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Arsenic Removal from Drinking Water by Adsorptive Media U.S. EPA Demonstration Project at Oak Manor Municipal Utility District at Alvin, TX Final Performance Evaluation Report

by

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Sally Gutierrez, Director
National Risk Management Research Laboratory

ABSTRACT

This report documents the activities performed and the results obtained for the EPA arsenic removal technology demonstration project at the Oak Manor Municipal Utility District (MUD) facility in Alvin, TX. The objectives of the project were to evaluate 1) the effectiveness of a Severn Trent Services (STS) Adsorptive Media System – Arsenic Package Unit (APU)-30S – with the use of SORB 33™ media in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 μg/L, 2) the reliability of the treatment system, 3) the simplicity of required system operation and maintenance (O&M) and operator skills, and 4) the cost-effectiveness of the technology. The project also characterized water in the distribution system and process residuals produced by the treatment system.

The STS APU-30S system consisted of two 63-in × 86-in adsorption vessels configured in series with 53.6 ft^3 of SORB 33™ media loaded in the lead vessel and 70.3 ft^3 in the lag vessel. The SORB 33™ media is an iron-based adsorptive media developed by Bayer AG and packaged under the name SORB 33™ by STS. The system was designed for a flowrate of 150 gal/min (gpm), corresponding to a design empty bed contact time (EBCT) of about 6.2 min (or 3.1 min/vessel) and a hydraulic loading rate of 6.9 gpm/ft^2. Actual flowrate through the system averaged 129 gpm during the performance evaluation study, yielding an EBCT of 7.2 min.

During the two-year performance evaluation study that began on April 25, 2006, and ended on April 8, 2008, the treatment system operated for a total of 4,628 hr (or 6.7 hr/day), treating approximately 35,358,250 gal or 38,140 bed volumes (BV) of water. (Bed volumes were calculated based on 124 ft^3 of media in both vessels.) The system continued to operate throughout the two-year study duration with only a few minor repairs and adjustments. The flowrate, pressure data, and other operational parameters were within the vendor specifications.

Source water from Wells 1 and 2 contained 40.2 μg/L (on average) of total arsenic, which existed primarily as soluble As(III) (i.e., 31.5 μg/L). Prechlorination was effective at oxidizing As(III) to As(V), converting 98% of soluble arsenic to As(V). Arsenic breakthrough at 10 μg/L occurred after treating 9,527,220 gal (or 10,277 BV) of water following the lead vessel and 26,638,090 gal (or 28,736 BV) following the lag vessel. At the conclusion of the performance evaluation study, the system treated approximately 35,358,250 gal (or 38,140 BV) of water with 23.2 and 10.5 μg/L of total arsenic present in the effluent of the lead and lag vessels, respectively. Bed volumes were calculated based on 124 ft^3 of media in both lead and lag vessels.

Prechlorination also was effective in oxidizing soluble iron and manganese in source water, reducing their concentrations to below the method detection limit (MDL) of 25 μg/L for iron and 1.9 μg/L for manganese.

Backwash was manually initiated by the operator when differential pressure across the adsorption vessels was approaching or exceeded 10 psi. During the first year of system operation, backwash was effective in restoring differential pressure (Δp) across the lead vessel, reducing it from above 10 psi to the initial level of <4.0 psi. Since then, backwash became less effective. Gradual accumulation of precipitated solids or well sediments was thought to have contributed to the progressively less effective backwash observed. Δp across the lag vessel remained low and constant around 3.1 psi throughout the performance evaluation study, indicating that precipitated solids and well sediments were removed mostly by the lead vessel. During each backwash event, approximately 7.2 kg of solids were discharged along with 10,800 gal of backwash wastewater. The discharged solids comprised 2.8 g of arsenic, 804 g of iron, and 71.8 g of manganese.

Comparison of the distribution system sampling results before and after system startup showed noticeable decreases in arsenic (from 38.2 to 2.6 μg/L [on average]) and manganese concentrations (from 41.8 to 1.5 μg/L [on average]) at all three distribution system sampling locations. Initially, arsenic concentrations in the distribution system water were higher than those in the plant effluent, probably due to redissolution and/or resuspension of arsenic previously accumulated in the distribution system. The concentrations then decreased and essentially mirrored those in the plant effluent. Lead and copper concentrations did not appear to have been affected by the operation of the treatment system.

The capital investment cost for the treatment system was $179,750, including $124,103 for equipment, $14,000 for site engineering, and $41,647 for installation. Using the system's rated capacity of 150 gpm, the capital cost was $1,198/gpm (or $0.83/gpd). This calculation did not include the cost for a building addition to house the treatment system. The unit annualized capital cost was $0.22/1,000 gal, assuming the system operated 24 hours a day, 7 days a week, at the system design flowrate of 150 gpm. The system operated only 6.7 hr/day on average, producing 18,928,170 gal of water per year. At this reduced usage rate, the unit annualized capital cost increased to $0.90/1,000 gal. O&M cost included only incremental cost associated with media replacement and disposal, and labor. There was no incremental electricity or chemical consumption cost. The unit O&M cost is presented in graphical form as a function of projected media run length in this report.

