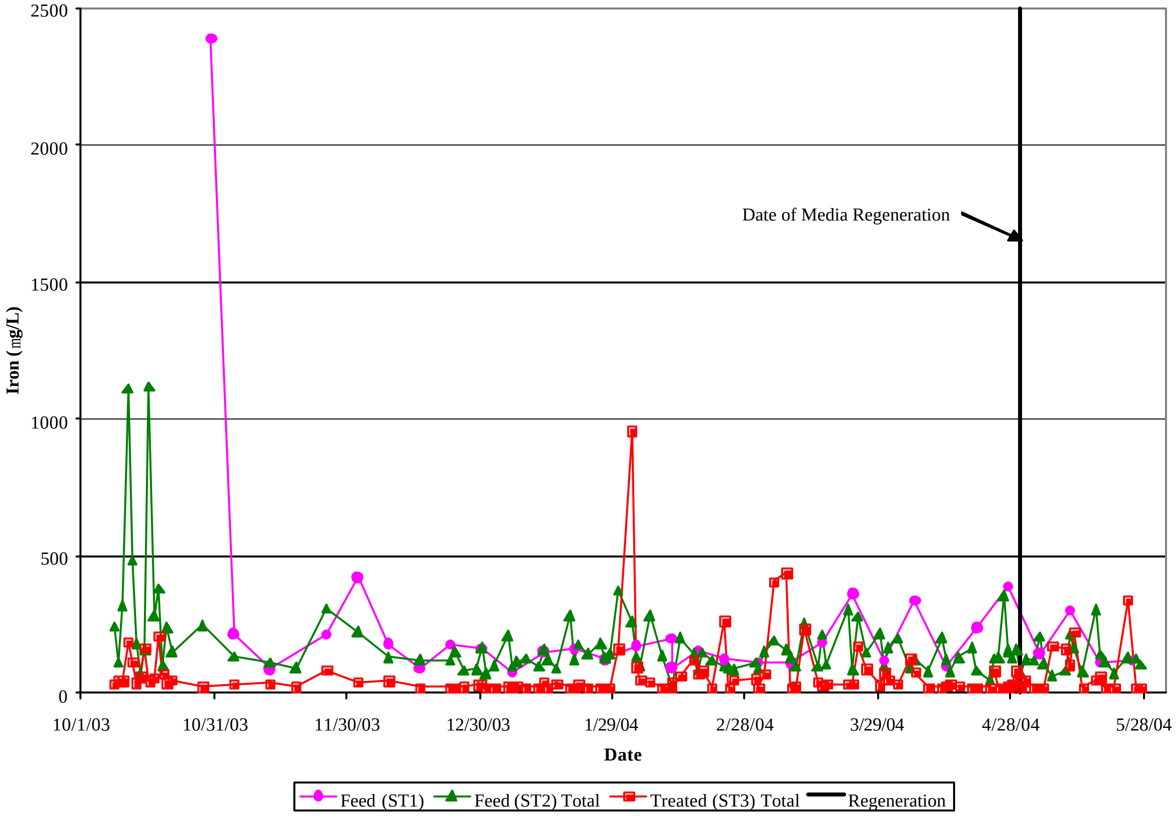

Figure 4-30. Capacity Test Feed Water Iron Concentration.

The total and soluble iron data, shown in Figure 31 and Figure 32, indicates that iron removal in the treatment unit occurred primarily by filtration of particulate iron. Figure 4-31 shows that much of the variability in the feed water iron concentration is a result of variable particulate iron concentrations. The feed (ST2) total iron concentration averaged 180 µg/L, as compared to the feed (ST2) soluble iron average concentration of 38 µg/L. Feed (ST2) soluble iron concentrations were more stable throughout the Capacity Test relative to the total iron concentration.

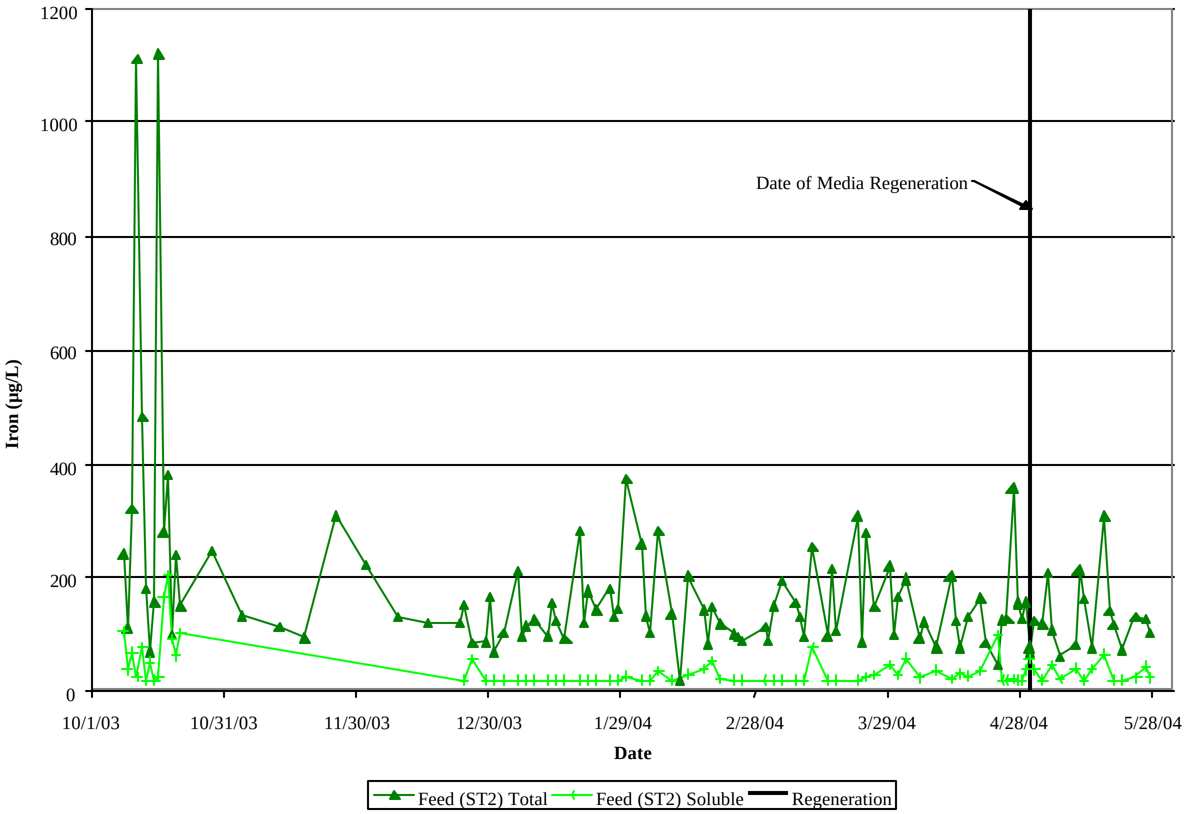

Figure 4-31. Capacity Test Feed (ST2) Total and Soluble Iron Concentration.

The treated water total and soluble iron concentrations are shown in Figure 4-32. The total treated water iron concentration averaged 68 µg/L, with 50 µg/L of soluble iron. Soluble iron composed 74% of the total treated water iron concentration as compared to the feed (ST2) water in which the soluble fraction made up 21% of the total iron concentration. It appears that the treated water iron spikes do not correlate to feed water iron spikes, known weather events, or operational events (such as backwash or pH adjustment) and can only be speculated to be caused by breakthrough of iron particles or release of filter material.

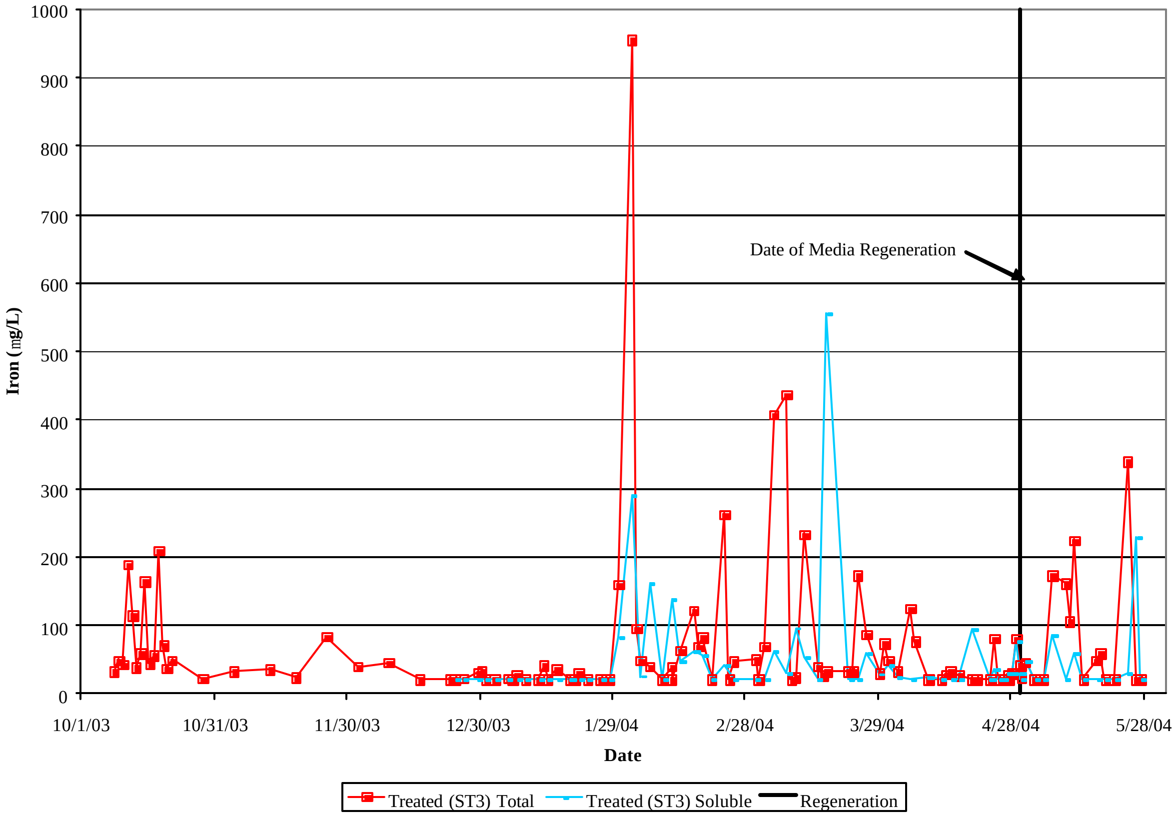

Figure 4-32. Capacity Test Treated Water Iron Concentration.

The raw water manganese concentration was generally stable, with the exception of two periods of particulate manganese spikes, as shown in Figure 4-33. The raw water manganese concentration was about double the SMCL of 50 µg/L and averaged 105 µg/L, of which 93% (98 µg/L) was soluble.

