

EPA/600/R-06/090
September 2006

Arsenic Removal from Drinking Water by Adsorptive Media
U.S. EPA Demonstration Project at
Spring Brook Mobile Home Park in Wales, ME
Six-Month Evaluation Report

by

Jody P. Lipps
Abraham S.C. Chen
Lili Wang

Battelle
Columbus, OH 43201-2693

Contract No. 68-C-00-185
Task Order No. 0029

for

Thomas J. Sorg
Task Order Manager

Water Supply and Water Resources Division
National Risk Management Research Laboratory
Cincinnati, Ohio 45268

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

DISCLAIMER

The work reported in this document is funded by the United States Environmental Protection Agency (EPA) under Task Order 0029 of Contract 68-C-00-185 to Battelle. It has been subjected to the Agency's peer and administrative reviews and has been approved for publication as an EPA document. Any opinions expressed in this paper are those of the author(s) and do not, necessarily, reflect the official positions and policies of the EPA. Any mention of products or trade names does not constitute recommendation for use by the EPA.

FOREWORD

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

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

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

Sally Gutierrez, Director
National Risk Management Research Laboratory

ACKNOWLEDGMENTS

The authors wish to extend their sincere appreciation to the owner/operator of Spring Brook Mobile Home Park in Wales, Maine. The owner monitored the treatment system and collected samples from the treatment system and distribution system on a regular schedule throughout this reporting period. This performance evaluation would not have been possible without his efforts.

ABSTRACT

This report documents the activities performed during and the results obtained from the first six months of the arsenic removal treatment technology demonstration project at the Spring Brook Mobile Home Park in Wales, ME. The objectives of the project are to evaluate the effectiveness of an Aquatic Treatment System, Inc. (ATS) As/1400CS arsenic removal system in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 µg/L, the reliability of the treatment system, the required system operation and maintenance (O&M) and operator's skills, and the capital and O&M costs of the technology. The project also characterizes the water in the distribution system and process residuals produced by the treatment process.

The ATS system consisted of two parallel treatment trains, each consisting of one 25-µm sediment filter, one 10-in-diameter, 54-in-tall oxidation column, and three 10-in-diameter, 54-in-tall adsorption columns connected in series. The columns were constructed of sealed polyglass and loaded with 1.5 ft³ each of either A/P Complex 2002 oxidizing media (consisting of activated alumina and sodium metaperiodate) or A/I Complex 2000 adsorptive media (consisting of activated alumina and a proprietary iron complex). Based on a design flow rate of 7 gal/min (gpm) through each train, the empty bed contact time (EBCT) in each column was 1.6 min (or 4.8 min for three columns in series) and the hydraulic loading rate to each column was 13 gpm/ft².

Between March 3 and September 9, 2005, the system operated an average of 3.4 hr/day for a total of 638 hrs, treating approximately 480,000 gal of water. This volume throughput was equivalent to 21,400 bed volumes (BVs) based on the 1.5-ft³ bed volume in a lead adsorption column or 7,143 BVs based on the 4.5-ft³ combined bed volume in the three adsorption columns. The oxidation columns were effective at converting As(III), the predominating arsenic species, to As(V) throughout the six month period, typically lowering the As(III) concentrations from an average of 29.4 ± 6.7 to <1 µg/L. The oxidation of As(III) to As(V) was achieved presumably through reaction with sodium metaperiodate. Iodide (I⁻) analysis in the treated water was not conducted during the first six months of the study. Subsequent samples collected during the continuation of this study show elevated iodide concentrations as high as 124 µg/L following the oxidizing and adsorption columns. The oxidation columns also showed some adsorptive capacity for arsenic (i.e., 0.14 µg/mg of media), initially removing arsenic to <1 µg/L. By about 5,000 BVs (based on the 1.5-ft³ bed volume in an oxidation column), arsenic had completely broken through the oxidation columns.

Arsenic concentrations after the lead columns reached 10 µg/L at approximately 6,000 BVs (based on the 1.5-ft³ bed volume in the lead adsorption column) from Train A and just under 5,000 BVs from Train B, and reached complete breakthrough at approximately 10,000 BVs and 9,000 BVs, respectively, from each train. Arsenic breakthrough from the lead columns occurred much sooner than projected (at 32,700 BVs) by the vendor. High pH values of the source water (ranging from 8.0 to 8.7) was thought to be the major factor for early arsenic breakthrough from the adsorption columns. Arsenic concentrations after the second set of lag columns reached 10 µg/L at approximately 15,000 BVs through both treatment trains, and reached complete breakthrough at about 19,000 BVs. The adsorptive capacity of the media was estimated to be 0.2 µg of arsenic/mg of media.

Several anions, including silica, sulfate, alkalinity, and fluoride were present in raw water at concentrations significant to potentially compete with arsenic for adsorption sites. Silica was consistently removed from 10.8 mg/L to 0.6–5.5 mg/L by (and did not reach complete breakthrough from), the oxidation and adsorption columns throughout the first six months of system operation. Even after the arsenic removal capacity was completely spent, the oxidation columns and the lead adsorption columns continued to show some capacity for silica removal. Of the other competitive anions, both media showed little or no removal capacity for sulfate or alkalinity. The treatment system removed fluoride from about

0.5 to < 0.1 mg/L initially, but fluoride completely broke through the oxidation and lead adsorption columns within 2,000 BVs.

Aluminum concentrations (existing primarily in the soluble form) in the treated water following the oxidation columns were about 20 to 30 µg/L higher than those in raw water, indicating leaching of aluminum from the oxidizing media. However, the concentrations were below the secondary drinking water standard for aluminum of 50 to 200 µg/L.

Comparison of distribution system sampling results before and after operation of the As/1400CS system showed a significant decrease in the average arsenic concentration at each of the three sampling locations during the first three months of system operation. During this period, arsenic concentrations were below 2.0 µg/L at all sampling locations. After the third month of operation, as arsenic began to break through the treatment system, the concentrations at the distribution locations also increased, exceeding the 10 µg/L target value. Neither lead nor copper concentrations appeared to have been affected by the operation of the system and remained well below the action levels of 15 µg/L for lead and 1.3 mg/L for copper.

The capital investment cost of \$16,475 included \$10,790 for equipment, \$1,800 for site engineering, and \$3,885 for installation. Using the system's rated capacity of 14 gpm (or 20,160 gal/day [gpd]), the capital cost was \$1,177/gpm of design flow (or \$0.82/gpd).

O&M cost included only incremental cost associated with the adsorption system, such as media replacement and disposal (for both oxidizing and adsorptive media), electricity consumption, and labor. Incremental cost for electricity consumption was negligible. Although media replacement and disposal was not performed during the first six months of operation, the estimated cost was \$2,465, \$4,015, and \$5,565 for changing out two, four, or six columns, respectively. Cost curves were constructed one each for replacing two, four, or six columns at a time to estimate media replacement cost per 1,000 gal of water treated as a function of the media working capacity.

CONTENTS

FOREWORD	iii
ACKNOWLEDGMENTS	iv
ABSTRACT.....	v
APPENDICES	viii
FIGURES.....	viii
TABLES	viii
ABBREVIATIONS AND ACRONYMS	ix
1.0 INTRODUCTION.....	1
1.1 Background.....	1
1.2 Treatment Technologies for Arsenic Removal	2
1.3 Project Objectives	2
2.0 CONCLUSIONS.....	5
3.0 MATERIALS AND METHODS	7
3.1 General Project Approach.....	7
3.2 System O&M and Cost Data Collection	8
3.3 Sample Collection Procedures and Schedules	8
3.3.1 Source Water Sample Collection.....	8
3.3.2 Treatment Plant Water Sample Collection	9
3.3.3 Residual Solid Sample Collection	9
3.3.4 Distribution System Water Sample Collection.....	9
3.4 Sampling Logistics.....	10
3.4.1 Preparation of Arsenic Speciation Kits.....	10
3.4.2 Preparation of Sampling Coolers.....	10
3.4.3 Sample Shipping and Handling	10
3.5 Analytical Procedures	11
4.0 RESULTS AND DISCUSSION.....	12
4.1 Facility Description.....	12
4.1.1 Source Water Quality	12
4.1.2 Distribution System	13
4.2 Treatment Process Description	13
4.3 Permitting and System Installation	17
4.4 System Operation.....	21
4.4.1 Operational Parameters.....	21
4.4.2 Residual Management	21
4.4.3 System Operation, Reliability, and Simplicity	22
4.5 System Performance	22
4.5.1 Treatment Plant Sampling	22
4.5.2 Distribution System Water Sampling	31
4.6 System Cost	36
4.6.1 Capital Cost	36
4.6.2 Operation and Maintenance Cost.....	36
5.0 REFERENCES.....	40

APPENDICES

- APPENDIX A: Operational Data
APPENDIX B: Analytical Data Results

FIGURES

Figure 4-1.	Pre-Existing Treatment Building at Spring Brook Mobile Home Park	12
Figure 4-2.	Pre-Existing Water Supply Pump, System Piping, and Hydropneumatic Tanks (shown in the background).....	13
Figure 4-3.	Schematic of As/1400CS Adsorption System (Provided by ATS)	16
Figure 4-4.	Process Flow Diagram and Sampling Locations.....	19
Figure 4-5.	As/1400CS Arsenic Adsorption System with Adsorption and Oxidation Columns Shown in Foreground, 25- μ m Sediment Filters Attached to Wall, and Hydropneumatic Tanks in Background	20
Figure 4-6.	Close-Up View of a Sample Tap (OA), a Pressure Gauge, and Copper Piping at Head of a Column	20
Figure 4-7.	Concentrations of Various Arsenic Species Across Treatment Train A	27
Figure 4-8.	Concentrations of Various Arsenic Species Across Treatment Train B	28
Figure 4-9.	Total Arsenic Breakthrough Curves for Treatment Train A (BVs Based on 1.5 ft ³ of Media Volume in One Column).....	29
Figure 4-10.	Total Arsenic Breakthrough Curves for Treatment Train B (BVs Based on 1.5 ft ³ of Media Volume in One Column).....	29
Figure 4-11.	Silica Concentrations Across Treatment Train A	32
Figure 4-12.	Silica Concentrations Across Treatment Train B.....	32
Figure 4-13.	Fluoride, Alkalinity, and Sulfate Concentrations Across Both Treatment Trains	33
Figure 4-14.	Total Aluminum Concentrations Across Treatment Train A.....	34
Figure 4-15.	Total Aluminum Concentrations Across Treatment Train B	34
Figure 4-16.	Media Replacement Cost Curves	38

TABLES

Table 1-1.	Summary of Round 1 and Round 2 Arsenic Removal Demonstration Locations, Technologies, and Source Water Quality	3
Table 3-1.	Pre-Demonstration Activities and Completion Dates	7
Table 3-2.	Evaluation Objectives and Supporting Data Collection Activities	7
Table 3-3.	Sample Collection Schedule and Analyses	9
Table 4-1.	Source Water Quality Data.....	14
Table 4-2a.	Physical and Chemical Properties of A/I Complex 2000 Adsorption Media	15
Table 4-2b.	Physical and Chemical Properties of A/P Complex 2002 Oxidation Media	15
Table 4-3.	Design Specifications of As/1400CS System.....	18
Table 4-4.	Summary of As/1400CS System Operation	21
Table 4-5.	Summary of Arsenic, Iron, Manganese, and Aluminum Analytical Results.....	23
Table 4-6.	Summary of Water Quality Parameter Measurements	25
Table 4-7.	Distribution System Sampling Results	35
Table 4-8.	Capital Investment for As/1400CS Treatment System.....	37
Table 4-9.	Summary of O&M Cost	38

ABBREVIATIONS AND ACRONYMS

AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
As	arsenic
ATS	Aquatic Treatment Systems, Inc.
BV	bed volume(s)
C/F	coagulation/filtration
Ca	calcium
Cl	chlorine
Cu	copper
DO	dissolved oxygen
EBCT	empty bed contact time
EPA	United States Environmental Protection Agency
F	fluoride
Fe	iron
gpd	gallons per day
gpm	gallons per minute
HIX	hybrid ion exchanger
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IX	ion exchange
LCR	(EPA) Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MDWP	Maine Drinking Water Program
MEI	Magnesium Electron, Inc.
Mg	magnesium
Mn	manganese
mV	millivolts
N/A	not analyzed
Na	sodium
NaOCl	sodium hypochlorite
ND	not detected
NSF	NSF International

ABBREVIATIONS AND ACRONYMS (Continued)

O&M	operation and maintenance
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
Pb	lead
PO ₄	orthophosphate
POU	point-of-use
psi	pounds per square inch
PVC	polyvinyl chloride
QA	quality assurance
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RO	reverse osmosis
RPD	relative percent difference
SBMHP	Spring Brook Mobile Home Park
SDWA	Safe Drinking Water Act
SiO ₂	silica
SO ₄	sulfate
STS	Severn Trent Services
TCLP	Toxicity Characteristic Leaching Procedure
VOC	volatile organic compound
VSWV	very small water systems

1.0 INTRODUCTION

1.1 Background

The Safe Drinking Water Act (SDWA) mandates that the United States Environmental Protection Agency (EPA) identify and regulate drinking water contaminants that may have adverse human health effects and are known or anticipated to occur in public water supply systems. In 1975, under the SDWA, EPA established a maximum contaminant level (MCL) for arsenic at 0.05 mg/L. Amended in 1996, the SDWA required that EPA develop an arsenic research strategy and publish a proposal to revise the arsenic MCL by January 2000. On January 18, 2001, EPA finalized the arsenic MCL at 0.01 mg/L (EPA, 2001). In order to clarify the implementation of the original rule, EPA revised the rule text on March 25, 2003 to express the MCL as 0.010 mg/L (10 µg/L) (EPA, 2003). The final rule requires all community and non-transient, non-community water systems to comply with the new standard by January 23, 2006.

In October 2001, EPA announced an initiative for additional research and development of cost-effective technologies to help small community water systems (<10,000 customers) meet the new arsenic standard, and to provide technical assistance to operators of small systems in order to reduce compliance costs. As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, on-site demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems. Shortly thereafter, an announcement was published in the *Federal Register* requesting water utilities interested in participating in the first round of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 sites from a list of 115 to be the host sites for the demonstration studies.

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the 17 host sites. EPA received 70 technical proposals for the 17 host sites, with each site receiving from one to six proposals. In April 2003, an independent technical panel reviewed the proposals and provided its recommendations to EPA on the technologies that it determined were acceptable for the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the Round 1 demonstration program. Using the information provided by the review panel, EPA, in cooperation with the host sites and the drinking water programs of the respective states, selected one technical proposal for each site. As of February 2006, 11 of the 12 systems have been operational and the performance evaluations of two systems have been completed.

Upon additional congressional funding, EPA published another announcement in the *Federal Register* soliciting water utilities interested in participating in the Round 2 demonstration program. Among the 32 water systems selected by EPA in June 2003 was the Spring Brook Mobile Home Park (SBMHP) facility in Wales, ME.

In September 2003, EPA again solicited proposals from engineering firms and vendors for arsenic removal technologies. EPA received 148 technical proposals for the 32 host sites, with each site receiving from two to eight proposals. In April 2004, another technical panel was convened by EPA to review the proposals and provide recommendations to EPA with the number of proposals per site ranging from none (for two sites) to a maximum of four. The final selection of the treatment technology at the sites that received at least one proposal was made, again through a joint effort by EPA, the state regulators, and the host site. Since then, two sites have decided to withdraw from the demonstration program, reducing the number of sites to 28. The As/1400CS arsenic treatment system from Aquatic Treatment System, Inc. (ATS) was selected for demonstration at the SBMHP site in September 2004.

1.2 Treatment Technologies for Arsenic Removal

The technologies selected for the Round 1 and Round 2 demonstration host sites include 25 adsorptive media (AM) systems (the Oregon Institute of Technology [OIT] site has 3 AM systems), 13 coagulation/filtration (C/F) systems, 2 ion exchange (IX) systems, and 17 point-of-use (POU) units (including 9 under-the-sink reverse osmosis [RO] units at the Sunset Ranch Development site and 8 AM units at the OIT site), and 1 process modification to an existing conventional C/F system. Table 1-1 summarizes the locations, technologies, vendors, system flowrates, and key source water quality parameters (including arsenic, iron, and pH) at the 40 demonstration sites. The technology selection and system design for the 12 Round 1 demonstration sites have been reported in an EPA report (Wang et al., 2004) posted on an EPA Web site (<http://www.epa.gov/ORD/NRMRL/arsenic/resource.htm>).

1.3 Project Objectives

The objective of the Round 1 and Round 2 arsenic demonstration program is to conduct 40 full-scale arsenic treatment technology demonstration studies on the removal of arsenic from drinking water supplies. The specific objectives are to:

- Evaluate the performance of the arsenic removal technologies for use on small systems.
- Determine the required system operation and maintenance (O&M) and operator skill levels.
- Determine the capital and O&M costs of the technologies.
- Characterize process residuals produced by the technologies.

This report summarizes the performance of the ATS system operation at SBMHP in Wales, ME, during the first six months from March 7 through September 9, 2005. The types of data collected included system operational data, water quality data (both across the treatment train and in the distribution system), and capital and preliminary O&M cost data.

Table 1-1. Summary of Round 1 and Round 2 Arsenic Removal Demonstration Locations, Technologies, and Source Water Quality

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH (S.U.)
<i>Northeast/Ohio</i>							
Wales, ME	Springbrook Mobile Home Park	AM (A/I Complex)	ATS	14	38 ^(a)	<25	8.6
Bow, NH	White Rock Water Company	AM (G2)	ADI	70 ^(d)	39	<25	7.7
Goffstown, NH	Orchard Highlands Subdivision	AM (E33)	AdEdge	10	33	<25	6.9
Rollinsford, NH	Rollinsford Water and Sewer District	AM (E33)	AdEdge	100	36 ^(a)	46	8.2
Dummerston, VT	Charette Mobile Home Park	AM (A/I Complex)	ATS	22	30	<25	7.9
Felton, DE	Town of Felton	C/F (Macrolite)	Kinetico	375	30 ^(a)	48	8.2
Stevensville, MD	Queen Anne's County	AM (E33)	STS	300	19 ^(a)	270 ^(b)	7.3
Newark, OH	Buckeye Lake Head Start Building	AM (ARM 200)	Kinetico	10	15 ^(a)	1,312 ^(b)	7.6
Springfield, OH	Chateau Estates Mobile Home Park	AM (E33)	AdEdge	150	25 ^(a)	1,615 ^(b)	7.3
<i>Great Lakes/Interior Plains</i>							
Brown City, MI	City of Brown City	AM (E33)	STS	640	14 ^(a)	127 ^(b)	7.3
Pentwater, MI	Village of Pentwater	C/F (Macrolite)	Kinetico	400	13 ^(a)	466 ^(b)	6.9
Sandusky, MI	City of Sandusky	C/F (Aeralater)	USFilter	340	16 ^(a)	1,387 ^(b)	6.9
Delavan, WI	Vintage on the Ponds	C/F (Macrolite)	Kinetico	40	20 ^(a)	1,499 ^(b)	7.5
Greenville, WI	Town of Greenville	C/F (Macrolite)	Kinetico	375	17	7827 ^(b)	7.3
Climax, MN	City of Climax	C/F (Macrolite)	Kinetico	140	39 ^(a)	546 ^(b)	7.4
Sabin, MN	City of Sabin	C/F (Macrolite)	Kinetico	250	34	1,470 ^(b)	7.3
Sauk Centre, MN	Big Sauk Lake Mobile Home Park	C/F (Macrolite)	Kinetico	20	25 ^(a)	3,078 ^(b)	7.1
Stewart, MN	City of Stewart	C/F&AM (E33)	AdEdge	250	42 ^(a)	1,344 ^(b)	7.7
Lidgerwood, ND	City of Lidgerwood	Process Modification to a C/F System	Kinetico	250	146 ^(a)	1,325 ^(b)	7.2
<i>Midwest/Southwest</i>							
Lyman, NE	Village of Lyman	C/F (Macrolite)	Kinetico	350	20	<25	7.5
Arnaudville, LA	United Water Systems	C/F (Macrolite)	Kinetico	385	35 ^(a)	2,068 ^(b)	7.0
Alvin, TX	Oak Manor Municipal Utility District	AM (E33)	STS	150	19 ^(a)	95	7.8
Bruni, TX	Webb Consolidated Independent School District	AM (E33)	AdEdge	40	56 ^(a)	<25	8.0
Wellman, TX	City of Wellman	AM (E33)	AdEdge	100	45	<25	7.7
Anthony, NM	Desert Sands Mutual Domestic Water Consumers Association	AM (E33)	STS	320	23 ^(a)	39	7.7
Nambe Pueblo, NM	Indian Health Services	AM (E33)	AdEdge	145	33	<25	8.5
Taos, NM	Town of Taos	AM (E33)	STS	450	14	59	9.5
Rimrock, AZ	Arizona Water Company	AM (E33)	AdEdge	90 ^(e)	50	170	7.2
Tohono O'odham Nation, AZ	Tohono O'odham Utility Authority	AM (E33)	AdEdge	50	32	<25	8.2
Valley Vista, AZ	Arizona Water Company	AM (AAFS50)	Kinetico	37	41	<25	7.8

Table 1-1. Summary of Round 1 and Round 2 Arsenic Removal Demonstration Locations, Technologies, and Source Water Quality (Continued)

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH
<i>Far West</i>							
Three Forks, MT	City of Three Forks	C/F (Macrolite)	Kinetico	250	64	<25	7.5
Fruitland, ID	City of Fruitland	IX (A300E)	Kenetico	250	44	<25	7.4
Homedale, ID	Sunset Ranch Development	POU RO ^(c)	Kinetico	75 gpd	52	134	7.5
Okanogan, WA	City of Okanogan	C/F (Electromedia II)	Filtronic	750	18	69 ^(b)	8.0
Klamath Falls, OR	Oregon Institute of Technology	AM (Adsorbisia/ARM 200/ArsenX) and POU AM ^(f)	Kinetico	60/60/30	33	<25	7.9
Vale, OR	City of Vale	IX (A520)	Kinetico	525	17	<25	7.5
Reno, NV	South Truckee Meadows General Improvement District	AM (GFH)	USFilter	350	39	<25	7.4
Susanville, CA	Richmond School District	AM (A/I Complex)	ATS	12	37 ^(a)	125	7.5
Lake Isabella, CA	Upper Bodfish Well CH2-A	AM (HIX)	VEETech	50	35	125	7.5
Tehachapi, CA	Golden Hills Community Service District	AM (Isolux)	MEI	150	15	<25	6.9

AM = adsorptive media process; C/F = coagulation/filtration; HIX = hybrid ion exchanger; IX = ion exchange process

ATS = Aquatic Treatment Systems; MEI = Magnesium Elektron, Inc.; STS = Severn Trent Services

- (a) Arsenic existing mostly as As(III)
- (b) Iron existing mostly as Fe(II)
- (c) Including 9 residential units
- (d) System reconfigured from parallel to series operation due to lower flowrate of 40 gpm
- (e) System reconfigured from parallel to series operation due to lower flowrate of 30 gpm
- (f) Including 8 under-the-sink units

2.0 CONCLUSIONS

Based on the information collected during the first six months of system operation, the following conclusions were made relating to the overall objectives of the treatment technology demonstration study.