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ABBREVIATIONS AND ACRONYMS

Δp	differential pressure
AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
APU	arsenic package unit
As	arsenic
ATS	Aquatic Treatment Systems
BET	Brunauer, Emmett, and Teller
BV	bed volume(s)
Ca	calcium
C/F	coagulation/filtration
Cl	chlorine
CRF	capital recovery factor
Cu	copper
DO	dissolved oxygen
EBCT	empty bed contact time
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
FedEx	Federal Express
FRP	fiberglass reinforced plastic
gpd	gallons per day
gpm	gallons per minute
HDPE	high-density polyethylene
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
µm	micrometer
Mn	manganese
MUD	Municipal Utility District

mV	millivolts
Na	sodium
NA	not analyzed
NS	not sampled
NSF	NSF International
NTU	nephelometric turbidity units
O&M	operation and maintenance
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
P	phosphorus
P&ID	piping and instrumentation diagram
Pb	lead
psi	pounds per square inch
PLC	programmable logic controller
PO_4	phosphate
POU	point-of-use
PVC	polyvinyl chloride
QA	quality assurance
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RPD	relative percent difference
RO	reverse osmosis
SDWA	Safe Drinking Water Act
SiO_2	silica
SMCL	secondary maximum contaminant level
SO_4	sulfate
STS	Severn Trent Services
TCLP	Toxicity Characteristic Leaching Procedure
TCEQ	Texas Commission of Environmental Quality
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
V	vanadium
VOC	volatile organic compound(s)

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Ms. Tien Shiao, who is currently pursuing a Master's degree at Yale University, was the Battelle study lead for this demonstration project.

1.0 INTRODUCTION

1.1 Project Background

The Safe Drinking Water Act (SDWA) mandates that U.S. Environmental Protection Agency (EPA) identify and regulate drinking water contaminants that may have adverse human health effects and that are known or anticipated to occur in public water supply systems. In 1975 under the SDWA, EPA established a maximum contaminant level (MCL) for arsenic at 0.05 mg/L. Amended in 1996, the SDWA required that EPA develop an arsenic research strategy and publish a proposal to revise the arsenic MCL by January 2000. On January 18, 2001, EPA finalized the arsenic MCL at 0.01 mg/L (EPA, 2001). In order to clarify the implementation of the original rule, EPA revised the rule 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 host the demonstration studies.

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

In 2003, EPA initiated Round 2 arsenic technology demonstration projects that were partially funded with Congressional add-on funding to the EPA budget. In June 2003, EPA selected 32 potential demonstration sites and the Oak Manor Municipal Utility District (MUD) Water System in Alvin, TX 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. Severn Trent Service's (STS) SORB 33™ Arsenic Removal Technology was selected for demonstration at the Oak Manor MUD facility.

As of May 2010, 39 of the 40 systems were operational and the performance evaluation of 36 systems was completed.

1.2 Treatment Technologies for Arsenic Removal

The technologies selected for the Round 1 and Round 2 demonstration host sites include 25 adsorptive media (AM) systems (the Oregon Institute of Technology [OIT] site has three AM systems), 13 coagulation/filtration (C/F) systems, two ion exchange (IX) systems, and 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 As, Fe, 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 costs is provided in two EPA reports (Wang et al., 2004; Chen et al., 2004), which are posted on the EPA Web site at http://www.epa.gov/ORD/NRMRL/wswrd/dw/arsenic/index.html.

1.3 Project Objectives

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

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

This report summarizes the performance of the STS's system at the Oak Manor MUD in Alvin, TX from April 25, 2006 through April 8, 2008. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and O&M cost.

Table 1-1. Summary of Round 1 and Round 2 Arsenic Removal Demonstration Sites

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH (S.U.)
Northeast/Ohio							
Wales, ME	Springbrook Mobile Home Park	AM (A/I Complex)	ATS	14	38[a]	<25	8.6
Bow, NH	White Rock Water Company	AM (G2)	ADI	70[b]	39	<25	7.7
Goffstown, NH	Orchard Highlands Subdivision	AM (E33)	AdEdge	10	33	<25	6.9
Rollinsford, NH	Rollinsford Water and Sewer District	AM (E33)	AdEdge	100	36[a]	46	8.2
Dummerston, VT	Charette Mobile Home Park	AM (A/I Complex)	ATS	22	30	<25	7.9
Felton, DE	Town of Felton	C/F (Macrolite)	Kinetico	375	30[a]	48	8.2
Stevensville, MD	Queen Anne's County	AM (E33)	STS	300	19[a]	270[c]	7.3
Houghton, NY[d]	Town of Caneadea	C/F (Macrolite)	Kinetico	550	27[a]	1,806[c]	7.6
Newark, OH	Buckeye Lake Head Start Building	AM (ARM 200)	Kinetico	10	15[a]	1,312[c]	7.6
Springfield, OH	Chateau Estates Mobile Home Park	AM (E33)	AdEdge	250[e]	25[a]	1,615[c]	7.3
Great Lakes/Interior Plains							
Brown City, MI	City of Brown City	AM (E33)	STS	640	14[a]	127[c]	7.3
Pentwater, MI	Village of Pentwater	C/F (Macrolite)	Kinetico	400	13[a]	466[c]	6.9
Sandusky, MI	City of Sandusky	C/F (Aeralater)	Siemens	340[e]	16[a]	1,387[c]	6.9
Delavan, WI	Vintage on the Ponds	C/F (Macrolite)	Kinetico	40	20[a]	1,499[c]	7.5
Greenville, WI	Town of Greenville	C/F (Macrolite)	Kinetico	375	17	7827[c]	7.3
Climax, MN	City of Climax	C/F (Macrolite)	Kinetico	140	39[a]	546[c]	7.4
Sabin, MN	City of Sabin	C/F (Macrolite)	Kinetico	250	34	1,470[c]	7.3
Sauk Centre, MN	Big Sauk Lake Mobile Home Park	C/F (Macrolite)	Kinetico	20	25[a]	3,078[c]	7.1
Stewart, MN	City of Stewart	C/F&AM (E33)	AdEdge	250	42[a]	1,344[c]	7.7
Lidgerwood, ND	City of Lidgerwood	Process Modification	Kinetico	250	146[a]	1,325[c]	7.2
Midwest/Southwest							
Arnaudville, LA	United Water Systems	C/F (Macrolite)	Kinetico	770[e]	35[a]	2,068[c]	7.0
Alvin, TX	Oak Manor Municipal Utility District	AM (E33)	STS	150	19[a]	95	7.8
Bruni, TX	Webb Consolidated Independent School District	AM (E33)	AdEdge	40	56[a]	<25	8.0
Wellman, TX	City of Wellman	AM (E33)	AdEdge	100	45	<25	7.7
Anthony, NM	Desert Sands Mutual Domestic Water Consumers Association	AM (E33)	STS	320	23[a]	39	7.7
Nambe Pueblo, NM	Nambe Pueblo Tribe	AM (E33)	AdEdge	145	33	<25	8.5
Taos, NM	Town of Taos	AM (E33)	STS	450	14	59	9.5
Rimrock, AZ	Arizona Water Company	AM (E33)	AdEdge	90[b]	50	170	7.2
Tohono O'odham Nation, AZ	Tohono O'odham Utility Authority	AM (E33)	AdEdge	50	32	<25	8.2
Valley Vista, AZ	Arizona Water Company	AM (AAFS50/ARM 200)	Kinetico	37	41	<25	7.8

