

**Arsenic Removal from Drinking Water by Adsorptive Media
U.S. EPA Demonstration Project at Dummerston, VT
Six-Month Evaluation Report**

by

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Sally Gutierrez, Director
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ABSTRACT

This report documents the activities performed during and the results obtained from the first six months (from June 22, 2005 through December 22, 2005) of the arsenic removal treatment technology demonstration project at Charette Mobile Home Park (CMHP) in Dummerston, Vermont. The objectives of the project are to evaluate 1) the effectiveness of an Aquatic Treatment Systems's (ATS) arsenic removal system in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 $\mu\text{g/L}$, 2) the reliability of the treatment system, 3) the required system operation and maintenance (O&M) and operator's skills, and 4) the capital and O&M cost of the technology. The project also characterizes water in the distribution system and residuals produced by the treatment process.

The ATS system consisted of two parallel treatment trains, each having three 10-inch diameter, 54-inch tall, sealed polyglass columns connected in series to treat up to 11 gal/min (gpm) of water. Water supplied from three source water wells was chlorinated to provide chlorine residuals and then passed through a 25- μm sediment filter and the three adsorption columns in each train. Each adsorption column was loaded with 1.5 ft^3 of A/I Complex 2000 adsorptive media, which consisted of an activated alumina substrate and a proprietary iron complex. Based on the design flowrate of 11 gpm, the empty bed contact time (EBCT) in each column was 1 min and the hydraulic loading rate to each column was 20.4 gpm/ft^2 . The actual flowrate was much lower, averaging only 4.4 and 3.2 gpm for Trains A and B, respectively, for the first 23 weeks from June 27 through November 26, 2005, and 1.4 and 1.9 gpm for the remainder of the reporting period. As a result, each adsorption column had a much longer EBCT, ranging from 1.8 to 34 min throughout the entire study period. The highly variable and slow flowrates from the wells might be attributed, in part, to slow recovery rates of the aquifer resulting from a dry summer.

Between June 22, 2005, and December 22, 2005, the system operated an average of 5.9 hr/day for a total of 1,100 hr, treating approximately 302,000 gal of raw water containing 30.4 to 72.2 $\mu\text{g/L}$ of arsenic existing predominately as As(V). Arsenic concentrations after the lead columns reached 10 $\mu\text{g/L}$ at approximately 5,400 bed volumes (BV) from Train A and 5,000 BV from Train B. (Note that BV was calculated based on 1.5 ft^3 [or 11.2 gal] of media in each column.) Arsenic existing mostly as As(V) approached complete breakthrough (concentration equal to those in the influent) following the lead columns at approximately 12,000 BV. Arsenic breakthrough from the lead columns occurred sooner than projected (at 40,000 BV) by the vendor. It is presumed that relatively high pH values of source water (averaging 7.8), competing anions, such as silica, and higher influent arsenic concentrations (i.e., 45.1 $\mu\text{g/L}$, on average, compared to 30 $\mu\text{g/L}$ observed during the initial site visit) might have contributed to early arsenic breakthrough from the adsorption columns.

Aluminum concentrations (existing primarily in the soluble form) in the treated water following adsorption columns were approximately 10 to 30 $\mu\text{g/L}$ higher than those in raw water, indicating leaching of aluminum from the adsorptive media. Leaching of aluminum continued throughout the study period; however, there was a decreasing trend in aluminum in the treated water during the six months of evaluation.

Comparison of distribution system sampling results before and after operation of the system showed a significant decrease in arsenic concentrations at two of the three residences during the first six months of system operation. One residence had arsenic concentrations ranging from 16.3 to 26.0 $\mu\text{g/L}$ through the first three months of system operation. Starting from the fourth month, all three residences had arsenic concentrations below 3.1 $\mu\text{g/L}$. Lead and copper levels did not appear to have been impacted by the treatment system.

The capital investment cost of \$14,000 included \$8,990 for equipment, \$2,400 for site engineering, and \$2,610 for installation. Using the system's rated capacity of 22 gpm (or 31,680 gal/day [gpd]), the capital cost was \$636/gpm (or \$0.44/gpd).

O&M costs included only incremental cost associated with the adsorption system, such as media replacement and disposal, chemical supply, electricity consumption, and labor. The incremental cost for electricity was negligible. Although media replacement and disposal did not take place during the first six months of operation, the cost to change out two lead adsorption columns was estimated at \$2,785 based on information provided by the vendor. This cost was used to estimate the media replacement cost per 1,000 gal of water treated as a function of the media run length to the 10- $\mu\text{g/L}$ arsenic breakthrough from the third column in series.

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ABBREVIATIONS AND ACRONYMS

AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
As	arsenic
ATS	Aquatic Treatment Systems
bgs	below ground surface
BV	bed volume(s)
Ca	calcium
C/F	coagulation/filtration
Cl	chlorine
CMHP	Charette Mobile Home Park
Cu	copper
DO	dissolved oxygen
EBCT	empty bed contact time
EPA	U.S. 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
MEI	Magnesium Elektron, Inc.
Mg	magnesium
Mn	manganese
N/A	not analyzed
Na	sodium
NaOCl	sodium hypochlorite
ND	not detected
NRMRL	National Risk Management Research Laboratory
NSF	NSF International

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
TO	Task Order
VDEC	Vermont Department of Environmental Conservation
VSHA	Vermont State Housing Authority

1.0 INTRODUCTION

1.1 Background

The Safe Drinking Water Act (SDWA) mandates that the U. S. Environmental Protection Agency (EPA) identify and regulate drinking water contaminants that may have adverse human health effects and that 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 required 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 sites 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 project. 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 December 2006, 11 of the 12 systems were operational and the performance evaluations of six systems were 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 Charette Mobile Home Park (CMHP) in Dummerston, Vermont.

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, four sites have withdrawn 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 CMHP 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 three AM systems), 13 coagulation/filtration (C/F) systems, two ion exchange (IX) systems, 17 point-of-use (POU) units (including nine under-the-sink reverse osmosis [RO] units at the Sunset Ranch Development site and eight AM units at the OIT site), and one system modification. 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. An overview of the technology selection and system design for the 12 Round 1 demonstration sites and the associated capital cost is reported in two EPA reports (Wang et al., 2004; Chen et al., 2004), which are posted on the EPA Web site at <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.
- Characterize process residuals produced by the technologies.
- Determine the capital and O&M costs of the technologies.

This report summarizes the performance of the ATS system at the CMHP site in Vermont during the first six months from June 22 through December 22, 2005. The types of data collected included system operation, water quality data (both across the treatment train and in the distribution system), residuals, and capital and preliminary O&M cost.

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.)
Northeast/Ohio							
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 ^(b)	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 ^(c)	7.3
Newark, OH	Buckeye Lake Head Start Building	AM (ARM 200)	Kinetico	10	15 ^(a)	1,312 ^(c)	7.6
Springfield, OH	Chateau Estates Mobile Home Park	AM (E33)	AdEdge	150	25 ^(a)	1,615 ^(c)	7.3
Great Lakes/Interior Plains							
Brown City, MI	City of Brown City	AM (E33)	STS	640	14 ^(a)	127 ^(c)	7.3
Pentwater, MI	Village of Pentwater	C/F (Macrolite)	Kinetico	400	13 ^(a)	466 ^(c)	6.9
Sandusky, MI	City of Sandusky	C/F (Aeralater)	USFilter	340	16 ^(a)	1,387 ^(c)	6.9
Delavan, WI	Vintage on the Ponds	C/F (Macrolite)	Kinetico	40	20 ^(a)	1,499 ^(c)	7.5
Greenville, WI	Town of Greenville	C/F (Macrolite)	Kinetico	375	17	7827 ^(c)	7.3
Climax, MN	City of Climax	C/F (Macrolite)	Kinetico	140	39 ^(a)	546 ^(c)	7.4
Sabin, MN	City of Sabin	C/F (Macrolite)	Kinetico	250	34	1,470 ^(c)	7.3
Sauk Centre, MN	Big Sauk Lake Mobile Home Park	C/F (Macrolite)	Kinetico	20	25 ^(a)	3,078 ^(c)	7.1
Stewart, MN	City of Stewart	C/F&AM (E33)	AdEdge	250	42 ^(a)	1,344 ^(c)	7.7
Lidgerwood, ND	City of Lidgerwood	Process Modification	Kinetico	250	146 ^(a)	1,325 ^(c)	7.2
Midwest/Southwest							
Lyman, NE ^(d)	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 ^(c)	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
Far West							
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 ^(f)	Kinetico	75 gpd	52	134	7.5
Okanogan, WA	City of Okanogan	C/F (Electromedia-I)	Filtronics	750	18	69 ^(c)	8.0
Klamath Falls, OR	Oregon Institute of Technology	AM (Adsorbisia/ARM 200/ArsenX) and POU AM ^(g)	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) System reconfigured from parallel to series operation due to a reduced flowrate of 40 gpm.
- (c) Iron existing mostly as Fe(II).
- (d) Withdrawn from program in June 2006.
- (e) System reconfigured from parallel to series operation due to a reduced flowrate of 30 gpm.
- (f) Including nine residential units.
- (g) Including eight under-the-sink units.

2.0 SUMMARY AND CONCLUSIONS

Based on the information collected during the first six months of 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:

- A/I Complex 2000 adsorptive media was effective in removing arsenic to below its MCL of 10 µg/L. The run length to breakthrough at 10 µg/L, however, was short, ranging from 5,000 to 5,400 bed volumes (BV) for the two lead columns. Complete breakthrough from the lead columns occurred at approximately 12,000 BV, resulting in an adsorptive capacity of approximately 0.46 µg of As/mg of media. Note that the number of BV was calculated based on the volume of media in each column.
- Arsenic breakthrough from the lead columns occurred much sooner than projected (at 40,000 BV) by the vendor. It is presumed that relatively high pH values of the source water (averaging 7.8), competing anions, such as silica (see discussion under next bullet), and higher-than-expected influent arsenic concentrations (ranging from 30.4 to 72.2 µg/L and averaging 45.1 µg/L) might have contributed to the early arsenic breakthrough. The vendor's estimate was based on an influent arsenic concentration of 30 µg/L. However, the vendor's arsenic breakthrough also was projected using an EBCT of 1 min/column based on a flowrate of 11 gpm per treatment train. This EBCT was 2.6 to 8.1 times shorter than the actual EBCT that was caused by the low flowrates experienced by the source water wells.
- The presence of competing anions also might have contributed to the early arsenic breakthrough. The media was shown to be especially selective for silica, which continued to be removed even after the arsenic removal capacity was completely exhausted. Similar observations also were made at the Spring Brook Mobile Home Park (SBMHP) site in Wales, Maine, where similar concentrations of silica were measured in source water (Lipps et al., 2006).
- Aluminum concentrations (existing primarily in the soluble form) following the adsorptive columns were approximately 10 to 30 µg/L higher than those in raw water, indicating leaching of aluminum from the adsorptive media. The concentrations detected were below its secondary drinking water standard.

Simplicity of required system operation and maintenance and operator skill levels:

- The daily demand on the operator was typically 20 min to visually inspect the system and record operational parameters. Due to the small size of the system, operational parameters were only recorded three days per week.
- Operation of the As/2200CS 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/2200CS 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.

Technology Costs:

- Using the system's rated capacity of 22 gal/min (gpm) (or 31,680 gal/day [gpd]), the capital cost was \$636/gpm (or \$0.44/gpd).
- Although media replacement and disposal did not take place during the first six months of operation, the cost to change out two adsorption columns at a time was estimated to be \$2,785 based on information provided by the vendor.

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 June 22, 2005. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall performance of the system was evaluated based on its ability to consistently remove arsenic to below the target MCL of 10 µg/L through the collection of 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 Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	September 14, 2004
Project Planning Meeting Held	November 18, 2004
Draft Letter of Understanding Issued	December 2, 2004
Final Letter of Understanding Issued	January 12, 2005
Request for Quotation Issued to Vendor	January 28, 2005
Vendor Quotation Submitted to Battelle	February 28, 2005
Purchase Order Completed and Signed	March 9, 2005
Final Study Plan Issued	April 1, 2005
Engineering Package Submitted to VDEC	April 29, 2005
Permit issued by VDEC	May 23, 2005
System Installation and Shakedown Completed	June 22, 2005
Performance Evaluation Begun	June 22, 2005

VDEC = Vermont Department of Environmental Conservation

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 treated water
Reliability	-Unscheduled system downtime -Frequency and extent of repairs including a description of problems, materials and supplies needed, and associated labor and cost
System O&M and Operator Skill Requirements	-Pre- and post-treatment requirements -Level of system automation for system operation and data collection -Staffing requirements including number of operators and laborers -Task analysis of preventative maintenance including number, frequency, and complexity of tasks -Chemical handling and inventory requirements -General knowledge needed of relevant chemical processes and health and safety practices
Residual Management	-Quantity and characteristics of aqueous and solid residuals generated by process
System Cost	-Capital cost for equipment, engineering, and installation -O&M cost for chemical and/or media usage, electricity, and labor

The O&M and operator skill requirements were evaluated based on a combination of quantitative data and qualitative considerations, including the need for pre- and/or post-treatment, level of system automation, extent of the preventive maintenance activities, frequency of chemical and/or media handling and inventory, and general knowledge needed for relevant chemical processes and related health and safety practices. The staffing requirements for 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 the O&M cost per 1,000 gal of water treated. This task required tracking the capital cost for equipment, engineering, and installation, as well as the O&M cost for media replacement and disposal, chemical usage, electricity consumption, and labor. The O&M cost was limited to electricity and labor because media replacement did not take place during the first 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 according to the instructions provided by the vendor and Battelle. On a daily basis, the plant operator recorded system operational data, such as pressure, flowrate, totalizer and hour meter readings on a Daily System Operation Log Sheet; checked the sodium hypochlorite (NaOCl) level; and conducted visual inspections to ensure normal system operations. If any problems occurred, the plant operator contacted the Battelle Study Lead, who determined if the vendor should be contacted for troubleshooting. The plant operator recorded all relevant information, including the problem encountered, course of actions taken, materials and supplies used, and associated cost and labor, on the Repair and Maintenance Log Sheet. On a biweekly basis, the plant operator measured several water quality parameters on-site, including pH, temperature, dissolved oxygen (DO), and oxidation-reduction potential (ORP), and recorded the data on a Biweekly On-Site Water Quality Parameters Log Sheet.

The capital cost for the arsenic removal system consisted of the cost for equipment, site engineering, and system installation. The O&M cost consisted of the cost for media replacement and spent media disposal, chemical usage, electricity consumption, and labor. Consumption of NaOCl was tracked on the Daily System Operation Log Sheet. Electricity consumption was determined from utility bills. Labor for various activities, such as the routine system O&M, troubleshooting and repair, and demonstration-related work, were tracked using an Operator Labor Hour Log Sheet. The routine system O&M included activities such as completing field logs, ordering supplies, performing system inspections, and others as recommended by the vendor. The labor for demonstration-related work, including activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead and the vendor, was recorded but not used for cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate the system performance, samples were collected from the wellhead, across the treatment plant, and from the distribution system. Table 3-3 provides the sampling schedules and analytes measured during each sampling event. Specific sampling requirements for 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). The procedure for arsenic speciation is described in Appendix A of the QAPP.

3.3.1 Source Water. During the initial visit to the CMHP site, one set of source water samples was collected and speciated using an arsenic speciation kit described in Section 3.4.1. The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Analyses for the source water samples are listed in Table 3-3.

Table 3-3. Sample Collection Schedules and Analyses

Sample Type	Sample Locations^(a)	No. of Samples	Frequency	Analytes	Collection Date(s)
Source Water	At Wellhead (IN)	1	Once during initial site visit	Off-site: As (total, 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.	9/14/04
Treatment Plant Water	At Wellhead (IN), after Chlorination (AC), after Each Adsorption Column (TA to TF), and after Entire System (TT)	4-9	Weekly or Biweekly	On-site: pH, temperature, DO, ORP, and Cl ₂ (free and total). Off-site: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), Al (total and soluble), Ca, Mg, F, NO ₃ , SO ₄ , SiO ₂ , PO ₄ , turbidity, and/or alkalinity.	06/22/05 , 07/05/05, 07/19/05, 08/03/05, 08/16/05 , 08/29/05, 09/19/05, 09/27/05, 10/13/05 , 10/25/05, 11/01/05, 11/08/05, 11/28/05, 12/13/05
Distribution Water	Three LCR Residences	3	Monthly ^(b)	pH, alkalinity, As, Fe, Mn, Al, Cu, and Pb.	Baseline sampling: 12/07/04, 01/04/05, 02/01/05, 04/05/05, Monthly sampling: 07/27/05, 08/16/05, 09/20/05, 10/13/05, 11/08/05, 11/27/05
Residual Solids	Spent Media from Adsorption Columns	6	Once	TCLP metals	To be determined

(a) Abbreviations in parentheses correspond to the sample locations shown in Figure 4-4.

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

Bold font indicates that speciation was performed.

3.3.2 Treatment Plant Water. During the system performance evaluation study, weekly or bi-weekly samples were collected by the plant operator at four to nine locations across the treatment train, including at the wellhead [IN], after chlorination [AC], after each adsorption column [TA to TF], and after the entire system [TT]. Speciation was performed for As, Fe, Mn, and Al approximately every other month. On-site measurements for pH, temperature, DO, and ORP also were performed during each sampling event.

