

**Arsenic Removal from Drinking Water by Adsorptive Media
U.S. EPA Demonstration Project at
Woodstock Middle School in Woodstock, CT
Final Performance Evaluation Report**

by

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ABSTRACT

This report documents the activities performed for and the results obtained from the arsenic removal treatment technology demonstration project at the Woodstock Middle School in Woodstock, CT. The objectives of the project were to evaluate the effectiveness of Adsorbsia™ GTO™ media in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 µg/L. Additionally, this project evaluated (1) the reliability of the treatment system, (2) the required system operation and maintenance (O&M) and operator skill levels, and (3) the capital and O&M cost of the technology. The project also characterized the water in the distribution system and process residuals produced by the treatment process.

The 20 gal/min (gpm) arsenic treatment system consisted of two 24-in × 72-in lead/lag vessels. Rather than the design quantity of 7.5 ft³, each vessel was loaded with 7.0 ft³ of Adsorbsia™ GTO™ media, a titanium oxide-based adsorptive media developed by Dow chemical Company for arsenic removal. Operation of the system began on February 10, 2009, but logging of operational data did not begin until March 10, 2009. The types of data collected included those for system operation, water quality (both across the treatment train and in the distribution system), process residuals, and capital and O&M cost.

Through the performance evaluation study period from March 10, 2009, through September 30, 2010, the system treated approximately 544,600 gal of water supplied by two wells (No. 1 and No. 2). Daily run times averaged 1.0 hr/day. Based on two flow meters installed at the inlet to the adsorption vessels, system flowrates ranged from 14.7 to 16.9 gpm and averaged 16.4 gpm, equivalent to an average empty bed contact time (EBCT) of 3.2 min and an average hydraulic loading rate of 5.2 gpm/ft². The design EBCT and hydraulic loading rate were 2.8 min and 6.4 gpm/ft², respectively.

Arsenic concentrations in raw water ranged from 17.9 to 29.3 µg/L and averaged 24.7 µg/L. Soluble As(V) was the predominating arsenic species, with concentrations ranging from 15.5 to 22.4 µg/L and averaging 19.6 µg/L. Both soluble As(V) and soluble As(III) were removed by Adsorbsia™ GTO™ media, but breakthrough at 10 µg/L from the lead vessel occurred rather early at 7,600 bed volumes (BV). BV was calculated based on 7.0 ft³ of media in the lead vessel. No plausible reason is offered to explain the short run length.

Comparison of the distribution system sampling results before and after the system startup showed a significant decrease in arsenic concentration from an average of 23.1 to 2.3 µg/L. The arsenic concentrations in the distribution system were either similar to or somewhat higher than those in the system effluent. Neither lead nor copper concentrations were affected by the operation of the system.

The capital investment cost for the system was \$51,895, including \$30,215 for equipment, \$10,110 for site engineering, and \$11,570 for installation. Using the system's rated capacity of 20 gpm (28,800 gal/day [gpd]), the normalized capital cost was \$2,594.75/gpm (\$1.80/gpd). The O&M cost included the cost for media replacement and disposal and labor. A cost curve was created to project the cost for media replacement and disposal based on the media run length experienced during an adsorption run.

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ABBREVIATIONS AND ACRONYMS

Δp	differential pressure
AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
As	arsenic
ATS	Aquatic Treatment Systems
bgs	below ground surface
BV	bed volume
Ca	calcium
Cl	chloride
C/F	coagulation/filtration
CRF	capital recovery factor
DO	dissolved oxygen
DEP	Department of Environmental Protection
DPH	Department of Public Health
EBCT	empty bed contact time
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
GFH	granular ferric hydroxide
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
HIX	hybrid ion exchanger
hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IR	iron removal
IX	ion exchange
LCR	Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MEI	Magnesium Elektron, Inc.
Mg	magnesium
Mn	manganese
mV	millivolts

ABBREVIATIONS AND ACRONYMS (Continued)

Na	sodium
NA	not analyzed
NaOCl	sodium hypochlorite
NRMRL	National Risk Management Research Laboratory
NS	not sampled
NSF	NSF International
NTU	nephelometric turbidity unit
O&M	operation and maintenance
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
P&ID	pipng and instrumentation diagram
PO ₄	orthophosphate
PLC	programmable logic controller
POU	point-of-use
psi	pounds per square inch
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RFP	Request for Proposal
RO	reverse osmosis
RPD	relative percent difference
Sb	antimony
SDWA	Safe Drinking Water Act
SiO ₂	silica
SMCL	secondary maximum contaminant level
SO ₄ ²⁻	sulfate
SOC	synthetic organic compound
STS	Severn Trent Services
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids

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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 text on March 25, 2003, to express the MCL as 0.010 mg/L (10 µg/L) (EPA, 2003). The final rule required all community and non-transient, non-community water systems to comply with the new standard by January 23, 2006.

In October 2001, EPA announced an initiative for additional research and development of cost-effective technologies to help small community water systems (<10,000 customers) meet the new arsenic standard, and to provide technical assistance to operators of small systems 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 that were partially funded with Congressional add-on funding to the EPA budget. In June 2003, EPA selected 32 potential demonstration sites. 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.

With additional funding from Congress, EPA selected 10 more sites for demonstration under Round 2a. Somewhat different from the Round 1 and Round 2 selection process, Battelle, under EPA's guidance, issued a Request for Proposal (RFP) on February 14, 2007, to solicit technology proposals from vendors and engineering firms. Upon closing of the RFP on April 13, 2007, Battelle received from 14 vendors a total of 44 proposals, which were reviewed by a three-expert technical review panel convened at EPA on May 2 and 3, 2007. Copies of the proposals and recommendations of the review panel were later

provided to and discussed with representatives of the 10 host sites and state regulators in a technology selection meeting held at each host site during April through August 2007. The final selections of the treatment technology were made, again, through a joint effort by EPA, the respective state regulators, and the host sites. A 20-gal/min (gpm) Adsorbsia™ GTO™ adsorptive media system fabricated by Siemens was selected for demonstration at Woodstock Middle School in Woodstock, CT.

As of May 2011, all 50 systems were operational and the performance evaluations of 49 systems were completed.

1.2 Treatment Technologies for Arsenic Removal

Technologies selected for Rounds 1, 2, and 2a demonstration included adsorptive media (AM), iron removal (IR), coagulation/filtration (C/F), ion exchange (IX), reverse osmosis (RO), point-of-use (POU) RO, and system/process modification. Table 1-1 summarizes the locations, technologies, vendors, system flowrates, and key source water quality parameters (including As, iron [Fe], and pH). Table 1-2 presents the number of sites for each technology. AM technology was demonstrated at 30 sites, including four with IR pretreatment. IR technology was demonstrated at 12 sites, including four with supplemental iron addition. C/F, IX, and RO technologies were demonstrated at three, two, and one sites, respectively. The Sunset Ranch Development site that demonstrated POU RO technology had nine under-the-sink RO units. The Oregon Institute of Technology (OIT) site classified under AM had three AM systems and eight POU AM units. The Lidgerwood site encompassed only system/process modifications. An overview of the technology selection and system design for the 12 Round 1 demonstration sites and the associated capital costs is provided in two EPA reports (Wang et al., 2004; Chen et al., 2004), which are posted on the EPA Web site at <http://www.epa.gov/ORD/NRMRL/arsenic/resource.htm>.

1.3 Project Objectives

The objective of the arsenic demonstration program was to conduct full-scale performance evaluations of treatment technologies for arsenic removal from drinking water supplies. The specific objectives were 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 cost of the technologies.

This report summarizes the performance of the Adsorbsia™ GTO™ AM system at the Woodstock Middle School in Woodstock, CT, from March 10, 2009, through September 30, 2010. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and O&M cost.

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

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH (S.U.)
Northeast/Ohio							
Carmel, ME	Carmel Elementary School	RO	Norlen’s Water	1,200 gpd	21	<25	7.9
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
Houghton, NY ^(c)	Town of Caneadea	IR (Macrolite)	Kinetico	550	27 ^(a)	1,806 ^(d)	7.6
Woodstock, CT	Woodstock Middle School	AM (Adsorbsia)	Siemens	17	21	<25	7.7
Pomfret, CT	Seely-Brown Village	AM (ArsenX ^{np})	SolmeteX	15	25	<25	7.3
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 ^(d)	7.3
Conneaut Lake, PA	Conneaut Lake Park	IR (Greensand Plus) with ID	AdEdge	250	28 ^(a)	157 ^(d)	8.0
Buckeye Lake, OH	Buckeye Lake Head Start Building	AM (ARM 200)	Kinetico	10	15 ^(a)	1,312 ^(d)	7.6
Springfield, OH	Chateau Estates Mobile Home Park	IR & AM (E33)	AdEdge	250 ^(e)	25 ^(a)	1,615 ^(d)	7.3
Great Lakes/Interior Plains							
Brown City, MI	City of Brown City	AM (E33)	STS	640	14 ^(a)	127 ^(d)	7.3
Pentwater, MI	Village of Pentwater	IR (Macrolite) with ID	Kinetico	400	13 ^(a)	466 ^(d)	6.9
Sandusky, MI	City of Sandusky	IR (Aeralater)	Siemens	340 ^(e)	16 ^(a)	1,387 ^(d)	6.9
Delavan, WI	Vintage on the Ponds	IR (Macrolite)	Kinetico	40	20 ^(a)	1,499 ^(d)	7.5
Goshen, IN	Clinton Christian School	IR & AM (E33)	AdEdge	25	29 ^(a)	810 ^(d)	7.4
Fountain City, IN	Northeastern Elementary School	IR (G2)	US Water	60	27 ^(a)	1,547 ^(d)	7.5
Waynesville, IL	Village of Waynesville	IR (Greensand Plus)	Peerless	96	32 ^(a)	2,543 ^(d)	7.1
Geneseo Hills, IL	Geneseo Hills Subdivision	AM (E33)	AdEdge	200	25 ^(a)	248 ^(d)	7.4
Greenville, WI	Town of Greenville	IR (Macrolite)	Kinetico	375	17 ^(a)	7,827 ^(d)	7.3
Climax, MN	City of Climax	IR (Macrolite) with ID	Kinetico	140	39 ^(a)	546 ^(d)	7.4
Sabin, MN	City of Sabin	IR (Macrolite)	Kinetico	250	34 ^(a)	1,470 ^(d)	7.3
Sauk Centre, MN	Big Sauk Lake Mobile Home Park	IR (Macrolite)	Kinetico	20	25 ^(a)	3,078 ^(d)	7.1
Stewart, MN	City of Stewart	IR &AM (E33)	AdEdge	250	42 ^(a)	1,344 ^(d)	7.7
Lidgerwood, ND	City of Lidgerwood	Process Modification	Kinetico	250	146 ^(a)	1,325 ^(d)	7.2
Lead, SD	Terry Trojan Water District	AM (ArsenX ^{np})	SolmeteX	75	24	<25	7.3
Midwest/Southwest							
Willard, UT	Hot Springs Mobile Home Park	IR & AM (Adsorbsia)	Filter Tech	30	15.4 ^(a)	332 ^(d)	7.5
Arnaudville, LA	United Water Systems	IR (Macrolite)	Kinetico	770 ^(e)	35 ^(a)	2,068 ^(d)	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

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

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH (S.U.)
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
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 ^(d)	8.0
Klamath Falls, OR	Oregon Institute of Technology	POE AM (Adsorbisia/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)	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; IR = iron removal; IR with ID = iron removal with iron addition; 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) Selected originally to replace Village of Lyman, NE site, which withdrew from program in June 2006; withdrew from program in 2007 and replace with a home system in Lewisburg, OH.

(d) Iron existing mostly as Fe(II).

(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.

Table 1-2. Number of Demonstration Sites Under Each Arsenic Removal Technology

Technologies	Number of Sites
Adsorptive Media ^(a)	26
Adsorptive Media with Iron Removal Pretreatment	4
Iron Removal (Oxidation/Filtration)	8
Iron Removal with Supplemental Iron Addition	4
Coagulation/Filtration	3
Ion Exchange	2
Reverse Osmosis	1
Point-of-use Reverse Osmosis ^(b)	1
System/Process Modifications	1

(a) OIT site at Klamath Falls, OR had three AM systems and eight POU AM units.

(b) Including nine under-the-sink RO units.

2.0 SUMMARY AND CONCLUSIONS

Based on the information collected during the 19 months of system operation, the following conclusions were made relating to the overall objectives of the treatment technology demonstration study.

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

- Adsorbsia™ GTO™ media was capable of removing both As(III) and As(V) from source water. However, its run length was short; arsenic concentrations in the lead vessel effluent reached 10 µg/L after treating only 395,000 gal (or 7,600 bed volumes [BV]) of water (BV was calculated based on 7 ft³ [or 52 gal] of media in the lead vessel). The cause of the short run length was unknown.
- Initial backwash was effective in removing media fines, reducing differential pressure (Δp) across the adsorption vessels to below 7.9 lb/in² (psi) (on average). Twenty-five BV, as recommended by the vendor, was needed to thoroughly backwash the media. Little or no increase in pressure differential was observed across the adsorption vessels throughout the study period.
- Although set for every 99 days, backwash appeared to occur randomly from every seven to every 77 days through most of the study period.
- Arsenic concentrations in distribution system water were significantly reduced from the baseline level of 23.1 µg/L [on average] to ≤ 3.5 µg/L after system startup. System operation did not appear to have an effect on lead and copper levels in the distribution system.

Required system O&M and operator skill levels:

- The daily demand on the operator was typically 20 min to visually inspect the system and record operational parameters. No other special skill was required to operate the system.

Process residuals produced by the technology:

- The only residual produced by system operation was backwash wastewater, which contained little or no solids.
- Under normal operating conditions, the amount of wastewater produced per backwash event was 540 to 660 gal, which brackets the design value of 600 gal.

Capital and O&M cost of the technology:

- The annualized unit capital cost was \$0.47/1,000 gal of water treated if the system operated at a 100% utilization rate. At an actual use rate of 349,000 gal per year, the unit cost increased to \$14.03/1,000 gal of water treated.
- The O&M cost per 1,000 gal of water treated was relatively high at \$4.77 for labor plus the media replacement and disposal cost.

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 Adsorbsia™ GTO™ arsenic removal system began on March 10, 2009, and ended on September 30, 2010. Table 3-2 summarizes 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, as described in the Study Plan (Battelle, 2008). The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement. The plant operator recorded unscheduled downtime and repair information on a Repair and Maintenance Log Sheet.

Table 3-1. Predemonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	December 15, 2006
Technology Selection Meeting Held	June 12, 2007
Project Planning Meeting Held	July 23, 2007
Draft Letter of Understanding Issued	July 30, 2007
Final Letter of Understanding Issued	August 10, 2007
Discharge Permit Obtained	September 28, 2007
Request for Quotation Issued to Vendor	November 8, 2007
Revised Vendor Quotation Received by Battelle	March 18, 2008
Purchase Order Completed and Signed	April 11, 2008
Engineering Package Submitted to CT DPH	October 29, 2008
Permit Issued by CT DPH	December 9, 2008
Equipment Arrived at Site	January 6, 2009
Final Study Plan Issued	January 26, 2009
System Installation and Shakedown Completed	January 28, 2009
System Operation Begun	February 10, 2009
Performance Evaluation Study Begun	March 10, 2009

DPH = Department of Public Health

The O&M and operator skill requirements were evaluated based on a combination of quantitative data and qualitative considerations, including the need for pre- and/or post-treatment, level of system automation, extent of preventative 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 quantity of aqueous and solid residuals generated was estimated by tracking the volume of backwash wastewater produced during each backwash cycle. Backwash water and solids were sampled and analyzed for chemical characteristics.

The cost of the system was evaluated based on the capital cost per gal/min (or gal/day [gpd]) of design capacity and the O&M cost per 1,000 gal of water treated. This task required tracking the capital cost for equipment, engineering, and installation, as well as the O&M cost for media replacement and disposal, chemical supply, electrical usage, and labor.

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 encountered, materials and supplies needed, and associated labor and cost incurred
System O&M and Operator Skill Requirements	–Pre- and post-treatment requirements –Level of 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 –General knowledge needed for relevant chemical processes and health and safety practices
Residual Management	–Quantity and characteristics of aqueous and solid residuals generated by system operation
Cost-Effectiveness	–Capital cost for equipment, engineering, and installation –O&M cost for chemical usage, electricity consumption, and labor

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 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 and conducted visual inspections to ensure normal system operations. If any problems occurred, the plant operator contacted the Battelle Study Lead, who determined if the vendor should be contacted for troubleshooting. The plant operator recorded all relevant information, including the problems encountered, course of actions taken, materials and supplies used, and associated cost and labor incurred on the Repair and Maintenance Log Sheet. The plant operator also measured temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and recorded the data on an Onsite Water Quality Parameters Log Sheet.

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

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected at the wellheads, across the treatment plant, during oxidation/filtration vessel backwash, and from the distribution system. Table 3-3 presents 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, 2007). The procedure for arsenic speciation is described in Appendix A of the QAPP.

Table 3-3. Sampling Schedule and Analytes

Sample Type	Sample Locations ^(a)	No. of Samples	Frequency	Analytes	Sampling Date
Source Water	IN	2 (Wells No. 1 and No. 2)	Once (during initial site visit)	Onsite: pH, temperature, DO, and ORP Offsite: As (III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), Sb (total and soluble), Na, Ca, Mg, V, Cl, F, NO ₃ , NO ₂ , NH ₃ , SO ₄ , SiO ₂ , P, TDS, TOC, turbidity, and alkalinity	12/15/06
Treatment Plant Water	IN, TA, TB	3	Speciation Sampling: Monthly (first week of each four-week cycle) ^(b)	Onsite: pH, temperature, DO, and ORP Offsite: As(III), As(V), As(total and soluble), Fe (total and soluble), Mn (total and soluble), Ti (total and soluble), Ca, Mg, F, NO ₃ , SO ₄ , SiO ₂ , P, turbidity, and alkalinity	03/10/09, 04/07/09, 05/06/09, 06/04/09, 07/02/09, 08/05/09, 08/27/09, 09/22/09, 10/29/09, 12/01/09, 12/30/09, 01/27/10, 02/24/10, 03/25/10, 04/21/10, 05/18/10, 06/15/10, 07/14/10, 08/10/10, 09/14/10, 10/06/10
			Regular Sampling: Monthly (third week of each four-week cycle)	Onsite: pH, temperature, DO, and ORP Offsite: As (total), Fe (total), Mn (total), Ti (total), SiO ₂ , P, turbidity, and alkalinity	03/25/09, 04/21/09, 05/19/09, 06/17/09, 08/13/09, 09/10/09, 10/15/09, 11/10/09, 12/15/09, 01/12/10, 02/09/10, 03/10/10, 04/07/10, 05/06/10, 06/03/10
Distribution Water ^(c)	Kitchen tap in school (DS)	1	Monthly	As (total), Fe (total), Mn (total), Cu, Pb, pH, and alkalinity	05/29/08, 11/14/08, 12/02/08, 01/07/09, 03/25/09, 04/22/09, 05/20/09, 06/16/09, 07/02/09, 08/12/09, 09/10/09, 10/15/09, 11/10/09, 12/15/09, 01/12/10, 02/09/10, 03/10/10, 04/07/10, 05/05/10, 06/02/10

(a) Abbreviations in parenthesis correspond to sample locations shown in Figure 4-5, i.e., IN = at wellhead; TA = after Vessel A; TB = after Vessel B.

(b) Analytes reduced to total and soluble As, Fe, Mn, and Ti during June, July, August, September, and October 2010 sampling events.

(c) Four baseline sampling events taking place in May, November, and December 2008, and January 2009 before system startup.

DO = dissolved oxygen; ORP = oxidation-reduction potential; TDS = total dissolved solids; TOC = total organic carbon; TSS = total suspended solids

3.3.1 Source Water. During the initial site visit on Decemebr 15, 2006, one set each of source water samples from Wells No. 1 and No. 2 were collected and speciated using arsenic speciation kits (see Section 3.4.1). Sample taps were 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.

