

**Arsenic Removal from Drinking Water by Adsorptive Media  
U.S. EPA Demonstration Project at  
Richmond Elementary School in Susanville, CA  
Six-Month Evaluation Report**

by

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Sally Gutierrez, Director  
National Risk Management Research Laboratory

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## ABSTRACT

This report documents the activities performed during and the results obtained from the first six months of the performance evaluation of the arsenic removal treatment technology at Richmond Elementary School in Susanville, California. The objectives of the project are to evaluate 1) the effectiveness of an Aquatic Treatment Systems, Inc. (ATS) arsenic removal system in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10  $\mu\text{g/L}$ , 2) the reliability of the treatment system, 3) the system operation and maintenance (O&M) and operator skill requirements, and 4) the capital and O&M cost of the technology. The project also characterizes the water in the distribution system and process residuals produced by the treatment process.

The ATS system consisted of one 25- $\mu\text{m}$  sediment filter, two 10-in diameter, 54-in tall oxidation columns, and three 10-in diameter, 54-in tall adsorption columns connected in series. The columns were constructed of sealed polyglass and loaded with 1.5  $\text{ft}^3$  each of either A/P Complex 2002 oxidizing media (consisting of activated alumina and sodium metaperiodate) or A/I Complex 2000 adsorptive media (consisting of activated alumina and a proprietary iron complex). Based on the design flowrate of 12 gal/min (gpm), the empty bed contact time (EBCT) in each column was 0.9 min (or 2.8 min for three adsorption columns in series) and the hydraulic loading rate to each column was 22  $\text{gpm/ft}^2$ .

Between September 7, 2005, and March 9, 2006, the As/1200CS system operated an average of 1.7 hr/day for a total of 207 hr, treating approximately 101,000 gal of water. This volume throughput was equivalent to 9,000 bed volumes (BV) based on 1.5  $\text{ft}^3$  of media in the lead adsorption column or 3,000 BV based on 4.5  $\text{ft}^3$  of media in three adsorption columns. The average system flowrate was 9.0 gpm, which yielded an average EBCT of 1.2 min in one adsorption column or 3.6 min in three adsorption columns.

The oxidizing media was effective at converting As(III), the predominant arsenic species, to As(V) throughout the six month period, typically lowering the As(III) concentrations from  $16.7 \pm 9.2 \mu\text{g/L}$  to  $<0.5 \mu\text{g/L}$ . Oxidation of As(III) was achieved, presumably, through a reaction with sodium metaperiodate, resulting in I<sup>-</sup> in the column effluent. Analyses of the column effluent indicated elevated iodine concentrations, which averaged 86.1  $\mu\text{g/L}$  (as I) following the oxidation columns and 112  $\mu\text{g/L}$  (as I) following the adsorption columns (compared to 11  $\mu\text{g/L}$  [as I], on average, in raw water). Iodine measured in the column effluent most likely was leached from the oxidation columns as  $\text{IO}_4^-$  or other reaction intermediates. The oxidizing media also showed a significant adsorptive capacity for arsenic (i.e., 0.20  $\mu\text{g/mg}$  of media), effectively removing it to  $<10 \mu\text{g/L}$  when processing the first 4,800 BV of water through the lead oxidation column. Arsenic concentrations after the lead oxidation column reached the influent levels after approximately 7,500 BV, based on the 1.5- $\text{ft}^3$  media bed in the column. After 9,000 BV or six months of system operation, the arsenic concentration after the second oxidation column was 10.7  $\mu\text{g/L}$ , which was still below the influent concentrations of about 31  $\mu\text{g/L}$ .

Arsenic concentrations remained below 0.2  $\mu\text{g/L}$  in the effluent of the lead adsorption column during the first six months of operation. This is because the oxidation columns had removed the majority of arsenic from source water before it reached the adsorption columns.

Aluminum concentrations (existing primarily in the soluble form) in the treated water following adsorption columns were about 14 to 35  $\mu\text{g/L}$  higher than those in raw water, indicating leaching of aluminum from the oxidizing and/or adsorptive media. Even with the increase in aluminum concentrations following the treatment system, the concentrations were below the secondary drinking water standard for aluminum of 50 to 200  $\mu\text{g/L}$ . Leaching of aluminum continued throughout the six-month study period.

Comparison of distribution system sampling results before and after the operation of the As/1200CS system showed a significant decrease in arsenic concentration at the three sampling locations during the first six months of system operation.

The capital investment cost of \$16,930 included \$8,640 for equipment, \$3,400 for site engineering, and \$4,890 for installation. Using the system's rated capacity of 12 gpm (or 17,280 gal per day [gpd]), the capital cost was \$1,410/gpm (or \$0.98/gpd). Annualized capital cost was \$1,598/yr based upon 7% interest rate and 20 year life. The unit capital cost was \$0.25/1,000 gal assuming the system operated continuously at 24 hr/day, 7 day/wk at 12 gpm. At the current usage rate, the unit capital cost increased to \$7.91/1,000 gal.

The O&M cost included only incremental cost associated with the adsorption system, such as media replacement and disposal (for both oxidizing and adsorptive media), electricity consumption, and labor. Incremental cost for electricity consumption was negligible. Although media replacement and disposal did not take place during the first six months of operation, the estimated cost was \$2,755, \$3,850, and \$4,945 for replacing one, two, or three columns, respectively (including replacement media, spent media disposal, shipping, labor and travel). Cost curves were constructed for replacing one, two, or three columns to estimate media replacement cost per 1,000 gal of water treated as a function of the media working capacity.

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## ABBREVIATIONS AND ACRONYMS

$\Delta p$	differential pressure
AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
As	arsenic
ATS	Aquatic Treatment Systems
AWWA	American Water Works Association
bgs	below ground surface
BV	bed volume(s)
Ca	calcium
CCR	California Code of Regulations
C/F	coagulation/filtration
Cl	chlorine
Cu	copper
DHS	Department of Health Services
DO	dissolved oxygen
EBCT	empty bed contact time
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
gpd	gallons per day
gpm	gallons per minute
HIX	hybrid ion exchanger
hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IX	ion exchange
LCR	(EPA) Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MEI	Magnesium Elektron, Inc.
Mg	magnesium
Mn	manganese
mV	millivolts

Na	sodium
N/A	not analyzed
NA	not applicable
NaOCl	sodium hypochlorite
ND	not detected
NS	not sampled
NSF	NSF International
O&M	operation and maintenance
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
Pb	lead
PO <sub>4</sub>	orthophosphate
POU	point-of-use
psi	pounds per square inch
PVC	polyvinyl chloride
QA	quality assurance
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RO	reverse osmosis
RPD	relative percent difference
SBMHP	Spring Brook Mobile Home Park
SDWA	Safe Drinking Water Act
SiO <sub>2</sub>	silica
SO <sub>4</sub>	sulfate
STS	Severn Trent Services
TCCI	TCCI Laboratories
TCLP	Toxicity Characteristic Leaching Procedure

## 1.0 INTRODUCTION

### 1.1 Background

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

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

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the 17 host sites. EPA received 70 technical proposals for the 17 host sites, with each site receiving from one to six proposals. In April 2003, an independent technical panel reviewed the proposals and provided its recommendations to EPA on the technologies that it determined were acceptable for the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration project. Using the information provided by the review panel, EPA, in cooperation with the host sites and the drinking water programs of the respective states, selected one technical proposal for each site. As of January 2007, 11 of the 12 systems have been operational and the performance evaluation of six systems has been completed.

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 and the water system at Richmond Elementary School in Susanville, California, was one of those selected.

In September 2003, EPA again solicited proposals from engineering firms and vendors for arsenic removal technologies. EPA received 148 technical proposals for the 32 host sites, with each site receiving from two to eight proposals. In April 2004, another technical panel was convened by EPA to review the proposals and provide recommendations to EPA with the number of proposals per site ranging from none (for two sites) to a maximum of four. The final selection of the treatment technology at the sites that received at least one proposal was made, again through a joint effort by EPA, the state regulators, and the host site. Since then, four sites have withdrawn from the demonstration program, reducing the number of sites to 28. The As/1200CS arsenic treatment system from Aquatic Treatment System, Inc. (ATS) was selected for demonstration at the Richmond Elementary School site in October 2004.

## **1.2 Treatment Technologies for Arsenic Removal**

The technologies selected for the Round 1 and Round 2 demonstration host sites include 25 adsorptive media (AM) systems (the Oregon Institute of Technology [OIT] site has three AM systems), 13 coagulation/filtration (C/F) systems, two ion exchange (IX) systems, 17 point-of-use (POU) units (including nine under-the-sink reverse osmosis [RO] units at the Sunset Ranch Development site and eight AM units at the OIT site), and one system modification. Table 1-1 summarizes the locations, technologies, vendors, system flowrates, and key source water quality parameters (including arsenic, iron, and pH) at the 40 demonstration sites. An overview of the technology selection and system design for the 12 Round 1 demonstration sites and the associated capital cost is provided in two EPA reports (Wang et al., 2004; Chen et al., 2004), which are posted on the EPA website at <http://www.epa.gov/ORD/NRMRL/arsenic/resource.htm>.

## **1.3 Project Objectives**

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

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

This report summarizes the performance of the ATS system at Richmond Elementary School in Susanville, California, during the first six months from September 7, 2005, through March 7, 2006. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and preliminary O&M cost.

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

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH (S.U.)
<i>Northeast/Ohio</i>							
Wales, ME	Springbrook Mobile Home Park	AM (A/I Complex)	ATS	14	38 <sup>(a)</sup>	<25	8.6
Bow, NH	White Rock Water Company	AM (G2)	ADI	70 <sup>(b)</sup>	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 <sup>(a)</sup>	46	8.2
Dummerston, VT	Charette Mobile Home Park	AM (A/I Complex)	ATS	22	30	<25	7.9
Felton, DE	Town of Felton	C/F (Macrolite)	Kinetico	375	30 <sup>(a)</sup>	48	8.2
Stevensville, MD	Queen Anne's County	AM (E33)	STS	300	19 <sup>(a)</sup>	270 <sup>(c)</sup>	7.3
Houghton, NY <sup>(d)</sup>	Town of Caneadea	C/F (Macrolite)	Kinetico	550	27 <sup>(a)</sup>	1,806 <sup>(c)</sup>	7.6
Buckeye Lake, OH	Buckeye Lake Head Start Building	AM (ARM 200)	Kinetico	10	15 <sup>(a)</sup>	1,312 <sup>(c)</sup>	7.6
Springfield, OH	Chateau Estates Mobile Home Park	AM (E33)	AdEdge	250 <sup>(e)</sup>	25 <sup>(a)</sup>	1,615 <sup>(c)</sup>	7.3
<i>Great Lakes/Interior Plains</i>							
Brown City, MI	City of Brown City	AM (E33)	STS	640	14 <sup>(a)</sup>	127 <sup>(c)</sup>	7.3
Pentwater, MI	Village of Pentwater	C/F (Macrolite)	Kinetico	400	13 <sup>(a)</sup>	466 <sup>(c)</sup>	6.9
Sandusky, MI	City of Sandusky	C/F (Aeralater)	USFilter	340 <sup>(e)</sup>	16 <sup>(a)</sup>	1,387 <sup>(c)</sup>	6.9
Delavan, WI	Vintage on the Ponds	C/F (Macrolite)	Kinetico	40	20 <sup>(a)</sup>	1,499 <sup>(c)</sup>	7.5
Greenville, WI	Town of Greenville	C/F (Macrolite)	Kinetico	375	17	7827 <sup>(c)</sup>	7.3
Climax, MN	City of Climax	C/F (Macrolite)	Kinetico	140	39 <sup>(a)</sup>	546 <sup>(c)</sup>	7.4
Sabin, MN	City of Sabin	C/F (Macrolite)	Kinetico	250	34	1,470 <sup>(c)</sup>	7.3
Sauk Centre, MN	Big Sauk Lake Mobile Home Park	C/F (Macrolite)	Kinetico	20	25 <sup>(a)</sup>	3,078 <sup>(c)</sup>	7.1
Stewart, MN	City of Stewart	C/F&AM (E33)	AdEdge	250	42 <sup>(a)</sup>	1,344 <sup>(c)</sup>	7.7
Lidgerwood, ND	City of Lidgerwood	Process Modification	Kinetico	250	146 <sup>(a)</sup>	1,325 <sup>(c)</sup>	7.2
<i>Midwest/Southwest</i>							
Arnaudville, LA	United Water Systems	C/F (Macrolite)	Kinetico	770 <sup>(e)</sup>	35 <sup>(a)</sup>	2,068 <sup>(c)</sup>	7.0
Alvin, TX	Oak Manor Municipal Utility District	AM (E33)	STS	150	19 <sup>(a)</sup>	95	7.8
Bruni, TX	Webb Consolidated Independent School District	AM (E33)	AdEdge	40	56 <sup>(a)</sup>	<25	8.0
Wellman, TX	City of Wellman	AM (E33)	AdEdge	100	45	<25	7.7
Anthony, NM	Desert Sands Mutual Domestic Water Consumers Association	AM (E33)	STS	320	23 <sup>(a)</sup>	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 <sup>(b)</sup>	50	170	7.2
Tohono O'odham Nation, AZ	Tohono O'odham Utility Authority	AM (E33)	AdEdge	50	32	<25	8.2
Valley Vista, AZ	Arizona Water Company	AM (AAFS50)	Kinetico	37	41	<25	7.8

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

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH
<i>Far West</i>							
Three Forks, MT	City of Three Forks	C/F (Macrolite)	Kinetico	250	64	<25	7.5
Fruitland, ID	City of Fruitland	IX (A300E)	Kinetico	250	44	<25	7.4
Homedale, ID	Sunset Ranch Development	POU RO <sup>(f)</sup>	Kinetico	75 gpd	52	134	7.5
Okanogan, WA	City of Okanogan	C/F (Electromedia-I)	Filtronics	750	18	69 <sup>(c)</sup>	8.0
Klamath Falls, OR	Oregon Institute of Technology	POE AM (Adsorbsia/ARM 200/ArsenX <sup>np</sup> ) and POU AM (ARM 200) <sup>(g)</sup>	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 <sup>(a)</sup>	125	7.5
Lake Isabella, CA	California Water Service Company	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; C/F = coagulation/filtration; GFH = granular ferric hydroxide; HIX = hybrid ion exchanger; IX = ion exchange; 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% after system was switched from parallel to serial configuration.
- (c) Iron existing mostly as Fe(II).
- (d) Replaced Village of Lyman, NE site which withdrew from program in June 2006.
- (e) Facilities upgraded Springfield, OH system from 150 to 250 gpm, Sandusky, MI system from 210 to 340 gpm, and Arnaudville, LA system from 385 to 770 gpm.
- (f) Including nine residential units.
- (g) Including eight under-the-sink units.