Performance of the arsenic removal technology for use on small systems:

- The A/P Complex 2002 oxidation media effectively converted As(III) to As(V) throughout the six-month period, typically lowering the As(III) concentrations from an average value of 29.4 to < 1 µg/L. The oxidation columns also showed some capacity for arsenic removal with an estimated arsenic loading of 0.14 µg of arsenic/mg of media.
- Breakthrough of arsenic at 10 µg/L through the lead columns of A/I Complex 2000 adsorptive media occurred at 6,000 BVs from Train A and just under 5,000 BVs from Train B. Arsenic reached complete breakthrough after the lead columns at approximately 10,000 BVs and 9,000 BVs, respectively. The adsorptive capacity was estimated to be 0.2 µg of As/mg of media.
- Because of the unexpected short media life, the media was not changed out until breakthrough from the entire three columns. Considering the three columns (in series) as one large vessel, the treatment trains had a BV capacity to 10 µg/L arsenic breakthrough of 5,300 BVs (Train A) and 5,200 BVs (Train B). Thus, the performance of the total system was similar to the performance for the first lead column of each treatment train.
- It is presumed that high pH values of source water (ranging from 8.0 to 8.7) might have contributed to early arsenic breakthrough from the adsorption columns, even though they were within the effective range (i.e., < 9.0) indicated by the vendor.
- The presence of competing anions also might have contributed to the early arsenic breakthrough. The media was shown to have high capacity for silica, which continued to be removed even after the arsenic removal capacity was completely exhausted.
- Aluminum concentrations (existing primarily in the soluble form) following the oxidation columns were about 20 to 30 µg/L higher than those in raw water, indicating leaching of aluminum from the oxidizing media. The concentrations detected were below its secondary drinking water standard.

Simplicity of required system O&M and operator skill levels:

- The daily demand on the operator was typically 15 min to visually inspect the system and record operational parameters. Due to the small size of the system, operational parameters were recorded only three days per week.
- Operation of the As/1400CS did not require additional skills beyond those necessary to operate the existing water supply equipment.

Process residuals produced by the technology:

- Because the system did not require backwash to operate, no backwash residuals were produced.
- The only residuals produced by the operation of the As/1400CS treatment system is spent media. The media was not replaced during the first six months of operation; therefore, no residual waste was produced during this period.

Technology Cost:

- Using the system's rated capacity of 14 gpm (or 20,160 gal/day [gpd]), the capital cost was \$1,177/gpm (or \$0.82/gpd) of design flowrate.
- Although media replacement and disposal did not take place during the first six months of operation, the cost to change-out two, four, or six oxidizing and/or adsorption columns was estimated to be \$2,465, \$4,015, and \$5,565, respectively.

3.0 MATERIALS AND METHODS

3.1 General Project Approach

Following the pre-demonstration activities summarized in Table 3-1, the performance evaluation study of the ATS treatment system began on March 7, 2005. Table 3-2 summarizes the types of data collected and/or considered as part of the technology evaluation process. The overall performance of the system was determined based on its ability to consistently remove arsenic to the target MCL of 10 µg/L; this was monitored through the collection of biweekly and monthly water samples across the treatment train. The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

Table 3-1. Pre-Demonstration Activities and Completion Dates

Activity	Date
Introductory Meeting Held	September 16, 2004
Project Planning Meeting Held	November 17, 2004
Draft Letter of Understanding Issued	December 3, 2004
Final Letter of Understanding Issued	December 20, 2004
Request for Quotation Issued to Vendor	December 22, 2004
Vendor Quotation Received by Battelle	January 25, 2005
Purchase Order Completed and Signed	February 15, 2005
Engineering Package Submitted to MDWP	February 16, 2005
Final Study Plan Issued	February 18, 2005
Permit issued by MDWP	February 18, 2005
Initial System Installation and Shakedown Completed	March 4, 2005
Performance Evaluation Begun	March 7, 2005

MDWP = Maine Drinking Water Program

Table 3-2. Evaluation Objectives and Supporting Data Collection Activities

Evaluation Objectives	Data Collection
Performance	-Ability to consistently meet 10 µg/L of arsenic in effluent
Reliability	-Unscheduled downtime for system -Frequency and extent of repairs to include labor hours, problem description, description of materials, and cost of materials
Simplicity of Operation and Operator Skill	-Pre- and post-treatment requirements -Level of system automation for data collection and system operation -Staffing requirements including number of operators and labor hours -Task analysis of preventive maintenance to include labor hours per month and number and complexity of tasks -Chemical handling and inventory requirements -General knowledge needed of safety requirements and chemical processes
Capital and O&M Costs	-Capital costs including equipment, engineering, and installation -O&M costs including chemical and/or media usage, electricity, and labor
Residual Management	-Quantity of the residuals generated by the process -Characteristics of the aqueous and solid residuals

Required O&M and operator skill levels were evaluated based on a combination of quantitative data and qualitative considerations, including any pre-treatment and/or post-treatment requirements, level of system automation, operator skill requirements, task analysis of the preventive maintenance activities, frequency of chemical and/or media handling and inventory requirements, and general knowledge needed for safety requirements and chemical processes. The staffing requirements on the system operation were recorded on an Operator Labor Hour Log Sheet.

The cost of the system was evaluated based on the capital cost per gpm (or gpd) of design capacity and O&M cost per 1,000 gal of water treated. This required the tracking of the capital cost for equipment, engineering, and installation, as well as the O&M cost for media replacement and disposal, electrical power use, and labor hours. The capital costs for the Round 1 sites has been reported in an EPA report (Chen et al., 2004) posted on an EPA website (<http://www.epa.gov/ORD/NRMRL/arsenic/resource.htm>). Data on O&M costs were limited to electricity and labor hours because media replacement did not take place during the six months of operation.

3.2 System O&M and Cost Data Collection

The plant operator performed daily, biweekly, and monthly system O&M and data collection following the instructions provided by Battelle. The plant operator recorded system operational data, such as pressure, flowrate, totalizer, and hour meter readings on a System Operation Log Sheet and conducted visual inspections to ensure normal system operations on a regular basis. If any problems occurred, the plant operator would contact the Battelle Study Lead, who then would determine if ATS should be contacted for troubleshooting. The plant operator recorded all relevant information on the Repair and Maintenance Log Sheet. The plant operator measured water quality parameters, biweekly, including temperature, pH, dissolved oxygen (DO), and oxidation-reduction potential (ORP), and recorded the data on a Weekly On-Site Water Quality Parameters Log Sheet.

The capital cost for the ATS system consisted of cost for equipment, site engineering, and system installation and startup. The O&M cost consisted of cost for the media replacement and spent media disposal, electricity consumption, and labor. Labor hours for various activities, such as the routine system O&M, system troubleshooting and repair, and demonstration-related work, were tracked using an Operator Labor Hour Log Sheet. The routine O&M included activities such as completing field logs, ordering supplies, performing system inspection, and others as recommended by the equipment vendor. The demonstration-related work included activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead. The demonstration-related activities were recorded but not included in the cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate the system performance, samples were collected from the wellhead, treatment plant, and distribution system. Table 3-3 provides the sampling schedule and analytes measured during each sampling event. Specific sampling requirements for arsenic speciation, analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2004).

3.3.1 Source Water Sample Collection. During the initial visit to the SBMHP site, one set of source water samples was collected for detailed water quality analyses. The source water also was speciated for particulate and soluble As, iron (Fe), manganese (Mn), aluminum (Al), and As(III) and As(V). The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Arsenic speciation kits and containers for water quality samples were prepared as described in Section 3.4.

Table 3-3. Sample Collection Schedule and Analyses

Sample Type	Sample Locations ^(a)	No. of Samples	Frequency	Analytes	Date(s) Samples Collected
Source Water	At Wellhead (IN)	1	Once during the initial site visit	As (total, particulate, and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), Al (total and soluble), Na, Ca, Mg, V, Sb, Cl, F, NO ₃ , SO ₄ , SiO ₂ , PO ₄ , TOC, alkalinity, and pH	09/16/04
Treatment Plant Water	At Wellhead (IN), After Oxidation Column (OA and OB), After Adsorption Column (TA to TF), and After Entire System (TT)	5-7	Biweekly	On-site: pH, temperature, DO, ORP. Off-site: As (total, particulate, and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), Al (total and soluble), Ca, Mg, F, NO ₃ , S ²⁻ , SO ₄ , SiO ₂ , PO ₄ , turbidity, and/or alkalinity	03/09/05 , 03/22/05, 04/05/05 , 04/19/05, 05/04/05 , 05/17/05, 06/01/05 , 06/15/05, 06/29/05 , 07/13/05, 07/27/05 , 08/09/05, 08/24/05
Distribution Water	Two LCR and One Non-LCR Residences	3	Monthly ^(b)	pH, alkalinity, As, Fe, Mn, Pb, and Cu	Baseline sampling ^(b) : 12/15/04, 01/10/05, 02/02/05, 02/23/05, Monthly sampling: 04/05/05, 05/04/05, 06/15/05, 07/13/05, 08/09/05
Residual Solid	Spent Media from Oxidation and Adsorption Columns	8	Once	TCLP metals	To be determined

(a) Abbreviations in parentheses corresponding to sample locations shown in Figure 4-4

(b) Four baseline sampling events performed before system became operational

Bold font indicates that speciation was performed.

3.3.2 Treatment Plant Water Sample Collection. During the system performance evaluation study, samples were collected by the plant operator every other week at five to seven locations across the treatment train, including at the wellhead [IN], after the oxidation columns [OA and OB], and after the adsorption columns [TA to TF]. Speciation was performed for As, Fe, Mn, and Al during every other sampling event (approximately once per month). On-site measurements for pH, temperature, DO, and ORP also were performed during each sampling event.

3.3.3 Residual Solid Sample Collection. Because the system did not require backwash, no backwash residuals were produced during system operations. Additionally, because media replacement did not take place during the first six months of operation, there were no spent media samples collected.

3.3.4 Distribution System Water Sample Collection. Samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically arsenic, lead, and copper levels. From December 2004 to February 2005, prior to the startup of the treatment system, four sets of baseline distribution water samples were collected from three

locations within the distribution system. Following the startup of the arsenic adsorption system, distribution system sampling continued on a monthly basis at the same three locations.

The three homes selected for the sampling included two LCR residences that were included in the Lead and Copper Rule (LCR) sampling in the past and one non-LCR residence. The samples were collected following an instruction sheet developed according to the *Lead and Copper Rule Reporting Guidance for Public Water Systems* (EPA, 2002). First-draw samples were collected from cold-water faucets that had not been used for at least 6 hrs to ensure that stagnant water was sampled. The sampler recorded the date and time of last water use before sampling and the date and time of sample collection for calculation of the stagnation time. Analytes for the baseline samples coincided with the monthly distribution system water samples as described in Table 3-3. Arsenic speciation was not performed for the distribution water samples.

3.4 Sampling Logistics

All sampling logistics including arsenic speciation kits preparation, sample cooler preparation, and sample shipping and handling are discussed as follows.

3.4.1 Preparation of Arsenic Speciation Kits. The arsenic field speciation method used an anion exchange resin column to separate the soluble arsenic species, As(V) and As(III) (Edwards et al., 1998). Arsenic speciation kits were prepared in batches at Battelle laboratories according to the procedures detailed in Appendix A of the EPA-endorsed QAPP (Battelle, 2004).

3.4.2 Preparation of Sampling Coolers. All sample bottles were new and contained appropriate preservatives. Each sample bottle was taped with a pre-printed, colored-coded, and waterproof label. The sample label consisted of sample identification (ID), date and time of sample collection, sampler initials, sampling location, where the sample was to be sent to, analysis required, and preservative. The sample ID consisted of a two-letter code for a specific water facility, the sampling date, a two-letter code for a specific sampling location, and a one-letter code for the specific analysis to be performed. The sampling locations were color-coded for easy identification. Pre-labeled bottles were placed in one of the plastic bags (each corresponding to a specific sampling location) in a sample cooler. When arsenic speciation samples were to be collected, an appropriate number of arsenic speciation kits also were included in the cooler. When appropriate, the sample cooler was also packed with bottles for the three distribution system sampling locations.

In addition, a packet containing all sampling and shipping-related supplies, such as latex gloves, sampling instructions, chain-of-custody forms, prepaid Federal Express air bills, ice packs, and bubble wrap, also was placed in the cooler. The chain-of-custody forms and prepaid UPS air bills had already been completed with the required information except for the operator's signature. The sample coolers were shipped via UPS to the facility approximately one week prior to the scheduled sampling date.

3.4.3 Sample Shipping and Handling. After sample collection, samples for off-site analyses were packed carefully in the original coolers with wet ice and shipped to Battelle. Upon receipt, sample custodians verified that all samples indicated on the chain-of-custody forms were included and intact. Sample label identifications were checked against the chain-of-custody forms and the samples were logged into the laboratory sample receipt log. Discrepancies, if noted, were addressed by the field sample custodian, and the Battelle Study Lead was notified.

Samples for water quality analyses by Battelle's subcontract laboratories were packed in coolers at Battelle and picked up by a courier from either American Analytical Laboratories (AAL) (Columbus, OH) or TCCI Laboratories (New Lexington, OH). The samples for arsenic speciation analyses were

stored at Battelle's inductively coupled plasma-mass spectrometry (ICP-MS) Laboratory. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time, and disposed of properly thereafter.

3.5 Analytical Procedures

The analytical procedures are described in detail in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2004). Field measurements of pH, temperature, and DO/ORP were conducted by the plant operator using a WTW Multi 340i handheld meter, which was calibrated prior to use following the procedures provided in the user's manual. The plant operator collected a water sample in a 400-mL plastic beaker and placed the Multi 340i probe in the beaker until a stable, measured value was reached.

Laboratory quality assurance/quality control (QA/QC) of all methods followed the guidelines provided in the QAPP (Battelle, 2004). Data quality in terms of precision, accuracy, method detection limit (MDL), and completeness met the criteria established in the QAPP, i.e., relative percent difference (RPD) of 20%, percent recovery of 80-120%, and completeness of 80%. The quality assurance (QA) data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover and to be shared with the other 27 demonstration sites included in the Round 2 arsenic study.

4.0 RESULTS AND DISCUSSION

4.1 Facility Description

The SBMHP water system in Wales, ME, supplies water to 14 mobile homes. The water treatment building, shown in Figure 4-1, is located at 339 Leeds Junction Rd., Wales, ME. The water source is groundwater from a developed spring with a flowrate, based on pump data, of approximately 14 gal/min (gpm). The average daily use rate was estimated to be 3,500 gal/day (gpd) according to the Park owner. The pre-existing water system included only a supply pump (Figure 4-2) and two 120-gal pressure tanks to provide storage and required pressure to the distribution system.



Figure 4-1. Pre-Existing Treatment Building at Spring Brook Mobile Home Park

4.1.1 Source Water Quality. Source water samples were collected on September 16, 2004, and subsequently analyzed for the analytes shown in Table 3-3. The results of the source water analyses, along with those provided by the facility to EPA for the demonstration site selection and those obtained from the Maine Drinking Water Program (MDWP), are presented in Table 4-1.

The MDWP test data showed the total arsenic concentrations of source water to range from 35 to 39 $\mu\text{g/L}$. The September 16, 2004, sampling results of Battelle found the total arsenic concentration in source water to be 37.7 $\mu\text{g/L}$, of which 33.4 $\mu\text{g/L}$ (or about 90%) was As(III).

The pH value measured by the facility was 8.5 and by Battelle 8.6, both of which are higher than the range of 6.5 to 8.0 typically desired for the arsenic adsorptive media. Because the vendor indicated that the A/I Complex 2000 media could effectively remove arsenic as long as the pH values of source water were less than 9.0, pH adjustment was not added.



Figure 4-2. Pre-Existing Water Supply Pump, System Piping, and Hydropneumatic Tanks (shown in the background)

The concentrations of iron ($<25 \mu\text{g/L}$) and other ions in raw water were sufficiently low, therefore, pre-treatment prior to the adsorption process was not required. The concentrations of orthophosphate, silica, and fluoride also were sufficiently low (i.e., <0.06 , 10.7 , and 0.4 mg/L , respectively) and, therefore, were not expected to affect the arsenic adsorption on the A/I Complex 2000 media.

4.1.2 Distribution System. The distribution system consists of a looped distribution line constructed primarily of polyvinyl chloride (PVC) pipe. The connections to the distribution system and piping within the residences themselves also are believed to be PVC.

Compliance samples from the distribution system are collected quarterly for bacterial analysis and every three years for herbicides, pesticides, volatile organic compounds (VOCs), and inorganics. LCR samples are collected from customer taps at five residences every three years. Tests for gross alpha are conducted every four years.

4.2 Treatment Process Description

The ATS As/1400CS adsorption system uses A/P Complex 2002 oxidizing media to oxidize As(III) and A/I Complex 2000 adsorptive media to adsorb As(V). The A/P Complex 2002 media consists of activated alumina and sodium metaperiodate and A/I Complex 2000 media consists of activated alumina and a proprietary iron complex. Tables 4-2a and 4-2b present physical and chemical properties of the adsorptive and oxidizing media. Both media have NSF International (NSF) Standard 61 listing for use in drinking water.

The ATS As/1400CS system is a fixed-bed downflow adsorption system designed for use at small water systems with flowrates of around 14 gpm . When the media reaches its capacity, the spent media may be removed and disposed of after being subjected to the EPA Toxicity Characteristic Leaching Procedure (TCLP) test.

