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Arsenic Removal from Drinking Water by Adsorptive Media U.S. EPA Demonstration Project at Dummerston, VT Final Performance Evaluation Report

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Sally Gutierrez, Director
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ABSTRACT

This report documents the activities performed and the results obtained for the arsenic removal treatment technology demonstration project at Charette Mobile Home Park (CMHP) in Dummerston, Vermont. The objectives of the project were to evaluate: (1) the effectiveness of an Aquatic Treatment Systems (ATS) arsenic removal system in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 µg/L, (2) the reliability of the treatment system, (3) the required system operation and maintenance (O&M) and operator skills, and (4) the capital and O&M cost of the technology. The project also characterized 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-in diameter, 54-in 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 through each train, 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 2.8 and 3.3 gpm for Trains A and B, respectively, throughout the evaluation period. A 50% reduction in flow was observed after the 23rd week of operation. The flowrate increased again after the 39th week but fluctuated greatly after this point. As a result, each adsorption column had a much longer EBCT, ranging from 1.6 to 56.1 min throughout the entire study period. The highly variable and low flowrates from the wells might be attributed, in part, to slow recovery rates of the aquifer resulting from a dry summer.

Between June 24, 2005, and October 10, 2006, the system operated at an average of 7.6 hr/day for a total of 3,636 hr, treating approximately 745,000 gal of water which contained 20.8 to 101 µg/L of arsenic existing predominately as soluble As(V). During the first 34-week-long test run, arsenic concentrations following the lead columns reached 10 µg/L after treating 5,700 and 5,400 bed volumes (BV) of water through Trains A and B, respectively. (BV was calculated based on 1.5ft^3 [or 11.2 gal] of media in an individual column.) Arsenic concentrations reached 10 µg/L in the system effluent (following the final columns) after treating approximately 17,400 and 17,600 BV through Trains A and B, respectively (or 5,800 and 5,900 BV, respectively, if considering the three columns in each train as one large column).

Media were replaced after approximately 8 months of operation and arsenic concentrations reached 10 µg/L in the system effluent (after the second lag column) after approximately 15,000 BV and 17,000 BV for Trains A and B, respectively (or 5,000 and 5670 BV, respectively, if considering the three columns in each train as one large column). Arsenic concentrations in the effluent of the new lead columns were around 10 µg/L at the time of the media changeout.

Arsenic breakthrough occurred sooner than projected (at 40,000 BV in the lead column) by the vendor. It is presumed that relatively high pH values of source water (averaging 7.6), competing anions, such as silica, and higher influent arsenic concentrations (i.e., 41.3 µg/L, on average, compared to 30 µg/L observed during the initial site visit) might have contributed, in part, to early arsenic breakthrough from the adsorption columns. The arsenic mass removed by the adsorption media during the two runs ranged between 0.30 and 0.49 µg of As/mg of dry media per column.

Aluminum concentrations in the treated water following adsorption columns (existing primarily in the soluble form) were approximately 10 to 30 µg/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 concentration in the treated water during each test run.

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. One residence had elevated arsenic concentrations ranging from 16.3 to 26.0 µg/L through the first three months. Starting from the fourth month, all three residences had arsenic concentrations below 3.1 µg/L. After the sixth month, arsenic concentrations began to increase and media were changed out after 34 weeks of operation. Arsenic concentrations decreased again after the changeout. The wells were not able to generate enough water to meet the demand of CMHP, so water was hauled in and stored in the 5,500 gal atmospheric storage tank (where water treated from the ATS system was stored). Therefore, distribution sampling was discontinued after April 2006 because the results were not representative of the treated water from the ATS system. 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). Annualized capital cost was $1,321/yr based upon a 7% interest rate and 20 year life. The unit capital cost was $0.11/1,000 gal assuming the system operated continuously 24 hr/day, 7 days a week at 22 gpm. At the current use rate of 1,565 gal/day, the unit capital cost increased to $2.31/1,000 gal.

Operation and maintenance (O&M) costs included only incremental cost associated with the adsorption system, such as media replacement and disposal, electricity consumption, and labor. The incremental cost for electricity was negligible. Media replacement of the lead and first lag columns in each Train occurred on February 14, 2006, after 34 weeks of system operation. The cost to replace the four columns was $3,910 for media, labor and travel. 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-µg/L arsenic breakthrough from the third column in series.

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FIGURES

TABLES

ABBREVIATIONS AND ACRONYMS

AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
As	arsenic
ATS	Aquatic Treatment Systems
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
hp	horsepower
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
UV	ultraviolet
VDEC	Vermont Department of Environmental Conservation
VSHA	Vermont State Housing Authority

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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 (As) 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 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 Round 1 of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 out of 115 sites to host 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 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.

In 2003, EPA initiated Round 2 arsenic technology demonstration projects which were partially funded with Congressional add-on funding to the EPA budget. In June 2003, EPA selected 32 potential demonstration sites and the water system at Charette Mobile Home Park (CMHP) in Dummerston, Vermont, was one of those selected.

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. Aquatic Treatment Systems, Inc's. (ATS's) As/2200CS arsenic treatment system was selected for demonstration at the CMHP site in September 2004.

As of January 2008, 37 of the 40 systems were operational and the performance evaluations of 26 systems were completed.

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/wswrd/dw/arsenic/publications.html.

1.3 Project Objectives

The objective of the Round 1 and Round 2 arsenic demonstration program is to conduct 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 from June 22, 2005 through October 10, 2006. 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 Arsenic Removal Demonstration Sites

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality As (µg/L)	Source Water Quality Fe (µg/L)	Source Water Quality 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
Houghton, NY[(d)]	Town of Caneadea	C/F (Macrolite)	Kinetico	550	27[(a)]	1,806[(c)]	7.6
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	250[(e)]	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)	Siemens	340[(e)]	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							
Arnaudville, LA	United Water Systems	C/F (Macrolite)	Kinetico	770[(e)]	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	Nambe Pueblo Tribe	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[(b)]	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/ARM 200)	Kinetico	37	41	<25	7.8

Table 1-1. Summary of Arsenic Removal Demonstration Sites (Continued)

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality As (µg/L)	Fe (µg/L)	pH (S.U.)
		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)	Kinetico	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	POE AM (Adsorbsia/ARM 200/ArsenX^{np}) and POU AM (ARM 200)[g]	Kinetico	60/60/30	33	<25	7.9
Vale, OR	City of Vale	IX (Arsenex II)	Kinetico	525	17	<25	7.5
Reno, NV	South Truckee Meadows General Improvement District	AM (GFH/Kemiron)	Siemens	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; RO = reverse osmosis
ATS = Aquatic Treatment Systems; MEI = Magnesium Elektron, Inc.; STS = Severn Trent Services
(a) Arsenic existing mostly as As(III).
(b) Design flowrate reduced by 50% due to system reconfiguration from parallel to series operation.
(c) Iron existing mostly as Fe(II).
(d) Replaced Village of Lyman, NE site which withdrew from the program in June 2006.
(e) Facilities upgraded systems in Springfield, OH from 150 to 250 gpm, Sandusky, MI from 210 to 340 gpm, and Arnaudville, LA from 385 to 770 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 16 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 7,000 bed volumes (BV) for each column according to the two test runs performed. Complete breakthrough following the lead columns occurred at approximately 12,000 BV, resulting in an adsorptive capacity between 0.45 and 0.49 µg of As/mg of dry media. System breakthrough at 10 µg/L was between 17,000 and 18,000 BV (or 5,700 and 6,000 BV if considering the three columns in each train as one large column) for both runs. BV was calculated based on the volume of media in each column.

- Arsenic breakthrough from the lead columns occurred much sooner than the 40,000 BV projected by the vendor. It is presumed that relatively high pH values of the source water (averaging 7.7), competing anions, such as silica, and higher-than-expected influent arsenic concentrations (ranging from 20.8 to 101 µg/L and averaging 41.3 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 empty bed contact time (EBCT) of 1 min/column based on a flowrate of 11 gallons per minute (gpm) per treatment train, compared to the actual EBCT of 1.6 to 56.1 min caused by the lower flowrates experienced by the source water wells.

- Some aluminum (i.e., 10 to 30 µg/L) was observed to leach out from the adsorption columns.

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

- Very little attention was needed to operate and maintain the system. The daily demand on the operator was typically 10 min to visually inspect the system and record operational parameters.

- Operation of the treatment system did not require additional skills beyond those necessary to operate the existing water supply equipment.

Process residuals produced by the technology:

- The system did not require backwash to operate. As a result, no backwash residual was produced.

- The only residual produced by the treatment system was spent media. The media in the lead and first lag columns in each train were replaced on February 14, 2006, after approximately 34 weeks of operation.

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).

- The cost to change out four adsorption columns (lead and first lag column in each train) at a time was estimated to be $3,910 based on the invoice provided by the vendor.

3.0 MATERIALS AND METHODS

3.1 General Project Approach

Following the predemonstration activities summarized in Table 3-1, the performance evaluation study of the ATS treatment system began on June 22, 2005 and ended on October 10, 2006. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall system performance was evaluated based on its ability to consistently remove arsenic to below the 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. Any unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

The O&M and operator skill requirements were assessed through quantitative data and qualitative considerations, including the need for pre- and/or post-treatment, level of system automation, extent of 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 the tracking of the capital cost for equipment, engineering, and installation, as well as the O&M cost for media replacement and disposal, chemical supply, electrical power use, and labor.

Table 3-1. Predemonstration 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 Began	June 22, 2005

VDEC = Vermont Department of Environmental Conservation

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 regular basis, the plant operator recorded system operational data, such as pressure, flowrate, totalizer, and hour meter readings on a 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 would contact the

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

Evaluation Objectives	Data Collection
Performance	-Ability to consistently meet 10 µg/L of arsenic MCL 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

Battelle Study Lead, who determined if ATS should be contacted for troubleshooting. The plant operator recorded all relevant information, including the problems encountered, course of actions taken, materials and supplies used, and associated cost and labor incurred on the Repair and Maintenance Log Sheet. On a biweekly basis, the plant operator measured several water quality parameters on-site, including temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and residual chlorine, and recorded the data on an 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, chemical usage, electricity consumption, and labor. Labor for various activities, such as the routine system O&M, troubleshooting and repairs, 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, replenishing NaOCl solutions, 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 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, one set of source water samples was collected and speciated using an arsenic speciation kit (see 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. Analytes 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)	On-site: pH, temperature, DO, and ORP Off-site: As (total, and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), Al (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, Cl, F, NH_3, NO_3, NO_2, SO_4, SiO_2, PO_4, alkalinity, turbidity, TDS, and TOC	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)[b] 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, 10/04/05, **10/13/05,** 10/25/05, 11/01/05, 11/08/05, 11/28/05, **12/13/05,** 01/05/06, 01/25/06, 01/31/06, 02/15/06, 02/28/06, 03/16/06, 03/29/06, **04/11/06,** 04/27/06, 05/10/06, 06/01/06, **06/05/06,** 06/22/06, 07/11/06, 07/18/06, **08/02/06,** 08/17/06, 09/07/06, 09/18/06, **09/26/06,** 10/10/06
Distribution Water	Three LCR Residences	3	Monthly[c]	Total As, Fe, Mn, Al, Cu, and Pb, pH and alkalinity	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, 12/13/05, 01/26/06, 02/14/06, 04/11/06
Residual Solids	Spent Media from Adsorption Columns	4	Once	TCLP and total Al, As, Cd, Ca, Cu, Fe, Pb, Mg, Mn, Ni, P, Si, and Zn	02/14/06

(a) Abbreviations in parentheses corresponding to sample locations shown in Figure 4-4.
(b) Taken only at AC, TA to TF, and TT.
(c) Four baseline sampling events performed before system startup. Sampling discontinued after April 2006 when water was delivered to site to keep up with demand.

LCR = lead and copper rule; TCLP = toxicity characteristic leaching procedure
Bold font indicates that speciation was performed.

3.3.2 Treatment Plant Water. During the system performance evaluation study, samples were collected by the plant operator weekly or bi-weekly 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 analytes listed in Table 3-3 also were performed during each sampling event.

3.3.3 Residual Solid. Because the system did not require backwash, no backwash residuals were produced during system operations. Spent media samples were collected from each of the columns replaced on February 14, 2006. ATS collected one gallon of sample from each column and shipped the samples to Battelle. Approximately 200 g of the spent media from each container were collected and placed in one container. After being homogenized, one aliquot was tested for TCLP. Another aliquot (approximately 100 g) was air-dried, crushed (using a mortar and pestle), acid-digested, and analyzed for the metals listed in Table 3-3.

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 start-up from December 2004 to April 2005, four sets of baseline distribution water samples were collected from three residences that were part of the historic sampling network under the Lead and Copper Rule (LCR). Following system startup, distribution system water sampling continued on a monthly basis at the same locations until April 2006 when the Vermont State Housing Authority (VSHA) had to deliver water to meet the Park's demand because the wells were not supplying enough water. The delivered water was stored in the 5,500-gal atmospheric storage tank before being treated by the ATS system for distribution.

Samples were collected following an instruction sheet developed according to the *Lead and Copper Rule Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The dates and times of last water usage before sampling and of sample collection were recorded for calculating the stagnation time. All samples were collected from a cold-water faucet that had not been used for at least 6 hr to ensure that stagnant water was sampled.

3.4 Sampling Logistics

3.4.1 Preparation of Arsenic Speciation Kits. The arsenic field speciation method used an anion exchange resin column to separate the soluble arsenic species, As(V) and As(III) (Edwards et al., 1998). 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 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 separate Ziploc® bags and packed in the cooler.

In addition, all sampling- and shipping-related materials, such as disposable gloves, sampling instructions, chain-of-custody forms, prepaid/addressed FedEx air bills, and bubble wrap, were included. The chain-of-custody forms and air bills were complete except for the operator's signature and the sample dates and times. 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 metals analyses were stored at Battelle's inductively coupled plasma-mass spectrometry (ICP-MS) laboratory. Samples for other water quality analyses by Battelle's subcontract laboratories, including American Analytical Laboratories (AAL) in Columbus, Ohio, Belmont Labs in Englewood, Ohio, and TCCI Laboratories in New Lexington, Ohio, were packed in separate coolers and picked up by couriers. The chain-of-custody forms remained with the samples from the time of preparation through collection, analysis, and final disposal. 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, Belmont Labs, 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 to 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 Multi-340i 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, supplied water to approximately 14 mobile homes. The water treatment building, shown in Figure 4-1, was located on Dummerston Station Road. The water source was 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 approximately 2,500 gpd. The preexisting system included a 5,500-gal atmosphere storage tank, two booster pumps, and four pressure tanks (Figure 4-2). The only treatment for the preexisting water system was chlorination via injection of a 0.625% NaOCl solution for disinfection.

Figure 4-1. Preexisting 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 3-3. The results of the source water analyses, along with those provided by the facility to EPA for the demonstration site selection and those obtained from the 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 μg/L. Based on the September 14, 2004, sampling results, the total arsenic concentration in the source water was 30.0 μg/L, of which 28.6 μg/L (or 95%) existed as soluble As(V). This speciation result is consistent with the relatively high DO and ORP values of 6.1 mg/L and 212 mV, respectively, measured during sampling.

pH values of source water ranged between 7.8 and 8.1. The vendor indicated that the A/I Complex 2000 media could effectively remove arsenic as long as the pH values of source water were less than 9.0. As such, no pH adjustment was planned at the site.

Figure 4-2. Preexisting Pressure Tanks and Booster Pumps

Concentrations of iron (<25 µg/L) and other ions in raw water were sufficiently low so pretreatment prior to the adsorption process was not required. Concentrations of orthophosphate and fluoride also were sufficiently low (i.e., <0.1 and <0.2 mg/L, respectively) and, therefore, not expected to affect 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 Spring Brook Mobile Home Park (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 on arsenic adsorption was carefully monitored throughout the study period.

Other water quality parameters as presented in Table 4-1 had sufficiently low concentrations and, therefore, were not expected to affect arsenic adsorption on the A/I Complex 2000 media.

4.1.2 Distribution System and Treated Water Quality. According to a VDEC Sanitary Survey, 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 (P^2 Environmental, 2005).

Compliance samples from the distribution system were collected monthly for bacterial analysis. Under the EPA LCR, samples were 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 µg/L, similar to those in source water. Lead concentrations ranged from the method reporting limit of 5 to 6 µg/L; copper concentrations ranged from the method reporting limit of 30 to 300 µg/L. Radium-226 and Radium-228 were present at 0.2 and 0.5 pCi/L, respectively, which was 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
Date		-	9/14/04	1999–2004	2000–2004
pH		8.0	7.9	7.8–8.1	N/A
Temperature	°C	N/A	11.1	N/A	N/A
DO	mg/L	N/A	6.1	N/A	N/A
ORP	mV	N/A	212	N/A	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 uses A/I Complex 2000 adsorptive media for arsenic removal. The A/I Complex 2000 adsorptive media consist of activated alumina and a proprietary iron complex. Table 4-2 presents physical and chemical properties of the adsorptive media, which has NSF International (NSF) Standard 61 listing for use in drinking water.

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

Physical Properties	
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
Chemical Analysis	
Constituent	**Value**
Al_2O_3 (%, dry)	90.89
$NaIO_4$ (%, dry)	3.21
$Fe(NH_4)_2(SO_4)_2•6H_2O$ (%, dry)	5.90

The ATS As/2200 CS system is a fixed-bed downflow adsorption system designed for use at small water systems with flowrates of around 22 gpm. Upon exhaustion, the columns containing spent media are dewatered and shipped to ATS's shop in Massachusetts. The spent media can be either disposed of after being subjected to the EPA Toxicity Characteristic Leaching Procedure (TCLP) test or recycled for beneficiary use according to the vendor.

The system at CMHP was configured in series with water being split into two treatment trains. The system was designed for the lead column to be removed upon exhaustion and each of the two lag columns to be moved forward one position (i.e., the first lag column would become the lead column and the second lag column would become the first lag column). A new column loaded with virgin media would then be placed at the end of each treatment train. Figure 4-3 shows a schematic diagram of the system. Major system components are described as follows:

- **Chlorine Feed System.** Chlorine was injected after water from the three supply wells was combined. The feed system consisted of a 30-gal chemical day tank and a Walchem EZ Series feed pump with a maximum capacity of 1.0 gal/hr. Proper operation of the feed system was tracked by the operator through measurements of free chlorine across the treatment train. To maintain a target level of 0.2 to 0.4 mg/L (as Cl_2) of free chlorine residual, a 0.625% NaOCl solution was used at a rate of 0.44 mL/min when the well pumps were running.

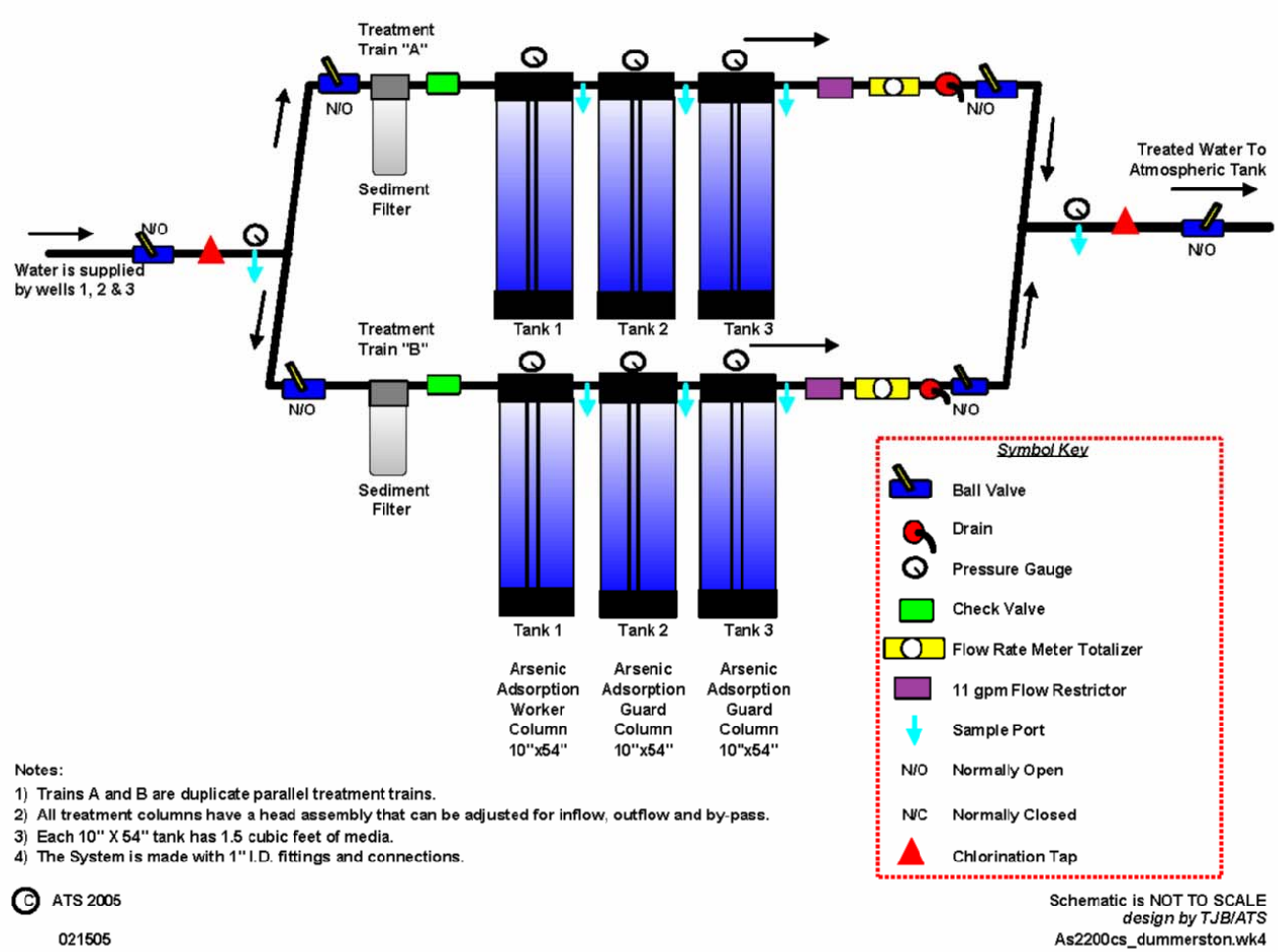


Figure 4-3. Schematic of ATS As/2200CS System with Series Operation

- **Sediment Filters.** One 25-µm sediment filter was installed at the head of each treatment train. The 6-in × 20-in filters were used to remove any large particles so that they did not flow into and accumulate in the adsorption columns.