## 2.0 SUMMARY AND CONCLUSIONS

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

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

- The A/P Complex 2002 oxidizing media was effective at converting As(III) to As(V) throughout the six-month study period, typically lowering As(III) concentrations from an average of 16.7 to <0.5 µg/L. The oxidizing media also showed some adsorptive capacity for arsenic with an estimated adsorptive density of 0.20 µg of arsenic/mg of media.
- Breakthrough of arsenic at 10 µg/L through the lead adsorption column did not occur during the first six months of operation.
- The media was shown to have high capacity for silica. After 9,000 bed volumes (BV) (or six months into system operation), silica concentrations were reduced from 13.2 mg/L in raw water to 4.7 mg/L after treatment.
- Some aluminum was leached from the oxidizing and adsorptive media, elevating its concentrations to as high as 35.3 µg/L in the column effluent, although concentrations never exceeded the primary or secondary maximum contaminant levels (MCLs).

### *Required system operation and maintenance and operator skill levels:*

- The weekly demand on the operator was typically 20 min to visually inspect the system and record operational parameters.
- Operation of the As/1200CS did not require additional skills beyond those necessary to operate the existing water supply equipment.

### *Process residuals produced by the technology:*

- Because the system did not require backwash to operate, no backwash residuals were produced.
- The only residuals produced by the operation of the As/1200CS treatment system would be spent media. The media was not replaced during the first six months of operation; therefore, no residual waste was produced during this period.

### *Technology cost:*

- Using the system's rated capacity of 12 gpm (or 17,280 gal/day [gpd]), the capital cost was \$1,410/gpm (or \$0.98/gpd).
- Although media replacement and disposal did not take place during the first six months of operation, the cost to change out one, two, or three oxidation and/or adsorption columns was estimated to be \$2,755, \$3,850, and \$4,945, respectively, which included the cost for replacement media, spent media disposal, shipping, labor and travel.

### 3.0 MATERIALS AND METHODS

#### 3.1 General Project Approach

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

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

**Table 3-1. Predemonstration Study Activities and Completion Dates**

<b>Activity</b>	<b>Date</b>
Introductory Meeting Held	October 26, 2004
Project Planning Meeting Held	April 13, 2005
Draft Letter of Understanding Issued	April 22, 2005
Final Letter of Understanding Issued	May 13, 2005
Request for Quotation Issued to Vendor	May 25, 2005
Vendor Quotation Received	June 8, 2005
Purchase Order Completed and Signed	July 5, 2005
Engineering Package Submitted to California DHS	July 29, 2005
System Installation and Shakedown Completed	August 16, 2005
Final Study Plan Issued	August 17, 2005
Permit issued by California DHS	August 30, 2005
Performance Evaluation Began	September 7, 2005

DHS = Department of Health Services



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

<b>Evaluation Objectives</b>	<b>Data Collection</b>
Performance	-Ability to consistently meet 10 µg/L of arsenic in treated water
Reliability	-Unscheduled system downtime -Frequency and extent of repairs including a description of problems, materials and supplies needed, and associated labor and cost
System O&M and Operator Skill Requirements	-Pre- and post-treatment requirements -Level of automation for system operation and data collection -Staffing requirements including number of operators and laborers -Task analysis of preventative maintenance including number, frequency, and complexity of tasks -Chemical handling and inventory requirements -General knowledge needed 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 ATS should be contacted for troubleshooting. The plant operator recorded all relevant information, including the problems encountered, course of actions taken, materials and supplies used, and associated cost and labor incurred, on a Repair and Maintenance Log Sheet. The plant operator measured water quality parameters biweekly, including temperature, pH, dissolved oxygen (DO), and oxidation-reduction potential (ORP), and recorded the data on a Weekly On-Site Water Quality Parameters Log Sheet.

The capital cost for the 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, electricity consumption, and labor. Electricity consumption was determined from utility bills. Labor for various activities, such as routine system O&M, troubleshooting and repairs, and demonstration-related work, were tracked using an Operator Labor Hour Log Sheet. The routine system O&M included activities such as completing field logs, 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 the cost analysis.

### 3.3 Sample Collection Procedures and Schedules

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

**Table 3-3. Sample Collection Schedule and Analyses**

Sample Type	Sample Location(s) <sup>(a)</sup>	No. of Samples	Sampling Frequency	Analytes	Date(s) Samples Collected
Source Water	At Wellhead (IN)	1	Once during initial site visit	On-site: pH, temperature, DO, and ORP  Off-site: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), Al (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, Cl, F, NH <sub>3</sub> , NO <sub>3</sub> , NO <sub>2</sub> , SO <sub>4</sub> , SiO <sub>2</sub> , PO <sub>4</sub> , alkalinity, turbidity, TDS, and TOC	10/26/04
Treatment Plant Water	At Wellhead (IN), After Oxidation Column (OA and OB), After Adsorption Column (TA to TC)	3-6	Weekly or Biweekly	On-site: pH, temperature, DO, and ORP  Off-site: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), Al (total and soluble), Ca, Mg, F, I, NO <sub>3</sub> , S <sup>2-</sup> , SO <sub>4</sub> , SiO <sub>2</sub> , PO <sub>4</sub> , alkalinity, and/or turbidity	<b>09/19/05</b> , 10/17/05, <b>11/02/05</b> , 11/21/05, <b>11/29/05</b> , 12/14/05, <b>01/05/06</b> , 01/17/06, <b>02/02/06</b> , 02/16/06, <b>03/02/06</b> , 03/15/06
Distribution Water	Three LCR Locations	3	Monthly <sup>(b)</sup>	Total As, Fe, Mn, Cu, and Pb, alkalinity, and pH	Baseline sampling: 07/21/05, 08/04/05, 08/24/05  Monthly sampling: 10/17/05, 11/21/05, 12/07/05, 01/19/06, 02/16/06, 03/15/06
Residual Solids	Spent Media from Adsorption Columns	6	Once	TCLP metals	To be determined

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

(b) Three baseline sampling events performed before system became operational.

Bold font indicates that speciation was performed.

**3.3.1 Source Water Sample Collection.** During the initial visit to Richmond Elementary School, one set of source water samples from the well were collected for detailed water quality analysis. The source water also was speciated for particulate and soluble As, iron, manganese, aluminum, uranium, vanadium and As(III) and As(V). The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Arsenic speciation kits and containers for water quality samples were prepared as described in Section 3.4.1.

**3.3.2 Treatment Plant Water Sample Collection.** During the system performance evaluation study, samples were collected by the plant operator weekly or bi-weekly at three to six locations across the treatment train, including at the wellhead (IN), after the oxidation columns (OA and OB), and after the adsorption columns (TA to TC). Speciation was performed for As, Fe, Mn, and Al approximately once a month. On-site measurements for pH, temperature, DO, and ORP also were performed during each sampling event.

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

**3.3.4 Distribution System Water Sample Collection.** Samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically, the arsenic, lead, and copper levels. From July to August 2005, prior to the startup of the treatment system, three sets of baseline distribution water samples were collected from three locations within the distribution system. Following the startup of the arsenic adsorption system, distribution system sampling continued on a monthly basis at the same locations.

The three locations selected were sample taps within the school that had been included in the Lead and Copper Rule (LCR) sampling in the past. The samples were collected following an instruction sheet developed according to the *Lead and Copper Rule Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). First-draw samples were collected from cold-water faucets that had not been used for at least six hours to ensure that stagnant water was sampled. Analytes for the baseline samples coincided with the monthly distribution system water samples as described in Table 3-3. Arsenic speciation was not performed for the distribution water samples.

### **3.4 Sampling Logistics**

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

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

**3.4.2 Preparation of Sampling Coolers.** For each sampling event, a sample cooler was prepared with the appropriate number and type of sample bottles, disc filters, and/or speciation kits. All sample bottles were new and contained appropriate preservatives. Each sample bottle was affixed with a pre-printed, colored-coded label consisting of the sample identification (ID), date and time of sample collection, collector's name, site location, sample destination, analysis required, and preservative. The sample ID consisted of a two-letter code for the specific water facility, sampling date, a two-letter code for a specific sampling location, and a one-letter code 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 locations were placed in separate Ziplock™ bags and packed in the cooler.

In addition, all sampling- and shipping-related materials, such as disposable gloves, sampling instructions, chain-of-custody forms, prepaid/addressed FedEx air bills, and bubble wrap, were included. The chain-of-custody forms and air bills were complete except for the operator's signature and the sample dates and

times. After preparation, the sample cooler was sent to the site via FedEx for the following week's sampling event.

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

Samples for metal analyses were stored at Battelle's inductively coupled plasma-mass spectrometry (ICP-MS) laboratory. Samples for other water quality analyses were packed in separate coolers and picked up by couriers from American Analytical Laboratories (AAL) in Columbus, Ohio or TCCI Laboratories (TCCI) in New Lexington, Ohio, both of which were under contract with Battelle for this demonstration study. Sulfide samples were packed in coolers and shipped via FedEx to DHL Laboratories in Round Rock, TX. 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, 2004) were followed by Battelle ICP-MS, AAL, TCCI, and DHL Laboratories. Laboratory quality assurance/quality control (QA/QC) of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection limits (MDL), and completeness met the criteria established in the QAPP (i.e., relative percent difference [RPD] of 20%, percent recovery of 80 to 120%, and completeness of 80%). The quality assurance (QA) data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project.

Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a 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.

## 4.0 RESULTS AND DISCUSSION

### 4.1 Facility Description

The Richmond Elementary School building is located at 700-585 Richmond Road in Susanville, California, approximately 85 miles northwest of Reno, Nevada on U.S. 395. The Richmond School District has approximately 250 students and staff members during the academic year. The school building is served by a single well (Well No. 2) that operates at an estimated flowrate of 12 gpm. Figure 4-1 shows the pre-existing Well No. 2 pump house located near the southwest corner of the school building. Well No. 2 is 8-in in diameter and 145-ft deep with a screened interval extending from 75 to 145 ft below ground surface (bgs). The static water level is at approximately 20 ft bgs. Well No. 2 is equipped with a 1 ½ -horsepower (hp) Starite pump and operates for approximately 2.5 hr/day with an estimated maximum production rate of 2,000 gpd.



**Figure 4-1. Pre-Existing Well No. 2 Pump House  
at Richmond Elementary School**

There was no pre-existing treatment included at the facility. Groundwater from Well No. 2 was pumped directly to three hydropneumatic tanks located in the pump house prior to the distribution system. Figure 4-2 shows the three pre-existing pressure tanks and related system piping.

**4.1.1 Source Water Quality.** Source water samples were collected on October 26, 2004, and subsequently analyzed for the analytes shown in Table 3-3. The results of the source water analyses, along with those provided by the facility to EPA for the demonstration site selection and those obtained from EPA and the California Department of Health Services (DHS), are presented in Table 4-1.



**Figure 4-2. Pre-Existing Pressure Tanks**

Total arsenic concentrations of source water ranged from 24 to 37  $\mu\text{g/L}$ . Based on the October 26, 2004, sampling results, the total arsenic concentration in source water was 36.7  $\mu\text{g/L}$ , of which 31.9  $\mu\text{g/L}$  (or 87%) existed as As(III) and 4.7  $\mu\text{g/L}$  (or 13%) as As(V). This speciation result was consistent with a relatively low DO value of 1.0 mg/L measured during sampling. The ORP reading of 180 mV, however, was not as low as expected.

pH values of source water ranged between 7.0 and 8.5. The vendor indicated that the A/I Complex 2000 media could effectively remove arsenic as long as the pH values of source water were less than 9.0. As such, no pH adjustment was planned at this site.

Concentrations of iron (47 to 125  $\mu\text{g/L}$ ) and manganese (5.5 to 5.6  $\mu\text{g/L}$ ) in raw water were sufficiently low so pretreatment prior to the adsorption process was not required. Concentrations of orthophosphate and fluoride also were sufficiently low (i.e., <0.06 to 0.08 and <0.1 to 0.2 mg/L, respectively) and, therefore, not expected to affect As adsorption on the A/I Complex 2000 media. Silica concentration was 13.6 to 14.5 mg/L, similar to the level measured in source water at the Spring Brook Mobile Home Park (SBMHP) site in Wales, Maine. Because the A/I Complex 2000 media was shown to be especially selective for silica at the SBMHP site (Lipps et al., 2006), the effect of silica on the media for arsenic adsorption was carefully monitored throughout the study period.

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

**Table 4-1. Source Water Quality Data for Richmond Elementary School Site**

Parameter	Unit	Facility Data	EPA Data	Battelle Data	California DHS Historic Data
<i>Date</i>			12/02/03	10/26/04	1994–2000
pH	S.U.	7	N/A	7.5	7.0–8.5
Temperature	°C	N/A	N/A	12.3	N/A
DO	mg/L	N/A	N/A	1.0	N/A
ORP	mV	N/A	N/A	180	N/A
Total Alkalinity (as CaCO <sub>3</sub> )	mg/L	80	84	82	N/A
Hardness (as CaCO <sub>3</sub> )	mg/L	48	44	40	N/A
Turbidity	NTU	N/A	N/A	0.9	N/A
TDS	mg/L	N/A	N/A	138	99–184
TOC	mg/L	N/A	N/A	1.0	N/A
Nitrate (as N)	mg/L	N/A	N/A	0.1	<2
Nitrite (as N)	mg/L	N/A	N/A	<0.01	<0.4
Ammonia (as N)	mg/L	N/A	N/A	<0.05	N/A
Chloride	mg/L	6	<5	2.1	1.3–6.0
Fluoride	mg/L	N/A	N/A	<0.1	0.1–0.2
Sulfate	mg/L	5	16.9	17.0	5.1–13.6
Silica (as SiO <sub>2</sub> )	mg/L	N/A	13.6	14.5	N/A
Orthophosphate (as PO <sub>4</sub> )	mg/L	N/A	0.08	<0.06	N/A
As (total)	µg/L	34	30	36.7	24–37
As (soluble)	µg/L	N/A	N/A	36.6	N/A
As (particulate)	µg/L	N/A	N/A	0.1	N/A
As (III)	µg/L	N/A	N/A	31.9	N/A
As(V)	µg/L	N/A	N/A	4.7	N/A
Fe (total)	µg/L	<100	47	125	<100
Fe (soluble)	µg/L	N/A	NA	<25	N/A
Mn (total)	µg/L	<20	5.5	5.6	<30
Mn (soluble)	µg/L	N/A	N/A	5.5	N/A
U (total)	µg/L	N/A	N/A	0.8	N/A
U (soluble)	µg/L	N/A	N/A	0.8	N/A
V (total)	µg/L	N/A	N/A	0.4	N/A
V (soluble)	µg/L	N/A	N/A	0.2	N/A
Na (total)	mg/L	66	27.2	35.0	N/A
Ca (total)	mg/L	14	14.2	11.2	N/A
Mg (total)	mg/L	4	2.1	2.9	N/A

N/A = not analyzed

**4.1.2 Distribution System.** The original distribution system was installed in 1965 and was reported to consist of copper and galvanized iron piping. More recently, polyvinyl chloride (PVC) piping also was used. Compliance samples from the distribution system have been collected every three years for metals and other analytes such as chloride, fluoride, nitrate, and nitrite. LCR samples have been collected from five taps within the Richmond School building every five years.