3.3.2 Treatment Plant Water. During the system performance evaluation study, the plant operator collected water samples across the treatment train once every one to four weeks. In general, sampling alternated between regular and speciation sampling. Regular sampling involved taking samples at the wellhead (IN), after Vessel A (TA), and after Vessel B (TB) and having them analyzed for the analytes listed under “Regular Sampling” in Table 3-3. Speciation sampling involved collecting and speciating samples onsite at the same three locations and having them analyzed for the analytes listed under “Speciation Sampling” in Table 3-3.

During the last five sampling events in June, July, August, September, and October 2010, only total and soluble arsenic, iron, manganese, and titanium were speciated and analyzed.

3.3.3 Backwash Wastewater and Solids. Although the system was backwashed during the evaluation period, no backwash wastewater nor solids were collected because of lack of solids in the wastewater.

3.3.4 Spent Media. The media in the adsorption vessels were not replaced, therefore, no spent media were produced as residual solids during this demonstration study.

3.3.5 Distribution System Water. Water samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically, the arsenic, lead and copper levels. Prior to the system startup from May 29, 2008, to January 7, 2009, four sets of baseline distribution system water samples were collected. The first set of baseline samplers was collected from three locations in the school kitchen, at the nurses sink, and at the staff dining room sink with all locations used by the school for Lead and Copper Rule (LCR) sampling. The additional three sets of baseline samples were taken from the school kitchen. Following system startup, distribution system water sampling continued monthly at the kitchen sink.

The plant operator collected the samples following an instruction sheet developed in accordance with the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The date and time of last water usage before sampling and of actual sample collection were recorded for calculation of 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 soluble arsenic species, As(V) and As(III) (Edwards et al., 1998). Resin columns were prepared in batches at Battelle laboratories in accordance with the procedures detailed in Appendix A of the EPA-endorsed QAPP (Battelle, 2007).

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, color-coded label consisting of 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 a specific water facility, sampling date, a two-letter code for a specific sampling location, and a one-letter code 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 zip-lock 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 offsite 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 analyses were packed in separate coolers and picked up by couriers from American Analytical Laboratories (AAL) in Columbus, OH, which was under contract with Battelle for this demonstration study. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

3.5 Analytical Procedures

The analytical procedures described in detail in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2007) were followed by Battelle's ICP-MS laboratory and AAL. 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 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 VWR Symphony SP90M5 Handheld Multimeter, 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 Symphony SP90M5 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 and Pre-existing Treatment System Infrastructure

The Woodstock Middle School is located at 147A Route 169 in Woodstock, CT. The facility is a non-transient, non-community water system supplied by two wells (i.e., Wells No. 1 and No. 2) to approximately 510 students and staff. Prior to the demonstration study, the average daily production was 1,747 gpd. Wells No. 1 and No. 2 are both 6-in in diameter and 300-ft deep with a static water level at approximately 31 ft below ground surface (bgs). The well pumps are situated at 220 ft bgs. The wellheads are located approximately 200 to 250 ft from the school building and spaced laterally about 20 ft from each other. Each wellhead has its own sample tap located within the basement of the school building (see Figure 4-1). The wells operate simultaneously, producing a pressure of 12 psi to the influent of the pre-existing softening unit. Well No. 1 is equipped with a 1.5-horsepower (hp) submersible pump, which provides a flowrate of 8.1 gpm under field hydraulic head conditions. Well No. 2 is equipped with a 2.0-hp submersible pump, which is rated for a maximum flowrate of 10 gpm, at a total dynamic head of 480 ft of water. Well No. 2 provides a flowrate of 8.9 gpm under the field hydraulic head conditions. A softening unit was installed downstream of the combined wellheads to soften water prior to a 10,000-gal underground storage tank. The school eliminated the use of this softener after installation of the treatment system for the demonstration study.



Figure 4-1. Wellhead Inlet Piping and Raw Water Sample Taps for Wells No. 1 (on right) and No. 2 (on left)

The 10,000-gal underground storage tank is under atmospheric conditions and has an access hatch located in the basement (see Figure 4-2). Three booster pumps are used to supply pressurized water to the school's distribution system (Figure 4-3). The booster pumps are controlled by a control panel with alarm signals and on/off switches. Only one booster pump operates at a time. The site has access to a local sanitary sewer system.



Figure 4-2. 10,000-gal Underground Storage Tank for Water Supply and Softener Unit

4.1.1 Source Water Quality. Source water samples were collected on December 15, 2006, when two Battelle staff members traveled to the site to conduct an introductory meeting for this demonstration project. The source water also was filtered for soluble arsenic, iron, manganese, and antimony, and then speciated for As(III) and As(V) using the field speciation method modified by Battelle from Edwards (1998). In addition, pH, temperature, DO, and ORP were measured onsite using a field meter.

Analytical results from the December 15, 2006, source water sampling event are presented in Table 4-1 and compared to the data provided by EPA and the facility. Historical distribution system water quality data also were obtained and are summarized in Table 4-1. Overall, Battelle's data are comparable to those provided by EPA and the facility.

Results of the source water assessment and how it would influence water treatment are discussed briefly below.



Figure 4-3. Booster Pump Skid and Associated Pump Control Panel

Arsenic. Total arsenic concentrations in source water ranged from 20.4 to 25.0 µg/L (see Table 4-1). Based on the December 15, 2006 sampling results obtained by Battelle, arsenic existed almost entirely in the soluble form. Of the 19.7 to 22.1 µg/L of soluble arsenic, 17.7 to 18.2 µg/L existed as As(V) and 1.5 to 4.4 µg/L as As(III). Therefore, As(V) was the predominant species. The presence of As(V) as the predominant species is consistent with the relatively high ORP readings (ranging from 378 to 386 mV) measured with a handheld meter. The DO levels at 0.6 mg/L were lower than expected for oxidizing water. No prior information on arsenic speciation was available from EPA or the facility.

Iron and Manganese. Total iron concentrations in source water were less than the method reporting limit of 25 µg/L by ICP/MS (EPA Method 200.8). Due to the low iron content, the site was an ideal candidate for AM technology, which works best for water with low iron content. Total manganese levels in source water ranged from 15.0 to 18.4 µg/L, which are well below the secondary maximum contaminant level (SMCL) of 50 µg/L for manganese.

Competing Anions. Depending on the technology selected, removal of arsenic potentially can be influenced by competing anions such as silica and phosphate. Based on the results shown in Table 4-1, the concentrations for silica (14.0 to 14.7 mg/L) and total phosphorous (<0.2 mg/L [as PO₄]) in raw water do not appear to be high enough to impact the adsorption process.

Other Water Quality Parameters. Battelle's data indicate a pH range of 7.4 to 8.0, which is within the commonly accepted range of 5.5 to 8.5 for effective arsenic removal using AM. Both total organic carbon (TOC) (<1.0 mg/L) and ammonia (<0.05 mg/L) levels are less than their respective

Table 4-1. Raw and Treated Water Quality Data at Woodstock Middle School

Parameter	Unit	EPA Data				Battelle Data		Facility Data
		Well No. 1 Raw	Well No. 2 Raw	After Softening	Office after Softening	Well No. 1 Raw	Well No. 2 Raw	Distribution ^(a)
Date		05/03/06				12/15/06		03/25/04–09/27/05
pH	S.U.	NA	NA	NA	NA	7.4	8.0	7.9–8.4 [8.3]
Temperature	°C	NA	NA	NA	NA	12.3	11.7	NA
DO	mg/L	NA	NA	NA	NA	0.6	0.6	NA
ORP	mV	NA	NA	NA	NA	378	386	NA
Total Alkalinity (as CaCO ₃)	mg/L	70.7	71.0	72.2	71.8	90.0	78.0	NA
Total Hardness (as CaCO ₃)	mg/L	77.8	75.1	9.9	7.0	86.2	80.4	NA
Turbidity	NTU	NA	NA	NA	NA	0.3	0.5	0.4–6.0 [3.2]
TDS	mg/L	NA	NA	NA	NA	112	132	NA
TOC	mg/L	NA	NA	NA	NA	<1.0	<1.0	NA
Nitrate (as N)	mg/L	<0.02	<0.02	<0.02	<0.02	<0.05	<0.05	<0.10
Nitrite (as N)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.05	<0.05	<0.010
Ammonia (as N)	mg/L	<0.03	<0.03	<0.03	<0.03	<0.05	<0.05	NA
Chloride	mg/L	NA	NA	NA	NA	7	7	7.9–14 [10]
Fluoride	mg/L	NA	NA	NA	NA	0.3	0.3	0.38
Sulfate	mg/L	23.4	22.6	23.8	22.1	19.0	20.0	21–28 [25]
Silica (as SiO ₂)	mg/L	14.7	14.4	13.9	13.7	14.5	14.0	NA
Total P (as PO ₄)	mg/L	<0.2	<0.2	<0.2	<0.2	<0.02	<0.02	NA
Al (total)	µg/L	<25	<25	<25	<25	NA	NA	NA
As (total)	µg/L	24	25	21	21	20.4	22.4	20
As (soluble)	µg/L	NA	NA	NA	NA	19.7	22.1	NA
As (particulate)	µg/L	NA	NA	NA	NA	0.7	0.3	NA
As(III)	µg/L	NA	NA	NA	NA	1.5	4.4	NA
As(V)	µg/L	NA	NA	NA	NA	18.2	17.7	NA
Fe (total)	µg/L	24	12	85	97	<25	<25	ND–71 [40]
Fe (soluble)	µg/L	NA	NA	NA	NA	<25	<25	NA
Mn (total)	µg/L	15.0	16.0	5.0	4.0	16.1	18.4	ND–26 [0.01]
Mn (soluble)	µg/L	NA	NA	NA	NA	15.8	18.4	NA
Sb (total)	µg/L	<25	<25	<25	<25	<0.1	0.2	NA
Sb (soluble)	µg/L	NA	NA	NA	NA	<0.1	<0.1	NA
V (total)	µg/L	NA	NA	NA	NA	0.3	<0.1	NA
Na (total)	mg/L	9.9	9.5	3.9	4.0	11.0	10.0	2.0–9.4 [5.8]
Ca (total)	mg/L	29.1	28.1	3.7	2.6	32.2	30.0	NA
Mg (total)	mg/L	1.3	1.2	0.2	0.1	1.4	1.3	NA
Cu (total)	Mg/L	NA	NA	NA	NA	NA	NA	0.052–0.16 [0.086]
Pb (total)	Mg/L	NA	NA	NA	NA	NA	NA	ND–0.060 [<0.015]

(a) minimum–maximum [average]

DO = dissolved oxygen; NA = not available; ORP = oxidation-reduction potential; TDS = total dissolved solids; TOC = total organic carbon

reporting limits. Total hardness concentrations ranged from 75.1 to 86.2 mg/L (as CaCO₃) and the total alkalinity values from 70.7 to 90.0 mg/L (as CaCO₃). Turbidity readings ranged from 0.3 to 0.5 nephelometric turbidity units (NTU) in Battelle's source water samples for Wells No. 1 and 2. However, the facility reported historic turbidity results up to 6 NTU in the treated water. Although not applicable to groundwater sources unless under the influence of surface water, the facility reported this value as exceeding the treatment technique standard of 1 NTU or 0.3 NTU in 95% of daily samples in any month. The facility also reported that the color of the water at 30 color units had historically exceeded the SMCL of 15 mg/L. All other analytes were below detection limits and/or anticipated to be low enough not to adversely affect the arsenic removal process.

4.1.2 Predemonstration Treated Water Quality. The existing treatment process at the Woodstock Middle School was a water softening unit. The water quality after softening and in the distribution system is shown in Table 4-1. Water quality analysis after softening showed that water hardness decreased from 75.1–77.8 to 7.0–9.9 mg/L (as CaCO₃). Other ions that decreased significantly in concentration after the water softening unit were manganese, sodium, calcium and magnesium (see Table 4-1). Arsenic concentrations decreased slightly from 24–25 to 21 µg/L, but iron concentrations increased from 12–24 to 85–97 µg/L.

4.1.3 Distribution System. The distribution system within the building consists primarily of copper piping. One location within the school was selected for monthly baseline and distribution system water sampling to evaluate the impact of the treatment system on the distribution system water quality. The location was selected from among the 10 LCR locations currently used by the school.

Compliance sampling for the entry point includes nitrate and nitrite (once every year); organic chemicals (once every year); pesticides, herbicides, and polychlorinated biphenyls (PCBs) (once every three years); and inorganic chemicals (once every three years). Compliance samples for the distribution system include total coliform (once every quarter); physical parameters (once every quarter); lead and copper (once every three years); and asbestos (once every nine years).

The operator for the Woodstock Middle School is required to be a Water Treatment Plant Class I Operator. The following requirements must be met: (1) pass the examination administered by CT DPH, (2) hold a high school diploma or high school equivalency diploma, and (3) one year of experience in operation of Class I or higher treatment plant(s).

4.2 Treatment Process Description

This section provides a general technology description and site-specific details on the Adsorbsia™ GTO™ arsenic removal system installed at the school.

4.2.1 Technology Description. Adsorbsia™ GTO™ is a white, free flowing granular, titanium oxide-based media manufactured by the Dow Chemical Company. The media can adsorb both soluble As(III) and soluble As(V), but has a higher capacity for soluble As(V). Adsorption occurs in a pH range of 5.5 to 8.5, but is less effective at the upper end of the range. According to the vendor, its adsorptive capacity for arsenic is independent of anions such as sulfate, phosphate, and vanadium, but not silica. The media is NSF International (NSF)-certified and is not regenerable. Based on the tests performed internally by Dow Chemical, spent media can pass the EPA's Toxicity Characteristic Leaching Procedure (TCLP) test. Table 4-2 summarizes key physical and chemical property of the media.

4.2.2 System Design and Treatment Process. The arsenic removal system at the Woodstock Middle School consists of a 3/4 hp booster pump, a 5-µm cartridge filter, and two adsorption vessels configured in series. Table 4-3 specifies key system design parameters. Figure 4-4 shows a system schematic of the treatment system. Figure 4-5 presents a process flowchart, along with planned sampling/analytical schedules. Key process steps are discussed below:

- **Intake** – Raw water from Wells No. 1 and No. 2 at an average flowrate of 8.1 and 8.9 gpm, respectively, was boosted with a ¾-hp booster pump (Grundfos Model No. CRN5-2) to reach an inlet pressure of approximately 25 psi (Figure 4-6). The well pumps and booster pump were controlled by a set of high/low level sensors in the 10,000-gal atmospheric storage tank. (Note that the booster pump was bypassed soon after system startup and that a pressure transducer was installed at the far end of the treatment system just before the atmospheric storage tank to provide back pressure.)

Table 4-2. Properties of Adsorbsia™ GTO™ Media

Property	Value/Description
Physical Property	
Color	White
Matrix	Nanocrystalline titanium oxide
Physical Form	Dry granular media
Bulk Density (g/cm ³)	0.71
Bulk Density (lb/ft ³)	44
Specific Surface Area (m ² /g)	200–300
Pore Volume (mL/g)	0.20–0.25
Moisture Content (%)	<15 (by weight)
Particle Size (U.S. Standard)	10 × 60 mesh
Chemical Property	
Active Ingredient	Titanium dioxide
Constituents	
Titanium Dioxide (%)	89.0–99.0
Binder (%)	1.0–10.0
Metal Oxide (%)	0.01–1.0
pH Range	4 to 9

Table 4-3. Design Features of Adsorbsia™ GTO™ Adsorption System

Parameter	Value	Remarks
Influent Specifications		
Total Arsenic Concentration (µg/L)	20.4 to 25	Based on source water samples taken on 05/03/06 to 12/15/06
Total Iron Concentration (µg/L)	<25	–
Adsorption		
No. of Vessels	2	–
Configuration	Series	–
Vessel Size (in)	24 D × 72 H	–
Vessel Cross Section (ft ² /vessel)	3.14	–
Media Volume (ft ³ /vessel)	7.5	–
Media Depth (in)	29	–
Peak Flowrate (gpm)	20	–
Hydraulic Loading Rate (gpm/ft ²)	6.4	Based on 20 gpm flowrate
EBCT (min/vessel)	2.8	Based 7.5 ft ³ of media and 20 gpm flowrate
Differential Pressure Across System (psi)	15	Across two vessels in series (clean beds)
Backwash/Fast Rinse Flowrate (gpm)	20	
Backwash Hydraulic Loading (gpm/ft ²)	6.4	
Backwash/Fast Rinse Duration (min/vessel)	10/5	
Backwash Wastewater Generated (gal/vessel)	300	
Design Backwash Frequency (time/month)	NA	To be determined onsite
Maximum Daily Production (gpd)	28,800	Based on peak flowrate and 24 hr/day run time
Estimated Daily Production (gpd)	9,600	Based on 8 hr/day run time; much higher than reported daily average of 1,747 gpd
Hydraulic Utilization (%)	6–33	Based on 1,747 (reported average) to 9,600 gpd (design estimate)
Projected Media Run Length to 10-µg/L As Breakthrough from Lead Vessel (BV)	108,000	Vendor Estimate
Throughput to 10-µg/L As Breakthrough (gal)	6,048,000	1 BV = 7.5 ft ³ = 56 gal
Projected Media Life (month)	21	Based on 9,600-gpd production
Effluent Specifications		
Total Arsenic Concentration (µg/L)	<10	–
Total Iron Concentration (µg/L)	<25	–

Figure 4-4. Schematic of Siemens's Adsorbisia™ GTO™ Arsenic Removal System at Woodstock Middle School