3.3.3 Residuals. Because the system did not require backwash, no backwash residuals were produced during system operation. 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. 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, the arsenic, lead, and copper levels. Prior to the system startup from December 2004 to April

2005, four sets of baseline distribution water samples were collected from three residences within the distribution system. Following the system startup, distribution system sampling continued on a monthly basis at the same three locations. The three homes selected were residences that were included in the Lead and Copper Rule (LCR) sampling in the past.

The home owners collected samples following an instruction sheet developed according to the *Lead and Copper Rule Monitoring and 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 hr to ensure that stagnant water was sampled. The dates and times of last water usage prior to sampling and sample collection were recorded 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 kit 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 uses an anion exchange resin column to separate the soluble arsenic species, As(V) and As(III) (Edwards et al., 1998). Resin columns 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. For each sampling event, a sample cooler was prepared with the appropriate number and type of sample bottles, disc filters, and/or speciation kits. All sample bottles were new and contained appropriate preservatives. Each sample bottle was affixed with a pre-printed, colored-coded, waterproof label consisting of the sample identification (ID), date and time of sample collection, collector's name, site location, sample destination, analysis required, and preservative. The sample ID consisted of a two-letter code for the specific water facility, sampling date, a two-letter code for a specific sampling location, and a one-letter code for designating the arsenic speciation bottle (if necessary). The sampling locations at the treatment plant were color-coded for easy identification. The labeled bottles for each sampling location were placed in a ziplock bag (each corresponding to a specific sample location) in the cooler. On a monthly basis, the sample cooler also included bottles for the distribution system sampling.

In addition, all sampling and shipping-related supplies, such as disposable gloves, sampling instructions, chain-of-custody forms, prepaid/pre-addressed FedEx air bills, and bubble wrap, were placed in each cooler. The chain-of-custody forms and air bills were completed except for the operator's signature and the sample date and time. After preparation, the sample cooler was sent to the site via FedEx for the following week's sampling event.

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, the sample custodian verified that all samples indicated on the chain-of-custody forms were included and intact. Sample IDs were checked against the chain-of-custody forms, and the samples were logged into the laboratory sample receipt log. Discrepancies noted by the sample custodian were addressed with the plant operator by the Battelle Study Lead.

Samples for metal analyses were stored at Battelle's Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS) Laboratory. Samples for other water quality analyses were packed in separate coolers and picked up by couriers from American Analytical Laboratories (AAL) in Columbus, Ohio, and TCCI

Laboratories in New Lexington, Ohio, both of which were under contract with Battelle for this demonstration study. 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 described in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2004) were followed by Battelle ICP-MS, AAL, and TCCI Laboratories. Laboratory quality assurance/quality control (QA/QC) of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection limits (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 upon completion of the Arsenic Demonstration Project.

Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a WTW Multi 340i handheld meter, which was calibrated for pH and DO prior to use following the procedures provided in the user's manual. The ORP probe also was checked for accuracy by measuring the ORP of a standard solution and comparing it to the expected value. The plant operator collected a water sample in a clean, plastic beaker and placed the WTW probe in the beaker until a stable value was obtained. The plant operator also performed free and total chlorine measurements using Hach chlorine test kits following the user's manual.

4.0 RESULTS AND DISCUSSION

4.1 Facility Description

The CMHP water system at Dummerston, Vermont, supplies water to approximately 14 mobile homes. The water treatment building, shown in Figure 4-1, is located on Dummerston Station Road. The water source is groundwater from three bedrock supply wells (Wells No. 1, No. 2, and No. 3) installed in 1999. The total combined flowrate from the three wells was estimated to be approximately 22 gpm based on a flow test conducted by the plant operator. The average daily use rate was estimated to be approximately 2,500 gpd. The pre-existing system included a 5,500-gal atmosphere storage tank, two booster pumps, and four pressure tanks (Figure 4-2). The only treatment for the pre-existing water system was chlorination via injection of a 0.625% NaOCl solution for disinfection.



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

4.1.1 Source Water Quality. Source water samples were collected on September 14, 2004, and subsequently analyzed for the analytes shown in Table 4-1. 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 Vermont Department of Environmental Conservation (VDEC), are presented in Table 4-1.

Total arsenic concentrations of source water ranged from 7.0 to 30.0 $\mu\text{g/L}$. Based on the September 14, 2004, sampling results, the total arsenic concentration in the source water was 30.0 $\mu\text{g/L}$, of which 28.6 $\mu\text{g/L}$ (or 95%) was As(V).



Figure 4-2. Pre-Existing Pressure Tanks and Booster Pumps

Concentrations of iron ($<25 \mu\text{g/L}$) and other ions in raw water were sufficiently low meaning that pretreatment prior to the adsorption process would not be required. Concentrations of orthophosphate and fluoride also were sufficiently low (i.e., <0.05 and $<0.1 \text{ mg/L}$, respectively) and, therefore, should not affect the arsenic adsorption on the A/I Complex 2000 media. Silica concentration was 12.3 mg/L , similar to the level measured in source water at the SBMHP site in Wales, Maine. Because the A/I Complex 2000 media was shown to be especially selective for silica at the SBMHP site (Lipps et al., 2006), the effect of silica to the media for arsenic adsorption was carefully monitored throughout the study period.

4.1.2 Distribution System. Information provided by P² Environmental indicated that the distribution system consisted of a looped distribution line constructed of approximately 950 ft of 3-in lead pipe, 850 ft of 2-in polyvinyl chloride (PVC) pipe, and 500 ft of 1-in polyethylene pipe, according to a VDEC Sanitary Survey (P² Environmental, 2005).

Compliance samples from the distribution system are collected monthly for bacterial analysis. Under the EPA LCR, samples are collected from customer taps at four residences and the pump station every three years. A summary of the distribution system water sampling results collected by VDEC is presented in Table 4-1. Arsenic concentration measured was $30 \mu\text{g/L}$, similar to those in source water. Lead concentrations ranged from the method reporting limit to $6 \mu\text{g/L}$; copper concentrations ranged from the method reporting limit to $300 \mu\text{g/L}$. Radium-226 and Radium-228 were present at 0.2 and 0.5 pCi/L, respectively, which were less than the 5-pCi/L MCL.

Table 4-1. Source and Treated Water Quality Data for Charette Mobile Home Park Site

Parameter	Unit	Facility Source Water Data ^(a)	Battelle Source Water Data	VDEC Source Water Data	VDEC Treated Water Data
<i>Date</i>		-	9/14/04	1999–2004	2000–2004
pH		8.0	7.9	7.8–8.1	N/A
Total Alkalinity (as CaCO ₃)	mg/L	135	137	190–215	N/A
Hardness (as CaCO ₃)	mg/L	188	156	N/A	N/A
Turbidity	NTU	N/A	0.4	0.4–1.8	N/A
TDS	mg/L	N/A	246	200–210	N/A
TOC	mg/L	N/A	<0.7	N/A	N/A
Nitrate (as N)	mg/L	N/A	0.24	<0.1	N/A
Nitrite (as N)	mg/L	N/A	<0.01	<0.002	N/A
Ammonia (as N)	mg/L	N/A	<0.05	N/A	N/A
Chloride	mg/L	45	51	<0.2–53	N/A
Fluoride	mg/L	N/A	<0.1	<0.2	N/A
Sulfate	mg/L	N/A	20.0	17–18	N/A
Silica (as SiO ₂)	mg/L	N/A	12.3	N/A	N/A
Orthophosphate (as PO ₄)	mg/L	0.07	<0.06	N/A	N/A
As(total)	mg/L	27	30.0	7–28	30.0
As (total soluble)	mg/L	N/A	30.1	N/A	N/A
As (particulate)	mg/L	N/A	<0.1	N/A	N/A
As(III)	mg/L	N/A	1.5	N/A	N/A
As(V)	mg/L	N/A	28.6	N/A	N/A
Fe (total)	mg/L	17	<25	60–150	N/A
Fe (soluble)	mg/L	N/A	<25	N/A	N/A
Mn (total)	mg/L	N/A	5.1	20–60	N/A
Mn (soluble)	mg/L	N/A	4.2	N/A	N/A
Al (total)	mg/L	N/A	<10	N/A	N/A
Al (soluble)	mg/L	N/A	<10	N/A	N/A
U (total)	mg/L	N/A	2.0	N/A	N/A
U (soluble)	mg/L	N/A	2.0	N/A	N/A
V (total)	mg/L	N/A	0.8	N/A	N/A
V (soluble)	mg/L	N/A	0.6	N/A	N/A
Pb (total)	mg/L	N/A	N/A	<5	<5–6
Cu (total)	mg/L	N/A	N/A	<30	<30–300
Na (total)	mg/L	32	22	17–23	N/A
Ca (total)	mg/L	75	28	23–39	N/A
Mg (total)	mg/L	N/A	21	N/A	N/A
Ra-226	pCi/L	N/A	<1	N/A	0.2
Ra-228	pCi/L	N/A	<1	N/A	0.5
Radon	pCi/L	N/A	N/A	ND–2.8	N/A
Gross Alpha	pCi/L	N/A	N/A	ND–3	N/A

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

N/A = not analyzed

ND = not detected

4.2 Treatment Process Description

The ATS As/2200CS adsorption system used A/I Complex 2000 adsorptive media for arsenic removal. The A/I Complex 2000 media consisted of a substrate of activated alumina onto which a proprietary iron complex was chemically “grafted.” Table 4-2 presents physical and chemical properties of the adsorptive media. The media has NSF International Standard 61 listing for use in drinking water.

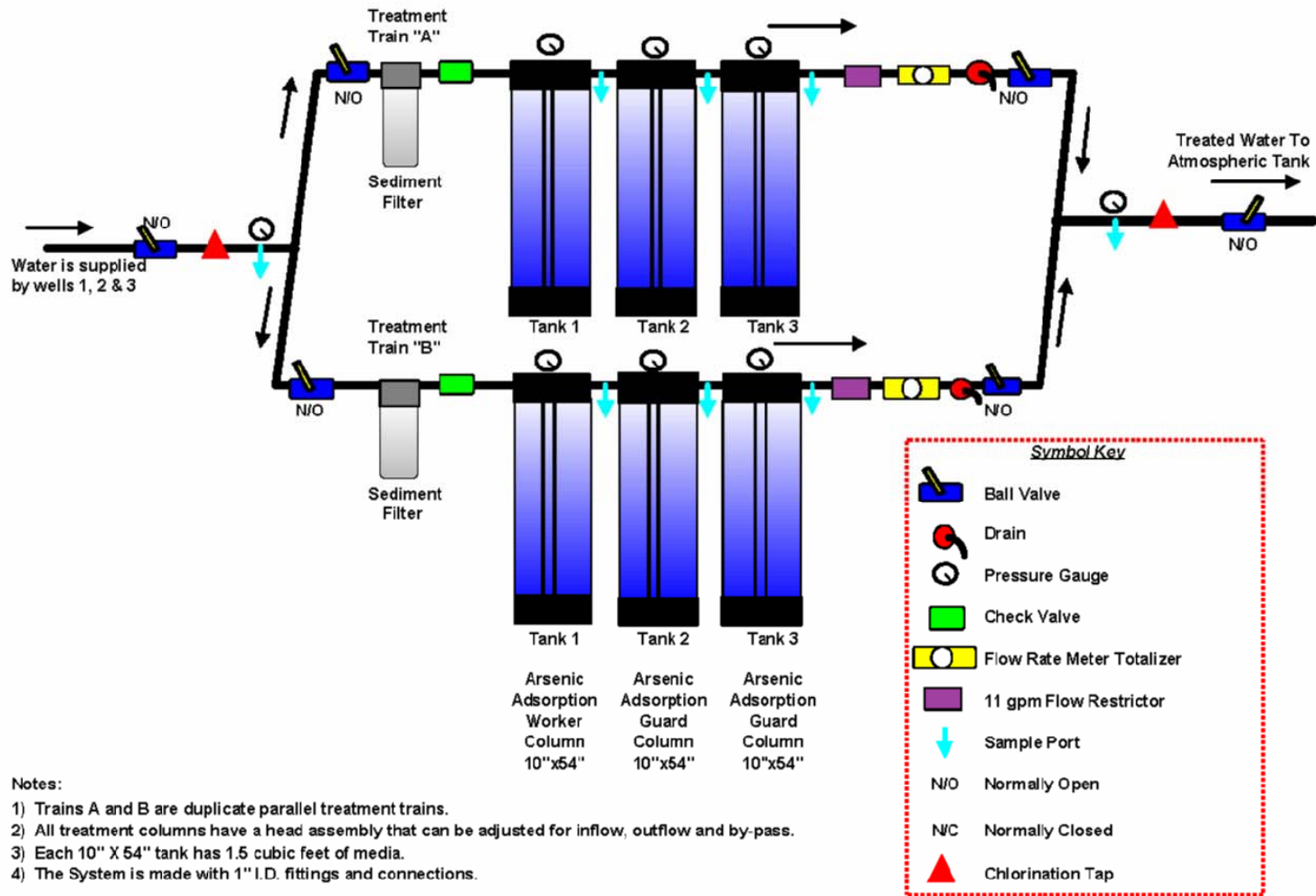
Table 4-2. Physical and Chemical Properties of A/I Complex 2000 Adsorption Media

<i>Physical Properties</i>	
Parameter	Value
Matrix	Activated alumina/iron complex
Physical Form	Granular solid
Color	Light brown/orange granules
Bulk Density (lb/ft ³)	51
Specific Gravity	1.5
Hardness (kg/in ²)	14–16
Particle Size Distribution (mesh)	28×48 (<2% fines)
Particle Size Distribution (mm)	0.589×0.295
BET Surface Area (m ² /g)	320
Attrition (%)	< 0.1
Moisture Content (%)	< 5
<i>Chemical Analysis</i>	
Constituent	Value
Al ₂ O ₃ (% , dry)	90.89
NaIO ₄ (% , dry)	3.21
Fe(NH ₄) ₂ (SO ₄) ₂ •6H ₂ O (% , dry)	5.90

The ATS As/2200 CS system was a six-column, fixed-bed downflow adsorption system designed for the CMHP with flowrates of around 22 gpm. The system consisted of two parallel treatment trains, each having three 10-in by 54-in, sealed polyglass columns connected in series (Figure 4-3). The system design planned for the lead column in each treatment train to be removed upon exhaustion and each of the lag columns to be moved forward one position (i.e. the first lag column became the lead column and the second lag column became the first lag column). A new column loaded with virgin media was then placed at the end of each treatment train as the second lag tank. This configuration should maximize the usage of the media capacity before its replacement. The spent media may be disposed of after being subjected to the EPA Toxicity Characteristic Leaching Procedure (TCLP) test.

Water pumped from the three wells was pre-chlorinated to maintain required chlorine residuals in the distribution system. The chemical feed system consisted of a day tank and a chemical feed pump with a maximum capacity of 1.0 gal/hr. The proper operation of the NaOCl feed system was tracked by the operator through measurements of free chlorine across the treatment train. To maintain a target-free chlorine residual of 0.2 to 0.4 mg/L (as Cl₂), a 0.625% NaOCl solution was injected into raw water at a rate of 0.44 mL/min when the well pumps were running.

After chlorination, water passed through a 25-µm sediment filter located at the head of each treatment train before going into the three adsorption columns, each containing 1.5 ft³ of A/I Complex 2000



Notes:

- 1) Trains A and B are duplicate parallel treatment trains.
- 2) All treatment columns 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.

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design by TJB/ATS
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Figure 4-3. Schematic of ATS As/2200CS System with Series Operation

adsorptive media. A flowmeter/totalizer was located on the downstream end of each treatment train to record the volume of water treated and measure the flowrate through each train.

Pressure gauges located at the system inlet just prior to the split to the two treatment trains, at the head of each column, and at the system outlet just after the two trains were combined, were used to monitor the system pressure and pressure drop across the treatment train. The treated water from each train combined before entering a 5,500-gal atmospheric storage 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 CMHP site is shown in Figure 4-5 and a close-up view of one of the adsorption columns is shown in Figure 4-6.