- **Adsorption Columns.** Following the sediment filter, each treatment train had three 10-in × 54-in sealed polyglass columns (by Park International) each loaded with 1.5 ft^3 of A/I Complex 2000 media. Each adsorption column had a riser tube and a valved head assembly to control inflow, outflow, and by-pass.

- **Totalizer/Flow Meter.** One Model F-1000 paddlewheel totalizer/flow meter (by Blue-White Industries) was installed on the downstream end of each treatment train to record flowrate and volume of water treated through the treatment train.

- **Storage Tank.** One 5,500 gal atmospheric storage tank was located at the system outlet to provide temporary storage of the treated water.

- **Booster Pumps and Pressure Tanks.** Two preexisting 2-horsepower (hp) multistage centrifugal CR-4 booster pumps (by Grundfos) and three 120-gal WM series captive air pressure tanks (by Well Mate) with a total storage capacity of approximately 500 gal were located after the atmospheric storage tank. The pressure tank/booster pump assembly was used to supply the treated water with the necessary pressure to the distribution system. The on/off settings of the booster pumps were controlled by the low/high pressure switch set at 30/50 pounds per square inch (psi) in the pressure tanks.

- **Pressure Gauges.** One each BII (0-100 psi) pressure gauge was installed at the system inlet just prior to the sediment filter, at the head of each column, and at the system outlet. The pressure gauges were used to monitor the system pressure and pressure drop across the treatment train.

- **Sampling Taps.** Sampling taps made of PVC by US Plastics were located prior to the system and following each adsorption tank for water sampling.

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 is presented in Figure 4-4. A photograph of the system installation is shown in Figure 4-5 and a close-up view of an adsorptive media column is shown in Figure 4-6.

4.3 Permitting and System Installation

Engineering plans for the system were prepared by ATS and reviewed by Roberts & Franzoni Engineering, Inc. The plans, consisting of a schematic and a written description of the As/2200CS system, were submitted to VDEC for approval on April 29, 2005. 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 additions or modifications. The As/2200 CS 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. The sediment filters were attached to the wall at the head of the treatment trains (Figure 4-5). The media columns were then set into place and plumbed together using copper piping and connections. The mechanical installation was complete on June 22, 2005. Before the

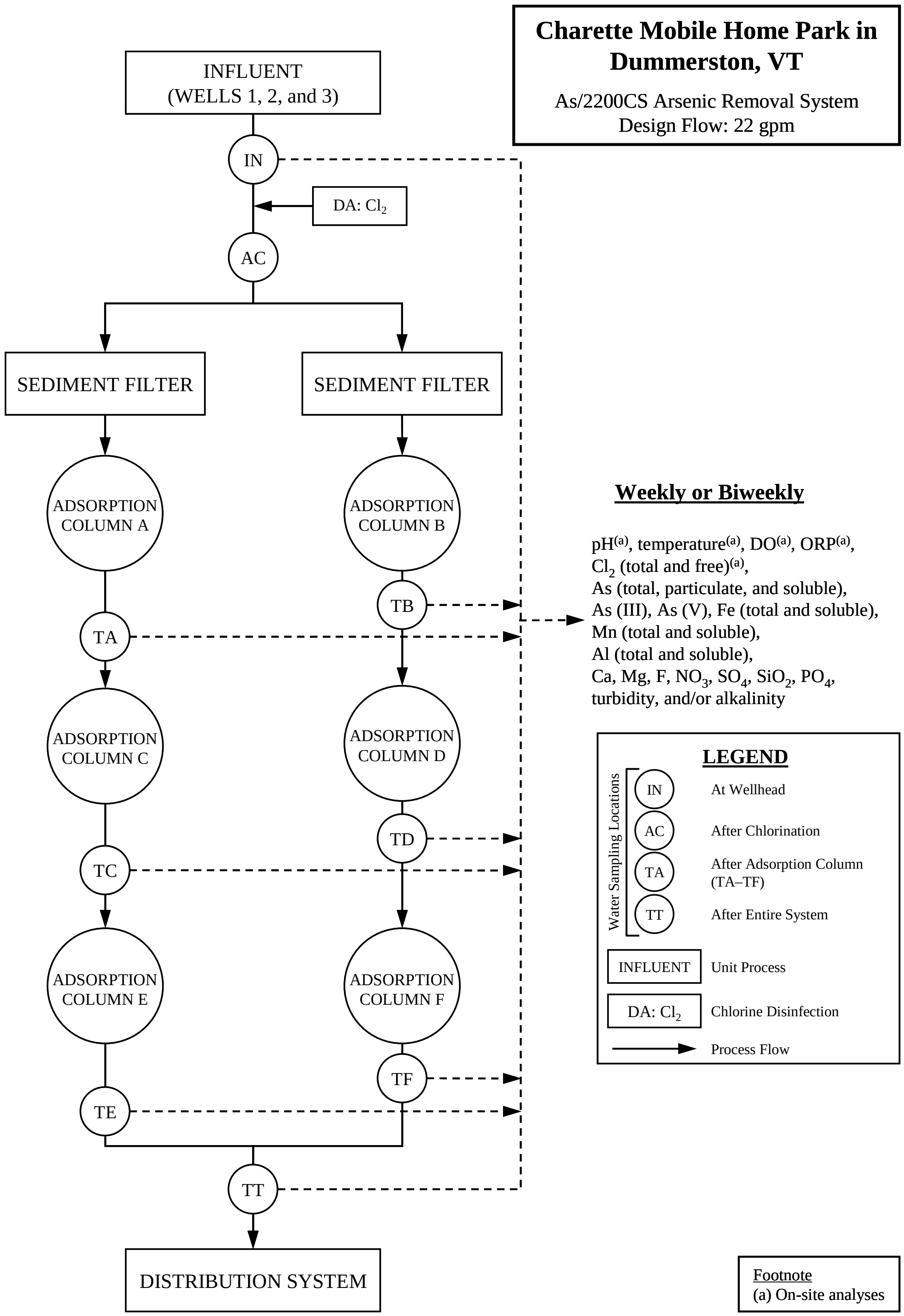
Table 4-3. Design Specifications of As/2200CS System

Parameter	Value	Remarks
Adsorption Columns		
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	Activated alumina/iron complex (See Table 4-2)
Media Quantity (lbs)	83	Per column
Media Volume (ft^3)	1.5	Per column
Service		
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
Maximum Use Rate (gpd)	2,500	Based on usage estimate provided by park
Estimated Working Capacity (BV)	40,100	Bed volumes to breakthrough to 10 µg/L from lead column
Throughput to Breakthrough (gal)	450,000	Vendor-provided estimate to breakthrough at 10 µg/L from lead column based on 1.5 ft^3 (11.2 gal) of media in lead column
Estimated Media Life (months)	12	Estimated frequency of media change-out in lead column based on throughput of 1,250 gpd per train
Backwash		
Backwash	-	No system backwash required

system was put online, the system piping was flushed and the columns were filled one at a time to check for leaks. Once all columns were filled, the system operated for a short period with the treated water going to the sewer. After it was determined that the system was operating properly, the first set of system samples and a sample for the total coliform test were collected. Upon receipt of the coliform test result (that indicated absence of bacteria) on June 24, 2005, the treated water was directed to the distribution system.

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters of the system were tabulated and attached as Appendix A. Key parameters are summarized in Table 4-4. From June 22, 2005, through October 10, 2006, the treatment system operated for 3,636 hr based on hour meter readings of the well pumps. The operational time represented a utilization rate of approximately 32% with the well pumps operating an average of 7.6 hr/day. The total system throughput during the first 34-week period was approximately 391,400 gal (or 195,700 per train). After changeout of the first two columns in each treatment train, the system ran for an additional 34 weeks, treating another 353,500 gal (or 176,750 per train) of water. This corresponds to 17,315 and 15,750 BV of water processed through a column containing 1.5 ft^3 (or 11.2 gal) of media throughout the first and second 34-week periods, respectively. For the entire system, i.e., six columns in two trains with 9 ft^3 (67.2 gal) of media, it treated approximately 5,824 BV and 5,260 BV, respectively, throughout the two 34-week test periods.



Note: After November 8, 2005, only As and SiO_2 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

Except for a few outliers, flowrates of the three source water wells ranged from 0.0 to 3.3 gpm and averaged 0.3 gpm for Well 1; from 0.3 to 3.1 gpm and averaged 1.1 gpm for Well 2; and from 0.9 to 5.0 gpm and averaged 2.8 gpm for Well 3 during the system operation. For unknown reasons, the flowrates of the source water wells reduced more than half after the 23rd week of operation and remained low for approximately 14 weeks. Afterwards, flowrates began to increase again, but were highly variable for the last 31 weeks of the study period (Figure 4-7). Table 4-5 details the fluctuations observed during the three time periods.

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

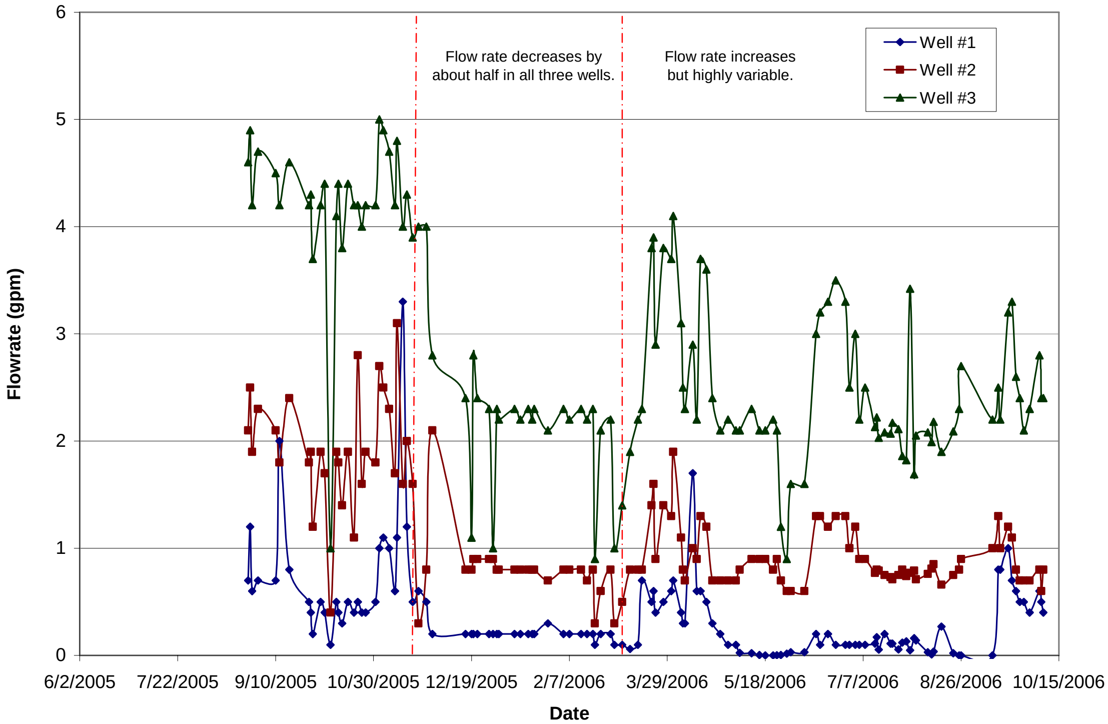
Operation Parameter		Values		
Media Run		Run 1	Run 2	Both Runs
Operating Duration		06/24/05-02/13/06	02/15/06-10/10/06	06/24/05-10/10/06
Total Operating Time (hr)		1,566	2,070	3,636
Average Daily Operating Time (hr/day)		6.7	8.7	7.6
Average of Influent Pressure [Range] (psi)		12.0 [0.0-30]	9.4 [0.0-25]	10.8 [0.0-30]
Average Flowrates of Source Water Wells [Range] (gpm)	Well #1	0.5 [0.0-3.3]	0.3 [0.0-1.7]	0.3 [0.0-3.3]
	Well #2	1.4 [0.3-3.1]	0.9 [0.3-1.9]	1.1 [0.3-3.1]
	Well #3	3.3 [0.9-5.0]	2.4 [0.9-4.1]	2.8 [0.9-5.0]
	Combined	6.7 [1.5-9.0]	4.2 [1.3-9.0]	4.2 [1.3-9.0]
Average Flowrates of Treatment Trains (gpm)	Train A	3.3 [0.2-6.2]	2.4 [0.5-5.1]	2.8 [0.2-6.2]
	Train B	3.9 [1.3-7.1]	2.6 [0.4-5.5]	3.2 [0.4-7.1]
	Combined	7.0 [0.2-13.3]	4.8 [0.8-10.5]	6.1 [0.2-13.3]
Throughput (gal)	Train A	193,700	163,800	357,500
	Train B	197,700	189,700	387,400
	Combined	391,400	353,500	744,900
Throughput (BV per train)[a]	Train A	17,140	14,600	31,740
	Train B	17,490	16,900	34,390
	Combined	34,630	31,500	66,130
Average EBCT (min)[a] per Column [Range]	Train A	3.4 [1.8-56.1]	4.7 [2.2-22.4]	4.0 [1.8-56.1]
	Train B	2.9 [1.6-8.6]	4.3 [2.0-28.0]	3.5 [1.6-28.0]
	Combined	1.6 [0.8-56.1]	2.3 [1.1-14.0]	1.8 [0.8-56.1]
Average Pressure Losses Across Trains (psi) [Range]	Train A	8.4 [0.0-16.0]	5.4 [0.0-14.0]	7.1 [0.0-16.0]
	Train B	6.9 [0.0-15.0]	2.1[0.0-9.0]	5.4 [0.0-15.0]

(a) Calculated based on 1.5 ft^3 (or 11.22 gal) of media in lead column.

The treatment system showed similar flowrate fluctuations coinciding with those of the wells. The ranges of flowrates for Trains A and B throughout the study period were 0.3 to 6.2 and 0.3 to 7.1 gpm, respectively (compared to the design flowrate of 11 gpm per train) (Figure 4-7). These resulted in EBCT values ranging from 1.8 and 56.1 min per column for Train A and from 1.6 and 28.0 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 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 1,647 gpd, which was approximately 66% of that provided by the park. The flowrates also were affected by the influent pressure to the system. Because there was no pressure tank/booster pump prior to the system, influent pressures were typically low, ranging from 0 to 30 psi (Figure 4-8).

The pressure loss across each column ranged from 0 to 20 psi and averaged 3 psi. The total pressure loss across each treatment train (three columns in series) varied between the two runs and the two treatment trains. During Run 1, the treatment trains had an average pressure loss of 6.9 to 8.4 psi. However, in Run 2, Train A had an average pressure loss of 5.4 psi while Train B had an average pressure loss only of 2.1 psi. The average influent pressure at the head of the system from the wells was 12 psi for Run 1 and 9.4 psi for Run 2. The average pressure following the last column in Train A was similar for both Runs 1 and 2 at 3.6 and 4.1 psi, respectively. Train B had a wider variance between Run 1 and Run 2 for the average pressure following the last column with Run 1 average pressure at 5.3 psi and Run 2 average pressure at 9.1 psi. The treated water was fed into a 5,500 gal atmospheric storage tank so that the pressure was



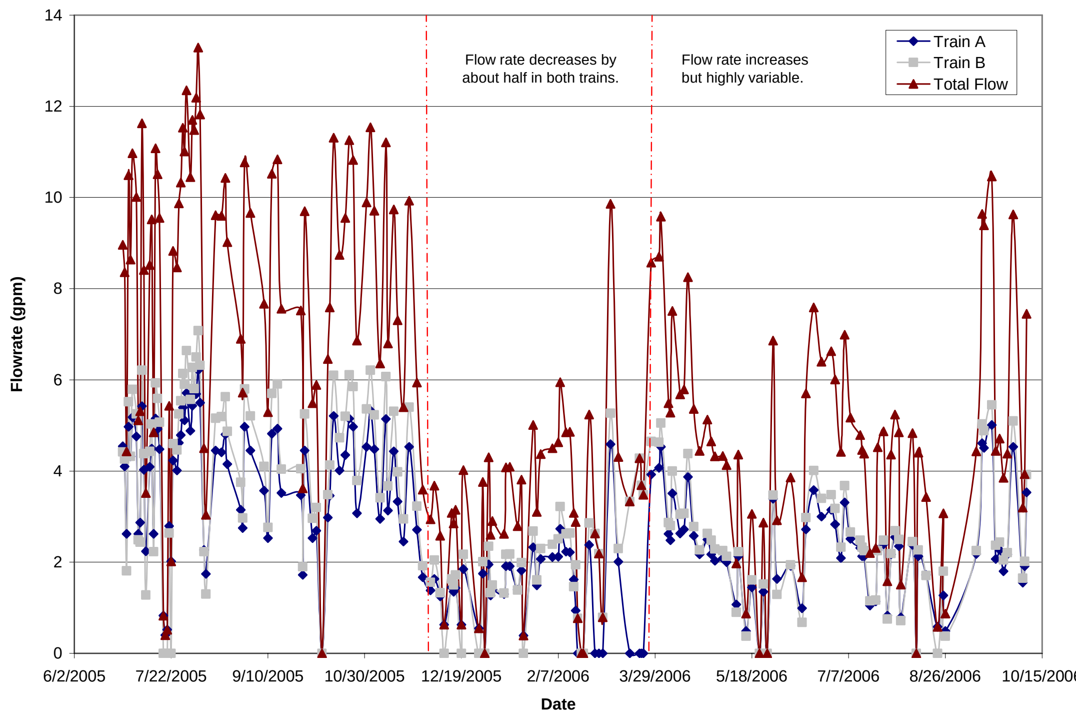


Figure 4-7. Average Flowrate of Three Source Wells and the Treatment System

Table 4-5. Summary of Flowrate and Pressure Variations During System Operation

Date	06/24/05–11/29/05	12/01/06–03/14/06	03/16/06–10/07/06
Range and Average Flowrates for Each Well and Combined			
Well #1 (gpm)	0.1–3.3 (0.7)	0.0–0.3 (0.2)	0.0–1.7 (0.3)
Well #2 (gpm)	0.3–3.1 (1.9)	0.3–0.9 (0.8)	0.9–2.8 (2.1)
Well #3 (gpm)	1.0–5.0 (4.2)	0.9–2.8 (2.1)	0.9–4.1 (2.5)
Combined (gpm)	1.5–9.0 (6.7)	0.7–3.9 (3.1)	1.1–6.9 (3.7)
Range and Average Flowrates for Each Train and Combined			
Train A (gpm)	0.6–6.2 (3.6)	0.3–4.6 (1.4)	0.4–5.0 (2.1)
Train B (gpm)	0.3–7.1 (4.0)	0.2–5.3 (1.7)	0.3–5.5 (2.5)
Combined (gpm)	0.4–13.3 (8.2)	0.2–9.9 (3.3)	0.6–10.5 (4.8)
Range and Average Inlet System Pressure			
Inlet System Pressure (psi)	0–30 (14.9)	0.0–25 (6)	0–23 (9.7)

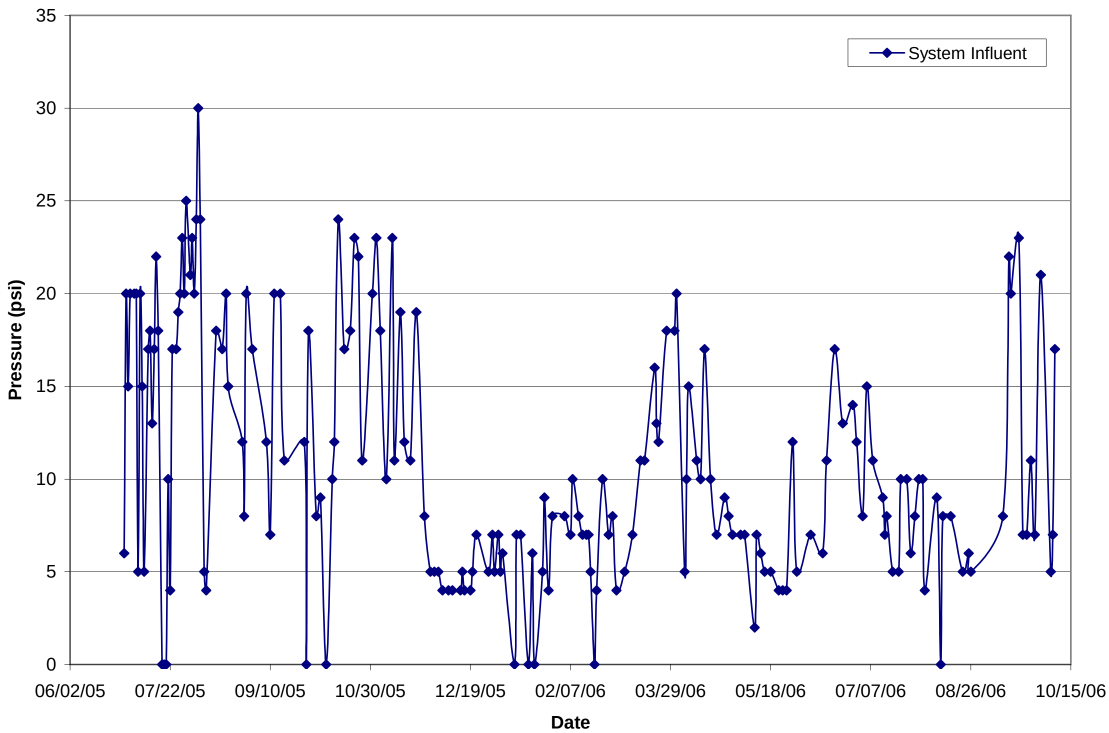


Figure 4-8. Influent Pressure from Three Source Wells

0 psi at the tank and preexisting pressure tanks; 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 was spent media. The media from the first two columns of each treatment train were replaced on February 14, 2006, after 34 weeks of operation. Because the system did not require backwash, no backwash residuals were produced.