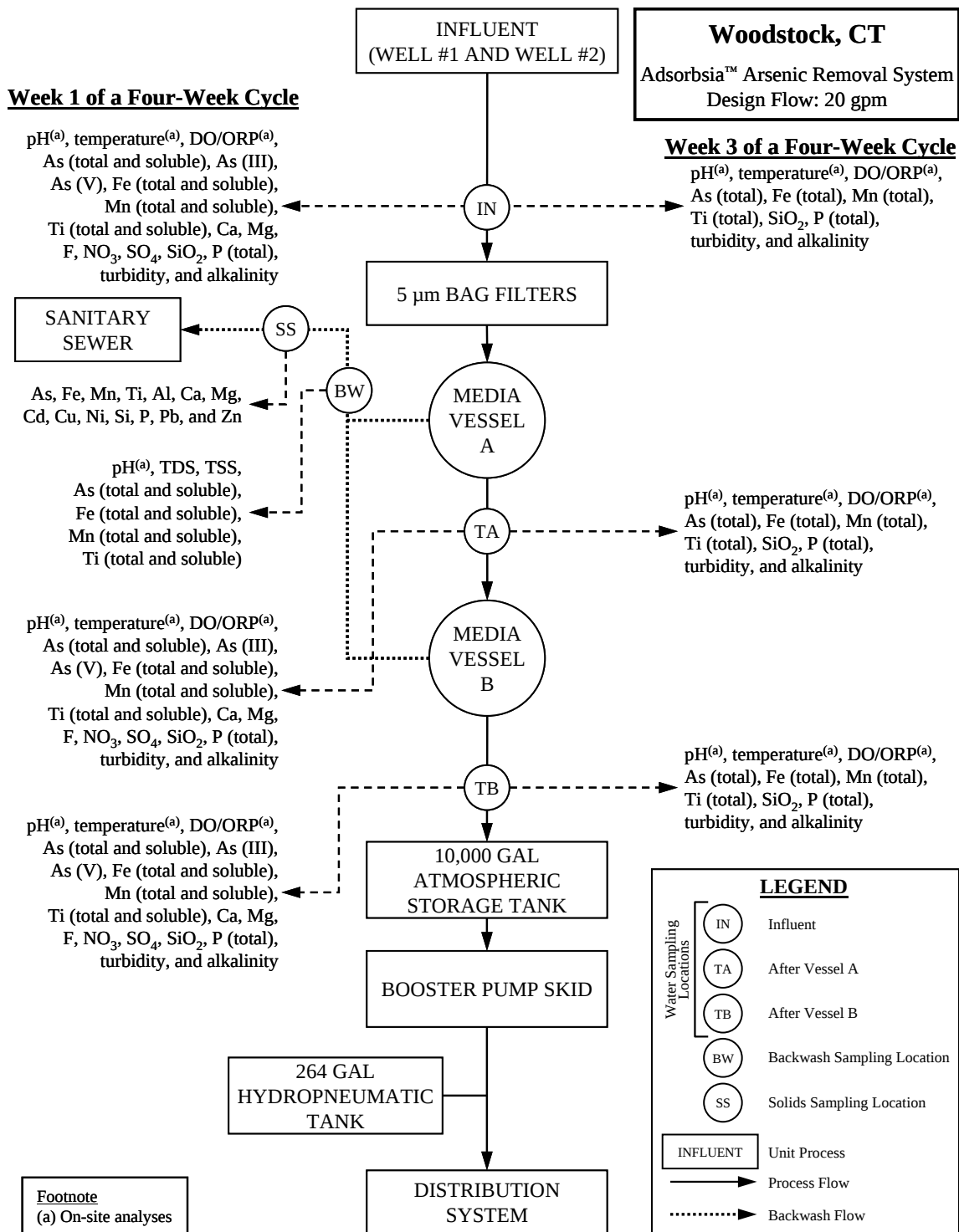


Figure 4-5. Process Flow Diagram and Planned Sampling/Analytical Schedules

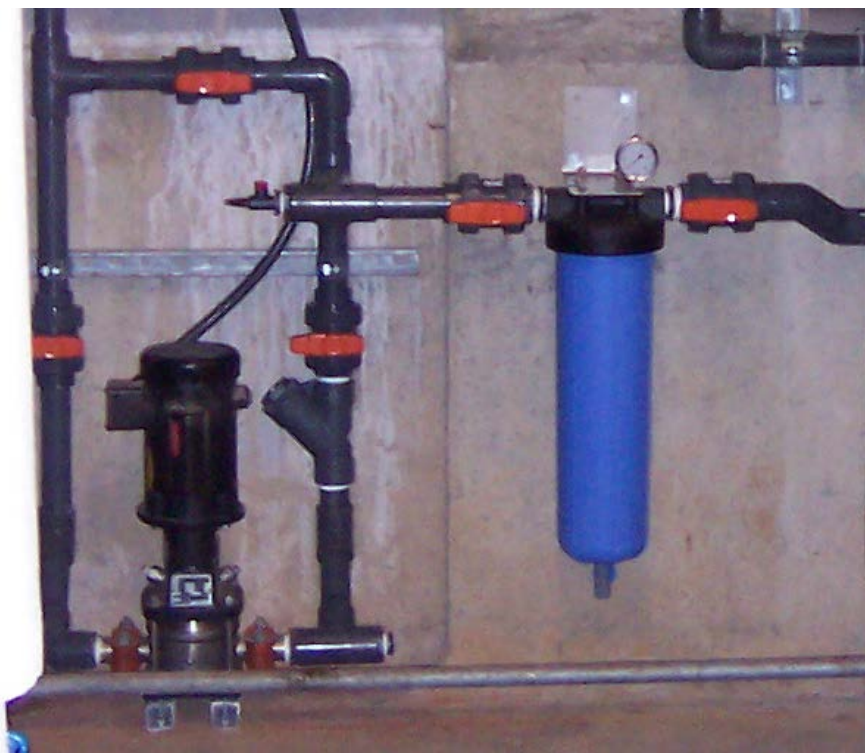


Figure 4-6. Booster Pump and Bag Filter Assembly

- **Pre-filter** – Prior to the treatment system, raw water from the wells passed through a 5- μm bag filter (Figure 4-6) to remove sediments and/or particles. The filter bag was not changed for the duration of the demonstration because the pressure drop across the cartridge never reached 10 psi.
- **Adsorption** – The adsorption system consisted of two 24-in $\times$ 72-in adsorption vessels in a series (lead/lag) configuration (Figures 4-7 and 4-8). Each vessel was designed to contain 7.5 ft^3 of Adsorbsia™ GTO™ media supported by 3.0 ft^3 of gravel underbedding (only 7.0 ft^3 of media was actually loaded). The vessels were of composite polyethylene and fiberglass construction.

Based on a design flowrate of 20 gpm, the empty bed contact time (EBCT) was 2.8 min for each vessel or 5.6 for the lead/lag system. The Δp across a clean lead/lag system was 15 psi.

- **Backwash** – The backwash frequency was determined based on the rate of differential pressure buildup across the adsorption vessels. The design backwash flowrate was 20 gpm and the design backwash duration was 10 min. The backwash step was followed with a 4-min settling period and a 5-min fast rinse at a flowrate of 20 gpm. The total amount of wastewater produced was 300 gal per vessel, or 600 gal for the lead/lag system.
- **Media Replacement** – Adsorbsia™ GTO™ media is not regenerable and must be disposed of after it is exhausted. Spent media can be disposed of as a non-hazardous waste after it passes the EPA TCLP test. The media was expected to last for 21 months and, therefore, not be disposed of during the study period.



Figure 4-7. Adsorption Vessels

- **Treated Water Storage and Distribution** – The treated water was sent to the 10,000-gal atmospheric storage tank. A booster pump skid equipped with three Alyan pumps (Model #CPS12065) was used to provide pressure to the distribution system. Pump No. 1 is rated at 5 hp [224 ft of H₂O], pump No. 2 at 10 hp [150 of H₂O], and pump No. 3 at 10 hp [150 of H₂O]). The booster pump skid was connected to a 264-gal hydropneumatic tank, which turned the well pumps on/off based on a low pressure of 90 psi and a high pressure of 100 psi.

4.3 System Installation

Siemens completed installation and shakedown of the system on January 28, 2009. The following briefly summarizes system installation activities, including permitting, system offloading, installation, shakedown, and startup.

4.3.1 Permitting. Design drawings and a process description of the proposed treatment system were submitted to CT DPH by TurnKey Compliance Solution, LLC, a subcontractor to Siemens, on October 29, 2008. CT DPH provided comments/concerns on December 3, 2008. The comments received were:



Figure 4-8. Adsorption System Valve Tree and Piping Configuration

- (1) It was difficult to read the piping and instrumentation diagram (P&ID).
- (2) The project might be held up due to issues related to discharge of backwash wastewater to the sewer.

In response to the comments, TurnKey Compliance Solution provided a clearer copy of the P&ID to CT DPH and informed CT DPH that the school had already received a wastewater discharge permit from CT Department of Environmental Protection (DEP) on September 28, 2007. The permit was issued on December 9, 2008.

Upon receipt of the permit, it was noted that the site owner had to complete an Operator Verification Form and a Certificate of Completion Form once the system was installed. These forms were submitted to CT DPH on January 9, 2009.

4.3.2 Installation, Shakedown, and Startup. System components were delivered to the Woodstock Middle School on January 6, 2009. Installation activities included offloading, staging (see Figure 4-9), plumbing (from the adsorption vessels to the booster pump and hydropneumatic tanks), and wiring. Due to the delivery of incorrect solenoid valves with the system, installation could not be completed until the correct ones were received, which occurred on January 19, 2009. The final installation and wiring were completed on January 21, 2009.



Figure 4-9. Offloading and Staging of Equipment

On January 21, 2009, Siemens inspected the system (see Figure 4-10) and associated piping connections, verified electrical wiring and relays, and performed hydraulic testing before media loading. Upon completion, 7.0 ft³ (instead of 7.5 ft³) of media was loaded into each vessel with approximately 34 in of freeboard above the media beds. Freeboards after gravel loading was not measured. After control heads were reinstalled, the system was re-pressurized and the adsorption vessels were backwashed individually at a maximum flowrate of 10 gpm for 20 min (see more detailed discussion about backwash in Section 4.4.2). Afterwards, the control heads were removed to re-measure the freeboards, which remained at 34 in. Sodium hypochlorite (NaOCl) was added to the adsorption vessels on the evening of January 27, 2009, and the system was thoroughly flushed the next day. Samples taken showed negative results for bacteria.



Figure 4-10. Treatment System Installed
(From left to right: Booster Pump, Bag Filter, Adsorption Vessel A, and Adsorption Vessel B. One Hydropneumatic tank and one 10,000 gal Storage Tank not Shown)

The system remained offline until the arsenic treatment system was inspected by CT DPH on January 29, 2009, and a project completion letter to allow the system to be started was received by the school on February 3, 2009. The system became operational on February 10, 2009.

After startup, it was realized that the system was not operating against enough back pressure so it was shut down on February 11, 2009, to facilitate installation of a pressure transducer before the atmospheric tank. A decision was then made to create the needed back pressure by throttling a ball valve before the atmospheric tank and the system was turned on again on February 12, 2009. (The pressure transducer was eventually installed on March 25, 2009.) During hydraulic testing, the inlet pressure to the system was 10 psi; after the booster pump and with the valve throttled, the inlet pressure was 34 psi.

During installation, the system was set to backwash weekly at a flow rate of 10 gpm. The frequency was later changed to once every 30 days on February 17, 2009, per Battelle's request.

On February 27, 2009, the operator noticed that readings on the totalizers at the wellheads were decreasing instead of advancing; however, this problem did not occur again. It also was observed that only one well pump was operating and with the booster pump in operation the flowrate to the system was

a mere 9 gpm instead of the designed value of 20 gpm. Previously with both well pumps operating and the booster pump turned on, the flowrate to the system was about 20 gpm.

On March 9 and 10, 2009, two Battelle staff members visited the school to inspect the system and provide operator training. Table 4-4 summarizes the punch-list items and corrective actions taken. The Battelle staff members observed that the arsenic treatment system was configured in parallel although the engineering drawing showed that the system should be configured in series as requested by CT DPH. On March 25 through 27, 2009, Siemens visited the school to correct the system configuration and several other punch-list items listed in Table 4-4.

Table 4-4. Punch-List Items and Corrective Actions

Date	Issue/Problem Encountered	Corrective Action	Work Performed By
03/09/09–03/25/09	System configured for parallel operation instead of series operation	System re-configured for series operation by opening/closing selected valves	Siemens
02/27/09–03/24/09	Pressure reducing valve (PRV) not installed per Siemens' design	PRV installed to provide extra protection to the system piping	Siemens
03/09/09–03/24/09	Pressure switch to trigger booster pump not installed per Siemens' design	Pressure switch installed to trigger booster pump at pressure <60 psi	Siemens
03/09/09–04/17/09	Pressure to booster pump lower than vendor-recommended range of 12 to 15 psi	¾-in flowmeter/totalizer and associated piping after each well pump replaced with 1.5-in and/or 1-in flowmeter/totalizer and piping to minimize pressure loss (this corrective action eventually not done)	Woodstock Middle School
03/09/09–03/27/09	Pressure gauge at inlet incorrect size (0-100 psi)	Inlet pressure gauge replaced with a 0-60 psi gauge	Siemens
03/09/09–03/27/09	Pressure gauge missing on outlet line leading to atmospheric storage tank	A 0-30 psi pressure gauge installed on outlet line	Siemens
03/09/09–03/24/09	Incorrect sample taps (4) installed on treatment system	All four sample taps replaced with ¼-in valve with a barb fitting	Siemens
03/09/09–03/24/09	Leaks observed at T-joint at distribution booster pump	Leaky T-joint replaced with a new T-joint	Siemens
03/09/09–04/17/09	Backwash flowrate lower than vendor- recommended flowrate of 20 gpm	Supply line relocated from 264-gal hydropneumatic tank to 10,000-gal storage tanking using a 1-in line	Woodstock Middle School
03/09/09–03/24/09	Backwash missing a co-current fast rinse step	A fast rinse duration of 5 min at 20 gpm added into programming of valve controller	Siemens
03/09/09–03/24/09	Duration between backwash events too short	Backwash frequency changed from every 7 days to every 30 days in late February 2009, then to every 99 days to allow better control over backwashing by operator	Siemens

As noted in Section 4.3.3, a booster pump was installed between the well pumps and the adsorption vessels to provide sufficient pressure for system operation. During Battelle's site visit on March 9, 2009, the booster pump was bypassed because the pressure transducer required to create back pressure had not been installed. Several tests were conducted on the system with and without bypassing the booster pump.

The pressure at the wellhead was 20 psi, but once the booster pump was turned on, the pressure at the wellhead decreased to zero. Both with and without bypassing, the pressure after the booster pump was 10 psi. Siemens determined that a pressure loss at the inlet to the booster pump had occurred due to the small size of the piping that fed into the booster pump. The piping from the well pumps was 1.5 and 1 in, but the combined flow piping was reduced to ¾ in. This reduced size apparently caused restriction and had to be changed to 1.5 in to ensure proper functioning of the booster pump. This change, however, was never made and the booster pump remained bypassed for the entire demonstration study.

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters for the 19-month demonstration study were tabulated and are attached as Appendix A. Table 4-5 summarizes key parameters. The system began to operate on February 10, 2009, but logging of operational data did not begin until March 10, 2009 when two Battelle staff members visited the site to inspect the system and provide operator training. During the first month of operation, the system was turned off for just one day on February 11, 2009, for installation of a pressure transducer on the far side of the treatment system (before the atmospheric tank) to create sufficient back pressure on the system. The system, however, was restarted on February 12 without the transducer and a valve at the end of the system was throttled to create the needed back pressure. The pressure transducer was eventually installed on March 25, 2009.

From March 10, 2009, through the end of the performance evaluation study on September 30, 2010, Wells No. 1 and No. 2 operated for a total of 560.9 and 562.7 hr, respectively. The total number of days the system was operating, regardless whether the school was in session or out of session, was 570 days. Therefore, the average daily system run time was about 1 hr/day (note that Wells No. 1 and No. 2 operated simultaneously).

Based on readings from the totalizers installed at the wellheads, Wells No. 1 and No. 2 produced 259,850 and 284,760 gal of water, respectively, during the entire study period. The amount of water produced by Well No. 2 was slightly higher (9.6%) than that by Well No. 1. This was reflected by the slightly higher flowrate of Well No. 2, i.e., 8.9 vs. 8.1 gpm as noted in Section 4.1.

The total amount of water produced by Wells No. 1 and No. 2 was 544,610 gal, which is comparable to the amounts, i.e., 528,000 and 541,000 gal, registered by the totalizers installed on the influent side of Adsorption Vessels A and B, respectively. These amounts included the 21,000 and 26,000 gal registered by Vessels A and B totalizers, respectively, when the system was configured in parallel. Siemens visited the school on March 25, 2009, to change the system configuration in series.

Well flowrates were calculated by dividing incremental wellhead totalizer readings by respective run times (after removing obvious outliers). The average flowrate from Well No. 1 was 7.1 gpm and the average flowrate from Well No. 2 was 7.7 gpm, compared to the 8.1 and 8.9 gpm reported by the operator prior to the study.

After the flow was combined and boosted, it flowed through Vessels A and then Vessel B before entering the 10,000-gal atmospheric storage tank. Instantaneous flowrate readings tracked by the flow meters installed on the inlet of the vessels were constant, ranging from 15.6 to 16.7 gpm and averaging 16.3 gpm for Vessel A and ranging from 14.7 to 16.9 gpm and averaging 16.4 gpm for Vessel B. These data did not include those before March 25, 2009, when the system was incorrectly configured in parallel or those from May 8 through 13, 2009, when the operator reported extremely low flowrate (e.g. 1.7 gpm) through Vessel A, but normal flow through Vessel B. The lack of flow through Vessel A was due to a defective seal (loose O- ring), which was repaired by Siemens on May 13, 2009. Once the seal was repaired, Siemens tested and backwashed the system.

Table 4-5. Summary of System Operation Parameters

Operational Parameter	Values/Conditions
Duration	03/10/09–09/30/10
Total Operating Time (hr)	560.9 (Well No. 1) 562.7 (Well No. 2)
Total Operating Days (day)	570
Average Daily Run Time (hr/day)	1.0
Individual Well Production (gal)	259,850 (Well No. 1) 284,760 (Well No. 2)
Total Well Production (gal)	544,610
Throughput (gal)	528,000 (Vessel A) 541,000 (Vessel B)
Calculated Well Flowrate (gpm) ^(a)	7.1 [3.0–9.4] (Well No. 1) 7.7 [2.8–10.5] (Well No. 2)
Instantaneous Flowrate (gpm) ^(a,b)	16.3 [15.6–16.7] (Vessel A) 16.4 [14.7–16.9] (Vessel B)
EBCT (min/vessel) ^(c)	3.2 [3.3–3.1] (Vessel A) 3.2 [3.5–3.1] (Vessel B)
Hydraulic Loading Rate (gpm/ft ²)	5.2 [5.0–5.3] (Vessel A) 5.2 [4.7–5.4] (Vessel B)
Pressure at Wellhead (psi)	28.8 [20–36] (Well No. 1) 28.8 [20–36] (Well No. 2)
Pressure After Booster Pump (psi) ^(d)	23.0 [15–32]
Pressure After Filter Cartridge (psi)	21.7 [14–31]
Pressure Prior to Vessel A (psi)	21.2 [13–30]
Pressure After Vessel A (psi)	13.1 [10–23.5]
Pressure After Vessel B (psi)	4.7 [2–11]
Δp Across Vessel A (psi)	8.3 [2–10]
Δp Across Vessel B (psi)	8.4 [1–17.5]

(a) After omitting obvious outliers.

(b) Not including data prior to March 25, 2009, when system was incorrectly configured in parallel.

(c) Based on instantaneous flowrates and 7.0 ft³ (or 52 gal) of media in each vessel.

(d) With booster pump bypassed.

Based on 7.0 ft³ (or 52 gal) of media in each vessel and instantaneous flowrate, the average EBCT and hydraulic loading rate were 3.2 min/vessel and 5.2 gpm/ft², respectively, compared to the design values of 2.8 min/vessel and 6.4 gpm/ft².