## 4.2 Treatment Process Description

The ATS As/1200CS adsorption system uses A/P Complex 2002 oxidizing media to oxidize As(III) to As(V) and then A/I Complex 2000 adsorptive media to remove As(V). The A/P Complex 2002 oxidizing media consists of activated alumina and sodium metaperiodate and the A/I Complex 2000 adsorptive media consists of activated alumina and a proprietary iron complex. Tables 4-2a and 4-2b present physical and chemical properties of the adsorptive and oxidizing media, respectively. Both media have NSF International (NSF) Standard 61 listing for use in drinking water.

The ATS As/1200CS system is a fixed-bed downflow adsorption system designed for use at small water systems with flowrates of around 12 gpm. When the media reaches its capacity, the spent media may be removed and disposed of after being subjected to the EPA Toxicity Characteristic Leaching Procedure (TCLP) test. ATS has the columns containing spent media shipped to their office in Massachusetts for disposal.

The system at Richmond Elementary School is configured in series. The system is designed for the lead column to be removed upon exhaustion and each of the two lag columns to be moved forward one position (i.e. the first lag column becomes the lead column, and the second lag column becomes the first lag column). A new column loaded with virgin media is then placed at the end of each treatment train.

Figure 4-3 shows a schematic diagram of the system composed of the following major system components:

- **Three pre-existing pressure tanks** that included two Model WX-252 and one Model WX-302 Well-X-TROL tanks by AMTROL with a total storage capacity of approximately 250 gal. The pressure tanks were located at the system inlet and served as a temporary storage for well water. The well pump was turned on when the pressure in the tanks had dropped to below 40 pounds per square inch (psi) and the well pump was turned off after the tanks had been refilled and the pressure in the tanks had reached 62 psi.
- **One 25- $\mu$ m sediment filter** that was 6-in in diameter by 20-in tall. Located at the head of the treatment train, the filter was used to remove sediment and avoid introducing large particles directly into the treatment columns.
- **Five 10-in in diameter, 54-in tall sealed polyglass columns (Park International)** with the first two loaded with the oxidizing media (1.5 ft<sup>3</sup>/column) and the remaining three loaded with the adsorptive media (1.5 ft<sup>3</sup>/column). All columns have riser tubes as well as a valved head assembly to control inflow, outflow, and by-pass.
- **One totalizer/flow meter (Blue-White Industries F-1000)** located on the downstream end of the treatment train to record the flowrate and volume of water treated through the treatment train.
- **One 180-gal Well-Rite pressure tank (by Flexcon Industries in Randolph, Maine) fitted with a ¾-hp Goulds booster pump (Model No. C48A94A06).** Located at the system outlet, the booster pump/pressure tank assembly was used to “pull” water from the three pressure tanks at the system inlet through the two oxidation and three adsorption columns; provide temporary storage of the treated water; and supply the treated water with the needed pressure to the distribution system. Upon demand in the distribution system, the pressure tank was



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

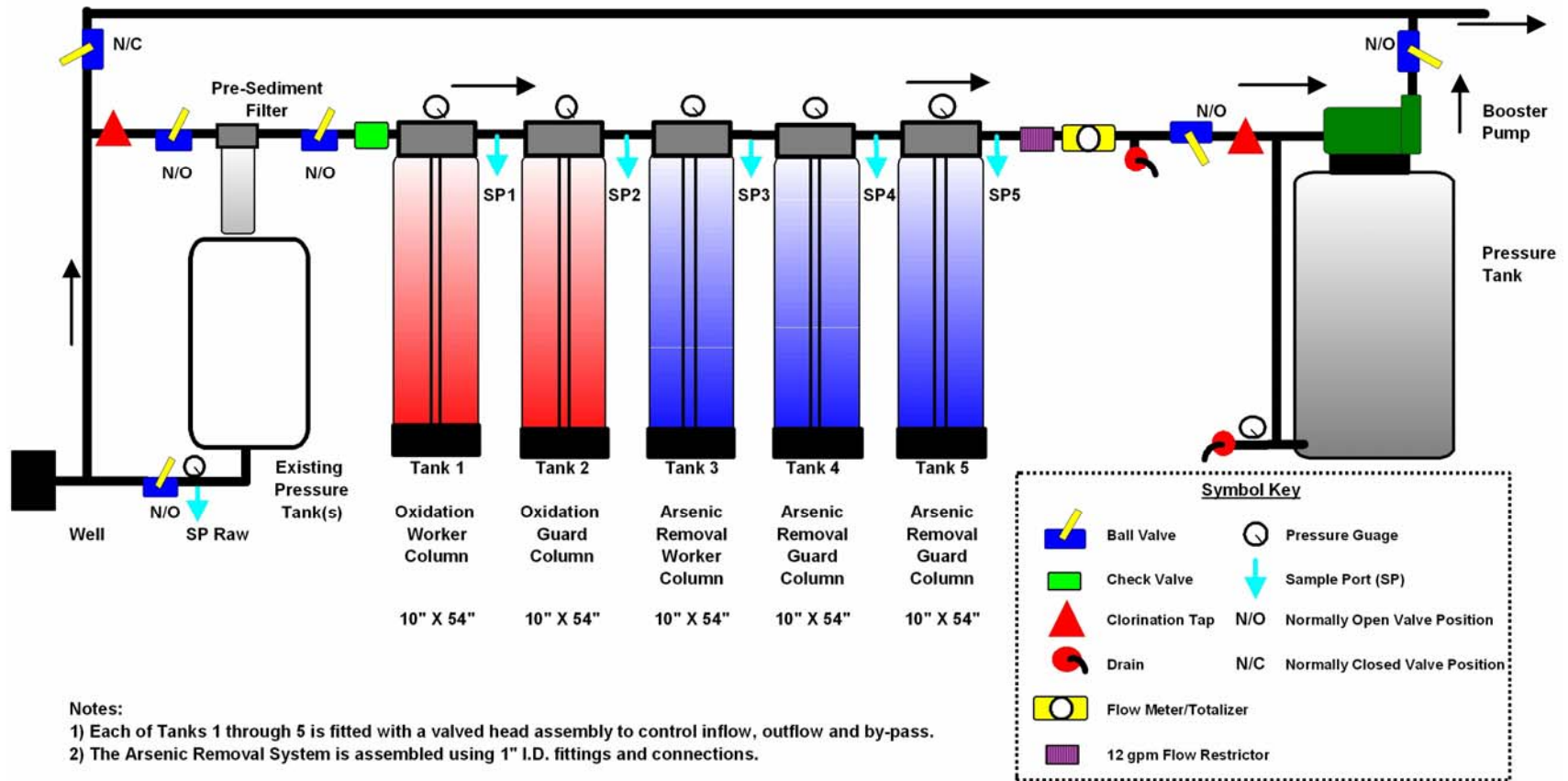
Parameter	Value
<i>Physical Properties</i>	
Matrix	Activated alumina/iron complex
Physical form	Granular solid
Color	Light brown/orange granules
Bulk Density (lb/ft <sup>3</sup> )	55
Specific Gravity (dry)	1.5
Hardness (kg/in <sup>2</sup> )	14–16
Effective Size (mm)	0.42
BET surface area (m <sup>2</sup>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

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

Parameter	Value
<i>Physical Properties</i>	
Matrix	Activated alumina/metaperiodate complex
Physical form	Granular solid
Color	White granules
Bulk Density (lb/ft <sup>3</sup> )	52 (dry)/61 (wet)
Specific Gravity (dry)	1.5
Hardness (lb/in <sup>2</sup> )	14-16
Effective Size (mm)	0.42
Bulk Relative Density (g/cm <sup>3</sup> )	0.90
BET surface area (m <sup>2</sup> /g)	220
Attrition (%)	< 0.1
Moisture Content (%)	< 5
Particle Size Distribution (Tyler mesh)	28×48 (less than 2% fines)
<i>Chemical Analysis</i>	
<b>Constituents</b>	<b>Weight (%)</b>
Al <sub>2</sub> O <sub>3</sub>	96.59 (dry)
NaIO <sub>4</sub>	3.41 (dry)

gradually emptied and the corresponding pressure gradually reduced. The booster pump was triggered when the pressure in the tank had reduced to 45 psi. After refilling the tank with the treated water, the booster pump was turned off as the pressure in the tank had reached the high pressure value of 65 psi.

- **Pressure gauges** located at the system inlet just prior to the sediment filter, at the head of each column, and at the system outlet or at the pressure tank. The pressure gauges were used to monitor the system pressure and pressure drop across the treatment train.



- Notes:**
- 1) Each of Tanks 1 through 5 is fitted with a valved head assembly to control inflow, outflow and by-pass.
  - 2) The Arsenic Removal System is assembled using 1" I.D. fittings and connections.

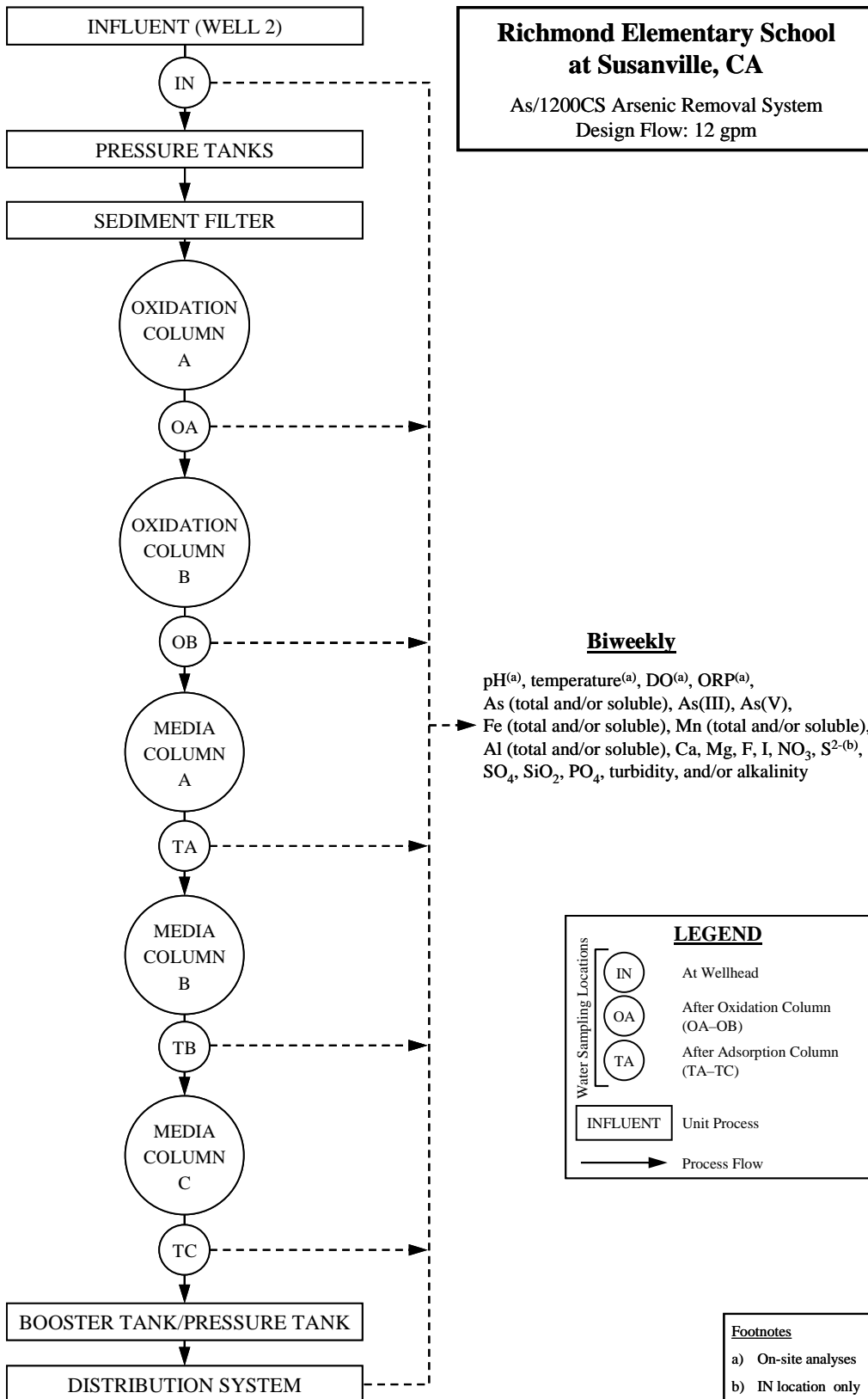
Figure 4-3. Schematic of ATS As/1200CS System with Series Operation

- **Sampling taps.** Sample collection ports (US Plastics) made of PVC were located prior to the system and following each oxidation and adsorption tank.