Table 4-3. Design Specifications of As/2200CS System

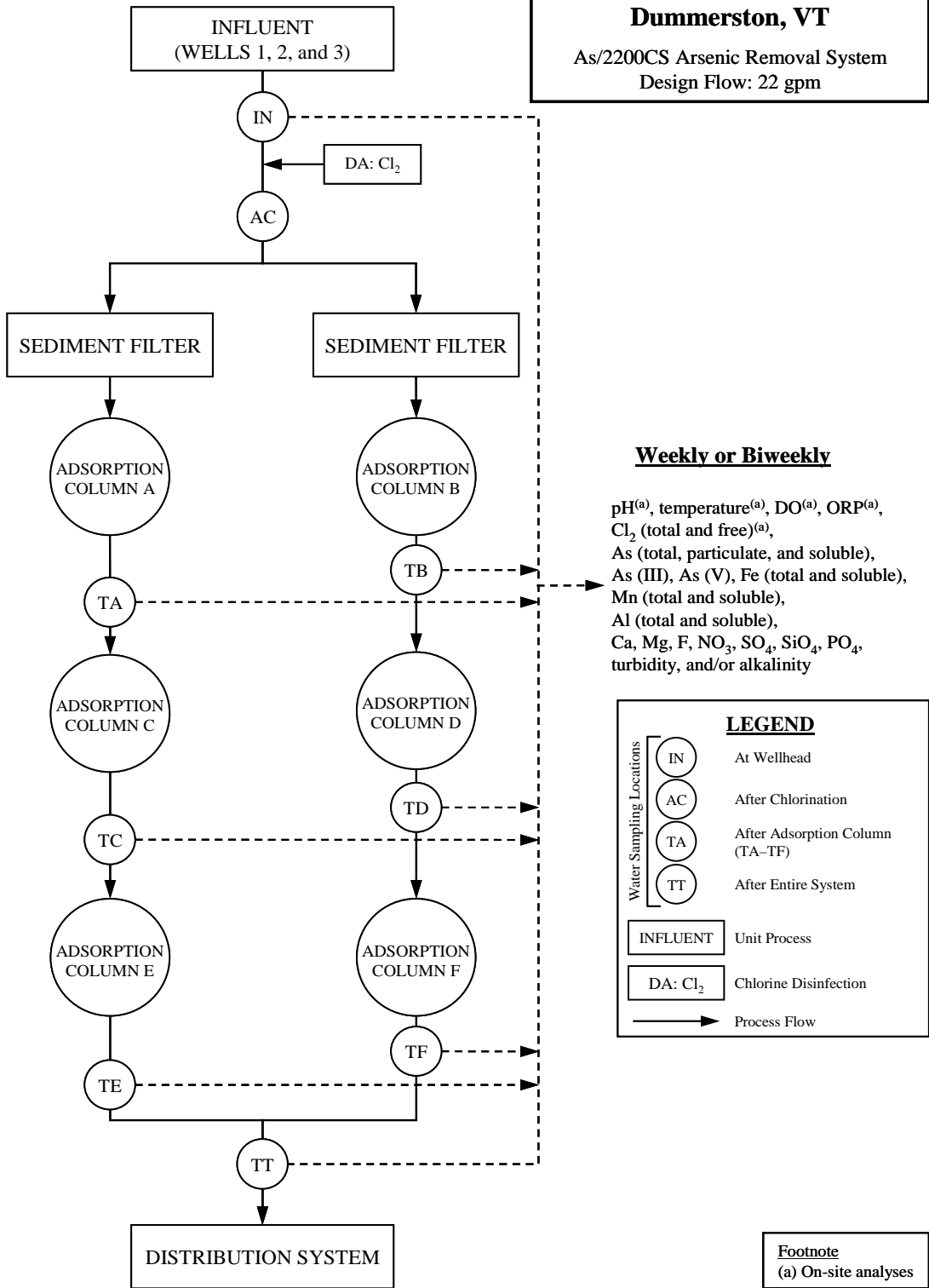
Parameter	Value	Remarks
<i>Adsorption Columns</i>		
Column Size (in)	10 D × 54 H	-
Cross-Sectional Area (ft ² /column)	0.54	-
Number of Columns	6	3 columns per train, 2 trains in parallel
Configuration	Series	3 columns in series per train
Media Type	A/I Complex 2000	-
Media Quantity (lbs)	83	Per column
Media Volume (ft ³)	1.5	Per column
<i>Service</i>		
System Flowrate (gpm)	22	11 gpm per train
Hydraulic Loading Rate (gpm/ft ²)	20.4	-
EBCT (min)/column	1.0	Per column, 3.0-min total EBCT for 3 adsorption columns in each train
Average Use Rate (gpd)	2,500	Based on usage estimate provided by park
Estimated Media Life (months)	12	Estimated frequency of media change-out in lead column based on throughput of 1,250 gpd per train
<i>Backwash</i>		
Backwash	-	No system backwash required

4.3 Permitting and System Installation

Engineering plans for the system were prepared by ATS and its subcontractor, Roberts & Franzoni Engineering, and submitted to VDEC for approval on April 29, 2005. The plans included a schematic of the As/2200CS system along with a written description of the system. The approval was granted by VDEC on May 23, 2005.

The system was placed in the existing treatment building, shown in Figure 4-1, without any modifications. The As/2200CS system, consisting of factory-packed adsorption columns and pre-assembled system valves, gauges, and sample taps, was delivered to the site by ATS on June 21, 2005. The system installation began that same day, including some re-work of the existing system piping. The sediment filters were attached to the wall at the head of each treatment train (Figure 4-5). The adsorption columns were then set into place and plumbed together using copper piping and connections. The

Charette Mobile Home Park in Dummerston, VT
 As/2200CS Arsenic Removal System
 Design Flow: 22 gpm



Note: After November 8, 2005, only As and SiO₄ analyzed at TA-TF locations and speciation performed bimonthly

Figure 4-4. Process Flow Diagram and Sampling Locations



Figure 4-5. As/2200CS System with Adsorption Columns Shown in Foreground and Sediment Filters Attached to Wall



Figure 4-6. Close-up View of a Sample Tap (TE), a Pressure Gauge, and Copper Piping at End of Treatment Train A

mechanical installation was complete on June 22, 2005. Before the system was put online, the system piping was flushed and the tanks were filled one at a time to check for leaks. Once all tanks were filled, the system was operated for a short period with the treated water going to the sewer. After it was determined that the system had been operating properly, a sample was collected for the total coliform measurement. Upon receipt of the test result (that indicated absence of bacteria), the treated water was directed to the distribution system. The first set of treatment plant water samples was collected on June 22, 2005, after installation and shakedown of the system were complete; but the system was by-passed until June 24, 2005, after the total coliform sample result was obtained.

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 June 22, 2005, through December 22, 2005, the treatment system operated for 1,100 hr based on hour meter readings of the well pumps. The operational time represented a utilization rate of approximately 25% over the 26-week study period with the well pumps operating an average of 5.9 hr/day. The total system throughput during this 26-week period was approximately 302,000 gal (or 151,000 per train).

Except for a few outliers, flowrates of the three source water wells ranged from 0.2 to 1.2 gpm and averaged 0.6 gpm for Well 1; from 0.8 to 3.1 gpm and averaged 1.9 gpm for Well 2; and from 3.7 to 5.0 gpm and averaged 4.3 gpm for Well 3 during the first 23 weeks of system operation. For unknown reasons, the flowrates of the source water wells reduced approximately by half (from 6.8 to 3.5 gpm for average combined flowrate) after the 23rd week of operation and remained low for the last four weeks of the study period. As shown in Figure 4-7, the average flowrate of Well 1 dropped from 0.7 to 0.2 gpm, Well 2 from 1.9 to 0.9 gpm, and Well 3 from 4.2 to 2.3 gpm.

The treatment system showed a similar drop in flowrates coinciding with the wells. The flowrate of Treatment Train A dropped from 4.4 to 1.4 gpm and Treatment Train B from 3.2 to 1.9 over the same time period. The ranges of flowrates throughout the first 23 weeks for Trains A and B were 0.6–5.6 and 0.3–6.4 gpm, respectively (compared to the design flowrate of 11 gpm per train) (Figure 4-7). These resulted in EBCT values ranging from 2.1 and 18 min per column for Train A and from 1.8 and 34 min per column for Train B (compared to the design EBCT of 1.0 min per column or 3.0 min for three columns). The average EBCT per column in Train A increased from 2.6 to 8.1 min and Train B from 3.6 to 5.9 min after the 23rd week of operation.

The highly variable flowrates are believed to have been caused, in part, by drying up and slow recovery rates of the source water wells. Based on the average flowrate and average daily operating time, the average daily use rate was approximately 1,641 gpd, which was about 65% of that provided by the park.

The pressure loss across each column ranged from 0 to 15 pounds per square inch (psi) and averaged 4 psi. The total pressure loss across each treatment train (three columns in series) averaged 13 psi. The average influent pressure at the head of the system from the wells was 13.5 psi, and the average pressure following the last column in each treatment train was 5 psi. The treated water was fed into a 5,500 gal atmospheric storage tank so the pressure was 0 psi at the tank and pre-existing pressure tanks and booster pumps were used to feed the distribution system from the atmospheric storage tank.

4.4.2 Residuals Management. The only residuals produced by the operation of the As/2200CS 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.

Table 4-4. Summary of As/2200CS System Operations

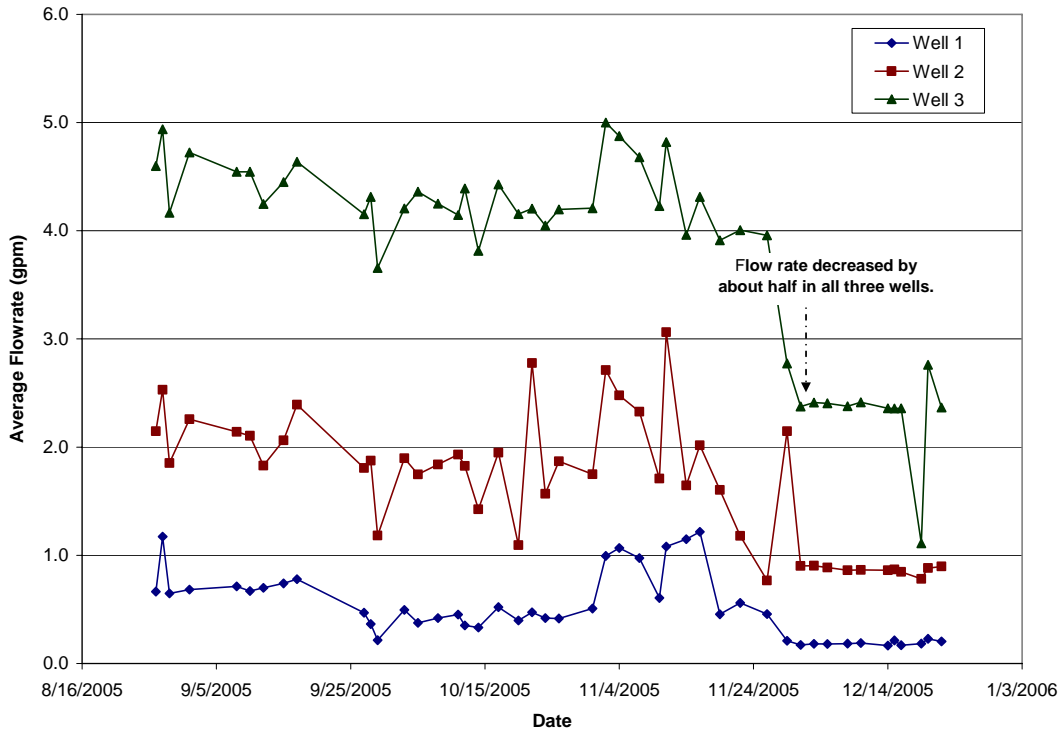
Operational Parameter	Value		
Operating Duration	June 24, 2005 to December 22, 2005		
Total Operating Time (hr)	1,100		
Average Daily Operating Time (hr/day)	5.9		
Throughput (gal for both trains)	302,000		
Throughput (BV per train) ^(a)	13,600 ^(b)		
Range of Flowrate of Source Water Wells (gpm)	<u>08/27/05 – 11/26/05</u>		<u>11/29/05 – 12/22/05</u>
	0.22 – 1.22	Well 1	0.17 – 0.23
	0.77 – 3.06	Well 2	0.78 – 0.90
	3.66 – 5.00	Well 3	1.11 – 2.77
Average Flowrate of Source Water Wells (gpm)	<u>08/27/05 – 11/26/05</u>		<u>11/29/05 – 12/22/05</u>
	0.63	Well 1	0.19
	1.93	Well 2	0.87
	4.33	Well 3	2.34
Range of Flowrates of Treatment Trains (gpm)	<u>06/27/05 – 11/26/05</u>		<u>11/29/05 – 12/22/05</u>
	0.6 – 5.6	Train A	0.8 – 4.1
	0.3 – 6.4	Train B	0.6 – 3.3
Average Flowrate of Treatment Trains (gpm)	<u>06/27/05 – 11/26/05</u>		<u>11/29/05 – 12/22/05</u>
	4.4	Train A	1.4
	3.2	Train B	1.9
Range of EBCT (min) ^(a) per column	<u>06/27/05 – 11/26/05</u>		<u>11/29/05 – 12/22/05</u>
	2.1 – 18	Train A	2.7 – 14
	1.8 – 34	Train B	3.4 – 20
Average EBCT (min) ^(a) per column	<u>06/27/05 – 11/26/05</u>		<u>11/29/05 – 12/22/05</u>
	2.6	Train A	8.1
	3.6	Train B	5.9
Range of Daily Use Rate (gpd)	300 – 4,500		
Average Daily Use Rate (gpd)	1,641		
Average Pressure Loss across Each Column (psi)	4		

(a) Calculated based on 1.5 ft³ (or 11.22 gal) of media in lead column.

(b) Arsenic breakthrough at 10 µg/L from lead columns at 5,000–6,000 BV and from the first lag columns at 12,500 BV.

4.4.3 System Operation, Reliability and Simplicity. One operational difficulty encountered was insufficient water from the three wells used to supply the treatment system. This might have been caused by a low water table resulting from a dry summer in Vermont. There also was an imbalance of flow to the two treatment trains during the first month of the demonstration. Train A was treating approximately 30% more water than Train B. Additional discussion regarding system operation and operator skill requirement are provided below.

Source Water Wells



Treatment Trains

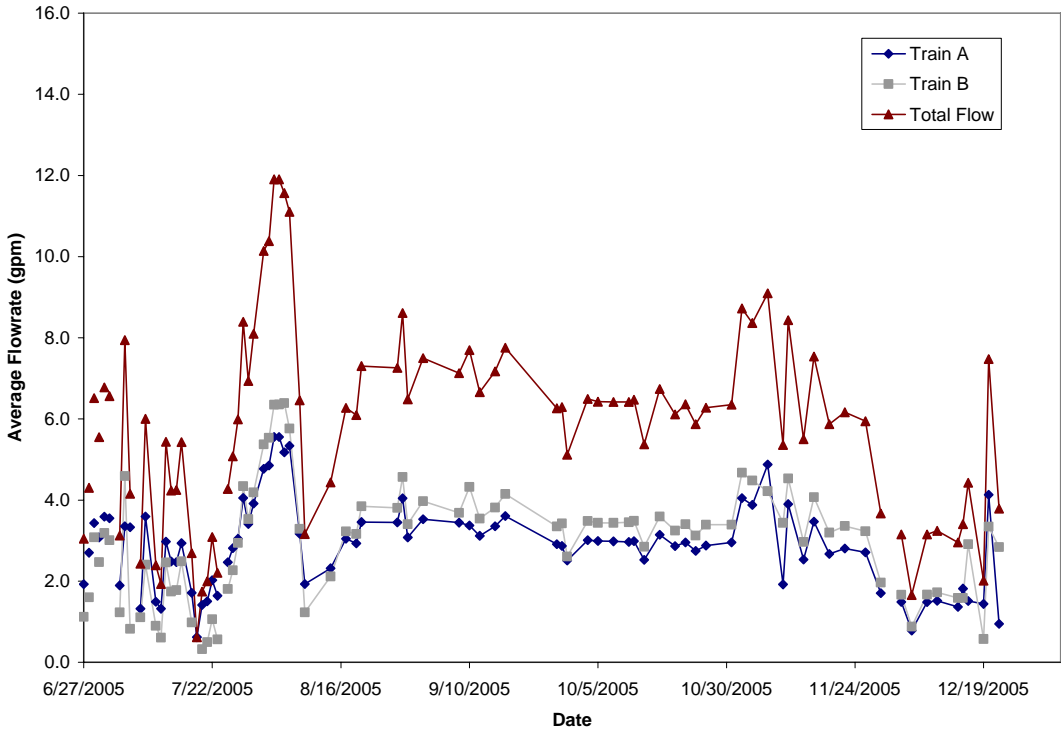


Figure 4-7. Average Flowrate of Three Source Wells and the Treatment System

Pre- and Post-Treatment Requirements. Because arsenic existed predominately as As(V), oxidation of As(III) to As(V) was not required. However, for disinfection purposes, prechlorination was performed using the pre-existing chlorine addition system. No other pre- or post-treatment was required for this system.

System Controls. The As/2200CS adsorption system was a passive system, requiring only the operation of the supply well pumps to send water through the adsorption columns to the 5,500-gal atmospheric storage tank and booster pumps to supply water to 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 pumps and booster pumps, which were in place prior to the installation of the ATS treatment system. The system operation was controlled by a float valve in the atmospheric storage tank.

Operator Skill Requirements. Under normal operating conditions, the skills required to operate the As/2200CS system were minimal. The operation of the 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 treatment system operator visited the site about three times per week to check the system for leaks, and record flow, volume, and pressure readings.

Chemical/Media Handling and Inventory Requirements. NaOCl was used for pre-chlorination. The operator ordered chemicals as had been done prior to the installation of the As/2200CS system.

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.

Arsenic. The key parameter for evaluating the effectiveness of the As/2200CS adsorption system was the concentration of arsenic in the treated water. The treatment plant water was sampled on 15 occasions during the first six months of system operation (including one event with duplicate samples taken), with field speciation performed on four of the 15 occasions.

Figure 4-8 contains four bar charts each showing the concentrations of total As, particulate As, As(III), and As(V) across Treatment Trains A and B and the entire system. Total As concentrations in raw water ranged from 30.4 to 72.2 µg/L and averaged 45.1 µg/L (Table 4-5). As(V) was the predominating species, ranging from 29.1 to 44.4 µg/L and averaging 39.3 µg/L. As(III) also was present in source water, ranging from 0.4 to 3 µg/L and averaging 1.8 µg/L. Particulate As was low with concentrations typically less than 1 µg/L. The influent arsenic concentrations measured during this six-month period were generally higher than those in the raw water sample collected on September 14, 2006 (Table 4-1).