From March 10 through 24, 2009, while the system was configured in parallel and the booster pump was bypassed, average pressure readings at the wellheads were 17 and 16 psi at Wells No. 1 and 2, respectively (see Figure 4-11). Once the system was placed in series and the pressure transducer installed (with the booster pump still being bypassed), average pressure readings at both wellheads increased to 28.8 psi (Table 4-5). The pressure after the booster pump (with the pump bypassed) was 23 psi (on average), which was reduced to 21.7, 13.1, and 4.7 psi after the filter cartridge, Vessel A, and Vessel B, respectively. As shown in Figure 4-11, from March 25 through June 10, 2009, as high as 30 psi was measured at the inlet to Vessel A and as much as 26 psi pressure differential was measured across the system. Siemens suggested that the elevated inlet pressure and pressure differential were caused by a combination of the system not having been thoroughly backwashed since startup and the inlet line to the system was still at ¾ in. The system was thoroughly backwashed on June 10, 2009 (see Section 4.4.2),

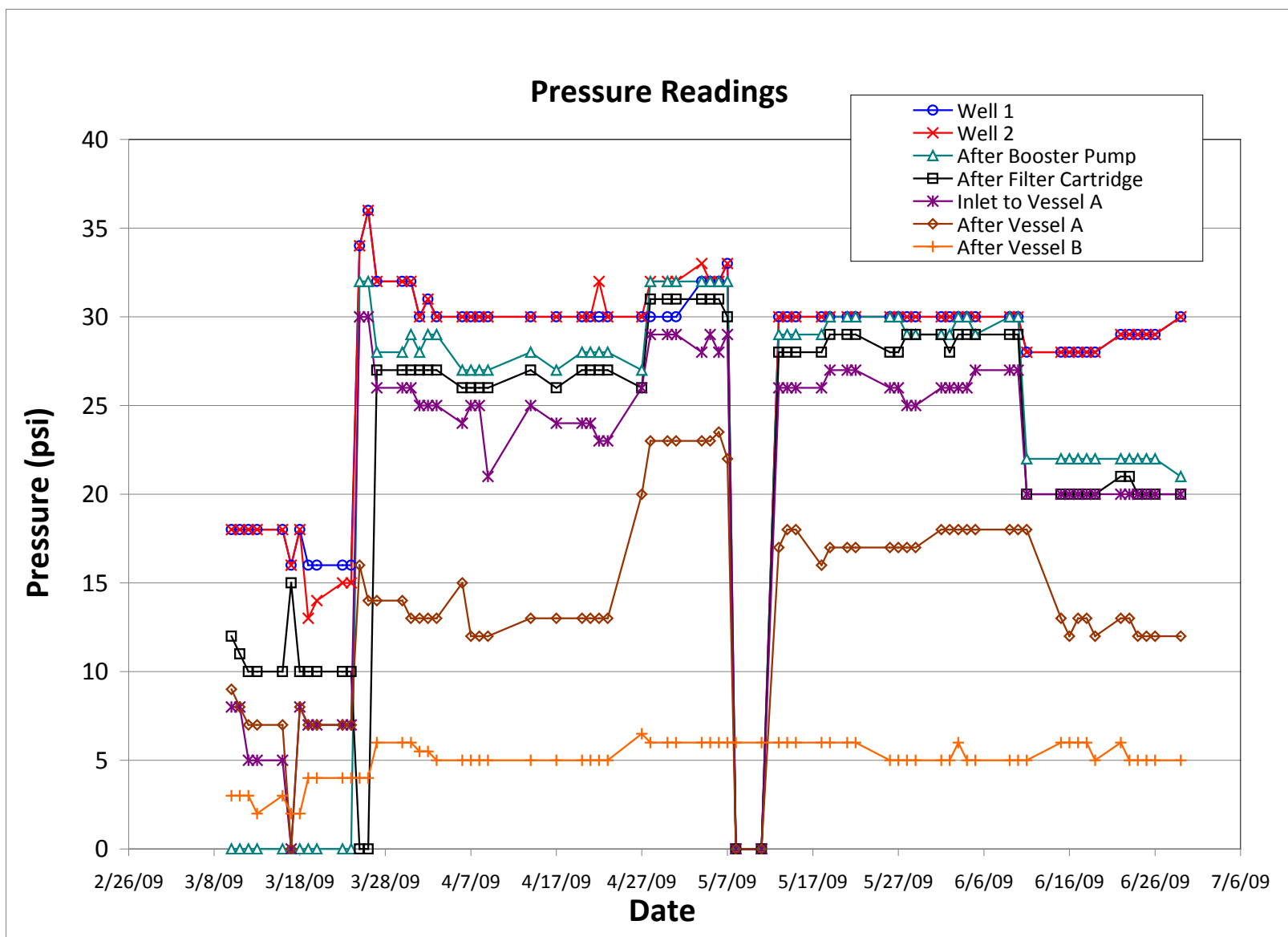


Figure 4-11. Pressure Readings Across Treatment Train (from March 10 through June 30, 2009)

after which average differential pressure was reduced to 7.9 psi for Vessel A and 7.5 psi for Vessel B. After June 10, 2009, through the end of the performance evaluation study on September 30, 2010, pressure readings across the treatment train remained rather similar to those recorded between June 10 through June 30, 2009, and therefore, were not included in Figure 4-11.

4.4.2 Backwash. Each adsorption vessel was designed for a backwash at 20 gpm for 10 min followed by a fast rinse at 20 gpm for 5 min, generating 300 gal of wastewater. During system installation, the system was backwashed briefly at a maximum flowrate of 10 gpm for 20 min. On March 10, 2010, when Battelle staff visited the school, backwash of both vessels was attempted. Soon after the initiation of backwash, a flowrate of 6.3 gpm and a system pressure of 110 psi were observed. Both flowrate and pressure continued to decrease, ending at 2.2 gpm and 20 psi by the conclusion of backwash. The flowrates experienced were much lower than the design value of 20 gpm. Water for backwash originated from the 264-gal hydropneumatic tank located downstream from the 10,000-gal atmospheric tank and the booster pump skid (Section 4.2). It appeared that the booster pumps were not triggered when the system pressure reached the 90-psi low pressure setpoint, thus causing the flowrate and pressure to drop. Siemens recommended that the backwash water line be moved so that it connected to the distribution system.

The backwash frequency was set initially for once every seven days but changed to once every 30 days on February 16, 2009 (Table 4-6). The system was then backwashed automatically on March 17, 2009, but generated only 28 gal of wastewater. Since then, the system was backwashed once every six to eight days on March 25, March 31, and April 7, 2009, and generated only 30 to 45 gal of wastewater during each backwashing event (note that only Vessel A was backwashed). This represents a backwash/fast rinse flowrate of 2.0 to 3.0 gpm, assuming that the backwash and fast rinse durations were 10 and 5 min, respectively, as set. The low backwash flowrates observed were similar to that encountered during Battelle's site visit on March 10, 2010, suggesting that the backwash water line had not yet been moved as recommended by Siemens. Upon completion of installation of a new supply line by the operator on April 17, 2009, Siemens visited the school on April 27, 2009, to backwash the system and reported a significantly increased backwash and fast rinse flowrate of 14 gpm. The actual flowrate might have been higher (28.2 gpm) based on the 845 gal of wastewater produced during the backwash event. The backwash frequency was reset to 99 days (the maximum allowed) because little or no increase in Δp was observed across the adsorption vessels.

After backwash on April 27, 2009, Δp across Vessels A and B remained elevated at as high as 10 and 17.5 psi, respectively. Dow chemical believed that the system had still not been backwashed thoroughly and recommended that each vessel be backwashed for 30 min at the maximum bed expansion. Dow Chemical's rule of thumb was to backwash each vessel with 15 to 25 BV of water before system startup, but only approximately 9 BV was used by April 27, 2009. On June 11, 2009, Siemens conducted the 30-min backwash using approximately 826 gal (or 15 BV) of water for each vessel (see Table 4-6). Upon completion, Δp across both vessels was reduced to 7 psi and stayed constantly around 7 to 8 throughout the remainder of the study period.

After June 11, 2009, amounts of wastewater produced during all backwashing events ranged from 540 to 660 gal, excluding three outliers at 1,449 and 1,077 on August 26 and 27, 2009, due to a power outage and a subsequent system reset, and at 912 gal on March 17, 2010. The amounts of wastewater produced were very close to the design values of 600 gpm per event (see Table 4-3). However, the backwash frequency varied from 7 to 77 days, even though the system was set to backwash every 99 days. It appeared that the backwash timer was not functioning correctly even after being reset a number of times. A consistent backwashing pattern never occurred during the performance evaluation study.

Table 4-6. Summary of System Backwash Operations

Date	Actual Duration Between Backwashes (day)	Amount of Wastewater Produced (gal)	No. of Vessels Backwashed	Remarks
02/17/09	– ^(a)	–		Old backwash piping used until 04/27/09
03/17/09	28	28	1 (Vessel A)	–
03/25/09	8	30	1 (Vessel A)	–
03/31/09	6	45	1 (Vessel A)	–
04/07/09	7	43	1 (Vessel A)	–
04/27/09	20 ^(b)	845	2	Began to use new backwash piping
05/05/09	8	214	1 (Vessel ^(c))	–
05/08/09	3	71	1 (Vessel ^(c))	–
05/11/09	3	364	1 (Vessel ^(c))	–
05/13/09	2	562	2	–
05/28/09	15	232	1 (Vessel ^(c))	–
06/11/09	14	1,653	2	Each vessel backwashed for 30 min
07/09/09	28	542	2	–
08/26/09	48	1,449	?	System reset due to power surge
08/27/09	1	1,077	?	System reset due to power surge
09/03/09	7	540	2	–
10/21/09	48	550	2	–
11/13/09	23	655	2	–
12/10/09	27	656	2	–
01/28/10	49	657	2	–
03/04/10	35	655	2	–
03/17/10	13	912	2 ^(d)	–
06/02/10	77	656	2	–
06/10/10	8	659	2	–
07/01/10	21	660	2	–
09/09/10	70	656	2	–

(a) Backwash frequency set at once every 30 days in programmable logic controller (PLC).

(b) Backwash frequency set at once every 99 days in PLC.

(c) Not certain what vessel was backwashed.

(d) Not certain if only two vessels were backwashed.

4.4.3 Residual Management. Residuals expected included backwash wastewater, spent bag filters, and spent media. No AM nor bag filter was replaced during the study period; therefore, the only residuals produced was backwash wastewater. Backwash wastewater was discharged directly to the drain line to the sewer. No backwash wastewater or solids were collected during the performance evaluation study. The bag filter was not changed during the demonstration study.

4.4.4 System/Operation Reliability and Simplicity. Once placed into series operation, the main operational issues affecting the system were limited to (1) high inlet and differential pressure across the two adsorption vessels and (2) random backwash frequency (even though the timer was set for once every 30 or 99 days). The issue of high inlet and differential pressure was addressed through thorough vessel backwash; the random backwash issue was never resolved during the performance evaluation study. The system O&M and operator skill requirements are discussed below in relation to pre- and post-treatment requirements, levels of system automation, operator skill requirements, preventative maintenance activities, and frequency of chemical/media handling and inventory requirements.

Pre- and Post-Treatment Requirements. No pretreatment was required, but the raw water from the wells passed through a 5- μ m bag filter located upstream from the treatment system. The bag filter did not need to be changed during the performance evaluation study due to lack of solids. The pressure loss across the bag filter remained between 1 to 3 psi during the entire study period.

System Automation. The system was operated by interlocking well pump alternating on/off controls. The system also was fitted with automated controls to allow for automatic backwash for both adsorption vessels. The backwash frequency could be set on the controller but it appeared that that feature never worked adequately. On May 7 and 8, 2009, Siemens visited the school to change pistons in two controllers at the top of the vessels and replace an O-ring on the controller that blocked flow to Vessel B.

Operator Skill Requirements. Under normal operating conditions, the skills required to operate the Adsorbsia™ GTO™ system were minimal. The operator's duties were to record data from the system.

The Woodstock facility is a non-transient, non-community water system. According to CT DPH, all community and non-transient non-community water systems are required to have their water treatment plants, distribution systems, and small water systems operated by certified operators. To be certified as a water treatment plant operator, a person must demonstrate the ability to responsibly operate a plant of the given classification applied for (i.e., I, II, III, IV) by passing a written examination. The minimum education requirement is either a high school diploma or a high school equivalency diploma. Any amount of educational training beyond high school (12 years) in a field of study applicable to water treatment may be substituted for an equal amount of the experience requirement; however, one year of experience is required for all classes. Experience in class means experience gained in operating a particular class plant or the next lower class providing that the operator has direct responsible charge. Operators must renew their certificates every three years by meeting specific training hour requirements for renewal. The Woodstock school operator has a Class I certification.

Preventive Maintenance Activities. There was no regularly scheduled maintenance activity required for the operation of the treatment system.

4.5 System Performance

4.5.1 Treatment Plant Sampling. Water samples were collected on 40 occasions, including four duplicate and 21 speciation events at the IN, TA and TB sampling locations. One of the 21 speciation sampling events took place after September 30, 2010, when logging of operation data officially ended. Table 4-7 summarizes results of arsenic, iron, manganese, and titanium measured at the four sampling locations across the treatment train. Table 4-8 summarizes results of other water quality parameters. Appendix B contains a complete set of analytical results for the demonstration study. The results of the analysis of the water samples collected throughout the treatment plant are discussed below.

Arsenic. Figure 4-12 contains three bar charts showing concentrations of various arsenic species at the wellhead (after Wells No. 1 and No. 2 water combined) and after the lead (A) and lag vessel (B) measured during the 21 speciation events. Total arsenic concentrations in raw water ranged from 17.9 to 29.3 μ g/L and averaged 24.7 μ g/L, existing almost entirely as soluble arsenic. As(V) was the predominating species, with concentrations ranging from 15.5 to 22.4 μ g/L and averaging 19.6 μ g/L. The remaining soluble fraction was As(III), with concentrations ranging from 2.6 to 10.1 μ g/L and averaging 5.8 μ g/L. The presence of As(V) as the predominating species is consistent with elevated DO and ORP readings measured (i.e., 7.5 mg/L and 311 mV [on average], respectively). Aeration during sampling also could contribute to the high DO and ORP readings observed. Note that only three sets of DO measurements were made during the entire study period due to malfunctioning of handheld probes.

Table 4-7. Summary of Arsenic, Iron, Manganese, and Titanium Analytical Results

Parameter	Sampling Location	Sample Count	Concentration (µg/L)			Standard Deviation
			Minimum	Maximum	Average	
As (total)	IN	40	17.9	29.3	24.7	2.6
	TA	40	<0.1	17.2	-*	-*
	TB	40	<0.1	5.2	-*	-*
As (soluble)	IN	21	19.7	29.1	25.5	2.2
	TA	21	<0.1	18.0	-*	-*
	TB	21	<0.1	5.0	-*	-*
As (particulate)	IN	21	<0.1	1.5	0.2	0.4
	TA	21	<0.1	0.1	-*	-*
	TB	21	<0.1	0.2	-*	-*
As (III)	IN	20 ^(a)	2.6	10.1	5.8	1.9
	TA	21	<0.1	6.4	-*	-*
	TB	21	<0.1	1.4	-*	-*
As (V)	IN	20 ^(b)	15.5	22.4	19.6	2.2
	TA	21	<0.1	13.6	-*	-*
	TB	21	<0.1	4.4	-*	-*
Fe (total)	IN	39 ^(c)	<25	83	27	<25
	TA	40	<25	<25	<25	-
	TB	40	<25	<25	<25	-
Fe (soluble)	IN	21	<25	33	<25	<25
	TA	21	<25	<25	<25	-
	TB	21	<25	<25	<25	-
Mn (total)	IN	40	9.8	32.0	17.5	3.5
	TA	40	<0.1	1.2	0.2	0.2
	TB	40	<0.1	0.7	0.2	0.2
Mn (soluble)	IN	21	8.6	23.4	16.8	2.9
	TA	21	<0.1	0.6	0.2	0.2
	TB	21	<0.1	0.8	0.2	0.2
Ti (total)	IN	40	0.9	4.8	1.4	0.6
	TA	40	1.3	98.6	9.5	20.0
	TB	40	0.8	38.3	3.1	6.3
Ti (soluble)	IN	21	0.9	1.5	1.1	0.2
	TA	21	0.2	2.2	1.2	0.4
	TB	21	0.3	1.7	1.0	0.4

(a) One outlier (i.e., 27.4 µg/L) on 03/10/09 omitted.

(b) One outlier (i.e., 0.4 µg/L) on 03/10/09 omitted.

(c) One outlier (i.e., 189 µg/L) on 06/03/10 omitted.

* Not meaningful for concentrations related to breakthrough; see Figures 4-12 and 4-13 and Appendix B for results.

As shown by the second and the third bar charts, both soluble As(V) and soluble As(III) could be removed by Adsorbsia GTO™ media™. However, after treating approximately 395,000 gal (or 7,600 BV) of water (1 BV = 7.0 ft³ = 52 gal of media in one tank), arsenic concentrations following the lead vessel had already reached 10 µg/L. The 7,600 BV experienced was much shorter than the vendor-projected run length of 108,000 BV. By the end of the performance evaluation study, the arsenic concentration in the system effluent was 5.2 µg/L (on October 6, 2010). Figure 4-13 presents arsenic breakthrough curves.

Table 4-8. Summary of Other Water Quality Parameter Results

Parameter	Sampling Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as CaCO ₃)	IN	mg/L	33 ^(a)	68.1	87.9	76	4.9
	TA	mg/L	35	56.1	93.9	74	6.5
	TB	mg/L	35	56.1	82.8	73	6.3
Fluoride	IN	mg/L	16	0.3	2.0	0.5	0.4
	TA	mg/L	16	0.3	0.5	0.3	0.1
	TB	mg/L	16	0.3	2.4	0.5	0.5
Sulfate	IN	mg/L	16	18.1	26.1	22.3	2.0
	TA	mg/L	16	20.6	27.7	23.2	2.0
	TB	mg/L	16	19.4	27.2	22.8	2.0
Nitrate (as N)	IN	mg/L	16	<0.05	0.1	<0.05	0.0
	TA	mg/L	16	<0.05	<0.05	<0.05	-
	TB	mg/L	16	<0.05	<0.05	<0.05	-
Phosphorus (as P)	IN	µg/L	35	<10	<10	<10	-
	TA	µg/L	35	<10	<10	<10	-
	TB	µg/L	35	<10	<10	<10	-
Silica (as SiO ₂)	IN	mg/L	35	14.0	16.8	15.8	0.7
	TA	mg/L	35	1.3	17.9	13.3	3.7
	TB	mg/L	35	3.2	17.1	11.7	3.5
Turbidity	IN	NTU	35	0.1	4.0	1.0	0.8
	TA	NTU	34 ^(b)	0.1	19.0	2.2	3.7
	TB	NTU	35	0.2	9.3	1.3	1.6
pH	IN	S.U.	11	6.3	7.5	7.1	0.3
	TA	S.U.	11	6.7	7.6	7.3	0.3
	TB	S.U.	11	5.6	7.5	7.0	0.5
Temperature	IN	°C	10 ^(c)	6.5	22.7	14.4	4.3
	TA	°C	10 ^(c)	10.4	22.8	15.0	3.7
	TB	°C	9 ^(c)	11.6	22.8	15.5	3.8
Dissolved Oxygen (DO)	IN	mg/L	3	2.8	9.9	7.5	4.1
	TA	mg/L	3	2.1	9.7	6.8	4.1
	TB	mg/L	3	2.1	9.8	7.2	4.4
Oxidation- Reduction Potential (ORP)	IN	mg/L	12	244	417	311	58.4
	TA	mg/L	12	243	418	323	64.3
	TB	mg/L	11	19.5	396	274	126
Total Hardness (as CaCO ₃)	IN	mg/L	15 ^(d)	58.2	96.1	81.8	9.5
	TA	mg/L	15 ^(d)	67.0	89.5	79.8	6.9
	TB	mg/L	15 ^(d)	66.9	90.6	79.1	6.8
Ca Hardness (as CaCO ₃)	IN	mg/L	15 ^(e)	52.4	90.6	76.0	9.6
	TA	mg/L	15 ^(e)	61.8	84.8	74.1	7.1
	TB	mg/L	15 ^(e)	61.7	85.9	73.4	6.9
Mg Hardness (as CaCO ₃)	IN	mg/L	16	4.9	8.6	5.9	1.0
	TA	mg/L	16	4.7	7.7	5.8	0.9
	TB	mg/L	16	4.8	7.2	5.7	0.8

(a) Two outliers (i.e., 126 and 118 mg/L) on 04/21/10 and 06/03/10 omitted.

(b) One outlier (i.e., 62.0 NTU) on 04/07/09 omitted.

(c) Two outliers (i.e., 25.0°C) on 03/10/09 and 06/18/09 omitted.

(d) One outlier each (i.e., 127, 112, and 134 mg/L [as CaCO₃]) at IN, TA, and TB, respectively, on 10/29/09 omitted.

(e) One outlier each (i.e., 120, 105, and 127 mg/L [as CaCO₃]) at IN, TA, and TB, respectively, on 10/29/09 omitted.