Table 4-1. Source Water Quality Data

Parameter	Units	Facility Data ^(a)	Battelle Data	MDWP Data
<i>Sampling Date</i>		NA	09/16/04	04/29/99-04/13/04
pH	S.U.	8.5	8.6	N/A
Total Alkalinity (as CaCO ₃)	mg/L	64	65	N/A
Hardness (as CaCO ₃)	mg/L	50	53	N/A
Turbidity	NTU	N/A	0.1	N/A
TDS	mg/L	N/A	110	N/A
TOC	mg/L	<0.1	<0.7	N/A
Nitrate (as N)	mg/L	N/A	<0.04	ND
Nitrite (as N)	mg/L	N/A	<0.01	N/A
Ammonia (as N)	mg/L	N/A	<0.05	N/A
Chloride	mg/L	7.5	7.6	7-8
Fluoride	mg/L	N/A	0.4	N/A
Sulfate	mg/L	19.5	18.0	20-21
Silica (as SiO ₂)	mg/L	9.8	10.7	N/A
Orthophosphate (as PO ₄)	mg/L	0.044	<0.06	N/A
As (total)	µg/L	N/A	37.7	35-39
As (total soluble)	µg/L	38.0	38.0	N/A
As (particulate)	µg/L	N/A	<0.1	N/A
As(III)	µg/L	35.0	33.4	N/A
As(V)	µg/L	3.0	4.6	N/A
Fe (total)	µg/L	ND	<25	ND
Fe (soluble)	µg/L	N/A	<25	N/A
Mn (total)	µg/L	11.0	10.3	9-12
Mn (soluble)	µg/L	N/A	9.6	N/A
Al (total)	µg/L	N/A	13.5	N/A
Al (soluble)	µg/L	N/A	<10	N/A
U (total)	µg/L	N/A	0.9	N/A
U (soluble)	µg/L	N/A	0.9	N/A
V (total)	µg/L	N/A	0.4	N/A
V (soluble)	µg/L	N/A	0.1	N/A
Sb (total)	µg/L	N/A	0.8	ND
Sb (soluble)	µg/L	N/A	0.4	N/A
Pb (total)	µg/L	N/A	N/A	ND
Cu (total)	µg/L	N/A	N/A	0.5
Na (total)	mg/L	20.0	21.0	19.9-20.2
Ca (total)	mg/L	17.0	18.0	17.3-17.4
Mg (total)	mg/L	1.9	2.0	1.8-1.9

(a) Provided by facility to EPA for demonstration site selection.

N/A= not analyzed

ND= below detection limit

The system at SBMHP has two parallel treatment trains, each operating in series. The system design is based on change-out of the lead column in each treatment train upon exhaustion and each of the lag columns to be moved forward one position (i.e., the first lag column becomes the lead column, and the second lag column becomes the first lag column). A new column loaded with virgin media is then placed at the end of each treatment train. This configuration maximizes the usage of the media capacity before its replacement. Figure 4-3 presents a schematic diagram of the ATS As/1400CS adsorption system with the major system components discussed as follows:

Table 4-2a. Physical and Chemical Properties of A/I Complex 2000 Adsorption Media

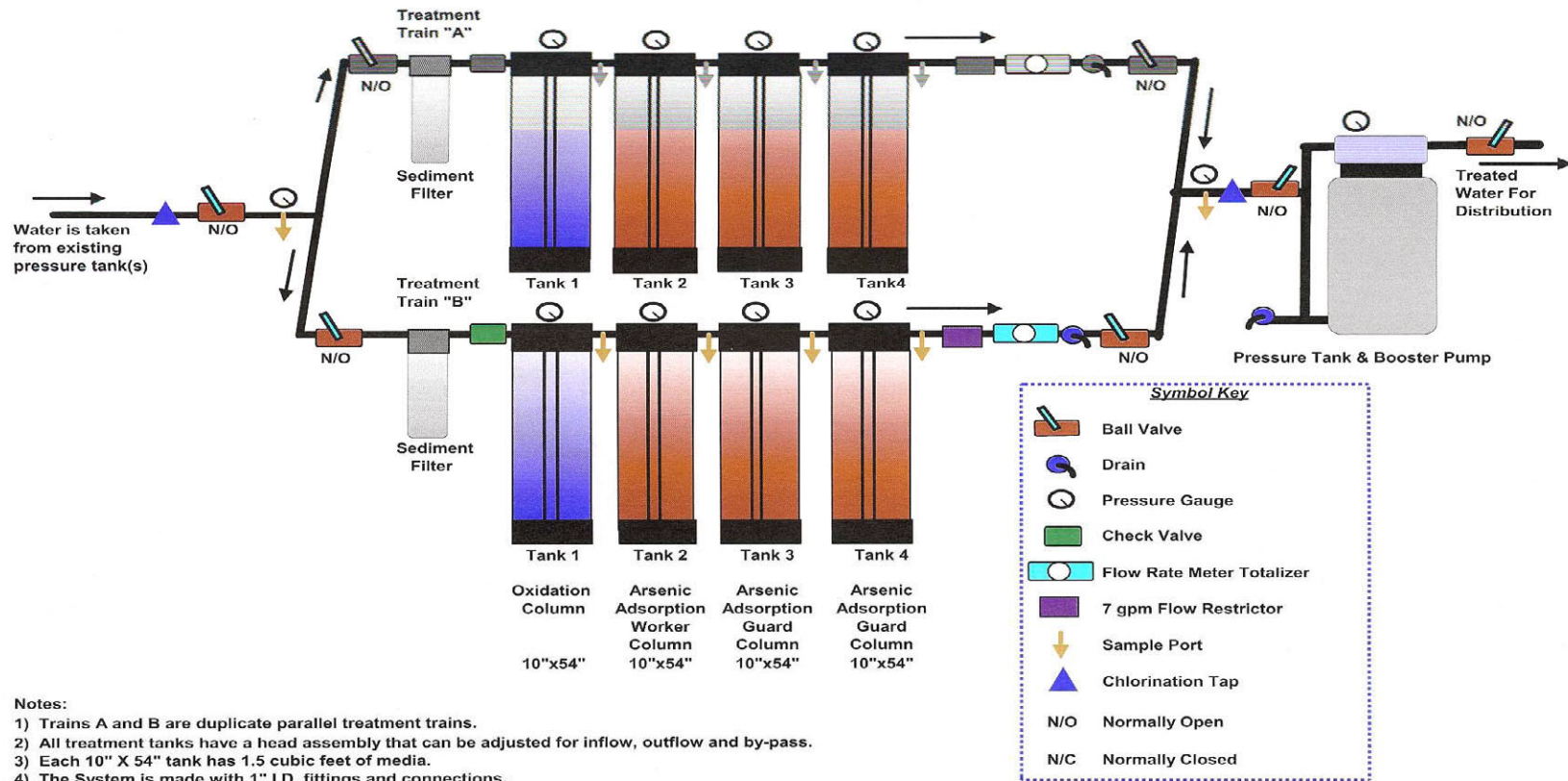
<i>Physical Properties</i>	
Parameter	Value
Matrix	Activated alumina/iron complex
Physical Form	Granular solid
Color	Light brown/orange
Bulk Density (lb/ft ³)	55
Specific Gravity (dry)	1.5
Hardness (kg/in ²)	14-16
Effective Size (mm)	0.42
BET Surface Area (m ² /g)	220
Attrition (%)	< 0.1
Moisture Content (%)	< 5
Particle Size Distribution (Tyler mesh)	28×48 (< 2% fines)
<i>Chemical Analysis</i>	
Constituents	Weight (Dry)
Al ₂ O ₃ (%)	90.89
NaIO ₄ (%)	3.21
Fe(NH ₄) ₂ (SO ₄) ₂ · 6H ₂ O (%)	5.90

Table 4-2b. Physical and Chemical Properties of A/P Complex 2002 Oxidation Media

<i>Physical Properties</i>	
Parameter	Value
Matrix	Activated alumina/metaperiodate complex
Physical Form	Granular solid
Color	White
Bulk Density (lb/ft ³)	52
Specific Gravity (dry)	1.5
Hardness (lb/in ²)	14-16
Effective Size (mm)	0.42
BET Surface Area (m ² /g)	220
Attrition (%)	< 0.1
Moisture Content (%)	< 5
Particle Size Distribution (Tyler mesh)	28×48 (< 2% fines)
<i>Chemical Analysis</i>	
Constituents	Weight (Dry)
Al ₂ O ₃ (%)	96.59
NaIO ₄ (%)	3.41

Source: ATS

As/1400CS Duplex Arsenic Removal System
for
Springbrook Mobile Home Park, Wales Maine



Notes:

- 1) Trains A and B are duplicate parallel treatment trains.
- 2) All treatment tanks have a head assembly that can be adjusted for inflow, outflow and by-pass.
- 3) Each 10" X 54" tank has 1.5 cubic feet of media.
- 4) The System is made with 1" I.D. fittings and connections.

© ATS 2004
122804

design by TJB/ATS
Schematic is NOT IS SCALE
As1400cs_wales.wk4

Figure 4-3. Schematic of As/1400CS Adsorption System (Provided by ATS)

- **Two pre-existing 120-gal pressure tanks** with a total storage capacity of approximately 240 gal. Located at the system inlet, the pressure tanks served as a temporary storage for well water. The well pump was turned on and off based on the low and high pressure settings of 40 and 60, respectively, with the pressure tanks.
- **Two 25- μ m sediment filters.** One filter was installed at the head of each treatment train to remove sediment and avoid introducing large particles directly into the treatment columns.
- **Eight 10-in-diameter, 54-in-high sealed polyglass columns (by Park International).** Each treatment train had four media columns with the first loaded with 1.5 ft³ of the oxidizing media and the remaining three with 1.5 ft³ (per column) of the adsorptive media. Each column was equipped with a riser tube and a valved head assembly to control inflow, outflow, and bypass.
- **One totalizer/flow meter (Model F-1000 by Blue-White Industries).** One each totalizer/flow meter was installed on the downstream end of the treatment train to record the flowrate and volume of water treated through the train.
- **One 120-gal Well-Rite pressure tank (by Flexcon Industries in Randolph, MA) fitted with a ½-hp Goulds booster pump (Model No. C48A94A06).** Located at the system outlet, the booster pump/pressure tank assembly was used to 1) “pull” water from the two pressure tanks at the system inlet through the one oxidation and three adsorption columns in each treatment train, 2) provide temporary storage of the treated water, and 3) supply the treated water with the needed pressure to the distribution system. Upon the demand in the distribution system, the pressure tank was gradually emptied and the corresponding pressure in the tank was gradually reduced. The booster pump was triggered when the pressure in the pressure tank had reduced to 40 psi. After refilling the tank with the treated water, the booster pump was turned off as the pressure in the tank had reached the high pressure setting of 60 psi.
- **Pressure gauges** located at the system inlet just prior to the tee to the two treatment trains, at the head of each column, after the two treatment trains combined, and at the pressure tank at the system outlet. The pressure gauges were used to monitor the system pressure and pressure drop across the treatment train.
- **Sampling taps.** Sample collection ports (US Plastics) made of PVC were located prior to the system and following each oxidation and adsorption tank.

The system was constructed using 1-in copper piping and fittings. The design features of the treatment system are summarized in Table 4-3, and a flow diagram along with the sampling/analysis schedule are presented in Figure 4-4. A photograph of the system installed at the SBMHP site is shown in Figure 4-5 and a close-up view of one of the oxidizing media columns is shown in Figure 4-6.

4.3 Permitting and System Installation

Engineering plans for the system were prepared by ATS and submitted to MDWP for approval on February 16, 2005. The plans included a schematic of the As/1400CS system along with a written description of the system. The approval was granted by MDWP on February 18, 2005.

Table 4-3. Design Specifications of As/1400CS System

Parameter	Value	Remarks
<i>Oxidation Columns</i>		
Column Size (in)	10 D × 54 H	–
Cross-Sectional Area (ft ² /column)	0.54	–
Number of Columns	2	1 column per train, 2 trains in parallel
Media Type	A/P Complex 2002	–
Media Quantity (lbs)	78	Per column
Media Volume (ft ³)	1.5	Per column
<i>Adsorption Columns</i>		
Column Size (in)	10 D × 54 H	–
Cross-Sectional Area (ft ² /column)	0.54	–
Number of Columns	6	3 columns per train, 2 trains in parallel
Configuration	Series	3 columns in series per train
Media Type	A/I Complex 2000	–
Media Quantity (lbs)	83	Per column
Media Volume (ft ³)	1.5	Per column
<i>Service</i>		
System Flowrate (gpm)	14	7 gpm per train, 2 trains in parallel
Hydraulic Loading Rate (gpm/ft ²)	13	–
EBCT (min/oxidation column)	1.6	Per column
EBCT (min/adsorption column)	1.6	4.8-min total EBCT for 3 adsorption columns in each train
Average Use Rate (gpd)	3,500	Based on usage estimate provided by park owner
Estimated Working Capacity (BV)	32,754	Bed volumes to breakthrough at 10 µg/L from lead column based on throughput of 1,750 gpd per train
Throughput To Breakthrough (gal)	367,500	Vendor-provided estimate to breakthrough at 10 µg/L from lead column based on 1.5 ft ³ (11.2 gal) of media in lead column
Estimated Media Life (months)	7	Estimated frequency of media change-out in lead column based on throughput of 1,750 gpd per train

The system was installed in the pre-existing treatment building, shown in Figure 4-1, without any addition. Because the system required only 20 ft² of floor space, the park owner made several improvements to the interior of the building, including adding a concrete floor and extending the wall of the treatment room inside the building to allow floorspace for installation and access to the system.

The As/1400CS system, consisting of the factory-packed oxidation and adsorption columns and preassembled valves, gauges, and sample taps, was delivered to the site on March 2, 2005. ATS began the system installation that same day with activities such as re-working and updating some of the entry and exit piping, attaching the sediment filters on the wall, and placing and plumbing together the media columns using copper piping and connections. The mechanical installation was completed on March 3, 2005. Before the system was put online, the system piping was flushed and the columns were filled with water one at a time to check for leaks. Once all columns were filled, the system was operated for a short period with the treated water being discharged to the sump. After it was determined that the system had been operating properly, the treated water was directed to the distribution. The flowmeter/totalizer on each train was reset at this time. The performance evaluation officially began on March 7, 2005.

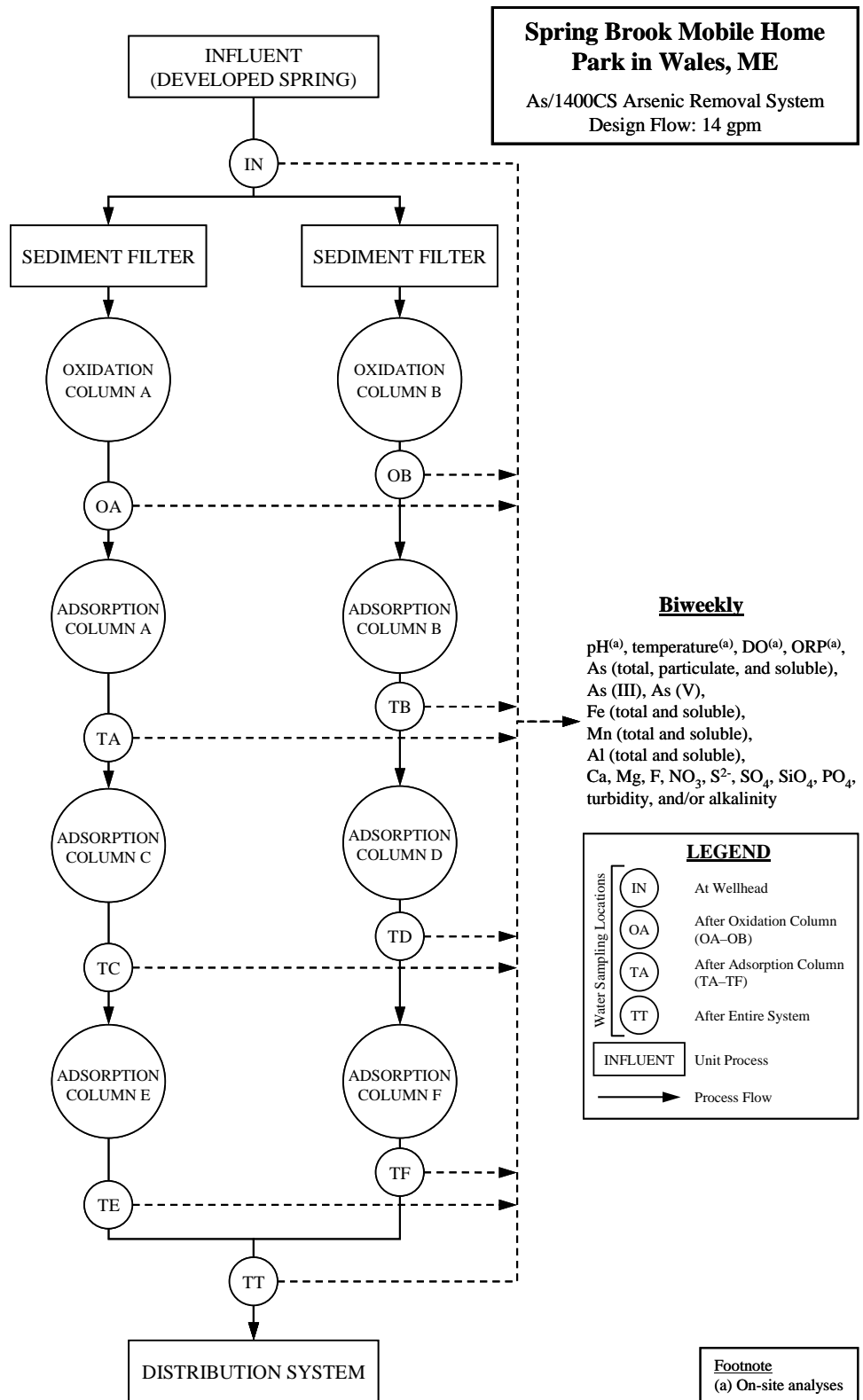


Figure 4-4. Process Flow Diagram and Sampling Locations



Figure 4-5. As/1400CS Arsenic Adsorption System with Adsorption and Oxidization Columns Shown in Foreground, 25- μ m Sediment Filters Attached to Wall, and Hydropneumatic Tanks in Background



Figure 4-6. Close-Up View of a Sample Tap (OA), a Pressure Gauge, and Copper Piping at Head of a Column

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters of the system are tabulated and attached as Appendix A. Key parameters are summarized in Table 4-4. From March 7, 2005, through September 9, 2005, the treatment system operated for 638 hrs based on the hour meter readings of the booster pump. The operational time represented a utilization rate of approximately 14% over the 27-week study period with the booster pump operating an average of 3.4 hr/day. The total system throughput from March 7, through September 9, 2005 was approximately 480,000 gal (or 240,000 per train). This corresponds to 21,400 bed volumes (BVs) of water processed through each train (1 BV = 1.5 ft³ [or 11.2 gal]). Considering the three adsorption columns of each treatment train as one vessel (i.e., 1 BV = 4.5 ft³ [or 33.6 gal]), the volume of water treated by each train would be equivalent to 7,143 BVs. The average flowrates through Trains A and B were 5.1 and 5.2 gpm, respectively (compared to the design flowrate of 7 gal per train), with an average empty bed contact time (EBCT) of 2.2 min per column or approximately 6.6 min per train (compared to the design EBCT of 1.6 min per column or 4.8 min per train). Based on the average flowrate and average daily operating time, the average daily use rate was about 2,120 gpd, which was about 60% of the average water usage estimated by the Park owner.

Table 4-4. Summary of As/1400CS System Operation

Parameter	Value
Total Operating Time (hrs) – From March 7, 2005 to September 9, 2005	638
Average Daily Operating Time (hr/day)	3.4
Throughput (gal for both trains)	480,000
Throughput (BV per tank in one train) ^(a)	21,400 ^(b)
Throughput (BV per train) ^(c)	7,143
Range of Flowrate (gpm per train)	4.3 – 5.8
Average Flowrate (gpm per train)	5.2
Average Daily Use Rate (gpd)	2,120
Average EBCT (min) ^(a)	2.2
Average Pressure Loss across Each Column (psi)	5

(a) Calculated based on 1.5 ft³ (or 11.2 gal) of media in lead column.

(b) Arsenic breakthrough at 10 µg/L from lead columns at 5,000–6,000 BVs, from the first set of lag columns at 11,000 BVs, and from the second set of lag columns at 15,000 BVs. Columns not replaced/rebedded during this study period.

(c) Calculated based on 4.5 ft³ (or 33.6 gal) of media in each train.

The pressure loss across each column ranged from 2 to 9 psi and averaged 5 psi. The total pressure loss across each treatment train (4 columns in series) averaged 19 psi. The average influent pressure at the head of the system from the existing pressure tanks was 45 psi, and the average pressure following the last column in each treatment train was 26 psi. The booster pump and pressure tank installed after the system provided pressure to feed the distribution system, and the average pressure after this tank was 44 psi, which was set to match the pressure from the existing pressure tanks.

4.4.2 Residual Management. The only residuals produced by the operation of the As/1400CS treatment system would be spent media. The media was not replaced during the first six months of operation; therefore, no residual waste was produced during this period. Because the system did not require backwash to operate, no backwash residuals were produced.