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

**Table 4-3. Design Specifications of ATS As/1200CS System**

Parameter	Value	Remarks
<b>Oxidation Columns</b>		
Column Size (in)	10 D × 54 H	-
Cross-Sectional Area (ft <sup>2</sup> /column)	0.54	-
Number of Columns	2	-
Configuration	Series	-
Media Type	A/P Complex 2002	-
Media Quantity (lbs)	78	Per column
Media Volume (ft <sup>3</sup> )	1.5	Per column
<b>Adsorption Columns</b>		
Column Size (in)	10 D × 54 H	-
Cross-Sectional Area (ft <sup>2</sup> /column)	0.54	-
Number of Columns	3	-
Configuration	Series	-
Media Type	A/I Complex 2000	-
Media Quantity (lbs)	83	Per column
Media Volume (ft <sup>3</sup> )	1.5	Per column
<b>Service</b>		
System Flowrate (gpm)	12	-
Hydraulic Loading Rate (gpm/ft <sup>2</sup> )	22	-
EBCT (min/column)	0.9	Per column, 3.0-min total EBCT for 3 adsorption columns
Maximum Use Rate (gpd)	2,000	Based on usage estimate provided by school
Estimated Working Capacity (BV)	42,720	Bed volumes to breakthrough to 10 µg/L from lead column
Throughput To Breakthrough (gal)	479,000	Vendor-provided estimate to breakthrough at 10 µg/L from lead column based on 1.5 ft <sup>3</sup> (11.2 gal) of media in lead column
Estimated Media Life (months)	8	Estimated frequency of media change-out in lead column based on throughput of 2,000 gpd
Backwash	-	No system backwash required



**Figure 4-4. Process Flow Diagram and Sampling Locations**



**Figure 4-5. As/1200CS System with Oxidation and Adsorption Columns Shown Against Wall and a Sediment Filter Attached to Wall**



**Figure 4-6. Close-up View of Oxidation and Adsorption Columns with Sample Taps and Labels**

### **4.3 Permitting and System Installation**

Engineering plans for the system were prepared by ATS and reviewed by NST Engineering, Inc. The plans consisting of a schematic and a written description of the As/1200CS system were submitted to the California DHS for approval on July 29, 2005. The approval granted by the California DHS was dated August 24, 2005, and received by Battelle on August 30, 2005.

The system was placed in the existing treatment building, shown in Figure 4-1, without any addition or modifications. The As/1200CS system, consisting of factory-packed adsorption columns and pre-assembled system valves, gauges, and sample taps, was shipped by ATS and delivered to the site on August 15, 2005. The system installation began that same day, including some re-work of the existing system piping. The sediment filter was attached to the wall at the head of the treatment train (Figure 4-5). The media columns were then set into place and plumbed together using copper piping and connections. The mechanical installation was completed on August 16, 2005. Before the system was put online, the system piping was flushed and the columns were filled one at a time to check for leaks. Once all columns were filled, the system was operated for a short period with the treated water going to the sewer. After it was determined that the system had been operating properly, the system and new pipe were disinfected according to American Water Works Association (AWWA) Standard C651-99 and a sample was collected for the total coliform test. The system was bypassed until August 30, 2005, after the satisfactory total coliform sample results were obtained. The first set of samples was collected on September 19, 2005, after the system was put online.

Several punch-list items were identified during a site visit on September 19, 2005, when a system inspection and operator training were performed by Battelle:

- A totalizer/flowmeter was installed after the booster pump/pressure tank following the As/1200CS system and measured only the flowrates from the pressure tank to the distribution. A second totalizer/flowmeter was installed on December 4, 2005, just prior to the booster pump/pressure tank to measure the flowrates and volume of water treated by the system.
- An hour meter was installed on the well pump rather than the booster pump. The wellhead hour meter tracked the amount of time that the well pump operated rather than the system. A second hour meter was installed on December 9, 2005, on the booster pump to determine the amount of time that the system operated.
- A check valve was installed on the line that by-passed the booster pump/pressure tank to the distribution system. To ensure proper system operation, the check valve was replaced with a ball valve to isolate the line between the end of the treatment train and the distribution system.

#### **4.4 System Operation**

**4.4.1 Operational Parameters.** The operational parameters of the system are tabulated and attached as Appendix A. Key parameters are summarized in Table 4-4. From September 7, 2005, through March 9, 2006, Well No. 2 operated for a total of only 74.8 hr, or 0.2 to 2.1 hr/day, based on the hour meter readings on the well pump. The average daily operating time was 0.7 hr/day, assuming a total of 114 days during the six-month period when the school was in session (i.e., less weekends, holidays, and Christmas break). Based on the totalizer and well pump hour meter readings, the Well No. 2 flowrates ranged from 12.0 to 30.7 gpm and averaged 25.2 gpm, excluding one outlier observed in November 2005 at 48.6 gpm. The measured flowrates were approximately two times the flowrate provided by the school in October 2004. No pump curve was available prior to the system installation.

The booster pump and the treatment system operated for approximately 207 hr based on the hour meter readings of the booster pump (note that before the hour meter was installed on the booster pump on December 9, 2005, the booster pump hours were estimated by multiplying the respective pump hours by a factor of 2.77, which is the ratio of total booster hours to total pump hours). The daily operational hours of the booster pump and the system ranged from 0.4 to 4.9 hr/day, excluding 4 outliers and averaged 1.8 hr/day. The operational time represented a utilization rate of approximately 7%.

The system flowrates ranged from 5.6 to 9.8 gpm and averaged 9.0 gpm, excluding one outlier on November 2, 2005 at 17.6 gpm. Therefore, the empty bed contact time (EBCT) for each column ranged from 1.1 and 2.0 min/column and averaged 1.2 min/column or approximately 3.6 min for the three adsorption columns in series (compared to the design value of 0.9 min per column or 2.7 min for three columns). Based on the average flowrate and average daily operating time, the average daily use range was about 900 gpd (based on 112 school days), which was about 45% of the estimate provided by the school.

**Table 4-4. Summary of As/1200CS System Operations**

Operational Parameter	Value	Remarks
Total Operating Time (hr)	207	From September 7, 2005 to March 9, 2006
Total Number of School Days (day)	114	Less weekends, holidays, and Christmas break
Well No. 2 Operating Time (hr/day)	0.2 – 2.1 (0.7)	
Booster Pump/Treatment System Operating Time (hr/day)	0.4 – 4.9 (1.8)	
Volume Throughput (gal)	101,000	
Volume Throughput (BV) <sup>(a)</sup>	9,000	Based on one column
Volume Throughput (BV) <sup>(b)</sup>	3,000	Based on three columns
Well No. 2 Flowrate (gpm)	15.5 – 30.7 (25.2)	
Booster Pump/Treatment System Flowrate (gpm)	5.6 – 9.8 (9.0)	
Daily Use Rate (gpd)	211 – 1,265 (900)	
EBCT (min/column) <sup>(a)</sup>	1.1 – 2.0 (1.2)	
Average Pressure in Each Column (psi) <sup>(c)</sup>	44, 41, 35, 30, 21, 17	
Average Pressure Loss across Each Column (psi)	5.5	

(a) Calculated based on 1.5 ft<sup>3</sup> (or 11.22 gal) of media in each column.

(b) Calculated based on 4.5 ft<sup>3</sup> (or 33.66 gal) of media in three columns in series.

(c) Pressure readings for IN, OA, OB, TA, TB, and TC, respectively (see Fig. 4-4 for locations).

Figure in parentheses denotes average.

The total system throughput during this 26-week period was approximately 101,000 gal. This corresponds to 9,000 BV of water processed through a column containing 1.5 ft<sup>3</sup> (or 11.2 gal) of media. For the three columns in series with 4.5 ft<sup>3</sup> of media, the system treated approximated 3,000 BV of water.

The pressure loss across each column ranged from 0 to 13 psi and averaged 5.5 psi. The total pressure loss across each treatment train (five columns in series) averaged 27 psi. The average influent pressure at the head of the system from the wells was 43.5 psi, and the average pressure following the last column in each treatment train was 16.6 psi. The booster pump and pressure tank installed after the system provided pressure to feed the distribution system, and the average pressure after this tank was 46.5 psi.

**4.4.2 Residual Management.** The only residuals produced by the operation of the As/1200CS treatment system would be spent media. The media was not replaced during the first six months of operation; therefore, no residual waste was produced during this period. Because the system did not require backwash to operate, no backwash residuals were produced.

**4.4.3 System Operation, Reliability and Simplicity.** The system encountered some operational difficulties soon after it began operation. On several occasions, the 180-gal pressure tank located at the system outlet did not provide sufficient water to meet the peak demand of the school. The school's plan

was to move two of the pressure tanks currently located at the system inlet to after the oxidation and adsorption columns to provide extra storage, but this modification did not occur in the first six months of operation. Note that the system was designed based on information provided by the school estimating the well flowrate to be approximately 12 gpm. Well pump data collected during the first six months of operation showed the well flowrate to be closer to 25 gpm. However, the average flowrate of the booster pump (and the system) was only 9 gpm. Therefore, it would take more time to fill up the 180-gal pressure tank at the system outlet than the 350-gal tanks at the system inlet. The combined effect of the less storage capacity at the system outlet and the longer time required to fill the 180-gal tank apparently had caused the system to be unable to meet the peak demand as observed. Additional discussion regarding system operation and operator skill requirement are provided below.

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

***System Controls.*** The As/1200CS adsorption system was a passive system, requiring only the operation of the supply well pump and booster pump to send water to the three pressure tanks at the system inlet and through the oxidation and adsorption columns to the pressure tank at the system outlet. The media columns themselves required no automated parts and all valves were manually activated. The inline flowmeters were battery powered so that the only electrical power required was that needed to run the supply well pump and booster pump. The system operation was controlled by the pressure switch in the pressure tank at the system outlet.

The facility at the Richmond School District is considered by California DHS to be a non-transient, non-community water system. Because it serves more than 25 of the same people for more than 60 days a year, it is considered a public water system. All individuals who operate or supervise the operation of a public water system in the state of California must possess a water treatment operator certificate. An individual who makes decisions addressing the operational activities must possess a distribution operator certificate. The operational activities are described in Title 22, Division 4, Chapter 13, Subsection 63770(b) of the California Code of Regulations (CCR, 2001).

Operator certifications are granted by the State of California after meeting minimum requirements which include passing an examination and maintaining a minimum amount of hours of specialized training. There are five grades of operators for both water treatment (T1-T5) and distribution (D1-D5). Because Richmond Elementary School has a simple water system and serves a population of less than 1,000, it qualifies as a Grade 1 (the lowest) for both treatment and distribution. The operator at the Richmond School District possesses a T1 and D1 certification.

***Operator Skill Requirements.*** Under normal operating conditions, the skills required to operate the As/1200CS system were minimal. The operation of the system did not appear to require additional skills beyond those necessary to operate the existing water supply system in place at the site.

***Preventative Maintenance Activities.*** The only regularly scheduled preventative maintenance activity recommended by ATS was to inspect the sediment filters monthly and replace as necessary. The treatment system operator visited the site about three times per week (approximately 20 min) to check the system for leaks, and record flow, volume, and pressure readings.

#### **4.5 System Performance**

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



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

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

Parameter	Sampling Location	Number of Samples	Concentration (µg/L)			Standard Deviation
			Minimum	Maximum	Average	
As (total)	IN	13 <sup>(a)</sup>	25.6	33.6	30.9	2.3
	OA-OB	11-13 <sup>(a)</sup>	(b)			
	TA-TC	11-13 <sup>(a)</sup>	(b)			
As (particulate)	IN	6	<0.1	<0.1	<0.1	0.0
	OA-OB	5	(b)			
	TA-TC	1-5	(b)			
As (III)	IN	6	8.9	28.5	16.7	9.2
	OA-OB	5	(b)			
	TA-TC	1-5	(b)			
As (V)	IN	6	3.4	22.5	14.5	8.7
	OA-OB	5	(b)			
	TA-TC	1-5	(b)			
Fe (total)	IN	13 <sup>(a)</sup>	<25	87.7	42.8	24.5
	OA-OB	6-11 <sup>(a)</sup>	<25	<25	<25	0.0
	TA-TC	3-12 <sup>(a)</sup>	<25	<25	<25	0.0
Fe (soluble)	IN	6	<25	25.2	<25	-
	OA-OB	5	<25	<25	<25	-
	TA-TC	1-5	<25	<25	<25	0.0
Mn (total)	IN	13 <sup>(a)</sup>	4.3	7.7	5.7	1.0
	OA-OB	6-11 <sup>(a)</sup>	<0.1	0.4	0.1	0.1
	TA-TC	3-12 <sup>(a)</sup>	<0.1	0.5	0.1	0.1
Mn (soluble)	IN	6	5.0	7.5	5.8	2.9
	OA-OB	5	<0.1	0.2	0.1	0.1
	TA-TC	1-5	<0.1	0.2	0.1	0.1
Total Al	IN	13 <sup>(a)</sup>	<10	<10	<10	0.0
	OA-OB	6-11 <sup>(a)</sup>	13.9	34.7	21.5	5.4
	TA-TC	2-12 <sup>(a)</sup>	17.5	35.3	24.0	4.7
Soluble Al	IN	6	<10	<10	<10	0.0
	OA-OB	5	15.1	27.7	19.6	3.8
	TA-TC	1-4	13.9	31.8	22.4	6.9

One-half of detection limit used for calculations involving non-detect samples.

Duplicate samples included in calculations.

(a) Including one duplicate sample

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

**Arsenic.** The key parameter for evaluating the effectiveness of the As/1200CS adsorption system was the concentration of arsenic in the treated water. The treatment plant water was sampled on 13 occasions during the first six months of system operation (including one event with duplicate samples taken), with field speciation performed on six of the 13 occasions.