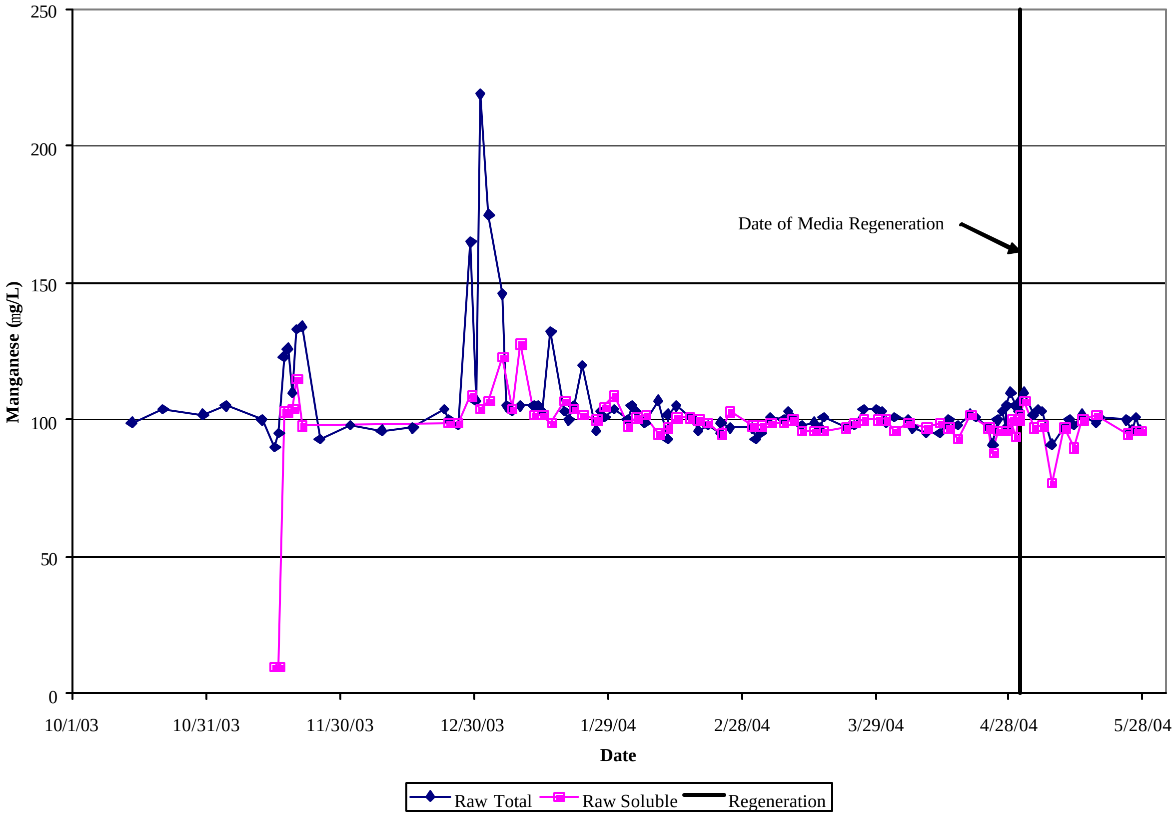

Figure 4-33. Capacity Test Raw Water Manganese Concentration.

The feed (ST1) manganese concentration was variable and was consistently greater than the raw and feed (ST2) concentration, as shown in Figure 4-34. The feed (ST1) average manganese concentration of 324 μg/L was skewed by a sample with a concentration of 2,390 μg/L. The treated water manganese concentration averaged 16 μg/L during the Capacity Test, indicating significant manganese removal within the treatment unit.

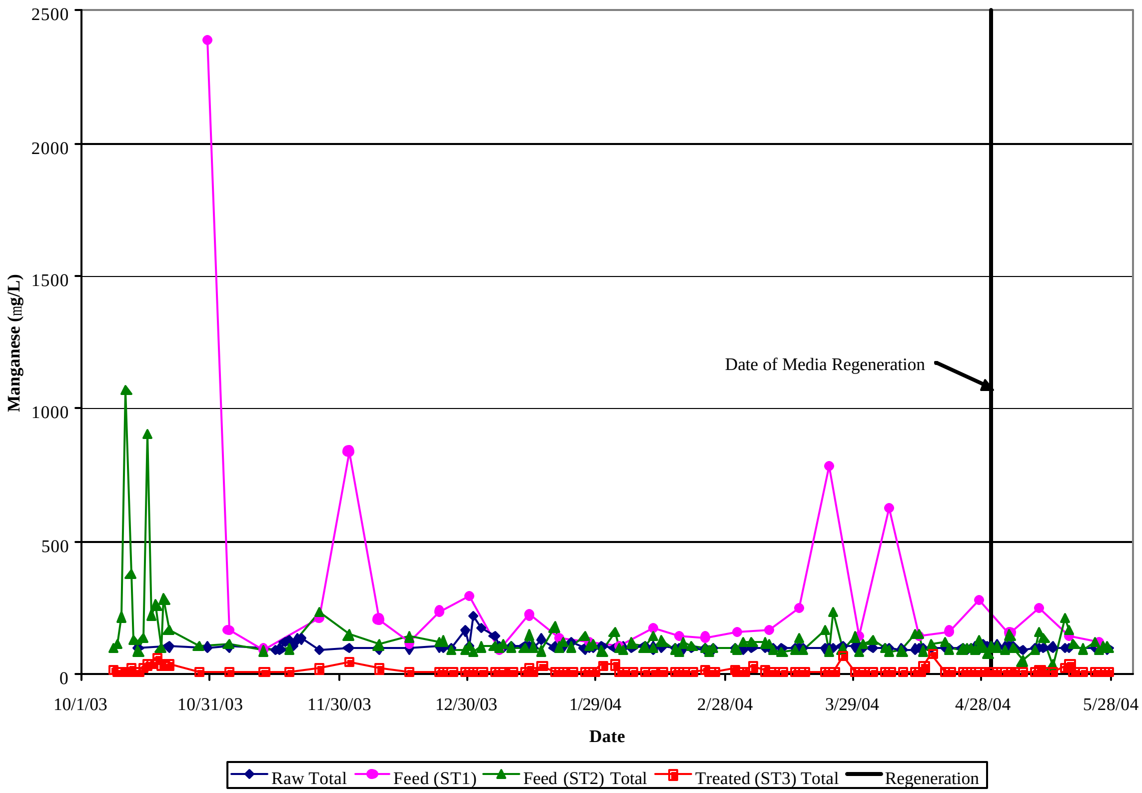

Figure 4-34. Capacity Test Manganese Concentration.

As shown in Figure 4-35, the variability of the feed (ST2) total manganese concentration is primarily due to the variability in particulate manganese concentration. The feed (ST2) soluble manganese concentration was relatively stable when compared to the feed (ST2) total manganese concentration. The feed (ST2) total manganese concentration averaged 140 µg/L, 33% greater than the raw water, with 52 µg/L in the soluble form.

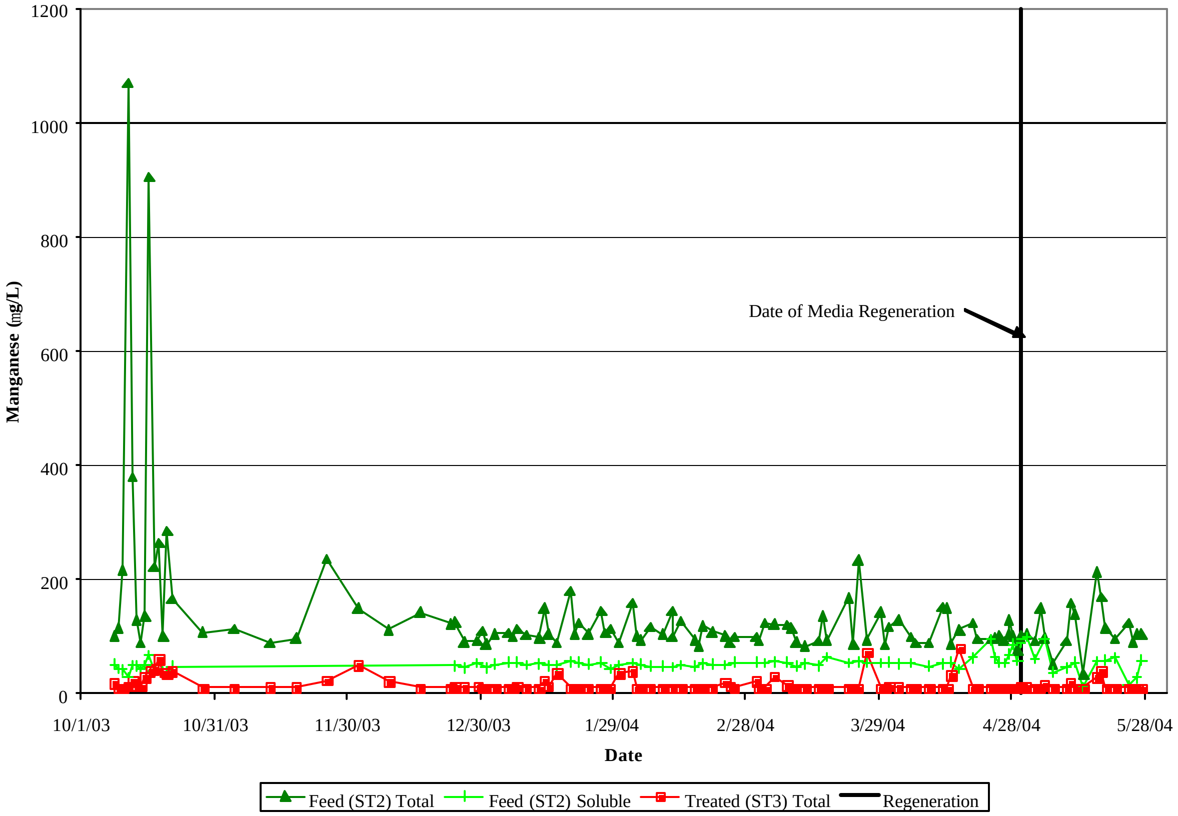

Figure 4-35. Capacity Test Feed (ST2) and Treated Manganese Concentration.

The treatment unit removed soluble manganese to less than the detection limit of 10 µg/L, as shown in Figure 4-36. However, some particulate manganese did pass through the filter, resulting in total manganese concentration spikes in the treated water.

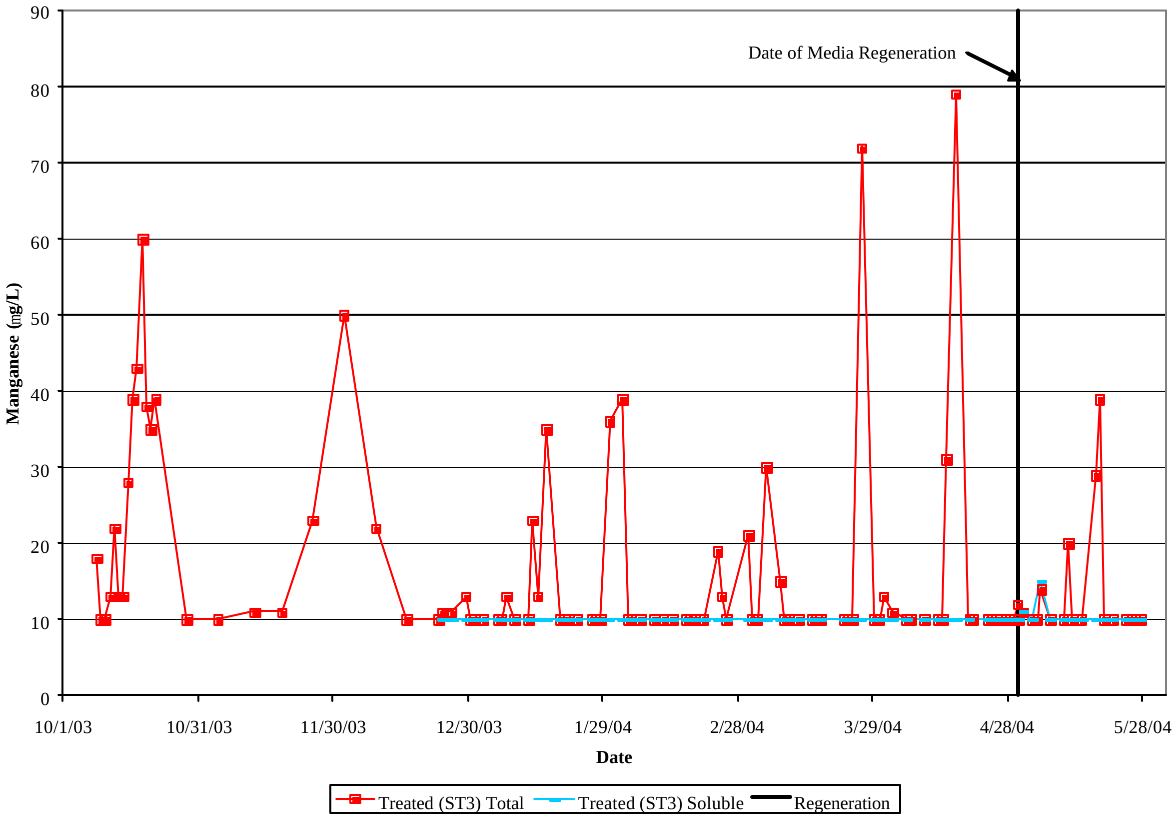

Figure 4-36. Capacity Test Treated Water Manganese Concentration.