4.4.3 System Operation, Reliability, and Simplicity. The only operational difficulty was encountered soon after the system start-up. The booster pump downstream of the treatment system did not cycle on and off as expected. In turn, the supply pressure from the downstream pressure tank was not sufficient to maintain adequate pressure to the distribution system. After troubleshooting, it was determined that a valve near the booster pump was inadvertently left open during the initial system installation. Once the valve was closed, the downstream booster pump began to work as designed and the pressure to the distribution system was maintained. Since then, the system had been operating uninterrupted throughout this study. Additional discussion regarding system operation and operator skill requirements are provided below.

Pre- and Post-Treatment Requirements. The only pre-treatment step was the oxidation of As(III) to As(V) via the oxidation media installed in the first column of each treatment train. No additional chemical addition or other pre- or post-treatment steps were used at the site.

System Controls. The As/1400CS adsorption system was a passive system, requiring only the operation of the supply well pump and booster pump to send water through the oxidation and adsorption columns and the distribution system. The media columns themselves required no automated parts and all valves were manually activated. The inline flowmeters were battery powered so that the only electrical power required was that needed to run the supply well pump and booster pump. The system operation was controlled by the pressure switch in the booster tank.

The level of operator certification is determined by the type and class of the public drinking water systems. MDWP's drinking water rules require all community and non-transient non-community public drinking water and distribution systems to be classified based on potential health risks. Classifications range from "very small water systems (VSWS)" (lowest) to "Class IV" (highest) for treatment systems and from "VSWS" to "Class IV" for distribution systems, depending on factors such as the system's complexity, size, and source water. SBMHP is classified as a "VSWS" distribution system and the plant operator has a matching "VSWS" license.

Operator Skill Requirements. Under normal operating conditions, the skill requirements to operate the As/1400CS system were minimal. The operation of the treatment system did not require additional skills beyond those necessary to operate the existing water supply system in place at the site.

Preventative Maintenance Activities. The only regularly scheduled preventative maintenance activity recommended by ATS was to inspect the sediment filters monthly and replace as necessary. The park owner/operator visited the site about 2 to 3 times per week to check the system for leaks, and record flow, volume, and pressure readings.

4.5 System Performance

The system performance was evaluated based on analyses of samples collected from the raw and treated water from the treatment and distribution systems.

4.5.1 Treatment Plant Sampling. Table 4-5 summarizes the arsenic, iron, manganese, and aluminum results from samples collected throughout the treatment plant. Table 4-6 summarizes the results of other water quality parameters. Appendix B contains a complete set of analytical results through the first six months of system operation. The results of the treatment plant sampling are discussed below.

Table 4-5. Summary of Arsenic, Iron, Manganese, and Aluminum Analytical Results

Parameter	Sampling Location	Number of Samples	Concentration (µg/L)			Standard Deviation
			Minimum	Maximum	Average	
As (total)	IN	14 ^(a)	34.9	50.2	39.0	4.1
	OA-OB	14 ^(a)	(b)			
	TA-TF	2-9				
	TT	7				
As (particulate)	IN	7	<0.1	1.50	0.30	0.5
	OA-OB	7	(b)			
	TA-TF	1-4				
As (III)	IN	7	21.9	38.0	29.4	6.7
	OA-OB	7	(b)			
	TA-TF	1-4				
As (V)	IN	7	0.2	15.1	9.5	6.7
	OA-OB	7	(b)			
	TA-TF	1-4				
Fe (total)	IN	14 ^(a)	<25	<25	<25	0.0
	OA-OB	14 ^(a)	<25	<25	<25	0.0
	TA-TF	2-9	<25	87.1	17.0	17.5
	TT	7	<25	42.2	16.7	11.2
Fe (soluble)	IN	7	<25	<25	<25	0.0
	OA-OB	7	<25	<25	<25	0.0
	TA-TF	1-4	<25	<25	<25	0.0
Mn (total)	IN	14 ^(a)	7.3	21.9	11.0	3.9
	OA-OB	14 ^(a)	<0.1	9.5	0.6	1.8
	TA-TF	2-9	<0.1	10.1	0.8	2.4
	TT	7	<0.1	0.5	0.2	0.2
Mn (soluble)	IN	7	7.2	15.2	10.2	2.8
	OA-OB	7	<0.1	0.4	0.1	0.1
	TA-TF	1-4	<0.1	0.5	0.1	0.1
Al (total)	IN	14 ^(a)	<10	21.4	12.7	5.5
	OA-OB	14 ^(a)	21.0	50.9	33.3	6.2
	TA-TF	2-9	11.4	42.6	29.8	9.2
	TT	7	<10	55.7	30.3	18.3
Soluble Al	IN	7	<10	<10	<10	0.0
	OA-OB	7	18.0	35.6	27.7	5.9
	TA-TF	1-4	<10	41.1	25.5	11.8

(a) Including two duplicate samples.

(b) Statistics not provided; see Figures 4-9 and 4-10 for As breakthrough curves.

Note 1: One-half of the detection limit used for samples with concentrations less than the detection limit for calculations. Duplicate samples included in the calculations.

Note 2: Two outlying total aluminum values, 138 µg/L at location TC and 132 µg/L at location TD, measured on June 29, 2005, excluded from this summary table.

Arsenic. The key parameter for evaluating the effectiveness of the As/1400CS adsorption system was the concentration of arsenic in the treated water. The treatment plant water was sampled on 14 occasions during the first six months of system operation (including one event with duplicate samples taken), with field speciation performed on 7 of the 14 occasions.

Table 4-6. Summary of Water Quality Parameter Measurements

Parameter	Sampling Location	Unit	Number of Samples	Concentration/Unit			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as CaCO ₃)	IN	mg/L	8	66	74	69	3.0
	OA-OB	mg/L	8	58	74	68	3.8
	TA-TF	mg/L	2-7	59	72	67	1.8
Fluoride	IN	mg/L	8	0.5	0.6	0.50	0.05
	OA-OB	mg/L	8	0.4	0.8	0.54	0.10
	TA-TF	mg/L	2-7	<0.1	0.7	0.50	0.18
Sulfate	IN	mg/L	8	18	39	22	7.0
	OA-OB	mg/L	8	18	38	22	6.3
	TA-TF	mg/L	2-7	16	40	22	6.9
Orthophosphate (as PO ₄)	IN	mg/L	8	<0.05	<0.05	<0.05	0.0
	OA-OB	mg/L	8	<0.05	<0.05	<0.05	0.0
	TA-TF	mg/L	2-7	<0.05	<0.05	<0.05	0.0
Silica (as SiO ₂)	IN	mg/L	8	9.8	11.5	10.8	0.5
	OA-OB	mg/L	8	(b)			
	TA-TF	mg/L	6				
Nitrate (as N)	IN	mg/L	8	<0.05	0.4	0.10	0.13
	OA-OB	mg/L	8	<0.05	0.3	0.10	0.09
	TA-TF	mg/L	2-7	<0.05	0.2	0.14	0.26
Turbidity	IN	NTU	8	0.1	0.5	0.3	0.2
	OA-OB	NTU	8	<0.1	0.2	0.1	0.1
	TA-TF	NTU	2-7	<0.1	0.4	0.2	0.1
pH	IN	S.U.	13	8.0 ^(c)	8.7	8.3	0.4
	OA-OB	S.U.	13	7.5	8.7	8.3	0.3
	TA-TF	S.U.	3-8	7.6	8.6	8.2	0.3
Temperature	IN	°C	13	7.5	14.1	11.3	2.1
	OA-OB	°C	13	7.6	14.7	11.0	2.0
	TA-TF	°C	3-8	7.8	14.6	11.6	2.2
Dissolved Oxygen	IN	mg/L	13	0.9	4.7	2.5	1.2
	OA-OB	mg/L	13	0.7	4.3	2.0	1.1
	TA-TF	mg/L	3-8	0.7	5.0	1.9	1.1
ORP	IN	mV	13	126	209	180	21.9
	OA-OB	mV	13	129	229	184	20.7
	TA-TF	mV	3-8	130	210	181	17.4
Total Hardness (as CaCO ₃)	IN	mg/L	14	37.9	58.1	48.7	5.8
	OA-OB	mg/L	14	37.2	64.0	47.7	6.2
	TA-TF	mg/L	2-9	36.7	87.0	48.2	10.9
Ca Hardness (as CaCO ₃)	IN	mg/L	14	31.4	49.8	41.4	5.4
	OA-OB	mg/L	14	30.7	55.0	40.5	5.7
	TA-TF	mg/L	2-9	30.6	71.9	40.9	9.3
Mg Hardness (as CaCO ₃)	IN	mg/L	14	6.4	8.4	7.3	0.6
	OA-OB	mg/L	14	5.7	9.0	7.3	0.8
	TA-TF	mg/L	2-9	5.7	13.0	7.2	1.6

(a) Including two duplicate samples.

(b) See Figures 4-13 and 4-14 for plots of silica concentrations.

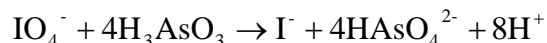
(c) Not including one outlier at pH 7.3.

Note: One-half of detection limit used for samples with concentrations less than detection limit for calculations. Duplicate samples included in calculations.

Figures 4-7 and 4-8 contain four bar charts each showing the concentrations of total As, particulate As, As(III), and As(V) across Treatment Trains A and B, respectively. (Note that the data for sampling locations TE and TT, as well as TF and TT, were plotted together since these locations represent treated water following the final adsorption column in each train.)

Total As concentrations in raw water ranged from 34.9 to 50.2 µg/L and averaged 39.0 µg/L (Table 4-5). As(III) was the predominating species, ranging from 21.9 to 38.0 µg/L and averaging 29.4 µg/L. As(V) also was present in source water, ranging from 0.2 to 15.1 µg/L and averaging 9.5 µg/L. Particulate As was low with concentrations typically less than 1 µg/L. The arsenic concentrations measured during this six-month period were consistent with those in raw water sampled on September 16, 2004 (Table 4-1).

The oxidation of As(III) to As(V) within the oxidation columns was achieved through reaction with the A/P Complex 2002 oxidizing media (Table 4-2b). The key ingredient in the oxidizing media is metaperiodate, which at pH values between 8.0 to 8.7 reacts with H₃AsO₃ to form HAsO₄²⁻, presumably, according to the following reaction:

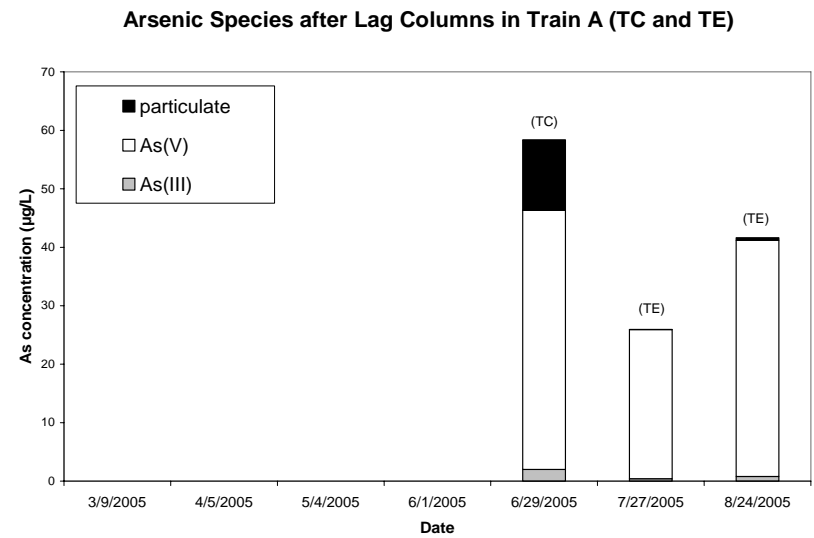
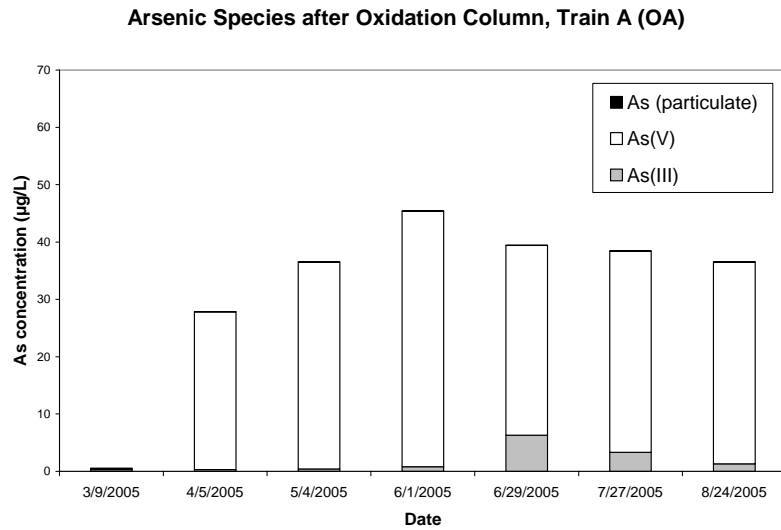
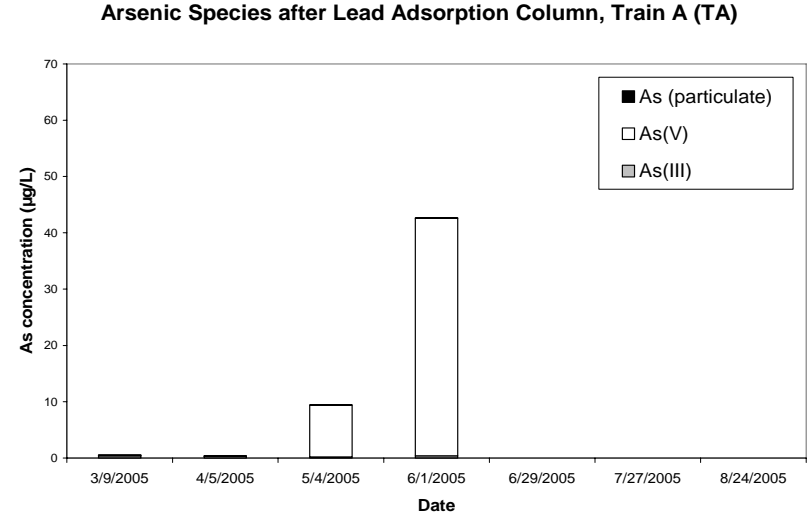
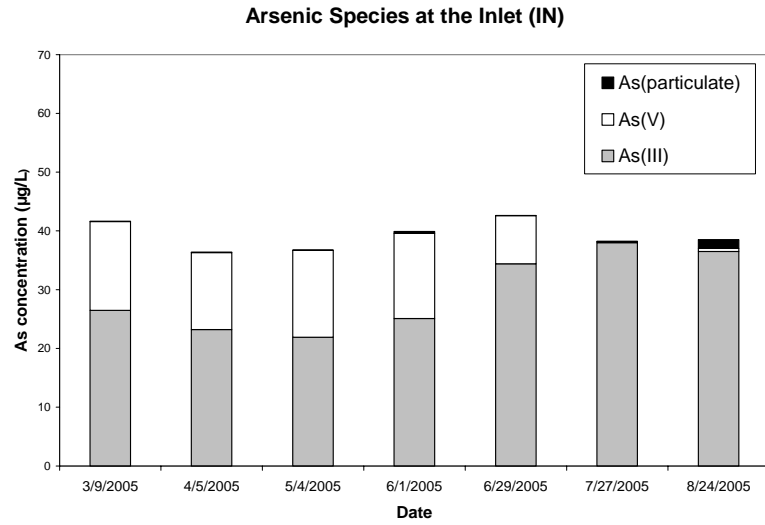


Iodide (I) analysis in the treated water was not conducted during the first six months of the demonstration. (Note: Subsequent samples collected during the continuation of the study showed that the iodide concentration in the treated water following the oxidizing and adsorption columns did increase, going from <10 µg/L in source water to as high as 124 µg/L in the treated water.)

As shown in Figures 4-7 and 4-8, the oxidation columns were effective at converting As(III) to As(V), typically lowering the As(III) concentrations to < 1 µg/L. As(III) concentrations were higher following the oxidation columns on June 29 and July 27, 2005, ranging from 3.3 to 6.3 µg/L. The cause of this bounce in As(III) concentration is not known.

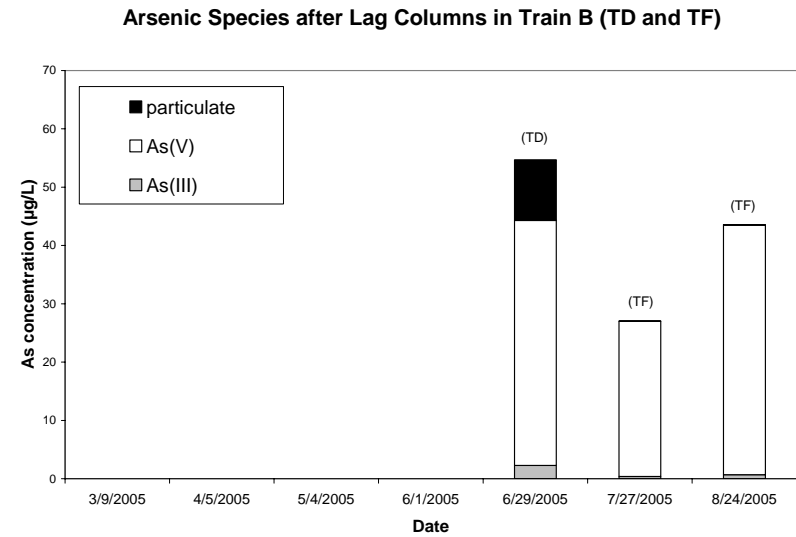
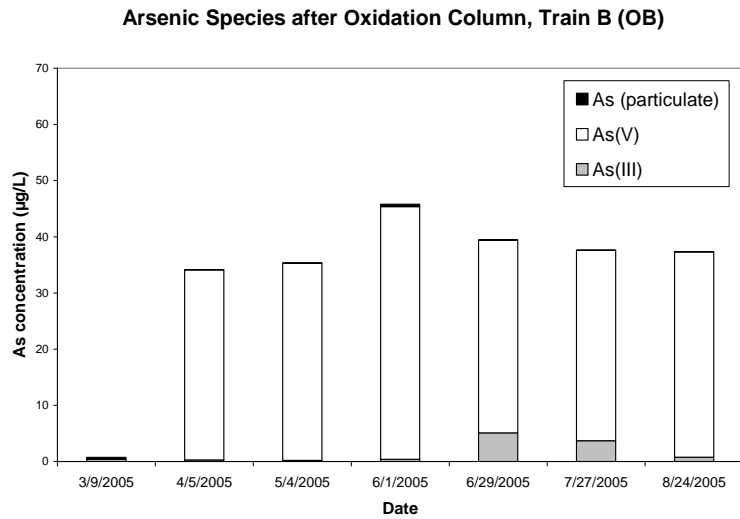
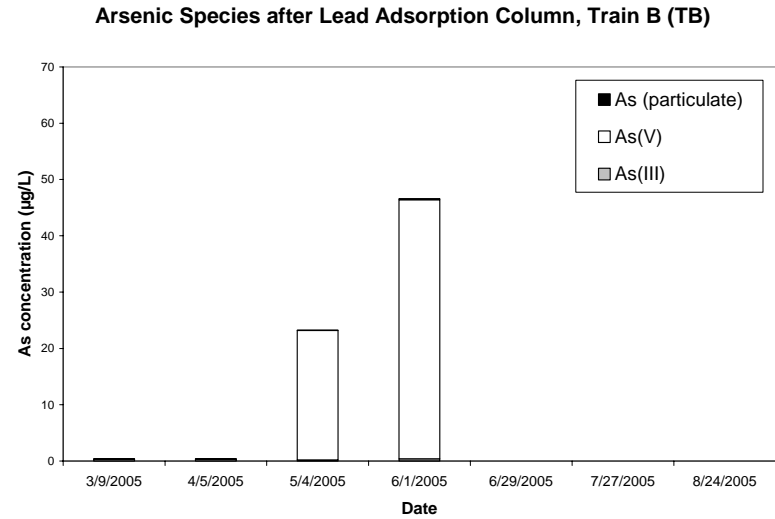
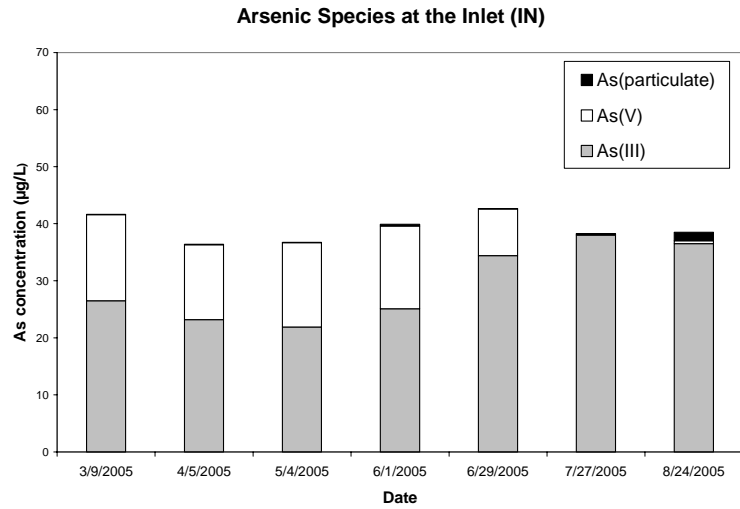
The ATS system test results for arsenic removal are shown in Figures 4-9 (Train A, OA-TE) and 4-10 (Train B, OB-TF) with total arsenic concentrations plotted against the bed volumes of water treated. (Note: BVs were calculated based on 1.5 ft³ or 11.2 gal of media in the lead column in each train). The results showed that the oxidizing media had some capacity for arsenic removal. For the first sampling event taking place 2 days after the system startup, total arsenic concentrations in the effluent of both of the oxidation columns were ≤0.5 µg/L. Total arsenic concentrations slowly increased thereafter to where, at 5,000 BVs, arsenic had completely broken through the oxidation columns and the arsenic concentrations were close to those in raw water. Based on the breakthrough curve data, the arsenic loading on the oxidation media was calculated to be 0.14 µg of As/mg of media.