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

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

AM = adsorptive media process; C/F = coagulation/filtration; HIX = hybrid ion exchanger; IX = ion exchange process; RO = reverse osmosis
ATS = Aquatic Treatment Systems; MEI = Magnesium Elektron, Inc.; STS = Severn Trent Services

(a) Arsenic existing mostly as As(III).
(b) Design flowrate reduced by 50% due to system reconfiguration from parallel to series operation.
(c) Iron existing mostly as Fe(II).
(d) Withdrew from program in 2007. Selected originally to replace Village of Lyman, NE site, which withdrew from program in June 2006.
(e) Facilities upgraded systems in Springfield, OH from 150 to 250 gpm, Sandusky, MI from 210 to 340 gpm, and Arnaudville, LA from 385 to 770 gpm.
(f) Including nine residential units.
(g) Including eight under-the-sink units.

2.0 SUMMARY AND CONCLUSIONS

Based on the information collected during the two-year performance evaluation study (from April 25, 2006 to April 8, 2008), 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:

- Prechlorination was effective in oxidizing As(III) to As(V), reducing As(III) concentrations from 31.5 µg/L (on average) in raw water to 0.7 µg/L (on average) after chlorination.
- SORB 33™ media effectively removed arsenic in source water. Breakthrough at 10 µg/L, however, occurred relatively early, after treating only 10,277 BV of water following the lead vessel and 28,736 BV following the lag vessel (bed volumes were calculated based on 124 ft^3 of media in both vessels).
- During the first half of the performance evaluation study, backwash was effective in restoring differential pressure (Δp) across the lead vessel, reducing it from above 10 psi to the initial level of less than 4.0 psi. Afterwards, backwash became progressively less effective, presumably caused by gradual accumulation of precipitated solids and well sediments.
- The treatment system significantly reduced arsenic concentrations in the distribution system from a background level of 38.2 µg/L (on average) to 2.6 µg/L. Initially, arsenic concentrations in the distribution system were higher than those in the plant effluent, presumably caused by redissolution and/or resuspension of arsenic previously accumulated in the distribution system. The arsenic concentrations then decreased to mirror those of the plant effluent. Lead and copper concentrations did not appear to have been affected by the operation of the system.

Required system O&M and operator skill levels:

- Under normal operating conditions, the skills required to operate the system were minimal, with a typical daily demand on the operator of only 40 min. Normal operation of the system did not appear to require additional skills beyond those necessary to operate the existing water supply equipment. A Class C state-certified operator was required for operation of the Oak Manor MUD water treatment system.

Characteristics of residuals produced by the technology:

- Each backwash event produced approximately 10,800 gal of wastewater and 7.2 kg of solids (including 6.3 kg from the lead vessel and 0.9 kg from the lag vessel). Arsenic constituted only 0.04% by weight of the solids.

Capital and O&M cost of the technology:

- The unit annualized capital cost was $0.22/1,000 gal if the system operated at a 100% utilization rate. The system's actual unit annualized capital cost was $0.90/1,000 gal, based on 6.7 hr/day of system operation and 18,928,170 gal/year of water production.
- O&M cost included only incremental cost associated with media replacement and disposal, and labor. There was no incremental electricity cost or chemical consumption cost.

3.0 MATERIALS AND METHODS

3.1 General Project Approach

Following the predemonstration activities summarized in Table 3-1, the performance evaluation study of the STS treatment system began on April 25, 2006, and ended on April 8, 2008. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall system performance was evaluated based on its ability to consistently remove arsenic to below the target MCL of 10 μg/L through the collection of water samples across the treatment train, as described in the Study Plan (Battelle, 2006). 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 assessed through quantitative data and qualitative considerations, including the need for any pre- and/or post-treatment, level of system automation, extent of preventative maintenance activities, frequency of chemical and/or media handling and inventory, and general knowledge needed for relevant chemical processes and related health and safety practices. The staffing requirements for the system operation were recorded on an Operator Labor Hour Log Sheet.

The quantity of aqueous and solid residuals generated was estimated by tracking the amount of backwash wastewater produced during each backwash cycle and the need to replace the media upon arsenic breakthrough. Backwash wastewater and spent media were sampled and analyzed for chemical characteristics.