Chloride concentrations were unaffected by the treatment process, as shown in Figure 4-37. The feed and treated chloride concentrations averaged 36.9 mg/L and 37.0 mg/L, respectively, during the Capacity Test and were greater than the chloride concentrations in the two raw water samples, likely as a result of the sodium hypochlorite addition. A noticeable decrease in chloride concentration was observed in late April and early May as a result of the previously described HTWSA hypochlorite feed pump malfunction.

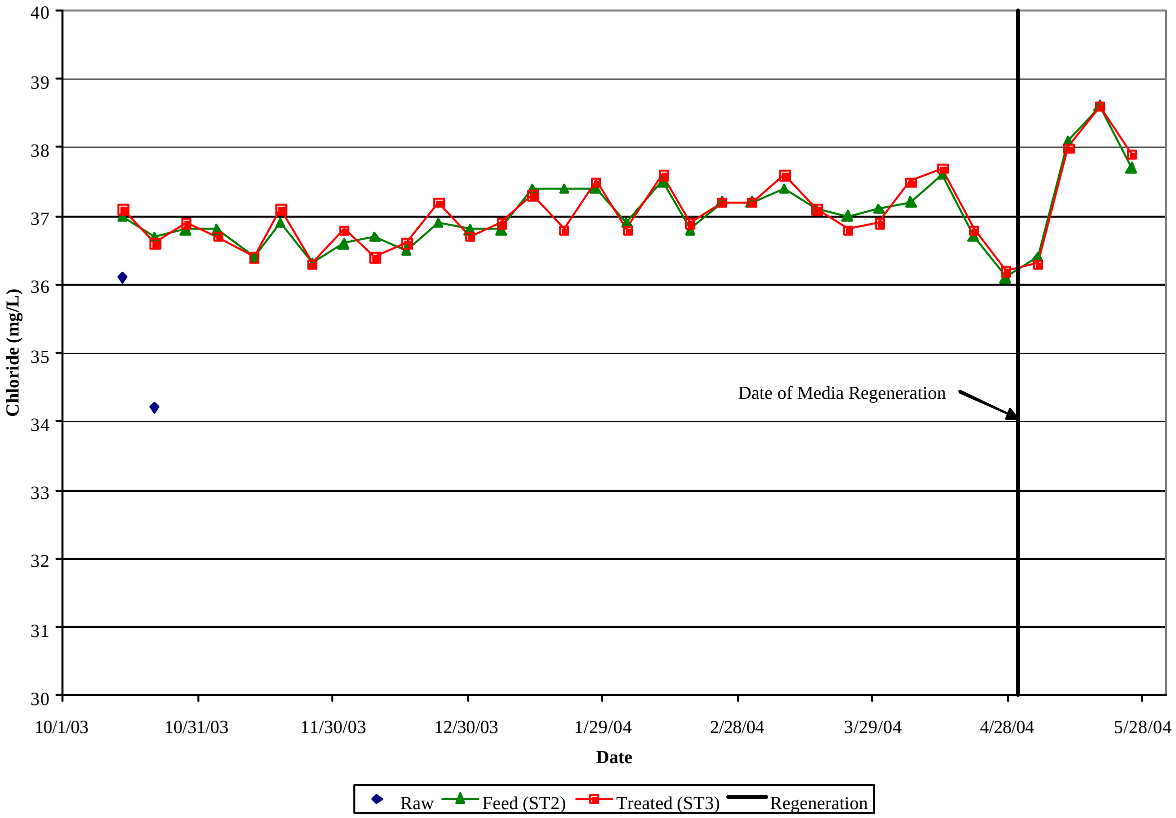

Figure 4-37. Capacity Test Chloride Concentration.

Sulfate concentrations were also unaffected by the treatment process during the early part of the Capacity Test. However, as shown in Figure 4-38, during the majority of the Capacity Test, the treated water sulfate concentration was greater than the acidified feed (ST2) sulfate concentration. A sulfate increase from the raw or feed (ST1) to the feed (ST2) or treated water was expected as a result of the sulfuric acid addition. However, during the Capacity Test, the feed (ST2) sulfate concentration averaged 155 mg/L and the treated water sulfate concentration averaged 160 mg/L, which is within the 95% confidence interval calculated for the feed (ST2) water.

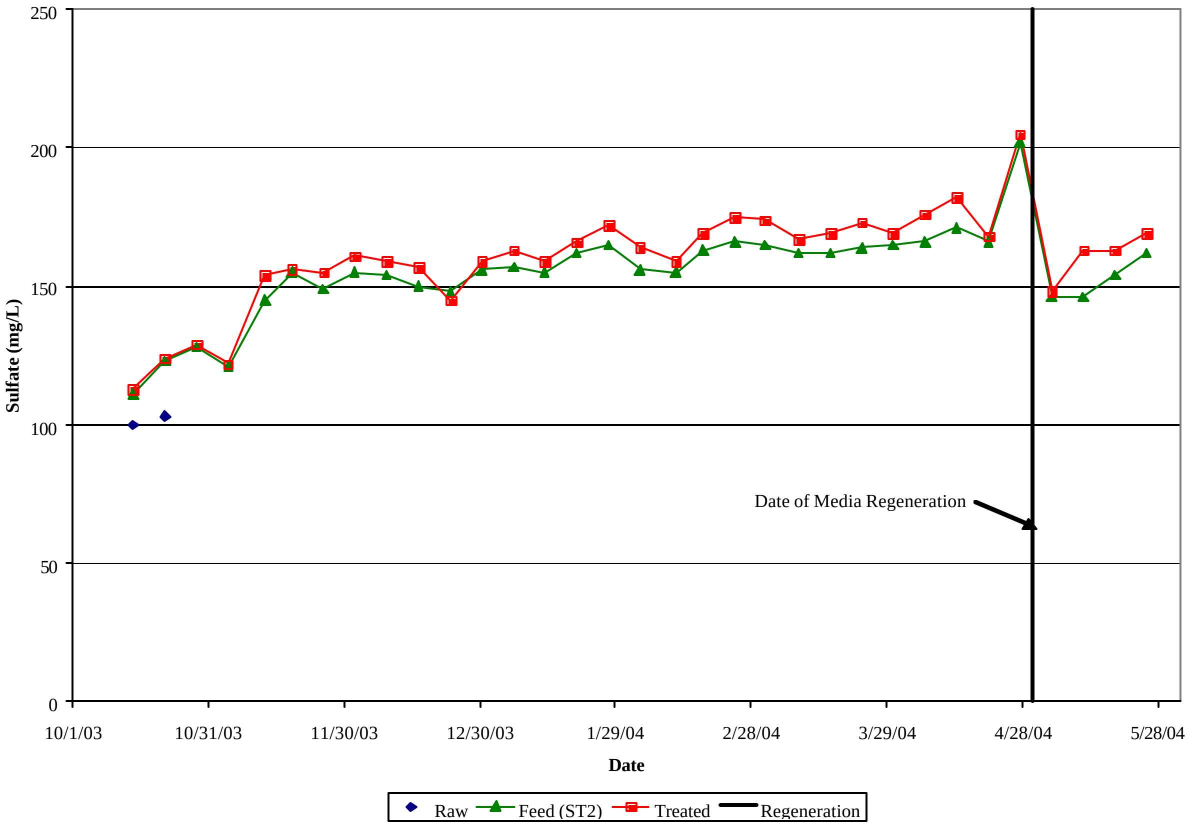

Figure 4-38. Capacity Test Sulfate Concentration.

As shown in Figure 4-39, feed (ST2) phosphorous concentrations were low, only slightly greater than the MDL for some samples. However, phosphorus was removed from the feed water to below the MDL of 0.010 mg/L in the treated water by the media for much of the Capacity Test. During the last several weeks of the test, following the media regeneration, feed (ST2) phosphorus concentrations increased, as did the treated water concentrations of phosphorus. Some removal of phosphorus continued to occur within the treatment unit during the time of increased feed (ST2) phosphorus concentrations.

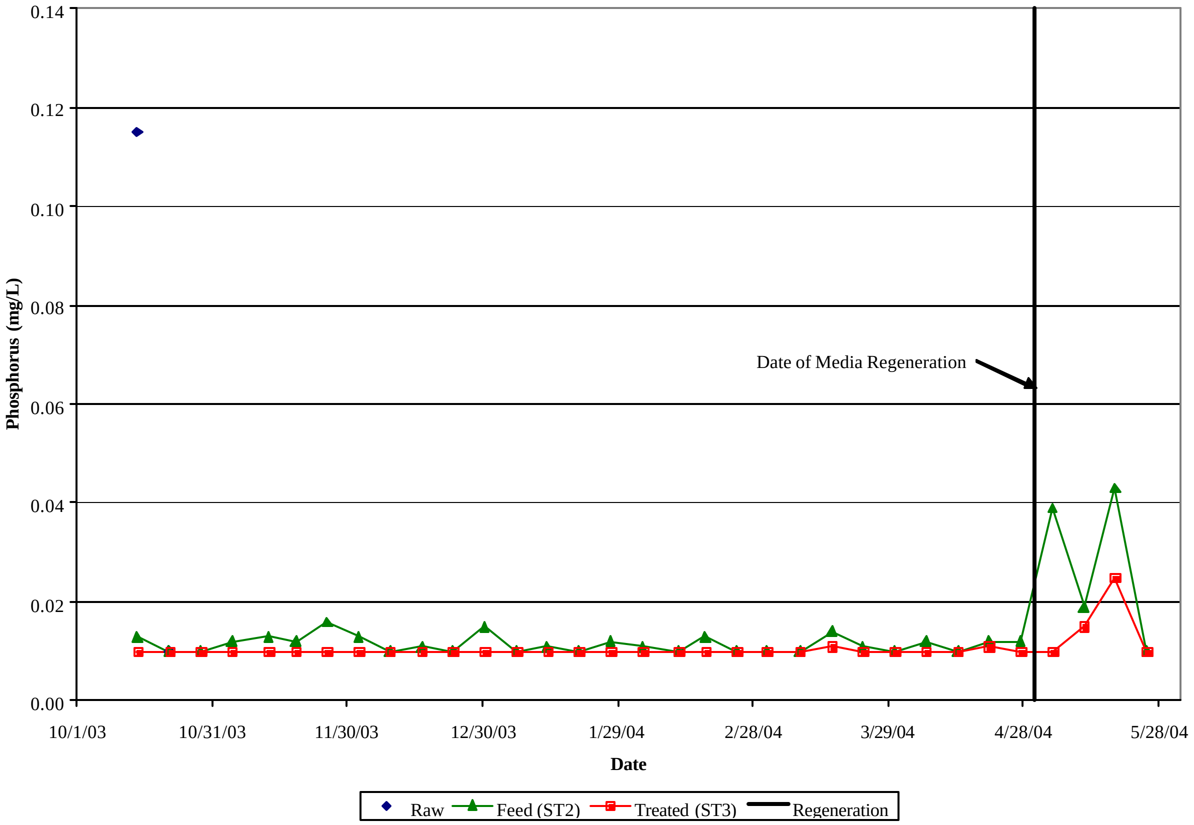

Figure 4-39. Capacity Test Phosphorus Concentration.

4.4.5 Capacity Test Laboratory Arsenic Analyses

The results of Capacity Test arsenic analyses performed by the NSF laboratory are summarized in Table 4-14. NSF Laboratory arsenic analyses for the period following media regeneration are summarized in Table 4-15.