**Table 4-6. Summary of Water Quality Parameter Measurements**

Parameter	Sampling Location	Unit	Number of Samples	Concentration/Standard Unit			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as CaCO <sub>3</sub> )	IN	mg/L	8 <sup>(a)</sup>	83	91	87.6	2.3
	OA-OB	mg/L	2-6 <sup>(a)</sup>	79	97	87.0	5.5
	TA-TC	mg/L	7 <sup>(a)</sup>	79	92	85.9	3.8
Fluoride	IN	mg/L	8 <sup>(a)</sup>	0.1	0.2	0.2	0.16
	OA-OB	mg/L	2-6 <sup>(a)</sup>	0.1	0.2	0.2	0.19
	TA-TC	mg/L	7 <sup>(a)</sup>	<0.1	0.3	0.1	0.10
Sulfate	IN	mg/L	8 <sup>(a)</sup>	16	23	17.7	2.3
	OA-OB	mg/L	2-6 <sup>(a)</sup>	16	22	17.5	2.0
	TA-TC	mg/L	7 <sup>(a)</sup>	16	23	18.3	2.2
Iodine (as I)	IN	mg/L	7 <sup>(a)</sup>	1.4	24.5	10.8	8.6
	OA-OB	mg/L	1-6 <sup>(a)</sup>	17.5	196	91.2	66
	TA-TC	mg/L	1-7 <sup>(a)</sup>	36.1	264	130	98
Phosphorus (as PO <sub>4</sub> )	IN	mg/L	7 <sup>(a)</sup>	<0.03	0.1	<0.03	0.0
	OA-OB	mg/L	1-6 <sup>(a)</sup>	<0.03	<0.03	<0.03	0.0
	TA-TC	mg/L	7 <sup>(a)</sup>	<0.03	<0.03	<0.03	0.0
Silica (as SiO <sub>2</sub> )	IN	mg/L	13 <sup>(a)</sup>	13.2	15.3	14.4	0.7
	OA-OB	mg/L	11-13 <sup>(a)</sup>	5.6	12.9	9.6	2.0
	TA-TC	mg/L	11-13 <sup>(a)</sup>	2.2	9.0	7.8	2.0
Nitrate (as N)	IN	mg/L	8 <sup>(a)</sup>	<0.05	0.40	0.08	0.13
	OA-OB	mg/L	2-6 <sup>(a)</sup>	<0.05	0.20	0.05	0.06
	TA-TC	mg/L	7 <sup>(a)</sup>	<0.05	0.10	<0.05	0.03
Turbidity	IN	NTU	8 <sup>(a)</sup>	0.2	1.7	1.0	0.6
	OA-OB	NTU	2-6 <sup>(a)</sup>	<0.1	2.3	0.9	0.8
	TA-TC	NTU	7 <sup>(a)</sup>	0.2	2.7	1.0	1.0
pH	IN	S.U.	6	8.3	8.5	8.4	0.1
	OA-OB	S.U.	1-6	7.8	8.2	8.0	0.2
	TA-TC	S.U.	5	7.4	7.8	7.6	0.1
Temperature	IN	°C	6	12.8	16.2	14.6	1.3
	OA-OB	°C	1-6	12.3	15.9	14.4	1.1
	TA-TC	°C	5	12.8	15.8	14.2	1.0
DO	IN	mg/L	6	0.9	3.0	1.6	0.8
	OA-OB	mg/L	6	0.5	2.6	1.5	0.8
	TA-TC	mg/L	4-5	0.4	2.8	1.8	0.9
ORP	AC	mg/L	6	134	321	201	65
	OA-OB	mg/L	6	141	316	216	67
	TA-TC	mg/L	4-5	135	320	202	48
Total Hardness (as CaCO <sub>3</sub> )	IN	mg/L	8 <sup>(a)</sup>	33.2	46.2	41.3	4.0
	OA-OB	mg/L	3-6 <sup>(a)</sup>	31.3	50.7	40.8	6.1
	TA-TC	mg/L	7 <sup>(a)</sup>	31.1	58.7	42.3	9.1
Ca Hardness (as CaCO <sub>3</sub> )	IN	mg/L	8 <sup>(a)</sup>	25.1	36.1	32.3	3.6
	OA-OB	mg/L	3-6 <sup>(a)</sup>	23.5	40.2	32.0	5.3
	TA-TC	mg/L	7 <sup>(a)</sup>	23.4	48.0	34.2	8.2
Mg Hardness (as CaCO <sub>3</sub> )	IN	mg/L	8 <sup>(a)</sup>	7.7	10.0	8.9	0.8
	OA-OB	mg/L	3-6 <sup>(a)</sup>	7.7	10.5	8.8	1.0
	TA-TC	mg/L	7 <sup>(a)</sup>	7.7	11.7	9.1	1.3

One-half of detection limit used for calculations involving non-detect samples.

Duplicate samples included in calculations.

(a) Including one duplicate sample.

Figure 4-6 contains four bar charts each showing the concentrations of total As, particulate As, As(III), and As(V) at the wellhead, after the first and second oxidation columns and after the entire system. Total As concentrations in raw water ranged from 25.6 to 33.6 µg/L and averaged 30.9 µg/L (Table 4-5). As(III) was the predominating species with concentrations ranging from 8.9 to 28.5 µg/L and averaging 16.7 µg/L. As(III) concentrations decreased in raw water after the third month of operation for unknown reasons (Figure 4-6). As(V) also was present in source water, ranging from 3.4 to 22.5 µg/L and averaging 14.5 µg/L. Particulate As was low with concentrations typically less than 1 µg/L. The influent arsenic concentrations measured during this six-month period were consistent with those in the raw water sample collected on October 26, 2004 (Table 4-1), except for the lower levels of As(III) measured during the last four speciation events from November 2005 through March 2006.

Oxidation of As(III) to As(V) within the oxidation columns was achieved through a reaction with sodium metaperiodate, a key ingredient loaded on the A/P Complex 2002 oxidizing media for As(III) oxidation (Table 4-2b). At a pH value between 8.3 to 8.5, metaperiodate reacted with H<sub>3</sub>AsO<sub>3</sub>, presumably, following Equation 1:



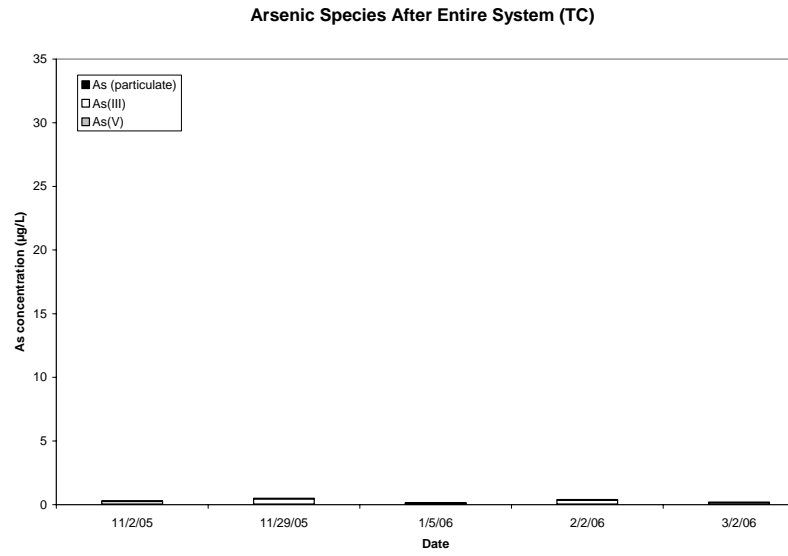
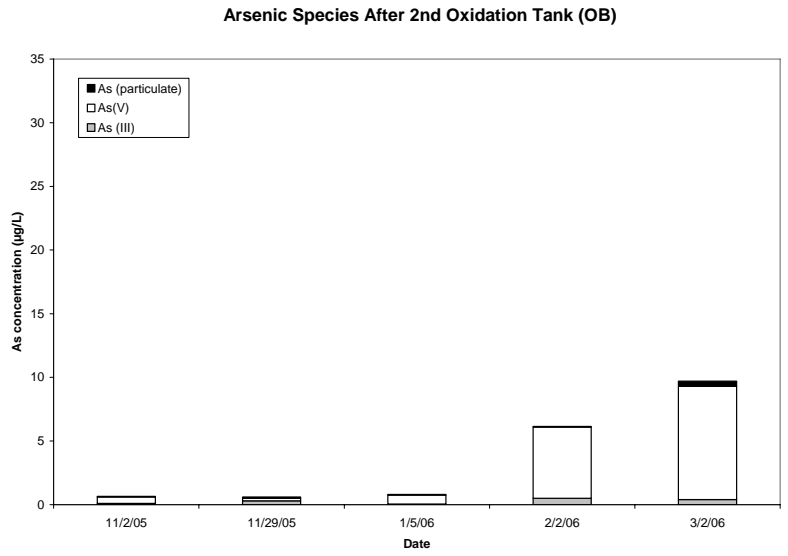
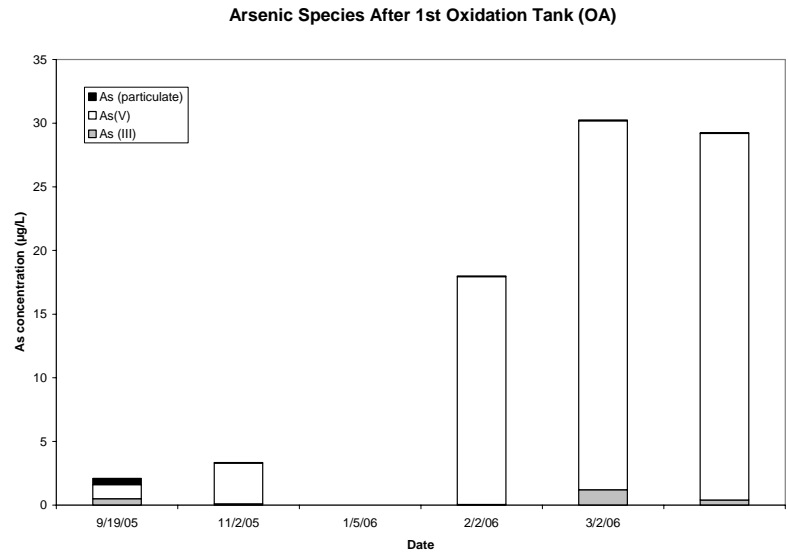
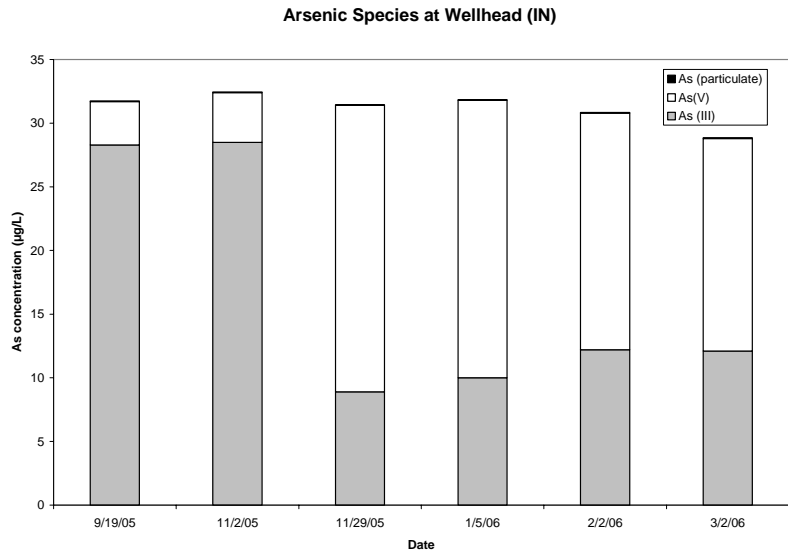
Further, metaperiodate would react with any soluble iron, existing as Fe(II), and soluble manganese, existing as Mn(II), in raw water following Equations 2 and 3:



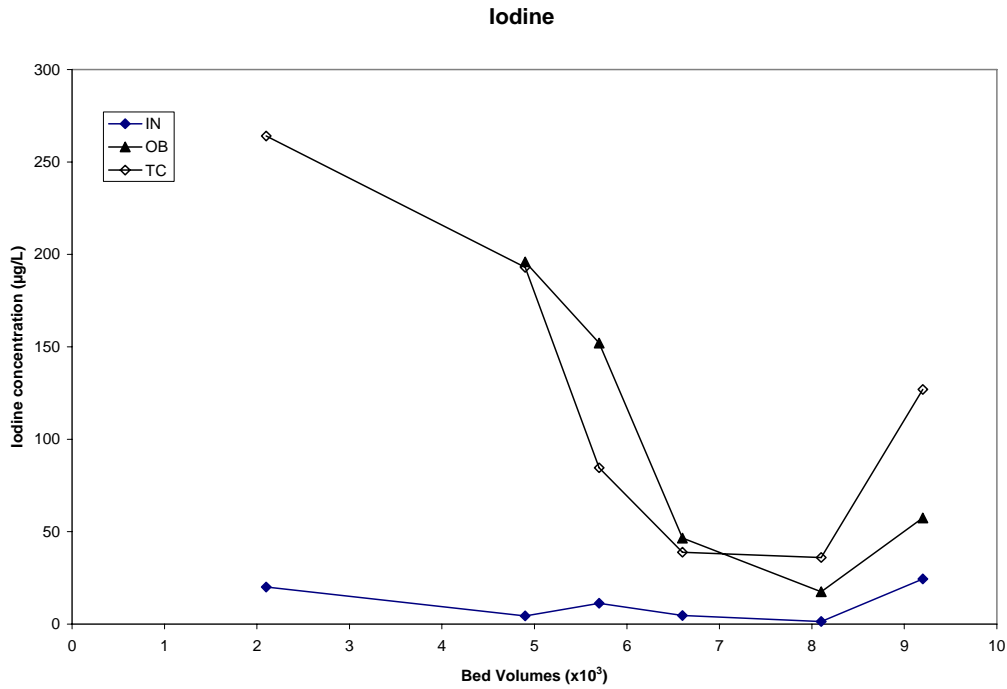
Therefore, to oxidize 16.7, <25, and 5.8 µg/L of As(III), Fe(II), and Mn(II), respectively, the average amounts measured in raw water, only 4.2, 3.6 (one half the detection limit used for calculation), and 3.3 µg/L of I<sup>-</sup> would be produced stoichiometrically and leached into the column effluent. As such, the total amount of I<sup>-</sup> produced would be 11.1 µg/L, which is lower than the analytical reporting limit of 200 µg/L for I<sup>-</sup> by EPA Method 300.0 by ion chromatography. This observation is consistent with the analytical results (<200 µg/L of I<sup>-</sup>) reported for the samples collected at the wellhead, after the oxidation columns, and after the adsorption columns on October 17, 2005.

Total iodine also was analyzed using ICP-MS on seven occasions (including one duplicate) during the first six months of system operation. Iodine concentrations following the oxidation and adsorption columns averaged 86.1 and 112 µg/L [as I], respectively, which were significantly higher than those measured in raw water (averaging 10.8 µg/L [as I]). Because only 11.1 µg/L of total iodine would exist as I<sup>-</sup>, the iodine present in the column effluent most likely was IO<sub>4</sub><sup>-</sup> or other reaction intermediates. It was possible that some IO<sub>4</sub><sup>-</sup> was leached from the oxidizing media, but the leaching followed an apparent decreasing trend as shown in Figure 4-7. The iodine concentrations in the treated water were significantly reduced to less than 40 µg/L [as I] after about five months into the system operation. The final sampling event on March 15, 2006, showed a rebound in iodine concentrations, i.e., 57.5 and 127 µg/L [as I] following the oxidation and adsorption columns. The iodine leaching will be closely monitored during the remainder of the performance evaluation study.