Table 3-1. Predemonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	November 2, 2004
Draft Letter of Understanding Issued	January 21, 2005
Final Letter of Understanding Issued	February 8, 2005
Request for Quotation Issued to Vendor	February 14, 2005
Vendor Quotation Received	March 20, 2005
Purchase Order Established	May 3, 2005
Letter Report Issued	May 12, 2005
Exception Request Submitted to TCEQ	July 8, 2005
APU-30S System Shipped	September 4, 2005
Engineering Package Submitted to TCEQ	September 9, 2005
Building Construction Begun	October 6, 2005
Building Completed	November 12, 2005
Exception Request Granted by TCEQ	November 21, 2005
System Permit Granted by TCEQ	December 16, 2005
Study Plan Issued	January 13, 2006
System Installation Completed	March 9, 2006
System Shakedown Completed	March 10, 2006
Performance Evaluation Begun	April 25, 2006

TCEQ = Texas Commission of Environmental Quality

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

Evaluation Objective	Data Collection
Performance	-Ability to consistently meet 10 µg/L of arsenic in treated water
Reliability	-Unscheduled system downtime -Frequency and extent of repairs including a description of problems, materials and supplies needed, and associated labor and cost
System O&M and Operator Skill Requirements	-Pre- and post-treatment requirements -Level of system automation for system operation and data collection -Staffing requirements including number of operators and laborers -Task analysis of preventative maintenance including number, frequency, and complexity of tasks -Chemical handling and inventory requirements -General knowledge needed for relevant chemical processes and health and safety practices
Residual Management	-Quantity and characteristics of aqueous and solid residuals generated by system operation
System Cost	-Capital cost for equipment, site engineering, and installation -O&M cost for media, chemical consumption, electricity usage, and labor

The cost of the system was evaluated based on the capital cost per gal/min (gpm) (or gal/day [gpd]) of design capacity and the O&M cost per 1,000 gal of water treated. This task required tracking of 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.

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 daily basis (except for most Saturdays and Sundays), the plant operator recorded system operational data, such as pressure, flowrate, totalizer, and hour meter readings on a Daily System Operation Log Sheet; checked weight of chlorine gas cylinders for chlorine consumption; and conducted visual inspections to ensure normal system operations. If any problem occurred, the plant operator contacted the Battelle Study Lead, who determined if the vendor should be contacted for troubleshooting. The plant operator recorded all relevant information, including the problems encountered, course of actions taken, materials and supplies used, and associated cost and labor incurred, on a Repair and Maintenance Log Sheet. On a bi-weekly to monthly basis, the plant operator measured temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and residual chlorine, and recorded the data on an Onsite Water Quality Parameters Log Sheet. Monthly (or as needed) backwash data also were recorded on a Backwash Log Sheet.

The capital cost for the arsenic removal system consisted of the cost for equipment, site engineering, and system installation. The O&M cost consisted of the cost for media replacement and spent media disposal, electricity, and labor. The gas chlorine consumption was tracked on the Daily System Operation Log Sheet. Because the chemical addition system was pre-existing, chlorine consumption was not counted towards the O&M cost. Electricity consumption was determined from utility bills. Labor for 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, replacing chlorine gas cylinders, 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 at the wellhead and across the treatment plant, during adsorption vessel backwash, and from the distribution system. Table 3-3 provides the planned sampling schedules and analytes measured during each sampling event. Figure 3-1 presents a flow diagram of the treatment system along with the analytes and schedules at each sampling location. Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2004). The procedure for arsenic speciation is described in Appendix A of the QAPP.

3.3.1 Source Water. Source water samples were collected from Well 2 during the initial visit to the site on November 2, 2004, and from Well 1 and Well 2 and after Wells 1 and 2 were combined on February 16, 2005. Before sampling, the sample tap was flushed for several minutes; special care was taken to avoid agitation, which could cause unwanted oxidation. The samples were analyzed for the analytes listed in Table 3-3. Onsite speciation was performed for the sample collected on November 2, 2004, using an arsenic speciation kit described in Section 3.4.1. No speciation was performed for the samples collected on February 16, 2005.

3.3.2 Treatment Plant Water. Treatment plant water samples were collected by the plant operator biweekly, on a four-week cycle, for on- and off-site analyses. For the first week of each four-week cycle, samples were collected at the wellhead (IN), after chlorination (AC), after the lead adsorption vessel (TA), and after the lag adsorption vessel (TB), and speciated and analyzed for the analytes listed under speciation sampling in Table 3-3. During the third week of each four-week cycle, samples were collected from the same four locations and analyzed for the analytes listed under non-speciation sampling in Table 3-3.

Over the course of the demonstration study, several changes were made to the orginally planned sampling schedule:

- During November 15, 2006, through August 22, 2007, the sampling frequency was reduced from once every two weeks to once every four weeks, except for the May 30, 2007, event that did not take place until two weeks later.
- Starting from September 12, 2007, the sampling frequency was increased again to once every two to four weeks to better monitor the arsenic breakthrough (except for the January 2 and March 13, 2008, events that took place five and six weeks, respectively, after the previous sampling events.)
- Measurements for SiO_2, turbidity, and alkalinity were discontinued from July 25, 2007. Measurements for Ca, Mg, F, NO_3, and SO_4 were discontinued from August 22, 2007. Measurements for P were discontinued on March 13, 2008.
- NH_3 was analyzed at all four sampling locations during October 3, 2007, through April 8, 2008.

3.3.3 Backwash Wastewater. Backwash wastewater samples were collected from both vessels by the plant operator during backwash events. Tubing, connected to the tap on the discharge line of each vessel, directed a portion of backwash wastewater at about 1 gpm into a clean, 32-gal container over the entire backwash duration from each vessel. After the content in the container was thoroughly mixed, composite samples were collected and/or filtered onsite with 0.45-µm disc filters. Analytes for the backwash samples are listed in Table 3-3.