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. After the first month, flow became more balanced and at the end of the first run, Train A received 49% and Train B received 51% of the water. At the beginning of the second run, Train B was treating more than 75% of the flow. By the end of the evaluation, Train A treated approximately 46% and Train B treated 54% of the water. Additional discussion regarding system operation and operator skill requirement are provided below.

4.4.3.1 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 preexisting chlorine addition system. No other pre- or post-treatment was required for this system.

4.4.3.2 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.

4.4.3.3 Operator Skill Requirements. Under normal operating conditions, the skills required to operate the treatment 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.

The CMHP treatment facility is considered by VDEC as a public community water system. A public system is one that has 15 or more service connections or that serves 25 or more people. A community system is one that serves residents on a year-round basis. Individuals who operate or supervise the operation of a public water system in the state of Vermont must possess an operator certificate.

The five classes of water systems in Vermont are Classes 1, 2, 3, 4 and D. Classes 1, 2, 3, and 4 apply to water systems with their own source(s) of supply and Class D applies to systems that distribute water. Class 3 applies to systems that fall under one of the following categories: 1) disinfection by other than chlorine or ultraviolet (UV); 2) sequestering or filtering of manganese or iron; 3) fluoridation; 4) corrosion control; 5) pH control; 6) air stripping; 7) granular activated adsorption; 8) ion exchange; or 9) aeration. Although treatment of arsenic through adsorption is not specifically listed under Class 3, the treatment system falls under Class 3 (VDEC, 2007). The operator at CMHP possesses a Class 3 certification.

4.4.3.4 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 approximately three times per week to check the system for leaks, and record flow, volume, and pressure readings.

4.4.3.5 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 treatment system.

4.5 System Performance

The performance of the treatment system was evaluated based on analyses of samples collected from the raw and treated water from the treatment and distribution systems. The system ran from June 22, 2005, through February 14, 2006, when the first two columns in each train (i.e., TA through TD), were changed out. The second set of lag columns (TE and TF) were switched to the lead position and four new columns were added as lag columns. The system operated for an additional 34 weeks before the arsenic levels in the effluent from the system (following the third columns) had reached 10 µg/L and the study was completed.

4.5.1 Treatment Plant Sampling. Table 4-6 summarizes the arsenic, iron, manganese, and aluminum results from samples collected throughout the treatment plant for the two runs. Table 4-7 summarizes the results of other water quality parameters. Appendix B contains a complete set of analytical results through the 68 weeks of system operation. The results of the treatment plant sampling are discussed below.

4.5.1.1 Arsenic. The key parameter for evaluating the effectiveness of the treatment system was the concentration of arsenic in the treated water. The treatment plant water was sampled on 36 occasions during the 68 weeks of system operation (with duplicate samples taken on three and field speciation performed on eight of the 36 occasions).

Figure 4-9 contains three bar charts each showing the concentrations of total As, particulate As, and soluble As, including As(III) and As(V), across the entire system for Runs 1 and 2. Total As concentrations in raw water ranged from 20.8 to 101 µg/L and averaged 41.3 µg/L (Table 4-6). Soluble As(V) was the predominating species, with concentrations ranging from 20.6 to 67.0 µg/L and averaging 37.5 µg/L. Soluble As(III) also was present in source water, with concentrations ranging from 0.2 to 3 µg/L and averaging 1.2 µg/L. Particulate As was low with concentrations typically less than 1 µg/L. The influent arsenic concentrations measured during this 68-week period were generally higher than those in the raw water sampled during the initial site visit on September 14, 2004 (Table 4-1).

Arsenic concentrations after the lead columns reached 10 µg/L at approximately 5,700 BV from Train A (TA) and 5,400 BV from Train B (TB) (Figure 4-10) (note that BV was calculated based on the amount of media, i.e., 1.5 ft^3, in each lead column). Arsenic, existing almost entirely of As(V) (Figure 4-9), 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 the vendor indicated that the media could effectively remove arsenic as long as the pH values were less than 9.0, the relatively high pH values of source water (averaging 7.6; see Table 4-7) might have contributed, in part, to early arsenic breakthrough from the adsorption columns. Influent arsenic concentrations during the 68-week 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 41.3 µg/L during the 68 weeks 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 the flowrate was much higher than the actual flowrate (see Table 4-4).

Based on the breakthrough curves shown in Figure 4-10 and the resulting mass removal data summarized in Table 4-8, the arsenic loading on the adsorption media was estimated to be between 0.45 and 0.49 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 4-11 by the amount of dry media (1.5 ft^3) in each lead column (see Appendix C). The total arsenic mass removed during Run 1 by the lead columns in Trains A and B (TA

Table 4-6. Summary of Arsenic, Iron, Manganese, and Aluminum Analytical Results

Parameter	Sampling Location	Number of Samples	Concentration (µg/L)			Standard Deviation
			Minimum	Maximum	Average	
As (total)	IN	19 [19][a]	28.8 [20.8]	72.2 [101]	42.2 [40.5]	12.7 [21.5]
	AC	4 [4]	25.7 [21.5]	25.7 [79.7]	25.7 [43.0]	– [21.6]
	TA-TF	8–19 [19][a]	[b]			
	TT	16 [19]				
As (particulate)	IN	4 [4]	<0.1 [0.2]	1.2 [10.1]	0.34 [3.5]	0.58 [4.5]
	AC	1 [3]	<0.1 [0.3]	<0.1 [4.4]	<0.1 [1.7]	– [2.3]
	TA-TD	2–3 [0]	[b]			
	TT	2 [4]				
As (III)	IN	4 [4]	0.4 [0.2]	3.0 [1.1]	1.8 [0.53]	1.1 [0.4]
	AC	1 [4]	0.5 [0.2]	0.5 [1.2]	0.5 [0.58]	– [0.4]
	TA-TD	2–3 [0]	[b]			
	TT	2 [4]				
As (V)	IN	4 [4]	29.1 [20.6]	44.4 [67.0]	39.3 [35.7]	6.9 [21.4]
	AC	1 [4]	25.5 [20.0]	25.5 [67.0]	25.5 [40.8]	– [20.1]
	TA-TD	2–3 [0]	[b]			
	TT	2 [4]				
Fe (total)	IN	19 [19][a]	<25 [<25]	45.4 [108]	<25 [<25]	7.6 [28.6]
	AC	1 [4]	<25 [<25]	<25 [<25]	<25 [<25]	– [0]
	TA-TF	1–13 [3][a]	<25 [<25]	<25 [<25]	<25 [<25]	0.0 [0.0]
	TT	16 [19][a]	<25 [<25]	<25 [<25]	<25 [<25]	0.0 [0.0]
Fe (soluble)	IN	4 [4]	<25 [<25]	<25 [<25]	<25 [<25]	0.0
	AC	1 [4]	<25 [<25]	<25 [<25]	<25 [<25]	– [0.0]
	TA-TD	2–3 [0]	<25 [–]	<25[c] [–]	<25[c] [–]	0.0[c] [–]
	TT	2 [4]	<25 [<25]	<25 [<25]	<25 [<25]	0.0 [0.0]
Mn (total)	IN	19 [19][a]	1.7 [1.9]	35.9 [37.9]	9.0 [10.9]	9.8 [11.8]
	AC	1 [4]	12.1 [2.5]	12.1 [4.7]	12.1 [3.9]	– [1.1]
	TA-TF	1–11 [3][a]	<0.1 [<0.1]	0.8 [0.6]	0.2 [0.2]	0.2 [0.2]
	TT	16 [19][a]	<0.1 [<0.1]	0.3 [1.6]	0.1 [0.3]	0.1 [0.5]
Mn (soluble)	IN	4 [4]	<0.1 [1.1[	9.5 [3.2]	4.8 [2.3]	4.8 [0.9]
	AC	1 [4]	1.2 [1.6]	1.2 [2.7]	1.2 [2.1]	– [0.5]
	TA-TD	23 [0]	<0.1 [–]	0.8 [–]	0.3 [–]	0.3 [–]
	TT	2 [4]	<0.1 [<0.1]	0.2 [0.2]	0.1 [0.2]	0.1 [0.1]
Al (total)	IN	19 [19] [a]	<10 [<10]	<10 [<10]	<10 [<10]	0.0 [0.0]
	AC	1 [4]	<10 [<10]	<10 [<10]	<10 [<10]	– [0.0]
	TA-TF	1–11 [2][a]	<10 [10.0]	30.3 [16.3]	17.1 [12.0]	5.6 [1.8]
	TT	16 [19][a]	<10 [<10]	27.4 [20.8]	18.2 [14.2]	6.6 [4.3]
Al (soluble)	IN	4 [4]	<10 [<10]	<10 [<10]	<10 [<10]	0.0 [0.0]
	AC	1 [4]	10.2 [<10]	10.2 [<10]	10.2 [<10]	– [0.0]
	TA-TD	2–3 [0]	<10 [–]	20.8 [–]	13.5 [–]	5.4 [–]
	TT	2 [4]	14.1 [12.8]	20.9 [17.3]	17.5 [15.5]	4.8 2.0]

Duplicate samples included in calculations.
Run 2 analytical results shown in brackets.
(a) Including one duplicate sample.
(b) Statistics not provided; see figure 4-8 for As breakthrough curves.

Table 4-7. Summary of Other Water Quality Parameter Analytical Results

Parameter	Sampling Location	Unit	Number of Samples	Concentration/Unit Minimum	Maximum	Average	Standard Deviation
Alkalinity (as $CaCO_3$)	IN	mg/L	15 [9]	110 [121]	141 [156]	128 [140]	7.3 [13.1]
	TA-TF	mg/L	1–10 [0]	44 [−]	165 [−]	133 [−]	26.8 [−]
	TT	mg/L	12 [9]	110 [125]	154 [141]	137 [134]	13.7 [4.4]
Fluoride	IN	mg/L	15 [9]	<0.1 [<0.1]	<0.1 [0.3]	<0.1 [0.1]	0.0 [0.08]
	TA-TF	mg/L	1–10 [0]	<0.1 [−]	3.7 [−]	0.28 [−]	0.86 [−]
	TT	mg/L	13 [9]	<0.1 [<0.1]	0.1 [0.2]	0.05 [0.07]	0.01 [0.05]
Sulfate	IN	mg/L	15 [9]	16 [22]	24 [24]	20.3 [22.9]	2.2 [0.7]
	TA-TF	mg/L	1–10 [0]	15 [−]	70 [−]	24.6 [−]	12.1 [−]
	TT	mg/L	12 [9]	17 [20]	28 [25]	21.6 [23.3]	2.8 [1.5]
Orthophosphate (as PO_4)	IN	mg/L	8 [0]	<0.05 [−]	<0.05 [−]	<0.05 [−]	0.0 [−]
	TA-TD	mg/L	2–8 [0]	<0.05 [−]	<0.05 [−]	<0.05 [−]	0.0 [−]
	TT	mg/L	7 [0]	<0.05 [−]	<0.05 [−]	<0.05 [−]	0.0 [−]
Phosphorus (as P)	IN	mg/L	8 [9]	<0.03 [<0.03]	<0.03 [<0.03]	<0.03 [<0.03]	0.0 [0.0]
	TA-TF	mg/L	2–3 [0]	<0.03 [−]	<0.03 [−]	<0.03 [−]	0.0 [−]
	TT	mg/L	6 [9]	<0.03 [<10]	<0.03 [<10]	<0.03 [<10]	0.0 [0.0]
Silica (as SiO_2)	IN	mg/L	18 [19]	10.6 [10.7]	16.8 [13.3]	12.6 [11.5]	1.4 [0.6]
	TA-TF	mg/L	8–17 [19]	0.4 [0.1]	14.7 [12.5]	9.8 [9.4]	2.4 [2.8]
	TT	mg/L	15 [19]	0.3 [0.2]	10.3 [10.6]	7.0 [7.7]	3.4 [3.1]
Nitrate (as N)	IN	mg/L	15 [9]	<0.05 [<0.05]	0.2 [0.2]	0.11 [0.08]	0.06 [0.06]
	TA-TF	mg/L	1–9 [0]	<0.05 [−]	0.10 [−]	0.08 [−]	0.03 [−]
	TT	mg/L	11 [9]	<0.05 [<0.05]	0.4 [0.2]	0.12 [0.11]	0.10 [0.05]
Turbidity	IN	NTU	15 [9]	<0.1 [0.2]	1.3 [0.9]	0.3 [0.4]	0.3 [0.2]
	TA-TF	NTU	1–10 [0]	<0.1 [−]	1.6 [−]	0.2 [−]	0.3 [−]
	TT	NTU	12 [9]	<0.1 [0.1]	0.5 [0.7]	0.2 [0.4]	0.2 [0.2]
pH	IN	S.U.	16 [10]	7.0 [6.5]	8.4 [8.4]	7.7 [7.5]	0.3 [0.2]
	AC	S.U.	4 [8]	7.5 [7.2]	8.1 [8.0]	7.8 [7.7]	0.3 [0.3]
	TA-TF	S.U.	1–9 [0]	6.5 [−]	8.4 [−]	7.6 [−]	0.6 [−]
	TT	S.U.	13 [10]	6.9 [7.0]	8.3 [8.0]	7.6 [7.5]	0.5 [0.3]
Temperature	IN	°C	16 [10]	9.1 [7.4]	15.9 [13.5]	12.2 [10.6]	2.3 [2.0]
	AC	°C	4 [8]	7.7 [7.4]	10.7 [12.2]	9.4 [10.2]	1.3 [1.5]
	TA-TF	°C	1–8 [0]	10.7 [−]	16.3 [−]	13.1 [−]	2.0 [−]
	TT	°C	13 [10]	9.6 [8.8]	17.2 [14.3]	12.9 [11.6]	2.8 [1.8]
Free Chlorine (as Cl_2)	AC	mg/L	7 [6]	0.0 [0.1]	1.0 [0.4]	0.4 [0.3]	0.4 [0.1]
	TT	mg/L	12 [9]	0.0 [0.1]	0.5 [0.4]	0.2 [0.2]	0.1 [0.1]
Total Chlorine (as Cl_2)	AC	mg/L	7 [6]	0.0 [0.1]	0.7 [0.4]	0.3 [0.3]	0.3 [0.1]
	TT	mg/L	8 [6]	0.0 [0.1]	0.5 [0.4]	0.3 [0.2]	0.2 [0.1]
Total Hardness (as $CaCO_3$)	IN	mg/L	16 [8]	147 [143]	205 [174]	173 [156]	15.2 [10.7]
	TA-TF	mg/L	1–11 [0]	143 [−]	211 [−]	170 [−]	19.0 [−]
	TT	mg/L	13 [8]	150 [140]	214 [174]	171 [160]	17.2 [13.2]
Ca Hardness (as $CaCO_3$)	IN	mg/L	16 [8]	69.5 [72.8]	92.8 [83.7]	80.4 [77.7]	6.9 [3.3]
	TA-TF	mg/L	1–11 [0]	62.9 [−]	96.2 [−]	78.9 [−]	9.5 [−]
	TT	mg/L	13 [8]	67.6 [74.0]	92.6 [81.4]	79.3 [78.4]	7.0 [2.8]
Mg Hardness (as $CaCO_3$)	IN	mg/L	16 [8]	77.4 [68.4]	113 [91.7]	92.7 [80.3]	10.0 [8.9]
	TA-TF	mg/L	1–11 [0]	79.1 [−]	116 [−]	91.5 [−]	11.1 [−]
	TT	mg/L	13 [8]	82.0 [65.8]	125 [93.1]	91.8 [81.7]	12.1 [11.0]

One-half of detection limit used for nondetect samples for calculations.
Run 2 analytical results shown in brackets.
Duplicate samples included in calculations.

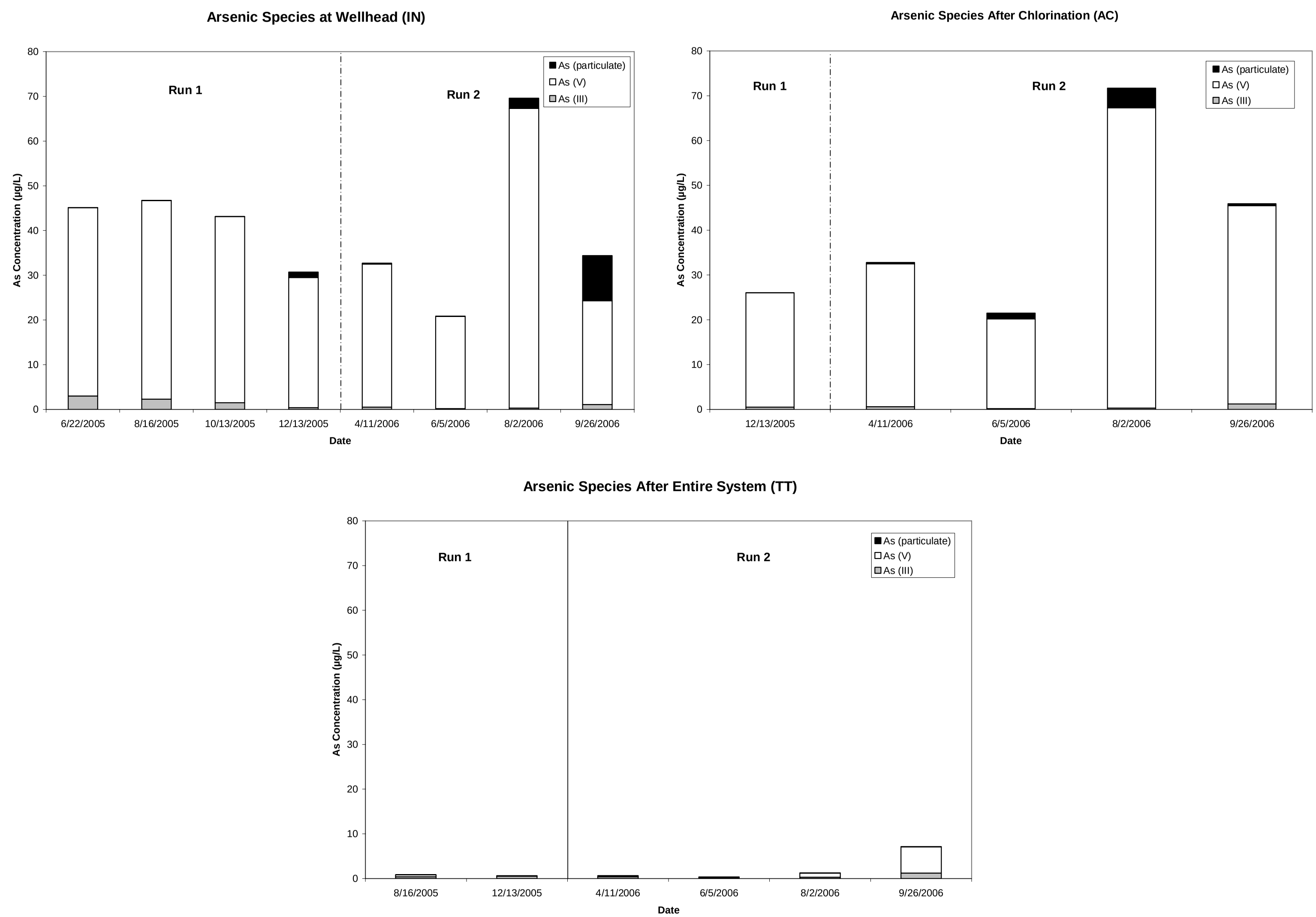
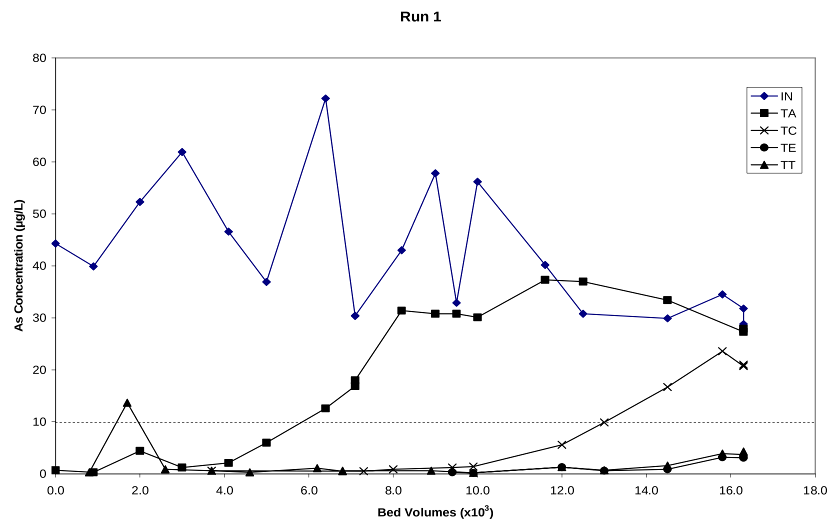
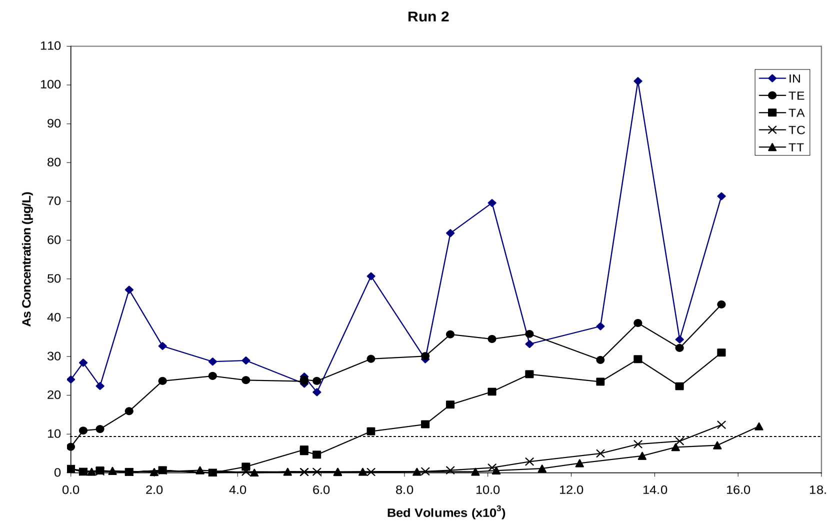