Arsenic concentrations after the lead columns reached 10 µg/L at approximately 5,400 BV from Train A (TA) and 5,000 BV from Train B (TB) (Figure 4-9) (Note that BV was calculated based on the amount of

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

Parameter	Sampling Location	No. of Samples	Concentration (µg/L)			Standard Deviation
			Minimum	Maximum	Average	
As (total)	IN	15 ^(a)	30.4	72.2	45.1	12.7
	AC	1	25.7	25.7	25.7	-
	TA-TF	4-15 ^(a)	(b)			
	TT	12				
As (particulate)	IN	4	<0.1	1.20	0.34	0.58
	AC	1	<0.1	<0.1	<0.1	-
	TA-TD	2-3	(b)			
	TT	2				
As (III)	IN	4	0.4	3.0	1.8	1.1
	AC	1	0.5	0.5	0.5	-
	TA-TD	2-3	(b)			
	TT	2				
As (V)	IN	4	29.1	44.4	39.3	6.9
	AC	1	25.5	25.5	25.5	-
	TA-TD	2-3	(b)			
	TT	2				
Fe (total)	IN	15 ^(a)	<25	<25	<25	0.0
	AC	1	<25	<25	<25	-
	TA-TF	1-11 ^(a)	<25	<25	<25	0.0
	TT	12 ^(a)	<25	<25	<25	0.0
Fe (soluble)	IN	4	<25	<25	<25	0.0
	AC	1	<25	<25	<25	-
	TA-TD	2-3	<25	<25	<25	0.0
	TT	2	<25	<25	<25	0.0
Mn (total)	IN	15 ^(a)	1.7	35.9	7.8	8.5
	AC	1	12.1	12.1	12.1	-
	TA-TF	1-11 ^(a)	<0.1	0.8	0.2	0.2
	TT	12 ^(a)	<0.1	0.3	0.1	0.1
Mn (soluble)	IN	4	<0.1	9.5	4.8	4.8
	AC	1	1.2	1.2	1.2	-
	TA-TD	2-3	<0.1	0.8	0.3	0.3
	TT	2	<0.1	0.2	0.1	0.1
Al (total)	IN	15 ^(a)	<10	<10	<10	0.0
	AC	1	<10	<10	<10	-
	TA-TF	1-11 ^(a)	<10	30.3	17.1	5.6
	TT	12 ^(a)	12.1	27.4	21.0	4.9
Al (soluble)	IN	4	<10	<10	<10	0.0
	AC	1	10.2	10.2	10.2	-
	TA-TD	2-3	<10	20.8	13.5	5.4
	TT	2	14.1	20.9	17.5	4.8

Duplicate samples were included in the calculations.

(a) Including one duplicate sample

(b) Statistics not provided; see figure 4-8 for As breakthrough curves.

Table 4-6. Summary of Water Quality Parameter Measurements

Parameter	Sampling Location	Unit	No. of Samples	Minimum	Maximum	Average	Standard Deviation
Alkalinity (as CaCO ₃)	IN	mg/L	12	110	141	128	8.2
	TA-TF	mg/L	1-10	44	163	132	26.5
	TT	mg/L	9	110	154	136	13.7
Fluoride	IN	mg/L	12	<0.1	<0.1	0.05	0.00
	TA-TF	mg/L	1-10	<0.1	3.7	0.28	0.86
	TT	mg/L	9	<0.1	0.1	0.06	0.02
Sulfate	IN	mg/L	12	16	24	20.3	2.5
	TA-TF	mg/L	1-10	15	70	24.6	12.1
	TT	mg/L	9	17	28	21.7	3.2
Orthophosphate (as PO ₄)	IN	mg/L	8	<0.05	<0.05	<0.05	0.0
	TA-TD	mg/L	2-8	<0.05	<0.05	<0.05	0.0
	TT	mg/L	7	<0.05	<0.05	<0.05	0.0
Phosphorus (total)	IN	mg/L	5	<0.03	<0.03	<0.03	0.0
	TA-TF	mg/L	2-3	<0.03	<0.03	<0.03	0.0
	TT	mg/L	3	<0.03	<0.03	<0.03	0.0
Silica (as SiO ₂)	IN	mg/L	14	10.6	16.8	12.8	1.6
	TA-TF	mg/L	4-13	0.4	14.7	9.4	2.9
	TT	mg/L	11	0.3	9.2	5.9	3.4
Nitrate (as N)	IN	mg/L	11	<0.05	0.20	0.10	0.05
	TA-TF	mg/L	1-9	<0.05	0.10	0.08	0.03
	TT	mg/L	8	<0.05	0.40	0.13	0.12
Turbidity	IN	NTU	12	<0.1	1.3	0.3	0.4
	TA-TF	NTU	1-10	<0.1	1.6	0.2	0.3
	TT	NTU	9	<0.1	0.5	0.2	0.2
pH	IN	S.U.	13	7.0	8.2	7.8	0.4
	AC	S.U.	2	7.7	7.7	7.7	-
	TA-TF	S.U.	1-9	6.5	8.4	7.6	0.6
	TT	S.U.	10	7.0	8.3	7.6	0.5
Temperature	IN	°C	13	10.2	15.9	12.9	1.9
	TA-TF	°C	1-8	10.6	16.3	12.9	1.9
	TT	°C	10	10.4	17.2	13.8	2.6
Free Chlorine (as Cl ₂)	AC	mg/L	7	0.0	1.0	0.4	0.4
	TT	mg/L	10	0.0	0.5	0.2	0.1
Total Chlorine (as Cl ₂)	AC	mg/L	6	0.0	0.7	0.3	0.3
	TT	mg/L	7	0.0	0.5	0.3	0.2
Total Hardness (as CaCO ₃)	IN	mg/L	13	147	205	175	16.0
	TA-TF	mg/L	1-11	143	211	170	19.6
	TT	mg/L	10	150	214	173	19.1
Ca Hardness (as CaCO ₃)	IN	mg/L	13	69.5	92.8	80.9	7.2
	TA-TF	mg/L	1-11	62.9	96.2	78.9	9.5
	TT	mg/L	10	67.6	92.6	79.3	8.0
Mg Hardness (as CaCO ₃)	IN	mg/L	13	77.4	113	93.8	10.7
	TA-TF	mg/L	1-11	79.1	116	91.5	11.1
	TT	mg/L	10	82.4	125	93.8	13.1

One-half of detection limit used for nondetect samples for calculations.
Duplicate samples included in calculations.

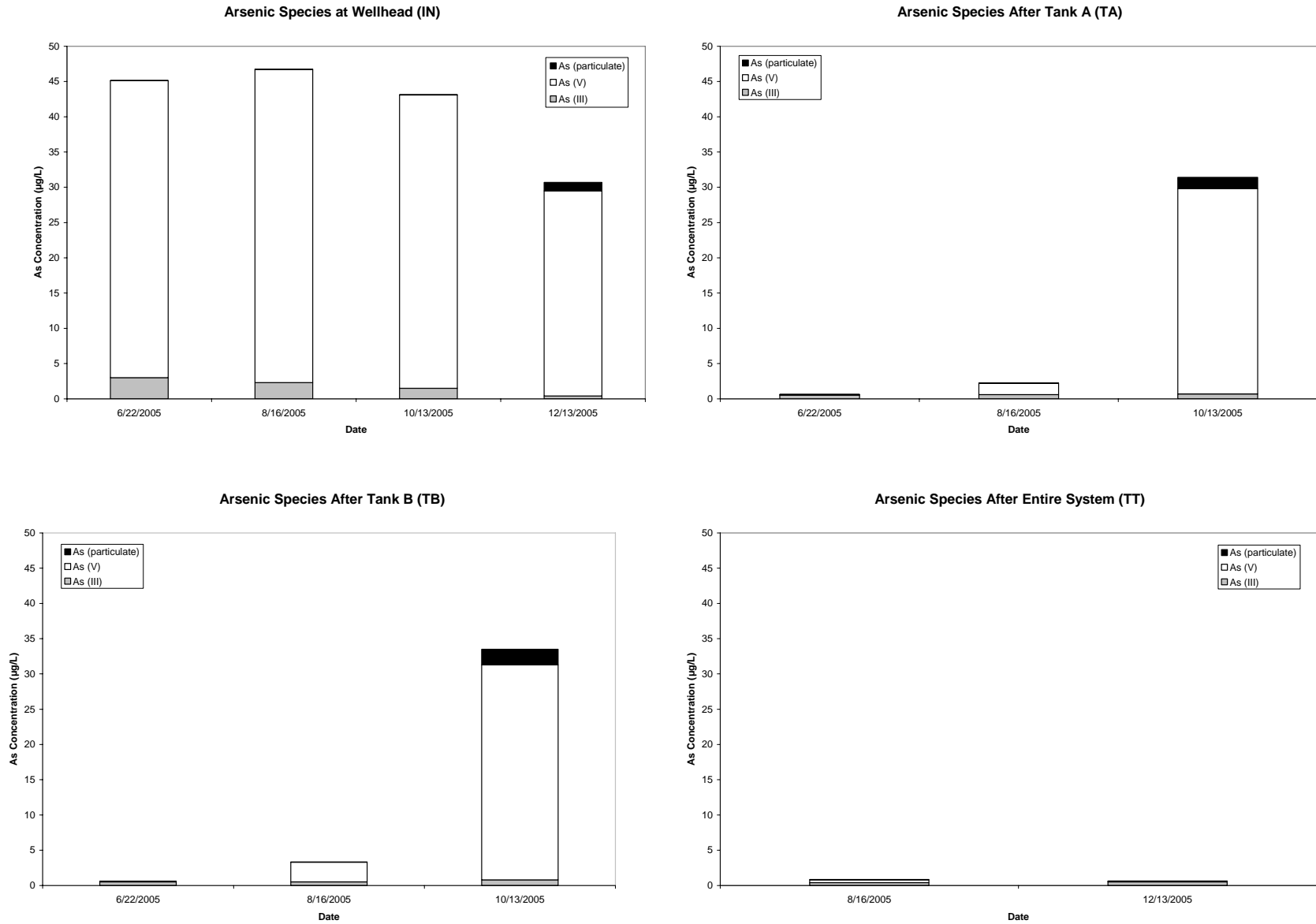


Figure 4-8. Concentrations of Various Arsenic Species Across Treatment Trains A and B and Entire System

media, i.e., 1.5 ft³, in each lead column.) Arsenic, existing almost entirely of As(V) (Figure 4-8), approached complete breakthrough (concentrations equal to those in the influent) after the lead columns at approximately 12,000 BV. Arsenic breakthrough from the lead columns occurred much sooner than projected by the vendor (i.e., at 40,000 BV). Although within the vendor-provided effective range of <9.0, the relatively high pH values of source water (averaging 7.8; see Table 4-6) might have contributed to early arsenic breakthrough from the adsorption columns. Influent arsenic concentrations during the six-month evaluation also were, on average, higher than those collected historically by the facility, Battelle, and VDEC. The vendor-estimated breakthrough was based on approximately 30 µg/L of As, compared to the average raw water arsenic concentration of 45.1 µg/L during the first six-months of operation. However, the vendor's arsenic breakthrough also was projected using an EBCT of 1 min/column based on a flowrate of 11 gpm per treatment train; this EBCT was much shorter than the actual EBCT and this flowrate was much higher than the actual flowrate (see Table 4-4).

Based on the breakthrough curves shown in Figure 4-9, the arsenic loading on the adsorption media was estimated to be between 0.44 and 0.47 µg of As/mg of media in the lead columns. The loading was calculated by dividing the arsenic mass represented by the shaded areas in Figure 4-10 by the amount of media (1.5 ft³) in each lead column. The arsenic mass removed by Columns A and B were estimated to be 16.4 and 15.1 g, respectively, as shown in Table 4-7.

Breakthrough curves for the first and second sets of lag columns (TC–TF) and the entire system (i.e., TT after Trains A and B combined) also are presented in Figure 4-9. Arsenic concentrations from the first set of lag columns (TC and TD) reached 10 µg/L at approximately 13,000 and 12,500 BV, respectively (or 6,500 and 6,250 BV, respectively, if considering the set of the lead and first lag columns in each train as one large column). Arsenic concentrations from the second lag column in each treatment train (TE and TF) and the system effluent remained below 10 µg/L throughout the first six months of evaluation.

Competing Anions. Among the anions analyzed, silica, sulfate, alkalinity (existing primarily as HCO₃⁻ at pH values between 7.0 and 8.2), and nitrate were present in raw water with significant concentrations (Table 4-6) and could compete with arsenic for adsorption sites. As shown in Figure 4-11, silica was consistently removed by, and did not reach complete breakthrough from the adsorption columns throughout the first six months of system operation. Of the other competitive anions, including HCO₃⁻, SO₄²⁻, and NO₃⁻, the adsorptive media showed little or no capacity (Figure 4-12).

Aluminum. As shown in Table 4-5, total aluminum concentrations in source water were below detection. Aluminum concentrations (existing primarily in soluble form) in the treated water following the adsorption columns were about 10 to 30 µg/L higher than those in raw water, indicating leaching of aluminum from the adsorptive media. With the increase in aluminum concentration following the treatment system, the concentrations, however, were below the secondary drinking water standard for aluminum of 50 to 200 µg/L. Leaching of aluminum continued throughout the study period; however, there was a decreasing trend in aluminum concentration in treated water during the six months of evaluation (Figure 4-13).

Iron and Manganese. Iron concentrations, both total and dissolved, were consistently less than the reporting limit of 25 µg/L in source water and across the treatment trains (Table 4-5). Manganese concentrations in source water also were low, ranging from 1.7 to 35.9 µg/L and averaging 7.8 µg/L. Manganese concentrations in the treated water following the adsorption columns were typically below the reporting limit (<1 µg/L), indicating complete removal of manganese by the adsorptive media.

Other Water Quality Parameters. Fluoride, orthophosphate, total phosphorus, total chlorine and hardness concentrations remained relatively constant throughout the treatment train.