Table 3-3. Sampling Schedule and Analyses

Sample Type	Sample Locations[a]	No. of Samples	Frequency	Analytes	Collection Date(s)
Source Water	IN	1	From Well 2 during initial site visit on 11/02/04 and from Well 1, Well 2, and after Wells 1 and 2 combined on 02/16/05	On-site: pH, temperature, DO, and/or ORP Off-site: As(III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, Cl, F, NO_3, NO_2, NH_3, SO_4, SiO_2, PO_4, turbidity, alkalinity, TDS, and/or TOC	11/02/04 and 02/16/05
Treatment Plant Water	IN, AC, TA, TB	4	Speciation Sampling: Once every four weeks (from 04/25/06 to 10/11/06) Once every six to eight weeks (from 11/15/06 to 10/03/07)	On-site: pH, temperature, DO, ORP, and/or Cl_2 (free and total)[b] Off-site: As(III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), Ca, Mg, F, NO_3, NH_3, SO_4, SiO_2, P, turbidity, and/or alkalinity	04/25/06, 05/23/06, 06/21/06, 07/19/06, 08/16/06, 09/12/06, 10/11/06, 11/15/06, 01/10/07, 03/07/07, 05/02/07, 06/27/07, 08/22/07, 10/03/07
			Non-speciation sampling: Once every four weeks (from 05/09/06 to 09/27/06) Once every two to ten weeks (from 12/13/06 to 04/08/08)	On-site: pH, temperature, DO, ORP, and/or Cl_2 (free and total)[b] Off-site: As (total), Fe (total), Mn (total), NH_3, SiO_2, P, turbidity, and/or alkalinity	05/09/06, 06/06/06, 07/05/06, 08/01/06, 08/29/06, 09/27/06, 12/13/06, 02/06/07, 04/04/07, 06/12//07, 07/25/07, 09/12/07, 11/06/07, 11/27/07, 01/02/08, 01/29/08, 03/13/08, 03/25/08, 04/08/08
Backwash Wastewater	BW	2	Monthly or as needed	As(total and soluble), Fe(total and soluble), Mn(total and soluble), pH, TDS, and TSS	07/14/06, 08/09/06, 09/19/06, 10/31/06, 12/05/06, 01/30/07, 03/13/07, 04/10/07, 05/09/07, 06/26/07, 08/29/07
Backwash Solids	BW	1 per vessel	Once	Total Al, As, Ca, Cd, Cu, Fe, Mg, Mn, Ni, P, Pb, Si, and Zn	11/01/06
Distribution Water	Three homes (with only one LCR sampling location)	3	Monthly (from 05/17/06 to 04/04/07)	As (total), Fe (total), Mn (total), Cu (total), Pb (total), pH, and alkalinity	Baseline sampling: 03/16/05, 04/20/05, 05/18/05, 06/14/05

Table 3-3. Sampling Schedule and Analyses (Continued)

Sample Type	Sample Locations[(a)]	No. of Samples	Frequency	Analytes	Collection Date(s)
					Monthly sampling: 05/17/06, 06/07/06, 07/19/06, 08/15/06, 09/13/06, 10/10/06, 11/21/06, 12/13/06, 01/10/07, 02/07/07, 03/07/07, 04/04/07
Spent Media	From spent media in vessels	3	Once (after end of study)	TCLP and total As, Ba, Ca, Fe, Mg, Mn, P, and Si	10/14/08

(a) Abbreviations corresponding to sample locations in Figure 3-1: IN = at wellhead; AC = after chlorination; TA = after lead Vessel A; TB = after lag Vessel B; BW = at backwash wastewater discharge line
(b) Onsite chlorine measurements not performed at IN location.
(c) NH_3 measured from 09/12/07 through 04/08/08.
(d) Measurements for alkalinity, SiO_2, and turbidity discontinued on 07/25/07.
(e) Measurement for P discontinued on 03/13/08.

3.3.4 Residual Solids. Residual solids consisted of backwash solids and spent media samples. Backwash solids/water mixtures were collected after solids settled in the 32-gal backwash containers and the supernatant carefully decanted. The samples were air-dried, acid-digested, and analyzed for the analytes listed in Table 3-3.

Three spent media samples were collected from the top, middle, and bottom of the exhausted lead vessel during the media changeout conducted on October 14, 2008, approximately 6 months after the end of the performance evaluation study. Spent media were removed from the vessel using a vacuum truck. Representative samples were collected at each level and stored in an unpreserved 1-gal wide-mouth high-density polyethylene (HDPE) bottle. One aliquot of each sample was air-dried and acid-digested for the analytes listed in Table 3-3.

3.3.5 Distribution System Water. Water samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically on the levels of arsenic, lead, and copper. Prior to system startup from March to June 2005, four sets of monthly baseline water samples were collected from three residences, designated as DS1, DS2, and DS3, within the distribution system. The DS1 residence located originally on 224 Oak Manor Drive was sampled only twice on March 16 and April 20, 2005, before being changed to the final location on 95 Oak Trail. The DS2 residence located orginally on 98 Shady Oak Drive was sampled only once on March 16, 2005, before being changed to the final location of 61 Shady Oak Drive. The DS3 residence located on 7 Kenny Court was used for all baseline sampling events. Following system startup, distribution system sampling continued on a monthly basis through April 2007, at the same three locations as discussed. The distribution system sampling was discontinued after April 4, 2007.

The distribution system water samples were taken following an instruction sheet developed by Battelle according to the *Lead and Copper Rule Reporting Guidance for Public Water Systems* (EPA, 2002). First draw samples were collected from cold-water faucets that had not been used for at least six hours to ensure that stagnant water was sampled. The sampler recorded the date and time of last water use before sampling and the date and time of sample collection for calculation of the stagnation time. The samples were analyzed for the analytes listed in Table 3-3. Arsenic speciation was not performed for the distribution water samples.