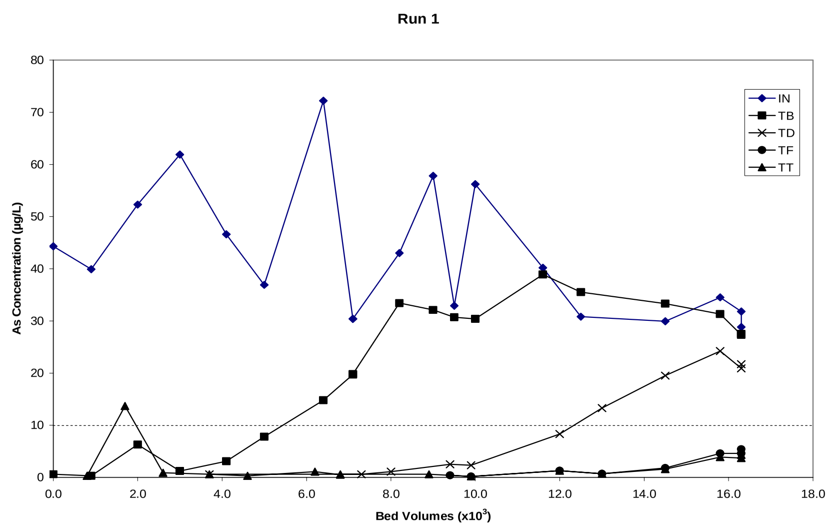
Figure 4-9. Concentrations of Various Arsenic Species Across Entire System

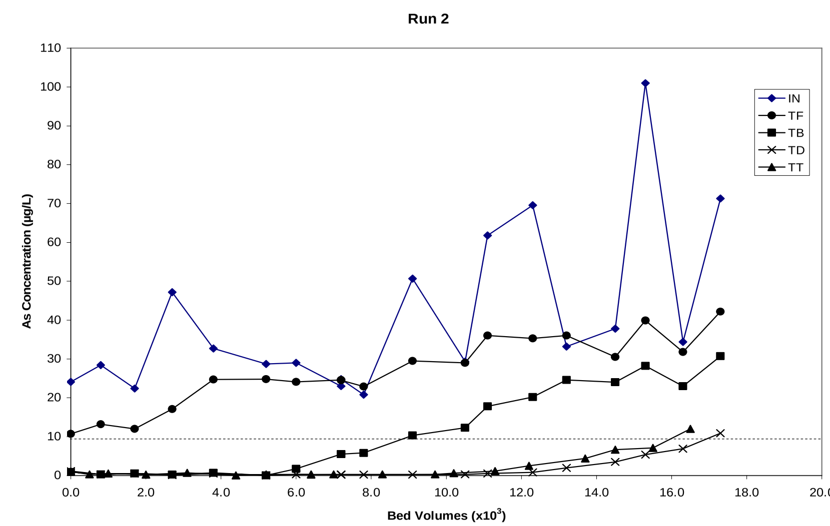
Train A





Train B



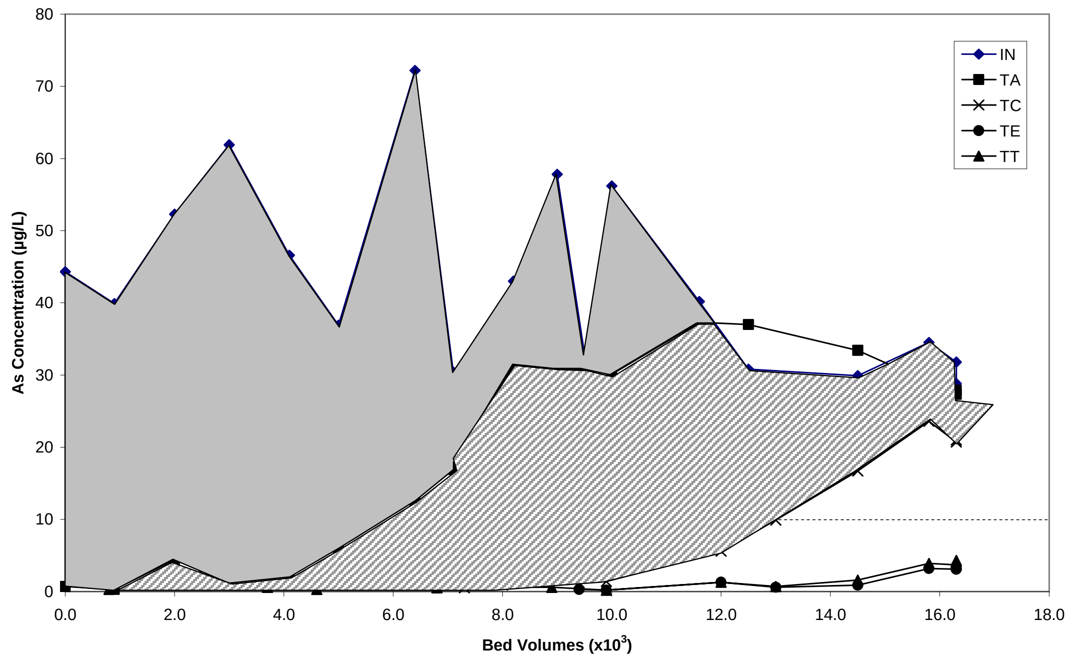


Note: 1 BV = 1.5 ft^3 for each column

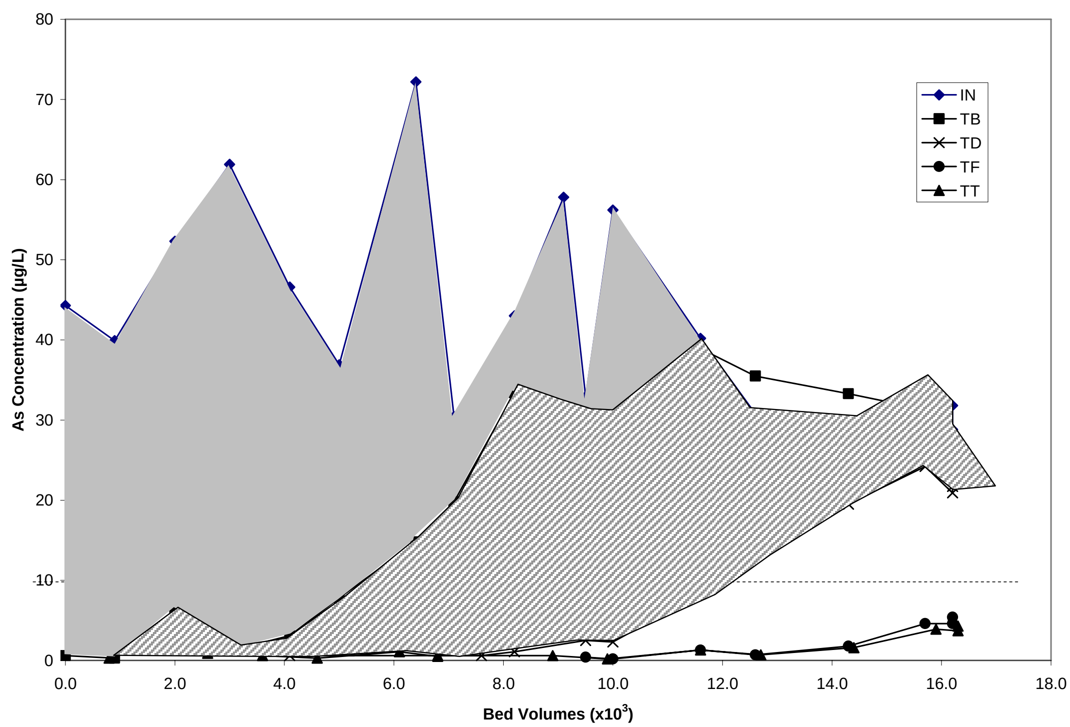
Figure 4-10. Total Arsenic Breakthrough Curves for Treatment Train A, Train B, and Entire System for Runs 1 and 2

Train A

Run 1



Train B



Note: 1 BV = 1.5 ft^3 for each column

Figure 4-11. Arsenic Mass Removed by Trains A and B During Run 1

and TB) was estimated to be 16.4 and 15.1 g, respectively. The first set of lag columns (i.e., Column TC and TD or the middle columns) removed an estimated 10.8 and 10.6 g, respectively, which were approximately 32% less than the mass removed by the lead columns. These lag columns did not reach their full capacity for arsenic before they were replaced. The final columns in each train, i.e., TE and TF, removed an estimated 2.9 and 3.4 g, respectively.

During Run 2, Columns TE and TF were moved to the lead position to maximize their usage for arsenic removal. Columns TE and TF removed an estimated 10.0 and 11.5 g, respectively, during Run 2, making their total arsenic mass removal 12.9 and 14.9 g, respectively. The first lag columns (i.e., middle columns, or TA and TB that were rebedded), removed an estimated 10.2 and 11.2 g of arsenic, respectively. The arsenic mass removed by the lead and first lag columns during Run 2 was very similar to that during Run 1. The final columns for Run 2 (i.e., TC and TD) removed an estimated 7.0 and 7.1 g of arsenic, respectively.

Breakthrough curves for the middle and final columns in each train (TC–TF) and the entire system (TT) also are presented in Figure 4-10. Breakthrough curves were plotted based on a BV of 1.5 ft^3 for each individual column. Arsenic concentrations from the middle 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 first two columns in each train as one large column). Arsenic concentrations from the final column in each treatment train (TE and TF) reached 10 µg/L at approximately 17,400 and 17,600 BV, respectively (or 5,800 and 5,900 BV, respectively, if considering all columns in each train as one large column). Table 4-8 summarizes the arsenic mass removed by each of the columns for the two runs and a detailed calculation of arsenic mass removed is provided in Appendix C.

Table 4-8. Arsenic Mass Removed by Columns A through F and Capacity of Media for Arsenic [(a)]

Column	Arsenic Mass Removed (µg) (Column Position)		Capacity[(b)] (µg of As/mg of media)	
	Run 1	Run 2	Run 1	Run 2
TA	16,450,288 (Lead)	10,196,282 (First lag)	0.49	0.30
TB	15,139,310 (Lead)	11,222,302 (First lag)	0.45	0.33
TC	10,849,436 (First lag)	7,000,376[(d)] (Second lag)	0.32	0.21
TD	10,583,800 (First lag)	7,068,112[(d)] (Second lag)	0.31	0.21
TE[(c)]	2,937,703 (Second lag)	12,955,621[(e)] (Lead)	0.09	0.38
TF[(c)]	3,425,869 (Second lag)	14,923,362[(e)] (Lead)	0.10	0.44

(a) More detailed tables of calculations provided in Appendix C.
(b) 33,660,400 mg of media in each column based on a bulk density of 51 lb/ft^3 and a moisture content of 3%.
(c) Columns switched to lead position during media changeout and new columns added on as lag columns.
(d) Columns not at full capacity for arsenic at end of evaluation.
(e) Combined arsenic mass removal during Run 1 and Run 2.

4.5.1.1 Silica, Sulfate, Bicarbonate and Nitrate. Among the anions analyzed, silica, sulfate, alkalinity (existing primarily as HCO_3^- at pH values between 7.0 and 8.2), and nitrate were present in significant concentrations in raw water (Table 4-7) and potentially could compete with arsenic for adsorptive sites. As shown in Figure 4-12, silica was consistently removed by (and did not reach complete breakthrough from) the adsorption columns throughout the two adsorption runs. However, HCO_3^-, SO_4^{2-}, and NO_3^-, showed little or no adsorptive capacity on the media (Figure 4-13).

4.5.1.3 Aluminum. As shown in Table 4-6, 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 throughout the evaluation (Figure 4-14).

4.5.1.4 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 4-6). Manganese concentrations in source water also were low, ranging from 1.7 to 37.9 µg/L and averaging 10.0 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.

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

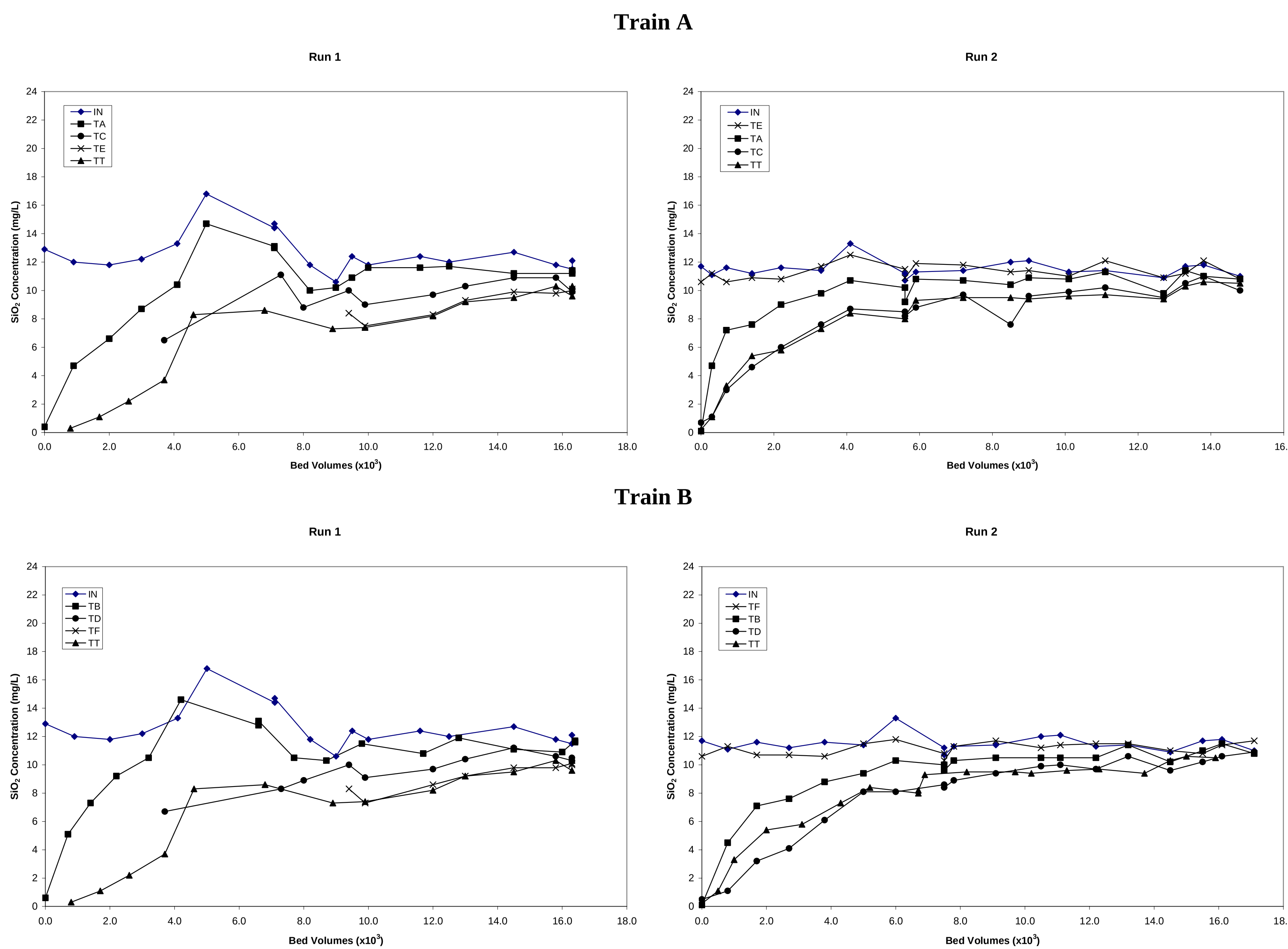
4.5.2 Spent Media Sampling. Spent A/I Complex 2000 media samples were collected from each lead and first lag columns during media changeout on February 14, 2006. The samples were collected according to Section 3.3.3 for TCLP and total metals analysis and the analytical results are presented in Tables 4-9 and 4-10, respectively.

4.5.2.1 TCLP. The TCLP results indicated that the spent media was non-hazardous and could be disposed of in a sanitary landfill. Barium was the only metal detected by the TCLP test at a concentration of 4.6 mg/L, which is well below the limit of 100 mg/L of Ba.

4.5.2.2 Metals. The spent media ICP-MS results indicate that the media removed arsenic as water passed through Columns A and C in Train A and Columns B and D in Train B, as evident by the decreasing arsenic loadings shown in Table 4-10. The arsenic loadings on the spent media based on the ICP-MS results and arsenic breakthrough curves are summarized in Table 4-11. A/I Complex 2000 dry media mass was calculated based on a moisture content of 3% based on results from the spent media analysis.

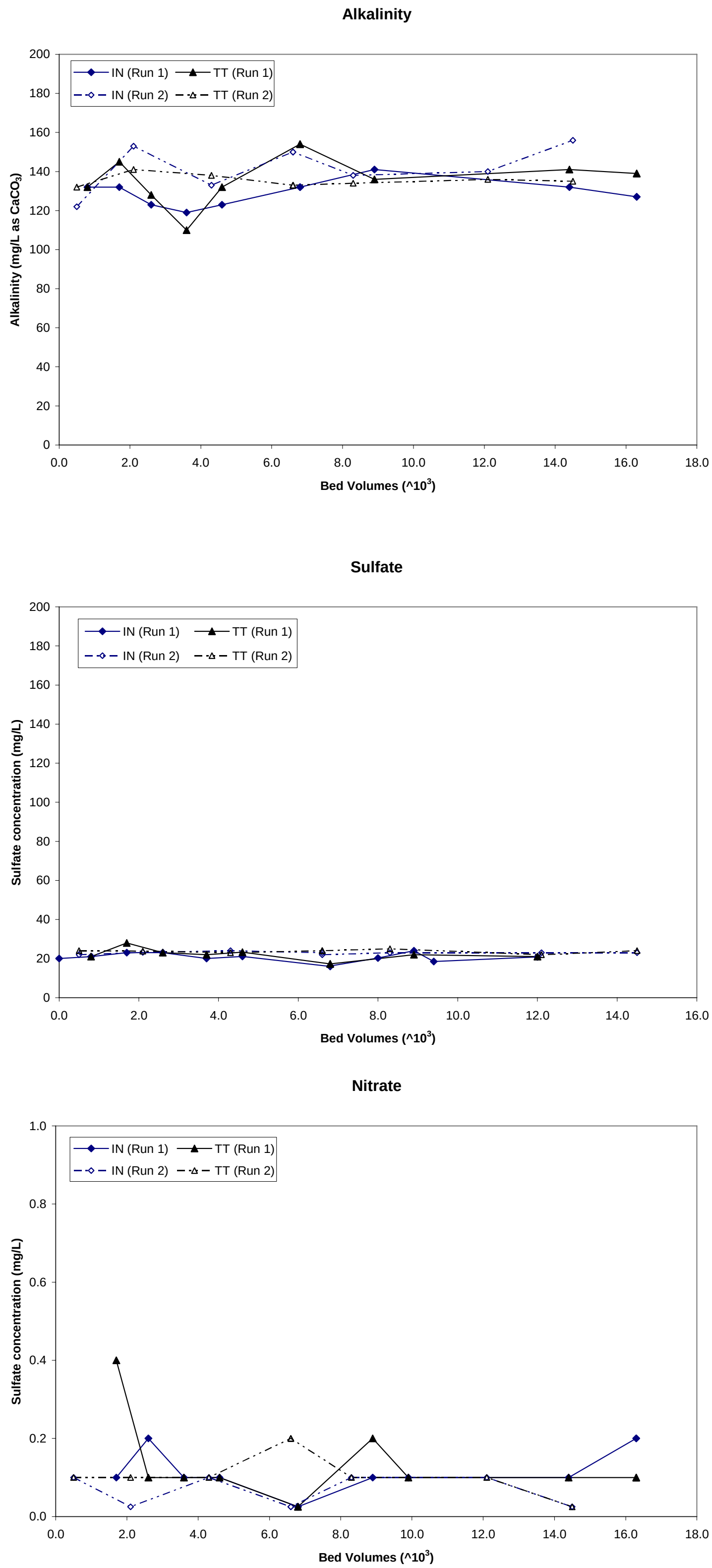
As expected, arsenic loading on the media was low, amounting to only 0.64 µg/mg of dry media (on average) on the lead vessels and 0.42 µg/mg (on average) on the first lag vessels. The arsenic loadings measured on the spent media by ICP-MS were 36% (for the lead columns) and 33% (for the first lag columns) higher than those estimated based on the breakthrough curves. It is unclear what may have contributed to the differences observed.