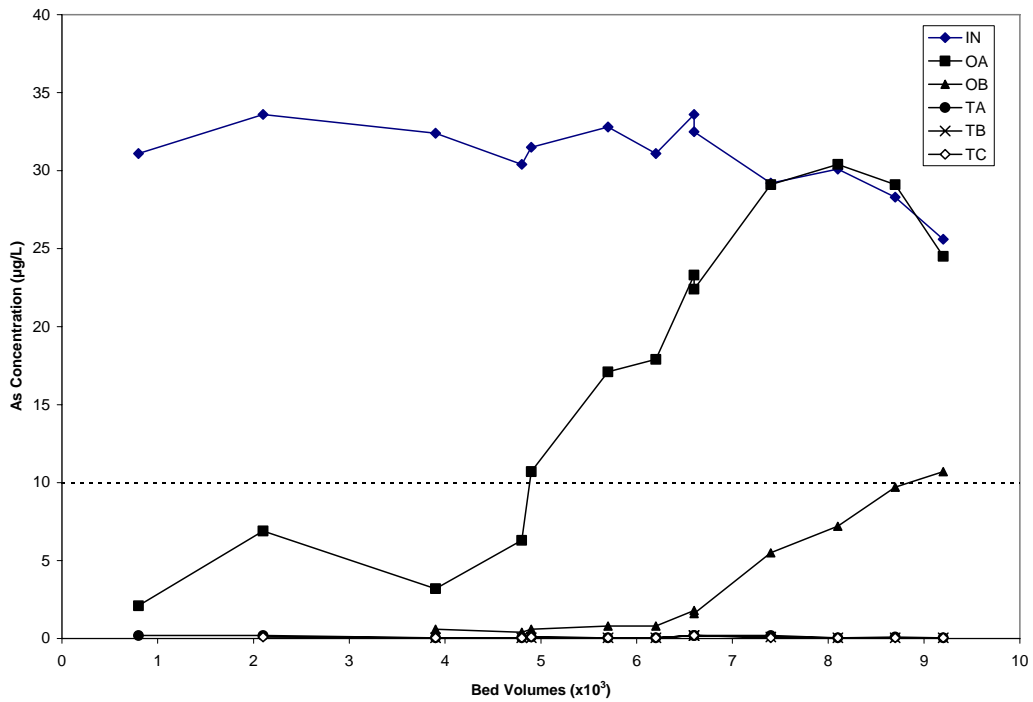
The test results for arsenic removal by the ATS system are shown in Figure 4-8 with total arsenic concentrations plotted against the bed volumes of water treated. Note that BV was calculated based on 1.5 ft<sup>3</sup> or 11.2 gal of media in a column. The results showed that the oxidizing media not only were effective at converting As(III) to As(V) but also had some adsorptive capacity for arsenic removal. For the first sampling event that occurred a couple weeks after system startup, the total arsenic concentration in the effluent of the lead oxidation column was 2.1 µg/L. The arsenic concentrations slowly increased



**Figure 4-7. Concentrations of Various Arsenic Species after Oxidation Columns A and B and Entire System**



**Figure 4-8. Iodine Concentrations across Treatment Train  
(BV Calculations Based upon 1.5 ft<sup>3</sup> of Media in Each Column)**

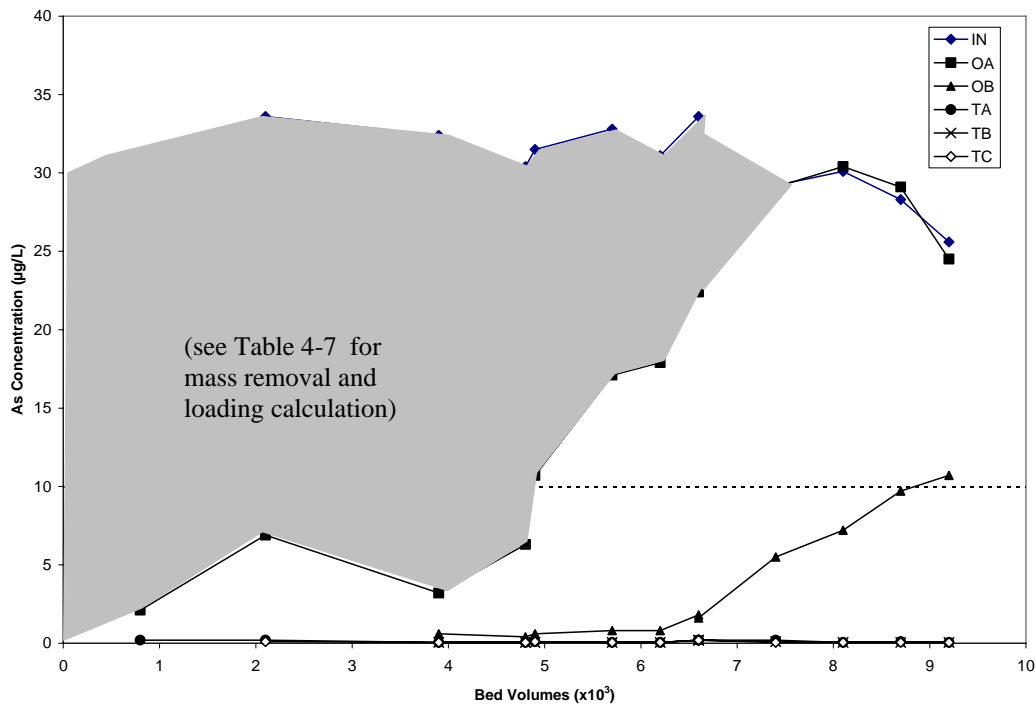


**Figure 4-9. Arsenic Concentration across Treatment Train  
(BV Calculations Based upon 1.5 ft<sup>3</sup> of Media in Each Column)**

thereafter to where arsenic had reached 10 µg/L, at about 4,800 BV, and then completely broken through the lead oxidation column, at about 7,500 BV, so that the concentrations following the lead oxidation column were close to those in raw water. Based on the breakthrough curves shown in Figure 4-8, the arsenic loading on the oxidation media was estimated to be 0.2 µg/mg of media, which was identical to the adsorptive density for the A/I Complex 2000 adsorptive media observed at the Wales, Maine demonstration site (Lipps et al., 2006). Note that the arsenic loading was calculated by dividing the arsenic mass represented by the shaded area in Figure 4-9 by the amount of media, i.e., 1.5 ft<sup>3</sup>, in the column. The arsenic mass removed by Oxidation Column A was estimated to be 7.0 g as shown in Table 4-7.

Arsenic was detected at concentrations greater than 1 µg/L after the lag oxidation column at approximately 6,500 BVs. By 9,200 BVs (or six months into the system operation), the concentration after the lag oxidation column reached 10.7 µg/L. Arsenic concentrations after the lead adsorption column remained at or below 0.2 µg/L in the first six months of operation.

Among the anions analyzed, silica, sulfate, alkalinity (existing primarily as HCO<sub>3</sub><sup>-</sup> at pH values between 8.3 and 8.5) and nitrate were present in raw water (Table 4-6) and potentially could compete with arsenic for adsorption sites. As shown in Figure 4-10, some silica was consistently removed by each oxidation and adsorption columns throughout the first six months of system operation. Of the other competitive anions, including HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, and NO<sub>3</sub><sup>-</sup>, neither the oxidizing nor the adsorptive media showed removal capacity (Figure 4-11).



**Figure 4-10. Arsenic Mass Removed for Oxidation Column A**

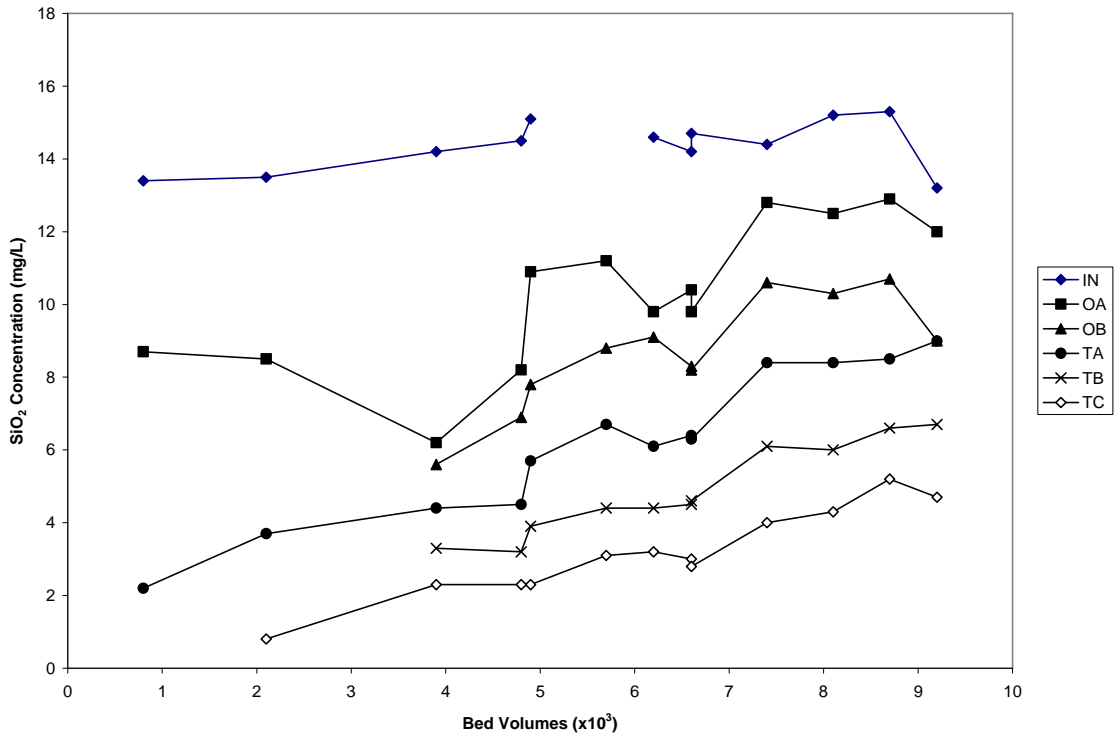
**Table 4-7. Arsenic Mass Removed by Oxidation Column A**

Bed Volumes Treated between Sampling Points	Concentration (µg/L)			µg/L × BV <sup>(a)</sup>	Mass (µg)
	Influent	OA	Difference		
0.0	30.0	<0.1	30.0	-	-
400	31.1	2.1	29.0	11,800	501,172
1,600	33.6	6.9	26.7	44,560	1,892,561
1,900	32.4	3.2	29.2	53,105	2,255,486
800	30.4	6.3	24.1	21,320	905,507
100	31.5	10.7	20.8	2,245	95,350
800	32.8	17.1	15.7	14,600	620,094
500	31.1	17.9	13.2	7,225	306,862
400	33.1	22.9	10.2	4,680	198,770
900	29.2	29.1	0.1	5,040	214,060
<b>Total</b>				<b>164,575</b>	<b>6,989,862</b>
<b>Media in First Oxidation Column (mg)</b>				<b>35,380,800</b>	
<b>Media Loading (µg of As/mg of media)</b>				<b>0.2</b>	

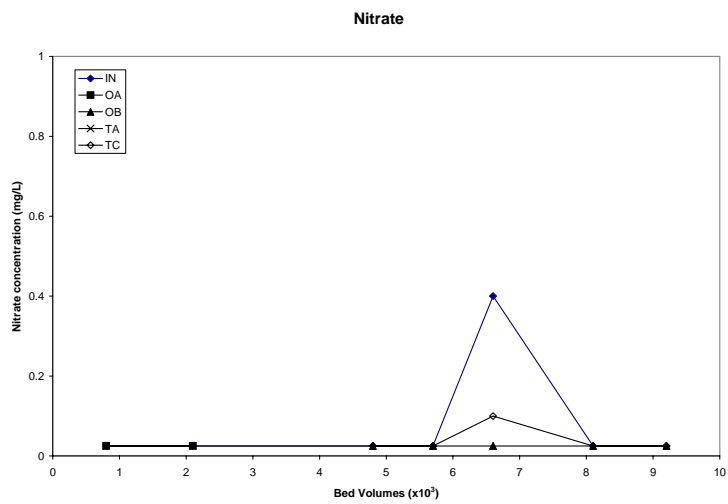
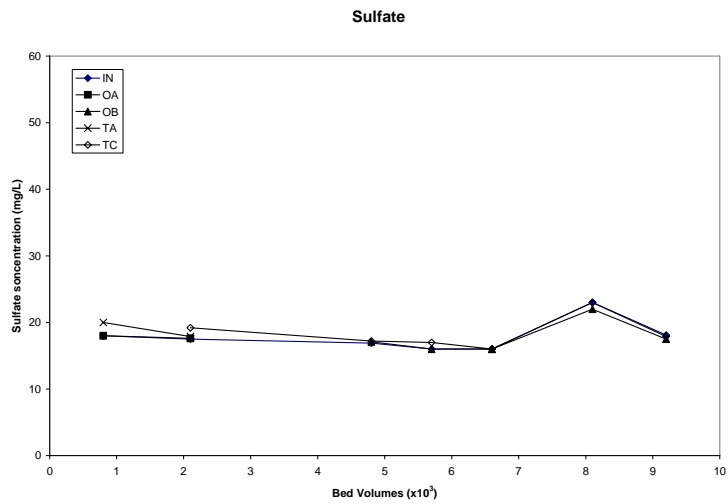
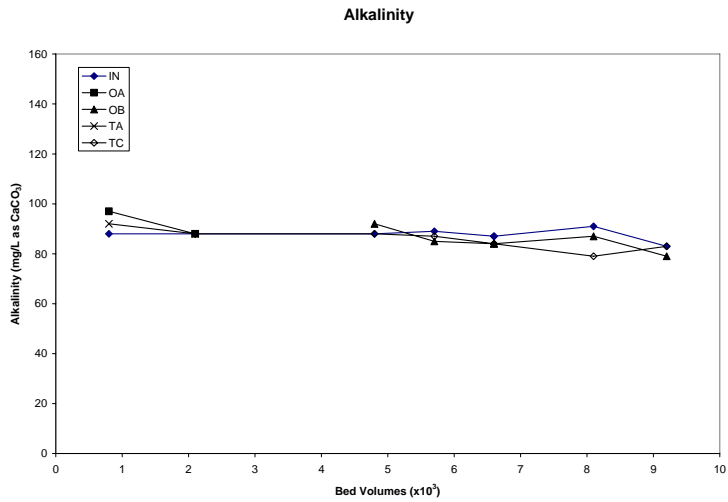
(a) 1 BV = 1.5 ft<sup>3</sup> = 11.22 gal

Media in each column = 35,380,800 mg based on a bulk density of 52 lb/ft<sup>3</sup>.