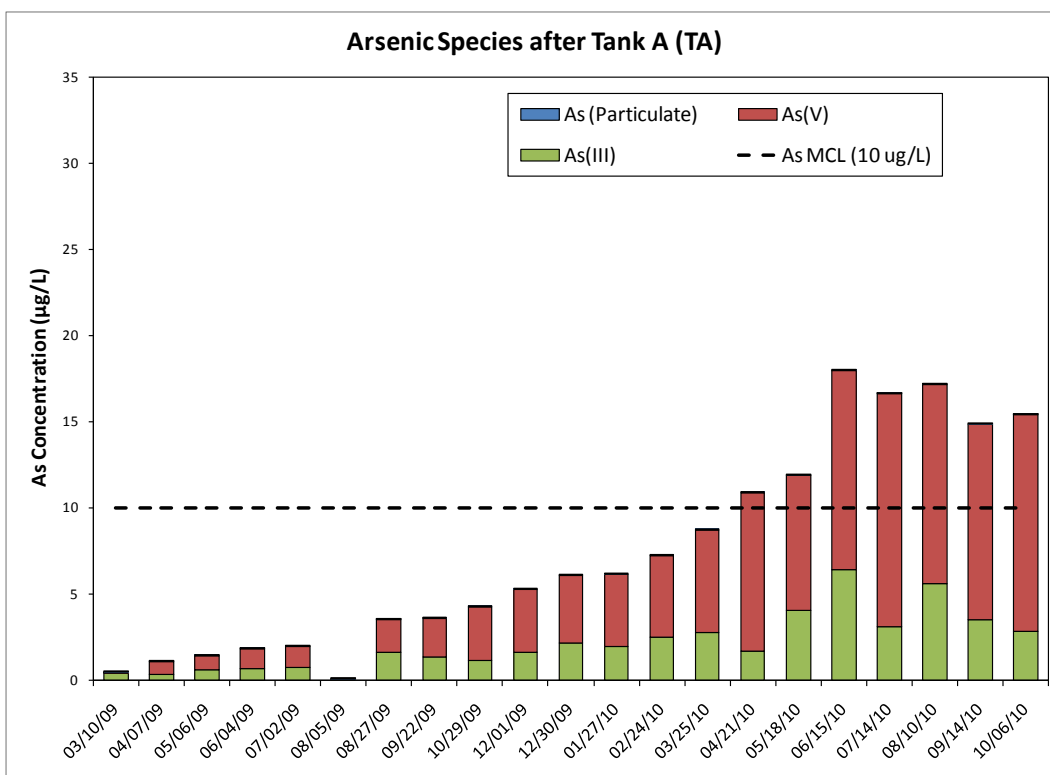
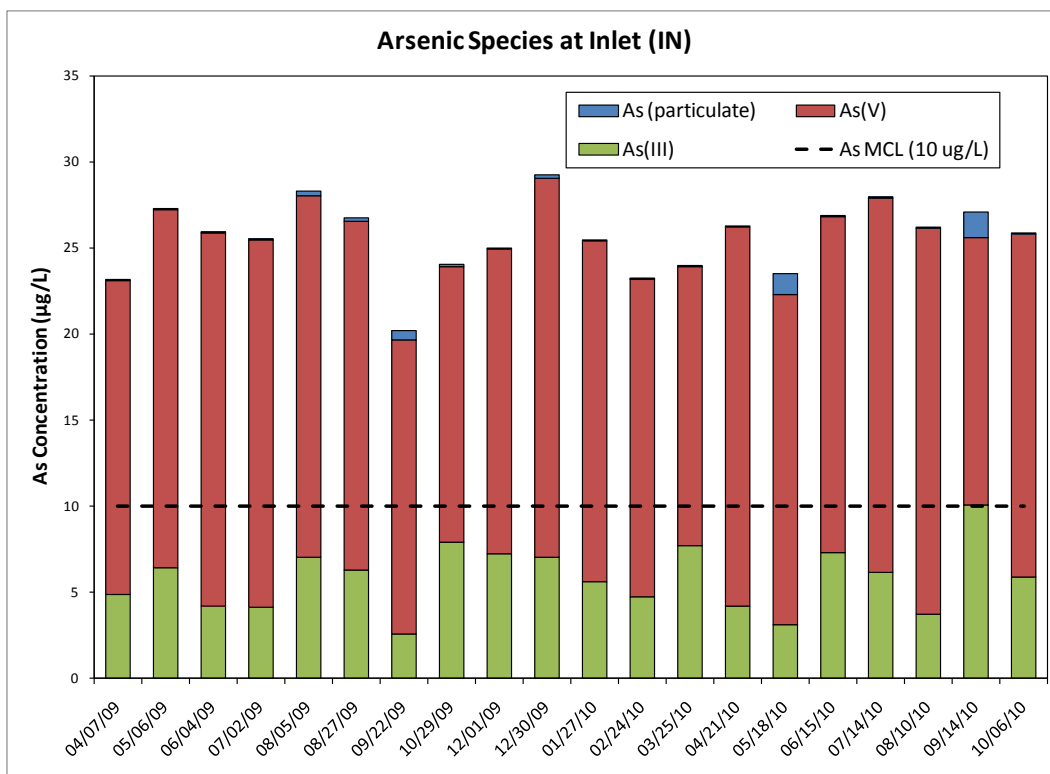


Figure 4-12. Concentrations of Various Arsenic Species at IN, TA and TB Sampling Locations

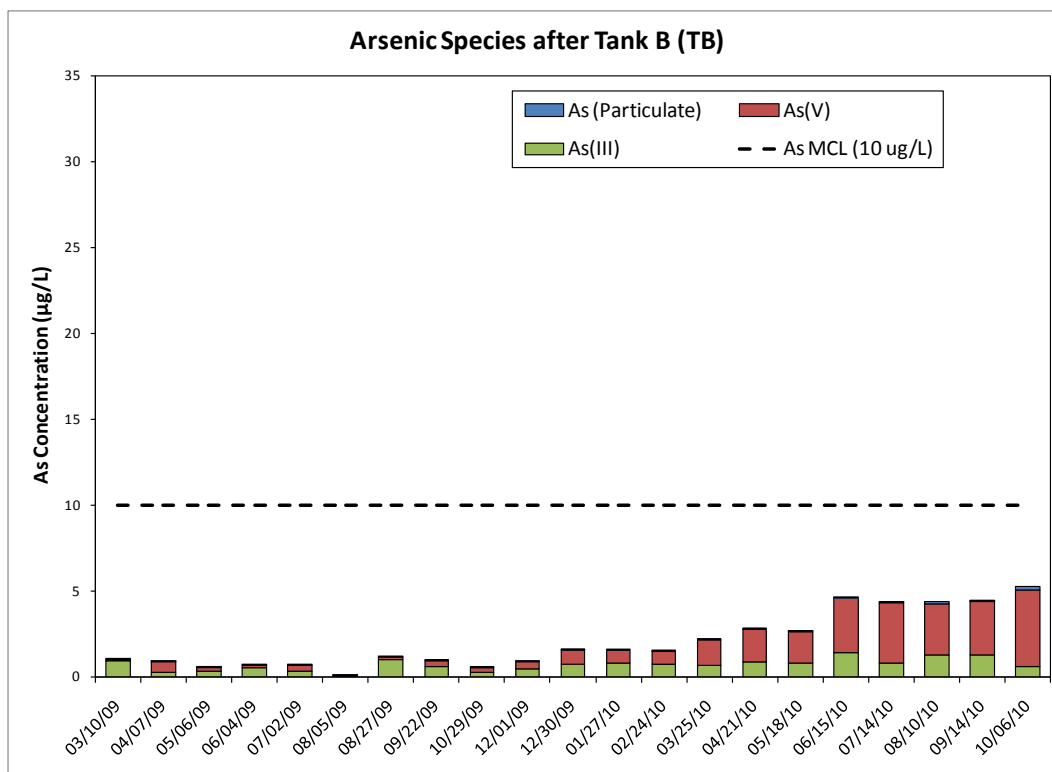


Figure 4-12. Concentrations of Various Arsenic Species at IN, TA and TB Sampling Locations (Continued)

Why Adsorbisia GTO™ media™ achieved such a short run length is unknown. Iron concentrations in raw water were mostly below the MDL of 25 µg/L. Manganese concentrations also were low, ranging from 9.8 to 32.0 µg/L, and averaging 17.5 µg/L. Manganese existed almost entirely in the soluble form and was removed by the media to 0.2 µg/L (on average). Concentrations of competing anions such as phosphorus and silica also were low, either <10 µg/L (the MDL for phosphorus) or at 15.8 mg/L (as SiO₂). Some silica was removed by the media. Immediately after system startup, silica was reduced to as low as 1.3 mg/L (as SiO₂) following the lead vessel. Silica concentrations gradually increased to the raw water level after treating 145,600 gal (or 2,800 BV) of water (1 BV = 7.0 ft³ = 52 gal). pH values ranged from 5.6 to 7.6 and averaged 7.2 throughout the treatment train. This pH range was considered ideal for arsenic adsorption.

Titanium. Total titanium concentrations in source water were low, ranging from 0.9 to 4.8 µg/L and averaging 1.4 µg/L. Total titanium concentrations following the lead and lag vessels increased slightly to 9.5 and 3.1 µg/L (on average), respectively, due primarily to leaching of titanium-oxide particles. The highest detected titanium concentration was 98.6 µg/L.

Other Water Quality Parameters. Alkalinity values ranged from 56.1 to 93.9 mg/L (as CaCO₃) across the treatment train. Concentrations of total hardness, existing primarily as calcium hardness (about 92.9%), ranged from 58.2 to 96.1 mg/L (as CaCO₃), and remained essentially unchanged across the treatment train. Fluoride concentrations ranged from 0.3 to 2.4 mg/L; sulfate from 18.1 mg/L to 27.7 mg/L; both did not appear to be affected by the AM system. Nitrate was not detected in any sample but one at 0.1 mg/L.

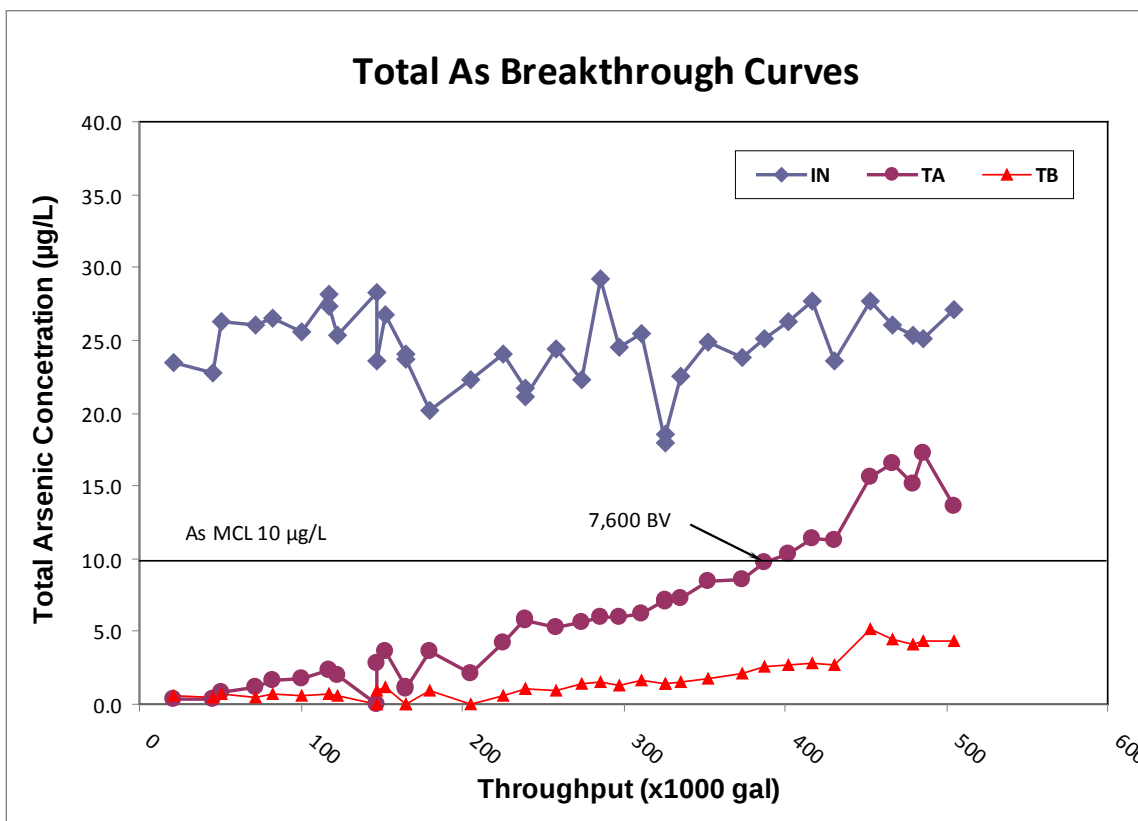


Figure 4-13. Total Arsenic Breakthrough Curves from Lead and Lag Vessels

4.5.2 Distribution System Water Sampling. Prior to the installation/operation of the treatment system, four first draw baseline distribution system water samples were collected. The first baseline samples were collected on May 29, 2008, from three locations, i.e., the kitchen sink, the nurses station, and the staff dining areas. The three additional baseline samples were collected from the kitchen sink only on November 14, 2008, December 2, 2008 and January 4, 2009. After system startup, distribution system water sampling continued on a monthly basis from the kitchen sink. Table 4-9 presents results of the distribution system water sampling.

The most noticeable change in the distribution samples since system startup was a decrease in arsenic concentration. Baseline arsenic concentrations ranged from 22.0 to 25.7 µg/L and averaged 23.1 µg/L. After system startup, arsenic concentrations were reduced to 0.6 to 3.5 µg/L. Iron concentrations were below the MDL of 25 µg/L both before and after system startup with a few exceptions at 43, 39, 39 and 32 µg/L. Baseline manganese concentrations were low, ranging from 1.2 to 7.9 µg/L and averaging 4.3 µg/L. After system startup, its concentrations remained low for 11 of the 16 sampling events. The other five events had higher manganese concentrations ranging from 10.6 to 184 µg/L. Why the concentrations were elevated is not known.

Lead concentrations of all water samples collected before and after the installation of the treatment system averaged 1.3 µg/L within a range of <0.1 to 2.5 µg/L. Copper concentrations ranged from 85.6 to 480 µg/L across all sampling locations, with no samples exceeding the 1,300 µg/L action level both before and after system startup. The arsenic treatment system did not appear to have an effect on the lead or copper concentration in the distribution system.

Table 4-9. Distribution System Water Sampling Results

Sampling Event		Stagnation Time	pH	Alkalinity ^(b)	As	Fe	Mn	Pb	Cu
Date		hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
BL1 ^(a)	05/29/08	16.1	8.1	72.5	23.6	<25	6.0	1.1	124
		14.4	8.1	74.7	22.7	<25	6.5	0.3	85.6
		14.2	8.1	72.5	22.1	<25	7.9	1.2	101
BL2	11/14/08	15.3	8.1	69.1	22.6	<25	2.1	1.1	93.6
BL3	12/02/08	16.0	8.1	75.0	25.7	<25	2.1	0.9	107
BL4	01/07/09	16.1	8.1	65.2	22.0	<25	1.2	0.8	120
1	03/25/09	NA	7.7	63.3	1.3	<25	16.8	1.6	480
2	04/22/09	13.6	7.9	66.3	2.1	43	12.8	1.5	448
3	05/20/09	16.3	7.6	68.9	1.7	<25	7.5	1.2	435
4	06/16/09	16.0	7.5	66.3	1.8	<25	7.7	1.6	384
5	07/02/09	188	7.6	66.9	1.7	<25	10.6	1.4	250
6	08/12/09	135	7.6	66.3	3.5	<25	184	2.5	246
7	09/10/09	15.5	7.7	61.1	0.6	39	20.7	2.2	248
8	10/15/09	17.8	7.7	70.2	3.1	<25	6.8	1.1	276
9	11/10/09	16.5	7.9	70.7	2.2	39	6.6	0.9	275
10	12/15/09	NA	7.9	71.1	2.0	<25	4.9	1.6	240
11	01/12/10	16.5	7.8	83.3	2.8	<25	2.8	1.3	176
12	02/09/10	16.0	7.7	77.7	2.4	<25	3.1	0.8	156
13	03/10/10	16.5	8.0	77.6	2.4	<25	3.7	1.3	165
14	04/07/10	16.5	8.1	71.1	3.1	<25	3.4	<0.1	149
15	05/05/10	16.0	7.9	71.7	3.0	<25	3.2	1.0	134
16	06/02/10	16.0	8.1	76.0	3.5	32	2.8	1.1	108

(a) First baseline sampling event taking place at three locations, including school kitchen sink, nurses sink, and staff dining room. All additional baseline and distribution sampling performed at kitchen sink.

(b) as CaCO₃.

BL = baseline sampling; NA = not available; NS = not sampled
Lead action level = 15 µg/L; copper action level = 1.3 mg/L

4.6 System Cost

The cost of the treatment system was based on the capital cost per gpm (or gpd) of the design capacity and the O&M cost per 1,000 gal of water treated. This required tracking of the capital cost for the equipment, site engineering, and installation and the O&M cost for media replacement and disposal, chemical supply, electricity consumption, and labor.

4.6.1 Capital Cost. The capital investment for equipment, site engineering, and installation for the 20-gpm treatment system was \$51,895 (Table 4-10). The equipment cost was \$30,215 (or 58% of the total capital investment), including \$24,007 for the treatment system and media, \$4,308 for vendor labor, and \$1,900 for freight.

The site engineering cost included the cost for the preparation of a process flow diagram and relevant mechanical drawings of the treatment system, piping, valves, and a backwash discharge line, as well as submission of a permit application package to CT DPH for approval. The site engineering cost was

Table 4-10. Capital Investment Cost for Adsorbsia™ GTO™ Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
24-in Diameter Fiberglass Pressure Vessels	2	\$5,476	–
Adsorbsia™ GTO™ Media	15ft ³	\$6,729	–
Process Valve/Pipe Rack	Lot	\$3,928	–
Instrumentation (i.e., Controller, Totalizers/Flowmeters, and Gauges)	1	\$1,192	–
Bag Filter and Housing	1	\$111	–
Booster Pump	1	\$6,571	–
<i>Subtotal</i>		\$24,007	–
Vendor Labor	–	\$4,308	
Shipping		\$1,900	
Equipment Total	–	\$30,215	58%
Engineering Cost			
Subcontractor Labor	–	\$10,110	–
Engineering Total	–	\$10,110	20%
Installation Cost			
Vendor Labor for System Start Up	–	\$8,185	–
Vendor Travel for System Start Up	–	\$2,154	–
Subcontractor Material	–	\$1,231	–
Installation Total	–	\$11,570	22%
Total Capital Investment	–	\$51,895	100%

\$10,110, or 20% of the total capital investment. All of the site engineering cost was incurred by a subcontractor, TurnKey Compliance Solutions, LLC.

The installation cost included the vendor travel to the site and vendor labor to unload and install the system, perform piping tie-ins and electrical work, and load and backwash the media. The installation cost was \$11,570, or 22% of the total capital investment.

The capital cost of \$51,895 was normalized to the system's rated capacity of 20 gpm (or 28,800 gpd), which results in \$2594.75/gpm (or \$1.80/gpd) of design capacity. The capital cost also was converted to an annualized cost of \$4,898/yr using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-yr return period. Assuming that the system operated 24 hr/day, 7 day/wk at the design flowrate of 20 gpm to produce 28,800 gpd, the unit capital cost would be \$0.47/1,000 gal. During the 19 month-long demonstration project, the system produced approximately 544,600 gal of water (see Table 4-5), equivalent to 349,000 gal per year. At this reduced rate of usage, the unit capital cost increased to \$14.03/1,000 gal.

4.6.2 Operation and Maintenance Cost. The O&M cost includes media replacement and disposal, chemical supply, electricity, and labor, as summarized in Table 4-11. Although media replacement did not occur during the performance evaluation study, the media replacement cost would represent the majority of the O&M cost. It was estimated that media replacement would cost \$5,808 for 7.5 ft³ of the media, labor, and disposal. This cost was used to estimate the media replacement cost per 1,000 gal of water treated as a function of the projected media run length to the 10-μg/L arsenic breakthrough (Figure 4-14).