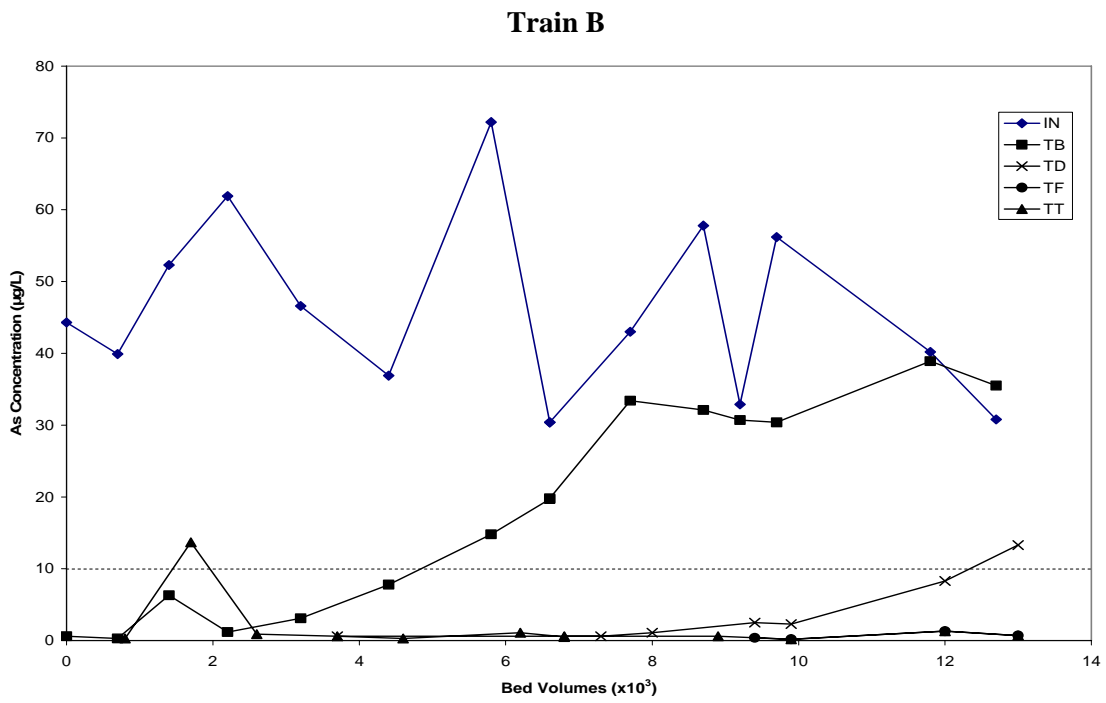
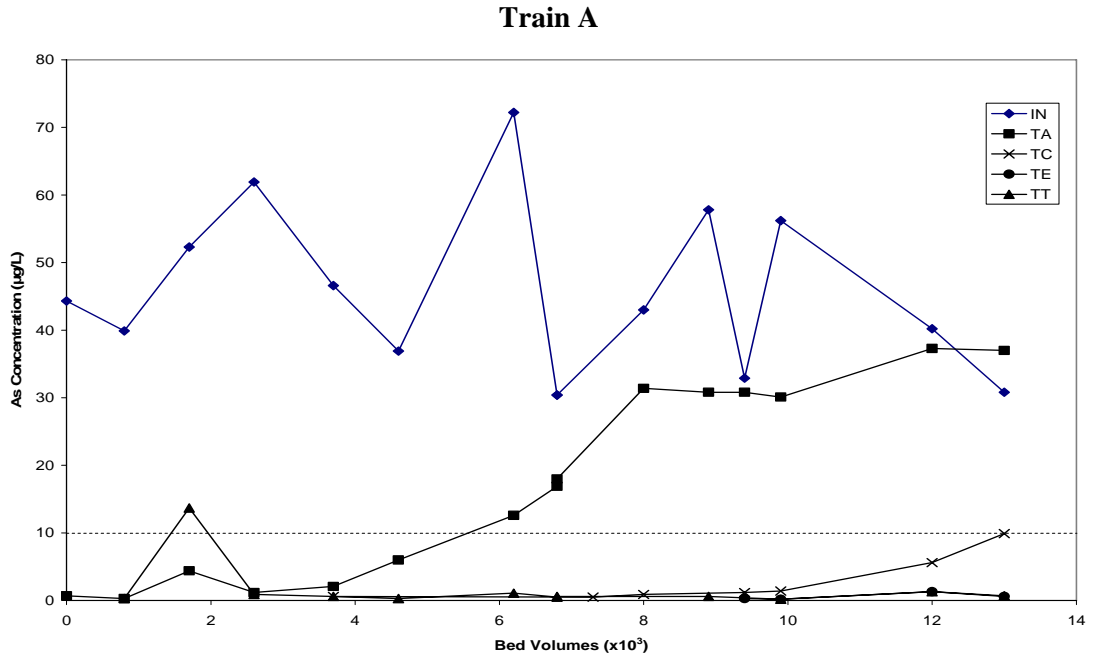
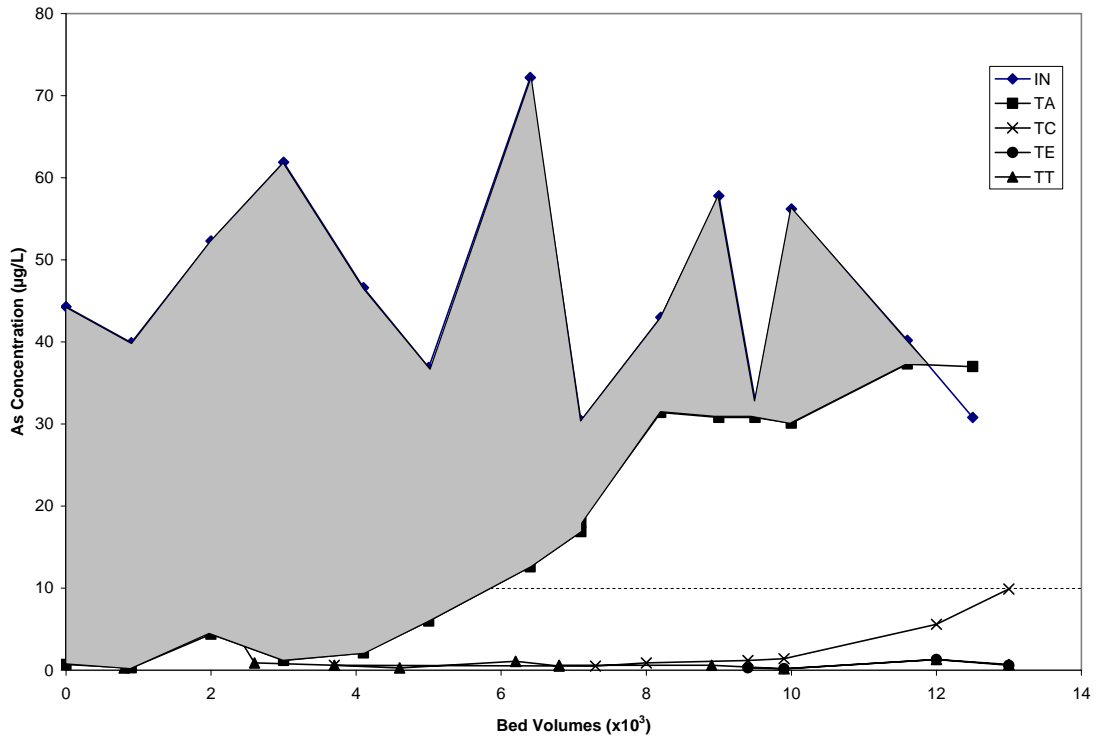


Figure 4-9. Total Arsenic Breakthrough Curves for Treatment Trains and Entire System (Each Column Breakthrough Curve Calculated Using Bed Volume of Each Column, i.e., 1.5 ft³)

Column A



Column B

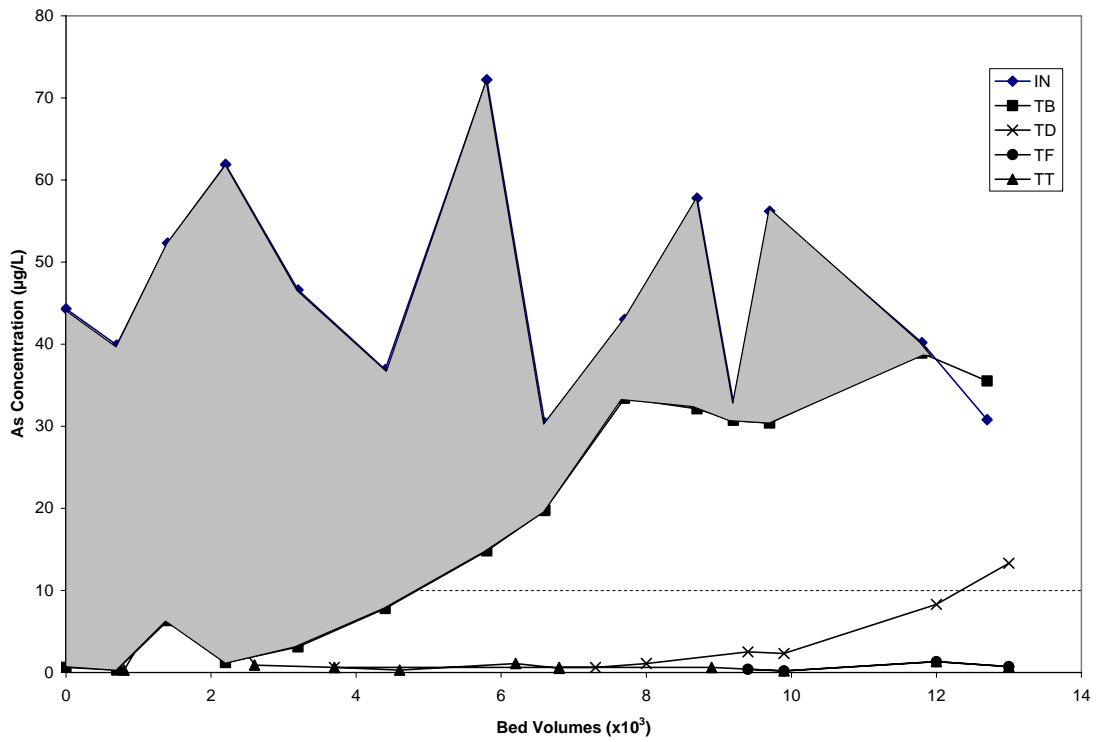


Figure 4-10. Arsenic Mass Removed by Columns A and B

Table 4-7. Arsenic Mass Removed by Columns A and B

Volume Treated (BV) ^(a)	Concentration (µg/L)			Mass Removed (µg) ^(b)
	Raw	After Column A	Difference	
0.0	44.30	0.70	43.60	-
900	39.90	0.30	39.60	1,588,460
1,100	52.30	4.40	47.90	2,042,912
1,000	61.90	1.20	60.70	2,306,240
1,100	46.60	2.10	44.50	2,459,140
900	36.90	6.00	30.90	1,439,807
1,400	72.20	12.60	59.60	2,692,737
700	30.40	16.90	13.50	1,087,288
1,100	43.00	31.40	11.60	586,116
800	57.80	30.80	27.00	654,072
500	32.90	30.80	2.10	310,047
500	56.20	30.10	26.10	301,553
1,600	40.20	37.30	2.90	985,355
Total Arsenic Removed by Column A				16,454,000

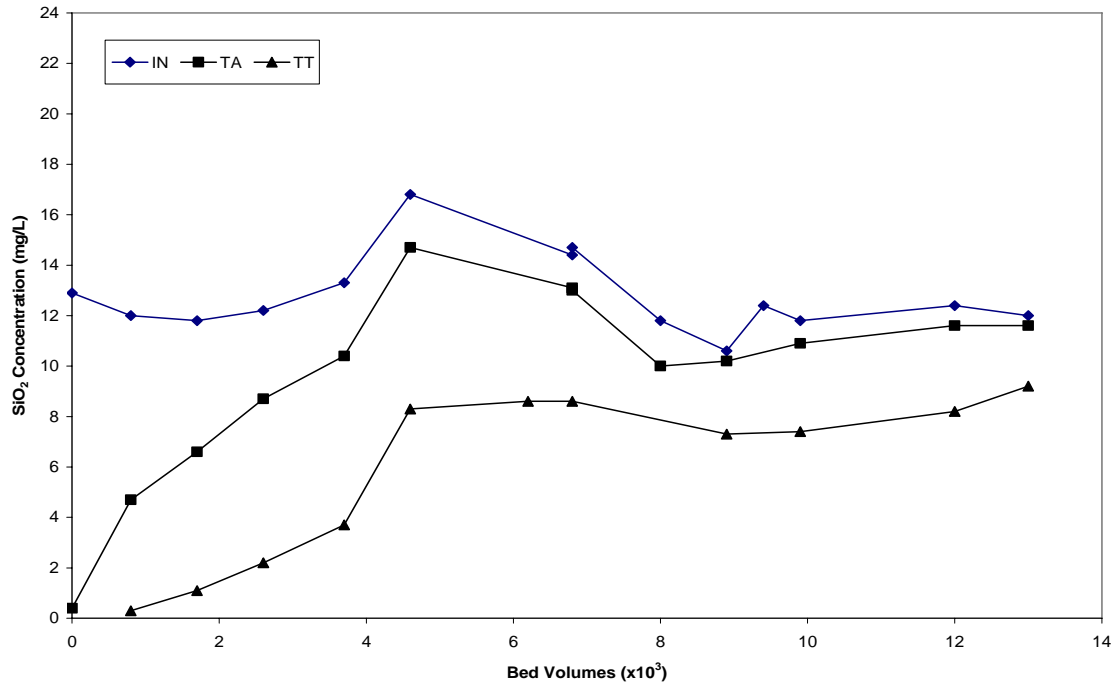
Volume Treated (BV) ^(a)	Concentration (µg/L)			Mass Removed (µg) ^(b)
	Raw	After Column B	Difference	
0.0	44.30	0.60	43.70	-
700	39.90	0.30	39.60	1,240,188
700	52.30	6.30	46.00	1,274,166
800	61.90	1.20	60.70	1,813,562
1,000	46.60	3.10	43.50	2,212,800
1,200	36.90	7.80	29.10	1,851,787
1,400	72.20	14.80	57.40	2,573,815
800	30.40	19.70	10.70	1,155,244
1,100	43.00	33.40	9.60	475,688
1,000	57.80	32.10	25.70	751,758
500	32.90	30.70	2.20	297,305
500	56.20	30.40	25.80	297,305
2,100	40.20	38.90	1.30	1,210,457
Total Arsenic Removed by Column B				15,154,000

(a) 1 BV = 1.5 ft³ = 11.22 gal = 42.41 L

(b) Mass Removed (µg) = average difference in concentration (µg/L) x Volume Treated (BV) x 42.41 (L/BV)

Media in each column = 34,700,400 mg based on a bulk density of 51 lb/ft³

Train A



Train B

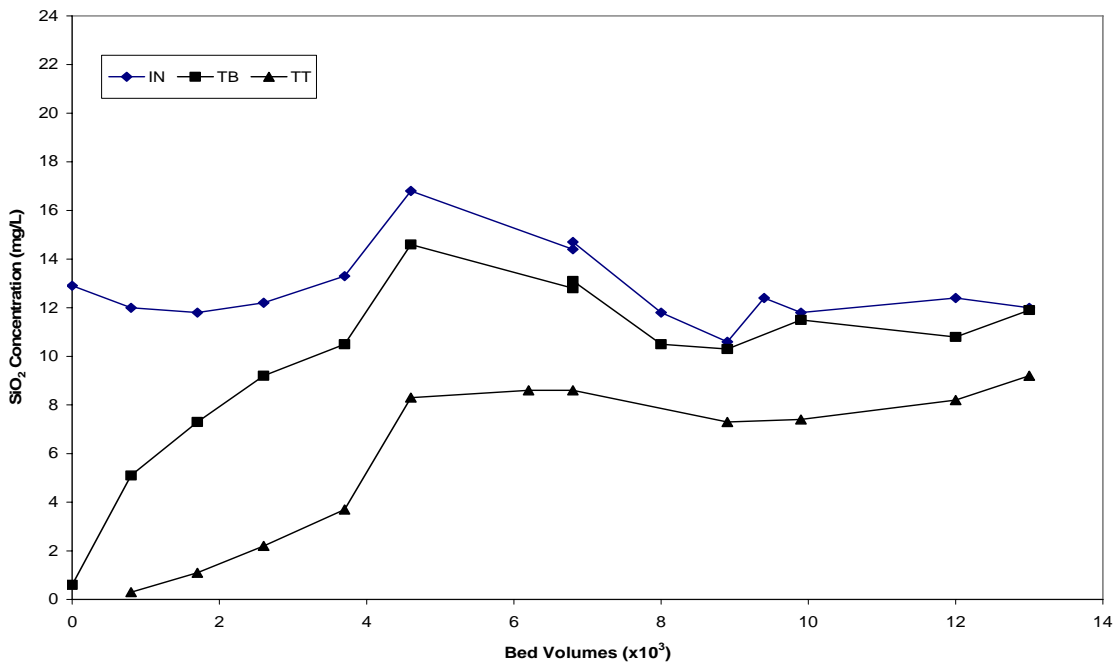


Figure 4-11. Silica Concentrations Across Treatment Trains and Entire System

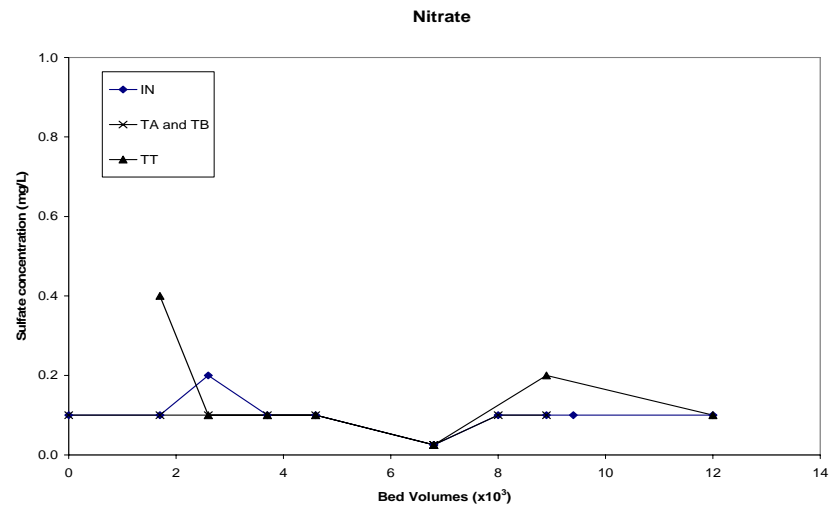
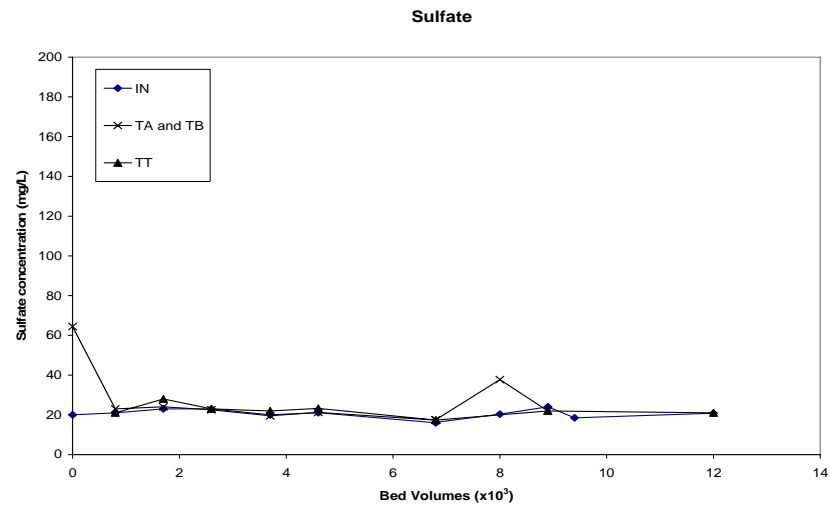
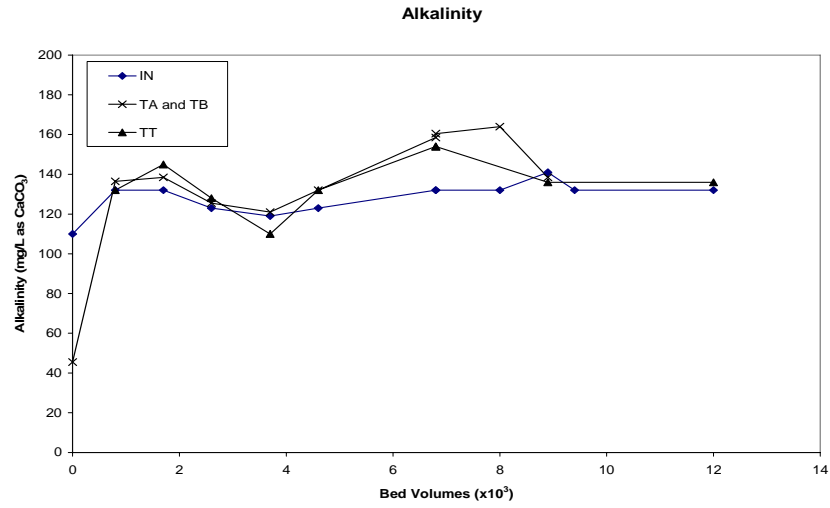