For calculation of the media's capacity to remove arsenic from the feed water, 434,107 gallons were treated from October 8, 2003 through April 22, 2004 during the Capacity Test. The treated water volume represents 25,231 media bed volumes, based on the calculated bed volume of 2.3 ft^3. At the request of the manufacturer, a one-week period of operation with a reduced feed (ST2) pH was conducted prior to the media regeneration. In response to the reduction in feed (ST2) pH, the treated water arsenic concentration was reduced during this period, as shown later in this section. However, the period of reduced pH operation was not included in the calculation of the media capacity. Based on the feed and treated water total arsenic concentrations during the Capacity Test, the capacity of the media for this system was 465.3 µg of arsenic per gram of media. As shown in Table 4-14, the feed water total arsenic concentration of 21 µg/L included 8 µg/L of arsenic in the particulate form. The mechanisms for removal of this particulate arsenic are not clear based on the test data, and could include adsorption and/or physical filtration of the particulate arsenic. The treated water arsenic was nearly all in the soluble form. As discussed in Section 4.5, the backwash water arsenic concentration averaged 539 mg/L. Based on 14 backwashes of 103 gallons each during the Capacity Text, the arsenic removed by each backwash represents only a fraction of the total arsenic removed from the feed water. If the arsenic in the backwash water is removed from the capacity calculation, the capacity of the media for arsenic in this system is reduced to 406 mg of arsenic per gram of media.

The media regeneration effectively returned the arsenic adsorption capacity of the media to approximately that of the new media. Within one day following media regeneration, the treated water total arsenic concentration was 5 µg/L. However, as shown in Tables 4-14 and 4-15 two post-regeneration samples, taken within several hours of returning the unit to service, had very high arsenic concentrations and skewed the post-regeneration arsenic results. The effect of media regeneration on treated water arsenic concentrations and the high arsenic concentrations observed immediately following the regeneration are shown and discussed in more detail later in this section.

Table 4-14. Capacity Test Laboratory Arsenic Analyses

	Raw				Feed (ST2)			
	Total Arsenic (µg/L)	Soluble Arsenic (µg/L)	Arsenic III (µg/L)	Calculated Arsenic V (µg/L)	Total Arsenic (µg/L)	Soluble Arsenic (µg/L)	Arsenic III (µg/L)	Calculated Arsenic V (µg/L)
Number of Samples	87	72	13	13	121	65	13	13
Mean	16	16	7	6	21	13	<2	10
Minimum	8	7	<2	2	12	8	<2	6
Maximum	24	20	14	12	63	18	<2	16
Standard Deviation	3	3	4	3	8	2	0	3
95% Confidence Interval	15 - 17	15 - 16	4 - 10	4 – 8	19 - 23	12 - 13	<2 - <2	8 - 12

	Treated			
	Total Arsenic (µg/L)	Soluble Arsenic (µg/L)	Arsenic III (µg/L)	Calculated Arsenic V (µg/L)
Number of Samples	121	65	13	13
Mean	7	8	<2	4
Minimum	2	3	<2	1
Maximum	20	19	<2	10
Standard Deviation	N/A	N/A	N/A	N/A
95% Confidence Interval	N/A	N/A	N/A	N/A

N/A = Statistics not appropriate for treated water arsenic concentrations.

Table 4-15. Post-Regeneration Laboratory Arsenic Analyses

	Raw				Feed (ST2)			
	Total Arsenic (µg/L)	**Soluble Arsenic (µg/L)**	**Arsenic III (µg/L)**	**Calculated Arsenic V (µg/L)**	**Total Arsenic (µg/L)**	**Soluble Arsenic (µg/L)**	**Arsenic III (µg/L)**	**Calculated Arsenic V (µg/L)**
Number of Samples	15	16	1	1	15	16	1	1
Mean	15	15	13	3	16	14	<2	11
Minimum	8	9	13	3	13	10	<2	11
Maximum	18	18	13	3	20	19	<2	11
Standard Deviation	3	3	N/A	N/A	2	2	N/A	N/A
95% Confidence Interval	13 - 17	13 - 17	N/A	N/A	15 - 17	13 - 15	N/A	N/A

	Treated			
	Total Arsenic (µg/L)	**Soluble Arsenic (µg/L)**	**Arsenic III (µg/L)**	**Calculated Arsenic V (µg/L)**
Number of Samples	15/13(1)	16/14(1)	1	1
Mean	18/4(1)	16/4(1)	<2	2
Minimum	2	2	<2	2
Maximum	200/6(1)	180/5(1)	<2	2
Standard Deviation	N/A	N/A	N/A	N/A
95% Confidence Interval	N/A	N/A	N/A	N/A

(1) A brief treated water arsenic spike occurred within 6 hours following regeneration. The statistics are presented both with and without the two treated water samples that had elevated arsenic concentrations.

N/A = Statistics not calculated for sample sets of less than 8. Statistics not appropriate for treated water arsenic concentrations.

During the Capacity Test, the raw water total arsenic concentration averaged 16 µg/L and was primarily soluble arsenic, which also averaged 16 µg/L. Based on the 13 samples speciated for arsenic, the soluble arsenic was comprised of variable fractions of arsenic III and arsenic V. Capacity Test and post-regeneration raw water arsenic concentrations are shown in Figure 4-40.

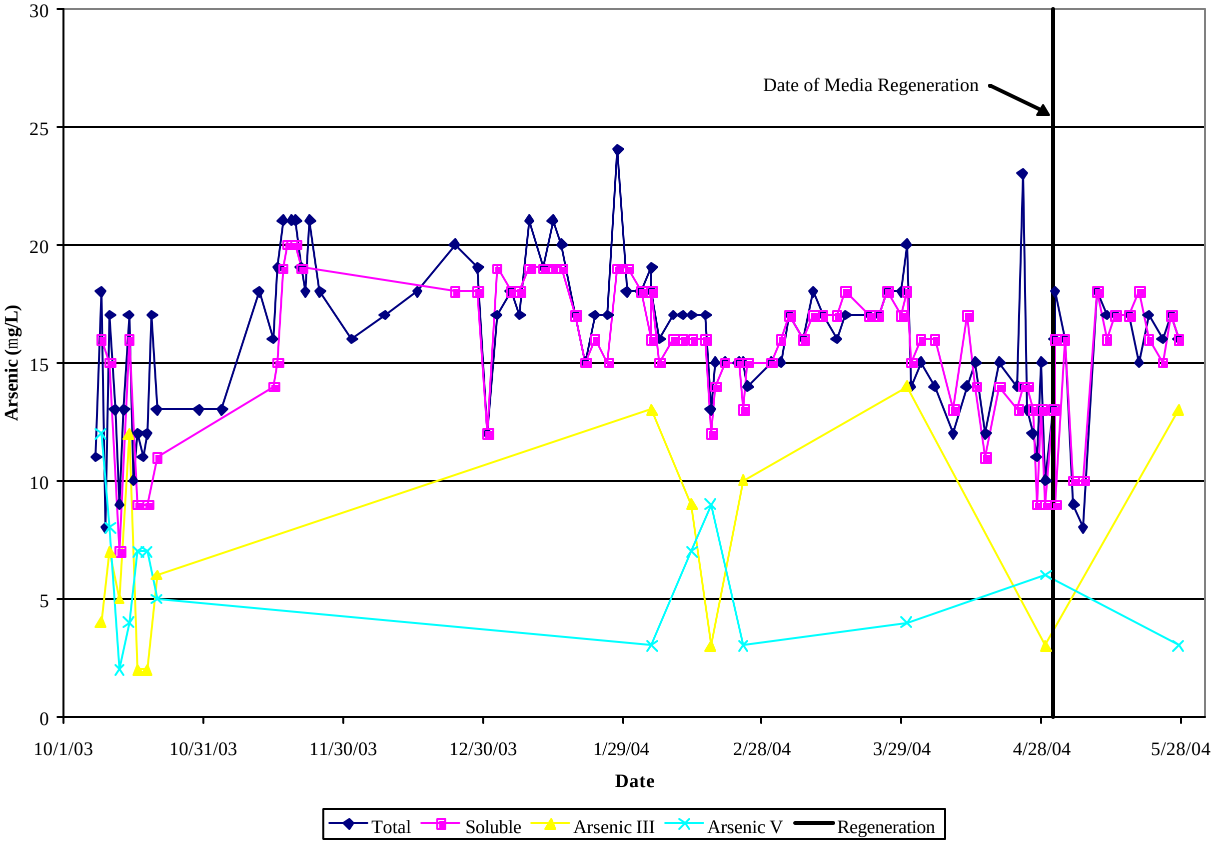

Figure 4-40. Capacity Test Raw Arsenic Concentration.

The feed (ST2) total arsenic concentration averaged 21 µg/L and was highly variable, especially during the first third of the Capacity Test, as shown in Figure 4-41. The feed (ST2) total arsenic concentration was 24% greater than the raw water total arsenic concentration. However, the feed (ST2) average soluble arsenic concentration of 13 µg/L was approximately 19% less than the average raw water soluble arsenic concentration. The increase and variability in feed (ST2) total arsenic concentration may have been a result of resuspension of particulate arsenic in the chlorine contact tank by the well pump operation. As shown in Table 4-14, Table 4-15, and Figure 4-41, the feed (ST2) soluble arsenic was completely converted to the arsenic V species prior to entering the treatment unit.

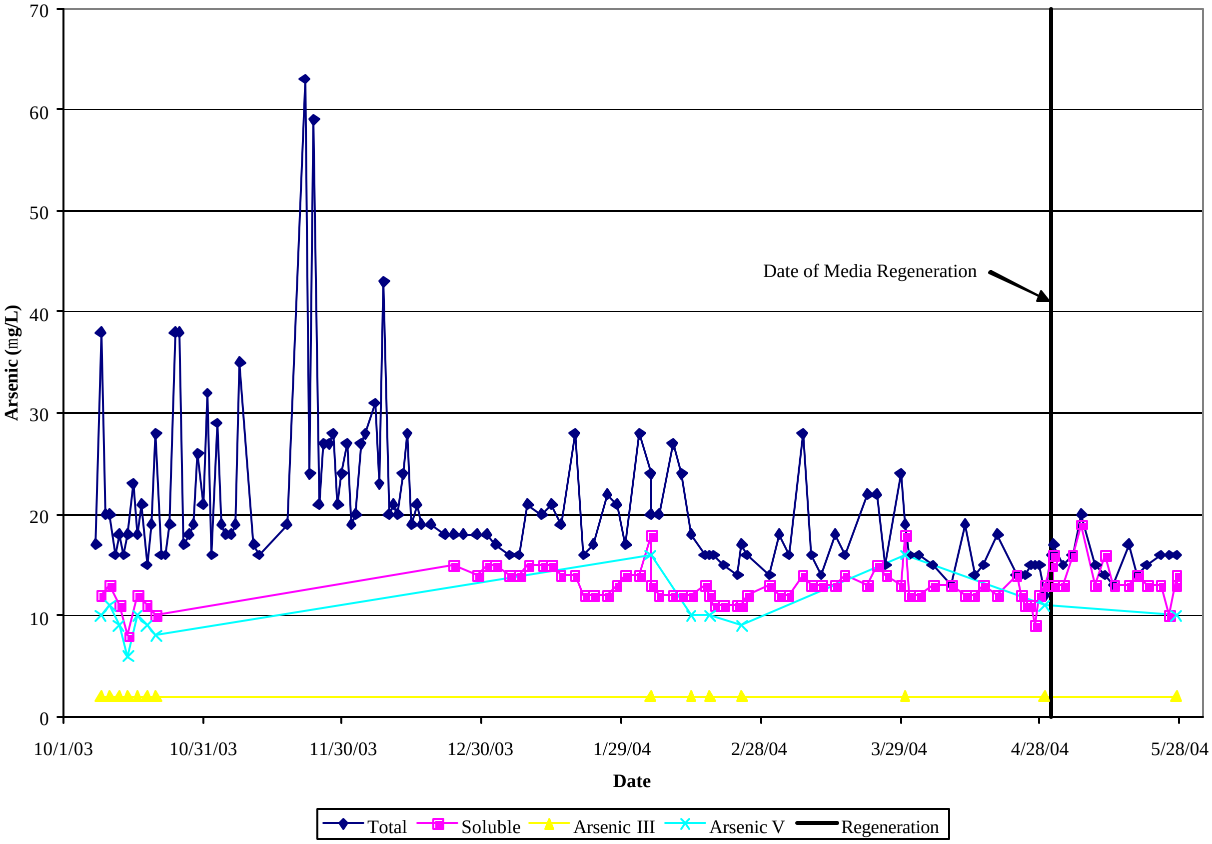

Figure 4-41. Capacity Test Feed (ST2) Arsenic Concentration.