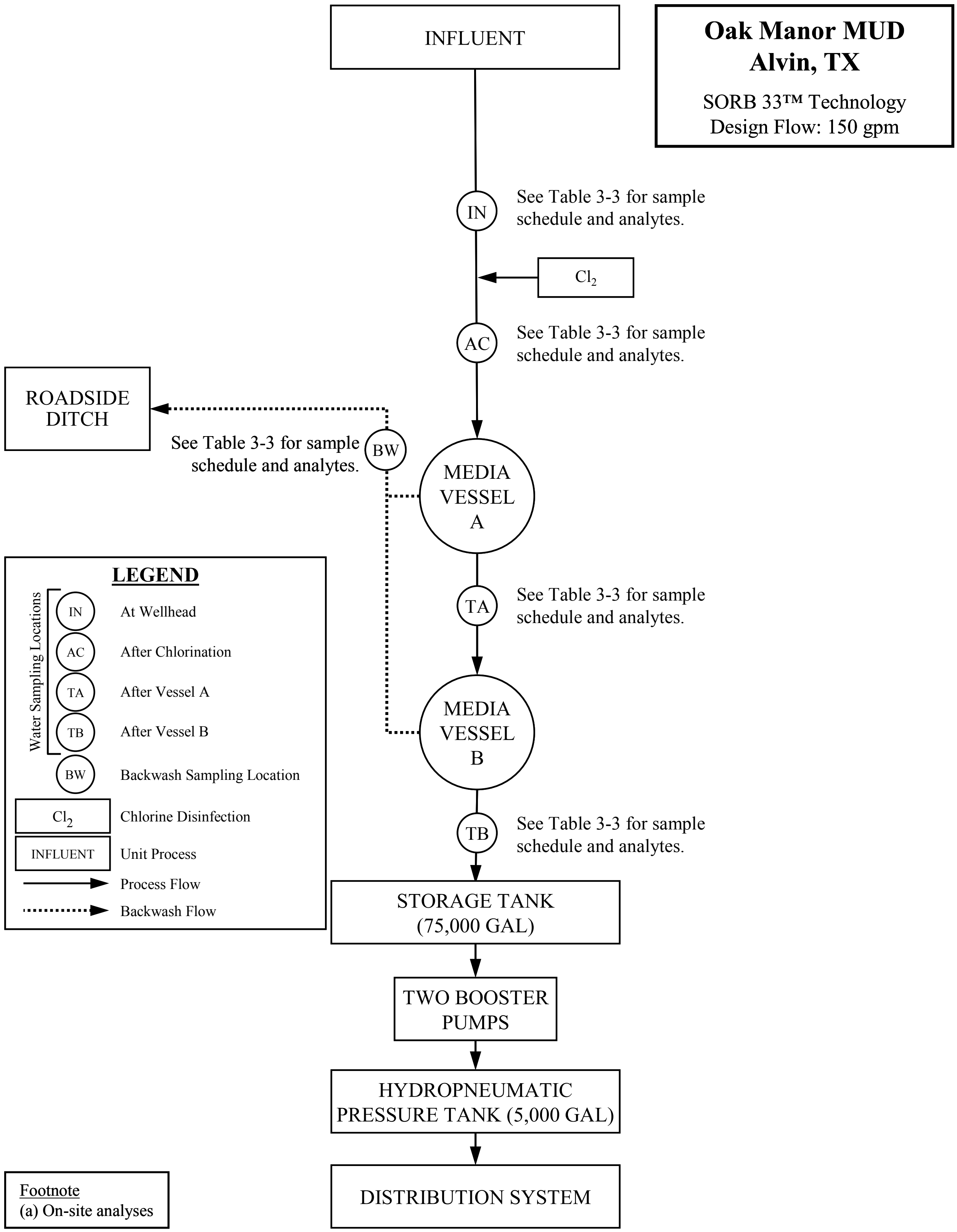


Figure 3-1. Process Flow Diagram and Sampling Schedule and Locations

3.4 Sampling Logistics

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

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

3.4.2 Preparation of Sampling Coolers. For each sampling event, a sample cooler was prepared with the appropriate number and type of sample bottles, disc filters, and/or speciation kits. All sample bottles were new and contained appropriate preservatives. Each sample bottle was affixed with a pre-printed, colored-coded, waterproof label consisting of the sample identification (ID), date and time of sample collection, collector's name, site location, sample destination, analysis required, and preservative. The sample ID consisted of a two-letter code for the specific water facility, sampling date, a two-letter code for a specific sampling location, and a one-letter code designating the arsenic speciation bottle (if necessary). The sampling locations at the treatment plant were color-coded for easy identification. The labeled bottles for each sampling location were placed in separate ziplock bags and packed in the cooler. When needed, the sample cooler also included bottles for the distribution system water sampling.

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

3.4.3 Sample Shipping and Handling. After sample collection, samples for off-site analyses were packed carefully in the original coolers with wet ice and shipped to Battelle. Upon receipt, the sample custodian checked sample IDs against the chain-of-custody forms and verified that all samples indicated on the forms were included and intact. Discrepancies noted by the sample custodian were addressed with the plant operator by the Battelle Study Lead. The shipment and receipt of all coolers by Battelle were recorded on a cooler tracking log.

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, OH and Belmont Labs in Englewood, OH, both of which were under contract with Battelle for this demonstration study. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

3.5 Analytical Procedures

The analytical procedures described in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2004) were followed by Battelle ICP-MS, AAL, and Belmont Laboratories. Laboratory quality assurance/quality control (QA/QC) of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection limit (MDL), and completeness met the criteria established in the QAPP (i.e., 20% relative percent difference [RPD], 80 to 120% percent recovery, and 80% completeness). The quality assurance (QA) data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project. Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a WTW Multi 340i handheld meter, which was calibrated for pH and DO prior to use following the procedures provided in the user's manual. The ORP probe also was checked for accuracy by measuring the ORP of a standard solution and comparing it to the expected value. The plant operator collected a water sample in a clean, plastic beaker and placed the WTW probe in the beaker until a stable value was obtained. The plant operator also performed free and total chlorine measurements using Hach chlorine test kits following the user's manual.