Figure 4-12. Alkalinity, Sulfate and Nitrate Concentrations Across Treatment Trains and Entire System

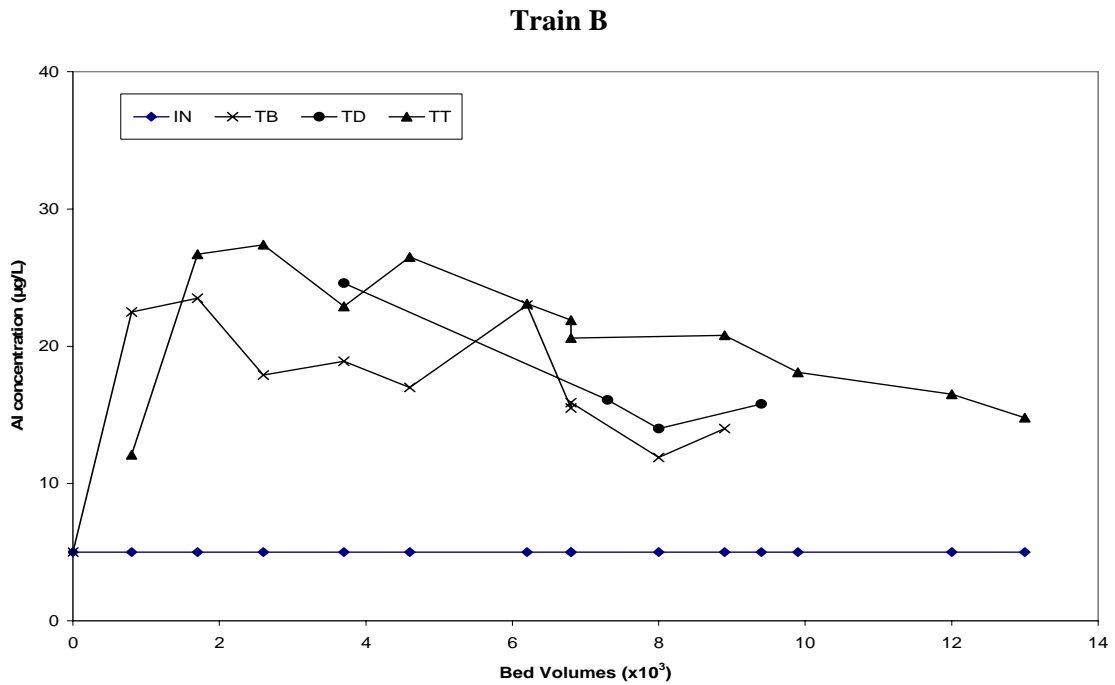
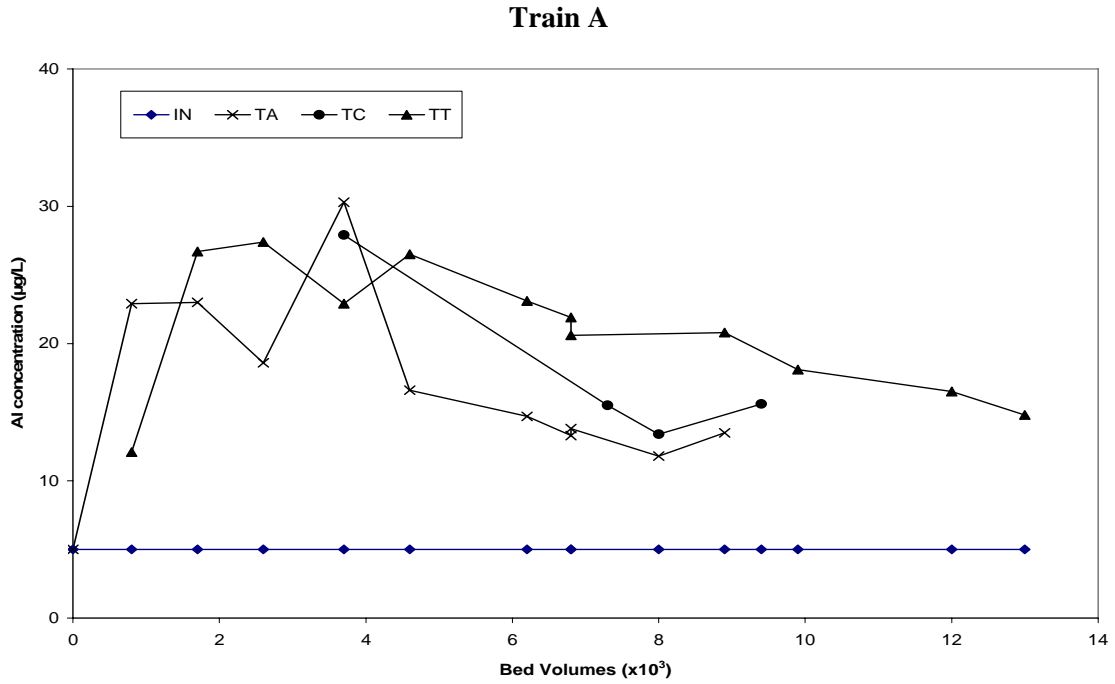


Figure 4-13. Total Aluminum Concentrations Across Treatment Trains and Entire System

4.5.2 Distribution System Water Sampling. Prior to the installation/operation of the treatment system, baseline distribution water samples were collected from three LCR residences on December 7, 2004; January 4, 2005; February 1, 2005; and April 5, 2005. Following the installation of the treatment system, distribution water sampling continued on a monthly basis at the same three locations. The results of the distribution system sampling are summarized in Table 4-8.

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 25.9 to 51.0 µg/L. After the treatment system was installed and put into service, arsenic concentrations ranged from 0.8 to 26.0 µg/L. One residence (Lot 1) had arsenic concentrations ranging from 16.3 to 26.0 µg/L for the first three months of operation. By the fourth month, all three residences had arsenic concentrations below 3.1 µg/L.

For the most part, iron and manganese concentrations in the distribution system were low and similar to those in raw water. Two residences (Lots 4 and 6) had elevated iron (as high as 602 µg/L) and manganese concentrations (as high as 83.2 µg/L) in the baseline samples. After the treatment system was installed and put into service, one sample taken from Lot 4 had an elevated iron concentration (i.e., 346 µg/L) and one taken from Lot 1 had an elevated manganese concentration (i.e., 50.1 µg/L). Other than a few exceptions (Lot 6, in particular), aluminum concentrations were higher in water collected after the startup of the treatment system.

One of each sample collected during the baseline sampling exceeded the lead action level of 15 µg/L, i.e., 37 µg/L from Lot 6 on January 4, 2005, and 22.1 µg/L from Lot 4 on December 7, 2005. After the treatment system was installed and put into service, lead levels in all samples were below 7.5 µg/L. Copper values were low and did not appear to be affected by the treatment system. The pH and alkalinity also remained fairly constant throughout the distribution system.

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 included the tracking of the capital cost for the treatment system such as equipment, engineering, and installation and the O&M cost for chemical supply, electrical power usage, and labor. No cost was incurred for building and discharge-related infrastructure improvements. If required, these costs would have been funded by the demonstration site and would not be included in the following cost analyses.

4.6.1 Capital Cost. The capital investment cost for equipment, site engineering, and installation were \$14,000 (see Table 4-9). The equipment cost was \$8,990 (or 64% of the total capital investment), which included \$4,060 for the treatment system mechanical hardware, \$2,880 for the A/I Complex 2000 adsorption media (i.e., \$320/ft³ or \$5.82/lb to fill six columns), and \$2,050 for the vendor's labor and shipping cost.

The engineering cost included the cost for the preparation of the system layout and footprint, design of the piping connections to the distribution tie-in points, and assembling and submission of the engineering plans for the permit application (Section 4.3). The engineering cost was \$2,400, which was 17% of the total capital investment.

The installation cost included the cost to unload and install the treatment system, complete the piping installation and tie-ins, and perform the system start-up and shakedown (Section 4.3). The installation costs were \$2,610, or 19% of the total capital investment.

Table 4-8. Distribution System Sampling Results

Sampling Event	Sampling Location	DS1 (Lot 1)										DS2 (Lot 6)							DS3 (Lot 4)									
		1st Draw										1st Draw							1st Draw									
		Stagnation Time (hrs)	pH	Alkalinity (as CaCO ₃) (mg/L)	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	Alkalinity (as CaCO ₃) (mg/L)	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	Alkalinity (as CaCO ₃) (mg/L)	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	12/7/2004	20.5	7.9	142	27.7	<25	4.1	0.8	2.2	82.0	11.8	7.8	142	29.0	<25	1.7	2.2	0.3	18.9	8.8	7.9	142	51.0	602	33.8	19.8	22.1	105
BL2	1/4/2005	12.0	7.7	136	25.9	<25	3.7	5.0	4.0	85.9	13.0	7.8	132	40.8	339	83.2	82.2	37.0	138	8.9	7.8	132	34.0	139	13.6	5.0	8.9	38.6
BL3	2/1/2005	16.0	7.3	138	30.8	<25	2.2	5.0	2.5	84.9	12.0	7.5	138	34.3	43.9	10.6	53.4	5.1	43.3	17.5	7.9	133	39.3	175	10.4	5.0	7.3	36.5
BL4	4/5/2005	11.0	7.7	132	30.7	<25	0.8	5.0	1.2	81.3	11.8	7.7	132	30.6	<25	0.8	10.9	0.6	29.6	20.0	7.8	141	33.3	25.9	4.9	5.0	2.5	17.2
1	7/27/2005	14.0	8.2	110	16.3	<25	50.1	15.9	1.0	32.3	12.3	7.6	132	2.5	<25	0.2	11.9	0.7	20.9	20.3	7.6	132	4.7	34.4	4.1	10.9	1.6	25.9
2	8/16/2005	8.8	8.2	110	26.0	<25	6.7	5.0	2.2	72.3	12.5	7.6	132	2.5	<25	0.5	13.9	0.5	29.6	11.4	7.6	141	11.2	346	16.6	17.6	7.5	55.5
3	9/20/2005	11.0	7.6	141	20.0	<25	0.6	5.0	1.3	82.5	12.8	7.7	150	2.1	<25	<0.1	14.1	0.3	20.9	7.7	7.8	141	6.5	128	2.7	18.5	3.6	35.0
4	10/13/2005	NA	7.7	154	1.0	<25	0.3	15.4	0.3	18.8	13.0	7.7	145	1.5	<25	0.2	13.9	0.3	21.6	21.4	7.7	145	2.9	<25	1.2	5.0	0.4	18.9
5	11/8/2005	7.0	7.3	132	0.9	<25	1.0	56.6	1.4	33.6	11.4	7.5	110	0.8	<25	0.1	12.9	0.6	18.3	23.8	7.9	132	3.1	48.8	4.0	19.7	2.3	28.2
6	11/27/2005	7.0	7.9	141	1.3	<25	0.1	54.1	0.2	16.5	11.3	8.0	145	1.2	<25	0.1	12.6	0.9	37.1	10.8	8.1	145	2.7	<25	0.5	18.4	0.4	20.8

NS = not sampled; NA = not available.

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

The unit for analytical parameters is µg/L except for alkalinity (mg/L as CaCO₃).

BL = Baseline Sampling

Using the system's rated capacity of 22 gpm (or 31,680 gpd), the capital cost was \$636/gpm (or \$0.44/gpd). The capital cost of \$14,000 was converted to an annualized cost of \$1,321/yr using a capital recovery factor of 0.09439 based on a 7% interest rate and a 20-yr return. Assuming that the system was operated 24 hr a day, 7 days a week at the design flowrate of 22 gpm to produce 11.6 million gal of water per year, the unit capital cost would be \$0.11/1,000 gal. However, since the system was operated an average of 5.9 hr/day with an average daily use rate of 1,641 gal/day (see Table 4-4), producing approximately 300,000 gal of water during the six-month period, the unit capital cost was increased to \$2.20/1,000 gal at this reduced rate of production.

Table 4-9. Summary of Capital Investment Cost

Description	Quantity	Cost	% of Capital Investment Cost
<i>Equipment Cost</i>			
Adsorption Media Tanks	6	\$720	–
A/I Complex 2000 Adsorptive Media	9 ft ³	\$2,880	–
25- μ m Sediment Filters	2	\$750	–
Piping and Valves	1	\$1,020	–
Flow Totalizers/Meters	2	\$1,120	–
Hour Meters	3	\$450	–
Procurement, Assembly, Labor	1	\$1,600	–
Freight	1	\$450	–
Equipment Total	–	\$8,990	64%
<i>Engineering Cost</i>			
Design/Scope of System	10 hr	\$1,500	–
Travel and Miscellaneous Expenses	1	\$300	–
Subcontractor Labor	–	\$600	–
Engineering Total	–	\$2,400	17%
<i>Installation Cost</i>			
Plumbing Supplies/Parts	1	\$500	–
Vendor Installation Labor (hr)	10	\$1,300	–
Vendor Travel (day)	2	\$710	–
Subcontractor Travel	–	\$100	–
Installation Total	–	\$2,610	19%
Total Capital Investment	–	\$14,000	100%

4.6.2 Operation and Maintenance Cost. The O&M cost for the As/2200CS treatment system includes only incremental cost associated with the adsorption system, such as media replacement and disposal, chemical supply, electricity, and labor (Table 4-10). Although the media was not actually replaced during the first six months of the study, the first set of tanks (“lead”) reached exhaustion around 12,000 BV. The cost to replace the media in the two lead tanks is estimated to be \$2,785 for media and labor.

For a three-column system operating in series, the media in the lead column is ideally replaced when the arsenic concentration in the lead column effluent equals the raw water concentration but before the arsenic concentration following the final lag column reaches the 10 μ g/L target value. Once the lead column is exhausted, the first and second lag columns are moved up to the lead and first lag positions and a column containing new media is placed in the final lag position. This method allows the media's

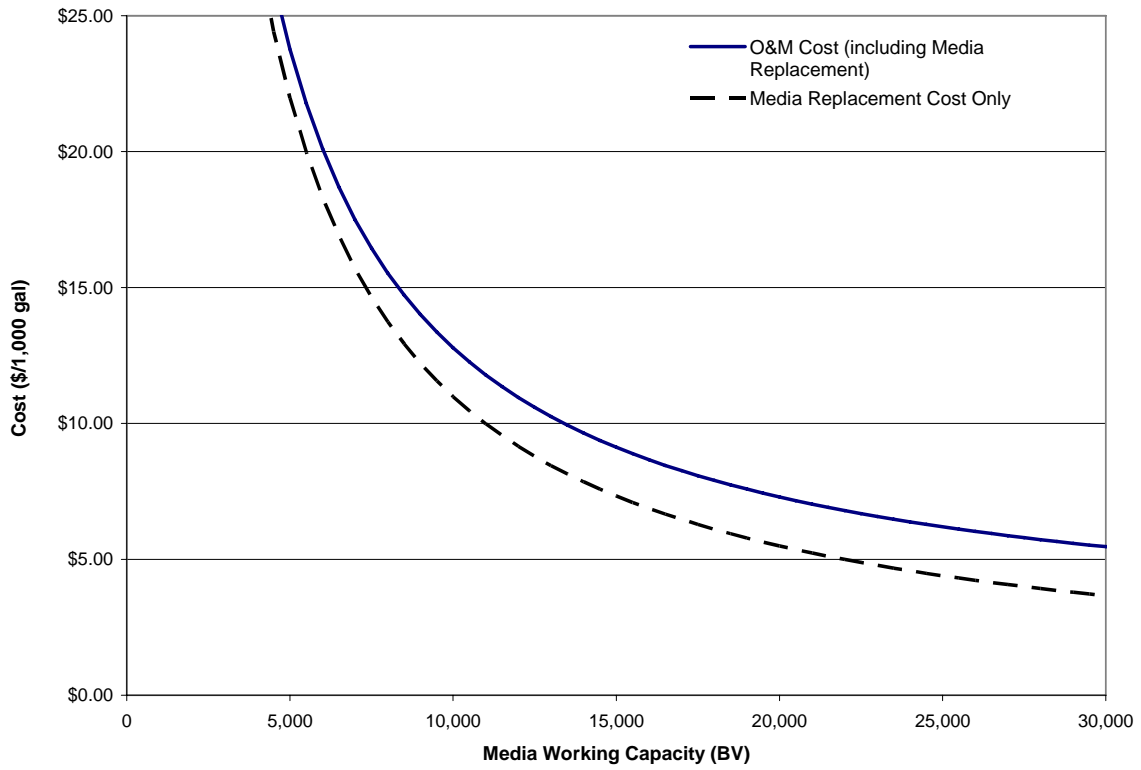
capacity for arsenic removal to be exhausted before its replacement. If the media exhibits a sharp adsorption front (with a typical S-shaped breakthrough curve) and if the anticipated run length is relatively short, replacement may be more cost-effective to wait until the first two or all three columns in the series need to be replaced.