During the first 4000 to 5,000 BVs of throughput, the total arsenic levels of the influent water to the first adsorption columns of each train steadily rose from around 0.5 µg/L to near 40 µg/L (i.e., the level in raw water). During this same period of time, the arsenic levels of the effluent from the first adsorptive media columns were near 1 µg/L. At 5,000 BVs for Train A and about 4000 BVs for Train B, the arsenic levels from the two columns began to increase. The effluent arsenic levels from these columns reached 10 µg/L at 7,000 BVs for Train A (TA) and 6,000 BVs Train B (TB). Assuming that the arsenic level to the two lead columns during the first 1,000 BVs was essentially less than the method detection limit, the actual number of BVs treated by these lead columns to 10 µg/L breakthrough was 6,000 BVs for Train A and 5,000 BVs for Train B. Figures 4-9 and 4-10 also show total breakthrough of these lead columns, where effluent and influent arsenic levels are the same, occurred at approximately 10,000 BVs for Train A and 9,000 BVs for Train B.



Note: No samples collected at location TA on 06/29/05, 07/27/05, or 08/24/05; TC sample collected only on 06/29/05; TE samples collected only on 07/27/05 and 08/24/05

Figure 4-7. Concentrations of Various Arsenic Species Across Treatment Train A



Note: No samples collected at location TB on 06/29/05, 07/27/05, or 08/24/05; TD sample collected only on 06/29/05; TF samples collected only on 07/27/05 and 08/24/05

Figure 4-8. Concentrations of Various Arsenic Species Across Treatment Train B

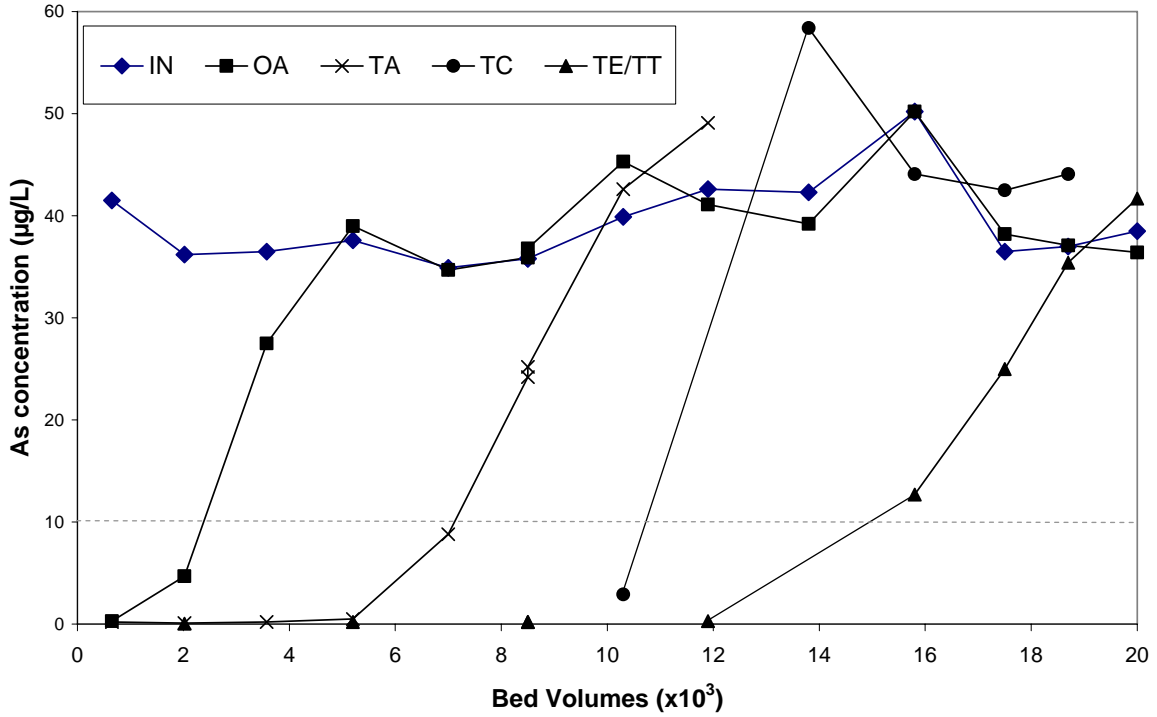


Figure 4-9. Total Arsenic Breakthrough Curves for Treatment Train A (BVs Based on 1.5 ft³ of Media Volume in One Column)

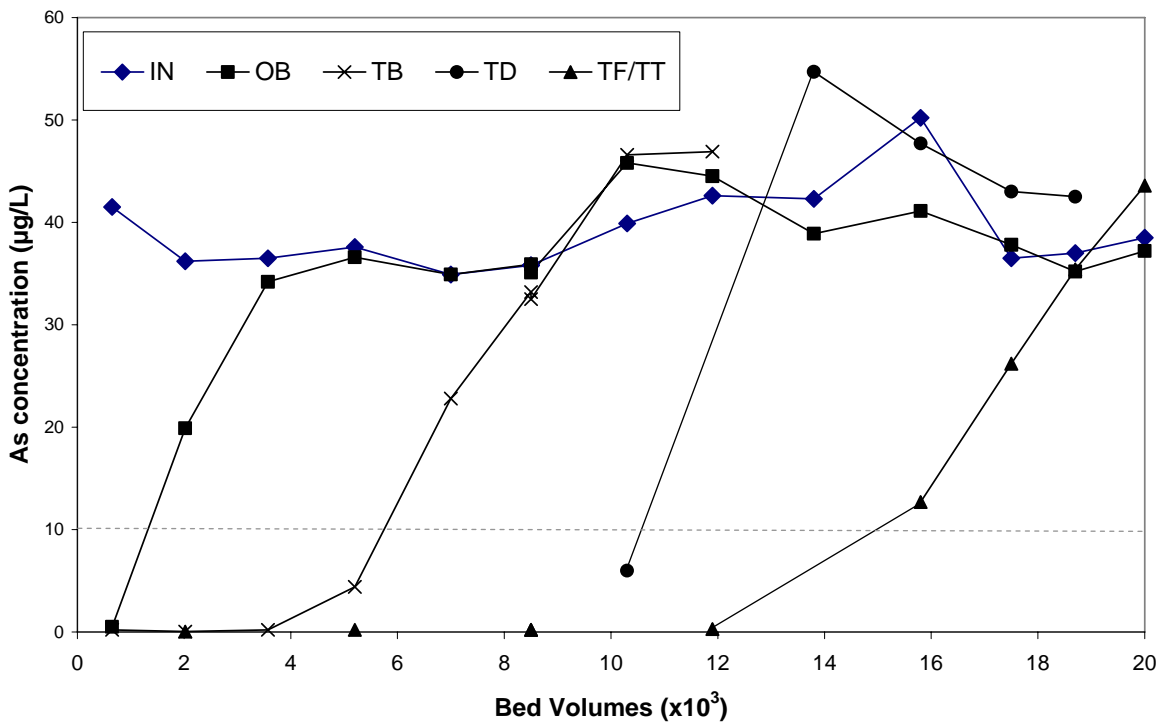


Figure 4-10. Total Arsenic Breakthrough Curves for Treatment Train B (BVs Based on 1.5 ft³ of Media Volume in One Column)

At about 10,000 BVs, the arsenic concentrations after the first set of lag columns (second set of media columns) were below 10 µ/L (2.9 and 6.0 µg/L at sampling locations TC and TD in Trains A and B, respectively). By 13,800 BV on June 29, 2005, its concentrations at these two locations had increased to above the influent levels at 58.4 and 54.7 µg/L. (Note that the June 29, 2005, samples taken at TC and TD showed elevated levels of arsenic, iron, manganese, aluminum, calcium, and magnesium. The cause of the concentration increase in these metals is no known.) Arsenic concentrations after the second set of lag columns (third set of media columns) reached 10 µg/L at approximately 15,000 BVs through both treatment trains. It reached complete breakthrough at about 19,000 BVs.

Because of the sharp breakthrough curves of all of the columns and lower than projected capacities, the media change-out did not occur until total breakthrough of the third and last column of each treatment train. Consequently, the finished water from the system had arsenic levels higher than the MCL for over two months. Because the MCL official compliance date was January 2006, the system was technically not out of compliance. Operating the system in this way (media change-out of all columns at one time) is equivalent to operating a single vessel system with sample taps along length of the vessel (or between columns). Under this operating condition, the media capacity to 10 µg/L of arsenic breakthrough using a media bed volume of the three columns, Train A had a bed volume capacity of approximately 5,300 BVs and Train B around 5,200 BVs. Thus, the performance of the total system was similar to the performance of the first lead column of each treatment train.

To take advantage of the series design and improve the economics of the system, the lead tanks are removed when total arsenic breakthrough (arsenic effluent equal arsenic influent) occurs. Because of early breakthrough during this first run (which was not expected), this change-out was not done. While a number of water quality factors might have played a role in the early breakthrough, the high pH values of 8.5–8.6 were thought to be the major factor.

Based on the breakthrough curves shown in Figures 4-9 and 4-10, the arsenic loading on the adsorption media was estimated to be between 0.20 to 0.21 µg of As/mg of media in the lead columns. The arsenic loadings on the first set of lag columns were 0.15 and 0.22 µg of As/mg of media. For the second set of lag columns, the arsenic loadings were estimated to be 0.22 µg of As/mg of media. The estimate for the first set of lag columns (Column TC in Figure 4-9 and Column TD in Figure 4-10) might be somewhat skewed, as there were few data points collected prior to breakthrough in these columns, resulting in an abrupt jump in As concentration rather than a smooth curve (Figure 4-9 and 4-10).

The arsenic breakthrough from the lead and lag columns in both treatment trains exhibited typical S-shaped curves, which are characteristic for fixed-bed adsorption columns of this type (Weber, 1972). This type of S-shaped curve may have varying degrees of steepness and position of breakpoint, the point of operation where the column is in equilibrium with the influent water and where little additional removal will occur. Factors that may affect the shape of the curve include adsorption kinetics and arsenic concentrations, pH values, and competitive anions in the influent water.

As shown in Figures 4-9 and 4-10, as the columns became exhausted with arsenic, arsenic concentrations measured during the subsequent sampling events were higher than those in the respective influent. This phenomenon, known as the chromatographic effect, was caused by the displacement of arsenic by competing anions with higher selectivity. The chromatographic effect appeared to be present for both the oxidizing and adsorptive media, but was most apparent with the adsorptive media reaching as high as 58 µg/L.

Among the anions analyzed, silica, sulfate, alkalinity (existing primarily as HCO_3^- at pH values between 7.3 and 8.7), and fluoride were present in raw water at significant concentrations (Table 4-6) that could potentially compete with arsenic for adsorption sites. As shown in Figures 4-11 and 4-12, silica was

consistently removed by, and did not reach complete breakthrough from, the oxidation and adsorption columns throughout the first six months of system operation. At 12,000 BVs, well after the arsenic removal capacity was completely spent, the oxidation columns and the lead adsorption columns continued to show some capacity for silica removal. Of the other competitive anions, both media showed little or no removal capacity for sulfate or alkalinity, but did remove fluoride from about 0.5 mg/L to < 0.1 mg/L initially (Figure 4-13). Fluoride completely broke through the oxidation and lead adsorption columns at 700 and 2,000 BVs, respectively, and exhibited similar characteristics of the chromatographic effect observed for arsenic.

Aluminum. Total aluminum concentrations in source water averaged 12.7 µg/L with aluminum existing mainly in particulate form. Concentrations of aluminum, primarily in soluble form, in the treated water following the oxidation columns were about 20 to 30 µg/L higher than those in raw water, indicating leaching of aluminum from both the oxidizing media. Initially, the aluminum concentrations following the oxidation columns were consistently higher than those following the adsorption columns (Figures 4-14 and 4-15), suggesting that the adsorptive media was removing some of the aluminum introduced by the oxidation media. After about 5,000 BVs, this trend discontinued and the aluminum concentrations follow both media were about the same. This observation indicated that aluminum leaching occurred primarily from the oxidation columns, but not from adsorption columns. Even with the increase in aluminum concentration following the treatment system, the concentrations were still below the secondary drinking water standard for aluminum of 50 to 200 µg/L. Leaching of aluminum continued throughout the study period.

Iron and Manganese. With the exception of only a few data points, iron concentrations, both total and dissolved, were less than the detection limit of 25 µg/L in the source water and across the treatment trains (Table 4-5). Manganese concentrations in source water were also low, ranging from 7.3 to 21.9 µg/L and averaging 11.0 µg/L. Manganese concentrations in the treated water following the oxidation columns typically were below the detection limit (<0.1 µg/L), indicating complete removal of manganese by oxidizing and adsorptive media.

Other Water Quality Parameters. The results for DO and ORP remained fairly consistent throughout the treatment train, appearing unaffected by the As/1400CS system. Orthophosphate (as PO₄) was less than the detection limit (<0.05 mg/L) for all samples. Total hardness ranged from 36.7 to 87.0 mg/L as CaCO₃, and remained constant across the treatment train.

4.5.2 Distribution System Water Sampling. Prior to the installation/operation of the treatment system, baseline distribution water samples were collected at two LCR and one non-LCR residences on December 15, 2004; January 10, 2005; February 2, 2005; and February 23, 2005. Following the installation of the treatment system, distribution water sampling continued on a monthly basis at the same three sampling locations. The results of the distribution system sampling are summarized in Table 4-7.

As expected, prior to the installation of the arsenic adsorption system, arsenic concentrations in the distribution system were similar to those measured in raw water, ranging from 29.9 to 40.0 µg/L. After the treatment system was installed and put into service, arsenic concentrations in the distribution system decreased significantly and closely mirrored those measured after the treatment system. As the arsenic concentrations increased after the last set of adsorption columns, the concentrations in the distribution system correspondingly increased.

Similar to those in raw water, iron and manganese concentrations were low in the distribution system. Lead and copper values were also low and did not appear to be affected by the treatment system. The pH and alkalinity also remained fairly constant throughout the distribution sampling.