OA = after Oxidation Column A



**Figure 4-11. Silica Concentrations across Treatment Train (BV Calculations Based upon 1.5 ft<sup>3</sup> of Media in Each Column)**



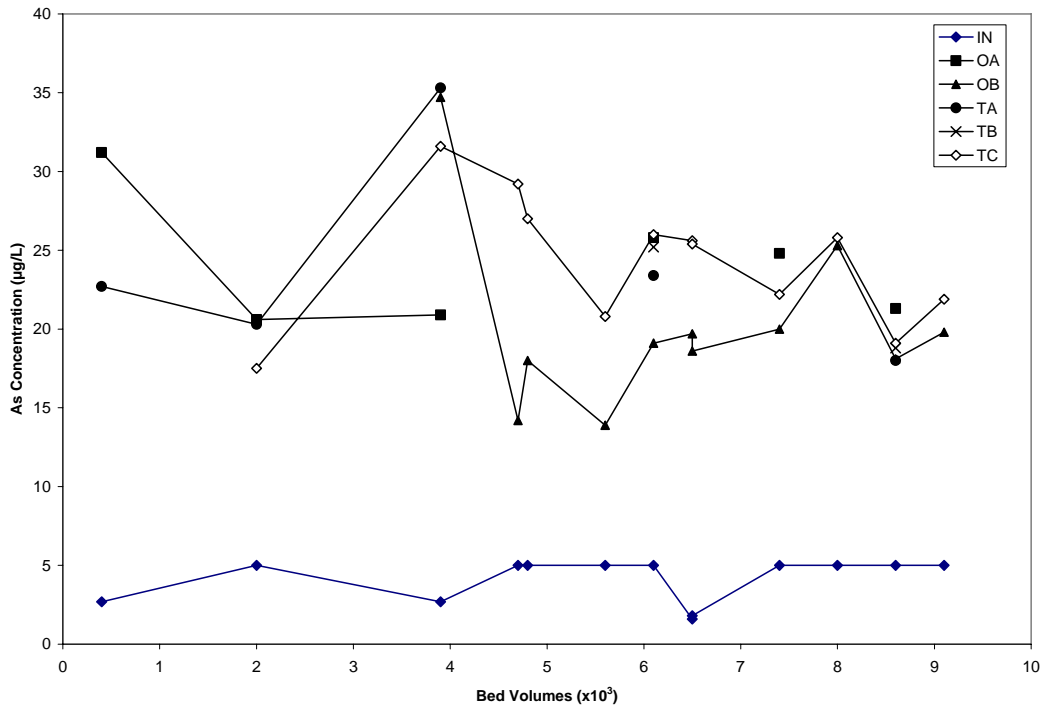
**Figure 4-12. Alkalinity, Sulfate and Nitrate Concentrations across Treatment Train (BV Calculations Based upon 1.5 ft<sup>3</sup> of Media in Each Column)**



**Aluminum.** As shown in Table 4-5, total aluminum concentrations in source water were below the reporting limit of 10 µg/L. Aluminum concentrations (existing primarily in the soluble form) in the treated water following the oxidation and adsorption columns were 14 to 35 µg/L higher than those in raw water, indicating leaching of aluminum from the oxidation and adsorptive media. Even with the increase in aluminum concentration following the treatment system, the concentrations were still below the secondary drinking water standard for aluminum of 50 to 200 µg/L. Leaching of aluminum continued throughout the study period as shown in Figure 4-12.

**Iron and Manganese.** Iron concentrations, both total and dissolved, were between less than the reporting limit and 87.7 µg/L in source water and below the reporting limit of 25 µg/L across the treatment train (Table 4-5). Manganese concentrations in source water also were low, ranging from 4.3 to 7.7 µg/L and averaging 5.7 µg/L. Manganese concentrations in the treated water following the adsorption columns were typically below the reporting limit (<1 µg/L).

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



**Figure 4-12. Aluminum Concentrations across Treatment Train (BV Calculations Based upon 1.5 ft<sup>3</sup> of Media in Each Column)**

**4.5.3 Distribution System Water Sampling.** Prior to the installation and operation of the treatment system, baseline distribution system water samples were collected from three LCR taps on July 21, 2005, August 4, 2005, and August 24, 2005. Following the installation of the treatment system, distribution water sampling continued on a monthly basis at the same three locations. The results of the distribution system sampling are summarized in Table 4-8. As expected, prior to the installation of the arsenic adsorption system, arsenic concentrations in the distribution system were similar to those measured in raw water, ranging from 11.6 to 43.3 µg/L, averaging 30.6 µg/L. After the treatment system was installed and put into service, arsenic concentrations in the distribution system were reduced

**Table 4-8. Distribution System Sampling Results**

Sampling Event		DS1 Hall Sink								DS2 Kitchen Sink								DS3 Office Room Sink							
		LCR								LCR								LCR							
		1st draw								1st draw								1st Draw							
		Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu
		hrs	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hrs	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hrs	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
No.	Date	hrs	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hrs	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	hrs	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
BL1	07/21/05	>12 <sup>(a)</sup>	8.0	88	31.2	<25	4.3	4.6	13.6	17.8	8.0	88	27.5	<25	4.8	1.0	4.5	17.8	8.0	88	35.1	32.4	5.0	10.4	7.0
BL2	08/04/05	>12 <sup>(a)</sup>	8.0	87	36.6	<25	5.4	1.8	8.7	>12 <sup>(a)</sup>	8.1	86	23.5	<25	4.4	0.8	2.9	>12 <sup>(a)</sup>	8.1	77	31.2	<25	5.5	2.4	5.9
BL3	08/24/05	>12 <sup>(a)</sup>	8.0	88	35.4	<25	4.9	3.8	27.2	>12 <sup>(a)</sup>	8.1	88	43.3	<25	4.7	3.2	69.4	>12 <sup>(a)</sup>	7.3	88	11.6	45.1	25.1	6.6	83.9
1	10/17/05	>12 <sup>(a)</sup>	7.0	88	1.2	<25	1.6	1.9	4.5	>12 <sup>(a)</sup>	7.1	88	1.1	<25	1.7	0.5	1.5	>12 <sup>(a)</sup>	7.3	88	1.1	<25	6.1	1.5	27.3
2	11/21/05	>12 <sup>(a)</sup>	7.5	88	1.4	<25	1.4	0.4	12.9	>12 <sup>(a)</sup>	7.7	83	1.1	<25	0.8	0.9	6.8	>12 <sup>(a)</sup>	7.9	83	1.4	<25	3.9	3.6	14.6
3	12/07/05	>12 <sup>(a)</sup>	7.7	83	0.8	<25	0.6	0.3	1.8	>12 <sup>(a)</sup>	7.7	83	0.9	<25	2.2	0.3	1.9	>12 <sup>(a)</sup>	7.7	81	1.3	<25	3.1	5.4	17.5
4	01/19/06	>12 <sup>(a)</sup>	7.6	85	1.0	<25	0.7	1.9	9.1	>12 <sup>(a)</sup>	7.6	86	0.8	<25	1.6	0.6	2.9	>12 <sup>(a)</sup>	7.6	86	1.4	32.8	2.7	5.9	31.5
5	02/16/06	>12 <sup>(a)</sup>	7.8	87	0.8	<25	0.6	0.3	1.6	>12 <sup>(a)</sup>	7.8	83	0.7	<25	0.3	<0.1	1.5	>12 <sup>(a)</sup>	7.8	83	1.1	<25	0.6	0.7	6.4
6	03/15/06	10.0	7.6	83	0.3	<25	0.1	0.6	8.7	9.9	7.8	83	0.3	<25	1.7	0.7	2.5	9.9	7.7	83	0.8	<25	0.4	1.9	38.7
7	04/11/06	19.0	7.8	88	1.6	36.5	0.6	0.7	9.9	7.5	7.8	88	1.8	<25	2.6	0.8	7.1	15.3	7.8	88	2.4	67.8	1.1	3.5	21.9
8	05/10/06	11.2	8.0	88	1.3	<25	0.4	<0.1	1.5	12.0	8.0	85	1.4	<25	0.6	<0.1	3.1	11.1	8.0	192	3.2	27.1	1.1	5.1	11.0
9	06/07/06	13.9	7.9	89	1.2	<25	0.2	0.1	2.6	10.8	7.9	86	1.1	<25	1.1	0.2	5.7	10.8	7.8	88	2.8	<25	0.8	4.5	10.8
10	07/19/06	10.0	7.8	92	1.2	<25	0.6	3.6	16.9	10.4	7.8	92	1.3	<25	1.6	1.9	12.2	11.0	7.9	97	4.6	211	3.0	10.6	24.2
11	08/16/06	>12 <sup>(a)</sup>	7.8	86	1.3	<25	0.5	1.1	15.1	>12 <sup>(a)</sup>	7.8	87	1.2	<25	0.4	0.6	9.3	>12 <sup>(a)</sup>	7.7	90	4.9	39.6	2.0	3.4	29.1
12	09/12/06	>12 <sup>(a)</sup>	7.7	88	0.5	<25	<0.1	2.0	15.5	13.3	7.6	88	2.9	28	1.4	6.8	14.8	13.3	7.7	86	0.7	<25	1.2	0.5	8.4

BL = Baseline sampling; NS = not sampled; NA = data not available.

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

<sup>(a)</sup> Exact stagnation time unknown

significantly to less than 1.5 µg/L (or 0.97 µg/L on average), which were higher than the concentrations ( $\leq 0.2$  µg/L) measured at the distribution entry point.

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

## 4.6 System Cost

The cost of the system was evaluated based on the capital cost per gpm (or gpd) of design capacity and the O&M cost per 1,000 gal of water treated. This required the tracking of the capital cost for the equipment, site engineering, and installation and O&M cost for the media replacement and disposal, electricity consumption, and labor. Because the pre-existing building and discharge-related infrastructure were utilized, no additional cost was incurred for building and discharge, the cost of which, if incurred, would have been funded by the demonstration host site according to the agreement established between EPA and the host site.

**4.6.1 Capital Cost.** The capital investment for equipment, site engineering, and installation was \$16,930 (see Table 4-9) as provided by ATS in a cost proposal to Battelle dated June 8, 2005. The equipment cost was \$8,640 (or 51% of the total capital investment), which included \$2,170 for the treatment system mechanical hardware, \$960 for 3 ft<sup>3</sup> of the A/P Complex 2002 oxidizing media (i.e., \$320/ft<sup>3</sup> or \$6.15/lb), \$1,440 for 9 ft<sup>3</sup> of the A/I Complex 2000 adsorptive media (i.e., \$320/ft<sup>3</sup> or \$5.82/lb), \$1,950 for the pressure tank and booster pump, and \$2,120 for vendor's labor and freight.

The engineering cost included the cost for the preparation of the system layout and footprint, design of the piping connections to the entry and distribution tie-in points, and assembling and submission of the engineering plans for the permit application (Section 4.3.1). The engineering cost was \$3,400, 20% of the total capital investment.

The installation cost included the cost of labor and materials to unload and install the treatment system, pressure tank, and booster pump complete the piping installation and tie-ins and perform the system start-up and shakedown (Section 4.3.3). The installation cost was \$4,890, or 29% of the total capital investment.

The capital cost of \$16,930 was normalized to \$1,410/gpm (or \$0.98/gpd) of the design capacity using the system's rated capacity of 12 gpm (or 17,280 gpd). The capital cost also was converted to an annualized cost of \$1,598/yr by multiplying by a capital recovery factor of 0.09439 based on a 7% interest rate and a 20-yr return. Assuming that the system operated 24 hr/day, 7 day/wk at the design flowrate of 12 gpm to produce 6,300,000 gal of water per year, the unit capital cost would be \$0.25/1,000 gal. During the first six months, the system operated an average of 1.7 hr/day at about 9 gpm (see Table 4-4), producing 101,000 gal of water. At this reduced rate of operation, the unit capital cost increased to \$7.91/1,000 gal.

**4.6.2 Operation and Maintenance Cost.** The O&M cost for the As/1200CS treatment system included only the incremental cost associated with the adsorption system, such as media replacement and disposal, electricity consumption, and labor, as presented in Table 4-10. Although the media was not actually replaced during the six-month period, based on the vendor quote, it would cost \$3,850 to replace the media in two columns (either oxidation or adsorption column) at the same time. This cost included \$1,550 for replacement media and spent media disposal (\$775/column or \$517/ft<sup>3</sup>), \$640 for shipping, \$260 of vendor labor, and \$1,400 of vendor travel. Assuming that the labor and travel cost is fixed and that the shipping cost is proportional to the number of media column replaced, it would cost \$2,755,

**Table 4-9. Summary of Capital Investment Cost**

Description	Quantity	Cost	% of Capital Investment Cost
<i>Equipment Cost</i>			
Oxidation Columns (Without Media)	2	\$240	–
A/P Complex 2002 Oxidizing Media (ft <sup>3</sup> )	3	\$960	–
Adsorption Columns (Without Media)	3	\$360	–
A/I Complex 2000 Adsorptive Media (ft <sup>3</sup> )	4.5	\$1,440	–
25-µm Sediment Filter	1	\$350	–
Piping and Valves	1	\$510	–
Flow Totalizer/Meter	1	\$560	–
Hour Meter	1	\$150	–
Pressure Tank/Booster Pump	1	\$1,950	–
Procurement, Assembly, Labor	1	\$1,000	–
Freight	1	\$1,120	–
<b>Equipment Total</b>	–	<b>\$8,640</b>	<b>51%</b>
<i>Engineering Cost</i>			
Design/Scope of System (hr)	10	\$1,500	–
Travel and Miscellaneous Expenses	1	\$1,400	–
Subcontractor Labor	–	\$500	–
<b>Engineering Total</b>	–	<b>\$3,400</b>	<b>20%</b>
<i>Installation Cost</i>			
Plumbing Supplies/Parts	1	\$300	–
Vendor Installation Labor (hr)	10	\$1,300	–
Subcontractor Labor (hr)	6	\$390	–
Vendor Travel (day)	2	\$2,800	–
Subcontractor Travel	–	\$100	–
<b>Installation Total</b>	–	<b>\$4,890</b>	<b>29%</b>
<b>Total Capital Investment</b>	–	<b>\$16,930</b>	<b>100%</b>

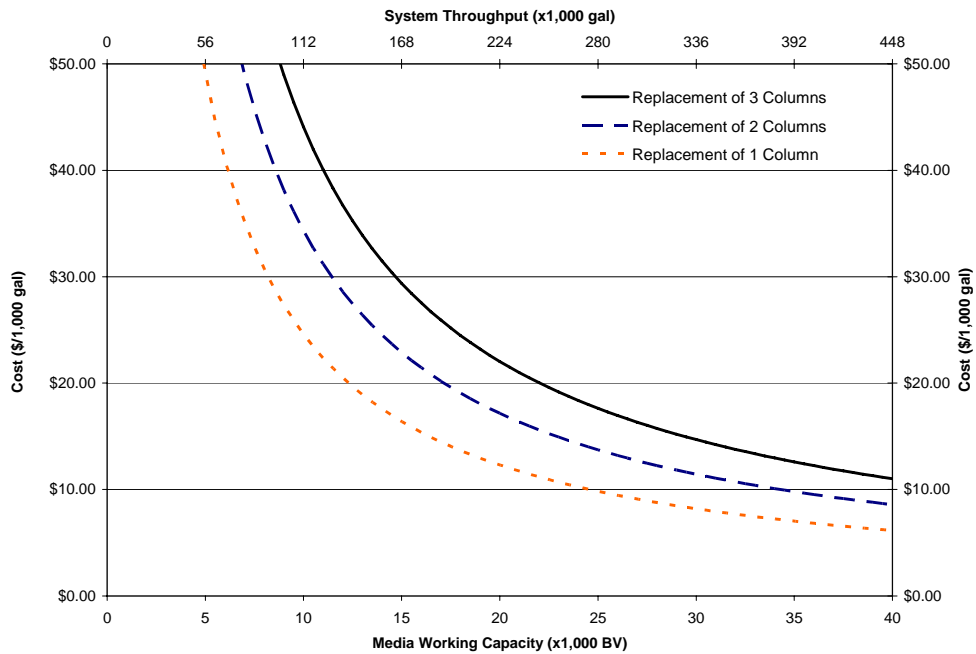
\$3,850, and \$4,945 for replacing one, two, and three columns, respectively (Table 4-10). By averaging the media replacement cost over the life of the media, the cost per 1,000 gal of water treated was plotted as a function of the media run length in BV or the system throughput in gal (see Figure 4-13). If the oxidizing media is not replaced at the same time as the adsorptive media, the unit replacement cost can be estimated separately from the cost curve for one or two columns. Note that the media BV were calculated by dividing the system throughput by the quantity of media in one column, i.e., 1.5 ft<sup>3</sup> or 11.2 gal.