The treated water arsenic concentration during the Capacity Test averaged 7 µg/L, all of which was soluble arsenic. The post-regeneration treated water arsenic concentration averaged 18 µg/L. As shown in Figure 4-42 and 4-43, the mean post-regeneration treated water total arsenic concentration was skewed by two samples with very high arsenic concentrations, which occurred immediately following the media regeneration. Two treated water arsenic samples collected within eight hours of the media regeneration had arsenic concentrations of 200 and 17 µg/L, respectively. The sample collected the day after media regeneration had an arsenic concentration of 4 µg/L. The post-regeneration treated water arsenic concentration ranged from 2 to 6 µg/L, with the exception of the two samples. Arsenic in the treated water was primarily soluble arsenic in the arsenic V species. Following the regeneration process, the arsenic removal capacity of the media appeared to return to a level approximately equal to that of the new media, the elevated treated water arsenic concentrations for several hours following the media regeneration could be problematic in a full-scale operation and may need to be addressed in the manufacturer's regeneration and operating procedures.

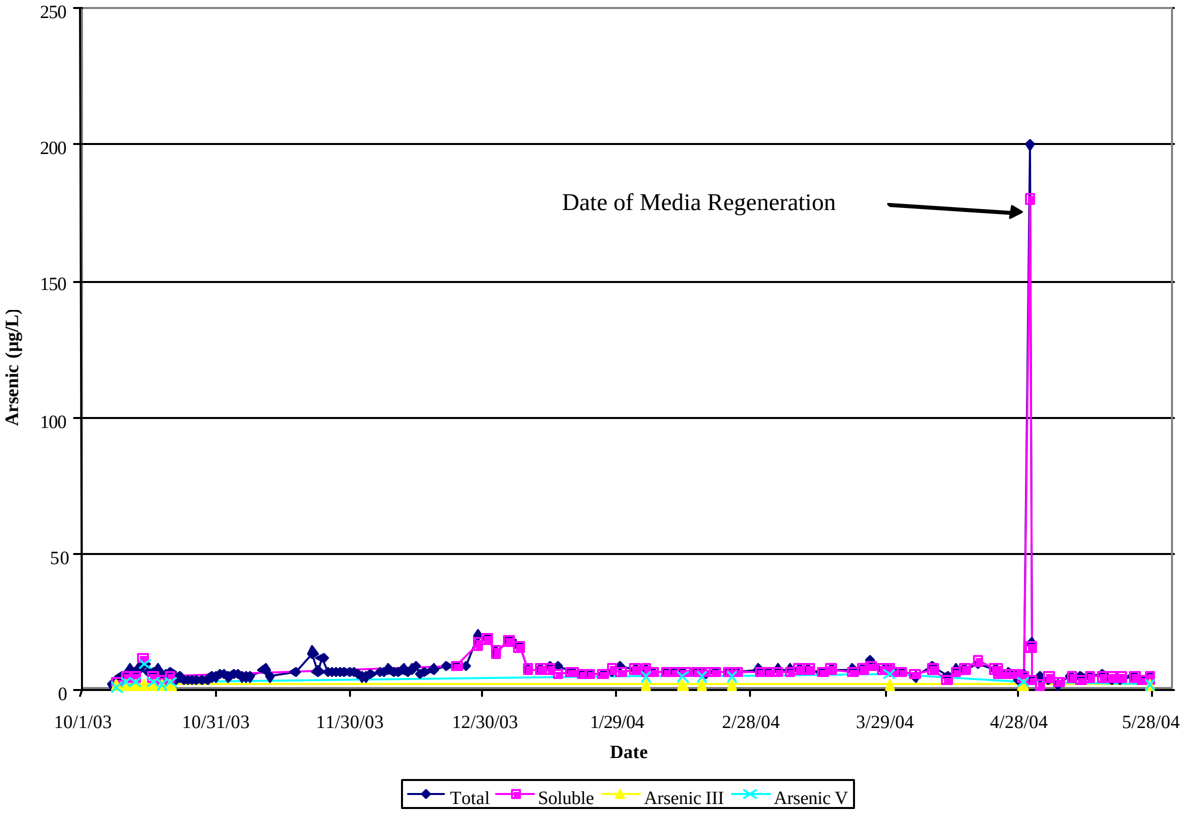

Figure 4-42 Capacity Test Treated Water Arsenic Concentration.

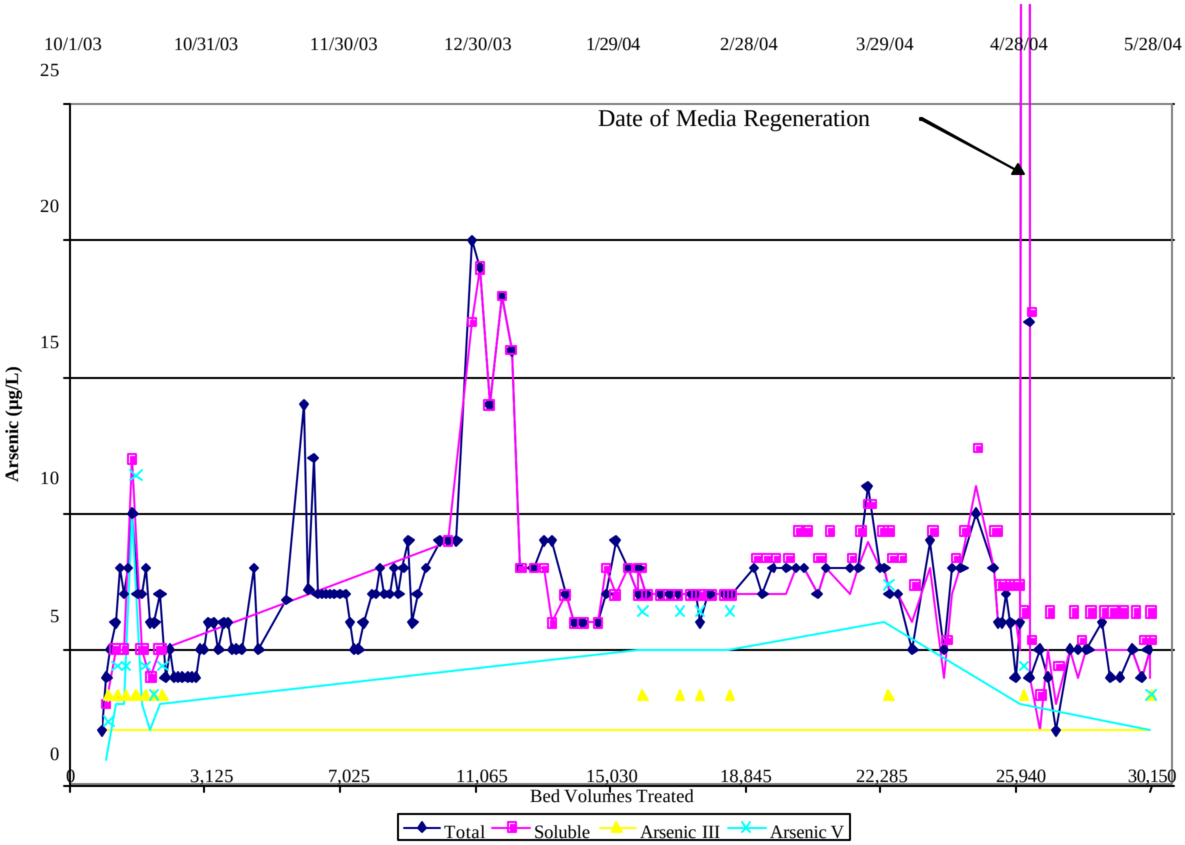

Figure 4-43. Capacity Test Treated Water Arsenic Concentration (0-25 µg/L Scale).

Raw, feed, and treated water total arsenic concentrations are shown for the Capacity Test in Figure 4-44.

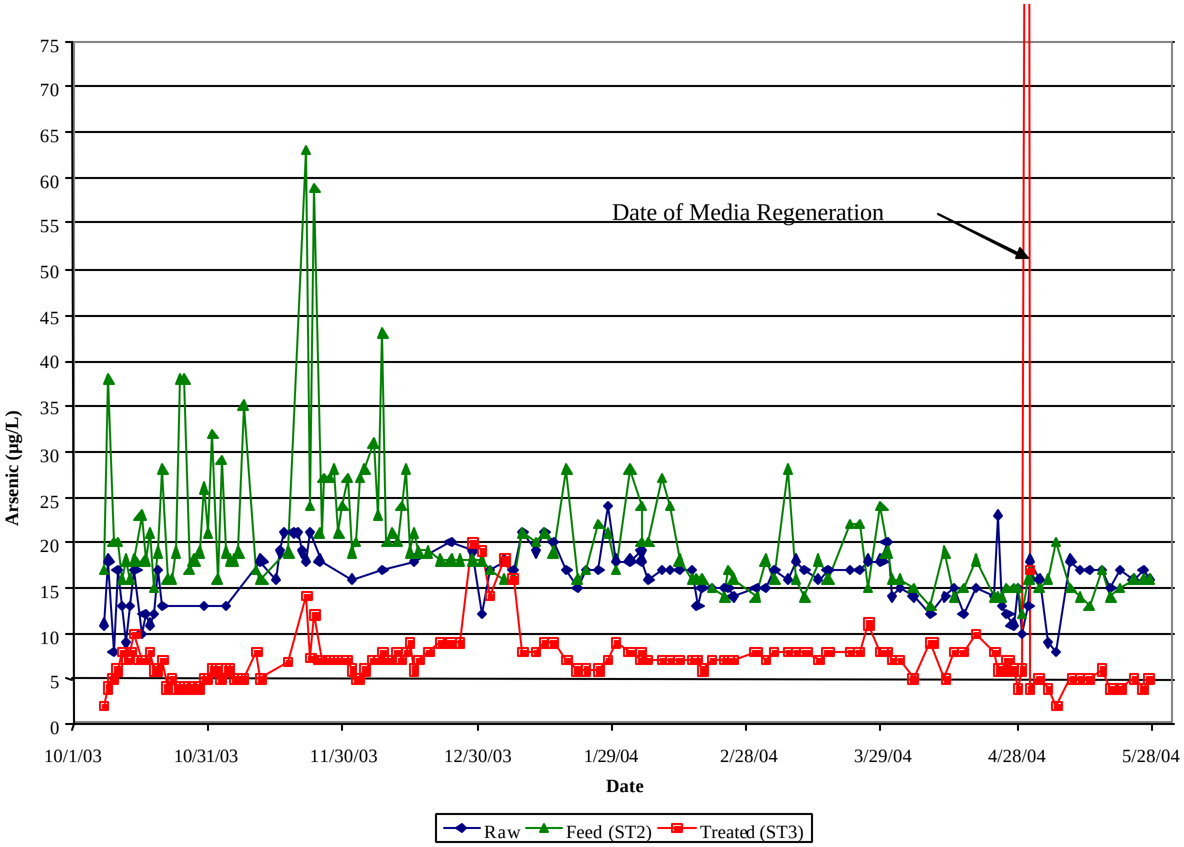

Figure 4-44. Capacity Test Total Arsenic Concentration.

The manufacturer indicated that maintaining the specified feed (ST2) and treated water pH is critical to achieving efficient arsenic removal. As shown in Figure 4-45, feed (ST2) and treated water pH does appear to have a significant impact on the arsenic removal capacity of the media. For example, near December 30, 2003, when optimal pH was not maintained due to acid feed pump operational problems, the treated water arsenic concentration increased noticeably in conjunction with the increase in treated water pH.