Table 4-11. Operation and Maintenance Cost for Woodstock Treatment System

Cost Category	Value	Assumptions
Volume Processed (gal)	544,600	From March 10, 2009 through September 30, 2010; equivalent to 349,000 gal per year
<i>Media Replacement and Disposal</i>		
Media Replacement and Disposal (\$)	5,808	For 7.5 ft ³ in lead vessel
Adsorbsia™ GTO™ Media Replacement and Disposal cost (\$/1,000 gal)	See Figure 4-14	
<i>Chemical Usage</i>		
Chemical Cost (\$/1,000)	0	No chemical usage
<i>Electricity</i>		
Electricity Cost (\$/1,000 gal)	–	Electrical costs assumed negligible
<i>Labor</i>		
Average Weekly Labor (hr)	1.6	20 min/day for 5 days
Annual Labor Cost (\$)	1,664	At \$20/hr for 52 weeks
Labor Cost per 1,000 gal Treated (\$)	4.77	
Total O&M Cost/1,000 gal	See Figure 4-14	Total O&M cost = media replacement and disposal cost + \$4.77

Comparison of electrical bills provided by the school prior to system installation and since startup did not indicate any noticeable increase in power consumption by the treatment system. Therefore, electrical cost associated with operation of the treatment system was negligible. Under normal operating conditions, routine labor activities to operate and maintain the system consumed approximately 20 min/day or 1.6 hr/week. Assuming an hourly rate of \$20/hr, the estimated labor cost would be \$4.77/1,000 gal of water treated.

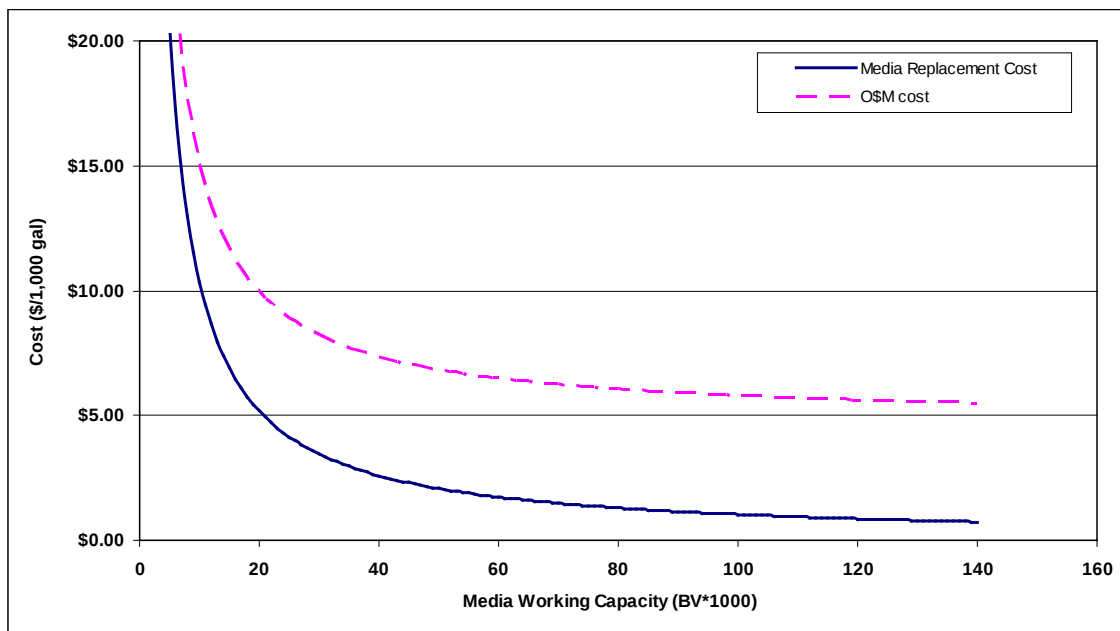


Figure 4-14. Media Replacement and Total O&M Cost Curves

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APPENDIX A

OPERATIONAL DATA

Table A-1. EPA Arsenic Demonstration Project at Woodstock, CT- Daily System Operation Log Sheet

Week No.	Date	Well Pumps		Vessel A			Vessel B			Pressure			Backwash
		Operating time	Cumulative Operating Time	Instant Flow rate	Totalizer X1000	Bed Volumes Treated	Instant Flow rate	Totalizer X1000	Bed Volumes Treated ^(a)	Inlet Pressure Vessel A	Outlet Pressure Vessel A	Outlet Pressure Vessel B	Backwash Totalizer
		(hr)	(hr)	(gpm)	(gal)	BV	(gpm)	(gal)	BV	(psi)	(psi)	(psi)	(gal)
1	03/10/09	NA	NA	11.1	NA	N/A	6.1	NA	N/A	8	9	3	1,818
	03/11/09	2.1	2.1	11.2	NA	N/A	6.1	NA	N/A	8	8	3	1,818
	03/12/09	0.1	2.2	7.9	NA	N/A	9.6	NA	N/A	5	7	3	1,818
	03/13/09	0.0	2.2	7.9	NA	N/A	9.6	NA	N/A	5	7	2	1,818
2	03/16/09	0.0	2.2	7.9	NA	N/A	9.6	NA	N/A	5	7	3	1,818
	03/17/09	4.3	6.5	5.8	NA	N/A	11.5	NA	N/A	14	14	2	1,846
	03/18/09	0.3	6.8	7.9	NA	N/A	9.6	NA	N/A	8	8	2	1,846
	03/19/09	2.9	9.7	6.4	NA	N/A	10.7	NA	N/A	7	7	4	1,846
	03/20/09	1.1	10.8	6.5	NA	N/A	10.5	NA	N/A	7	7	4	1,846
3	03/23/09	0.0	10.8	6.5	NA	N/A	10.5	NA	N/A	7	7	4	1,846
	03/24/09	0.0	10.8	6.5	NA	N/A	10.5	NA	N/A	7	7	4	1,846
	03/25/09	5.4	16.2	15.7	21	404	15.8	26	500	30	16	4	1,876
	03/26/09	0.1	16.3	15.8	21	404	15.8	26	500	30	14	4	1,876
	03/27/09	18.2	34.5	15.7	37	712	15.9	43	827	26	14	6	1,876
4	03/30/09	0.0	34.5	15.7	37	712	15.9	43	827	26	14	6	1,876
	03/31/09	0.1	34.6	16.1	38	731	16.0	43	827	26	13	6	1,921
	04/01/09	2.5	37.1	16.1	40	769	16.2	45	865	25	13	5.5	1,921
	04/02/09	2.2	39.3	16.2	42	808	16.2	47	904	25	13	5.5	1,921
	04/03/09	0.0	39.3	16.3	42	808	16.1	47	904	25	13	5	1,921
5	04/06/09	3.8	43.1	16.3	45	865	16.2	51	981	24	15	5	1,921
	04/07/09	0.5	43.6	16.0	46	885	16.0	52	1,000	25	12	5	1,964
	04/08/09	0.0	43.6	16.0	46	885	16.0	52	1,000	25	12	5	1,964
	04/09/09	4.1	47.7	16.4	50	962	16.4	55	1,058	21	12	5	1,964
6	04/14/09	1.4	49.1	16.2	51	981	16.3	57	1,096	25	13	5	1,964
	04/17/09	0.1	49.2	16.2	51	981	16.1	57	1,096	24	13	5	1,964
7	04/20/09	0.1	49.3	16.4	51	981	16.1	57	1,096	24	13	5	1,964
	04/21/09	0.1	49.4	16.4	51	981	16.1	57	1,096	24	13	5	1,964
	04/22/09	4.7	54.1	16.4	56	1,077	16.0	61	1,173	23	13	5	1,964
	04/23/09	0.1	54.2	16.4	56	1,077	16.1	61	1,173	23	13	5	1,964
8	04/27/09	3.8	58.0	15.6	60	1,154	15.5	65	1,250	26	20	7	2,809
	04/28/09	1.2	59.2	15.6	61	1,173	15.6	66	1,269	29	23	6	2,809
	04/30/09	3.2	62.4	15.7	64	1,231	15.8	69	1,327	29	23	6	2,809
	05/01/09	0.1	62.5	15.7	64	1,231	15.7	69	1,327	29	23	6	2,809

Table A-1. EPA Arsenic Demonstration Project at Goshen, IN- Daily System Operation Log Sheet (Continued)

Week No.	Date	Well Pumps		Vessel A			Vessel B			Pressure			Backwash
		Operating time	Cumulative Operating Time	Instant Flow rate	Totalizer X1000	Bed Volumes Treated	Instant Flow rate	Totalizer X1000	Bed Volumes Treated ^(a)	Inlet Pressure Vessel A	Outlet Pressure Vessel A	Outlet Pressure Vessel B	Backwash Totalizer
		(hr)	(hr)	(gpm)	(gal)	BV	(gpm)	(gal)	BV	(psi)	(psi)	(psi)	(gal)
9	05/04/09	4.5	67.0	15.8	68	1,308	15.8	74	1,423	28	23	6	2,809
	05/05/09	0.7	67.7	15.6	68	1,308	15.6	74	1,423	29	23	6	3,023
	05/06/09	3.5	71.2	15.8	72	1,385	15.8	77	1,481	28	24	6	3,023
	05/07/09	0.6	71.8	15.8	72	1,385	15.8	78	1,500	29	22	6	3,023
	05/08/09	0.0	71.8	1.7	72	1,385	14.7	78	1,500	18	18	6	3,094
10	05/11/09	5.0	76.8	1.1	73	1,404	15.4	83	1,596	13	14	6	3,458
	05/13/09	4.7	81.5	15.9	77	1,481	16.1	87	1,673	26	17	6	4,020
	05/14/09	3.8	85.3	16.1	80	1,538	16.1	90	1,731	26	18	6	4,020
	05/15/09	0.1	85.4	15.9	80	1,538	15.9	91	1,750	26	18	6	4,020
	05/18/09	0.0	85.4	15.9	80	1,538	15.9	91	1,750	26	16	6	4,020
11	05/19/09	2.9	88.3	15.6	83	1,596	15.8	93	1,788	27	17	6	4,020
	05/21/09	6.4	94.7	16.0	89	1,712	16.0	99	1,904	27	17	6	4,020
	05/22/09	0.0	94.7	15.8	89	1,712	15.9	99	1,904	27	17	6	4,020
	05/26/09	0.1	94.8	16.1	89	1,712	16.0	99	1,904	26	17	5	4,020
12	05/27/09	4.3	99.1	15.8	92	1,769	16.1	101	1,942	26	17	5	4,020
	05/28/09	0.1	99.2	15.8	93	1,788	16.0	103	1,981	25	17	5	4,252
	05/29/09	0.1	99.3	16.0	93	1,788	16.2	103	1,981	25	17	5	4,252
	06/01/09	4.3	103.6	15.9	97	1,865	16.3	107	2,058	26	18	5	4,252
13	06/02/09	0.0	103.6	16.0	97	1,865	16.3	107	2,058	26	18	5	4,252
	06/03/09	3.8	107.4	16.0	100	1,923	16.2	111	2,135	26	18	6	4,252
	06/04/09	0.1	107.5	16.2	100	1,923	16.2	111	2,135	26	18	5	4,252
	06/05/09	1.2	108.7	16.2	102	1,962	16.3	112	2,154	27	18	5	4,252
	06/09/09	4.6	113.3	16.2	106	2,038	16.2	117	2,250	27	18	5	4,252
14	06/10/09	4.8	118.1	16.1	110	2,115	16.1	121	2,327	27	18	5	4,252
	06/11/09	0.1	118.2	16.4	110	2,115	16.4	121	2,327	20	18	5	5,905
	06/15/09	4.4	122.6	16.2	115	2,212	16.5	125	2,404	20	13	6	5,905
15	06/16/09	0.3	122.9	16.1	115	2,212	16.4	126	2,423	20	12	6	5,905
	06/17/09	2.0	124.9	16.1	117	2,250	16.5	128	2,462	20	13	6	5,905
	06/18/09	2.2	127.1	16.2	119	2,288	16.5	130	2,500	20	13	6	5,905
	06/19/09	0.1	127.2	16.5	119	2,288	16.5	130	2,500	20	12	5	5,905
	06/22/09	3.6	130.8	16.4	122	2,346	16.8	133	2,558	20	13	6	5,905
16	06/23/09	0.1	130.9	16.3	122	2,346	16.4	133	2,558	20	13	5	5,905
	06/24/09	0.0	130.9	16.3	122	2,346	16.5	133	2,558	20	12	5	5,905
	06/25/09	0.1	131.0	16.3	123	2,365	16.5	133	2,558	20	12	5	5,905
	06/26/09	0.0	131.0	16.4	123	2,365	16.7	133	2,558	20	12	5	5,905
	06/29/09	0.0	131.0	16.3	123	2,365	16.5	133	2,558	20	12	5	5,905
17	07/02/09	0.3	131.3	16.5	123	2,365	16.5	134	2,577	20	12	5	5,905

Table A-1. EPA Arsenic Demonstration Project at Goshen, IN- Daily System Operation Log Sheet (Continued)

Week No.	Date	Well Pumps		Vessel A			Vessel B			Pressure			Backwash
		Operating time	Cumulative Operating Time	Instant Flow rate	Totalizer X1000	Bed Volumes Treated	Instant Flow rate	Totalizer X1000	Bed Volumes Treated ^(a)	Inlet Pressure Vessel A	Outlet Pressure Vessel A	Outlet Pressure Vessel B	Backwash Totalizer
		(hr)	(hr)	(gpm)	(gal)	BV	(gpm)	(gal)	BV	(psi)	(psi)	(psi)	(gal)
18	07/09/09	3.5	134.8	16.3	126	2,423	16.7	137	2,635	20	12	5	6,447
19	07/14/09	0.0	134.8	16.2	126	2,423	16.6	137	2,635	20	12	5	6,447
	07/15/09	0.1	134.9	16.2	126	2,423	16.6	137	2,635	19	12	5	6,447
20	07/21/09	0.0	134.9	16.4	126	2,423	16.7	137	2,635	19	12	5	6,447
21	08/03/09	3.8	138.7	16.3	130	2,500	16.5	141	2,712	19	12	5	6,447
	08/05/09	18.6	157.3	16.5	147	2,827	16.7	158	3,038	19	13	5	6,447
	08/07/09	0.1	157.4	16.2	147	2,827	16.5	158	3,038	19	13	5	6,447
21	08/10/09	0.1	157.5	16.4	147	2,827	16.5	159	3,058	19	12	5	6,447
	08/14/09	0.4	157.9	16.4	148	2,846	16.5	159	3,058	19	12	5	6,447
22	08/17/09	0.0	157.9	16.5	148	2,846	16.7	159	3,058	19	12	5	6,447
	08/19/09	1.4	159.3	16.5	148	2,846	16.7	159	3,058	20	12	4	6,447
23	08/26/09	3.3	162.6	16.1	152	2,923	16.2	163	3,135	22	14	4	7,896
	08/27/09	0.1	162.7	16.2	152	2,923	16.4	163	3,135	20	12	4	8,973
	08/28/09	4.0	166.7	16.5	156	3,000	16.9	167	3,212	20	12	5	8,973
24	08/31/09	0.0	166.7	16.3	156	3,000	16.4	167	3,212	19	11	4	8,973
	09/01/09	0.0	166.7	16.5	156	3,000	16.6	167	3,212	19	11	5	8,973
	09/03/09	4.3	171.0	16.4	160	3,077	16.3	171	3,288	20	12	4	9,513
25	09/08/09	3.8	174.8	16.2	163	3,135	16.2	175	3,365	18	12	4	9,513
	09/09/09	0.1	174.9	16.2	163	3,135	16.3	175	3,365	19	12	4	9,513
	09/10/09	1.4	176.3	16.0	165	3,173	16.3	176	3,385	20	12	4	9,513
	09/11/09	2.8	179.1	16.3	167	3,212	16.4	179	3,442	20	12	4	9,513
26	09/15/09	4.1	183.2	16.2	171	3,288	16.5	182	3,500	20	12	4	9,513
	09/17/09	4.5	187.7	16.2	175	3,365	16.5	187	3,596	21	12	5	9,513
27	09/21/09	0.1	187.8	16.2	175	3,365	16.4	187	3,596	20	12	5	9,513
	09/22/09	4.5	192.3	16.3	180	3,462	16.3	191	3,673	20	12	5	9,513
	09/24/09	4.7	197.0	16.4	184	3,538	16.5	196	3,769	20	11	5	9,513
28	09/28/09	3.9	200.9	16.4	188	3,615	16.4	199	3,827	21	12	4	9,513
	09/30/09	0.1	201.0	16.5	188	3,615	16.5	199	3,827	20	12	4	9,513
	10/01/09	4.3	205.3	16.3	192	3,692	16.4	203	3,904	20	12	5	9,513
29	10/05/09	0.0	205.3	16.5	192	3,692	16.4	204	3,923	20	12	11	9,513
	10/08/09	8.2	213.5	16.5	200	3,846	16.6	211	4,058	21	12	11	9,513
30	10/13/09	3.9	217.4	16.5	203	3,904	16.4	215	4,135	20	12	11	9,513
	10/15/09	1.4	218.8	16.2	205	3,942	16.4	216	4,154	21	12	11	9,513
	10/16/09	3.3	222.1	16.4	208	4,000	16.3	220	4,231	20	12	11	9,513
31	10/21/09	4.6	226.7	16.5	212	4,077	16.5	224	4,308	20	12	5	10,063
	10/22/09	3.9	230.6	16.4	216	4,154	16.5	228	4,385	20	12	5	10,063

Table A-1. EPA Arsenic Demonstration Project at Goshen, IN- Daily System Operation Log Sheet (Continued)

Week No.	Date	Well Pumps		Vessel A			Vessel B			Pressure			Backwash
		Operating time	Cumulative Operating Time	Instant Flow rate	Totalizer X1000	Bed Volumes Treated	Instant Flow rate	Totalizer X1000	Bed Volumes Treated ^(a)	Inlet Pressure Vessel A	Outlet Pressure Vessel A	Outlet Pressure Vessel B	Backwash Totalizer
		(hr)	(hr)	(gpm)	(gal)	BV	(gpm)	(gal)	BV	(psi)	(psi)	(psi)	(gal)
32	10/26/09	3.7	234.3	16.5	219	4,212	16.5	231	4,442	20	12	5	10,063
	10/28/09	6.0	240.3	16.3	225	4,327	16.2	237	4,558	20	12	5	10,063
	10/29/09	0.0	240.3	16.3	225	4,327	16.4	237	4,558	20	12	5	10,063
33	11/02/09	6.2	246.5	16.3	231	4,442	16.3	243	4,673	21	12	5	10,063
	11/04/09	2.9	249.4	16.5	234	4,500	16.7	245	4,712	21	11	5	10,063
34	11/09/09	6.0	255.4	16.3	239	4,596	16.4	251	4,827	21	12	5	10,063
	11/13/09	3.8	259.2	16.6	243	4,673	16.7	255	4,904	21	12	5	10,718
35	11/17/09	3.1	262.3	16.5	247	4,750	16.4	258	4,962	21	12	5	10,718
	11/19/09	5.1	267.4	16.2	251	4,827	16.6	263	5,058	21	12	5	10,718
36	11/24/09	4.1	271.5	16.6	255	4,904	16.8	267	5,135	21	13	5	10,718
37	12/01/09	3.6	275.1	16.5	258	4,962	16.7	270	5,192	21	13	5	10,718
	12/04/09	4.9	280.0	16.3	263	5,058	16.4	275	5,288	21	11	5	10,718
38	12/07/09	3.7	283.7	16.4	266	5,115	16.5	278	5,346	21	12	5	10,718
	12/10/09	3.9	287.6	16.2	270	5,192	16.4	282	5,423	21	12	5	11,374
39	12/14/09	4.4	292.0	16.3	274	5,269	16.4	286	5,500	21	13	5	11,374
	12/15/09	0.1	292.1	16.4	274	5,269	16.2	286	5,500	21	13	5	11,374
	12/17/09	4.5	296.6	16.4	279	5,365	16.3	291	5,596	21	13	5	11,374
40	12/21/09	3.9	300.5	16.6	282	5,423	16.5	294	5,654	21	13	5	11,374
	12/22/09	0.0	300.5	16.6	282	5,423	16.8	295	5,673	21	13	5	11,374
	12/23/09	4.2	304.7	16.4	286	5,500	16.5	299	5,750	21	13	5	11,374
41	12/30/09	0.1	304.8	16.7	286	5,500	16.6	299	5,750	21	12	5	11,374
42	01/05/10	0.4	305.2	16.5	287	5,519	16.7	299	5,750	21	13	5	11,374
	01/07/10	4.1	309.3	16.1	291	5,596	16.7	303	5,827	21	13	5	11,374
	01/08/10	3.6	312.9	16.5	294	5,654	16.6	306	5,885	22	13	5	11,374
43	01/12/10	2.8	315.7	16.3	297	5,712	16.4	309	5,942	21	12	5	11,374
	01/12/10	5.5	321.2	16.5	302	5,808	16.3	314	6,038	21	12	5	11,374
44	01/19/10	2.5	323.7	16.2	304	5,846	16.3	317	6,096	21	13	5	11,374
	01/20/10	1.9	325.6	16.4	306	5,885	16.3	319	6,135	22	13	5	11,374
45	01/27/10	4.7	330.3	16.5	311	5,981	16.3	323	6,212	21	13	5	11,374
	01/28/10	3.7	334.0	16.2	314	6,038	16.3	326	6,269	22	13	5	12,031
46	02/02/10	6.0	340.0	16.3	319	6,135	16.4	332	6,385	23	14	5	12,031
	02/05/10	3.6	343.6	16.4	323	6,212	16.5	335	6,442	22	14	5	12,031
47	02/09/10	3.9	347.5	16.2	326	6,269	16.3	339	6,519	22	13	5	12,031
	02/10/10	0.0	347.5	16.5	326	6,269	16.5	339	6,519	22	13	5	12,031
48	02/18/10	4.6	352.1	16.2	331	6,365	16.4	343	6,596	22	12	5	12,031