Besides aluminum, all metals analyzed on the spent media were below 1.0% (by weight). The average aluminum composition was 39%, equivalent to 74% as Al_2O_3. This amount was significantly lower than the 91% listed in the ATS's material specifications (Table 4-2). The spent media results also showed that



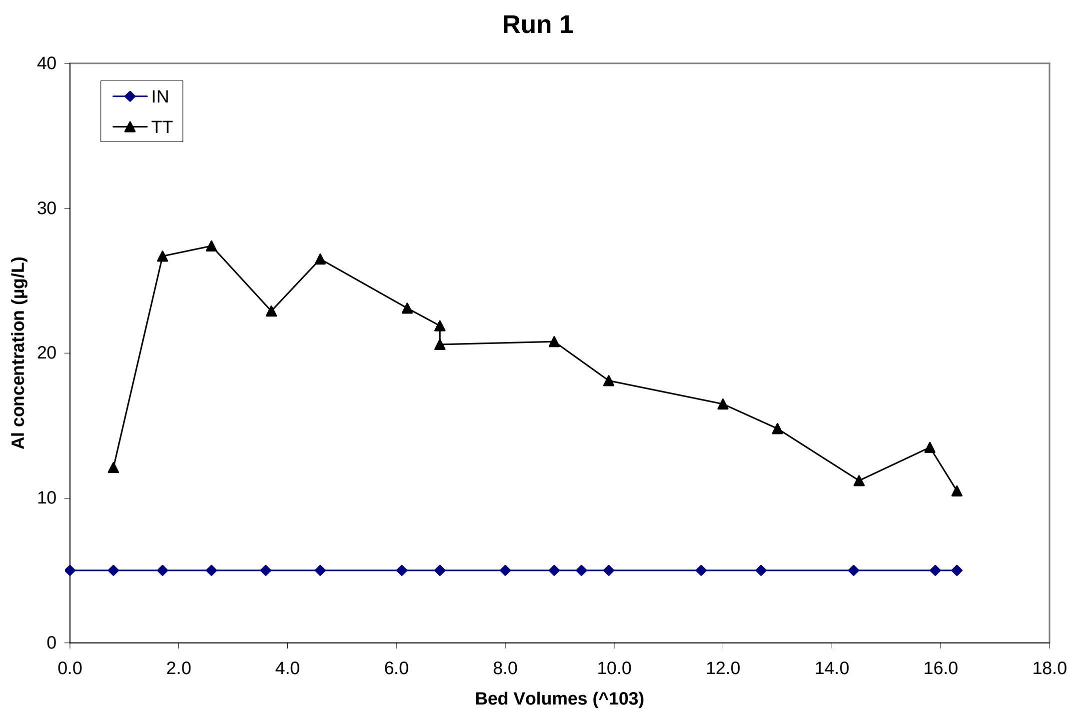
Note: 1 BV = 1.5 ft^3 for each column

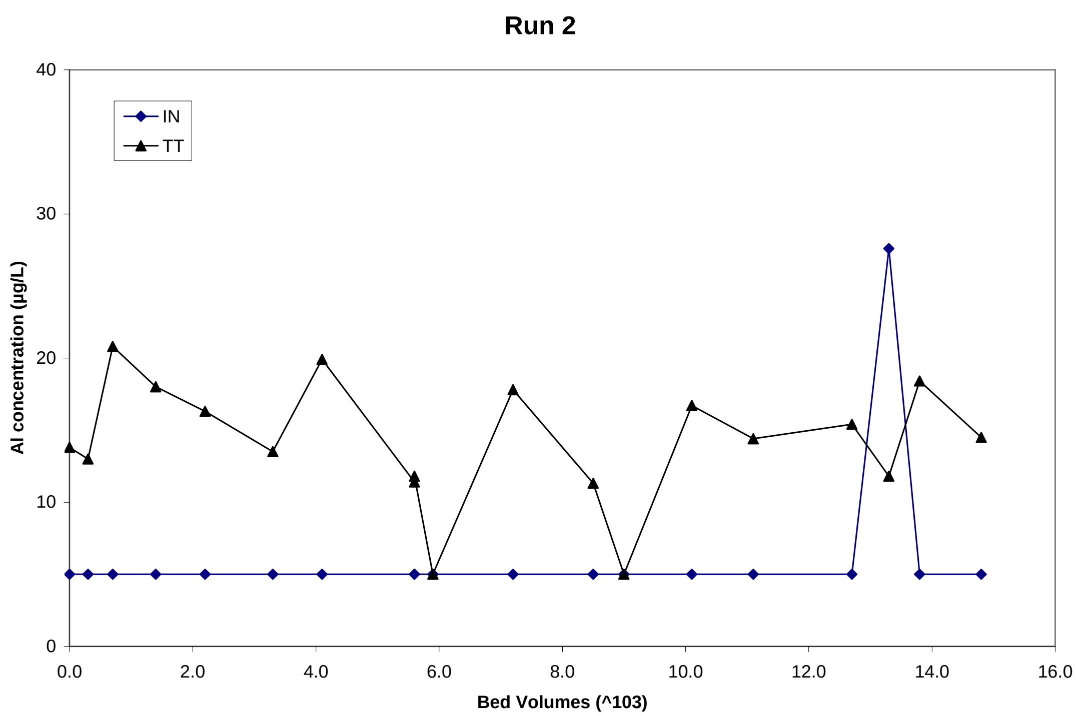
Figure 4-12. Silica Concentrations Across Treatment Trains and Entire System



Note: 1 BV = 1.5 ft^3 for each column

Figure 4-13. Alkalinity, Sulfate and Nitrate Concentrations Across Treatment Trains and Entire System for Runs 1 and 2





Note: 1 BV = 1.5 ft^3 for each column

Figure 4-14. Total Aluminum Concentrations Across Entire System for Runs 1 and 2

Table 4-9. TCLP Results of a Composite Spent Media Sample

Analyte	TCLP Concentration (mg/L)
Arsenic	<0.10
Barium	4.6
Cadmium	<0.010
Chromium	<0.010
Lead	<0.050
Mercury	<0.0020
Selenium	<0.10
Silver	<0.010

Table 4-10. Spent Media Metals Results[(a)]

		Sampling Location			
Parameter	**Unit**	**TA**	**TB**	**TC**	**TD**
Bed Volume	BV^3	17.2	17.5	17.2	17.5
Aluminum	µg/g	384,832	374,348	404,135	410,177
		360,951	393,355	404,246	409,579
Arsenic	µg/g	678	606	412	401
		592	670	413	406
Cadmium	µg/g	1.42	1.58	1.81	2.01
		1.53	1.70	1.92	2.13
Calcium	µg/g	8,986	7,647	9,091	9,029
		8,721	7,911	9,061	9,057
Copper	µg/g	1,413	1,053	181	129
		1,368	1,047	178	136
Iron	µg/g	7,387	7,097	5,606	4,907
		6,570	7,379	5,590	4,955
Lead	µg/g	5.32	3.01	0.85	0.87
		4.78	2.95	0.85	0.92
Magnesium	µg/g	1,887	1,805	1,866	1,835
		1,891	1,832	1,843	1,763
Manganese	µg/g	262	169	18.9	38.9
		239	170	18.3	40.4
Nickel	µg/g	53.6	35.3	9.43	8.75
		53.2	37.4	8.44	9.03
Phosphorus	µg/g	302	351	368	339
		320	376	341	352
Silica	µg/g	392	518	650	611
		311	450	674	395
Zinc	µg/g	551	372	<50	<50
		538	370	<50	<50

(a) With analyses of duplicate samples

Table 4-11. Summary of Media Capacity for Arsenic

	Breakthrough Curves[a] Table 4-8	Spent Media[b] Table 4-10
	µg As/mg of dry media	
TA	0.49	0.64
TB	0.45	0.64
TC	0.32	0.41
TD	0.31	0.40

(a) Calculations account for 3% moisture content of A/I Complex 2000 media.
(b) Averages of duplicate samples.

the media had some capacities for positively charged metal ions, such as copper, lead, manganese, nickel, and zinc. For example, zinc in the lead vessels had an average concentration of 0.46 µg/mg, while zinc was not detected in the first lag vessels above the reporting limit of 0.05 µg/mg.

4.5.3 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 4-12.

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 system startup, As concentrations remained elevated from 16.3 to 26.0 µg/L at Lot 1 and from 4.7 to 11.2 µg/L at Lot 4 during the first one to three months. Since then, arsenic concentrations decreased to below 3 µg/L before steadily increasing to 6.8 µg/L at Lots 1 and 6 and 4.8 µg/L at Lot 4 just before media changeout. One additional sample was collected two months after the media changeout and the As concentrations were between 1.0 and 2.4 µg/L. Distribution system water sampling was discontinued after April 2006 when the Park began hauling water in to keep up with demand. The hauled water was mixed with the treated water in the 5,500 gallon storage tank prior to distribution.

Prior to system startup, iron and manganese concentrations in the distribution system were low and similar to those in raw water. Two residences (Lots 4 and 6), however, had elevated iron (as high as 602 µg/L) and manganese concentrations (as high as 83.2 µg/L). After system startup, iron concentrations were mostly near or below the method reporting limit of 25 µg/L, except for two samples taken from Lot 4 that had elevated concentrations of 128 and 346 µg/L. Manganese concentrations were similar to those of the treated water, except for one sample taken from Lot 1 which had an elevated concentration of 50.1 µg/L.

With the exception of two samples collected at Lot 6 prior to system startup, aluminum concentrations were slightly higher in water collected after system startup. Although aluminum concentrations were higher in the distribution system than the source water, the concentrations were well below the secondary MCL of 200 µg/L.

One sample collected at Lots 6 and 4 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, 2004). After system startup, lead concentrations at all distribution locations were below 7.5 µg/L. Copper values ranged from 17.2 to 138 µg/L and averaged 63.4 µg/L prior to system startup and ranged from 1.9 to

Table 4-12. Distribution System Sampling Results

No. of Sampling Events		DS1									DS2									DS3								
	Address	Lot 1									Lot 6									Lot 4								
	Sample Type	LCR									LCR									LCR								
	Flushed / 1st Draw	1st Draw									1st Draw									1st Draw								
	Sampling Date	Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Al	Pb	Cu	Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Al	Pb	Cu	Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Al	Pb	Cu
BL1	12/7/2004	20.5	7.9	142	27.7	<25	4.1	<10	2.2	82.0	11.8	7.8	142	29.0	<25	1.7	<10	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	<10	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	<10	8.9	38.6
BL3	2/1/2005	16.0	7.3	138	30.8	<25	2.2	<10	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	<10	7.3	36.5
BL4	4/5/2005	11.0	7.7	132	30.7	<25	0.8	<10	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	<10	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	<10	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	<10	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	<10	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	1.1	19.7	2.3	28.2
6	12/13/2005	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
7	1/26/2006	8.0	7.9	125	3.5	<25	<0.1	48.6	0.1	9.2	10.5	8.1	130	4.2	<25	2.9	22.4	1.3	9.3	22.5	8.1	134	3.4	<25	<0.1	13.2	0.2	4.5
8	2/14/2006	6.5	8.1	133	6.8	<25	<0.1	<10	<0.1	1.9	8.5	8.0	133	6.8	<25	<0.1	<10	<0.1	6.6	20.2	8.1	129	4.8	<25	2.8	<10	0.2	2.0
9	4/11/2006	6.5	7.8	133	1.0	<25	0.5	17.8	1.3	26.2	10.6	7.8	128	1.2	<25	0.3	24.2	0.2	30.0	10.9	7.8	128	2.4	47.1	4.2	11.9	0.6	15.3

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 $CaCO_3$).
BL = Baseline Sampling

82.5 µg/L and averaged 25.7 µg/L after system startup. All samples analyzed for copper were below the action level of 1.3 mg/L. The pH and alkalinity remained relatively constant throughout distribution system water sampling.

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, this cost 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 for equipment, site engineering, and installation was \$14,000 (see Table 4-13). 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/ft^3 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.

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 7.6 hr/day with an average daily use rate of 1,565 gal/day (see Table 4-4), producing approximately 571,200 gal of water per year, the unit capital cost was increased to \$2.31/1,000 gal at this reduced rate of production.

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 4-14).

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 µg/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 to be fully utilized 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 treatment train need to be replaced. At Dummerston, the first two sets of columns (lead and first lag) were changed out on February 14, 2006, after 34 weeks of operation. The cost of the changeout for four columns (i.e.,

Table 4-13. Summary of Capital Investment Cost

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Cost			
Adsorption Media Columns	6	$720	–
A/I Complex 2000 Adsorptive Media (ft^3)	9	$2,880	–
25-µm 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%**
Engineering Cost			
Design/Scope of System (hr)	10	$1,500	–
Travel and Miscellaneous Expenses	1	$300	–
Subcontractor Labor	–	$600	
Engineering Total	–	**$2,400**	**17%**
Installation Cost			
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%**

Table 4-14. Summary of O&M Cost

Cost Category	Value	Remarks
Volume Processed (gal)	391,400	Amount of water processed through both Trains during Run 1
Media Replacement and Disposal		
Media ($/ft^3$)	517	For replacement media
Media Volume (ft^3)	6.0	Amount of media in four columns (i.e., two lead and two first lag columns)
Total Media Replacement ($)	3,100	Vendor invoice
Labor ($)	260	Vendor invoice
Travel and Delivery ($)	550	Vendor invoice
Subtotal ($)	3,910	Vendor invoice
Media Replacement and Disposal ($/1,000 gal)	See Figure 4-15	Based upon media run length at 10-µg/L arsenic breakthrough from third adsorption column
Chemical Usage		
Chemical ($)	0.000	No additional chemical required
Electricity		
Electricity ($/1,000 gal)	0.001	Electrical cost assumed negligible
Labor		
Average Weekly Labor (hr)	1	10 min/day, 3 day/week
Labor Cost ($)	340	17 hr at $20/hr
Labor Cost ($/1,000 gal)	0.87	–
Total O&M cost ($/1,000 gal)	See Figure 4-14	Based upon media run length at 10-µg/L arsenic breakthrough from third column

two sets of the lead and first lag columns) was $3,910 (see cost breakdown in Table 4-4). The spent media was returned to ATS and sold for use in another product; therefore, there was no additional cost for disposal of spent media. By averaging the media replacement cost (i.e., $3,910) over the life of the media, the cost per 1,000 gal of water treated was plotted as a function of the media run length in BV. To be consistent with the operational data, the media run length in BV was calculated by dividing the system throughput through each train by the quantity of media in the lead column, i.e., 1.5 ft^3 (or 11.2 gal). As shown in Figure 4-15, the unit media replacement cost is $9.96/1,000 gal for a media run length of 17,500 BV (or 195,700 gal per train or 391,400 gal for the entire system).

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 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 10 min/day, 3 day/week as noted in Section 4.4.3. Therefore, the estimated labor cost was $0.87/1,000 gal of water treated (Table 4-14).

The unit O&M cost is driven by the cost to replace the spent media and is a function of the media run length (see Figure 4-15). As shown in this figure, the unit O&M cost would be $10.87/1,000 gal for a media run length of 17,500 BV or treating 391,400 gal of water.

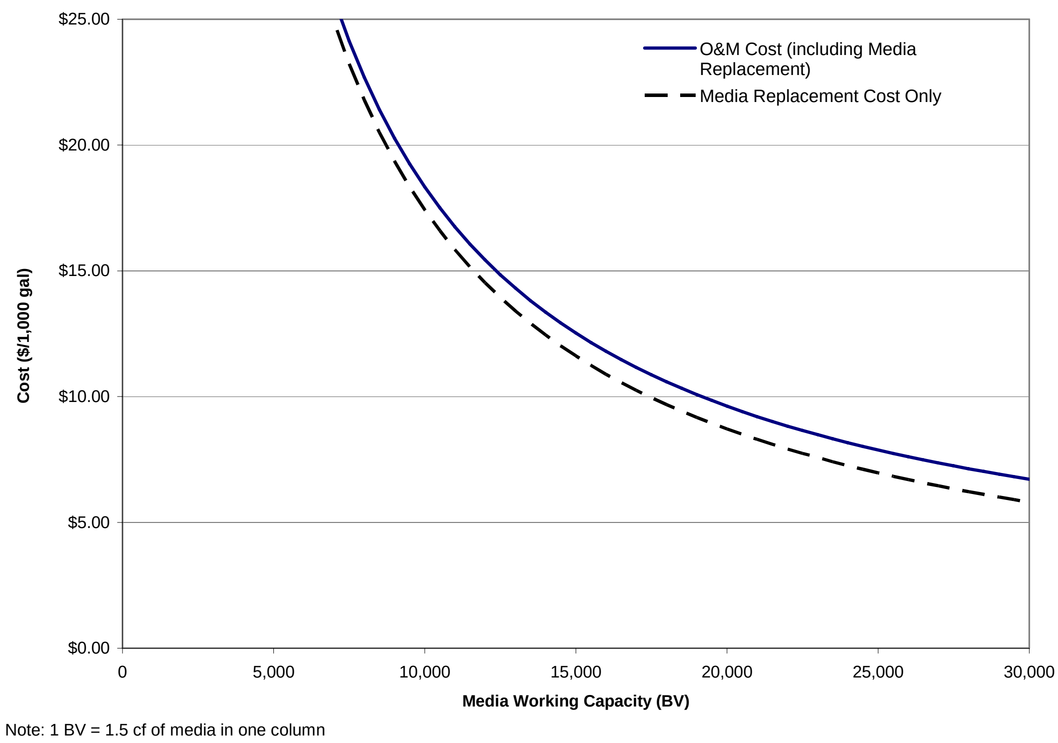


Figure 4-15. O&M and Media Replacement Cost (for Replacement of Four Columns at a Time)

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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	21	499.6	22	0
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	4032.7	359	4.26	2437.4	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
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
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	1351	4.4
	07/15/05	145.4	6.6	4.92	18794	1675	5.59	13238	1180	32032	1427	4.3
	07/16/05	150.6	5.2	4.48	19710	1757	5.07	14015	1249	33725	1502	5.4
5	07/18/05	172.0	21.4	0.83	21918	1953	0.00	15279	1362	37197	1658	2.7
	07/19/05	192.0	20.0	0.40	22663	2020	0.00	15279	1362	37942	1691	0.6
	07/20/05	201.2	9.2	0.52	23453	2090	0.00	15461	1378	38914	1734	1.8
	07/21/05	210.8	9.6	2.79	24355	2171	2.64	15759	1405	40114	1788	2.1
	07/22/05	220.3	9.5	2.02	25509	2274	0.00	16365	1459	41874	1866	3.1
	07/23/05	224.9	4.6	4.23	25972	2315	4.60	16524	1473	42496	1894	2.3
6	07/25/05	236.9	12.0	4.01	27746	2473	4.46	17826	1589	45572	2031	4.3
	07/26/05	241.7	4.8	4.62	28590	2548	5.25	18506	1649	47096	2099	5.3
	07/27/05	245.2	3.5	4.79	29248	2607	5.54	19141	1706	48389	2156	6.2
	07/28/05	247.7	2.5	5.39	29856	2661	6.14	19792	1764	49648	2212	8.4
	07/29/05	251.6	3.9	5.11	30653	2732	5.90	20618	1838	51271	2285	6.9
	07/30/05	254.0	2.4	5.71	31240	2784	6.64	21246	1894	52486	2339	8.4