Sodium hypochlorite was added to the water prior to the installation of the system so the cost was not tracked for the chemical addition. There were no additional electrical requirements added by ATS with the exception of the hour meters on each well. The well pumps and booster pumps were in place at the treatment building prior to the installation of the As/2200CS treatment system. Therefore, the electrical cost associated with the system operation was assumed to be negligible.

The routine, non-demonstration-related labor activities consumed about 20 min/day, 3 day/week as noted in Section 4.4.3. Therefore, the estimated labor cost was \$1.80/1,000 gal of water treated (Table 4-10).

Table 4-10. Summary of O&M Cost

Cost Category	Value	Remarks
Volume Processed (gal)	300,000	From June 24, 2005 through December 22, 2005
<i>Media Replacement and Disposal</i>		
Media (\$/ft ³)	\$517	For replacement columns and spent media disposal
Media Volume (ft ³)	3.0	Amount of media in two lead columns
Total Media Replacement (\$)	\$1,550	Vendor quote
Labor (\$)	\$390	Vendor quote
Travel and Delivery (\$)	\$845	Vendor quote
Subtotal	\$2,785	Vendor quote
Media Replacement and Disposal (\$/1,000 gal)	See Figure 4-14	Based upon media run length at 10- μ g/L arsenic breakthrough from third adsorption column
<i>Chemical Usage</i>		
Chemical (\$)	\$0.000	No additional chemical required
<i>Electricity</i>		
Electricity (\$/1,000 gal)	\$0.001	Electrical cost assumed negligible
<i>Labor</i>		
Average Weekly Labor (hr)	1	20 min/day, 3 day/week
Labor Cost (\$)	\$540	27 hr at \$20/hr
Labor Cost (\$/1,000 gal)	\$1.80	–
Total O&M cost (\$/1,000 gal)	See Figure 4-14	Based upon media run length at 10- μ g/L arsenic breakthrough from third adsorption column



Note: 1 BV = media volume in lead

Figure 4-14. O&M and Media Replacement Cost (for Replacement of Two Columns at a Time)

5.0 REFERENCES

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APPENDIX A
OPERATIONAL DATA

EPA Arsenic Demonstration Project at CMHP in Dummerston, VT – Summary of Daily System Operation

Week No.	Date	Supply Well Hour Meter 2		Treatment Train A			Treatment Train B			System		
		Cumulative Hour Meter Reading	Operational Hours	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Total Cumulative Volume Treated	Total Cumulative Bed Volumes Treated	Avg Flowrate
		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
1	06/23/05	9.1		System was bypassed								
	06/24/05	12.9	3.8	0.00	263.4	23	0.00	236.2	0	499.6	22	0
	06/25/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	06/26/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
2	06/27/05	37.2	24.3	4.54	3134.2	279	4.42	1876.7	168	4973.4	221	3.1
	06/28/05	43.1	5.9	4.10	NM	NM	4.26	NM	217	6470.1	288	4.2
	06/29/05	48.1	5.0	2.62	4913.2	438	1.81	3223.7	286	8111.3	361	5.5
	06/30/05	50.6	2.5	4.97	5583.5	498	5.52	3776.9	333	9276.7	413	7.8
	07/01/05	55.3	4.7	4.32	6602.5	588	4.32	4682.4	413	11188.1	498	6.8
	07/02/05	58.5	3.2	5.18	7237.8	645	5.79	5210.2	464	12448	554	6.6
	07/03/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
3	07/04/05	74.7	16.2	4.76	9090.6	810	5.25	6414.2	572	15504.8	691	3.1
	07/05/05	79.9	5.2	2.62	10156.7	905	2.49	7874	702	18030.7	803	8.1
	07/06/05	84.1	4.2	2.87	10995.5	980	2.44	8082.5	720	19078	850	4.2
	07/07/05	NM	NM	5.42	11745.2	1047	6.21	8436.5	752	20181.7	899	NM
	07/08/05	96.6	12.5	4.03	12750.6	1136	4.38	9282.1	827	22032.7	982	3.9
	07/09/05	101.9	5.3	2.24	13914.9	1240	1.28	10062.1	897	23977	1068	6.1
	07/10/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
4	07/11/05	118.0	16.1	4.09	15355	1369	4.43	10930	974	26285	1171	2.4
	07/12/05	130.2	12.2	4.49	16337.9	1456	5.03	11384	1015	27721.9	1235	2.0
	07/13/05	135.2	5.0	2.62	17248.9	1537	2.23	12136.5	1082	29385.4	1309	5.5
	07/14/05	138.8	3.6	5.15	17801	1587	5.93	12524	1116	30325	1334	4.4
	07/15/05	145.4	6.6	4.92	18794	1675	5.59	13238	1180	32032	1410	4.3
	07/16/05	150.6	5.2	4.48	19710	1757	5.07	14015	1249	33725	1485	5.4
	07/17/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
5	07/18/05	172.0	21.4	0.83	21918	1953	0.00	15279	1362	37197	1640	2.7
	07/19/05	192.0	20.0	0.40	22663	2020	0.00	15279	1362	37942	1673	0.6
	07/20/05	201.2	9.2	0.52	23453	2090	0.00	15461	1378	38914	1717	1.8
	07/21/05	210.8	9.6	2.79	24355	2171	2.64	15759	1405	40114	1770	2.1
	07/22/05	220.3	9.5	2.02	25509	2274	0.00	16365	1459	41874	1849	3.1
	07/23/05	224.9	4.6	4.23	25972	2315	4.60	16524	1473	42496	1876	2.3
	07/24/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM

EPA Arsenic Demonstration Project at CMHP in Dummerston, VT – Summary of Daily System Operation (Continued)

Week No.	Date	Supply Well Hour Meter 2		Treatment Train A			Treatment Train B			System		
		Cumulative Hour Meter Reading	Operational Hours	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Total Cumulative Volume Treated	Total Cumulative Bed Volumes Treated	Avg Flowrate
		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
6	07/25/05	236.9	12.0	4.01	27746	2473	4.46	17826	1589	45572	2013	4.3
	07/26/05	241.7	4.8	4.62	28590	2548	5.25	18506	1649	47096	2081	5.3
	07/27/05	245.2	3.5	4.79	29248	2607	5.54	19141	1706	48389	2139	6.2
	07/28/05	247.7	2.5	5.39	29856	2661	6.14	19792	1764	49648	2195	8.4
	07/29/05	251.6	3.9	5.11	30653	2732	5.90	20618	1838	51271	2267	6.9
	07/30/05	254.0	2.4	5.71	31240	2784	6.64	21246	1894	52486	2321	8.4
	07/31/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
7	08/01/05	258.8	4.8	4.88	32670	2912	5.57	22858	2037	55528	2457	10.6
	08/02/05	260.7	1.4	5.43	33252	2964	6.27	23522	2096	56774	2513	14.8
	08/03/05	262.8	2.1	5.67	33952	3026	5.81	24322	2168	58274	2579	11.9
	08/04/05	264.5	1.7	5.69	34485	3074	6.50	24932	2222	59417	2630	11.2
	08/05/05	265.9	1.4	6.21	34951	3115	7.08	25507	2273	60458	2677	12.4
	08/06/05	268.2	2.3	5.50	35688	3181	6.32	26302	2344	61990	2745	11.1
	08/07/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
8	08/08/05	281.2	13.0	2.27	38160	3401	2.23	28868	2573	67028	2969	6.5
	08/09/05	289.9	8.7	1.74	39155	3490	1.30	29504	2630	68659	3042	3.1
	08/10/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	08/11/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	08/12/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	08/13/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	08/14/05	320.6	30.7	4.45	43426	3870	5.16	33403	2977	76829	3406	4.4
9	08/15/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	08/16/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	08/17/05	335.3	14.7	4.41	46110	4110	5.19	36249	3231	82359	3653	6.3
	08/18/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	08/19/05	343.6	8.3	4.8	47570	4240	5.63	37823	3371	85393	3788	6.1
	08/20/05	349.4	5.8	4.15	48773	4347	4.87	39162	3490	87935	3901	7.3
	08/21/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM

EPA Arsenic Demonstration Project at CMHP in Dummerston, VT – Summary of Daily System Operation (Continued)

Week No.	Date	Supply Well Hour Meter 2		Treatment Train A			Treatment Train B			System		
		Cumulative Hour Meter Reading	Operational Hours	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Total Cumulative Volume Treated	Total Cumulative Bed Volumes Treated	Avg Flowrate
		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
10	08/22/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	08/23/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	08/24/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	08/25/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	08/26/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	08/27/05	376.4	27	3.15	54360	4845	3.75	45330	4040	99690	4425	7.3
	08/28/05	379.1	2.70	2.75	55015	4903	2.97	46070	4106	101085	4487	8.6
11	08/29/05	382.7	3.6	4.97	55680	4963	5.80	46805	4172	102485	4550	6.5
	08/30/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	08/31/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/01/05	395.4	12.7	4.45	58366	5202	5.21	49832	4441	108198	4804	7.5
	09/02/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/03/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/04/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
12	09/05/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/06/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/07/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/08/05	421.0	25.6	3.57	63652	5673	4.1	55492	4946	119144	5292	7.1
	09/09/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/10/05	430.9	9.9	2.53	65655	5852	2.76	58060	5175	123715	5496	7.7
	09/11/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
13	09/12/05	437.1	6.2	4.82	66815	5955	5.70	59377	5292	126192	5606	6.7
	09/13/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/14/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/15/05	448.9	11.8	4.93	69190	6167	5.91	62080	5533	131270	5832	7.2
	09/16/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/17/05	456.7	7.8	3.52	70877	6317	4.04	64023	5706	134900	5994	7.8
	09/18/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM

EPA Arsenic Demonstration Project at CMHP in Dummerston, VT – Summary of Daily System Operation (Continued)

Week No.	Date	Supply Well Hour Meter 2		Treatment Train A			Treatment Train B			System		
		Cumulative Hour Meter Reading	Operational Hours	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Total Cumulative Volume Treated	Total Cumulative Bed Volumes Treated	Avg Flowrate
		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
14	09/19/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/20/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/21/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/22/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/23/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/24/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/25/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
15	09/26/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	09/27/05	504.6	47.9	3.47	79269	7065	4.05	73666	6566	152935	6798	6.3
	09/28/05	511.0	6.4	1.72	80353	7162	1.9	74960	6681	155313	6904	6.2
	09/29/05	514.1	3.1	4.45	80820	7203	5.25	75445	6724	156265	6946	5.1
	09/30/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/01/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
10/02/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
16	10/03/05	537.3	23.2	2.53	85029	7578	2.96	80311	7158	165340	7351	6.5
	10/04/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/05/05	543.5	6.2	2.69	86105	7674	3.2	81548	7268	167653	7454	6.2
	10/06/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/07/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/08/05	610.4	66.9	0	88468	7885	0	82784	7378	171252	7614	0.9
	10/09/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
17	10/10/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/11/05	621.7	11.3	2.98	90515	8067	3.48	85165	7590	175680	7811	6.5
	10/12/05	626.9	5.2	3.46	91446	8150	4.13	86253	7687	177699	7901	6.5
	10/13/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/14/05	635.9	9.0	5.21	92810	8272	6.1	87791	7825	180601	8031	5.4
	10/15/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
10/16/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	

EPA Arsenic Demonstration Project at CMHP in Dummerston, VT – Summary of Daily System Operation (Continued)

Week No.	Date	Supply Well Hour Meter 2		Treatment Train A			Treatment Train B			System		
		Cumulative Hour Meter Reading	Operational Hours	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Total Cumulative Volume Treated	Total Cumulative Bed Volumes Treated	Avg Flowrate
		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
18	10/17/05	648.9	13.0	4.01	95282	8492	4.73	90615	8076	185897	8267	6.8
	10/18/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/19/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/20/05	662.3	13.4	4.35	97585	8697	5.2	93223	8309	190808	8485	6.1
	10/21/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/22/05	671.0	8.7	5.15	99146	8837	6.11	95020	8469	194166	8635	6.4
19	10/23/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/24/05	682.9	11.9	4.97	101107	9011	5.85	97249	8667	198356	8822	5.9
	10/25/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/26/05	693.6	10.7	3.07	102973	9178	3.79	99449	8864	202422	9003	6.3
	10/27/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/28/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/29/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
20	10/30/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	10/31/05	713.6	20.0	4.53	106521	9494	5.36	103520	9226	210041	9343	6.3
	11/01/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	11/02/05	718.7	5.1	5.33	107784	9606	6.21	104978	9356	212762	9464	8.9
	11/03/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	11/04/05	726.5	7.8	4.48	109647	9772	5.23	107129	9548	216776	9643	8.6
	11/05/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
21	11/06/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	11/07/05	737.1	10.6	2.95	112837	10057	3.41	109887	9794	222724	9908	9.4
	11/08/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	11/09/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	11/10/05	749.1	12.0	5.14	114255	10183	6.07	112423	10020	226678	10084	5.5
	11/11/05	752.8	3.7	3.13	115121	10260	3.67	113429	10110	228550	10167	8.4
	11/12/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
11/13/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	

EPA Arsenic Demonstration Project at CMHP in Dummerston, VT – Summary of Daily System Operation (Continued)

Week No.	Date	Supply Well	Hour Meter 2	Treatment Train A			Treatment Train B			System		
		Cumulative Hour Meter Reading	Operational Hours	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Total Cumulative Volume Treated	Total Cumulative Bed Volumes Treated	Avg Flowrate
		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
22	11/14/05	769.6	16.8	4.43	117705	10491	5.31	116456	10379	234161	10417	5.6
	11/15/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	11/16/05	777.7	8.1	3.33	119370	10639	3.98	118410	10553	237780	10579	7.4
	11/17/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	11/18/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	11/19/05	793.8	16.1	2.45	122048	10878	2.95	121612	10839	243660	10841	6.1
	11/20/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
23	11/21/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	11/22/05	805.9	12.1	4.53	124135	11064	5.40	124112	11062	248247	11045	6.3
	11/23/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	11/24/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	11/25/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	11/26/05	827.6	21.7	2.71	127650	11377	3.23	128301	11435	255951	11388	5.9
	11/27/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
24	11/28/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	11/29/05	857.4	29.8	1.67	130728	11651	1.92	131846	11751	262574	11684	3.7
	11/30/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	12/01/05	875.7	18.3	NM	NM	NM	NM	NM	NM	NM	NM	NM
	12/02/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	12/03/05	892.6	35.2	1.38	133941	11938	1.56	135440	12071	269381	11987	2.1
	12/04/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM

EPA Arsenic Demonstration Project at CMHP in Dummerston, VT – Summary of Daily System Operation (Continued)

Week No.	Date	Supply Well	Hour Meter 2	Treatment Train A			Treatment Train B			System		
		Cumulative Hour Meter Reading	Operational Hours	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Flow Rate	Cumulative Volume Treated	Cumulative Bed Volumes Treated	Total Cumulative Volume Treated	Total Cumulative Bed Volumes Treated	Avg Flowrate
		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
25	12/05/05	912.7	37.0	1.63	135688	12093	2.05	137403	12246	273091	12152	1.7
	12/06/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	12/07/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	12/08/05	938.6	25.9	1.25	138004	12300	1.33	140006	12478	278010	12372	3.2
	12/09/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	12/10/05	963.8	21.2	0.63	139937	12472	0	142197	12674	282134	12555	3.2
12/11/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
26	12/12/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	12/13/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	12/14/05	994.8	35.0	1.45	142815	12729	1.63	145542	12972	288357	12833	3.0
	12/15/05	1004.2	9.4	1.35	143840	12820	1.5	146437	13051	290277	12918	3.4
	12/16/05	1016.0	11.8	1.43	144911	12915	1.72	147605	13156	292516	13058	3.2
	12/17/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
12/18/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
27	12/19/05	1043.9	27.9	0.63	146251	13035	0.00	148567	13241	294818	13208	1.4
	12/20/05	1054.1	10.2	1.85	148778	13260	2.17	150613	13424	299391	13412	7.5
	12/21/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	12/22/05	1072.7	18.6	NM	149837	13354	NM	151736	13524	301573	13600	2.0
	12/23/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	12/24/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
12/25/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	