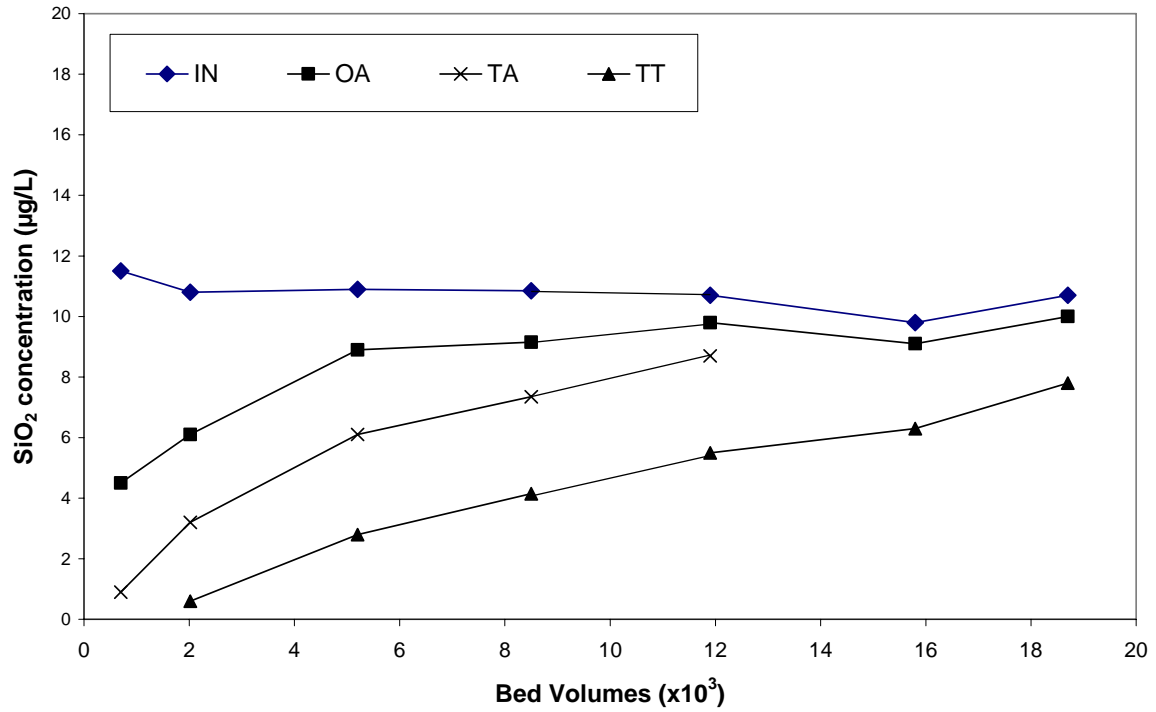


Figure 4-11. Silica Concentrations Across Treatment Train A

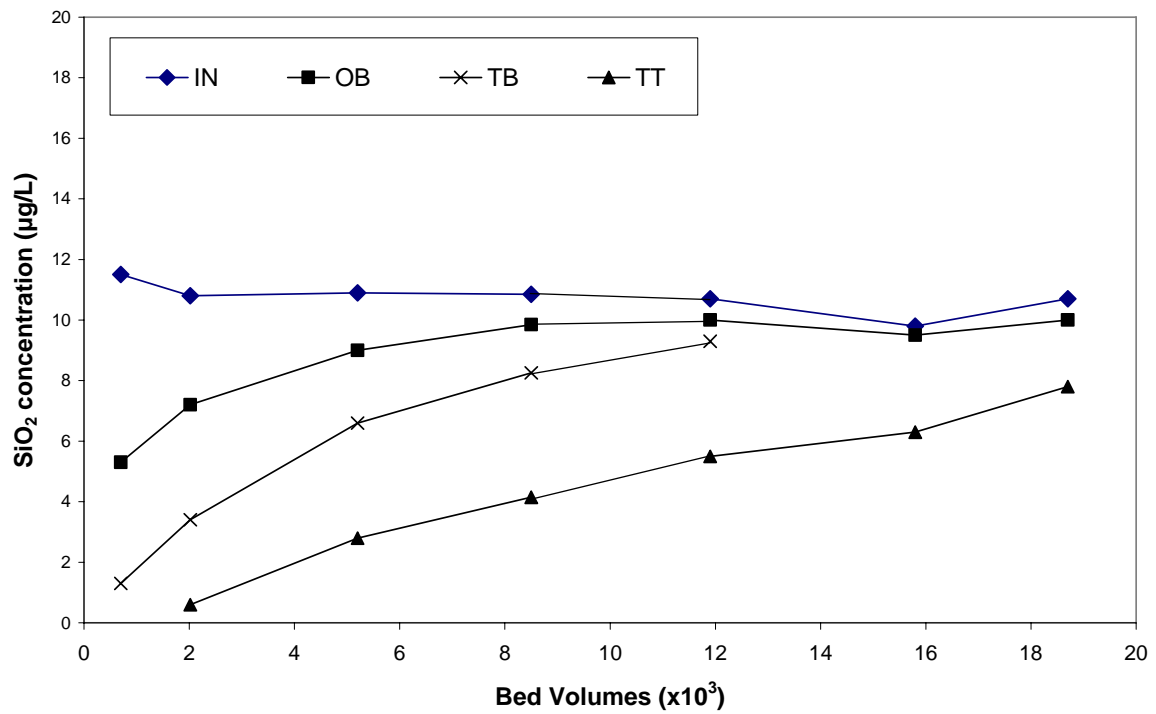


Figure 4-12. Silica Concentrations Across Treatment Train B

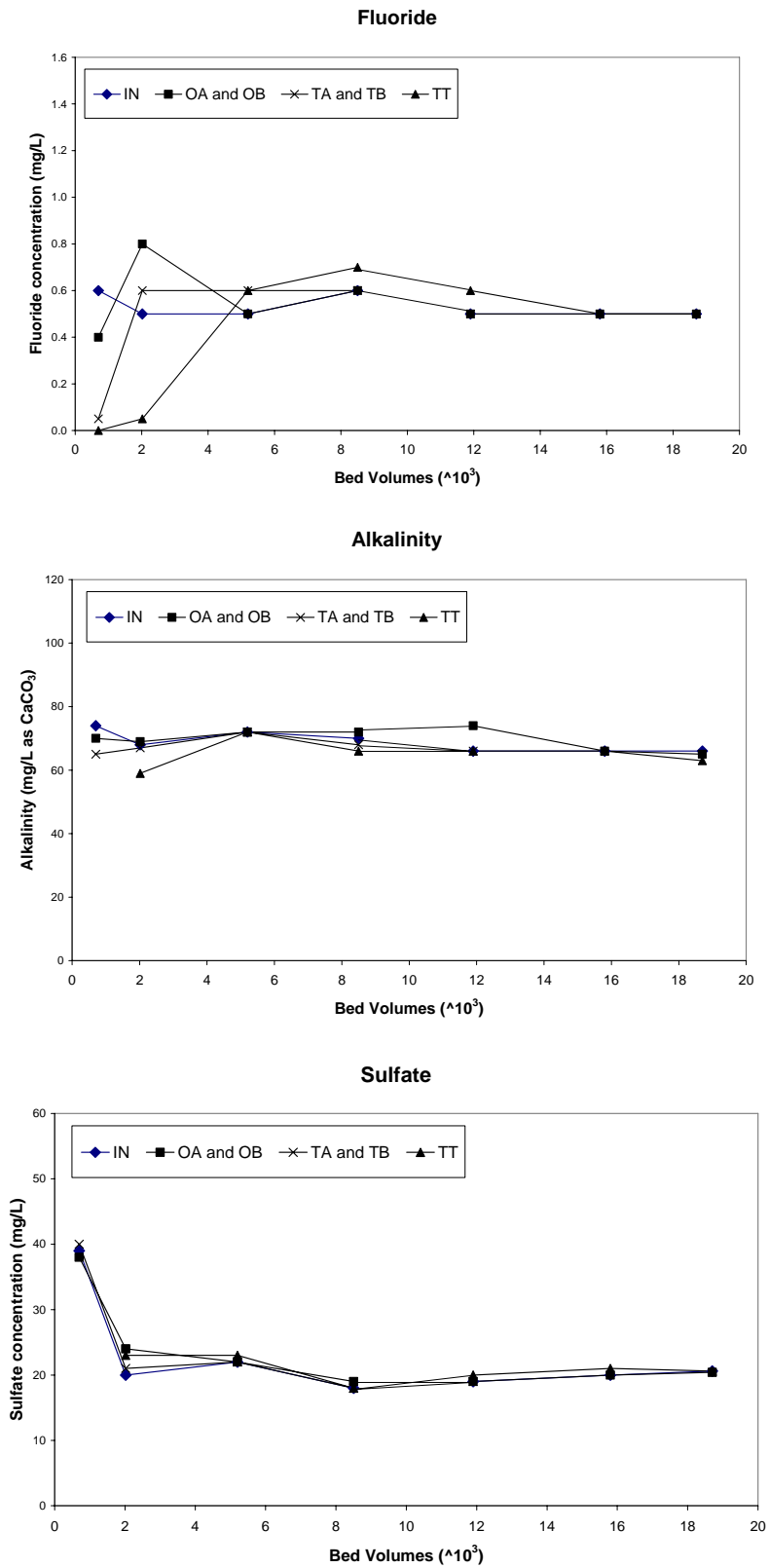


Figure 4-13. Fluoride, Alkalinity, and Sulfate Concentrations Across Both Treatment Trains

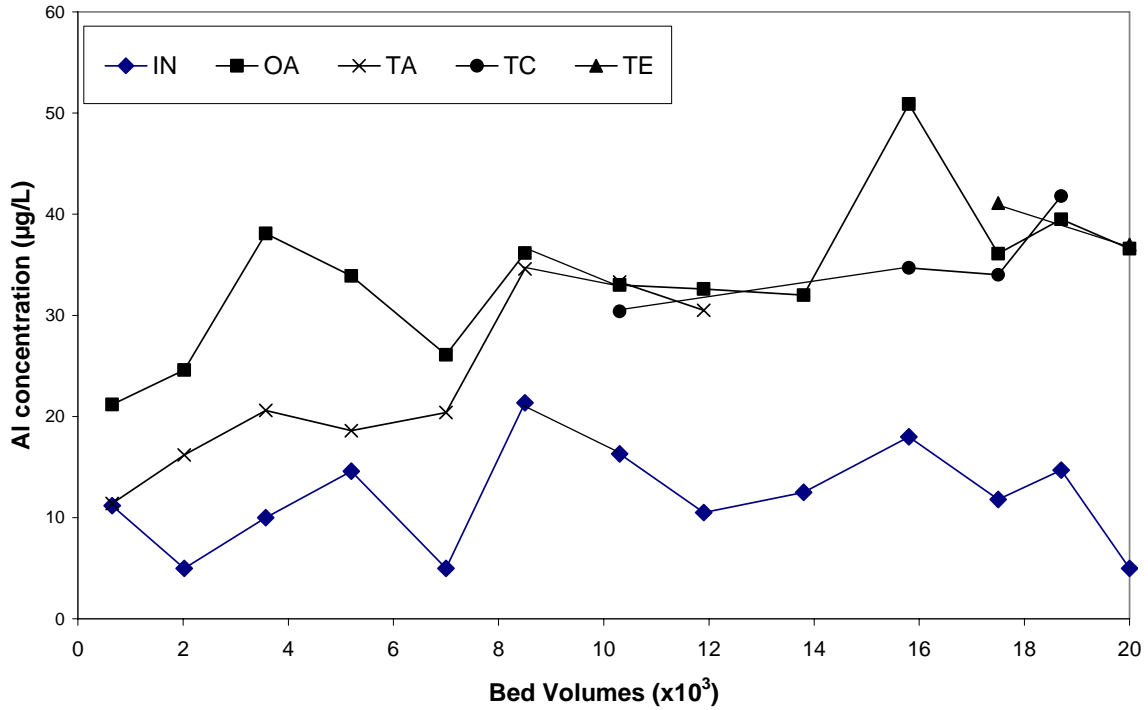


Figure 4-14. Total Aluminum Concentrations Across Treatment Train A

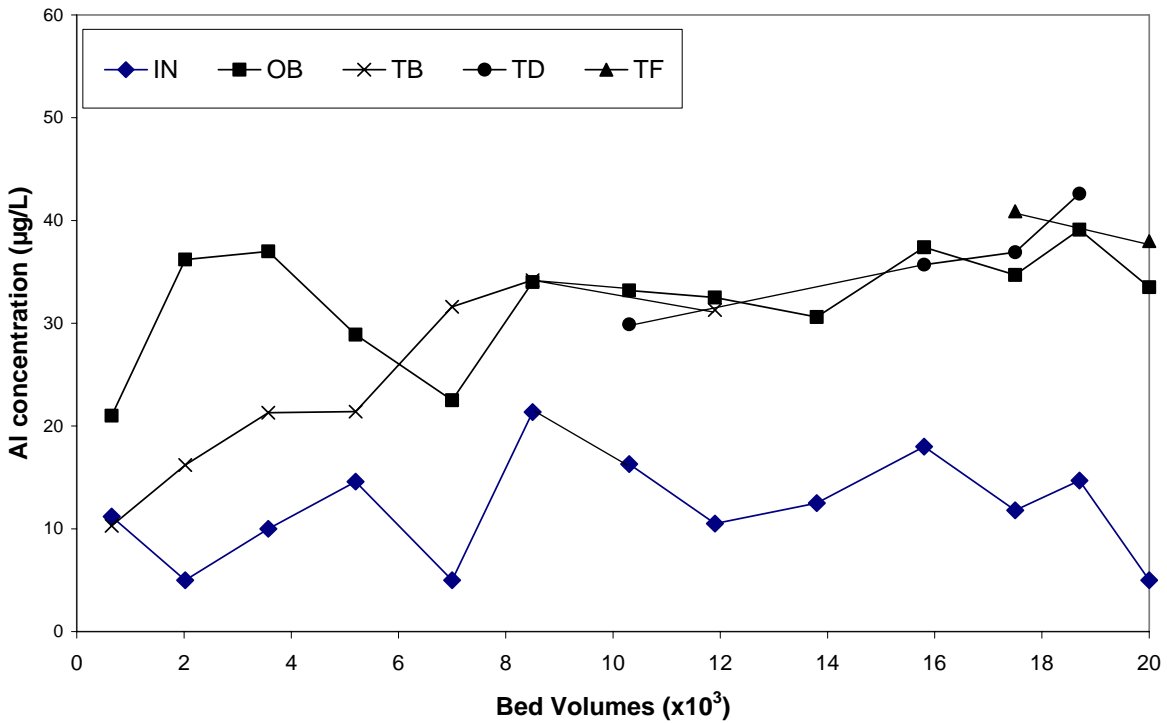


Figure 4-15. Total Aluminum Concentrations Across Treatment Train B

Table 4-7. Distribution System Sampling Results

Sampling Event	Sampling Location	Treatment Effluent	DS1									DS2									DS3								
	Sampling Date	Total As (µg/L)	Stagnation Time (hrs)	pH (S.U)	Alkalinity (mg/L as CaCO ₃)	Total As (µg/L)	Total Fe (µg/L)	Total Mn (µg/L)	Total Al (µg/L)	Total Pb (µg/L)	Total Cu (µg/L)	Stagnation Time (hrs)	pH (S.U)	Alkalinity (mg/L as CaCO ₃)	Total As (µg/L)	Total Fe (µg/L)	Total Mn (µg/L)	Total Al (µg/L)	Total Pb (µg/L)	Total Cu (µg/L)	Stagnation Time (hrs)	pH (S.U)	Alkalinity (mg/L as CaCO ₃)	Total As (µg/L)	Total Fe (µg/L)	Total Mn (µg/L)	Total Al (µg/L)	Total Pb (µg/L)	Total Cu (µg/L)
BL1 ^(a)	12/15/04	NS	7.8	7.4	57	36.1	44.5	3.1	<10	1.0	55.1	9.0	7.5	57	38.0	<25	3.5	<10	0.9	11.9	7.6	7.9	57	35.9	<25	2.6	<10	0.5	33.5
BL2 ^(a)	01/10/05	NS	7.2	8.1	65	30.6	<25	2.1	<10	<0.1	13.8	10.0	8.1	64	29.9	<25	2.1	<10	0.2	6.7	7.8	8.2	66	31.3	<25	1.8	<10	0.3	30.1
BL3 ^(a)	02/02/05	NS	7.0	7.9	71	39.6	<25	2.8	<10	0.4	26.5	8.0	8.2	69	40.0	<25	3.8	<10	0.2	8.1	8.5	8.2	70	39.5	<25	3.4	<10	0.1	17.9
BL4 ^(a)	02/23/05	NS	7.3	7.6	73	35.4	<25	2.4	<10	0.4	26.2	9.0	7.7	70	37.1	<25	3.1	<10	0.9	15.8	8.3	8.2	71	36.6	<25	2.2	<10	0.2	27.6
1	04/05/05	<0.2	7.0	8.0	63	1.5	<25	0.5	12.2	0.8	114	9.0	7.9	66	0.8	<25	0.6	14.8	0.7	15.1	9.0	7.8	66	2.4	<25	1.6	13.3	1.4	78.2
2	05/04/05	NS	8.4	7.8	68	0.8	<25	0.6	<10	1.2	65.6	8.3	7.9	72	<0.1	<25	0.2	<10	1.1	4.3	8.3	7.8	70	0.6	<25	0.8	<10	0.3	25.1
3	06/15/05	0.3	7.7	7.7	66	0.7	<25	1.1	24.5	0.6	18.2	10.5	7.8	66	0.5	<25	5.2	21.1	1.1	5.8	9.0	7.8	66	2.0	<25	1.5	29.6	0.7	26.6
4	07/13/05	12.7	7.3	7.5	66	10.4	<25	0.5	<10	0.2	55.2	8.0	8.0	66	11.4	<25	0.5	36.6	0.5	3.5	9.2	8.0	66	11.1	<25	0.7	28.9	0.4	15.3
5	08/09/05	35.4	7.4	8.0	67	29.0	<25	0.5	17.0	0.5	57.4	13.8	8.0	71	32.5	<25	2.5	39.7	0.7	2.0	8.3	8.0	75	32.2	<25	0.7	37.1	0.3	11.0

(a) Baseline sampling prior to system installation

DS = Distribution sampling

NS = Not sampled

Lead action level = 15 µg/L; copper action level = 1.3 mg/L

The aluminum concentrations in all baseline samples were below the detection limit of 10 µg/L. After the system was installed, the aluminum concentrations were as high as 39.7 µg/L, similar to the concentrations observed after the treatment system. As mentioned previously, since the A/P Complex 2002 oxidation media and the A/I Complex 2000 adsorption media are alumina-based, it can be expected that the media would contribute some aluminum to the water during treatment. The high pH values probably played a role as aluminum is more soluble at higher pH values than near neutral pH values.

4.6 System Cost

The cost of the system was evaluated based on the capital cost per gpm (or gpd) of design capacity and the O&M cost per 1,000 gal of water treated. This required the tracking of the capital cost for the equipment, site engineering, and installation, and the O&M cost for chemical supply, electricity consumption, and labor. The cost associated with improvements to the building and any other infrastructure was not included in the capital cost. These activities were not included in the scope of the demonstration project and were funded separately by the facility.

4.6.1 Capital Cost. The capital investment for equipment, site engineering, and installation was \$16,475 (see Table 4-8). The equipment cost was \$10,790 (or 65% of the total capital investment), which included \$4,900 for the treatment system mechanical hardware, \$960 for 3 ft³ of the A/P Complex 2002 oxidizing media (i.e., \$320/ft³ or \$6.15/lb), \$2,880 for 9 ft³ of the A/I Complex 2000 adsorptive media (i.e., \$320/ft³ or \$5.82/lb), and \$2,050 for the vendor's labor and freight.

The engineering cost included the cost for the preparation of the system layout and footprint, design of the piping connections to the entry and distribution tie-in points, design of the additional pressure tank and booster pump, and assembling and submission of the engineering plans for the permit application (Section 4.3.1). The engineering cost was \$1,800, or 11% of the total capital investment.

The installation cost included the cost of labor and materials to unload and install the treatment system, pressure tank, and booster pump, complete the piping installation and tie-ins, and perform the system start-up and shakedown (Section 4.3.3). The installation, which was performed by ATS, cost \$3,885, or 24% of the total capital investment.

The total capital cost of \$16,475 was normalized to \$1,177/gpm (\$0.82/gpd) of design capacity using the system's rated capacity of 14 gpm (or 20,160 gpd). The capital cost also was converted to an annualized cost of \$1,555/year using a capital recovery factor of 0.09439 based on a 7% interest rate and a 20-year return period. Assuming that the system operated 24 hr/day, 7 day/week at the design flowrate of 14 gpm to produce 7,400,000 gal of water per year, the unit capital cost would be \$0.21/1,000 gal. In fact, the system operated an average of 3.4 hr/day at just over 10 gpm (Table 4-4), producing approximately 480,000 gal of water during the six-month period. At this reduced rate of operation, the unit capital cost increased to \$1.62/1,000 gal of water treated.

4.6.2 Operation and Maintenance Cost. The O&M cost for the As/1400CS treatment system included only incremental cost associated with the treatment system, such as media replacement and disposal, chemical supply, electricity consumption, and labor, as presented in Table 4-9. For this demonstration study, the treatment system was allowed to continue to operate until the system reached complete arsenic breakthrough. Therefore, the media was not replaced during the six-month period. Based on the vendor quote, it would cost \$1,550 for replacement of media, spent media disposal, and shipping to replace two adsorption or oxidation columns and \$915 for labor and travel. Assuming that the labor and travel cost was fixed, it would cost \$2,465, \$4,015, and \$5,565 for replacing two, four, or six columns, respectively (Table 4-9). By averaging the one-time media replacement cost over the life of the

Table 4-8. Capital Investment for As/1400CS Treatment System

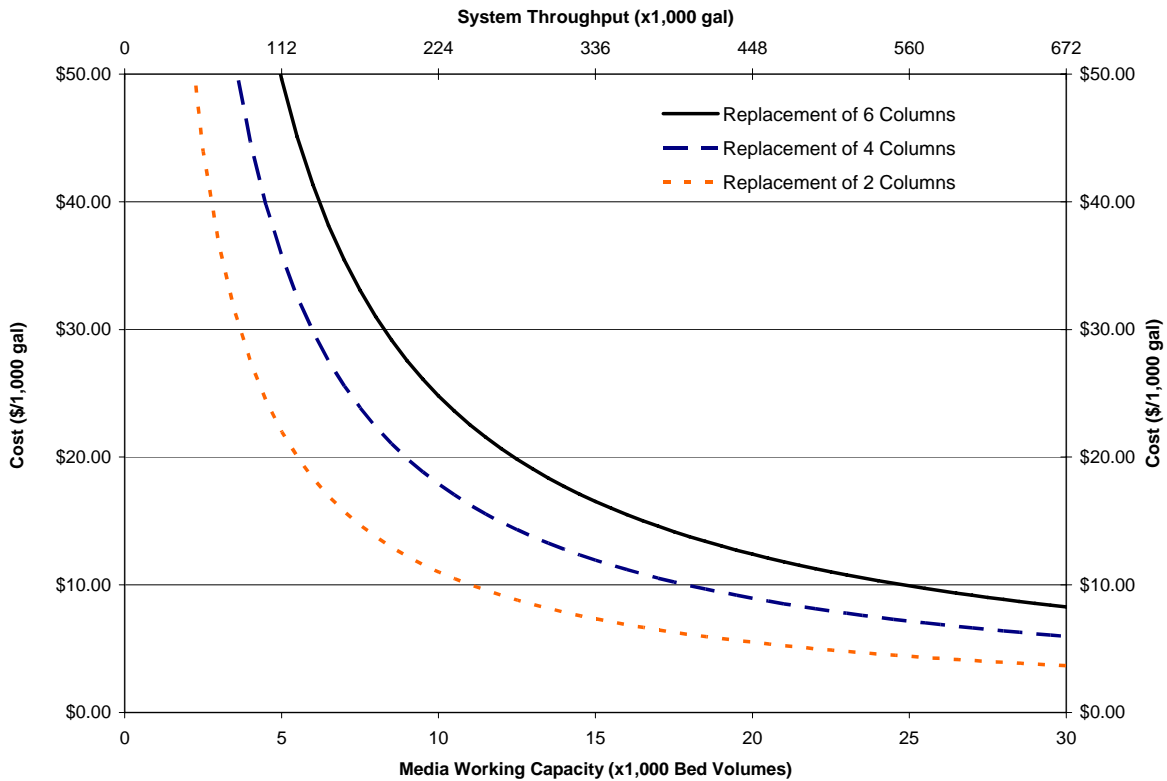
Description	Quantity	Cost	% of Capital Investment Cost
<i>Equipment Cost</i>			
Oxidizing Media Columns	2	\$240	–
A/P Complex 2002 Oxidizing Media (ft ³)	3	\$960	–
Adsorptive Media Columns	6	\$720	–
A/I Complex 2000 Adsorptive Media (ft ³)	9	\$2,880	–
25-µm Sediment Filters	2	\$750	–
Pressure Tank and Booster Pump	1	\$900	–
Piping and Valves	1	\$1,110	–
Flow Totalizer/Meter	2	\$1,120	–
Hour Meter	1	\$60	–
Procurement, Assembly, Labor	1	\$1,600	–
Freight	1	\$450	–
Equipment Total	–	\$10,790	65%
<i>Engineering Cost</i>			
Design/Scope of System (hr)	10	\$1,500	–
Travel and Miscellaneous Expenses	1	\$300	–
Engineering Total	–	\$1,800	11%
<i>Installation Cost</i>			
Plumbing Supplies/Parts	1	\$500	–
Electrical Supplies/Parts	1	\$200	–
Vendor Installation Labor (hr)	10	\$1,300	–
Mechanical Subcontractor Labor (hr)	10	\$850	–
Electrical Subcontractor Labor (hr)	3	\$225	–
Vendor Travel (day)	2	\$710	–
Subcontractor Travel	–	\$100	–
Installation Total	–	\$3,885	24%
Total Capital Investment	–	\$16,475	100%

media, the cost per 1,000 gal of water treated was plotted as a function of the media run length in BVs or the system throughput in gallons (see Figure 4-16). Because the oxidation column might not be replaced at the same time as the adsorptive media, the unit replacement cost can be estimated separately from the cost curve for 2 columns. Note that the media BVs were calculated based on the quantity of media in one column (i.e., 1.5 ft³ or 11.2 gal of media). When converting from BVs to the system throughput, the media run length was multiplied by 22.4 gal/BV to account for two treatment trains.