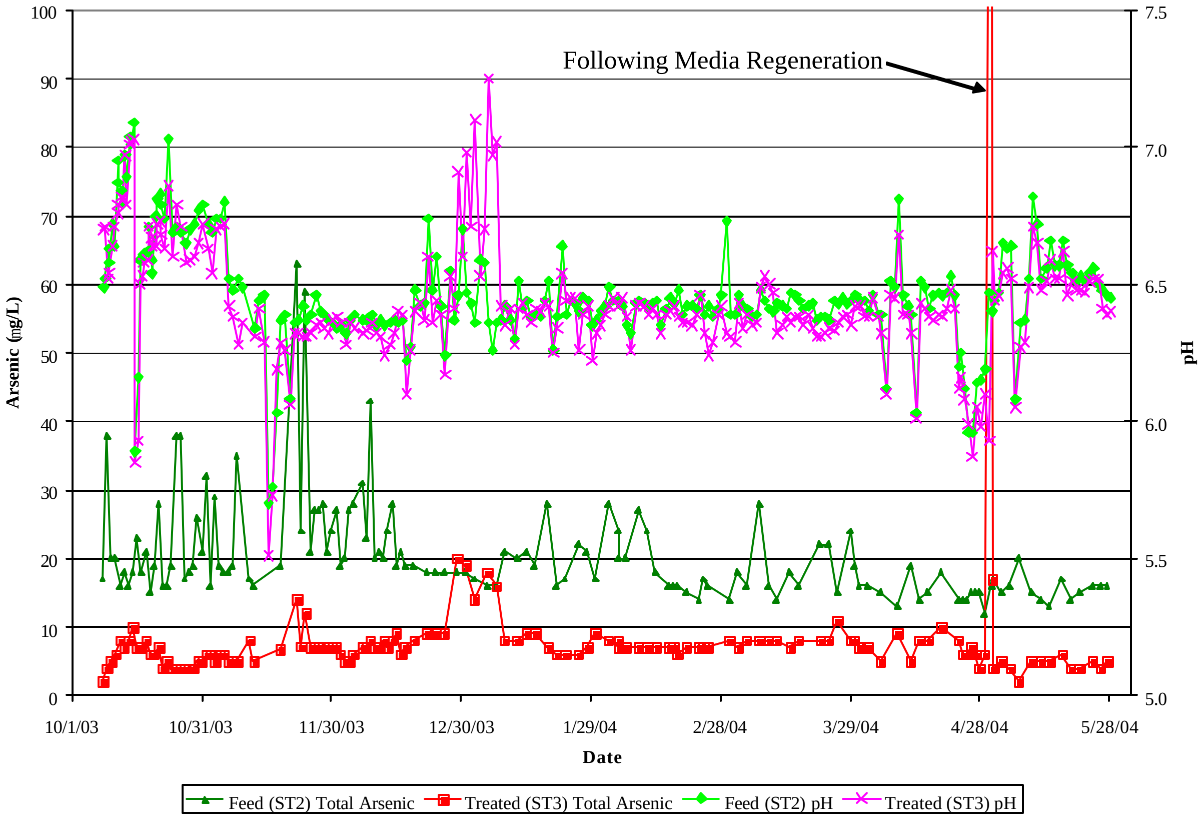

Figure 4-45. Capacity Test Arsenic Concentration and pH.

Figure 4-46 shows feed (ST2) and treated water arsenic concentration as well as feed (ST2) and treated water FAC concentration. FAC oxidizes arsenic III to the arsenic V species, which the manufacturer indicates can be removed by MEDIA G2®.

As shown in Figure 4-46, the feed (ST2) FAC concentration was generally maintained above 0.5 mg/L, and averaged 0.75 mg/L, which was adequate to convert the arsenic to the arsenic V species. HTWSA experienced problems with the sodium hypochlorite feed pump in late April 2004, and the FAC concentration was reduced to near zero. However, the media was already nearing "exhaustion", with treated water concentrations near 10 µg/L. The media was regenerated during the period of low FAC concentration. Following the regeneration, the media produced treated water with an arsenic concentration of 5 µg/L through May 9, 2004, when a continuous FAC concentration was reestablished in the feed water. Although the treatment unit arsenic removal efficiency did not appear to be affected by the low FAC concentration, because the low FAC concentration occurred at a time when the media was nearing exhaustion and then newly regenerated, conclusions on the long-term effect of low or no FAC concentration in the feed water cannot be made.

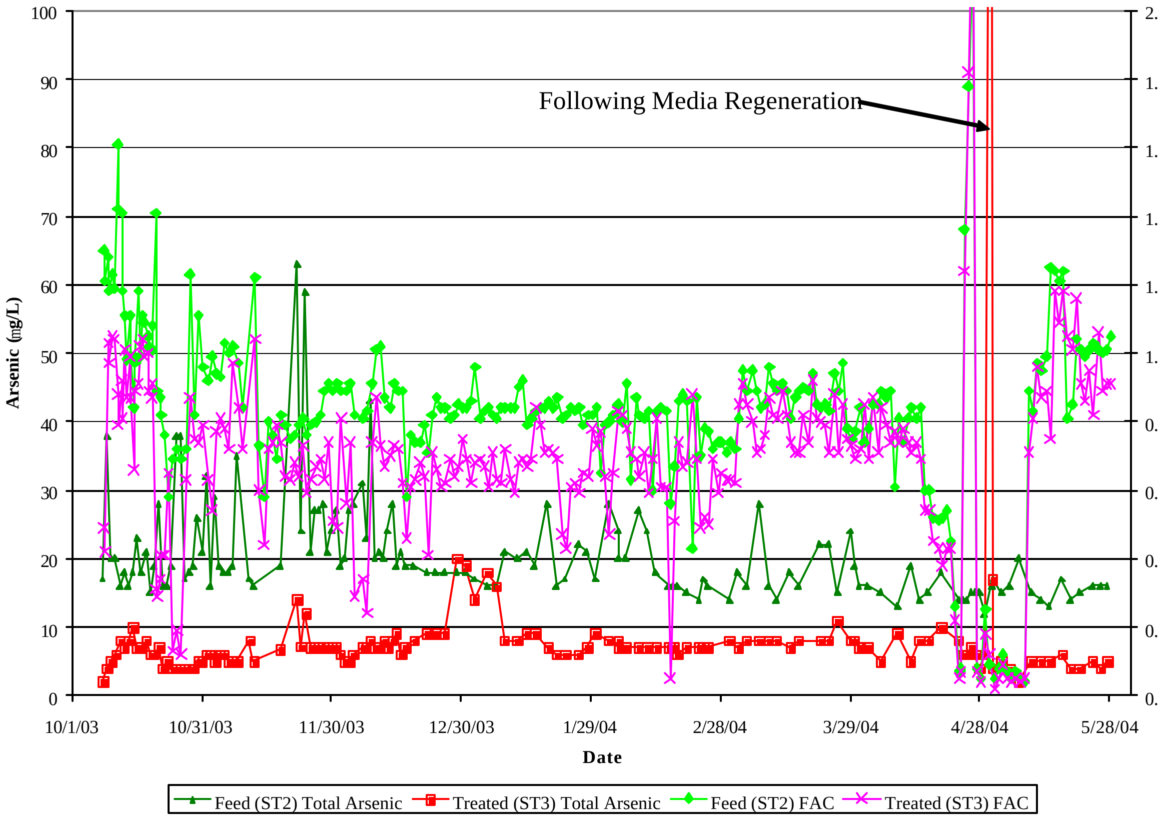

Figure 4-46. Capacity Test Arsenic and FAC.

4.4.6 Capacity Test Equipment Operation

During the Capacity Test, minimal time and/or attention were required to operate the pilot test equipment, although significant time was spent conducting on-site analyses. The time required for daily operation of the treatment unit included approximately ten minutes to monitor the flow rate, acid tank level, totalizer and loss of head readings, and verification that there were no leaks in the system. Periodically refilling the acid batch tank required additional time. Operational problems with the acid feed pump required significant operational attention during those events, as pH adjustment is a critical parameter to maintain the treatment system performance. Permanent installation of the equipment would also require daily pH and FAC analyses or online monitoring equipment, as well as periodic on-site arsenic analyses and/or collection of samples for laboratory analyses. FAC and pH analyses require 15 to 20 minutes. On those days in which on-site arsenic analyses with a field test kit are also performed, the total analytical time is about 45 minutes.

The pilot adsorption media filter is manually operated and uses electricity only for powering the feed water solenoid valve and the chemical feed pumps for metering sulfuric acid, sodium hypochlorite, and caustic soda. Chemical, electricity, and media consumption are described in Section 2.3.2. A total of 590.5 gallons of 0.5% sulfuric acid solution were used during the test for pH adjustment. This corresponds to approximately 1.16 gallons of sulfuric acid per 1,000 gallons treated. Fifty gallons of 1% caustic soda were used during the media regeneration, corresponding to 0.11 gallons per 1,000 gallons treated. Sodium hypochlorite was used by HTWSA for disinfection of the well supply and was not fed as part of the test. Therefore, sodium hypochlorite usage was not measured. The electricity used by the chemical feed pumps and solenoid valve was not measured as part of the test.

One to 1.5 hours of operator time was required for each manual backwash of the filter. The adsorption media is regenerated in place and requires the operator to backwash the filter, to prepare and feed a caustic soda solution and a sulfuric acid solution, and to monitor the effluent pH before returning the unit to service. Including a pre-regeneration backwash, media regeneration required about five hours of operator time. Media regeneration is discussed in Section 4.6.

4.5 Capacity Test Backwash Water Quality, Quantity, and Flow Rate

Fifteen manual filter backwashes were performed during the Capacity Test. Filter backwashes were performed twice per month, based on the filter approaching the maximum allowable pressure drop of 10 psi, as indicated by the manufacturer. The first filter backwash was performed during the second week of the Integrity Test. This backwash was performed prior to reaching the time or pressure drop criteria for initiating a backwash in order to fulfill the requirements of the Integrity Test plan. The sampling protocol and flow rate calibration procedures detailed in Chapter 3 were followed for both the backwash and rinse wastewater. The results of the analyses of composite samples for these wastewaters are presented on Table 4-16.

The backwash water was turbid and dark brown in color, likely due to the very high concentration of iron and manganese detected in the laboratory sample. The high concentrations of iron and manganese in the backwash water indicate iron and manganese were physically filtered from the water. This was anticipated given that much of the feed water iron and manganese was in the particulate form. The aluminum and silica concentrations in the wastewater were much greater than the average treated water concentrations, indicating that silica and aluminum were displaced from the media during backwash. In addition, phosphorus concentrations in the backwash water samples were much greater than the feed water concentrations.

The backwash water arsenic concentration averaged 539 µg/L. However, the soluble arsenic concentration in the backwash water averaged 12 µg/L, which is equal to the feed (ST2) soluble arsenic concentration. This indicates that the elevated arsenic concentration in the backwash water is a result of the removal of particulate arsenic accumulation from the filter, rather than desorption of arsenic from the media.

The manual filter backwash procedure described in the manufacturer's operating instructions was generally followed during backwash and rinse. The manufacturer's Operations Manual indicates that the filter should be backwashed for 15 minutes at a flow rate of 3.2 gpm initially during startup, but should be backwashed for 15 minutes at a rate of 3.9 gpm after initial startup. However, a backwash rate of 3.2 gpm was inadvertently used for the first two backwashes after initial startup.

The manufacturer's operating instructions state that the filter should be rinsed until the rinse water is clear (approximately 15 minutes) at the normal operating flow rate of 1.7 gpm. At the specified rinse rate, variable rinse durations were required for the rinse water to clear. Therefore, the volume of rinse water used varied from 48 to 110 gallons per backwash.

Wastewater from each filter backwash and rinse was discharged to a sanitary sewer adjacent to the well station. The total water usage for each backwash and rinse was 200 gallons, for a total backwash and rinse water usage of 2,800 gallons. The backwash and rinse water usage represents 0.5% of the total throughput of 519,400 gallons during the test, including the Integrity, Capacity, and Post-Regeneration phases.