Table A-1. EPA Arsenic Demonstration Project at Goshen, IN- Daily System Operation Log Sheet (Continued)

Week No.	Date	Well Pumps		Vessel A			Vessel B			Pressure			Backwash
		Operating time	Cumulative Operating Time	Instant Flow rate	Totalizer X1000	Bed Volumes Treated	Instant Flow rate	Totalizer X1000	Bed Volumes Treated ^(a)	Inlet Pressure Vessel A	Outlet Pressure Vessel A	Outlet Pressure Vessel B	Backwash Totalizer
		(hr)	(hr)	(gpm)	(gal)	BV	(gpm)	(gal)	BV	(psi)	(psi)	(psi)	(gal)
49	02/23/10	4.4	356.5	16.4	335	6,442	16.4	348	6,692	22	13	5	12,031
	02/24/10	0.0	356.5	16.3	335	6,442	16.3	348	6,692	21	13	5	12,031
	02/26/10	4.9	361.4	16.4	340	6,538	16.5	352	6,769	21	13	5	12,031
50	03/01/10	0.0	361.4	16.4	340	6,538	16.5	352	6,769	21	13	5	12,031
	03/04/10	5.6	367.0	16.4	345	6,635	16.3	357	6,865	22	13	5	12,686
51	03/09/10	8.3	375.3	16.5	352	6,769	16.7	365	7,019	22	14	5	12,686
	03/10/10	0.0	375.3	16.5	352	6,769	16.7	365	7,019	22	13	5	12,686
52	03/17/10	11.7	387.0	16.5	363	6,981	16.6	376	7,231	22	14	5	13,598
53	03/23/10	7.2	394.2	16.7	370	7,115	16.8	383	7,365	21	13	5	13,598
	03/25/10	3.6	397.8	16.5	374	7,192	16.6	386	7,423	21	13	5	13,598
54	03/30/10	6.3	404.1	16.5	380	7,308	16.5	392	7,538	20	13	5	13,598
55	04/06/10	7.4	411.5	16.5	387	7,442	16.6	400	7,692	20	13	5	13,598
	04/07/10	0.0	411.5	16.5	387	7,442	16.6	400	7,692	20	12	4	13,598
	04/09/10	3.7	415.2	16.4	390	7,500	16.5	403	7,750	20	12	4	13,598
56	04/14/10	12.0	427.2	16.5	402	7,731	16.5	415	7,981	20	12	4	13,598
57	04/21/10	0.1	427.3	16.6	402	7,731	16.6	415	7,981	20	12	4	13,598
58	04/27/10	4.4	431.7	16.6	406	7,808	16.6	419	8,058	20	12	4	13,598
	04/29/10	0.0	431.7	16.6	406	7,808	16.6	419	8,058	19	12	4	13,598
59	05/04/10	7.9	439.6	16.6	413	7,942	16.6	427	8,212	19	12	4	13,598
	05/06/10	3.9	443.5	16.4	417	8,019	16.5	430	8,269	19	12	4	13,598
	05/07/10	0.2	443.7	16.5	417	8,019	16.5	430	8,269	19	12	4	13,598
60	05/11/10	3.6	447.3	16.5	421	8,096	16.6	434	8,346	20	12	4	13,598
	05/12/10	3.7	451.0	16.4	424	8,154	16.5	437	8,404	19	12	4	13,598
	05/13/10	0.0	451.0	16.6	424	8,154	16.3	437	8,404	19	12	4	13,598
	05/14/10	3.7	454.7	16.4	428	8,231	16.5	441	8,481	19	12	4	13,598
61	05/17/10	0.1	454.8	16.4	428	8,231	16.6	441	8,481	18	12	4	13,598
	05/18/10	3.7	458.5	16.3	431	8,288	16.7	445	8,558	20	12	4	13,598
	05/19/10	5.8	464.3	16.4	437	8,404	16.5	450	8,654	20	12	4	13,598
	05/21/10	4.2	468.5	16.5	441	8,481	16.5	454	8,731	20	12	4	13,598
62	05/27/10	5.5	474.0	16.6	446	8,577	16.5	459	8,827	19	11	4	13,598
	05/28/10	3.7	477.7	16.5	450	8,654	16.3	463	8,904	19	11	4	13,598
63	06/01/10	1.8	479.5	16.4	451	8,673	16.4	465	8,942	18	11	4	13,598
	06/02/10	1.7	481.2	16.3	453	8,712	16.3	466	8,962	19	11	4	14,254
	06/03/10	0.1	481.3	16.3	453	8,712	16.4	466	8,962	19	11	4	14,254
64	06/08/10	6.2	487.5	16.4	459	8,827	16.6	472	9,077	19	11	4	14,254
	06/10/10	4.3	491.8	16.5	463	8,904	16.5	476	9,154	20	12	4	14,913
	06/11/10	5.0	496.8	16.5	467	8,981	16.5	481	9,250	20	12	4	14,913

Table A-1. EPA Arsenic Demonstration Project at Goshen, IN- Daily System Operation Log Sheet (Continued)

Week No.	Date	Well Pumps		Vessel A			Vessel B			Pressure			Backwash
		Operating time	Cumulative Operating Time	Instant Flow rate	Totalizer X1000	Bed Volumes Treated	Instant Flow rate	Totalizer X1000	Bed Volumes Treated ^(a)	Inlet Pressure Vessel A	Outlet Pressure Vessel A	Outlet Pressure Vessel B	Backwash Totalizer
		(hr)	(hr)	(gpm)	(gal)	BV	(gpm)	(gal)	BV	(psi)	(psi)	(psi)	(gal)
65	06/15/10	0.3	497.1	16.4	467	8,981	16.4	481	9,250	20	12	4	14,913
	06/17/10	3.5	500.6	16.4	471	9,058	16.6	485	9,327	20	12	4	14,913
	06/18/10	3.0	503.6	16.1	474	9,115	16.3	487	9,365	20	12	4	14,913
66	06/30/10	5.4	509.0	16.4	479	9,212	16.5	493	9,481	19	11	3	14,913
	07/01/10	0.0	509.0	16.5	479	9,212	16.3	493	9,481	19	11	3	15,573
67	07/06/10	0.1	509.1	16.2	479	9,212	16.3	493	9,481	18	10	3	15,573
	07/08/10	0.0	509.1	16.1	479	9,212	16.4	493	9,481	18	10	3	15,573
68	07/14/10	0.0	509.1	16.2	479	9,212	16.5	493	9,481	18	10	3	15,573
	07/16/10	4.0	513.1	16.2	483	9,288	16.6	496	9,538	19	11	3	15,573
70	07/29/10	0.0	513.1	16.3	483	9,288	16.5	496	9,538	17	10	2	15,573
	07/30/10	0.0	513.1	16.3	483	9,288	16.5	496	9,538	18	10	2	15,573
71	08/04/10	0.1	513.2	16.3	483	9,288	16.5	496	9,538	18	10	2	15,573
72	08/09/10	3.5	516.7	16.3	486	9,346	16.4	500	9,615	18	10	2	15,573
	08/10/10	0.1	516.8	16.5	486	9,346	16.6	500	9,615	18	10	2	15,573
	08/13/10	0.2	517.0	16.5	487	9,365	16.5	500	9,615	18	10	2	15,573
73	08/18/10	0.0	517.0	16.3	487	9,365	16.6	500	9,615	18	10	2	15,573
	08/19/10	0.0	517.0	16.4	487	9,365	16.6	500	9,615	18	10	2	15,573
74	08/30/10	3.3	520.3	16.2	490	9,423	16.5	504	9,692	18	10	2	15,573
	09/01/10	4.9	525.2	16.4	494	9,500	16.3	508	9,769	18	10	2	15,573
	09/02/10	0.1	525.3	16.3	494	9,500	16.3	508	9,769	18	10	2	15,573
75	09/08/10	3.7	529.0	16.1	498	9,577	16.3	511	9,827	18	10	2	15,573
	09/09/10	3.7	532.7	16	501	9,635	16.3	515	9,904	18	10	2	16,229
	09/10/10	0.1	532.8	16.3	501	9,635	16.3	515	9,904	18	10	2	16,229
76	09/14/10	4.0	536.8	16.2	505	9,712	16.3	519	9,981	18	11	2	16,229
	09/15/10	4.1	540.9	16.1	509	9,788	16.4	523	10,058	18	11	2	16,229
	09/17/10	3.8	544.7	16.2	513	9,865	16.5	526	10,115	19	11	2	16,229
77	09/21/10	3.8	548.5	16.0	516	9,923	16.2	530	10,192	20	12	3	16,229
78	09/29/10	12.3	560.8	16.3	528	10,154	16.5	541	10,404	18	11	2	16,229
	09/30/10	0.1	560.9	16.3	528	10,154	16.4	541	10,404	18	11	2	16,229

NA = not available

(a) BV based on 7.5 cubic feet of media in each vessel

APPENDIX B
ANALYTICAL DATA

Table B-1. Analytical Results from Long-Term Sampling at Woodstock, CT

Sampling Date		03/10/09			03/25/09			04/07/09			04/21/09			05/06/09		
Sampling Location	Parameter Unit	IN	TA	TB	IN	TA	TB	IN	TA	TB	IN	TA	TB	IN	TA	TB
Bed Volume	10 ³	-	-	-	-	0.4	0.5	-	0.9	1.0	-	1.0	1.1	-	1.4	1.5
Alkalinity (as CaCO ₃)	mg/L	74.8	56.1	56.1	76.0	63.3	59.1	81.2	71.6	69.3	75.4	65.7	65.7	77.6	70.3	67.9
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	0.4	0.3	0.3	-	-	-	0.3	0.4	0.5	-	-	-	0.4	0.4	0.3
Nitrate (as N)	mg/L	21.7	21.8	21.4	-	-	-	22.7	27.7	21	-	-	-	21.6	22.1	22.0
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	<0.05	<0.05	<0.05	-	-	-	<0.05	<0.05	<0.05
Phosphorus (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Silica (as SiO ₂)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	15.4	1.3	3.2	14.0	2.7	4.4	14.5	7.0	5.1	15.3	7.6	5.6	16.7	10.8	6.8
pH	S.U.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Temperature	°C	0.1	0.3	2.3	0.7	11.0	2.2	0.4	62.0	2.5	0.4	2.2	1.3	0.4	19.0	0.4
DO	mg/L	7.1	6.7	6.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	25.0	25.0	25.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Hardness (as CaCO ₃)	mg/L	2.8	2.1	2.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ca Hardness (as CaCO ₃)	mg/L	260	259	257	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mg Hardness (as CaCO ₃)	mg/L	85.8	71.4	74.5	-	-	-	72.9	69.8	68.9	-	-	-	96.1	89.2	87.8
As (total)	µg/L	77.1	63.7	67.3	-	-	-	67.2	64.3	63.4	-	-	-	90.6	84.0	82.6
As (soluble)	µg/L	8.6	7.7	7.2	-	-	-	5.7	5.5	5.5	-	-	-	5.5	5.2	5.2
As (particulate)	µg/L	27.7	0.3	0.8	23.5	0.3	0.6	22.8	0.3	0.5	26.3	0.8	0.7	26.1	1.2	0.5
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	µg/L	27.8	0.3	0.9	-	-	-	23.1	1.0	0.9	-	-	-	27.3	1.4	0.6
Fe (total)	µg/L	<0.1	<0.1	<0.1	-	-	-	<0.1	<0.1	<0.1	-	-	-	<0.1	<0.1	<0.1
Fe (soluble)	µg/L	27.4	0.4	0.9	-	-	-	4.9	0.3	0.3	-	-	-	6.4	0.6	0.3
Mn (total)	µg/L	0.4	<0.1	<0.1	-	-	-	18.2	0.8	0.6	-	-	-	20.9	0.8	0.3
Mn (soluble)	µg/L	<25	<25	<25	<25	<25	<25	29	<25	<25	<25	<25	<25	29	<25	<25
Ti (total)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ti (soluble)	µg/L	<25	<25	<25	-	-	-	<25	<25	<25	-	-	-	<25	<25	<25
		20.6	0.5	0.7	18.7	0.4	0.4	14.8	1.2	0.3	14.2	0.2	0.3	19.2	0.4	0.3
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		19.8	0.5	0.7	-	-	-	13.9	0.5	0.3	-	-	-	19.0	0.4	0.3
		1.3	2.5	6.2	1.1	28.2	15.7	1.1	75.8	4.5	1.4	26.2	5.6	1.4	33.4	1.4
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1.1	0.2	0.3	-	-	-	0.9	1.5	0.6	-	-	-	1.3	0.9	0.6

Table B-1. Analytical Results from Long-Term Sampling at Woodstock, CT (Continued)

Sampling Date		05/19/09			06/04/09			06/17/09 ^(a)			07/02/09		
Sampling Location	Parameter Unit	IN	TA	TB	IN	TA	TB	IN	TA	TB	IN	TA	TB
Bed Volume	10 ³	-	1.6	1.8	-	1.9	2.1	-	2.3	2.5	-	2.4	2.6
Alkalinity (as CaCO ₃)	mg/L	68.1	70.7	73.2	77.9	75.8	69.5	79.1	72.7	72.7	77.6	70.9	73.1
		-	-	-	-	-	-	79.1	74.9	70.6	-	-	-
Fluoride	mg/L	-	-	-	0.3	0.3	0.3	-	-	-	0.4	0.3	0.3
Sulfate	mg/L	-	-	-	23.4	22	22.6	-	-	-	25.8	26.3	25.0
Nitrate (as N)	mg/L	-	-	-	<0.05	<0.05	<0.05	-	-	-	<0.05	<0.05	<0.05
Phosphorus (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
		-	-	-	-	-	-	<10	<10	<10	-	-	-
Silica (as SiO ₂)	mg/L	16.8	11.9	8.5	15.9	12.2	8.7	16.6	12.7	9.9	15.6	9.6	12.1
		-	-	-	-	-	-	16.2	12.9	9.9	-	-	-
Turbidity	NTU	0.8	1.5	1.0	0.9	1.0	0.9	0.6	1.0	0.7	0.7	0.1	0.5
		-	-	-	-	-	-	0.4	1.4	1.2	-	-	-
pH	S.U.	7.0	7.4	7.5	NA	NA	NA	7.5	7.4	7.2	7.5	7.6	7.1
Temperature	°C	13.2	13.3	13.2	NA	NA	NA	25.0	25.0	25.0	15.3	14.5	14.8
DO	mg/L	9.9	8.6	9.8	NA	NA	NA	9.9	9.7	9.6	NA	NA	NA
ORP	mV	391	387	383	NA	NA	NA	264	267	268	256	260	263
Total Hardness (as CaCO ₃)	mg/L	-	-	-	83.2	80.3	78.0	-	-	-	93.8	89.5	90.6
Ca Hardness (as CaCO ₃)	mg/L	-	-	-	78.3	75.6	72.9	-	-	-	88.9	84.8	85.9
Mg Hardness (as CaCO ₃)	mg/L	-	-	-	4.9	4.8	5.1	-	-	-	4.9	4.7	4.8
As (total)	µg/L	26.5	1.6	0.7	25.6	1.7	0.6	28.2	2.4	0.7	25.4	2.0	0.6
		-	-	-	-	-	-	27.3	2.3	0.7	-	-	-
As (soluble)	µg/L	-	-	-	25.9	1.8	0.6	-	-	-	25.5	2.0	0.7
As (particulate)	µg/L	-	-	-	<0.1	<0.1	<0.1	-	-	-	<0.1	<0.1	<0.1
As (III)	µg/L	-	-	-	4.2	0.6	0.5	-	-	-	4.1	0.7	0.3
As (V)	µg/L	-	-	-	21.7	1.2	0.1	-	-	-	21.3	1.2	0.4
Fe (total)	µg/L	<25	<25	<25	49	<25	<25	<25	<25	<25	<25	<25	<25
		-	-	-	-	-	-	<25	<25	<25	-	-	-
Fe (soluble)	µg/L	-	-	-	<25	<25	<25	-	-	-	<25	<25	<25
Mn (total)	µg/L	17.9	0.4	0.2	18.9	0.3	0.3	18.6	0.2	0.2	16.0	<0.1	<0.1
		-	-	-	-	-	-	18.2	0.2	0.2	-	-	-
Mn (soluble)	µg/L	-	-	-	17.6	0.3	0.3	-	-	-	15.8	<0.1	0.3
Ti (total)	µg/L	1.1	10.2	0.8	1.3	1.6	0.9	1.4	1.5	0.8	1.1	4.4	1.0
		-	-	-	-	-	-	1.3	1.5	1.1	-	-	-
Ti (soluble)	µg/L	-	-	-	1.0	0.8	0.6	-	-	-	1.0	0.9	0.8

Table B-1. Analytical Results from Long-Term Sampling at Woodstock, CT (Continued)