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
7	08/01/05	258.8	4.8	4.88	32670	2912	5.57	22858	2037	55528	2475	10.6
	08/02/05	260.7	1.4	5.43	33252	2964	6.27	23522	2096	56774	2530	14.8
	08/03/05	262.8	2.1	5.67	33952	3026	5.81	24322	2168	58274	2597	11.9
	08/04/05	264.5	1.7	5.69	34485	3074	6.50	24932	2222	59417	2648	11.2
	08/05/05	265.9	1.4	6.21	34951	3115	7.08	25507	2273	60458	2694	12.4
	08/06/05	268.2	2.3	5.50	35688	3181	6.32	26302	2344	61990	2762	11.1
8	08/08/05	281.2	13.0	2.27	38160	3401	2.23	28868	2573	67028	2987	6.5
	08/09/05	289.9	8.7	1.74	39155	3490	1.30	29504	2630	68659	3060	3.1
	08/14/05	320.6	30.7	4.45	43426	3870	5.16	33403	2977	76829	3424	4.4
9	08/17/05	335.3	14.7	4.41	46110	4110	5.19	36249	3231	82359	3670	6..3
	08/19/05	343.6	8.3	4.8	47570	4240	5.63	37823	3371	85393	3805	6.1
	08/20/05	349.4	5.8	4.15	48773	4347	4.87	39162	3490	87935	3919	7.3
10	08/27/05	376.4	27	3.15	54360	4845	3.75	45330	4040	99690	4443	7.3
	08/28/05	379.1	2.70	2.75	55015	4903	2.97	46070	4106	101085	4505	8.6
11	08/29/05	382.7	3.6	4.97	55680	4963	5.80	46805	4172	102485	4567	6.5
	09/01/05	395.4	12.7	4.45	58366	5202	5.21	49832	4441	108198	4822	7.5
12	09/08/05	421.0	25.6	3.57	63652	5673	4.1	55492	4946	119144	5309	7.1
	09/10/05	430.9	9.9	2.53	65655	5852	2.76	58060	5175	123715	5513	7.7
13	09/12/05	437.1	6.2	4.82	66815	5955	5.70	59377	5292	126192	5624	6.7
	09/15/05	448.9	11.8	4.93	69190	6167	5.91	62080	5533	131270	5850	7.2
	09/17/05	456.7	7.8	3.52	70877	6317	4.04	64023	5706	134900	6012	7.8
15	09/27/05	504.6	47.9	3.47	79269	7065	4.05	73666	6566	152935	6815	6.3
	09/28/05	511.0	6.4	1.72	80353	7162	1.9	74960	6681	155313	6921	6.2
	09/29/05	514.1	3.1	4.45	80820	7203	5.25	75445	6724	156265	6964	5.1
16	10/03/05	537.3	23.2	2.53	85029	7578	2.96	80311	7158	165340	7368	6.5
	10/05/05	543.5	6.2	2.69	86105	7674	3.2	81548	7268	167653	7471	6.2
	10/08/05	610.4	66.9	0	88468	7885	0	82784	7378	171252	7632	0.9
17	10/11/05	621.7	11.3	2.98	90515	8067	3.48	85165	7590	175680	7829	6.5
	10/12/05	626.9	5.2	3.46	91446	8150	4.13	86253	7687	177699	7919	6.5
	10/14/05	635.9	9.0	5.21	92810	8272	6.1	87791	7825	180601	8048	5.4
18	10/17/05	648.9	13.0	4.01	95282	8492	4.73	90615	8076	185897	8284	6.8
	10/20/05	662.3	13.4	4.35	97585	8697	5.2	93223	8309	190808	8503	6.1
	10/22/05	671.0	8.7	5.15	99146	8837	6.11	95020	8469	194166	8653	6.4

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		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
19	10/24/05	682.9	11.9	4.97	101107	9011	5.85	97249	8667	198356	8839	5.9
	10/26/05	693.6	10.7	3.07	102973	9178	3.79	99449	8864	202422	9020	6.3
20	10/31/05	713.6	20.0	4.53	106521	9494	5.36	103520	9226	210041	9360	6.3
	11/02/05	718.7	5.1	5.33	107784	9606	6.21	104978	9356	212762	9481	8.9
	11/04/05	726.5	7.8	4.48	109647	9772	5.23	107129	9548	216776	9660	8.6
21	11/07/05	737.1	10.6	2.95	112837	10057	3.41	109887	9794	222724	9925	9.4
	11/10/05	749.1	12.0	5.14	114255	10183	6.07	112423	10020	226678	10102	5.5
	11/11/05	752.8	3.7	3.13	115121	10260	3.67	113429	10110	228550	10185	8.4
22	11/14/05	769.6	16.8	4.43	117705	10491	5.31	116456	10379	234161	10435	5.6
	11/16/05	777.7	8.1	3.33	119370	10639	3.98	118410	10553	237780	10596	7.4
	11/19/05	793.8	16.1	2.45	122048	10878	2.95	121612	10839	243660	10858	6.1
23	11/22/05	805.9	12.1	4.53	124135	11064	5.40	124112	11062	248247	11062	6.3
	11/26/05	827.6	21.7	2.71	127650	11377	3.23	128301	11435	255951	11406	5.9
24	11/29/05	857.4	29.8	1.67	130728	11651	1.92	131846	11751	262574	11701	3.7
	12/01/05	875.7	18.3	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	12004	2.1
25	12/05/05	912.7	37.0	1.63	135688	12093	2.05	137403	12246	273091	12170	1.7
	12/08/05	938.6	25.9	1.25	138004	12300	1.33	140006	12478	278010	12389	3.2
	12/10/05	963.8	21.2	0.63	139937	12472	0	142197	12674	282134	12573	3.2
26	12/14/05	994.8	35.0	1.45	142815	12729	1.63	145542	12972	288357	12850	3.0
	12/15/05	1004.2	9.4	1.35	143840	12820	1.5	146437	13051	290277	12935	3.4
	12/16/05	1016.0	11.8	1.43	144911	12915	1.72	147605	13156	292516	13035	3.2
27	12/19/05	1043.9	27.9	0.63	146251	13035	0.00	148567	13241	294818	13238	1.4
	12/20/05	1054.1	10.2	1.85	148778	13260	2.17	150613	13424	299391	13342	7.5
	12/22/05	1072.7	18.6	NM	149837	13354	NM	151736	13524	301573	13439	2.0
28	12/28/05	1132.8	60.1	0.55	153950	13721	0	156124	13915	310074	13818	2.4
	12/30/05	1148.7	15.9	1.75	155318	13843	2.01	157556	14042	312874	13942	2.9
	12/31/05	1157.1	8.4	0.00	156065	13910	0	158336	14112	314401	14010	3.0
29	01/02/06	1178.8	21.70	1.95	157878	14071	2.35	160250	14283	318128	14177	2.9
	01/03/06	1187.4	8.6	1.27	158560	14132	1.33	160947	14345	319507	14238	2.7
	01/04/06	1196.9	9.5	1.40	159375	14205	1.5	161766	14418	321141	14311	2.9

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		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
30	01/10/06	1255.3	58.4	1.30	164406	14653	1.32	166885	14874	331291	14763	2.9
	01/11/06	1263.4	8.1	1.91	165087	14714	2.17	167529	14931	332616	14822	2.7
	01/13/06	1282.1	18.7	1.91	166705	14858	2.18	169237	15084	335942	14970	3.0
31	01/17/06	1320.5	38.4	1.40	170093	15160	1.39	172737	15395	342830	15277	3.0
	01/19/06	1340.3	19.8	1.82	171825	15314	1.99	174481	15551	346306	15432	2.9
	01/20/06	1350.4	10.1	0.39	172705	15393	0	175341	15628	348046	15510	2.9
32	01/25/06	1393	42.6	2.33	176605	15740	2.68	179256	15976	355861	15858	3.1
	01/27/06	1416.3	23.3	1.49	178467	15906	1.61	181227	16152	359694	16029	2.7
	01/29/06	1435.2	18.9	2.07	180191	16060	2.3	183062	16316	363253	16187	3.1
33	02/04/06	1489.5	54.3	2.11	184935	16483	2.39	188130	16767	373065	16625	3.0
34	02/07/06	1517.6	28.1	2.12	187323	16695	2.51	190730	16999	378053	16847	3.0
	02/08/06	1529.3	11.7	2.73	188846	16831	3.22	191858	17100	380704	16965	3.8
	02/11/06	1558.4	29.1	2.23	190880	17012	2.62	194659	17349	385539	17181	2.8
35	02/13/06	1574.9	16.5	2.22	192316	17140	2.64	196234	17490	388550	17315	3.0
	02/14/06	Media Changeout										
	02/15/06	1593.7	18.8	1.62	0	0	1.46	0	0	0	0	0.0
	02/16/06	1604.5	10.8	0.94	259	23	1.94	796	71	1055	47	1.6
	02/17/06	1615.5	11	0.00	704	63	0.77	1692	151	2396	107	2.0
	02/19/06	1632.8	17.3	0.00	1471	131	0.00	2320	207	3791	169	1.3
36	02/20/06	1651	18.2	0.00	1499	134	0.00	2584	230	4083	182	0.3
	02/23/06	1685.7	34.7	2.38	2487	222	2.86	4645	414	7132	318	1.5
	02/26/06	1713.8	28.1	0.00	2927	261	2.63	7161	638	10088	450	1.8
37	02/28/06	1733.8	20	0.00	2927	261	2.19	8994	802	11921	531	1.5
	03/02/06	1775.8	42	0.00	2927	261	0.79	9879	880	12806	571	0.4
38	03/06/06	1875.1	59.3	0.00	2928	261	0.00	10883	970	13811	615	0.3
	03/07/06	1875.1	0	4.59	NM	NM	5.27	NM	NM	NM	NM	NM
39	03/10/06	1900.5	40	2.01	5605	500	2.3	14107	1257	19712	878	2.5
	03/14/06	1938.8	38.3	2.73	NM	NM	3.12	17531	1562	NM	NM	NM
	03/16/06	1952.6	13.8	0.00	7518	670	3.33	19115	1704	26633	1187	2.2
40	03/21/06	1976.8	24.2	0.00	11063	986	4.28	23297	2076	34360	1531	5.3
	03/22/06	1981.7	4.9	0.00	11867	1058	3.69	24365	2172	36232	1615	6.4
	03/23/06	1989.1	7.4	0.00	11867	1058	3.48	25374	2261	37241	1660	2.3

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		hr	hr	gpm	gal	BV	gpm	gal	BV	gal	BV	gpm
41	03/27/06	2008.3	19.2	3.92	14156	1262	4.65	28797	2567	42953	1914	5.0
	03/31/06	2028.1	19.8	4.07	17153	1529	4.63	32124	2863	49277	2196	5.3
	04/01/06	2031.2	3.1	4.53	17748	1582	5.05	32774	2921	50522	2251	6.7
42	04/05/06	2061.2	30	2.62	21446	1911	2.87	36954	3294	58400	2602	4.4
	04/06/06	2068.9	7.7	2.48	22223	1981	2.80	37843	3373	60066	2677	3.6
	04/07/06	2076.8	7.9	3.51	22869	2038	4.00	38577	3438	61446	2738	2.9
43	04/11/06	2108.2	31.4	2.63	24203	2157	3.05	42304	3770	66507	2964	2.7
	04/13/06	2124.6	16.4	2.72	25718	2292	3.07	44226	3942	69944	3117	3.5
	04/15/06	2130.7	6.1	3.87	26677	2378	4.38	45304	4038	71981	3208	5.6
44	04/18/06	2150.3	19.6	2.58	29582	2637	2.78	48545	4327	78127	3482	5.2
	04/21/06	2178.2	27.9	2.17	32248	2874	2.27	51373	4579	83621	3726	3.3
45	04/25/06	2215.7	37.5	2.50	35473	3162	2.63	54801	4884	90274	4023	3.0
	04/27/06	2233	17.3	2.17	37010	3299	2.48	56491	5035	93501	4167	3.1
	04/29/06	2253	20	2.03	38503	3432	2.29	58286	5195	96789	4313	2.7
46	05/03/06	2291	38	2.08	41429	3692	2.25	61707	5500	103136	4596	2.8
	05/05/06	2311	20	2.00	42757	3811	2.13	63464	5656	106221	4734	2.6
47	05/10/06	2327	48	1.07	47006	4189	0.9	67753	6039	114759	5114	3.0
	05/11/06	2367	8	2.13	47725	4254	2.23	68492	6104	116217	5179	3.0
48	05/15/06	2430	63	0.49	50701	4519	0.38	71245	6350	121946	5434	1.5
	05/18/06	2459	29	1.45	53268	4748	1.61	73842	6581	127110	5664	3.0
49	05/22/06	2499	40	0.00	56691	5053	0	77468	6904	134159	5979	2.9
	05/24/06	2517	18	1.35	58201	5187	1.52	79151	7054	137352	6121	3.0
	05/26/06	2547	20	0.00	59475	5301	0	80465	7172	139940	6236	2.2
50	05/29/06	2550	13	3.39	60054	5352	3.47	81072	7226	141126	6289	1.5
	05/31/06	2601	40	1.63	62572	5577	1.29	83558	7447	146130	6512	2.1
51	06/07/06	2667	77	1.92	67568	6022	1.94	88775	7912	156343	6967	2.2
52	06/13/06	2711	44	0.99	73313	6534	0.68	94908	8459	168221	7496	4.5
	06/15/06	2722	11	2.72	74747	6662	2.98	96496	8600	171243	7631	4.6
53	06/19/06	2745	23	3.58	77772	6932	4.01	99857	8900	177629	7916	4.6
	06/23/06	2770	25	3.00	81181	7235	3.4	102322	9120	183503	8177	3.9
54	06/28/06	2796	26	3.15	84847	7562	3.48	106369	9480	191216	8521	4.9
	06/30/06	2815	19	2.83	86725	7730	3.18	108468	9667	195193	8698	3.5

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
55	07/03/06	2835	20	2.09	89110	7942	2.33	111081	9900	200191	8921	4.2
	07/05/06	2851	16	3.31	90609	8076	3.68	112765	10050	203374	9063	3.3
	07/08/06	2878	27	2.51	93211	8308	2.66	115508	10295	208719	9301	3.3
56	07/13/06	2927	49	2.31	97548	8694	2.48	120031	10698	217579	9696	3.0
	07/14/06	2937	10	2.13	98450	8775	2.33	121003	10785	219453	9780	3.1
	07/15/06	2948	11	2.13	99404	8860	2.25	122016	10875	221420	9867	3.0
57	07/18/06	2974	26	1.05	101630	9058	1.15	124394	11087	226024	10072	3.0
	07/21/06	3004	30	1.14	104127	9280	1.17	127000	11319	231127	10300	2.8
	07/22/06	3012	8	2.27	104843	9344	2.25	127735	11385	232578	10364	3.0
58	07/25/06	3037	25	2.39	106299	9474	2.48	129896	11577	236195	10526	2.4
	07/27/06	3059	22	0.83	108207	9644	0.75	131852	11752	240059	10698	2.9
	07/29/06	3079	20	2.17	109939	9798	2.19	133634	11910	243573	10854	2.9
59	07/31/06	3097	18	2.55	111466	9935	2.69	135183	12048	246649	10991	2.8
	08/02/06	3115	18	2.35	113091	10079	2.5	136846	12197	249937	11138	3.0
	08/03/06	3135	20	0.79	114747	10227	0.72	138550	12348	253297	11288	2.8
60	08/09/06	3182	47	2.38	118666	10576	2.45	142575	12707	261241	11642	2.8
	08/11/06	3199	17	0.00	120104	10704	0	144241	12856	264345	11780	3.0
	08/12/06	3209	10	2.13	120994	10784	2.27	144942	12918	265936	11851	2.7
61	08/16/06	3246	37	1.72	124025	11054	1.71	147949	13186	271974	12120	2.7
62	08/22/06	3302	56	0.58	128742	11474	0	152559	13597	281301	12536	2.8
	08/25/06	3333	31	1.27	131218	11695	1.8	154740	13791	285958	12743	2.5
	08/26/06	3339	6	0.49	131747	11742	0.38	155570	13865	287317	12804	3.8
65	09/11/06	3468	129	2.18	145804	12995	2.25	165147	14719	310951	13857	3.1
	09/14/06	3490	22	4.61	145192	12940	5.03	169557	15112	314749	14026	2.9
	09/15/06	3498	8	4.51	146450	13053	4.88	170879	15230	317329	14141	5.4
66	09/19/06	3517	19	5.01	149677	13340	5.45	174264	15532	323941	14436	5.8
	09/21/06	3530	13	2.07	151597	13511	2.37	176323	15715	327920	14613	5.1
	09/23/06	3544	14	2.27	153185	13653	2.44	178082	15872	331267	14762	4.0
67	09/25/06	3558	14	1.80	154604	13779	2.05	179638	16011	334242	14895	3.5
	09/27/06	3576	18	2.17	156315	13932	2.21	181526	16179	337841	15055	3.3
	09/30/06	3598	22	4.53	158455	14123	5.1	183818	16383	342273	15253	3.4
68	10/05/06	3631	33	1.55	162382	14473	1.65	188134	16768	350516	15620	4.2
	10/06/06	3640	9	1.91	163187	14544	2.02	189010	16846	352197	15695	3.1
	10/07/06	3645	5	3.53	163778	14597	3.92	189651	16903	353429	15750	4.1

APPENDIX B

ANALYTICAL DATA TABLES

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

Sampling Date		06/22/05			07/05/05				07/19/05				08/03/05					08/16/05						
Sampling Location																								
Parameter	Unit	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
Silica (as SiO2)	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[d]	NA[d]	6.5
Temperature	^0C	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[d]	NA[d]	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 $CaCO_3$.
(b) As PO_4.
(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 Parameter	**Unit**	**IN**	**AC**	**TA**	**TB**	**TT**	**IN**	**TA**	**TB**	**TT**	**IN**	**TA**	**TB**	**TT**	**TC**	**TD**	**IN**	**AC**	**TA**	**TB**	**TC**	**TD**
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	mg/L[a]	123	-	132	132	132	-	-	-	-	132	163	154	154	132	141	132	-	163	154	132	132
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 16.2	16.9 17.1	17.8 17.9	17.3 17.3	14.5 -	17.5 -	20.3 -	- -	45.4 -	30.0 -	23.1 -	21.5 -
Nitrate (as N)	mg/L	0.1[d] -	- -	0.1[d] -	0.1[d] -	0.1[d] -	- -	- -	- -	- -	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	<0.05 -	<0.05 -	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 -	- -	- -	- -	- -	- -	- -
Total P	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<10	-	<10	<10	<10	<10
Silica (as SiO2)	mg/L	16.8 -	- -	14.7 -	14.6 -	8.3 -	- -	- -	- -	- -	14.4 14.7	13.1 13	12.8 13.1	8.6 8.6	11.1 -	8.3 -	11.8 -	- -	10 -	10.5 -	8.8 -	8.9 -
Turbidity	NTU	0.2 -	- -	<0.1 -	0.1 -	<0.1 -	- -	- -	- -	- -	0.1 0.1	<0.1 <0.1	<0.1 0.1	<0.1 0.3	0.1 -	<0.1 -	0.2 -	- -	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[c]	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	8.1	-	8.0	8.0	NA[c]	NA[c]
Temperature	°C	13.8	-	13.7	13.5	16.2	12.7	NA[c]	NA[c]	11.8	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	11.8	-	11.1	11.1	NA[c]	NA[c]
Free Chlorine	mg/L	-	0.3	-	-	0.3	-	-	-	0.2	-	-	-	NA[c]	-	NA[c]	-	0.7	-	-	-	-
Total Chlorine	mg/L	0.4	0.4	-	-	0.4	-	-	-	0.2	-	-	-	NA[c]	-	NA[c]	-	0.7	-	-	-	-
Total Hardness	mg/L[a]	191 -	- -	191 -	193 -	171 -	147 -	155 -	153 -	171 -	163 164	146 147	143 145	155 150	153 -	158 -	177 -	- -	152 -	157 -	173 -	174 -
Ca Hardness	mg/L[a]	88.7 -	- -	89.0 -	91.8 -	83.7 -	69.5 -	71.6 -	69.7 `	78.9 -	73.7 73.2	65.2 66.0	62.9 65.5	71.0 67.6	70.2 -	73.8 -	81.5 -	- -	70.2 -	72.8 -	80.3 -	80.9 -
Mg Hardness	mg/L[a]	103 -	- -	102 -	101 -	87.2 -	77.4 -	83.6 -	83.1 -	92.1 -	89.1 91.3	80.6 81.3	79.7 79.1	83.6 82.4	82.7 -	84.0 -	95.4 -	- -	82.1 -	84.2 -	92.4 -	93.4 -
As (total)	µg/L	36.9 -	- -	6.0 -	7.8 -	0.3 -	72.2 -	12.6 -	14.8 -	1.1 -	30.4 30.4	16.9 18.0	19.7 19.8	0.5 0.6	0.5 -	0.6 -	43.0 -	- -	31.4 -	33.4 -	0.9 -	1.1 -
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
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 -	<25 -	<25 -
Soluble Fe	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<25	-	<25	<25	<25	<25
Total Mn	µg/L	4.1 -	- -	<0.1 -	<0.1 -	<0.1 -	35.9 -	<0.1 -	<0.1 -	0.2 -	2.2 2.1	<0.1 <0.1	<0.1 <0.1	<0.1 <0.1	<0.1 -	<0.1 -	5.1 -	- -	<0.1 -	<0.1 -	<0.1 -	<0.1 -
Soluble Mn	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4	-	<0.1	<0.1	<0.1	<0.1
Total Al	µg/L	<10 -	- -	16.6 -	17.0 -	26.5 -	<10 -	14.7 -	23.0 -	23.1 -	<10 <10	13.3 13.8	15.5 15.9	21.9 20.6	15.5 -	16.1 -	<10 -	- -	11.8 -	11.9 -	13.4 -	14.0 -
Soluble Al	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<10	-	11.3	12.3	14.9	12.5

(a) As $CaCO_3$. (b) As PO_4.
(c) Rerun results were similar. Data are 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		10/25/05					11/01/05							11/08/05								
Sampling Location Parameter	Unit	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	mg/L[(a)]	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	-	-	-	-	-	-	-	-
Total P	µg/L	<10	-	<10	<10	<10	<10	-	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Silica (as SiO2)	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	^{0}C	11.0	-	10.7	10.6	12.9	11.7	-	-	11.8	11.6	11.3	11.7	11.9	-	-	-	-	-	-	11.7
Free Chlorine	mg/L	-	1.0	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3
Total Chlorine	mg/L	-	0.3	-	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Hardness	mg/L[(a)]	166	-	165	164	174	194	-	-	165	167	168	171	-	-	-	-	-	-	-	-
Ca Hardness	mg/L[(a)]	79.5	-	77.2	77.0	83.4	81.0	-	-	79.1	81.0	80.8	82.1	-	-	-	-	-	-	-	-
Mg Hardness	mg/L[(a)]	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
Total Fe	µg/L	<25	-	<25	<25	<25	<25	-	-	<25	<25	<25	<25	<25	-	-	-	-	-	-	<25
Total Mn	µg/L	4.1	-	<0.1	<0.1	<0.1	4.1	-	-	<0.1	0.2	0.2	0.3	5.6	-	-	-	-	-	-	<0.1
Total Al	µg/L	<10	-	13.5	14.0	20.8	<10	-	-	15.6	15.8	18.3	18.5	<10	-	-	-	-	-	-	18.1