NM = not measured

APPENDIX B

ANALYTICAL DATA TABLES

Table B-1. Analytical Results from Long-Term Sampling, Dummerston, VT

Sampling Date		6/22/2005			7/5/2005				7/19/2005				8/3/2005					8/16/2005						
Sampling Location	Parameter	IN	TA	TB	IN	TA	TB	TT	IN	TA	TB	TT	IN	AC	TA	TB	TT	IN	AC	TA	TB	TC	TD	TT
Bed Volume	10 ³	-	-	-	-	0.9	0.7	0.8	-	2.0	1.4	1.7	-	-	3.0	2.2	2.6	-	-	4.1	3.2	-	-	3.7
Alkalinity	mg/L ^(a)	110	47 ^(c)	44 ^(c)	132	141	132	132	132	132	145	145	123	-	123	128	128	119	-	119	123	132	136	110
Fluoride	mg/L	<0.1	3.7 ^(c)	3.2 ^(c)	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1
Sulfate	mg/L	20	70 ^(c)	59 ^(c)	21	23	23	21	23	24	24	28	23	-	23	22	23	20	-	19	20	21	20	22
Nitrate (as N)	mg/L	0.1	0.1	0.1	-	-	-	-	0.1	0.1	0.1	0.4	0.2	-	0.1	0.1	0.1	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	<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
Total P (as PO ₄)	mg/L ^(b)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	12.9	0.4	0.6	12.0	4.7	5.1	0.3	11.8	6.6	7.3	1.1	12.2	-	8.7	9.2	2.2	13.3	-	10.4	10.5	6.5	6.7	3.7
Turbidity	NTU	0.3	<0.1	1.6	0.4	<0.1	0.1	0.1	1.3	0.7	0.4	0.5	0.2	-	<0.1	<0.1	<0.1	0.1	-	0.6	0.1	<0.1	<0.1	0.1
pH	S.U.	7.7	6.5	6.6	7.8	7.6	NA ^(d)	7.0	7.0	7.0	7.2	7.0	7.5	-	7.4	7.5	7.6	8.1	-	8.4	6.9	NA ^(c)	NA ^(c)	6.5
Temperature	°C	13.9	14.2	14.0	15.9	11.9	NA ^(d)	15.2	15.6	16.3	17.1	16.0	15.7	-	12.3	12.3	16.0	12.8	-	14.8	14.5	NA ^(c)	NA ^(c)	17.2
DO	mg/L	5.8	5.6	5.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ORP	mV	173	449	322	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Free Chlorine	mg/L	-	-	-	-	-	-	0.3	-	-	-	0.2	-	0.3	-	-	0.3	-	0.0	-	-	-	-	0.0
Total Chlorine	mg/L	-	-	-	-	-	-	NA ^(d)	-	-	-	NA ^(d)	-	0.0	-	-	NA ^(d)	-	0.0	-	-	-	-	0.0
Total Hardness	mg/L ^(a)	178	169	188	177	172	177	164	159	161	165	164	183	-	169	183	214	205	-	211	209	203	206	197
Ca Hardness	mg/L ^(a)	83.9	69.0	74.0	85.5	80.1	79.3	73.7	80.1	81.0	82.2	80.2	89.5	-	82.2	88.1	88.8	92.8	-	95.4	96.0	94.2	96.2	92.6
Mg Hardness	mg/L ^(a)	94.4	100	114	91.8	91.9	97.4	90.2	78.7	80.0	82.5	83.4	93.8	-	87.1	95.1	125	112	-	116	113	109	110	105
As (total)	µg/L	44.3	0.7	0.6	39.9	0.3	0.3	0.3	52.3	4.4 ^(c)	6.3 ^(c)	13.7 ^(c)	61.9	-	1.2	1.2	0.9	46.6	-	2.1	3.1	0.6	0.6	0.6
As (soluble)	µg/L	45.0	0.7	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	46.8	-	2.2	3.3	0.7	0.8	0.8
As (particulate)	µg/L	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1
As (III)	µg/L	3.0	0.5	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	2.3	-	0.6	0.5	0.5	0.5	0.4
As (V)	µg/L	42.1	0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	44.4	-	1.6	2.8	0.2	0.4	0.4
Total Fe	µg/L	<25	<25	<25	<25	<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	-	270	<25	<25	<25	<25
Total Mn	µg/L	9.7	0.8	0.8	4.2	0.2	0.3	0.3	13.4	0.2	0.3	0.3	4.4	-	<0.1	<0.1	0.1	8.4	-	0.1	0.1	0.4	0.2	0.1
Soluble Mn	µg/L	9.5	0.8	0.8	-	-	-	-	-	-	-	-	-	-	-	-	-	8.4	-	0.1	0.2	0.3	0.2	0.2
Total Al	µg/L	<10	<10	<10	<10	22.9	22.5	12.1	<10	23.0	23.5	26.7	<10	-	18.6	17.9	27.4	<10	-	30.3	18.9	27.9	24.6	22.9
Soluble Al	µg/L	<10	<10	<10	-	-	-	-	-	-	-	-	-	-	-	-	-	<10	-	16.0	16.7	20.8	20.0	20.9

- (a) As CaCO₃.
- (b) As PO₄.
- (c) Rerun results were similar. Data is questionable.
- (d) Water quality measurement not recorded by operator.

IN = influent; TA = after Tank A; TB = after Tank B; TC = after Tank C; TD = after Tank D; TT = after combined effluent;
 NA = Not available

Table B-1. Analytical Results from Long-Term Sampling, Dummerston, VT (Continued)

Sampling Date		08/29/05					09/19/05				09/27/05				10/04/05		10/13/05					
Sampling Location		IN	AC	TA	TB	TT	IN	TA	TB	TT	IN	TA	TB	TT	TC	TD	IN	AC	TA	TB	TC	TD
Parameter	Unit																					
Bed Volume	10 ³	-	-	5.0	4.4	4.6	-	6.4	5.8	6.1	-	7.1	6.6	6.8	7.8	7.2	-	-	8.2	7.7	-	-
Alkalinity (as CaCO ₃)	mg/L	123	-	132	132	132	-	-	-	-	132	163	154	154	132	141	132	-	163	154	132	132
		-	-	-	-	-	-	-	-	-	132	163	158	154	-	-	-	-	-	-	-	-
Fluoride	mg/L	<0.1	-	0.1	0.1	0.1	-	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	<0.1
		-	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-
Sulfate	mg/L	21.1	-	21.2	21.2	23.3	-	-	-	-	16.0	16.9	17.8	17.3	14.5	17.5	20.3	-	45.4	30.0	23.1	21.5
		-	-	-	-	-	-	-	-	-	16.2	17.1	17.9	17.3	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	0.1 ^(a)	-	0.1 ^(a)	0.1 ^(a)	0.1 ^(a)	-	-	-	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.1	-	0.1	0.1	0.1	0.1
		-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-
Orthophosphate (as PO ₄)	mg/L	<0.05	-	<0.05	<0.05	<0.05	-	-	-	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-
Total P (as PO ₄)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.03	-	<0.03	<0.03	<0.03	<0.03
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	16.8	-	14.7	14.6	8.3	-	-	-	-	14.4	13.1	12.8	8.6	11.1	8.3	11.8	-	10	10.5	8.8	8.9
		-	-	-	-	-	-	-	-	-	14.7	13	13.1	8.6	-	-	-	-	-	-	-	-
Turbidity	NTU	0.2	-	<0.1	0.1	<0.1	-	-	-	-	0.1	<0.1	<0.1	<0.1	0.1	<0.1	0.2	-	0.1	0.1	0.1	0.3
		-	-	-	-	-	-	-	-	-	0.1	<0.1	0.1	0.3	-	-	-	-	-	-	-	-
pH	S.U.	7.7	-	7.2	7.5	7.6	7.5	7.8	7.6	7.8	NA ^(d)	NA ^(d)	NA ^(d)	NA ^(d)	NA ^(d)	NA ^(d)	8.1	-	8.0	8.0	NA ^(d)	NA ^(d)
Temperature	°C	13.8	-	13.7	13.5	16.2	12.7	NA ^(d)	NA ^(d)	11.8	NA ^(d)	NA ^(d)	NA ^(d)	NA ^(d)	NA ^(d)	NA ^(d)	11.8	-	11.1	11.1	NA ^(d)	NA ^(d)
DO	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ORP	mV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Free Chlorine (as Cl ₂)	mg/L	-	0.3	-	-	0.3	-	-	-	0.2	-	-	-	NA ^(d)	-	NA ^(d)	-	0.7	-	-	-	-
Total Chlorine (as Cl ₂)	mg/L	0.4	0.4	-	-	0.4	-	-	-	0.2	-	-	-	NA ^(d)	-	NA ^(d)	-	0.7	-	-	-	-
Total Hardness (as CaCO ₃)	mg/L	191	-	191	193	171	147	155	153	171	163	146	143	155	153	158	177	-	152	157	173	174
		-	-	-	-	-	-	-	-	-	164	147	145	150	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	88.7	-	89.0	91.8	83.7	69.5	71.6	69.7	78.9	73.7	65.2	62.9	71.0	70.2	73.8	81.5	-	70.2	72.8	80.3	80.9
		-	-	-	-	-	-	-	-	-	73.2	66.0	65.5	67.6	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	103	-	102	101	87.2	77.4	83.6	83.1	92.1	89.1	80.6	79.7	83.6	82.7	84.0	95.4	-	82.1	84.2	92.4	93.4
		-	-	-	-	-	-	-	-	-	91.3	81.3	79.1	82.4	-	-	-	-	-	-	-	-
As (total)	µg/L	36.9	-	6.0	7.8	0.3	72.2	12.6	14.8	1.1	30.4	16.9	19.7	0.5	0.5	0.6	43.0	-	31.4	33.4	0.9	1.1
		-	-	-	-	-	-	-	-	-	30.4	18.0	19.8	0.6	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	43.1	-	29.8	31.3	0.7	1.1
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.1	-	1.6	2.2	0.2	<0.1
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5	-	0.7	0.8	0.6	0.5
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	41.6	-	29.1	30.5	0.1	0.6
Fe (total)	µg/L	<25	-	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	-	<25	<25	<25	<25
		-	-	-	-	-	-	-	-	-	<25	<25	<25	<25	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<25	-	<25	<25	<25	<25
Mn (total)	µg/L	4.1	-	<0.1	<0.1	<0.1	35.9	<0.1	<0.1	0.2	2.2	<0.1	<0.1	<0.1	<0.1	<0.1	5.1	-	<0.1	<0.1	<0.1	<0.1
		-	-	-	-	-	-	-	-	-	2.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4	-	<0.1	<0.1	<0.1	<0.1
Al (total)	µg/L	<10	-	16.6	17.0	26.5	<10	14.7	23.0	23.1	<10	13.3	15.5	21.9	15.5	16.1	<10	-	11.8	11.9	13.4	14.0
		-	-	-	-	-	-	-	-	-	<10	13.8	15.9	20.6	-	-	-	-	-	-	-	-
Al (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<10	-	11.3	12.3	14.9	12.5

(a) Reanalyzed outside of holding time.

(b) Water quality measurement not recorded by operator.

IN = influent; TA = after Tank A; TB = after Tank B; TC = after Tank C; TD = after Tank D; TT = after combined effluent;
NA = Not available

Table B-1. Analytical Results from Long-Term Sampling, Dummerston, VT (Continued)

Sampling Date	Sampling Location Parameter Unit	10/25/05					11/01/05							11/08/05							
		IN	AC	TA	TB	TT	IN	TA	TB	TC	TD	TE	TF	IN	TA	TB	TC	TD	TE	TF	TT
Bed Volume	10 ³	-	-	9.0	8.7	8.8	-	9.5	9.2	-	-	-	9.3	-	10.0	9.7	-	-	-	-	9.9
Alkalinity (as CaCO ₃)	mg/L	141	-	141	136	136	132	-	-	132	136	132	132	-	-	-	-	-	-	-	-
Fluoride	mg/L	<0.1	-	<0.1	<0.1	<0.1	<0.1	-	-	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-
Sulfate	mg/L	24	-	22	22	22	18.5	-	-	20.7	20.6	20.8	20.6	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	0.1	-	0.1	0.1	0.2	0.1	-	-	0.1	0.1	0.1	0.1	-	-	-	-	-	-	-	-
Orthophosphate (as PO ₄)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as PO ₄)	mg/L	<0.03	-	<0.03	<0.03	<0.03	<0.03	-	-	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Silica (as SiO ₂)	mg/L	10.6	-	10.2	10.3	7.3	12.4	-	-	10.0	10.0	8.4	8.3	11.8	10.9	11.5	9.0	9.1	7.5	7.3	7.4
Turbidity	NTU	<0.1	-	0.1	0.2	0.1	0.2	-	-	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-
pH	S.U.	8.2	-	8.2	8.2	8.1	8.1	-	-	8.0	8.1	8.1	8.1	8.0	-	-	-	-	-	-	8.3
Temperature	°C	11.0	-	10.7	10.6	12.9	11.7	-	-	11.8	11.6	11.3	11.7	11.9	-	-	-	-	-	-	11.7
DO	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ORP	mV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Free Chlorine (as Cl ₂)	mg/L	-	1.0	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3
Total Chlorine (as Cl ₂)	mg/L	-	0.3	-	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Hardness (as CaCO ₃)	mg/L	166	-	165	164	174	194	-	-	165	167	168	171	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	79.5	-	77.2	77.0	83.4	81.0	-	-	79.1	81.0	80.8	82.1	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	86.6	-	87.6	86.5	90.3	113	-	-	85.7	86.5	87.3	88.9	-	-	-	-	-	-	-	-
As (total)	µg/L	57.8	-	30.8	32.1	0.6	32.9	30.8	30.7	1.2	2.5	0.3	0.4	56.2	30.1	30.4	1.4	2.3	0.2	0.2	0.2
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	<25	-	<25	<25	<25	<25	-	-	<25	<25	<25	<25	<25	-	-	-	-	-	-	<25
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	4.1	-	<0.1	<0.1	<0.1	4.1	-	-	<0.1	0.2	0.2	0.3	5.6	-	-	-	-	-	-	<0.1
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Al (total)	µg/L	<10	-	13.5	14.0	20.8	<10	-	-	15.6	15.8	18.3	18.5	<10	-	-	-	-	-	-	18.1
Al (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

IN = influent; TA = after Tank A; TB = after Tank B; TC = after Tank C; TD = after Tank D; TT = after combined effluent;
NA = Not available

Table B-1. Analytical Results from Long-Term Sampling, Dummerston, VT (Continued)

Sampling Date		11/28/05 ^(a)										12/13/05							
Sampling Location	Unit	IN	AC	TA	TB	TC	TD	TE	TF	TT	IN	AC	TA	TB	TC	TD	TE	TF	TT
Bed Volume	10 ³	-	-	11.6	11.8	-	-	-	-	11.7	-	-	12.5	12.7	-	-	-	-	12.6
Alkalinity (as CaCO ₃)	mg/L	132	-	-	-	-	-	-	-	136	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	<0.1	-	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	20.8	-	-	-	-	-	-	-	21	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	0.1	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-
Orthophosphate (as PO ₄)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as PO ₄)	mg/L	<0.03	-	-	-	-	-	-	-	<0.03	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	12.4	-	11.6	10.8	9.7	9.7	8.3	8.6	8.2	12	-	11.6	11.9	10.3	10.4	9.3	9.2	9.2
Turbidity	NTU	0.7	-	-	-	-	-	-	-	0.4	-	-	-	-	-	-	-	-	-
pH	S.U.	7.8	7.6	-	-	-	-	-	-	7.7	7.3	7.7	-	-	-	-	-	-	7.9
Temperature	°C	10.2	10.7	-	-	-	-	-	-	10.5	10.7	10.7	-	-	-	-	-	-	10.4
DO	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ORP	mV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Free Chlorine (as Cl ₂)	mg/L	-	0.5	-	-	-	-	-	-	0.5	-	0.1	-	-	-	-	-	-	0.1
Total Chlorine (as Cl ₂)	mg/L	-	0.4	-	-	-	-	-	-	0.4	-	0.3	-	-	-	-	-	-	0.1
Total Hardness (as CaCO ₃)	mg/L	165	-	-	-	-	-	-	-	172	-	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	72.4	-	-	-	-	-	-	-	73.2	-	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	92.9	-	-	-	-	-	-	-	98.5	-	-	-	-	-	-	-	-	-
As (total)	µg/L	40.2	-	37.3	38.9	5.6	8.3	1.3	1.3	1.3	30.8	25.7	37.0	35.5	9.9	13.3	0.6	0.7	0.7
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	29.6	26.0	-	-	-	-	-	-	0.6
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	1.2	<0.1	-	-	-	-	-	-	0.1
As (III)	µg/L	-	-	-	-	-	-	-	-	-	0.4	0.5	-	-	-	-	-	-	0.5
As (V)	µg/L	-	-	-	-	-	-	-	-	-	29.1	25.5	-	-	-	-	-	-	<0.1
Fe (total)	µg/L	<25	-	-	-	-	-	-	-	<25	<25	<25	-	-	-	-	-	-	<25
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	<25	<25	-	-	-	-	-	-	<25
Mn (total)	µg/L	11.9	-	-	-	-	-	-	-	<0.1	1.7	12.1	-	-	-	-	-	-	0.1
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	<0.1	1.2	-	-	-	-	-	-	<0.1
Al (total)	µg/L	<10	-	-	-	-	-	-	-	16.5	<10	<10	-	-	-	-	-	-	14.8
Al (soluble)	µg/L	-	-	-	-	-	-	-	-	-	<10	10.2	-	-	-	-	-	-	14.1

(a) Water quality measurements taken on 11/27/05.

IN = influent; TA = after Tank A; TB = after Tank B; TC = after Tank C; TD = after Tank D; TT = after combined effluent;
 NA = Not available