Sampling Date		08/05/09			08/13/09 ^(b)			08/27/09			09/10/09		
Sampling Location	Unit	IN	TA	TB	IN	TA	TB	IN	TA	TB	IN	TA	TB
Bed Volume	10 ³	-	2.8	3.0	-	2.8	3.1	-	2.9	2.9	-	3.2	3.4
Alkalinity (as CaCO ₃)	mg/L	72.9	77.5	72.9	70.9	77.7	70.9	70.0	72.3	72.3	68.5	66.7	61.1
		-	-	-	-	-	-	-	-	-	68.5	66.7	64.8
Fluoride	mg/L	2.0	0.4	2.4	-	-	-	0.3	0.3	0.4	-	-	-
Sulfate	mg/L	22.8	21.3	23.9	-	-	-	26.1	24.5	22.2	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	0.1	<0.05	<0.05	-	-	-
Phosphorus (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
		-	-	-	-	-	-	-	-	-	<10	<10	<10
Silica (as SiO ₂)	mg/L	15.9	15.6	11.7	15.0	15.3	11.1	15.8	14.6	11.8	15.9	13.0	11.0
		-	-	-	-	-	-	-	-	-	16.2	12.9	10.7
Turbidity	NTU	0.4	6.6	1.9	1.3	0.8	1.2	1.4	6.4	9.3	1.2	0.9	0.4
		-	-	-	-	-	-	-	-	-	3.0	1.5	0.8
pH	S.U.	NA	NA	NA	7.0	7.3	7.2	7.2	7.5	7.3	7.3	7.4	7.3
Temperature	°C	NA	NA	NA	22.7	22.8	22.8	18.9	20.1	20.8	15.3	14.4	14.7
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	309	356	373	244	260	265	294	402	396
Total Hardness (as CaCO ₃)	mg/L	82.4	84.4	81.0	-	-	-	85.7	79.0	79.5	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	75.0	77.0	73.9	-	-	-	79.8	73.8	74.3	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	7.4	7.3	7.1	-	-	-	5.8	5.3	5.2	-	-	-
As (total)	µg/L	28.3	<0.1	<0.1	23.6	2.8	0.9	26.8	3.6	1.2	24.0	1.2	<0.1
		-	-	-	-	-	-	-	-	-	23.6	1.1	<0.1
As (soluble)	µg/L	28.1	<0.1	<0.1	-	-	-	26.5	3.5	1.2	-	-	-
As (particulate)	µg/L	0.2	<0.1	<0.1	-	-	-	0.2	<0.1	<0.1	-	-	-
As (III)	µg/L	7.0	<0.1	<0.1	-	-	-	6.3	1.6	1.0	-	-	-
As (V)	µg/L	21.0	<0.1	<0.1	-	-	-	20.3	1.9	0.2	-	-	-
Fe (total)	µg/L	<25	<25	<25	60	<25	<25	39	<25	<25	67	<25	<25
		-	-	-	-	-	-	-	-	-	66	<25	<25
Fe (soluble)	µg/L	<25	<25	<25	-	-	-	<25	<25	<25	-	-	-
Mn (total)	µg/L	23.4	0.2	0.3	12.1	0.3	0.3	16.3	0.9	0.7	17.8	0.2	0.2
		-	-	-	-	-	-	-	-	-	17.8	0.2	0.2
Mn (soluble)	µg/L	23.4	0.2	0.3	-	-	-	16.1	0.6	0.8	-	-	-
Ti (total)	µg/L	1.2	27.0	6.5	1.1	3.3	0.8	1.1	98.6	38.3	1.2	2.1	2.2
		-	-	-	-	-	-	-	-	-	1.2	2.5	1.2
Ti (soluble)	µg/L	1.2	1.3	1.7	-	-	-	1.1	2.2	1.7	-	-	-

Table B-1. Analytical Results from Long-Term Sampling at Woodstock, CT (Continued)

Sampling Date		09/22/09			10/15/09			10/29/09			11/10/09		
Sampling Location	Parameter Unit	IN	TA	TB	IN	TA	TB	IN	TA	TB	IN	TA	TB
Bed Volume	10 ³	-	3.5	3.7	-	3.9	4.2	-	4.3	4.6	-	4.6	4.8
Alkalinity (as CaCO ₃)	mg/L	68.5	75.9	72.2	77.6	77.6	70.2	70.6	69.6	71.9	75.2	79.8	77.5
		-	-	-	-	-	-	-	-	-	79.8	79.8	79.8
Fluoride	mg/L	0.3	0.3	0.3	-	-	-	0.6	0.3	0.4	-	-	-
Sulfate	mg/L	22.5	22.9	27.2	-	-	-	21.9	23.3	23.5	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	<0.05	<0.05	<0.05	-	-	-
Phosphorus (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
		-	-	-	-	-	-	-	-	-	<10	<10	<10
Silica (as SiO ₂)	mg/L	14.9	14.0	11.4	14.3	12.9	11.0	16.1	15.0	12.7	16.8	16.1	14.0
		-	-	-	-	-	-	-	-	-	16.8	15.9	13.6
Turbidity	NTU	0.2	0.4	0.3	0.5	0.5	0.2	2.6	3.2	3.8	0.4	1.1	0.3
		-	-	-	-	-	-	-	-	-	0.3	1.2	0.3
pH	S.U.	6.3	7.2	6.9	NA	NA	NA	6.7	7.4	7.4	NA	NA	NA
Temperature	°C	14.7	15.0	15.1	NA	NA	NA	13.0	13.2	13.4	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	256	243	71.4	NA	NA	NA	344	326	19.5	NA	NA	NA
Total Hardness (as CaCO ₃)	mg/L	81.7	82.7	80.3	-	-	-	127	112	134	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	76.2	77.2	74.7	-	-	-	120	105	127	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	5.6	5.6	5.6	-	-	-	7.0	7.0	7.1	-	-	-
As (total)	µg/L	20.2	3.6	0.9	22.3	2.1	<0.1	24.1	4.2	0.6	21.6	5.9	1.1
		-	-	-	-	-	-	-	-	-	21.1	5.8	1.0
As (soluble)	µg/L	19.7	3.6	0.9	-	-	-	23.9	4.3	0.5	-	-	-
As (particulate)	µg/L	0.5	<0.1	<0.1	-	-	-	0.2	<0.1	<0.1	-	-	-
As (III)	µg/L	2.6	1.3	0.6	-	-	-	7.9	1.1	0.2	-	-	-
As (V)	µg/L	17.1	2.3	0.3	-	-	-	16.0	3.1	0.3	-	-	-
Fe (total)	µg/L	<25	<25	<25	<25	<25	<25	83	<25	<25	<25	<25	<25
		-	-	-	-	-	-	-	-	-	<25	<25	<25
Fe (soluble)	µg/L	<25	<25	<25	-	-	-	<25	<25	<25	-	-	-
Mn (total)	µg/L	17.8	0.1	0.1	16.9	0.2	0.1	18.6	0.3	0.2	20.1	<0.1	<0.1
		-	-	-	-	-	-	-	-	-	19.3	<0.1	<0.1
Mn (soluble)	µg/L	17.6	0.1	0.1	-	-	-	17.8	0.3	0.4	-	-	-
Ti (total)	µg/L	1.6	2.0	1.3	1.4	1.3	1.0	1.7	2.3	1.4	1.1	2.6	1.6
		-	-	-	-	-	-	-	-	-	1.2	2.4	1.4
Ti (soluble)	µg/L	1.5	1.5	1.2	-	-	-	1.4	1.5	1.2	-	-	-

Table B-1. Analytical Results from Long-Term Sampling at Woodstock, CT (Continued)

Sampling Date		12/01/09			12/15/09			12/30/09			01/12/10		
Sampling Location	Parameter Unit	IN	TA	TB	IN	TA	TB	IN	TA	TB	IN	TA	TB
Bed Volume	10 ³	-	5.2	5.4	-	5.3	5.5	-	5.5	5.8	-	5.7	5.9
Alkalinity (as CaCO ₃)	mg/L	76.3	78.6	74	86.7	77.8	73.3	78.1	75.7	82.8	74.5	67.9	72.3
		-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.5	0.5	0.4	-	-	-	0.6	0.4	0.4	-	-	-
Sulfate	mg/L	23.6	24.1	24.4	-	-	-	23.0	25.4	25.4	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	<0.05	<0.05	<0.05	-	-	-
Phosphorus (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	16.5	15.7	13.5	15.9	15.8	14.5	16.4	15.4	13.5	16.6	15.6	14.2
		-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	4.0	0.7	2.4	0.3	1.3	0.4	1.9	2.6	2.0	0.8	0.7	0.2
		-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	7.1	6.7	5.6	NA	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	12.8	14.2	12.8	NA	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	337	323	324	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Hardness (as CaCO ₃)	mg/L	81.1	83.7	81.1	-	-	-	86.3	83.7	84.3	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	75.8	78.2	75.7	-	-	-	80.3	77.8	78.4	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	5.3	5.5	5.3	-	-	-	6.0	5.9	6.0	-	-	-
As (total)	µg/L	24.4	5.3	0.9	22.2	5.7	1.5	29.3	6.0	1.5	24.5	6.0	1.3
		-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	24.9	5.3	0.9	-	-	-	29.1	6.1	1.6	-	-	-
As (particulate)	µg/L	<0.1	<0.1	<0.1	-	-	-	0.2	<0.1	<0.1	-	-	-
As (III)	µg/L	7.2	1.6	0.5	-	-	-	7.0	2.1	0.7	-	-	-
As (V)	µg/L	17.7	3.7	0.5	-	-	-	22.0	3.9	0.9	-	-	-
Fe (total)	µg/L	32	<25	<25	35	<25	<25	<25	<25	<25	<25	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	<25	<25	<25	-	-	-	<25	<25	<25	-	-	-
Mn (total)	µg/L	13.7	0.1	0.1	15.6	0.2	0.2	16.8	0.1	<0.1	17.5	0.1	<0.1
		-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	13.8	0.1	0.1	-	-	-	16.5	0.1	<0.1	-	-	-
Ti (total)	µg/L	1.2	2.6	1.0	1.4	3.9	1.5	1.5	1.8	1.5	1.2	1.8	1.1
		-	-	-	-	-	-	-	-	-	-	-	-
Ti (soluble)	µg/L	1.1	1.0	0.9	-	-	-	1.3	1.5	1.2	-	-	-

Table B-1. Analytical Results from Long-Term Sampling at Woodstock, CT (Continued)

Sampling Date		01/27/10			02/09/10			02/24/10			03/10/10 ^(a)		
Sampling Location	Parameter Unit	IN	TA	TB	IN	TA	TB	IN	TA	TB	IN	TA	TB
Bed Volume	10 ³	-	6.0	6.2	-	6.3	6.5	-	6.4	6.7	-	6.8	7.0
Alkalinity (as CaCO ₃)	mg/L	78.2	80.5	73.6	82.3	77.7	80.0	80.0	77.7	75.4	72.9	77.6	82.4
		-	-	-	82.3	73.1	77.7	-	-	-	-	-	-
Fluoride	mg/L	0.3	0.3	0.3	-	-	-	0.4	0.4	0.3	-	-	-
Sulfate	mg/L	19.9	20.9	19.4	-	-	-	21.8	21.9	22.6	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	<0.05	<0.05	<0.05	-	-	-
Phosphorus (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
		-	-	-	<10	<10	<10	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	16.7	15.6	15.1	15.9	14.8	13.5	15.6	14.4	13.3	15.0	14.2	13.6
		-	-	-	16.3	14.6	13.7	-	-	-	-	-	-
Turbidity	NTU	0.9	0.5	0.4	1.3	1.0	1.5	0.7	0.4	0.5	1.2	1.5	0.6
		-	-	-	1.0	1.2	1.1	-	-	-	-	-	-
pH	S.U.	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.9	7.6	7.4
Temperature	°C	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.5	10.4	11.6
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	360	381	393
Total Hardness (as CaCO ₃)	mg/L	69.5	67.0	66.9	-	-	-	89.2	78.1	74.3	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	64.1	61.8	61.7	-	-	-	83.5	73.1	68.7	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	5.4	5.2	5.2	-	-	-	5.7	5.0	5.5	-	-	-
As (total)	µg/L	25.5	6.2	1.6	17.9	7.2	1.4	22.5	7.3	1.5	24.9	8.4	1.7
		-	-	-	18.5	7.0	1.4	-	-	-	-	-	-
As (soluble)	µg/L	25.4	6.1	1.6	-	-	-	23.2	7.2	1.5	-	-	-
As (particulate)	µg/L	<0.1	<0.1	<0.1	-	-	-	<0.1	<0.1	<0.1	-	-	-
As (III)	µg/L	5.6	1.9	0.8	-	-	-	4.7	2.5	0.7	-	-	-
As (V)	µg/L	19.8	4.2	0.8	-	-	-	18.5	4.7	0.8	-	-	-
Fe (total)	µg/L	53	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
		-	-	-	<25	<25	<25	-	-	-	-	-	-
Fe (soluble)	µg/L	<25	<25	<25	-	-	-	<25	<25	<25	-	-	-
Mn (total)	µg/L	19.8	0.1	0.1	13.0	0.2	0.2	21.5	0.3	<0.1	18.4	0.2	0.2
		-	-	-	13.0	0.2	0.2	-	-	-	-	-	-
Mn (soluble)	µg/L	18.1	0.1	0.1	-	-	-	19.0	0.1	<0.1	-	-	-
Ti (total)	µg/L	2.0	2.8	1.3	1.1	1.4	1.5	1.9	1.6	1.5	1.4	4.0	2.8
		-	-	-	1.0	1.4	1.4	-	-	-	-	-	-
Ti (soluble)	µg/L	1.2	1.2	1.2	-	-	-	1.0	0.8	0.8	-	-	-

Table B-1. Analytical Results from Long-Term Sampling at Woodstock, CT (Continued)

Sampling Date		03/25/10			04/07/10			04/21/10			05/06/10		
Sampling Location	Parameter Unit	IN	TA	TB	IN	TA	TB	IN	TA	TB	IN	TA	TB
Bed Volume	10 ³	-	7.2	7.4	-	7.4	7.7	-	7.7	8.0	-	8.0	8.3
Alkalinity (as CaCO ₃)	mg/L	74.1	71.9	76.3	75.6	75.6	80.0	126	80.0	82.3	87.9	80.9	78.6
		-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.5	0.3	0.5	-	-	-	0.3	0.4	0.4	-	-	-
Sulfate	mg/L	18.1	22.0	20.8	-	-	-	21.7	24.4	21.2	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	<0.05	<0.05	<0.05	-	-	-
Phosphorus (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	15.6	14.7	14.1	16.1	15.7	15.9	15.7	15.6	15.6	15.6	15.5	15.2
		-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	0.4	0.8	0.4	0.3	0.2	0.3	1.6	1.5	1.9	0.9	0.5	0.9
		-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	NA	NA	NA	11.9	11.9	-	NA	NA	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	417	418	-	NA	NA	NA	NA	NA	NA
Total Hardness (as CaCO ₃)	mg/L	77.0	78.4	79.0	-	-	-	58.2	73.2	72.9	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	71.6	72.7	73.5	-	-	-	52.4	67.5	67.3	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	5.5	5.7	5.5	-	-	-	5.8	5.7	5.6	-	-	-
As (total)	µg/L	23.8	8.6	2.2	25.1	9.8	2.5	26.2	10.3	2.7	27.7	11.4	2.8
		-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	23.9	8.7	2.2	-	-	-	26.2	10.8	2.8	-	-	-
As (particulate)	µg/L	<0.1	<0.1	<0.1	-	-	-	<0.1	<0.1	<0.1	-	-	-
As (III)	µg/L	7.7	2.7	0.6	-	-	-	4.2	1.7	0.9	-	-	-
As (V)	µg/L	16.2	5.9	1.5	-	-	-	22.0	9.2	1.9	-	-	-
Fe (total)	µg/L	<25	<25	<25	<25	<25	<25	47	<25	<25	<25	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	<25	<25	<25	-	-	-	<25	<25	<25	-	-	-
Mn (total)	µg/L	16.9	<0.1	<0.1	32.0	0.2	0.1	15.8	0.2	0.1	17.3	0.1	<0.1
		-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	19.2	<0.1	<0.1	-	-	-	14.8	0.1	<0.01	-	-	-
Ti (total)	µg/L	4.8	1.6	1.6	1.4	1.6	1.3	1.5	1.6	1.4	1.1	1.3	0.9
		-	-	-	-	-	-	-	-	-	-	-	-
Ti (soluble)	µg/L	1.2	1.3	1.1	-	-	-	1.2	1.2	1.3	-	-	-

Table B-1. Analytical Results from Long-Term Sampling at Woodstock, CT (Continued)

Sampling Date		05/18/10			06/03/10			06/15/10			07/14/10		
Sampling Location	Unit	IN	TA	TB	IN	TA	TB	IN	TA	TB	IN	TA	TB
Bed Volume	10 ³	-	8.3	8.6	-	8.7	9.0	-	9.0	9.3	-	9.2	9.5
Alkalinity (as CaCO ₃)	mg/L	76.3	76.3	76.3	118	93.9	78.2	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	0.3	0.3	0.3	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	20.2	20.6	22.2	-	-	-	-	-	-	-	-	-
Phosphorus (as P)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-
	µg/L	<10	<10	<10	<10	<10	<10	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	15.9	16.3	15.3	16.1	17.9	17.1	-	-	-	-	-	-
pH	S.U.	-	-	-	-	-	-	-	-	-	-	-	-
Temperature	°C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Hardness (as CaCO ₃)	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ca Hardness (as CaCO ₃)	mg/L	84.3	86.5	86.9	-	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	78.5	80.6	80.9	-	-	-	-	-	-	-	-	-
As (total)	µg/L	5.8	5.9	6.0	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	23.5	11.2	2.7	27.7	15.6	5.2	26.0	16.6	4.4	25.4	15.1	4.1
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	µg/L	22.3	11.9	2.6	-	-	-	26.8	18.0	4.6	27.9	16.6	4.3
As (V)	µg/L	1.2	<0.1	<0.1	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Fe (total)	µg/L	3.1	4.1	0.8	-	-	-	7.3	6.4	1.4	6.2	3.1	0.8
Fe (soluble)	µg/L	19.2	7.8	1.9	-	-	-	19.5	11.6	3.2	21.7	13.6	3.5
Mn (total)	µg/L	<25	<25	<25	189	<25	<25	<25	<25	<25	25	<25	<25
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-
Ti (total)	µg/L	<25	<25	<25	-	-	-	<25	<25	<25	<25	<25	<25
Ti (soluble)	µg/L	16.8	0.1	<0.1	21.0	0.1	<0.1	15.4	0.2	0.1	16.1	0.2	<0.1
	µg/L	-	-	-	-	-	-	-	-	-	-	-	-
	µg/L	17.7	0.1	<0.1	-	-	-	14.8	0.2	<0.1	15.3	0.1	<0.1
	µg/L	1.2	1.4	1.2	1.8	7.0	2.4	1.1	2.4	1.3	1.5	4.2	1.5
	µg/L	-	-	-	-	-	-	-	-	-	-	-	-
	µg/L	1.1	1.1	1.0	-	-	-	0.9	1.1	1.0	0.9	1.1	1.0

Table B-1. Analytical Results from Long-Term Sampling at Woodstock, CT (Continued)

Sampling Date		08/10/10			09/14/10			10/06/10		
Sampling Location	Parameter Unit	IN	TA	TB	IN	TA	TB	IN	TA	TB
Bed Volume	10 ³	-	9.3	9.6	-	9.7	10.0	-	~10.2	~10.4
Alkalinity (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-
Phosphorus (as P)	µg/L	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	-	-	-	-	-	-	-	-	-
Turbidity	NTU	-	-	-	-	-	-	-	-	-
pH	S.U.	NA	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	NA	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	-
As (total)	µg/L	25.2	17.2	4.3	27.1	13.6	4.3	24.7	15.3	5.2
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	26.1	17.1	4.2	25.6	14.8	4.4	25.8	15.4	5.0
As (III)	µg/L	<0.1	0.1	0.1	1.5	<0.1	<0.1	<0.1	<0.1	0.2
As (V)	µg/L	3.7	5.6	1.3	10.1	3.5	1.3	5.9	2.8	0.6
Fe (total)	µg/L	22.4	11.5	2.9	15.5	11.4	3.1	19.9	12.6	4.4
Fe (soluble)	µg/L	53	<25	<25	31	<25	<25	52	<25	<25
Mn (total)	µg/L	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	<25	<25	<25	33	<25	<25	<25	<25	<25
Ti (total)	µg/L	9.8	0.2	< 0.1	17.0	0.1	<0.1	17.2	0.2	0.1
Ti (soluble)	µg/L	-	-	-	-	-	-	-	-	-
		8.6	0.1	0.1	15.4	<0.1	<0.1	17.8	0.1	0.1
		1.2	1.7	1.2	1.2	3.0	1.6	0.9	2.1	1.0
		-	-	-	-	-	-	-	-	-
		0.9	1.1	1.0	1.0	1.0	1.0	0.9	0.9	0.9