Since the AS/1200CS system consists of three adsorptive columns in series, the media in the lead column will be replaced when the effluent from the third column reaches 10 µg/L of arsenic breakthrough. If the media in the second column also has completely exhausted its arsenic adsorptive capacity, then it needs to be replaced at the same time. Due to the use of partially exhausted column(s), it is expected that the run length for the subsequent service runs would be shorter than the initial run. Therefore, it would require more frequent change-out and a higher unit replacement cost. To reduce the change-out frequency and the associated scheduling and coordinating effort, it might be more cost-effective and convenient in the long run to replace the media in all three columns altogether. The decision on the number of columns to be changed out will be made during the later part of the study; the actual media replacement cost will be documented in the final report.

Additional electricity use associated with the hour meters on the booster pump and well pump and a new booster pump following the treatment system was minimal. The routine, non-demonstration-related labor activities consumed about 20 min/wk as noted in Section 4.4.3. Therefore, the estimated labor cost was \$1.80/1,000 gal of water treated (Table 4-10).

**Table 4-10. Summary of O&M Cost**

Cost Category	Value			Assumptions
Volume Processed (1,000 gal)	100			From September 9, 2005 through March 9, 2006
<b>Media Replacement and Disposal</b>				
Number of Columns Replaced	1	2	3	
Media Replacement and Disposal (\$)	775	1,550	2,325	\$755/column or \$517/ft <sup>3</sup> of media
Shipping (\$)	320	640	960	
Labor and Travel (\$)	1,660	1,660	1,660	Same cost for changing out 1, 2, or 3 columns
Subtotal (\$)	2,755	3,850	4,945	–
Media Replacement and Disposal Cost (\$/1,000 gal)	See Figure 4-13			–
<b>Electricity Consumption</b>				
Electricity Cost (\$/1,000 gal)	0.001			Electrical cost negligible
<b>Labor</b>				
Average Weekly Labor (hr)	0.33			20 min/wk
Labor Cost (\$)	180			9 hr × \$20/hr, labor rate = \$20/hr
Labor Cost (\$/1,000 gal)	1.80			–
<b>Total O&amp;M Cost (\$/1,000 gal)</b>	<b>Adsorptive media replacement + oxidizing media replacement + 1.80</b>			



Note: 1 BV = 1.5 cubic feet = 11.2 gal

**Figure 4-13. Media Replacement Cost Curves for As/1200CS System**

## 5.0 REFERENCES

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**APPENDIX A**  
**OPERATIONAL DATA**

**EPA Arsenic Demonstration Project at Richmond Elementary School in Susanville, CA – Summary of Daily System Operation**

Week No.	Date	Time	Well No. 2 Hour Meter		Booster Pump Hour Meter		Treatment System Flow Readings						Treatment System Pressure Readings					
			Operational Hours	Cumulative Operational Hours	Operational Hours <sup>(a)</sup>	Cumulative Operational Hours	Volume Treated	Cumulative Volume Treated	Bed Volumes Treated <sup>(b)</sup>	Cumulative Bed Volumes Treated	Average Flowrate (Booster Pump/System)	Average Flowrate (Well Pump)	IN	OA	OB	TA	TB	TC
			hrs	hrs	hrs	hrs	gal	gal	BV	BV	gpm	gpm	psi	psi	psi	psi	psi	psi
1	09/08/05	07:00	-	10.2	NM	28.3	-	3,040	-	271	NM	-	50	50	50	50	50	50
	09/09/05	10:55	0.5	10.7	1.4	29.7	643	3,683	57	328	7.7	21.4	41	38	32	27	18	13
2	09/12/05	15:45	1.1	11.8	3.1	32.8	1,238	4,921	110	438	6.8	18.8	53	53	53	53	52	53
	09/13/05	10:28	0.3	12.1	0.8	33.6	279	5,199	25	463	5.6	15.5	42	39	33	28	19	15
	09/14/05	11:00	0.7	12.8	1.9	35.5	717	5,916	64	527	6.2	17.1	55	57	57	57	55	57
	09/16/05	07:06	1.3	14.1	3.6	39.1	1,615	7,531	144	671	7.5	20.7	37	42	42	42	40	42
3	09/19/05	07:15	1.0	15.1	2.8	41.9	976	8,507	87	758	5.9	16.3	35	33	27	22	15	11
	09/20/05	07:10	1.1	16.2	3.1	45.0	1,390	9,897	124	882	7.6	21.1	36	42	42	42	40	42
7	10/17/05	10:25	11.1	27.3	30.8	75.8	13,668	23,565	1,218	2,100	7.3	24.1	38	35	29	24	15	10
9	11/01/05	13:06	-	-	-	-	20,360	43,925	1,815	3,915	NM	NM	40	38	32	25	16	12
10	11/02/05	10:07	7.1	34.4	19.7	95.5	360	44,285	32	3,947	17.6	48.6	41	38	32	26	16	11
12	11/21/05	14:15	-	-	-	-	9,313	53,598	830	4,777	NM	NM	NM	NM	NM	NM	NM	NM
13	11/29/05	14:20	7.9	42.3	21.9	117.4	1,029	54,627	92	4,869	7.9	21.8	37	35	30	26	18	16
	11/30/05	12:56	0.5	42.8	1.4	118.8	596	55,223	53	4,922	7.2	19.9	44	41	36	30	22	18
	12/04/05	12:15	1.5	44.3	4.2	123.0	1,938	57,161	173	5,095	7.8	21.5	48	45	38	31	21	15
14	12/05/05	14:45	0.3	44.6	0.8	123.8	439	57,600	39	5,134	8.8	24.4	47	44	37	31	21	16
	12/08/05	10:15	1.5	46.1	4.2	128.0	1,971	59,571	176	5,310	7.9	21.9	43	41	35	31	22	17
	12/09/05	10:30	0.8	46.9	2.2	130.2	1,107	60,678	99	5,409	8.3	23.1	45	41	36	31	22	19
15	12/12/05	14:04	1.6	48.5	4.4	134.6	2,613	63,291	233	5,642	9.8	22.3	36	35	29	24	15	11
	12/13/05	12:25	0.3	48.8	1.0	135.6	524	63,815	47	5,689	9.2	29.1	38	35	29	23	15	10
	12/14/05	09:30	0.3	49.1	0.7	136.3	367	64,182	33	5,722	8.7	20.4	36	33	27	22	15	11





**EPA Arsenic Demonstration Project at Richmond Elementary School in Susanville, CA – Summary of Daily System Operation (Continued)**

Week No.	Date	Time	Well No. 2 Hour Meter		Booster Pump Hour Meter		Treatment System Flow Readings						Treatment System Pressure Readings					
			Operational Hours	Cumulative Operational Hours	Operational Hours <sup>(a)</sup>	Cumulative Operational Hours	Volume Treated	Cumulative Volume Treated	Bed Volumes Treated <sup>(b)</sup>	Cumulative Bed Volumes Treated	Average Flowrate (Booster Pump/System)	Average Flowrate (Well Pump)	IN	OA	OB	TA	TB	TC
			hrs	Hrs	hrs	Hrs	gal	gal	BV	BV	gpm	gpm	psi	psi	psi	psi	psi	psi
24	02/14/06	10:15	0.6	67.2	1.6	185.4	897	89,739	80	8,001	9.3	24.0	42	39	33	26	17	12
	02/15/06	15:00	0.7	67.9	2.0	187.4	970	90,709	86	8,087	8.1	24.0	50	48	40	34	22	16
	02/16/06	14:00	0.2	68.1	0.5	187.9	264	90,973	24	8,111	8.8	23.8	44	42	34	28	18	12
	02/17/06	13:00	0.7	68.8	2.0	189.9	1,095	92,068	98	8,209	9.1	25.9	43	40	33	27	17	12
25	02/22/06	12:00	0.7	69.5	2.2	192.1	1,113	93,181	99	8,308	8.4	27.1	36	35	29	22	9	9
	02/24/06	11:05	0.9	70.4	2.5	194.6	1,324	94,505	118	8,426	8.8	24.6	37	24	29	23	11	11
26	02/27/06	12:00	0.8	71.2	2.0	196.6	1,042	95,547	93	8,519	8.7	21.4	54	51	44	36	25	18
	02/28/06	13:00	0.4	71.6	1.3	197.9	690	96,237	61	8,580	8.8	27.8	53	50	44	36	24	18
	03/01/06	12:00	0.3	71.9	0.8	198.7	443	96,680	39	8,619	9.2	25.3	42	39	31	26	16	11
	03/02/06	09:20	0.4	72.3	1.1	199.8	555	97,235	49	8,668	8.4	23.6	40	37	30	24	15	11
27	03/06/06	14:00	1.3	73.6	3.6	203.4	1,912	99,147	170	8,838	8.9	24.6	50	47	40	33	21	16
	03/07/06	07:20	0.2	73.8	0.4	203.8	211	99,358	19	8,857	8.8	17.6	52	48	41	34	23	18
	03/09/06	08:15	1.0	74.8	2.9	206.7	1,525	100,883	136	8,993	8.8	12.0	40	37	32	26	17	14

(a) booster pump hours estimated by multiplying well pump hours by 2.77 until booster pump hour meter installed on 12/09/05.

(b) 1 bed volume = 1.5 ft<sup>3</sup> = 11.22 gal

NM = not measured

**APPENDIX B**  
**ANALYTICAL DATA TABLES**







**Analytical Results from Long-Term Sampling, Susanville, CA (Continued)**

Sampling Date		03/02/06						03/15/06					
Sampling Location		IN	OA	OB	TA	TB	TC	IN	OA	OB	TA	TB	TC
Parameter	Unit												
Bed Volume	BV	-	-	-	-	-	8.7	-	-	-	-	-	9.2
Alkalinity (as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-	83	-	79	-	-	83
Fluoride	mg/L	-	-	-	-	-	-	0.2	-	0.2	-	-	0.3
Iodine (as I)	µg/L	-	-	-	-	-	-	24.5	-	57.5	-	-	127
Iodide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	17.9	-	17.5	-	-	18.1
Sulfide	µg/L	-	-	-	-	-	-	<5	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	<0.05	-	<0.05	-	-	<0.05
Orthophosphate (as PO <sub>4</sub> )	mg/L	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as PO <sub>4</sub> )	mg/L	-	-	-	-	-	-	<0.01	-	<0.01	-	-	<0.01
Silica (as SiO <sub>2</sub> )	mg/L	15.3	12.9	10.7	8.5	6.6	5.2	13.2	12.0	9.0	9.0	6.7	4.7
Turbidity	NTU	-	-	-	-	-	-	1.5	-	1.2	-	-	1.1
pH	S.U.	-	-	-	-	-	-	-	-	-	-	-	-
Temperature	°C	-	-	-	-	-	-	-	-	-	-	-	-
DO	mg/L	-	-	-	-	-	-	-	-	-	-	-	-
ORP	mV	-	-	-	-	-	-	-	-	-	-	-	-
Total Hardness (as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-	33.2	-	31.3	-	-	31.1
Ca Hardness (as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-	25.1	-	23.5	-	-	23.4
Mg Hardness (as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-	8.1	-	7.8	-	-	7.7
As (total)	µg/L	28.3	29.1	9.7	0.1	<0.1	0.1	25.6	24.5	10.7	<0.1	<0.1	<0.1
As (soluble)	µg/L	28.9	29.2	9.3	-	-	0.1	-	-	-	-	-	-
As (particulate)	µg/L	<0.1	<0.1	0.4	-	-	<0.1	-	-	-	-	-	-
As (III)	µg/L	12.1	0.4	0.4	-	-	0.1	-	-	-	-	-	-
As (V)	µg/L	16.7	28.8	8.9	-	-	<0.1	-	-	-	-	-	-
Fe (total)	µg/L	54.7	<25	<25	<25	<25	<25	<25	-	<25	-	-	<25
Fe (soluble)	µg/L	25.2	<25	<25	-	-	<25	-	-	-	-	-	-
Mn (total)	µg/L	6.5	<0.1	<0.1	<0.1	<0.1	<0.1	6.5	-	<0.1	-	-	<0.1
Mn (soluble)	µg/L	6.5	<0.1	<0.1	-	-	<0.1	-	-	-	-	-	-
Al (total)	µg/L	<10	21.3	18.1	18.0	18.8	19.1	<10	-	19.8	-	-	21.9
Al (soluble)	µg/L	<10	17.9	16.5	-	-	18.5	-	-	-	-	-	-