The arsenic breakthrough curves of the A/I Complex 2000 media exhibited a sharp adsorption front, as shown in Figures 4-9 and 4-10. When the effluent from the third adsorption column in each train reached 10 µg/L breakthrough after treating about 336,000 gal (or 15,000 BVs) of water, the adsorptive media in the first two columns had completely exhausted its arsenic adsorptive capacity. Should the four columns be changed-out at this time, the media replacement cost would be \$4,015, corresponding to \$11.95/1,000 gal. However, the subsequent service run with the third columns being moved up to the lead position and followed by two virgin columns being placed in the lag positions, the run length for the entire train would be shorter than the initial run (i.e., less than 15,000 BVs) due to the partially exhausted lead columns. Therefore, it would require more frequent change-out and a higher unit replacement cost. To reduce the change-out frequency and the associated scheduling and coordinating effort, it might be more cost-effective and convenient, in the long run, to replace the media in all six columns altogether. In

Table 4-9. Summary of O&M Cost

Cost Category	Value			Assumptions
Volume Processed (gal)	480,000			Through September 9, 2005
Media Replacement and Disposal				
Number of Columns Replaced	2	4	6	
Media Replacement and Disposal (\$)	1,550	3,100	4,650	\$755/column or \$517/ft ³ of media
Labor and Travel (\$)	915	915	915	Same cost for changing out of 2, 4, or 6 columns
Subtotal (\$)	2,465	4,015	5,565	
Media Replacement and Disposal Cost (\$/1,000 gal)	See Figure 4-15			
Chemical Supply				
Chemical Supply (\$/1,000 gal)	0.00			No chemical addition performed
Electricity Consumption				
Electricity Cost (\$/1,000 gal)	0.001			Electrical cost negligible
Labor				
Average Weekly Labor (hr)	1			20 min/day, 3 day/week
Labor Cost (\$)	540			27 hr × \$20/hr, labor rate = \$20/hr
Labor Cost (\$/1,000 gal)	1.13			–
Total O&M Cost (\$/1,000 gal)	Adsorptive media replacement + oxidizing media replacement + 1.13			



Note: 1 Bed Volume = 1.5 cubic feet = 11.2 gal (one train only)

Figure 4-16. Media Replacement Cost Curves

this case, the replacement cost would increase to \$5,565 or \$16.56/1,000 gal for six columns. Less change-out frequency could save labor, travel, and administrative cost.

No chemical cost was incurred. Comparison of electrical bills before and after system installation and startup did not indicate any noticeable increase in power consumption. Therefore, the electrical cost associated with the system operation was negligible. The routine, non-demonstration-related labor activities consumed about 20 min/day, 3 day/week as noted in Section 4.4.4. Therefore, the estimated labor cost was \$1.13/1,000 gal of water treated (Table 4-9).

5.0 REFERENCES

- Aquatic Treatment Systems. 2005. *Operations & Maintenance Manual, As/1400CS Duplex Arsenic Removal System, Springbrook Mobile Home Park, Wales, ME.* March.
- Battelle. 2004. *Revised Quality Assurance Project Plan for Evaluation of Arsenic Removal Technology.* Prepared under Contract No. 68-C-00-185, Task Order No. 0029, for U.S. EPA NRMRL. September 17.
- Battelle. 2005. *Final System Performance Evaluation Study Plan: U.S. EPA Demonstration of Arsenic Removal Technology at Wales, Maine.* Prepared under Contract No. 68-C-00-185, Task Order No. 0029 for U.S. EPA NRMRL. January 6.
- Chen, A.S.C., L. Wang, J. Oxenham, and W. Condit. 2004. *Capital Costs of Arsenic Removal Technologies: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1.* EPA/600/R-04/201. U.S. EPA NRMRL, Cincinnati, OH.
- Edwards, M., S. Patel, L. McNeill, H. Chen, M. Frey, A.D. Eaton, R.C. Antweiler, and H.E. Taylor. 1998. "Considerations in As Analysis and Speciation." *J. AWWA* (March): 103-113.
- U.S. Environmental Protection Agency (EPA). 2001. National Primary Drinking Water Regulations: Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring. *Fed. Register*, 66:14:6975. January 22.
- U.S. Environmental Protection Agency (EPA). 2002. *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems.* Prepared by U.S. EPA's Office of Water. EPA/816/R-02/009. February.
- U.S. Environmental Protection Agency (EPA). 2003. Minor Clarification of the National Primary Drinking Water Regulation for Arsenic. *Federal Register*, 40 CFR Part 141. March 25.
- Wang, L., W. Condit, and A. Chen. 2004. *Technology Selection and System Design: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1.* EPA/600/R-05/001. U.S. EPA NRMRL, Cincinnati, OH.
- Weber, W. 1972. *Physicochemical Processes for Water Quality Control.* Wiley-Interscience, New York.

APPENDIX A
OPERATIONAL DATA

EPA Arsenic Demonstration at SBMHP in Wales, ME – Summary of Daily System Operational Data

Week No.	Date	Booster Pump Hour Meter		Treatment Train A			Treatment Train B			System		
		Hour Meter Reading	Avg Operation Time	Flowrate	Cumulative Volume Treated	Cumulative Bed Volume Treated	Flowrate	Cumulative Volume Treated	Cumulative Bed Volume Treated	Total Cumulative Volume Treated	Total Cumulative Bed Volume Treated	Avg Flowrate
		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
1	3/7/2005	4.3	NM	NM	4438	396	NM	4464	398	8902	397	NA
	3/8/2005	4.8	0.50	2.12	5963	531	2.20	5981	533	11944	532	NA
	3/9/2005	5.3	0.50	0.57	7250	646	0.54	7266	648	14516	647	NA
	3/10/2005	5.8	0.50	0.91	8571	764	1.01	8590	766	17161	765	NA
	3/11/2005	6.3	0.50	1.41	10061	897	1.70	10082	899	20143	898	NA
	3/12/2005	6.9	0.60	0.63	11250	1003	0.60	11301	1007	22551	1005	NA
	3/13/2005	7.8	0.90	6.21	13150	1172	6.35	13190	1176	26340	1174	NA
2	3/14/2005	8.3	0.50	0.00	13659	1217	0.00	13696	1221	27355	1219	NA
	3/15/2005	8.5	0.20	0.35	14866	1325	0.30	14910	1329	29776	1327	NA
	3/16/2005	8.6	0.10	0.00	16057	1431	0.00	16109	1436	32166	1433	NA
	3/17/2005	8.7	0.10	0.44	16867	1503	0.43	16922	1508	33789	1506	NA
	3/18/2005	8.8	0.10	0.00	17871	1593	0.00	17936	1599	35807	1596	NA
	3/19/2005	8.9	0.10	1.33	18964	1690	1.32	19040	1697	38004	1694	NA
	3/20/2005	9.8	0.90	1.64	20228	1803	1.82	20312	1810	40540	1807	NA
3	3/21/2005	10.5	0.70	5.29	21610	1926	5.42	21723	1936	43333	1931	NA
	3/22/2005	10.6	0.10	3.04	22557	2010	3.47	22694	2023	45251	2017	NA
	3/23/2005	11.8	1.20	2.48	24239	2160	2.80	24415	2176	48654	2168	NA
	3/24/2005	11.9	0.10	3.31	25158	2242	3.42	25351	2259	50509	2251	NA
	3/25/2005	12.5	0.60	2.38	26483	2360	2.40	26705	2380	53188	2370	NA
	3/26/2005	15.1	2.60	4.06	28197	2513	4.13	28450	2536	56647	2524	NA
	3/27/2005	16.5	1.40	2.69	29395	2620	2.81	29689	2646	59084	2633	NA
4	3/28/2005	17.1	0.60	2.58	30453	2714	2.72	30129	2685	60582	2700	NA
	3/29/2005	18.2	1.10	3.46	31584	2815	3.65	31950	2848	63534	2831	NA
	3/30/2005	19.5	1.30	3.93	32801	2923	4.07	33208	2960	66009	2942	NA
	3/31/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA
	4/1/2005	22.1	2.60	5.20	35536	3167	5.33	35060	3125	70596	3146	NA
	4/2/2005	22.5	0.40	5.16	36048	3213	5.72	36557	3258	72605	3236	NA
	4/3/2005	24.7	2.20	4.71	38038	3390	4.96	38610	3441	76648	3416	NA
5	4/4/2005	25.2	0.50	5.12	39017	3477	5.24	39621	3531	78638	3504	NA
	4/5/2005	25.5	0.30	4.90	39950	3561	4.98	40175	3581	80125	3571	NA
	4/6/2005	27.3	1.80	5.21	41049	3659	5.48	41734	3720	82783	3689	NA
	4/7/2005	31.2	3.90	5.01	42371	3776	5.19	43086	3840	85457	3808	11.4
	4/8/2005	34	2.80	5.35	43319	3861	5.46	44053	3926	87372	3894	11.4
	4/9/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	4/10/2005	43.1	9.10	5.38	46305	4127	5.48	47089	4197	93394	4162	11.0

EPA Arsenic Demonstration at SBMHP in Wales, ME – Summary of Daily System Operational Data

Week No.	Date	Booster Pump Hour Meter		Treatment Train A			Treatment Train B			System			
		Hour Meter Reading	Avg Operation Time	Flowrate	Cumulative Volume Treated	Cumulative Bed Volume Treated	Flowrate	Cumulative Volume Treated	Cumulative Bed Volume Treated	Total Cumulative Volume Treated	Total Cumulative Bed Volume Treated	Avg Flowrate	
		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm	
6	4/11/2005	46.4	3.30	5.35	47400	4225	5.44	48203	4296	95603	4260	11.2	
	4/12/2005	48.6	2.20	5.68	48118	4289	5.79	48931	4361	97049	4325	11.0	
	4/13/2005	54.2	5.60	5.19	49994	4456	5.30	50840	4531	100834	4493	11.3	
	4/14/2005	57	2.80	5.23	50969	4543	5.30	51833	4620	102802	4581	11.7	
	4/15/2005	58.7	1.70	5.07	51512	4591	5.07	52386	4669	103898	4630	10.7	
	4/16/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
4/17/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
7	4/18/2005	74.2	15.50	5.42	56596	5044	5.49	57558	5130	114154	5087	11.0	
	4/19/2005	78	3.80	5.01	57826	5154	5.14	58816	5242	116642	5198	10.9	
	4/20/2005	84	6.00	5.28	58929	5252	5.42	59964	5344	118893	5298	6.3	
	4/21/2005	87.8	3.80	4.96	60166	5362	5.08	61246	5459	121412	5411	11.0	
	4/22/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	4/23/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
4/24/2005	100.6	12.80	5.16	64289	5730	5.27	65495	5837	129784	5784	10.9		
8	4/25/2005	106.3	5.70	5.14	66153	5896	5.27	67413	6008	133566	5952	11.1	
	4/26/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
	4/27/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
	4/28/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
	4/29/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
	4/30/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
5/1/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
9	5/2/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
	5/3/2005	137.8	31.50	5.27	76529	6821	5.40	77956	6948	154485	6884	11.1	
	5/4/2005	142	4.20	5.21	77895	6943	5.35	79342	7071	157237	7007	10.9	
	5/5/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
	5/6/2005	148.5	6.50	4.88	80034	7133	4.93	81512	7265	161546	7199	11.0	
	5/7/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
5/8/2005	163.6	15.10	4.91	85038	7579	4.97	86587	7717	171625	7648	11.1		
10	5/9/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
	5/10/2005	170.9	7.30	4.90	87516	7800	4.96	89088	7940	176604	7870	11.4	
	5/11/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
	5/12/2005	177.7	6.80	4.25	89777	8002	4.82	91376	8144	181153	8073	11.1	
	5/13/2005	178.9	1.20	5.01	90183	8038	5.07	91805	8182	181988	8110	11.6	
	5/14/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
5/15/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	

EPA Arsenic Demonstration at SBMHP in Wales, ME – Summary of Daily System Operational Data

Week No.	Date	Booster Pump Hour Meter		Treatment Train A			Treatment Train B			System		
		Hour Meter Reading	Avg Operation Time	Flowrate	Cumulative Volume Treated	Cumulative Bed Volume Treated	Flowrate	Cumulative Volume Treated	Cumulative Bed Volume Treated	Total Cumulative Volume Treated	Total Cumulative Bed Volume Treated	Avg Flowrate
		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
11	5/16/2005	190.4	11.50	4.96	94018	8380	5.01	95677	8527	189695	8453	11.2
	5/17/2005	193	2.60	5.01	94879	8456	5.07	96555	8606	191434	8531	11.1
	5/18/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	5/19/2005	202.1	9.10	5.14	97874	8723	5.32	99578	8875	197452	8799	11.0
	5/20/2005	204.5	2.40	4.81	98663	8793	4.85	100381	8947	199044	8870	11.1
	5/21/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
5/22/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
12	5/23/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	5/24/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	5/25/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	5/26/2005	227.7	23.20	4.58	106414	9484	4.64	108223	9646	214637	9565	11.2
	5/27/2005	230.9	3.20	4.88	107484	9580	4.93	109304	9742	216788	9661	11.2
	5/28/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
5/29/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
13	5/30/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	5/31/2005	247.6	16.70	4.84	113096	10080	4.86	114974	10247	228070	10164	11.3
	6/1/2005	250.1	2.50	5.08	113961	10157	5.13	115848	10325	229809	10241	11.6
	6/2/2005	255.6	5.50	5.05	115791	10320	5.15	117697	10490	233488	10405	11.1
	6/3/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	6/4/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
6/5/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
14	6/6/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	6/7/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	-	NM
	6/8/2005	279.3	23.70	5.38	123612	11017	5.46	125611	11195	249223	11106	11.1
	6/9/2005	281.5	2.20	5.27	124322	11080	5.32	126330	11259	250652	11170	10.8
	6/10/2005	284.6	3.10	5.16	125374	11174	5.20	127395	11354	252769	11264	11.4
	6/11/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
6/12/2005	294.8	10.20	5.21	128721	11472	5.25	130785	11656	259506	11564	11.0	
15	6/13/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	6/14/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	6/15/2005	305.7	10.90	5.13	132261	11788	5.21	134370	11976	266631	11882	10.9
	6/16/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	6/17/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	6/18/2005	317.7	12.00	5.10	136265	12145	5.21	138422	12337	274687	12241	11.2
6/19/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	

EPA Arsenic Demonstration at SBMHP in Wales, ME – Summary of Daily System Operational Data

Week No.	Date	Booster Pump Hour Meter		Treatment Train A			Treatment Train B			System		
		Hour Meter Reading	Avg Operation Time	Flowrate	Cumulative Volume Treated	Cumulative Bed Volume Treated	Flowrate	Cumulative Volume Treated	Cumulative Bed Volume Treated	Total Cumulative Volume Treated	Total Cumulative Bed Volume Treated	Avg Flowrate
		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
16	6/20/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	6/21/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	6/22/2005	336.9	19.20	5.12	142571	12707	5.20	144805	12906	287376	12806	11.0
	6/23/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	6/24/2005	348.3	11.40	4.80	146227	13033	4.81	148499	13235	294726	13134	10.7
	6/25/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
6/26/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
17	6/27/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	6/28/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	6/29/2005	370.8	22.50	5.07	153568	13687	5.10	155922	13897	309490	13792	10.9
	6/30/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	7/1/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	7/2/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
7/3/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
18	7/4/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	7/5/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	7/6/2005	403.7	32.90	5.10	164281	14642	5.14	166753	14862	331034	14752	10.9
	7/7/2005	409	5.30	5.53	166018	14797	5.44	168512	15019	334530	14908	11.0
	7/8/2005	418.3	9.30	5.07	168976	15060	5.12	171505	15286	340481	15173	10.7
	7/9/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
7/10/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
19	7/11/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	7/12/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	7/13/2005	438.4	20.10	5.29	175659	15656	5.31	178264	15888	353923	15772	11.1
	7/14/2005	443.6	5.20	5.21	177369	15808	5.27	178997	15953	356366	15881	7.8
	7/15/2005	447.5	3.90	5.04	178686	15926	5.09	181329	16161	360015	16043	15.6
	7/16/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
7/17/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
20	7/18/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	7/19/2005	465	17.50	5.10	184403	16435	5.19	187111	16677	371514	16556	11.0
	7/20/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	7/21/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	7/22/2005	475.1	10.10	5.13	187745	16733	5.19	190489	16978	378234	16855	11.1
	7/23/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
7/24/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	

EPA Arsenic Demonstration at SBMHP in Wales, ME – Summary of Daily System Operational Data

Week No.	Date	Booster Pump Hour Meter		Treatment Train A			Treatment Train B			System		
		Hour Meter Reading	Avg Operation Time	Flowrate	Cumulative Volume Treated	Cumulative Bed Volume Treated	Flowrate	Cumulative Volume Treated	Cumulative Bed Volume Treated	Total Cumulative Volume Treated	Total Cumulative Bed Volume Treated	Avg Flowrate
		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
21	7/25/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	7/26/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	7/27/2005	493.6	18.50	4.95	193897	17281	5.04	196705	17532	390602	17407	11.1
	7/28/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	7/29/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	7/30/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
7/31/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
22	8/1/2005	507.6	14.00	4.95	198613	17702	5.04	201477	17957	400090	17829	11.3
	8/2/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/3/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/4/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/5/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/6/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
8/7/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
23	8/8/2005	532.7	25.10	5.05	207163	18464	5.12	210114	18727	417277	18595	11.4
	8/9/2005	534.9	2.20	4.97	207890	18529	4.99	210847	18792	418737	18660	11.1
	8/10/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/11/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/12/2005	544.2	9.30	5.18	211033	18809	5.26	214021	19075	425054	18942	11.3
	8/13/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
8/14/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
24	8/15/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/16/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/17/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/18/2005	565.6	21.40	5.24	218229	19450	5.27	221265	19721	439494	19585	11.2
	8/19/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/20/2005	577.9	12.30	5.14	222369	19819	5.08	225445	20093	447814	19956	11.3
8/21/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
25	8/22/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/23/2005	583.7	5.80	5.31	224295	19991	5.33	227398	20267	451693	20129	11.1
	8/24/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/25/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/26/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/27/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
8/28/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	

EPA Arsenic Demonstration at SBMHP in Wales, ME – Summary of Daily System Operational Data

Week No.	Date	Booster Pump Hour Meter		Treatment Train A			Treatment Train B			System		
		Hour Meter Reading	Avg Operation Time	Flowrate	Cumulative Volume Treated	Cumulative Bed Volume Treated	Flowrate	Cumulative Volume Treated	Cumulative Bed Volume Treated	Total Cumulative Volume Treated	Total Cumulative Bed Volume Treated	Avg Flowrate
		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
26	8/29/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	8/30/2005	606.6	22.90	5.10	232034	20680	5.19	235225	20965	467259	20823	11.3
	8/31/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	9/1/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	9/2/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	9/3/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
27	9/4/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	9/5/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	9/6/2005	629.4	22.80	5.25	239858	21378	5.32	243155	21672	483013	21525	11.5
	9/7/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	9/8/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	9/9/2005	637.8	8.40	5.16	242801	21640	5.23	246138	21937	488939	21789	11.8
9/10/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
9/11/2005	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM

NOTES:

1 bed volume = 1.5 ft³ = 11.22 gallons

NM= not measured

NA= not available

APPENDIX B
ANALYTICAL RESULTS

Analytical Results

Sampling Date		03/09/05					03/22/05						04/05/05				
Sampling Location		IN	OA	OB	TA	TB	IN	OA	OB	TA	TB	TT	IN	OA	OB	TA	TB
Parameter	Unit																
Bed Volume	10 ³	-	-	-	0.7	0.7	-	-	-	2.0	2.0	2.0	-	-	-	3.6	3.6
Alkalinity	mg/L ^(a)	74	70	67	65	69	68	69	69	67	67	59	-	-	-	-	-
Fluoride	mg/L	0.6	0.4	0.5	<0.1	<0.1	0.5	0.8	0.7	0.6	0.6	<0.1	-	-	-	-	-
Sulfate	mg/L	39	38	38	39	40	20	24	20	21	21	23	-	-	-	-	-
Sulfide	mg/L	<5	-	-	-	-	-	-	-	-	-	-	<5	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.11	-	-	-	-	-
Orthophosphate	mg/L ^(b)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-
Silica (as SiO ₂)	mg/L	11.5	4.5	5.3	0.9	1.3	10.8	6.1	7.2	3.2	3.4	0.6	-	-	-	-	-
Turbidity	NTU	0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	0.2	<0.1	<0.1	-	-	-	-	-
pH	S.U.	8.4	7.6	7.7	7.6	7.6	8.4	8.1	8.1	7.8	7.7	7.5	8.5	7.8	7.5	7.6	7.7
Temperature	°C	7.5	7.6	7.7	8.1	8.0	11.5	11.4	11.4	11.2	11.2	11.2	9.5	8.5	7.9	8.5	7.8
DO	mg/L	4.7	4.3	4.3	5.0	4.5	2.8	3.5	2.7	2.3	2.5	2.6	2.4	2.4	2.6	1.8	1.8
ORP	mV	185	184	187	210	194	189	196	198	194	194	196	126	138	129	133	130
Total Hardness	mg/L ^(a)	47.3	43.7	43.2	43.3	42.2	54.3	49.8	53.1	50.8	50.3	48.4	53.7	51.5	44.1	45.7	40.0
Ca Hardness	mg/L ^(a)	40.7	37.8	37.4	37.5	36.8	46.6	42.7	45.7	43.4	43.0	41.2	46.5	44.7	37.3	38.1	33.7
Mg Hardness	mg/L ^(a)	6.5	5.9	5.7	5.8	5.5	7.7	7.1	7.4	7.3	7.2	7.2	7.2	6.8	6.8	7.5	6.3
As (total)	µg/L	41.5	0.3	0.5	0.2	0.2	36.2	4.7	19.9	0.1	<0.1	<0.1	36.5	27.5	34.2	0.2	0.2
As (soluble)	µg/L	41.6	<0.1	0.2	0.1	<0.1	-	-	-	-	-	-	36.4	27.8	34.1	0.1	0.1
As (particulate)	µg/L	<0.1	0.2	0.3	0.1	<0.1	-	-	-	-	-	-	0.1	<0.1	<0.1	<0.1	<0.1
As (III)	µg/L	26.5	0.3	0.4	0.4	0.3	-	-	-	-	-	-	23.2	0.3	0.3	0.3	0.3
As (V)	µg/L	15.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	13.1	27.5	33.8	<0.1	<0.1
Total Fe	µg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Soluble Fe	µg/L	<25	<25	<25	<25	<25	-	-	-	-	-	-	<25	<25	<25	<25	<25
Total Mn	µg/L	7.3	1.5	2.5	1.2	0.8	8.5	0.5	9.5	0.5	0.5	0.5	8.5	<0.1	<0.1	0.1	<0.1
Soluble Mn	µg/L	7.2	<0.1	0.1	<0.1	0.2	-	-	-	-	-	-	7.9	0.1	<0.1	<0.1	<0.1
Total Al	µg/L	11.2	21.2	21.0	11.4	10.3	<10	24.6	36.2	16.2	16.2	<10	10.0	38.1	37.0	20.6	21.3
Soluble Al	µg/L	<10	18.0	18.1	<10	<10	-	-	-	-	-	-	<10	33.8	35.6	17.3	18.9

(a) as CaCO₃. (b) as PO₄. IN = At Wellhead, OA= After Oxidation Column (Train A), OB = After Oxidation Column (Train B), TA = After First Adsorption Column in Series (Train A), TB = After First Adsorption Column in Series (Train B), TC = After Second Adsorption Column in Series (Train A), TD = After Second Adsorption Column in Series (Train B), TE = After Third Adsorption Column in Series (Train A), TF = After Third Adsorption Column in Series (Train B), TT = After the Entire System

Analytical Results

Sampling Date		04/19/05						05/04/05					05/17/05					
Sampling Location	Parameter	IN	OA	OB	TA	TB	TT	IN	OA	OB	TA	TB	IN	OA	OB	TA	TB	TT
Bed Volume	10 ³	-	-	-	5.2	5.2	5.2	-	-	-	6.9	7.1	-	-	-	8.5	8.6	8.5
Alkalinity	mg/L ^(a)	72	72	72	72	69	72	-	-	-	-	-	70	72	69	68	68	66
		-	-	-	-	-	-	-	-	-	-	-	69	70	58	66	69	66
Fluoride	mg/L	0.5	0.5	0.5	0.6	0.6	0.6	-	-	-	-	-	0.6	0.6	0.5	0.6	0.6	0.7
		-	-	-	-	-	-	-	-	-	-	-	0.5	0.6	0.5	0.6	0.6	0.7
Sulfate	mg/L	22	22	22	22	22	23	-	-	-	-	-	18	19	18	16	18	18
		-	-	-	-	-	-	-	-	-	-	-	18	18	18	18	18	18
Sulfide	mg/L	-	-	-	-	-	-	-	-	-	-	-	<5	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	0.07	0.18	0.09	0.07	1.11	0.06
		-	-	-	-	-	-	-	-	-	-	-	0.43	0.21	0.17	<0.05	0.05	0.11
Orthophosphate	mg/L ^(b)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
		-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silica (as SiO ₂)	mg/L	10.9	8.9	9.0	6.1	6.6	2.8	-	-	-	-	-	10.8	9.1	10.2	7.3	8.4	4.2
		-	-	-	-	-	-	-	-	-	-	-	10.9	9.2	9.5	7.4	8.1	4.1
Turbidity	NTU	0.5	0.2	0.1	0.3	0.3	0.3	-	-	-	-	-	0.3	0.1	0.2	<0.1	0.2	0.1
		-	-	-	-	-	-	-	-	-	-	-	0.5	0.2	0.2	0.4	0.2	0.1
pH	S.U.	8.7	8.4	8.6	8.3	8.2	7.9	8.3	8.4	8.5	8.2	8.2	8.5	8.1	8.4	8.4	8.3	7.0
Temperature	°C	10.7	10.6	10.9	11.0	11.1	11.0	9.6	9.1	9.4	9.5	9.4	9.6	9.3	9.4	9.4	9.4	9.5
DO	mg/L	1.5	1.1	1.4	1.0	1.5	1.1	1.9	1.4	2.0	1.6	1.5	4.0	1.6	1.5	1.7	1.5	2.0
ORP	mV	178	182	179	185	184	195	197	195	194	194	193	200	190	188	181	185	195
Total Hardness	mg/L ^(a)	37.9	41.8	37.3	36.7	37.1	35.1	48.5	48.1	49.0	48.3	49.9	49.1	50.2	48.9	48.7	48.8	47.5
		-	-	-	-	-	-	-	-	-	-	-	48.9	49.5	49.7	48.8	49.1	52.3
Ca Hardness	mg/L ^(a)	31.4	34.0	30.9	31.0	31.0	29.3	41.4	41.2	42.0	41.2	42.6	41.3	42.7	41.4	41.2	41.2	40.2
Mg Hardness	mg/L ^(a)	6.4	7.8	6.4	5.7	6.1	5.9	7.0	6.9	7.0	7.1	7.3	7.7	7.6	7.5	7.5	7.6	7.3
As (total)	µg/L	37.6	39.0	36.6	0.5	4.4	0.2	34.9	34.7	34.9	8.8	22.8	35.8	35.9	35.9	24.2	33.2	0.2
		-	-	-	-	-	-	-	-	-	-	-	35.8	36.8	35.1	25.2	32.5	0.2
As (soluble)	µg/L	-	-	-	-	-	-	36.7	36.5	35.3	9.4	23.2	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	21.9	0.4	0.2	0.2	0.2	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	14.8	36.1	35.1	9.2	23.0	-	-	-	-	-	-
Total Fe	µg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soluble Fe	µg/L	-	-	-	-	-	-	<25	<25	<25	<25	<25	-	-	-	-	-	-
Total Mn	µg/L	8.3	<0.1	<0.1	<0.1	<0.1	0.1	8.4	0.4	0.4	0.3	0.3	8.6	<0.1	<0.1	0.1	<0.1	<0.1
		-	-	-	-	-	-	-	-	-	-	-	8.8	<0.1	0.1	<0.1	<0.1	<0.1
Soluble Mn	µg/L	-	-	-	-	-	-	8.2	0.3	0.4	0.4	0.5	-	-	-	-	-	-
Total Al	µg/L	14.6	33.9	28.9	18.6	21.4	11.8	<10	26.1	22.5	20.4	31.6	21.4	36.2	34.8	32.0	33.3	55.7
		-	-	-	-	-	-	-	-	-	-	-	21.3	36.1	33.2	37.1	35.0	25.1
Soluble Al	µg/L	-	-	-	-	-	-	<10	23.3	20.4	19.6	20.6	-	-	-	-	-	-

(a) as CaCO₃. (b) as PO₄. IN = At Wellhead, OA= After Oxidation Column (Train A), OB = After Oxidation Column (Train B), TA = After First Adsorption Column in Series (Train A), TB = After First Adsorption Column in Series (Train B), TC = After Second Adsorption Column in Series (Train A), TD = After Second Adsorption Column in Series (Train B), TE = After Third Adsorption Column in Series (Train A), TF = After Third Adsorption Column in Series (Train B), TT = After the Entire System

Analytical Results

Sampling Date		06/01/05							06/15/05						06/29/05				
Sampling Location		IN	OA	OB	TA	TB	TC	TD	IN	OA	OB	TA	TB	TT	IN	OA	OB	TC	TD
Parameter	Unit																		
Bed Volume	10 ^{^3}	-	-	-	10.2	10.3	-	-	-	-	-	11.8	12.0	11.9	-	-	-	13.8	13.8
Alkalinity	mg/L ^(a)	-	-	-	-	-	-	-	66	74	68	66	66	66	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	0.5	0.5	0.5	0.5	0.5	0.6	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	19	19	19	19	19	20	-	-	-	-	-
Sulfide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	<5	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	0.1	0.1	0.1	0.1	0.1	0.1	-	-	-	-	-
Orthophosphate	mg/L ^(b)	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-
Silica (as SiO ₂)	mg/L	-	-	-	-	-	-	-	10.7	9.8	10.0	8.7	9.3	5.5	-	-	-	-	-
Turbidity	NTU	-	-	-	-	-	-	-	0.5	<0.1	0.2	0.2	0.2	<0.1	-	-	-	-	-
pH	S.U.	8.0	8.6	8.4	8.3	8.3	-	-	8.2	8.4	8.4	8.4	8.4	8.1	8.2	8.3	8.3	8.3	8.3
Temperature	°C	10.5	10.5	10.5	11.3	11.3	-	-	10.7	10.7	10.7	10.9	10.9	11.0	12.9	11.9	11.6	12.5	12.9
DO	mg/L	3.6	3.5	3.7	3.8	3.3	-	-	0.9	0.8	0.7	0.8	0.9	0.9	2.1	1.4	1.4	1.2	1.3
ORP	mV	174	229	212	177	195	-	-	209	209	208	203	201	204	190	189	186	185	182
Total Hardness	mg/L ^(a)	51.1	51.5	50.4	48.5	50.8	47.2	48.7	50.8	49.4	54.0	49.9	51.1	47.0	53.7	53.5	52.0	87.0	84.3
Ca Hardness	mg/L ^(a)	44.2	43.5	42.6	40.7	43.4	40.2	41.9	42.6	41.2	45.0	41.7	42.7	40.0	45.7	45.3	44.2	74.0	71.9
Mg Hardness	mg/L ^(a)	6.9	7.9	7.8	7.8	7.4	7.0	6.8	8.2	8.2	9.0	8.2	8.4	7.0	8.0	8.1	7.8	13.0	12.4
As (total)	µg/L	39.9	45.3	45.8	42.6	46.6	2.9	6.0	42.6	41.1	44.5	49.1	46.9	0.3	42.3	39.2	38.9	58.4	54.7
As (soluble)	µg/L	39.6	45.3	45.5	42.6	46.4	-	-	-	-	-	-	-	-	42.6	39.4	39.4	46.3	44.3
As (particulate)	µg/L	0.3	<0.1	0.4	<0.1	0.2	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	12.1	10.4
As (III)	µg/L	25.1	0.8	0.4	0.4	0.4	-	-	-	-	-	-	-	-	34.4	6.3	5.1	2.0	2.3
As (V)	µg/L	14.5	44.6	45.0	42.2	46.0	-	-	-	-	-	-	-	-	8.2	33.1	34.3	44.3	42.0
Total Fe	µg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	42.2	<25	<25	<25	80.4	87.1
Soluble Fe	µg/L	<25	<25	<25	<25	<25	-	-	-	-	-	-	-	-	<25	<25	<25	<25	<25
Total Mn	µg/L	10.8	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	13.1	0.1	<0.1	0.1	0.1	0.3	16.1	0.1	0.1	10.1	10.0
Soluble Mn	µg/L	9.8	<0.1	<0.1	0.1	<0.1	-	-	-	-	-	-	-	-	15.2	<0.1	<0.1	<0.1	<0.1
Total Al	µg/L	16.3	33.0	33.2	33.3	31.3	30.4	29.9	10.5	32.6	32.5	30.5	31.3	29.0	12.5	32.0	30.6	138	132
Soluble Al	µg/L	<10	26.7	24.9	41.1	24.5	-	-	-	-	-	-	-	-	<10	29.1	28.8	27.9	27.8

(a) as CaCO₃. (b) as PO₄. IN = At Wellhead, OA= After Oxidation Column (Train A), OB = After Oxidation Column (Train B), TA = After First Adsorption Column in Series (Train A), TB = After First Adsorption Column in Series (Train B), TC = After Second Adsorption Column in Series (Train A), TD = After Second Adsorption Column in Series (Train B), TE = After Third Adsorption Column in Series (Train A), TF = After Third Adsorption Column in Series (Train B), TT = After the Entire System

Analytical Results

Sampling Date		07/13/05						07/27/05						
Sampling Location		IN	OA	OB	TC	TD	TT	IN	OA	OB	TC	TD	TE	TF
Parameter	Unit													
Bed Volume	10 ³	-	-	-	-	-	15.8	-	-	-	17.3	17.5	17.3	17.5
Alkalinity	mg/L ^(a)	66	66	66	66	66	66	-	-	-	-	-	-	-
Fluoride	mg/L	0.5	0.5	0.5	0.5	0.5	0.5	-	-	-	-	-	-	-
Sulfate	mg/L	20	20	21	21	21	21	-	-	-	-	-	-	-
Sulfide	mg/L	<5	-	-	-	-	-	<5	-	-	-	-	-	-
Nitrate (as N)	mg/L	0.06	0.18	0.26	0.18	0.24	<0.05	-	-	-	-	-	-	-
Orthophosphate	mg/L ^(b)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	9.8	9.1	9.5	7.5	7.6	6.3	-	-	-	-	-	-	-
Turbidity	NTU	0.2	0.1	0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-
pH	S.U.	8.7	8.7	8.6	8.3	8.0	7.4	8.5	8.6	8.6	-	-	8.4	8.4
Temperature	°C	13.5	13.6	12.7	13.6	13.7	13.5	13.7	13.0	12.6	-	-	13.4	13.7
DO	mg/L	1.1	1.1	1.1	2.1	1.0	1.1	3.8	2.4	3.0	-	-	2.6	2.7
ORP	mV	178	179	177	179	176	179	184	180	181	-	-	183	183
Total Hardness	mg/L ^(a)	58.1	64.0	54.7	47.1	48.8	48.7	46.6	47.0	47.5	45.6	46.0	46.9	46.9
Ca Hardness	mg/L ^(a)	49.8	55.0	47.2	40.5	42.0	42.0	39.7	40.1	40.7	39.2	39.5	40.2	40.2
Mg Hardness	mg/L ^(a)	8.4	9.0	7.5	6.6	6.8	6.7	6.9	6.9	6.8	6.4	6.5	6.8	6.7
As (total)	µg/L	50.2	50.2	41.1	44.1	47.7	12.7	36.5	38.2	37.8	42.5	43.0	25.0	26.2
As (soluble)	µg/L	-	-	-	-	-	-	38.3	38.4	37.7	-	-	26.0	26.9
As (particulate)	µg/L	-	-	-	-	-	-	<0.1	<0.1	<0.1	-	-	<0.1	<0.1
As (III)	µg/L	-	-	-	-	-	-	38.0	3.3	3.7	-	-	0.4	0.4
As (V)	µg/L	-	-	-	-	-	-	0.2	35.1	33.9	-	-	25.5	26.6
Total Fe	µg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Soluble Fe	µg/L	-	-	-	-	-	-	<25	<25	<25	-	-	<25	<25
Total Mn	µg/L	21.9	0.1	0.1	<0.1	<0.1	<0.1	11.8	<0.1	0.1	<0.1	<0.1	<0.1	<0.1
Soluble Mn	µg/L	-	-	-	-	-	-	11.7	<0.1	<0.1	-	-	<0.1	<0.1
Total Al	µg/L	18.0	50.9	37.4	34.7	35.7	38.7	11.8	36.1	34.7	34.0	36.9	41.1	40.9
Soluble Al	µg/L	-	-	-	-	-	-	<10	33.0	30.9	-	-	37.7	38.0

(a) as CaCO₃. (b) as PO₄. IN = At Wellhead, OA= After Oxidation Column (Train A), OB = After Oxidation Column (Train B), TA = After First Adsorption Column in Series (Train A), TB = After First Adsorption Column in Series (Train B), TC = After Second Adsorption Column in Series (Train A), TD = After Second Adsorption Column in Series (Train B), TE = After Third Adsorption Column in Series (Train A), TF = After Third Adsorption Column in Series (Train B), TT = After the Entire System

Analytical Results

Sampling Date		08/09/05						08/24/05				
Sampling Location		IN	OA	OB	TC	TD	TT	IN	OA	OB	TE	TF
Parameter	Unit											
Bed Volume	10 ³	-	-	-	18.5	18.8	18.7	-	-	-	20.0	20.3
Alkalinity	mg/L ^(a)	66	65	67	67	66	63	-	-	-	-	-
Fluoride	mg/L	0.5	0.5	0.5	0.5	0.5	0.5	-	-	-	-	-
Sulfate	mg/L	21	20	21	21	21	21	-	-	-	-	-
Sulfide	mg/L	<5	-	-	-	-	-	<5	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	0.1	0.1	0.1	-	-	-	-	-
Orthophosphate	mg/L ^(b)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-
Silica (as SiO ₂)	mg/L	10.7	10	10.0	8.8	8.8	7.8	-	-	-	-	-
Turbidity	NTU	0.2	0.2	0.1	<0.1	<0.1	0.1	-	-	-	-	-
pH	S.U.	8.5	8.2	8.6	8.6	8.6	8.5	7.3	8.3	8.5	8.5	8.5
Temperature	°C	14.1	14.0	14.7	14.1	14.0	13.9	13.6	13.5	13.7	14.4	14.6
DO	mg/L	2.1	1.6	1.3	0.6	0.9	1.1	1.5	0.9	0.8	1.0	0.7
ORP	mV	148	168	167	170	170	178	177	173	173	173	175
Total Hardness	mg/L ^(a)	39.3	39.2	38.9	39.5	39.6	37.4	42.3	37.2	37.5	36.7	37.1
Ca Hardness	mg/L ^(a)	32.2	31.9	32.1	32.6	33.4	31.0	35.7	30.7	31.1	30.6	30.8
Mg Hardness	mg/L ^(a)	7.0	7.3	6.8	6.8	6.2	6.4	6.6	6.5	6.4	6.1	6.3
As (total)	µg/L	37.0	37.1	35.2	44.1	42.5	35.4	38.5	36.4	37.2	41.7	43.6
As (soluble)	µg/L	-	-	-	-	-	-	37.0	36.6	37.3	41.2	43.5
As (particulate)	µg/L	-	-	-	-	-	-	1.5	<0.1	<0.1	0.4	0.1
As (III)	µg/L	-	-	-	-	-	-	36.5	1.3	0.8	0.8	0.7
As (V)	µg/L	-	-	-	-	-	-	0.5	35.2	36.5	40.4	42.8
Total Fe	µg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Soluble Fe	µg/L	-	-	-	-	-	-	<25	<25	<25	<25	<25
Total Mn	µg/L	10.8	<0.1	0.2	<0.1	<0.1	0.2	11.0	<0.1	<0.1	<0.1	<0.1
Soluble Mn	µg/L	-	-	-	-	-	-	11.1	<0.1	<0.1	0.2	0.1
Total Al	µg/L	14.7	39.5	39.1	41.8	42.6	47.1	<10	36.6	33.5	37.0	38.0
Soluble Al	µg/L	-	-	-	-	-	-	<10	32.6	32.2	36.0	37.7

(a) as CaCO₃. (b) as PO₄. IN = At Wellhead, OA= After Oxidation Column (Train A), OB = After Oxidation Column (Train B), TA = After First Adsorption Column in Series (Train A), TB = After First Adsorption Column in Series (Train B), TC = After Second Adsorption Column in Series (Train A), TD = After Second Adsorption Column in Series (Train B), TE = After Third Adsorption Column in Series (Train A), TF = After Third Adsorption Column in Series (Train B), TT = After the Entire System