4.0 RESULTS AND DISCUSSION

4.1 Site Description

Located at 603 Mohawk Drive, Alvin, Texas, Oak Manor MUD's water system supplies drinking water to 189 homes from two wells (i.e., Wells 1 and 2) with a combined flowrate of approximately 150 gpm. Well 1, located one mile northeast of the treatment plant, has an average flowrate of 50 gpm. Well 2, located onsite, has an average flowrate of 100 gpm. The average flowrates from both wells were estimated from the facility's historical water usage data collected during July through December 2004.

4.1.1 Pre-existing System. Prior to the demonstration study, the water system operated for 8 to 9 hr/day with an average and peak daily demand of approximately 74,000 and 97,400 gpd, respectively. The pre-existing treatment included gas chlorination to maintain a target total chlorine residual of 1.5 to 2.0 mg/L (as Cl_2) and polyphosphate addition to reach a target dosage of 2.0 mg/L (as P). As shown in Figure 4-1, chlorine was added after the Wells 1 and 2 water combined, but prior to a 75,000-gal storage tank and a 5,000-gal hydropneumatic pressure tank (Figure 4-2). Polyphosphate was added to the Well 1 water just prior to the blending point (Figure 4-3). The well pumps were controlled automatically by a high- and a low-level sensor in the storage tank. Two booster pumps located immediately after the storage tank supplied water to the hydropneumatic tank and distribution system (Figure 4-4) based on a set of low/high pressure settings established for the hydropneumatic tank.

Figure 4-1. Chlorine Addition Point and Wells 1 and 2 Blending Point (Pre-existing)

Figure 4-2. Pre-existing Storage Tank (in Foreground) and Hydropneumatic Tank (in Background)

Figure 4-3. Pre-existing Polyphosphate Addition Point

Figure 4-4. Booster Pumps and Entry Piping to Distribution System

4.1.2 Source Water Quality. Source water samples were collected from Well 2 on November 2, 2004, and analyzed for the analytes shown in Table 3-3. Additional source water samples were collected on February 16, 2005, from Well 1, Well 2, and after Wells 1 and 2 combined. The results of the source water analyses, along with those provided by the facility to EPA for the demonstration site selection, are presented in Table 4-1.

Arsenic. Total arsenic concentrations in source water from Wells 1 and 2 ranged from 17.4 to 47.4 µg/L. The results of February 16, 2005, sampling revealed that Well 1 water contained more total arsenic than Well 2 water, with the concentration in Well 1 at 47.7 µg/L and in Well 2 at 17.4 µg/L. The sample collected after the blending point had a combined concentration of 34.5 µg/L, which was consistent with the average concentration of Wells 1 and 2 water before blending, but slightly higher than the 29 µg/L obtained by the facility (although not specified, it was assumed that this sample was taken after the blending point). Based on the speciation results for the water sample collected on November 2, 2004, essentially all of the total arsenic was in the soluble form. As(III) was the predominating species at 17.6 µg/L (or 94% of total arsenic), indicating the need for oxidation prior to adsorption. The presence of As(III) as the predominating arsenic species was consistent with the low DO and ORP readings, which were measured at 1.7 mg/L and 1 mV, respectively.

Iron and Manganese. Total iron concentration was 95 µg/L in the sample collected on November 2, 2004 from Well 2. Total iron concentration in the samples collected from Well 1, Well 2, and Wells 1 and 2 combined on February 16, 2005 were 73, 687, and 317 µg/L, respectively. Based on the November 2, 2004, speciation results, <40% of total iron existed in the soluble form. The presence of particulate iron in source water was carefully monitored during the demonstration study to determine if the measurement of particulate iron on November 2, 2004, was simply due to inadvertent aeration of the sample during sampling.

Table 4-1. Water Quality Data for Oak Manor MUD

Parameter	Unit	Raw Water					Historic Utility Distribution Water Data[c]
		Utility Data[a]	Battelle Data				
			Well 2	Well 1	Well 2	Wells 1 & 2 Combined[b]	
Sampling Date		NA	11/02/04	02/16/05	02/16/05	02/16/05	1998–2003
pH	S.U.	7.8	7.8	NS	NS	NS	7.7–8.0
Temperature	°C	NS	23.3	NS	NS	NS	NS
DO	mg/L	NS	1.7	NS	NS	NS	NS
ORP	mV	NS	1	NS	NS	NS	NS
Total Alkalinity (as $CaCO_3$)	mg/L	359	377	330	410	379	356–360
Hardness (as $CaCO_3$)	mg/L	42	43	NS	NS	NS	42.0–43.3
Turbidity	NTU	NS	0.3	0.3	8.7	2.0	NS
TDS	mg/L	NS	492	526	670	540	526–546
TOC	mg/L	NS	0.7	NS	NS	NS	NS
Nitrate (as N)	mg/L	NS	<0.04	<0.05	<0.05	<0.05	<0.01
Nitrite (as N)	mg/L	NS	<0.04	<0.05	<0.05	<0.05	<0.01
Ammonia (as N)	mg/L	NS	0.2	NS	NS	NS	NS
Chloride	mg/L	91	68.0	120.0	98.0	110.0	89.0–93.0
Fluoride	mg/L	NS	0.8	1.4	1.5	1.4	1.5–1.6
Sulfate	mg/L	2	<1.0	<1.0	2.0	1.0	2.0
Silica (as SiO_2)	mg/L	NS	16.8	15.8	15.5	16.7	NS
Orthophosphate (as P)	mg/L	NS	<0.06	<0.05	<0.05	<0.05	NS
As (total)	µg/L	29	18.8	47.7	17.4	34.5	28.2–30.7
As (soluble)	µg/L	NS	19.0	NS	NS	NS	NS
As (particulate)	µg/L	NS	<0.1	NS	NS	NS	NS
As (III)	µg/L	NS	17.6	NS	NS	NS	NS
As (V)	µg/L	NS	1.4	NS	NS	NS	NS
Fe (total)	µg/L	62	95	73	687[d]	317[d]	55.0–77.0
Fe (soluble)	µg/L	NS	37	NS	NS	NS	NS
Mn (total)	µg/L	58	61.6	48.0	65.2	55.4	37.5–62.0
Mn (soluble)	µg/L	NS	61.7	NS	NS	NS	NS
U (total)	µg/L	NS	1.5	<0.1	1.5	0.8	NS
U (soluble)	µg/L	NS	1.5	NS	NS	NS	NS
V (total)	µg/L	NS	2.1	1.4	1.2	1.3	NS
V (soluble)	µg/L	NS	1.9	NS	NS	NS	NS
Na	mg/L	201	259	194	273	201	191–210
Ca	mg/L	12	9.3	10.6	12.9	12.0	11.7–13.0
Mg	mg/L	3	4.8	2.9	3.8	3.2	2.0–3.6