(a) As $CaCO_3$

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		11/28/2005[b]									12/13/05									01/05/06								
Sampling Location / Parameter	Unit	IN	AC	TA	TB	TC	TD	TE	TF	TT	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	-	-	14.3	14.5	-	-	-	-	14.5
Alkalinity	mg/L[a]	132	-	-	-	-	-	-	-	136	-	-	-	-	-	-	-	-	-	132	-	-	-	-	-	-	-	141
Fluoride	mg/L	<0.1	-	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	<0.1
Sulfate	mg/L	20.8	-	-	-	-	-	-	-	21	-	-	-	-	-	-	-	-	-	21	-	-	-	-	-	-	-	22
Nitrate (as N)	mg/L	0.1	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	0.1
Total P	µg/L	<10	-	-	-	-	-	-	-	<10	-	-	-	-	-	-	-	-	-	<10	-	-	-	-	-	-	-	<10
Silica (as SiO2)	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	12.7	-	11.7	11.1	10.9	11.2	9.9	9.8	9.5
Turbidity	NTU	0.7	-	-	-	-	-	-	-	0.4	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	0.2
pH	S.U.	7.8	7.6	-	-	-	-	-	-	7.7	7.3	7.7	-	-	-	-	-	-	7.9	7.1	7.7	-	-	-	-	-	-	7.8
Temperature	^0C	10.2	10.7	-	-	-	-	-	-	10.5	10.7	10.7	-	-	-	-	-	-	10.4	9.1	9.9	-	-	-	-	-	-	10.5
Free Chlorine	mg/L	-	0.5	-	-	-	-	-	-	0.5	-	0.1	-	-	-	-	-	-	0.1	-	0.4	-	-	-	-	-	-	0.4
Total Chlorine	mg/L	-	0.4	-	-	-	-	-	-	0.4	-	0.3	-	-	-	-	-	-	0.1	-	0.4	-	-	-	-	-	-	0.4
Total Hardness	mg/L[a]	165	-	-	-	-	-	-	-	172	-	-	-	-	-	-	-	-	-	176	-	-	-	-	-	-	-	162
Ca Hardness	mg/L[a]	72.4	-	-	-	-	-	-	-	73.2	-	-	-	-	-	-	-	-	-	83.9	-	-	-	-	-	-	-	78.8
Mg Hardness	mg/L[a]	92.9	-	-	-	-	-	-	-	98.5	-	-	-	-	-	-	-	-	-	92.2	-	-	-	-	-	-	-	83.3
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	29.9	-	33.4	33.3	16.7	19.5	0.9	1.8	1.6
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	-	-	-	-	-	-	-	-	-
Total Fe	µg/L	<25	-	-	-	-	-	-	-	<25	<25	<25	-	-	-	-	-	-	<25	<25	-	-	-	-	-	-	-	<25
Soluble Fe	µg/L	-	-	-	-	-	-	-	-	-	<25	<25	-	-	-	-	-	-	<25	-	-	-	-	-	-	-	-	-
Total Mn	µg/L	11.9	-	-	-	-	-	-	-	<0.1	1.7	12.1	-	-	-	-	-	-	0.1	6.4	-	-	-	-	-	-	-	<0.1
Soluble Mn	µg/L	-	-	-	-	-	-	-	-	-	<0.1	1.2	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	-	-
Total Al	µg/L	<10	-	-	-	-	-	-	-	16.5	<10	<10	-	-	-	-	-	-	14.8	1.6	-	-	-	-	-	-	-	11.2
Soluble Al	µg/L	-	-	-	-	-	-	-	-	-	<10	10.2	-	-	-	-	-	-	14.1	-	-	-	-	-	-	-	-	-

(a) As $CaCO_3$.
(b) Water quality measurements were taken on 11/27/2005.

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		01/25/06									01/31/06									02/15/06								
Sampling Location Parameter	Unit	IN	AC	TA	TB	TC	TD	TE	TF	TT	IN	AC	TA	TB	TC	TD	TE	TF	TT	IN	AC	TA	TB	TC	TD	TE	TF	TT
Bed Volume	10^3	-	-	15.7	15.9	-	-	-	-	15.8	-	-	16.2	16.4	-	-	-	-	16.3	-	-	0.0	0.0	-	-	-	-	0.0
Alkalinity	mg/L[(a)]	- -	- -	- -	- -	- -	- -	- -	- -	- -	127 127	- -	- -	- -	- -	- -	- -	- -	139 139	- -	- -	- -	- -	- -	- -	- -	- -	- -
Fluoride	mg/L	- -	- -	- -	- -	- -	- -	- -	- -	- -	<0.1 <0.1	- -	- -	- -	- -	- -	- -	- -	<0.1 <0.1	- -	- -	- -	- -	- -	- -	- -	- -	- -
Sulfate	mg/L	- -	- -	- -	- -	- -	- -	- -	- -	- -	21.1 20.8	- -	- -	- -	- -	- -	- -	- -	21 21	- -	- -	- -	- -	- -	- -	- -	- -	- -
Nitrate (as N)	mg/L	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.2 0.2	- -	- -	- -	- -	- -	- -	- -	0.1 0.1	- -	- -	- -	- -	- -	- -	- -	- -	- -
Total P	µg/L	- -	- -	- -	- -	- -	- -	- -	- -	- -	<10 <10	- -	- -	- -	- -	- -	- -	- -	<10 <10	- -	- -	- -	- -	- -	- -	- -	- -	- -
Silica (as SiO2)	mg/L	11.8 -	- -	11.2 -	10.9 -	10.9 -	10.6 -	9.8 -	9.8 -	10.3 -	11.5 12.1	- -	11.2 11.4	11.7 11.6	9.9 10.1	10.3 10.5	10.0 10.1	10.1 10.0	9.6 10.3	11.7 -	- -	<0.2 -	<0.2 -	0.7 -	0.5 -	10.6 -	10.6 -	0.2 -
Turbidity	NTU	- -	- -	- -	- -	- -	- -	- -	- -	- -	0.4 0.4	- -	- -	- -	- -	- -	- -	- -	0.3 0.3	- -	- -	- -	- -	- -	- -	- -	- -	- -
pH	S.U.	8.4	8.1	-	-	-	-	-	-	8.0	7.2	7.5	-	-	-	-	-	-	7.8	7.3	7.7	-	-	-	-	-	-	7.1
Temperature	^{0}C	9.2	7.7	-	-	-	-	-	-	9.6	9.7	9.4	-	-	-	-	-	-	9.9	9.5	9.2	-	-	-	-	-	-	10.4
Free Chlorine	mg/L	-	-	-	-	-	-	-	-	0.4	-	-	-	-	-	-	-	-	0.3	-	0.1	-	-	-	-	-	-	0.1
Total Chlorine	mg/L	-	-	-	-	-	-	-	-	0.4	-	-	-	-	-	-	-	-	0.3	-	0.2	-	-	-	-	-	-	0.3
Total Hardness	mg/L[(a)]	- -	- -	- -	- -	- -	- -	- -	- -	- -	157 165	- -	- -	- -	- -	- -	- -	- -	172 160	- -	- -	- -	- -	- -	- -	- -	- -	- -
Ca Hardness	mg/L[(a)]	- -	- -	- -	- -	- -	- -	- -	- -	- -	71.7 80.1	- -	- -	- -	- -	- -	- -	- -	81.2 77.7	- -	- -	- -	- -	- -	- -	- -	- -	- -
Mg Hardness	mg/L[(a)]	- -	- -	- -	- -	- -	- -	- -	- -	- -	85.7 85.4	- -	- -	- -	- -	- -	- -	- -	90.8 82.0	- -	- -	- -	- -	- -	- -	- -	- -	- -
As (total)	µg/L	34.5 -	- -	- -	31.3 -	23.6 -	24.2 -	3.2 -	4.6 -	3.9 -	31.8 28.8	- -	27.3 27.9	27.3 27.5	20.7 21.0	20.9 21.7	3.1 3.4	4.6 5.4	3.7 4.3	24.1 -	- -	1.0 -	0.9 -	1.0 -	1.1 -	6.7 -	10.7 -	1.0 -
Total Fe	µg/L	45.4 -	- -	- -	- -	- -	- -	- -	- -	<25 -	<25 <25	- -	- -	- -	- -	- -	- -	- -	<25 <25	<25 -	- -	- -	- -	- -	- -	- -	- -	<25 -
Total Mn	µg/L	34.5 -	- -	- -	- -	- -	- -	- -	- -	<0.1 -	6.9 6.5	- -	- -	- -	- -	- -	- -	- -	<0.1 <0.1	5.4 -	- -	- -	- -	- -	- -	- -	- -	1.6 -
Total Al	µg/L	<10 -	- -	- -	- -	- -	- -	- -	- -	13.5 -	<10 <10	- -	- -	- -	- -	- -	- -	- -	10.5 <10	<10 -	- -	- -	- -	- -	- -	- -	- -	13.8 -

(a) As $CaCO_3$.

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		02/28/06									03/16/06									03/29/06								
Sampling Location / Parameter	Unit	IN	AC	TA	TB	TC	TD	TE	TF	TT	IN	AC	TA	TB	TC	TD	TE	TF	TT	IN	AC	TA	TB	TC	TD	TE	TF	TT
Bed Volume	10^3	-	-	0.3	0.8	-	-	-	-	0.5	-	-	0.9	2.0	-	-	-	-	1.4	-	-	1.5	2.8	-	-	-	-	2.1
Alkalinity	mg/L[(a)]	122[(b)]	-	-	-	-	-	-	-	132	-	-	-	-	-	-	-	-	-	153	-	-	-	-	-	-	-	141
Fluoride	mg/L	<0.1	-	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	<0.1
Sulfate	mg/L	22	-	-	-	-	-	-	-	24	-	-	-	-	-	-	-	-	-	23.2	-	-	-	-	-	-	-	23.8
Nitrate (as N)	mg/L	0.1	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-	<0.05	-	-	-	-	-	-	-	0.1
Total P	µg/L	<10	-	-	-	-	-	-	-	<10	-	-	-	-	-	-	-	-	-	<10	-	-	-	-	-	-	-	<10
Silica (as SiO2)	mg/L	11.1	-	4.7	4.5	1.1	1.1	11.2	11.3	1.1	11.6	-	7.2	7.1	3.0	3.2	10.6	10.7	3.3	11.2	-	7.6	7.6	4.6	4.1	10.9	10.7	5.4
Turbidity	NTU	0.2	-	-	-	-	-	-	-	0.6	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	0.7
pH	S.U.	8.4	7.7	-	-	-	-	-	-	7.3	-	-	-	-	-	-	-	-	-	7.9	7.8	-	-	-	-	-	-	7.7
Temperature	^{0}C	7.4	7.4	-	-	-	-	-	-	8.8	-	-	-	-	-	-	-	-	-	9.5	9.8	-	-	-	-	-	-	13.1
Free Chlorine	mg/L	-	0.2	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	0.2
Total Chlorine	mg/L	-	0.2	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	0.2
Total Hardness	mg/L[(a)]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	157	-	-	-	-	-	-	-	165
Ca Hardness	mg/L[(a)]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	72.8	-	-	-	-	-	-	-	76.8
Mg Hardness	mg/L[(a)]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	84.4	-	-	-	-	-	-	-	88.6
As (total)	µg/L	28.4	-	0.3	0.3	0.3	0.3	10.9	13.2	0.3	22.4	-	0.6	0.5	0.4	0.5	11.3	12.0	0.5	47.2	-	0.2	0.2	0.2	0.1	15.9	17.1	0.2
Total Fe	µg/L	<25	-	-	-	-	-	-	-	<25	<25	-	-	-	-	-	-	-	<25	<25	-	-	-	-	-	-	-	<25
Total Mn	µg/L	9.9	-	-	-	-	-	-	-	<0.1	15.5	-	-	-	-	-	-	-	<0.1	14.8	-	-	-	-	-	-	-	0.3
Total Al	µg/L	<10	-	-	-	-	-	-	-	13.0	<10	-	-	-	-	-	-	-	20.8	<10	-	-	-	-	-	-	-	18.0

(a) As $CaCO_3$.
(b) Sample reanalyzed outside of hold time.

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		04/11/06								
Parameter	Unit	IN	AC	TA	TB	TC	TD	TE	TF	TT
Bed Volume	10^3	-	-	2.2	3.8	-	-	-	-	3.1
Alkalinity	mg/L[(a)]	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-
Total P	µg/L	-	-	-	-	-	-	-	-	-
Silica (as SiO2)	mg/L	11.6	11.5	9.0	8.8	6.0	6.1	10.8	10.6	5.8
Turbidity	NTU	-	-	-	-	-	-	-	-	-
pH	S.U.	7.4	7.9	-	-	-	-	-	-	7.8
Temperature	^0C	8.5	9.8	-	-	-	-	-	-	9.7
Free Chlorine	mg/L	-	0.4	-	-	-	-	-	-	0.1
Total Chlorine	mg/L	-	0.4	-	-	-	-	-	-	0.1
Total Hardness	mg/L[(a)]	-	-	-	-	-	-	-	-	-
Ca Hardness	mg/L[(a)]	-	-	-	-	-	-	-	-	-
Mg Hardness	mg/L[(a)]	-	-	-	-	-	-	-	-	-
As (total)	µg/L	32.7	32.8	0.7	0.7	0.6	0.5	23.7	24.7	0.7
As (soluble)	µg/L	32.6	32.5	-	-	-	-	-	-	0.6
As (particulate)	µg/L	0.2	0.3	-	-	-	-	-	-	<0.1
As (III)	µg/L	0.5	0.6	-	-	-	-	-	-	0.4
As (V)	µg/L	32.0	31.9	-	-	-	-	-	-	0.2
Total Fe	µg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25
Soluble Fe	µg/L	<25	<25	-	-	-	-	-	-	<25
Total Mn	µg/L	3.4	3.8	0.1	<0.1	0.1	0.1	<0.1	<0.1	1.4
Soluble Mn	µg/L	2.3	2.5	-	-	-	-	-	-	0.2
Total Al	µg/L	<10	<10	12.2	12.4	16.3	14.6	10.0	10.4	16.3
Soluble Al	µg/L	<10	<10	-	-	-	-	-	-	15.3

Sampling Date		04/27/06								
Parameter	Unit	IN	AC	TA	TB	TC	TD	TE	TF	TT
Bed Volume	10^3	-	-	3.3	5.0	-	-	-	-	4.3
Alkalinity	mg/L[(a)]	133	-	-	-	-	-	-	-	138
Fluoride	mg/L	<0.1	-	-	-	-	-	-	-	<0.1
Sulfate	mg/L	24	-	-	-	-	-	-	-	23
Nitrate (as N)	mg/L	0.1	-	-	-	-	-	-	-	0.1
Total P	µg/L	<10	-	-	-	-	-	-	-	<10
Silica (as SiO2)	mg/L	11.4	-	9.8	9.4	7.6	8.1	11.7	11.5	7.3
Turbidity	NTU	0.2	-	-	-	-	-	-	-	0.1
pH	S.U.	8.0	7.5	-	-	-	-	-	-	7.8
Temperature	^0C	10.3	11.2	-	-	-	-	-	-	11.2
Free Chlorine	mg/L	-	0.4	-	-	-	-	-	-	0.4
Total Chlorine	mg/L	-	0.4	-	-	-	-	-	-	0.4
Total Hardness	mg/L[(a)]	154	-	-	-	-	-	-	-	162
Ca Hardness	mg/L[(a)]	78.9	-	-	-	-	-	-	-	80.5
Mg Hardness	mg/L[(a)]	75.1	-	-	-	-	-	-	-	81.0
As (total)	µg/L	28.7	-	<0.1	<0.1	<0.1	<0.1	25.0	24.8	<0.1
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-
Total Fe	µg/L	<25	-	-	-	-	-	-	-	<25
Soluble Fe	µg/L	-	-	-	-	-	-	-	-	-
Total Mn	µg/L	1.9	-	-	-	-	-	-	-	<0.1
Soluble Mn	µg/L	-	-	-	-	-	-	-	-	-
Total Al	µg/L	<10	-	-	-	-	-	-	-	13.5
Soluble Al	µg/L	-	-	-	-	-	-	-	-	-

Sampling Date		05/10/06								
Parameter	Unit	IN	AC	TA	TB	TC	TD	TE	TF	TT
Bed Volume	10^3	-	-	4.2	6.0	-	-	-	-	5.2
Alkalinity	mg/L[(a)]	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-
Total P	µg/L	-	-	-	-	-	-	-	-	-
Silica (as SiO2)	mg/L	13.3	-	10.7	10.3	8.7	8.1	12.5	11.8	8.4
Turbidity	NTU	-	-	-	-	-	-	-	-	-
pH	S.U.	7.5	8.0	-	-	-	-	-	-	8.0
Temperature	^0C	10.3	10.5	-	-	-	-	-	-	10.9
Free Chlorine	mg/L	-	0.3	-	-	-	-	-	-	0.3
Total Chlorine	mg/L	-	0.3	-	-	-	-	-	-	0.3
Total Hardness	mg/L[(a)]	-	-	-	-	-	-	-	-	-
Ca Hardness	mg/L[(a)]	-	-	-	-	-	-	-	-	-
Mg Hardness	mg/L[(a)]	-	-	-	-	-	-	-	-	-
As (total)	µg/L	29.0	-	1.6	1.7	0.3	0.3	23.9	24.1	0.3
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-
Total Fe	µg/L	84.7	-	-	-	-	-	-	-	<25
Soluble Fe	µg/L	-	-	-	-	-	-	-	-	-
Total Mn	µg/L	5.5	-	-	-	-	-	-	-	<0.1
Soluble Mn	µg/L	-	-	-	-	-	-	-	-	-
Total Al	µg/L	<10	-	-	-	-	-	-	-	19.9
Soluble Al	µg/L	-	-	-	-	-	-	-	-	-

(a) As $CaCO_3$.

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		06/01/06									06/05/06									06/22/06								
Sampling Location / Parameter	Unit	IN	AC	TA	TB	TC	TD	TE	TF	TT	IN	AC	TA	TB	TC	TD	TE	TF	TT	IN	AC	TA	TB	TC	TD	TE	TF	TT
Bed Volume	10^3	-	-	5.6	7.4	-	-	-	-	6.6	-	-	5.8	7.7	-	-	-	-	6.9	-	-	7.2	9.1	-	-	-	-	8.3
Alkalinity	mg/L[(a)]	150	-	-	-	-	-	-	-	133	-	-	-	-	-	-	-	-	-	138	-	-	-	-	-	-	-	134
		150	-	-	-	-	-	-	-	133	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	<0.1	-	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	<0.1
		<0.1	-	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	23	-	-	-	-	-	-	-	24	-	-	-	-	-	-	-	-	-	23	-	-	-	-	-	-	-	25
		22	-	-	-	-	-	-	-	24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	µg/L	<10	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	0.1
		<10	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P	mg/L	<10	-	-	-	-	-	-	-	<10	-	-	-	-	-	-	-	-	-	<10	-	-	-	-	-	-	-	<10
		<10	-	-	-	-	-	-	-	<10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO2)	mg/L	11.2	-	10.2	10.0	8.5	8.6	11.5	10.8	8.0	11.3	11.7	10.8	10.3	8.8	8.9	11.9	11.3	9.3	11.4	-	10.7	10.5	9.7	9.4	11.8	11.7	9.5
		10.7	-	9.2	9.6	8.2	8.4	10.9	10.3	8.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	0.3	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	0.2
		0.4	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	6.5	-	-	-	-	-	-	-	7.0	7.5	7.7	-	-	-	-	-	-	7.7	-	-	-	-	-	-	-	-	-
Temperature	^{0}C	12.7	-	-	-	-	-	-	-	14.3	12.4	12.2	-	-	-	-	-	-	12.6	-	-	-	-	-	-	-	-	-
Total Hardness	mg/L[(a)]	143	-	-	-	-	-	-	-	140	-	-	-	-	-	-	-	-	-	171	-	-	-	-	-	-	-	174
		147	-	-	-	-	-	-	-	143	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness	mg/L[(a)]	74.3	-	-	-	-	-	-	-	74.0	-	-	-	-	-	-	-	-	-	79.3	-	-	-	-	-	-	-	81.2
		77.2	-	-	-	-	-	-	-	76.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness	mg/L[(a)]	68.4	-	-	-	-	-	-	-	65.8	-	-	-	-	-	-	-	-	-	91.7	-	-	-	-	-	-	-	93.1
		69.5	-	-	-	-	-	-	-	66.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L	23.0	-	6.0	5.5	0.2	0.2	23.6	24.6	0.3	20.8	21.5	4.7	5.8	0.3	0.2	23.7	22.9	0.3	50.7	-	10.7	10.3	0.2	0.2	29.4	29.5	0.3
		24.8	-	5.6	5.5	0.2	0.2	24.0	24.5	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	20.8	20.2	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	<0.1	1.3	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	0.2	0.2	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	20.6	20.0	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-
Total Fe	µg/L	<25	-	-	-	-	-	-	-	<25	48.6	<25	-	-	-	-	-	-	<25	27.7	-	-	-	-	-	-	-	<25
		<25	-	-	-	-	-	-	-	<25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soluble Fe	µg/L	-	-	-	-	-	-	-	-	-	<25	<25	-	-	-	-	-	-	<25	-	-	-	-	-	-	-	-	-
Total Mn	µg/L	3.1	-	-	-	-	-	-	-	<0.1	5.9	4.7	-	-	-	-	-	-	<0.1	36.6	-	-	-	-	-	-	-	0.2
		3.9	-	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soluble Mn	µg/L	-	-	-	-	-	-	-	-	-	3.2	2.7	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	-	-
Total Al	µg/L	<10	-	-	-	-	-	-	-	11.4	<10	<10	-	-	-	-	-	-	<10	<10	-	-	-	-	-	-	-	17.8
		<10	-	-	-	-	-	-	-	11.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soluble Al	µg/L	-	-	-	-	-	-	-	-	-	<10	<10	-	-	-	-	-	-	12.8	-	-	-	-	-	-	-	-	-

(a) As $CaCO_3$.