Table 4-16. Capacity Test Backwash and Rinse Water Characteristics

	Units	Number of Samples	Backwash Average	Number of Samples	Rinse Average
Volume	gallons	15	103	14	90
Flow Rate	gpm	15	3.6	14	1.7
pH	unit	2	7.3	2	7.1
Turbidity	NTU	1	16.6	1	0.68
Arsenic	µg/L	13	539	13	16
Iron	µg/L	4	49,348	4	1,180
Manganese	µg/L	4	22,775	4	370
Aluminum	µg/L	4	4,290	4	259
Silica	mg/L	4	74.3	4	34.4
Sodium	mg/L	4	25.4	4	25.3
Chloride	mg/L	3	36.8	3	36.4
Sulfate	mg/L	3	152	3	126
Phosphorus	mg/L	3	1.07	3	0.020
Alkalinity	mg/L	2	166	2	165
FAC	mg/L	1	1.84	1	0.72
Calcium	mg/L	1	274	1	316
Hardness	mg/L	1	306	1	316
Fluoride	mg/L	1	0.49	1	0.50

4.6 Media Regeneration

Spent MEDIA G2® media must be regenerated by the operator by feeding an alkaline caustic soda solution to the media. The increase in pH above 10 with the addition of the alkaline solution causes the previously adsorbed arsenic to solubilize and release from the media. Following this step, the operator is required to feed sulfuric acid to the filter to neutralize the high pH caused by the caustic solution. Media regeneration was performed once during the Capacity Test. The combination of filter backwash and regeneration required about five hours of operator time, including setup and sample collection. Regeneration wastewater quality parameters are summarized in Table 4-17. The arsenic concentration in the regeneration and regeneration rinse waters are summarized in Table 4-18. Concentrations of sodium, silica, iron, manganese, and aluminum in the backwash and rinse waters far exceeded feedwater concentrations, indicating that the regeneration process had resulted in their removal from the filter media.

Regeneration produced approximately 50 gallons of regenerant wastewater. A portion of mixed regenerant wastewater was collected for TCLP analysis. The TCLP sample was filtered and analyzed according to the TCLP protocol. The results of TCLP analyses are summarized in Table 4-19. It is important to note that the manufacturer's standard procedure for treating spent regenerant water before discharge was not followed. The standard procedure is to adjust pH to 6.0, causing the arsenic and iron to form insoluble ferric arsenate, which will then settle out of solution. The manufacturer reports that, if the standard procedure is followed, the settled sludge and the supernatant will pass the TCLP test.

The arsenic concentration in the media regeneration wastewater TCLP analysis is greater than the TCLP regulatory limit. However, this does not imply that the spent media will not pass the TCLP test for disposal of the spent media. The ability to discharge regeneration wastewater with a relatively high arsenic concentration and potential impacts on the receiving wastewater treatment plant should be evaluated on an individual basis. Laboratory data qualifications for the arsenic results are included with the Wastewater TCLP Analytical Reports in Appendix M. In addition, wastewater was generated following regeneration due to rinsing of the filter bed until the treated water is within one pH unit of the feed water. Both of these wastewaters were discharged to the sanitary sewer during the media regeneration performed during the Capacity Test.

The media regeneration procedure is intended to remove arsenic from the media. Therefore, since the pilot system was operated for only one month following media regeneration, which would not have allowed for the accumulation of a significant quantity of arsenic, performing TCLP and California Waste Extraction Tests (CA WET) analyses on the media would not have been representative of the leaching characteristics of fully spent media. Therefore, TCLP and CA WET analyses were not performed, as planned, following the end of the post-regeneration testing.

Table 4-17. Regeneration Wastewater Quality

Date	Time	Sodium (mg/L)	Silica (mg/L)	Iron (mg/L)	Manganese (mg/L)	Aluminum (mg/L)	Description
4/30/2004	11:31	24.8	30.8	26	<10	<200	Regeneration Waste
4/30/2004	11:41	35.9	71.0	22	<10	<200	Regeneration Waste
4/30/2004	11:51	230	385	68	<10	2,900	Regeneration Waste
4/30/2004	12:25	1,110	454	86	<10	5,370	Regeneration Waste
4/30/2004	13:00	5,160	1,686	147	<10	16,300	Regeneration Rinse
4/30/2004	13:10	3,650	392	190,000	2,440	168,000	Regeneration Rinse
4/30/2004	13:30	4,320	907	23,300	329	32,900	Regeneration Rinse

Table 4-18. Regeneration Wastewater Arsenic Concentration

Date	Time	Arsenic (mg/L)	Description
4/30/2004	13:00	5,000	Regenerate Rinse
4/30/2004	13:10	1,800	Regenerate Rinse
4/30/2004	13:20	11,000	Regenerate Rinse Mix
4/30/2004	13:30	5,900	Regenerate Rinse/Composite

Table 4-19. Media Regeneration Wastewater Characterization

	TCLP Result		TCLP(1)
Parameter	Result (mg/L)	Reporting Limit (mg/L)	Regulatory Limit (mg/L)
Arsenic	10.3	0.40	5.0
Barium	ND	0.40	100.0
Cadmium	0.068	0.020	1.0
Chromium	ND	0.160	5.0
Copper	ND	0.040	N/A
Lead	ND	0.20	5.0
Mercury	ND	0.0004	0.2
Selenium	ND	0.40	N/A
Silver	ND	0.020	5.0
Zinc	ND	0.40	N/A

(1) 40 CFR 261.24 Toxicity Characteristics.

ND = Non-Detect.

Media gradation analyses indicate that following the test the media contained significantly less fine material than new media. The loss of fine-grained material could have occurred during normal operation or more likely during media backwashes. Media gradation reports are included in Appendix N.

4.7 Task 3: Documentation of Operating Conditions and Treatment Equipment

4.7.1 Introduction

During each day of verification testing, the arsenic adsorption media filter operating conditions were documented. The volumetric flow rate and feed water pH through the MEDIA G2® are both critical parameters, and were monitored and documented. MEDIA G2® performance is affected by the EBCT, which varies directly with the volumetric flow rate through the vessel. The MEDIA G2® performance was also shown to be sensitive to feed water pH, which varied directly with the quantity of acid that was metered to the feed water.

4.7.2 Experimental Objectives

The objective of this task was to accurately and fully document the operating conditions and performance of the equipment, as stated in Section 3.11. This task was performed in conjunction with both the system Integrity Test and the Capacity Test, as presented in Sections 4.3.3 and 4.4.2, respectively.

4.8 Task 4: Data Management

The data management plan was executed as presented in Task 4 (Data Management), located in Section 3.12. Data were entered into computer spreadsheets and submitted in electronic and hard copies. QA/QC forms, field notebooks, and photographs are included in the appendices of this report.

4.9 Task 5: Quality Assurance/Quality Control

4.9.1 Introduction

Appropriate quality assurance and quality control measures were performed to ensure the quality and integrity of all measurements of operational and water quality parameters during the ETV testing. QA/QC procedures for the operation of the arsenic adsorption media filter and the measured water quality parameters were maintained during the verification testing program, as specified in the test plan and described in Section 3.13.

On-site QA/QC activities were recorded in the logbooks, included as Appendix J. QA/QC efforts included review of laboratory raw data (run logs and bench sheets); calibration of on-site analytical instrumentation; calibration of totalizer meters; calibration of the flow meter; analyses of split samples to verify Hach Test Kit analyses for alkalinity, calcium, and hardness; pressure gauge calibration; collection of duplicate samples for on-site and laboratory analyses; and spiked sample analyses. Performance evaluation analyses were also performed by Gannett Fleming to demonstrate proficiency and accuracy of the analytical equipment and laboratory techniques required for all on-site water quality analyses. All data entry performed by the field engineer was checked by a second person.

An on-site system inspection and audit for sampling activities and field operations was conducted by NSF. The Gannett Fleming QA officer also conducted an on-site inspection during the first two weeks of operation.

4.9.2 Data Quality Indicators

Data quality indicators include the following:

- Representativeness;
- Accuracy;
- Precision;
- Statistical Uncertainty; and
- Completeness.

4.9.2.1 Representativeness. Representativeness refers to the degree to which the data accurately and precisely reflects the conditions or characteristics of the parameter, as measured by the data. Representativeness was ensured by executing consistent sample collection protocol, by using each method to its optimum capability to achieve a high level of accuracy and precision, and collecting sufficient data to be able to detect a change in operations.

4.9.2.2 Accuracy. Accuracy refers to the difference between a sample result and the true or reference value. Accuracy was optimized through equipment calibrations, collection of split samples, analysis of performance evaluation (PE) samples, and analysis of spiked samples, as specified in the PSTP.

4.9.2.2.1 Field Equipment Calibrations. Periodic calibration of field test equipment included calibration of the pressure gauges, flow meter, totalizer meter, portable turbidimeter, pH meter, portable colorimeter, and fluoride meter/electrode, as specified in Table 4-20.

Table 4-20. Field Instrument Calibration Schedule

Instrument	Calibration Method	Frequency	Acceptable Accuracy
Pressure Gauges	dead weight calibration tester	biannual	± 10%
Flow Meter	volumetric "bucket and stop watch"	weekly	± 10%
Totalizer Meter	volumetric "bucket and stop watch"	weekly	± 1.5%
Portable Turbidimeter	secondary turbidity standards primary turbidity standards	daily weekly	PE sample
Portable pH/ISE Meter with Combination pH/Temperature Electrode	three-point calibration using 4.0, 7.0 and 10.0 buffers	daily	± 5%
Portable Colorimeter	approximate 4.0 mg/L chlorine standard	daily	±25%
Thermometer (NIST-traceable)	calibration not required	N/A	
Portable pH/ISE Meter with Fluoride ISE	0.2 mg/L fluoride standard and 2.0 mg/L fluoride standard	daily	± 2%

Calibration tests were performed on the electronic flow meter and totalizer meter before the initiation of the Integrity Test. These calibration tests indicated accuracy within the stated ranges of the instrument manufacturers. The calibration data for the electronic flow meter indicated that a flow rate of 1.7 gpm was produced when the meter indicated 1.7 gpm. The calibration data for the totalizer meter indicated a production of approximately 10 gallons when the meter had an incremental reading of 10 gallons.

4.9.2.2.2 Split Samples. Split samples for alkalinity, calcium, and hardness were analyzed both on-site by field personnel and by the PADEP Laboratory staff to verify the accuracy of the Hach methods for on-site analyses of these parameters. The results of split sample analyses are included in Table 4-21.

Alkalinity analyses were not performed in the field on the day that split samples were collected for PADEP Laboratory analyses. Therefore, true split sample results for alkalinity were not available. However, field measured alkalinity was relatively stable during the Capacity Test. From May 19, 2004, through May 27, 2004, five raw water alkalinity sample results ranged from 148 mg/L to 152 mg/L. During the same time period five feed (ST2) results ranged from 124 mg/L to 128 mg/L and five treated water samples ranged from 112 mg/L to 120 mg/L. Although it does not provide a true split sample comparison, the average of the five sample results at each of the three locations was calculated for comparison to PADEP Laboratory results.

Split sample results for the raw and treated (ST3) were within the acceptable limits of accuracy of ±30% established by NSF. However, split sample results for the feed (ST2) water were generally outside the acceptable limits of accuracy. Feed (ST2) alkalinity measured on-site was greater than the alkalinity measured in the laboratory and was slightly outside the limits of acceptable accuracy. The on-site feed (ST2) calcium result was within acceptable accuracy limits when compared to one PADEP Laboratory result and outside the acceptable limits of accuracy when compared to a second PADEP Laboratory result. On-site feed (ST2) hardness results were not within the acceptable limits of accuracy as established by NSF.

Table 4-21. Split-Samples (May 25, 2004)

	Raw Water				
Parameter	**Field**	**PADEP Lab**	**% Difference**	**PADEP Lab**	**% Difference**
Alkalinity[1] (mg/L as CaCO3)	150	164	-8.5%	162	-7.4%
Calcium (mg/L as CaCO3)	-	228	-	229	-
Hardness (mg/L as CaCO3)	-	262	-	264	-
	Feed (ST2)				
Parameter	**Field**	**PADEP Lab**	**% Difference**	**PADEP Lab**	**% Difference**
Alkalinity[1] (mg/L as CaCO3)	126	94.4	33.5%	96.4	30.7%
Calcium (mg/L as CaCO3)	288	206	39.8%	229	25.8%
Hardness (mg/L as CaCO3)	374	241	55.2%	263	42.2%
	Treated (ST3)				
Parameter	**Field**	**PADEP Lab**	**% Difference**	**PADEP Lab**	**% Difference**
Alkalinity[1] (mg/L as CaCO3)	116	91.8	26.4%	92.2	25.8%
Calcium (mg/L as CaCO3)	278	229	21.4%	225	23.6%
Hardness (mg/L as CaCO3)	300	263	14.1%	259	15.8%

(1) Field alkalinity data is an average of five sample results from May 19, 2004, through May 27, 2004, because field alkalinity analyses were not performed May 25, 2004.