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		07/11/06								07/18/06								08/02/06								
Sampling Location		IN	TA	TB	TC	TD	TE	TF	TT	IN	TA	TB	TC	TD	TE	TF	TT	IN	AC	TA	TB	TC	TD	TE	TF	TT
Parameter	Unit																									
Bed Volume	10^3	-	8.4	10.4	-	-	-	-	9.5	-	9.0	11.1	-	-	-	-	10.2	-	-	9.6	11.8	-	-	-	-	11.0
Alkalinity	mg/L[(a)]	-	-	-	-	-	-	-	-	121	-	-	-	-	-	-	125	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	<1	-	-	-	-	-	-	20	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-
Total P	µg/L	-	-	-	-	-	-	-	-	<10	-	-	-	-	-	-	<10	-	-	-	-	-	-	-	-	-
Silica (as SiO2)	mg/L	12.0	10.4	10.5	7.6	9.9	11.3	11.2	9.5	12.1	10.9	10.5	9.6	10.0	11.4	11.4	9.4	11.3	10.8	10.5	10.6	9.9	9.7	11.0	11.5	9.6
Turbidity	NTU	-	-	-	-	-	-	-	-	0.5	-	-	-	-	-	-	0.5	-	-	-	-	-	-	-	-	-
pH	S.U.	7.4	-	-	-	-	-	-	7.7	7.7	-	-	-	-	-	-	7.5	NA[(b)]	NA[(b)]	-	-	-	-	-	-	NA[(b)]
Temperature	^0C	13.5	-	-	-	-	-	-	13.5	12.7	-	-	-	-	-	-	13.3	NA[(b)]	NA[(b)]	-	-	-	-	-	-	NA[(b)]
Free Chlorine	mg/L	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-	NA[(b)]
Total Hardness	mg/L[(a)]	-	-	-	-	-	-	-	-	162	-	-	-	-	-	-	171	-	-	-	-	-	-	-	-	-
	mg/L[(a)]	-	-	-	-	-	-	-	-	77.4	-	-	-	-	-	-	80.6	-	-	-	-	-	-	-	-	-
Ca Hardness	mg/L[(a)]	-	-	-	-	-	-	-	-	84.4	-	-	-	-	-	-	90.7	-	-	-	-	-	-	-	-	-
	µg/L	29.3	12.5	12.3	0.4	0.3	30.1	29.0	0.3	61.8	17.6	17.8	0.7	0.5	35.7	36.0	0.6	69.6	71.7	20.9	20.2	1.3	0.8	34.5	35.3	1.1
Mg Hardness	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	67.3	67.3	-	-	-	-	-	-	1.1
	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.3	4.4	-	-	-	-	-	-	<0.1
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.3	-	-	-	-	-	-	0.3
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	67.0	67.0	-	-	-	-	-	-	0.9
Total Fe	µg/L	<25	<25	<25	<25	<25	<25	<25	<25	61.6	-	-	-	-	-	-	<25	<25	<25	-	-	-	-	-	-	<25
Soluble Fe	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<25	<25	-	-	-	-	-	-	<25
Total Mn	µg/L	3.9	0.6	0.6	0.2	0.6	0.1	0.1	0.1	37.9	-	-	-	-	-	-	0.1	1.9	2.5	-	-	-	-	-	-	0.2
Soluble Mn	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.5	1.8	-	-	-	-	-	-	0.2
Total Al	µg/L	<10	11.4	11.0	12.2	11.9	10.8	10.7	11.3	<10	-	-	-	-	-	-	<10	<10	<10	-	-	-	-	-	-	16.7
Soluble Al	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<10	<10	-	-	-	-	-	-	17.3

(a) As $CaCO_3$.
(b) Water quality measurements 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		08/17/06								09/07/06								09/18/06							
Sampling Location / Parameter	Unit	IN	TA	TB	TC	TD	TE	TF	TT	IN	TA	TB	TC	TD	TE	TF	TT	IN	TA	TB	TC	TD	TE	TF	TT
Bed Volume	10^3	-	10.2	12.5	-	-	-	-	12.1	-	12.5	14.3	-	-	-	-	13.5	-	13.1	15.5	-	-	-	-	14.4
Alkalinity	mg/L[(a)]	140	-	-	-	-	-	-	136	-	-	-	-	-	-	-	-	156	-	-	-	-	-	-	135
Fluoride	mg/L	<0.1	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	0.2
Sulfate	mg/L	23	-	-	-	-	-	-	22	-	-	-	-	-	-	-	-	23	-	-	-	-	-	-	24
Nitrate (as N)	mg/L	0.1	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	<0.05	-	-	-	-	-	-	<0.05
Total P	µg/L	<10	-	-	-	-	-	-	<10	-	-	-	-	-	-	-	-	<10	-	-	-	-	-	-	<10
Silica (as SiO2)	mg/L	11.4	11.3	11.4	10.2	10.6	12.1	11.5	9.7	10.9	9.8	10.2	9.5	9.6	10.9	11.0	9.4	11.7	11.4	11.0	10.5	10.2	11.2	10.8	10.3
Turbidity	NTU	0.6	-	-	-	-	-	-	0.4	-	-	-	-	-	-	-	-	0.9	-	-	-	-	-	-	0.6
pH	S.U.	NA[(b)]	-	-	-	-	-	-	NA[(b)]	NA[(b)]	-	-	-	-	-	-	NA[(b)]	7.2	-	-	-	-	-	-	7.3
Temperature	^{0}C	NA[(b)]	-	-	-	-	-	-	NA[(b)]	NA[(b)]	-	-	-	-	-	-	NA[(b)]	12.0	-	-	-	-	-	-	11.3
Free Chlorine	mg/L	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	NA[(b)]	-	-	-	-	-	-	-	NA[(b)]
Total Hardness	mg/L[(a)]	156	-	-	-	-	-	-	172	-	-	-	-	-	-	-	-	174	-	-	-	-	-	-	153
	mg/L[(a)]	77.8	-	-	-	-	-	-	81.4	-	-	-	-	-	-	-	-	83.7	-	-	-	-	-	-	76.3
Ca Hardness	mg/L[(a)]	78.3	-	-	-	-	-	-	90.9	-	-	-	-	-	-	-	-	90.6	-	-	-	-	-	-	76.7
	µg/L	33.2	25.4	24.6	2.9	1.9	35.8	36.0	2.5	37.8	23.5	24.0	5.0	3.5	29.1	30.5	4.4	101	29.3	28.2	7.4	5.4	38.6	39.9	6.6
Mg Hardness	µg/L	<25	-	-	-	-	-	-	<25	<25	-	-	-	-	-	-	<25	108	-	-	-	-	-	-	<25
	µg/L	4.4	-	-	-	-	-	-	<0.1	6.7	-	-	-	-	-	-	<0.1	33.2	-	-	-	-	-	-	<0.1
Total Al	µg/L	<10	-	-	-	-	-	-	14.4	<10	-	-	-	-	-	-	15.4	27.6	-	-	-	-	-	-	11.8

(a) As $CaCO_3$.
(b) Water quality measurements 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		09/26/06									10/10/06							
Sampling Location / Parameter	Unit	IN	AC	TA	TB	TC	TD	TE	TF	TT	IN	TA	TB	TC	TD	TE	TF	TT
Bed Volume	10^3	-	-	13.8	16.1	-	-	-	-	14.9	-	14.9	17.2	-	-	-	-	16.0
Silica (as SiO2)	mg/L	11.8	12.4	11.0	11.5	11.0	10.6	12.1	11.4	10.6	11.0	10.8	10.8	10.0	10.9	10.8	11.7	10.5
pH	S.U.	NA[(a)]	NA[(a)]	-	-	-	-	-	-	NA[(a)]	NA[(a)]	-	-	-	-	-	-	NA[(a)]
Temperature	^0C	NA[(a)]	NA[(a)]	-	-	-	-	-	-	NA[(a)]	NA[(a)]	-	-	-	-	-	-	NA[(a)]
As (total)	µg/L	34.4	45.8	22.3	23.0	8.2	6.9	32.2	31.8	7.1	71.3	31.0	30.7	12.4	10.9	43.4	42.2	12.0
As (soluble)	µg/L	24.3	45.4	-	-	-	-	-	-	7.1	-	-	-	-	-	-	-	-
As (particulate)	µg/L	10.1	0.4	-	-	-	-	-	-	<0.1	-	-	-	-	-	-	-	-
As (III)	µg/L	1.1	1.2	-	-	-	-	-	-	1.2	-	-	-	-	-	-	-	-
As (V)	µg/L	23.2	44.3	-	-	-	-	-	-	5.9	-	-	-	-	-	-	-	-
Total Fe	µg/L	<25	<25	-	-	-	-	-	-	<25	<25	<25	<25	<25	<25	<25	<25	<25
Soluble Fe	µg/L	<25	<25	-	-	-	-	-	-	<25	-	-	-	-	-	-	-	-
Total Mn	µg/L	3.1	4.7	-	-	-	-	-	-	0.4	9.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Soluble Mn	µg/L	1.1	1.6	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-
Total Al	µg/L	<10	<10	-	-	-	-	-	-	18.4	<10	-	-	-	-	-	-	14.5
Soluble Al	µg/L	<10	<10	-	-	-	-	-	-	16.4	-	-	-	-	-	-	-	-

(a) Water quality measurements 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

APPENDIX C

ARSENIC MASS REMOVAL CALCULATIONS

Train A

Run 1

Volume Treated (BV)[a]	Concentration (µg/L)			Mass Removed (µg) [b]
	Raw	After Column A	Difference	
0.0	44.3	0.7	43.6	-
900	39.9	0.3	39.6	1,589,991
1,100	52.3	4.4	47.9	2,043,758
1,000	61.9	1.2	60.7	2,305,996
1,100	46.6	2.1	44.5	2,457,181
900	36.9	6.0	30.9	1,440,929
1,400	72.2	12.6	59.6	2,690,329
700	30.4	16.9	13.5	1,086,536
1,100	43.0	31.4	11.6	586,266
800	57.8	30.8	27.0	655,701
500	32.9	30.8	2.1	308,952
500	56.2	30.1	26.1	299,397
1,600	40.2	37.3	2.9	985,251
Total Arsenic Removed by Column A				**16,450,288**

Run 2

Volume Treated (BV)[a]	Concentration (µg/L)			Mass Removed (µg) [b]
	After Column E	After Column A	Difference	
0.0	6.7	1.0	5.7	-
300	10.9	0.3	10.6	103,834
500	11.3	0.6	10.7	226,141
700	15.9	0.2	15.7	392,402
800	23.7	0.7	23.0	657,400
1,200	25.0	0.05	25.0	1,221,796
800	23.9	1.6	22.3	802,640
1,400	23.6	6.0	17.6	1,186,123
300	23.7	4.7	19.0	233,148
1,300	29.4	10.7	18.7	1,040,671
1,300	30.1	12.5	17.6	1,002,025
600	35.7	17.6	18.1	424,829
1,000	34.5	20.9	13.6	673,113
900	35.8	25.4	10.4	458,651
1,700	29.1	23.5	5.6	577,561
900	38.6	29.3	9.3	284,746
1,000	32.2	22.3	9.9	407.690
1,000	43.4	31.0	12.4	473,515
Total Arsenic Removed by Column A				**10,196,282**

Run 1

Volume Treated (BV)[a]	Concentration (µg/L)			Mass Removed (µg) [b]
	After Column A	After Column C	Difference	
0	2.1	0.7	1.4	-
4,100	16.9	0.5	16.4	1,549,646
1,100	31.4	0.9	30.5	1,095,454
1,300	30.8	1.2	29.6	1,659,001
500	30.1	1.4	28.7	618,967
1,600	37.3	5.6	31.7	2,052,039
900	37.0	9.9	27.1	1,123,695
2,000	33.4	16.7	16.7	1,860,085
1,800	27.3	20.7	6.6	890,548
Total Arsenic Removed by Column C				**10,849,436**

Run 2

Volume Treated (BV)[a]	Concentration (µg/L)			Mass Removed (µg) [b]
	After Column A	After Column C	Difference	
0	0.6	0.4	0.2	-
700	0.2	0.2	0	2,973
800	0.7	0.6	0.1	1,699
1,200	0.05	0.05	0	2,548
800	1.6	0.3	1.3	22,083
1,400	6.0	0.2	5.8	211,065
300	4.7	0.3	4.4	64,976
1,300	10.7	0.2	10.5	411,300
1,300	12.5	0.4	12.1	623,851
600	17.6	0.7	16.9	369,469
1,000	20.9	1.3	19.6	775,036
900	25.4	2.9	22.5	804,551
1,700	23.5	5.0	18.5	1,479,999
900	29.3	7.4	21.9	772,063
1,000	22.3	8.2	14.1	764,419
1,000	31.0	12.4	18.6	694,347
Total Arsenic Removed by Column C				**7,000,376[c]**

Run 1

Volume Treated (BV)[a]	Concentration (µg/L)			Mass Removed (µg) [b]
	After Column C	After Column E	Difference	
0	1.2	0.3	0.9	-
500	1.4	0.2	1.2	22,296
1,600	5.6	1.3	4.3	186,858
900	9.9	0.6	9.3	259,902
2,000	16.7	0.9	15.8	1,065,939
1,300	23.6	3.2	20.4	999,265
500	20.7	3.1	17.6	403,443
Total Arsenic Removed by Column E				**2,937,703**

Note: Amount of mass removed before vessel was moved to the lead position for Run 2.

Run 2

Volume Treated (BV)[a]	Concentration (µg/L)			Mass Removed (µg) [b]
	Raw	After Column E	Difference	
Amount removed from Run 1				2,937,703
500	20.7	3.1	17.6	403,443
900	24.1	6.7	17.4	668,866
300	28.1	10.9	17.2	220,407
500	22.4	11.3	11.1	300,459
700	47.2	15.9	31.9	630,221
800	32.7	23.7	9.0	684,579
1,200	28.7	25.0	3.7	323,604
800	29.0	23.9	5.1	149,486
1,400	23.0	23.6	-0.6	133,773
300	20.8	23.7	-2.9	0
1,300	50.7	29.4	21.3	507,914
1,300	29.3	30.1	-0.8	565,882
600	61.8	35.7	26.1	322,330
1,000	69.6	34.5	35.1	1,299,512
900	33.2	35.8	-2.6	621,090
1,700	37.8	29.1	8.7	220,195
900	101.0	38.6	62.4	1,358,754
1,000	34.4	32.2	2.2	1,371,707
1,000	71.3	43.4	27.9	639,139
Total Arsenic Removed by Column E				**12,955,621**

Note: Amount of mass removed from both Run 1 and Run 2.

Train B

Run 1

Volume Treated (BV)[(a)]	Concentration (µg/L)			Mass Removed (µg)[(b)]
	Raw	After Column B	Difference	
0.0	44.3	0.6	43.7	-
700	39.9	0.3	39.6	1,238,146
700	52.3	6.3	46.0	1,272,332
800	61.9	1.2	60.7	1,812,521
1,000	46.6	3.1	43.5	2,212,567
1,200	36.9	7.8	29.1	1,849,893
1,400	72.2	14.8	57.4	2,571,419
800	30.4	19.7	10.7	1,156,820
1,100	43.0	33.4	9.6	474.152
1,000	57.8	32.1	25.7	749,555
500	32.9	30.7	2.2	296,212
500	56.2	30.4	25.8	297,274
2,100	40.2	38.9	1.3	1,208,418
Total Arsenic Removed by Column B				**15,139,310**

Run 2

Volume Treated (BV)[(a)]	Concentration (µg/L)			Mass Removed (µg)[(b)]
	After Column F	After Column B	Difference	
0	10.7	0.9	9.8	-
800	13.2	0.3	12.9	385,606
900	12.0	0.5	11.5	466,295
1,000	17.1	0.2	16.9	603,041
1,100	24.7	0.7	24.0	955,311
1,400	24.8	0.05	24.8	1,449,210
800	24.1	1.7	22.4	800,941
1,200	24.6	5.5	19.1	1,057,446
600	22.9	5.8	17.1	461,199
1,300	29.5	10.3	19.2	1,002,025
1,400	29.0	12.3	16.7	1,067,213
600	36.0	17.8	18.2	444,637
1,200	35.3	20.2	15.1	848,505
900	25.4	24.6	0.8	303,856
1,300	30.5	24.0	6.5	201,509
800	39.9	28.2	11.7	309,165
1,000	31.8	23.0	8.8	435,294
1,000	42.2	30.7	11.5	431,047
Total Arsenic Removed by Column B				**11,222,302**

Run 1

Volume Treated (BV)[(a)]	Concentration (µg/L)			Mass Removed (µg)[(b)]
	After Column B	After Column D	Difference	
0	3.1	0.8	2.3	-
4,100	19.7	0.6	19.1	1,863,058
1,100	33.4	1.1	32.3	1,200,562
1,300	30.7	2.5	28.2	1,670,042
500	30.4	2.3	28.1	597,733
1,600	38.9	8.3	30.6	1,994,283
900	35.5	13.3	22.2	1,009,033
2,000	33.3	19.5	13.8	1,528,837
1,300	31.3	24.2	7.1	576,924
500	27.3	20.9	6.4	143,329
Total Arsenic Removed by Column D				**10,583,800**

Run 2

Volume Treated (BV)[(a)]	Concentration (µg/L)			Mass Removed (µg)[(b)]
	After Column B	After Column D	Difference	
0	0.5	0.5	0	
1,000	0.2	0.1	0.1	2,123
1,100	0.7	0.5	0.2	7,007
1,400	0.05	0.05	0	5,945
800	1.7	0.3	1.4	23,782
1,200	5.5	0.2	5.3	170,720
600	5.8	0.2	5.6	138,869
1,300	10.3	0.2	10.1	433,383
1,400	12.3	0.3	12.0	656,975
600	17.8	0.5	17.3	373,291
1,200	20.2	0.8	19.4	935,139
900	24.6	1.9	22.7	804,551
1,300	24.0	3.5	20.5	1,192,493
800	28.2	5.4	22.8	735,541
1,000	23.0	6.9	16.1	825,997
1,000	30.7	10.9	19.8	762,295
Total Arsenic Removed by Column D				**7,068,112[(c)]**

Run 1

Volume Treated (BV)[(a)]	Concentration (µg/L)			Mass Removed (µg) [(b)]
	After Column D	After Column F	Difference	
0	2.5	0.4	2.1	-
500	2.3	0.2	2.1	44,591
1,600	8.3	1.3	7.0	309,165
900	13.3	0.7	12.6	374,565
2,000	19.5	1.8	17.7	1,286,771
1,300	24.2	4.6	19.6	1,029,629
500	20.9	4.6	16.3	381,148
Total Arsenic Removed by Column F				**3,425,869**

Note: Amount of mass removed before vessel was moved to the lead position for Run 2.

Run 2

Volume Treated (BV)[(a)]	Concentration (µg/L)			Mass Removed (µg) [(b)]
	Raw	After Column F	Difference	
Amount of mass removed from Run 1				3,425,869
1,200	24.1	10.7	13.4	756,774
800	28.1	13.2	14.9	480,734
900	22.4	12.0	10.4	483,495
1,000	47.2	17.1	30.1	859,971
1,100	32.7	24.7	8.0	889,911
1,400	28.7	24.8	3.9	353,756
800	29.0	24.1	4.9	149,486
1,200	23.0	24.6	-1.6	84,086
600	20.8	22.9	-2.1	0
1,300	50.7	29.5	21.2	527,237
1,400	29.3	29.0	0.3	639,139
600	61.8	36.0	25.8	332,522
1,200	69.6	35.3	34.3	1,531,385
900	33.2	25.4	7.8	804,551
1,300	37.8	30.5	7.3	416,821
800	101	39.9	61.1	1,161,916
1,000	34.4	31.8	2.6	1,352,596
1,000	71.3	42.2	29.1	673,113
Total Arsenic Removed by Column F				**14,923,362**

Note: Amount of mass removed from both Run 1 and Run 2.
(a) 1 BV = 1.5 ft^3 = 11.22 gal = 42.46771 L
(b) Mass Removed (µg) = average difference in concentration (µg/L) x Volume Treated (BV) x 42.4677 (L/BV)
(c) Column did not reach capacity before end of evaluation.
Media in each column = 33,660,400 mg based on a bulk density of 51 lb/ft^3 and a moisture content of 3%.