4.9.2.2.3 Performance Evaluation Samples for Water Quality Testing. PE samples are samples of known concentration prepared by an independent performance evaluation laboratory and provided as unknowns to an analyst to evaluate his or her analytical performance. Analyses of laboratory PE samples were conducted before the initiation of verification testing. The control limits for the PE samples were used to evaluate the field analytical method performance.

A PE sample comes with statistics that have been derived from the analysis of the sample by a number of laboratories using EPA-approved methods. These statistics include a true value of the PE sample, a mean of the laboratory results obtained from the analysis of the PE sample, and an acceptance range for sample values. The field laboratory and the PADEP Laboratory provided results from the analysis of the PE samples that meet the performance objectives of the verification testing. PE sample results for the PADEP Laboratory and the results of PE checks for on-site water quality parameters are included in Appendix O.

4.9.2.2.4 Spike Sample Analyses. Analyses of matrix spikes were performed by Gannett Fleming for on-site water quality parameters during the Capacity Test. Spike sample analyses results for alkalinity, calcium, hardness, fluoride, and FAC are included in Appendix J. Calcium spike sample percent recoveries were within the acceptable accuracy of 70 to 130% recovery, with the exception of one spike sample, which had only a 55% recovery. It is likely that the poor recovery percentage for this sample is a result of an error in entering data in the logbook rather than analytical error. The volume of titrant (1.1 mL) recorded in the logbook for the 40 mg/L spike was the same as the volume of titrant recorded for the 20 mg/L spike sample. Considered with the fact that all other calcium spike samples were within the acceptable range of accuracy, recording error is most likely the cause of the single unacceptable result.

Hardness spike sample percent recoveries were within the acceptable range of accuracy of 70 to 130% recovery established by NSF. Alkalinity spike sample percent recoveries were within the acceptable range of accuracy of 70 to 130% recovery, with the exception of one spike sample, which had a percent recovery of 138%. This sample represents less than 1% of the alkalinity spike samples performed. However, more than 30% of the FAC spike samples and nearly 50% of the fluoride spike samples analyzed were not within the acceptable accuracy range of 70 to 130% recovery.

The results of spike sample analyses performed by the PADEP Laboratory are included in the laboratory analysis summary tables included in Appendix K. Spike sample analyses were performed by the PADEP Laboratory at a frequency of 10%. Spike sample analysis percent recoveries for iron, manganese, aluminum, sodium, and silica were within the acceptable accuracy range of 70 to 130% recovery. Spike sample results for chloride and sulfate were within the acceptable accuracy range of 80 to 120% recovery and total phosphorus was within the acceptable accuracy range of 90 to 110% recovery.

The results of NSF laboratory spike sample analyses for arsenic are included in the laboratory QA/QC data in Appendix L. Spike sample analyses were performed by the NSF laboratory at a frequency of 10%. Percent recoveries for arsenic were within the acceptable accuracy range of 70 to 130% recovery.

4.9.2.3 Precision. Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error and can be measured by replication of analyses. The precision levels for all duplicate analyses were calculated.

On-site water quality relative percent deviation calculations are included with the On-site Water Quality Data in Appendix J. Relative percent deviations calculated for pH, FAC, temperature, alkalinity, calcium, hardness, and fluoride were all within the acceptable precision level of 30%. Approximately 10% of duplicate turbidity samples were not within the acceptable precision level.

Relative percent deviation calculations for PADEP Laboratory duplicates are included in Appendix K. The PADEP Laboratory performed duplicate analyses at a 10% minimum frequency. All PADEP Laboratory duplicate analyses were within the acceptable levels of precision of 30% for iron, manganese, aluminum, sodium, and silica; 20% for chloride and sulfate; and 10% for total phosphorus. No duplicates of the parameters analyzed by the PADEP Laboratory were collected in the field.

NSF relative percent deviation calculations for laboratory arsenic duplicates are included in Appendix L. All NSF laboratory arsenic duplicate analyses were within the acceptable precision level of 30%. All field duplicates of arsenic samples were within the acceptable precision level of 30%.

4.9.2.4 Statistical Uncertainty. Statistical uncertainty of water quality parameters (for data sets of eight or more parameters) was evaluated through the calculation of the 95% confidence interval around the sample mean.

4.9.2.5 Completeness. Completeness refers to the amount of valid, acceptable data collected from a measurement process compared to the amount expected to be obtained. The completeness objective for data generated during this verification test was based on the number of samples collected and analyzed for each parameter and/or method, as defined below.

Number of Samples Per Parameter and/or Method	Percent Completeness
0-10	80%
11-50	90%
> 50	95%

Completeness was defined as the following for all measurements:

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

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

Calculation of data completeness was made for on-site water quality measurements, PADEP Laboratory water quality measurements, and arsenic measurements. These calculations are presented in Appendix J, K, and L of this report, respectively.

During the Integrity Test, the completeness percentages for on-site water quality analyses were within the acceptable completeness levels; however, duplicates of some parameters were collected at a rate of 50% or 0% of that proposed. During the Capacity Test, the completeness percentages for on-site water quality analyses were within the acceptable completeness levels. Duplicates were also performed within the acceptable completeness levels, with the exception of feed (ST1) pH and turbidity, which were performed with a completeness of 88% and 50%, respectively. Additional on-site water quality samples, not specified in the test plan, were analyzed to better characterize the feed (ST1) and raw waters. Completeness for on-site water quality analyses during the post-regeneration period were within the acceptable completeness levels, with the exception of feed (ST1) pH (87%), and feed (ST2) and treated calcium, magnesium, hardness, and fluoride (33%). Duplicate analyses during the post-regeneration period were all within the acceptable completeness levels.

During the Integrity Test, samples for PADEP analyses were collected at 100% or greater completeness of the proposed amount specified in the test plan. However, field duplicates were not collected. During the Capacity Test, samples for PADEP analyses were within the acceptable completeness levels; however duplicates were not collected for any of the applicable parameters. Completeness ranged from 67% to greater than 100% of the proposed sample frequency specified in the test plan for PADEP parameters during the post-regeneration phase of the test. Those parameters that were not collected within the acceptable completeness level include sodium, silica, aluminum, chloride, sulfate, and phosphorus at the feed (ST2) and treated water locations. Additional samples (that were not specified in the test plan) were collected for the raw and feed (ST1) water.

Although duplicate arsenic samples were not collected during the Integrity Test, 100% or greater completeness was achieved for samples and duplicates during the Capacity Test, including the post-regeneration phase.

For the TCLP analysis of the regeneration wastewater, nickel was also supposed to be analyzed; however, this parameter was inadvertently missed. All other proposed parameters for TCLP analysis were analyzed for.

Chapter 5
References

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

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

Hach Water Analysis Handbook. Hach Company, Loveland, Colorado. 1992.

Standard Methods for Examination of Water and Wastewater. 20th ed., Washington, D.C., APHA. 1998.

U.S. EPA Drinking Water Methods for Chemical Parameters. EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Chapter 6
Vendor Comments

ADI International Inc. submitted the following comments concerning the ETV test and report. These statements were not validated in the verification test and are the opinion of ADI International Inc.:

"Results were as expected. Despite the relatively poor quality of the feed water (i.e., relatively high and variable turbidity, high manganese concentration, and the possibility of carry-over of accumulated iron particulate from the chlorine contact tank to the filter), consistent reduction of arsenic to below the 10 µg/L maximum contaminant level was obtained.

Feed water manganese and iron concentrations both consistently exceeded secondary maximum contaminant levels (manganese by as much as a factor of twenty); the filter reduced both to well below their MCLs. While other iron-based media may be adversely affected by high iron and/or manganese, MEDIA G2® is not (and in fact is an excellent filter for their removal, as was shown in this study and in numerous full-scale installations).

Throughout the majority of the capacity test the pH of the feed water was held in the desired 6.3 - 6.5 range. One significant variation occurred during the final week of 2003 and first week of 2004, when the pH increased to over 7.0. A corresponding increase in treated water arsenic concentration was seen at this time, but the concentration immediately declined again when pH was brought back under control. In a full-scale plant, automated pH control is used and such fluctuations should not occur.

During this test, raw water was used for backwashing. While acceptable, this is not ideal. Raw water of course contains arsenic, and its introduction into the gravel layer at the filter bottom during backwash means there is potential for an elevated arsenic output when the filter is put back into normal (downflow) service. In a full-scale plant, if treated water is used, this would not be the case, and less rinsing would be required to ensure steady low values of arsenic in the treated water.

As shown in the testing of backwash water, the media holds the arsenic tightly, resulting in a non-hazardous residual suitable for sewerage. Manganese and iron were readily backwashed from the media and meaning little accumulation within the filter bed. If no sewer is available, the backwash can be collected in a holding tank, where the solids will settle, and the supernatant can be slowly blended back into the raw water entering the plant.

The media was regenerated after seven months of operation. This was premature, as the media had not yet reached arsenic saturation (treated water was still well below 10 µg/L). However, due to time constraints, a regeneration was carried out anyway so that a sample of regenerant waste could be obtained. Therefore, the true adsorption capacity of the media was not determined. The outlet arsenic concentration was not trending upward (in fact it was trending slightly downward), so the filter could have remained in operation without need of regeneration for an indefinite period. One important observation is that the performance of the regenerated media returned to that of new media, as expected.

A brief spike in treated water arsenic concentration following regeneration was probably due to insufficient rinsing. In a full-scale plant this is addressed by rinsing the filters with slightly acidified water to neutralize traces of residual sodium hydroxide within the filter bed, followed by rinse-to-waste until on-site testing shows the filter pH has returned to neutral and arsenic concentration is acceptable. With the acid-dosed water rinse, the time elapsed before returning to service without fear of arsenic spikes is greatly reduced. The volume of wastewater production is also greatly reduced.

In reviewing the data on regeneration wastewater characteristics it is extremely important to note that the proper treatment of this waste was not carried out before TCLP testing. Proper procedure for dealing with this waste is to lower the pH to 6.0 and allow solids to settle. At this pH, the arsenic combines with the iron in the waste to form insoluble ferric arsenate, which settles out of solution. Both the settled sludge and the supernatant pass the TCLP test in all cases ADI has looked at.

One of the major advantages of this technology is its low operating cost. The consumables used were sulfuric acid (for pH correction of raw water), chlorine (for oxidation of arsenic and disinfection), and sodium hydroxide (for media regeneration). The calculated dosage of sulfuric acid was 73 mg/L. The need for pH correction depends on the particular water chemistry at a given site; many MEDIA G2® plants require no acid at all. Chlorine was added, at a dosage of 1.2 mg/L; this oxidizes the arsenic and provides disinfection for the water entering the distribution system. Many plants chlorinate their water anyway, in which case this would not be considered an additional operating expense. For those that do not already chlorinate, the need for chlorine for acceptable performance is dependent upon the particular water chemistry at the site (although the cost of a low dosage is relatively small anyway). Regeneration requires three bed volumes of 1% sodium hydroxide be passed through the filter to desorb the accumulated arsenic. The procedure involves injecting 50% NaOH into the raw water upstream of the filters at a rate equal to 1/50th of the raw water flow rate. The amount of waste created is minimal; the waste volume from this pilot plant was only 50 gallons after treating 434,107 gallons of raw water (and operation should have continued longer – the plant was regenerated prematurely). Typical waste volume from full-scale MEDIA G2 plants (including regeneration and monthly backwashing) is about 0.1% of treated water volume.

Electricity costs during the study were negligible – a few watts to run the metering pumps; actually, similar sized pumps could be used for full-scale plants.

Based on experience at over two dozen installed MEDIA G2 plants, typical operating cost is $0.10 - $0.25 per 1000 gallons, including chemicals, electricity, waste disposal, and media replacement. The lower end of the range would be for cases without pH correction and relatively low raw water arsenic concentration.

Overall, this testing proved the media's ability to provide excellent removal of arsenic, manganese and iron, with little operator attention and production of a very small volume of non-hazardous residuals."