NS = not sampled
(a) Provided to EPA for demonstration site selection; well number(s) not specified.
(b) Samples collected before storage tank with no chlorine or polyphosphate addition.
(c) Samples collected at point of entry into distribution system.
(d) Samples reanalyzed with similar results.

In general, adsorptive media technologies are best suited for source waters with relatively low iron levels (e.g., less than 300 µg/L of iron, which is the secondary maximum contaminant level [SMCL] for iron). Above 300 µg/L, taste, odor, and color problems can occur in treated water, along with an increased potential for fouling of the adsorption system components with iron particulates.

Manganese concentrations in source water ranged from 48.0 to 65.2 µg/L. Well 2 water appeared to contain more manganese, with concentrations ranging from 61.6 to 65.2 µg/L, compared to that of Well 1 water at 48.0 µg/L. The average concentration of water from Wells 1 and 2 sampled on February 16, 2005, was consistent with that of the combined well water (i.e., 56.6 versus 55.4 µg/L) and close to the 58.0 µg/L concentration provided by the facility. Based on the speciation result on November 2, 2004, manganese existed entirely in the soluble form.

Silica, Sulfate, and Orthophosphate. As shown in Table 4-1, silica levels ranged from 15.5 to 16.8 mg/L (as SiO_2); sulfate levels ranged from less than the method reporting limit of 1.0 mg/L to 2 mg/L; and orthophosphate levels were less than the method reporting limit of 0.05 mg/L (as P). Usually, arsenic adsorption can be influenced by the presence of competing anions such as silica and phosphate, but due to the low levels of these constituents, they were not expected to affect arsenic adsorption onto the SORB 33™ media.

Other Water Quality Parameters. A pH of 7.8 was measured for Well 2 water, which was within the STS target range of 6.0 to 8.0 for arsenic removal via adsorption. Therefore, pH adjustment was not recommended prior to arsenic adsorption. Nitrate and nitrite were not detected in either well. Ammonia at 0.2 mg/L (as N) was measured in Well 2 water. Chloride and fluoride were below their respective SMCLs. Alkalinity ranged from 330 to 410 mg/L (as $CaCO_3$). The only total organic carbon (TOC) sample was collected from Well 2 on November 2, 2004, which was measured at 0.7 mg/L. Uranium concentrations ranged from less than the method reporting limit of 0.1 µg/L to 1.5 µg/L, well below its MCL of 30 µg/L. Vanadium concentrations ranged from 1.2 to 2.1 µg/L. Sodium concentrations ranged from 194 to 273 mg/L for both wells. Calcium, magnesium, and hardness were low, ranging from 9.3 to 12.9 mg/L, 2.9 to 4.8 mg/L, and 42 to 43 mg/L (as $CaCO_3$), respectively. Total dissolved solids (TDS) ranged from 492 to 670 mg/L.

4.1.3 Historic Distribution Water Quality. Historic distribution water quality data collected by TCEQ from 1998 to 2003 also are presented in Table 4-1. The distribution water samples were collected at the entry point prior to entering into the distribution system and after polyphosphate and chlorine addition. As expected, the distribution water quality data were similar to the source water quality data obtained by Battelle and the facility. Total arsenic concentrations ranged from 28.2 to 30.7 µg/L. Total iron was the only constituent that had slightly lower distribution water quality results as compared to the source water quality results.

4.1.4 Distribution System and Regulatory Monitoring. Of the three residences selected for distribution system water sampling, only DS3 was part of the Oak Manor MUD's historic sampling network for Lead and Copper Rule (LCR) and monthly bacteriological sampling. Under the LCR, samples were collected from designated taps at 10 residences every three years. Additional regulatory monitoring directed by TCEQ included monthly sampling for coliform and volatile organic compounds (VOCs), and biyearly/quarterly for inorganics, nitrate, and radionuclides.

Based on the information provided by the facility, the distribution system was constructed primarily of 6-in cast-iron pipe. Piping within individual service hookups consisted primarily of ¾- to 1-in polyvinyl chloride (PVC) and ¾- to 1-in galvanized iron. The distribution system was supplied directly by the 75,000-gal storage tank.

4.2 Treatment Process Description

STS' Arsenic Package Unit (APU)-30S is a fixed-bed, down-flow adsorption system designed for arsenic removal for small systems with flowrates ranging from 5 to150 gpm. The unit uses Bayoxide® E33 (branded as SORB 33™ by STS), an iron-based adsorptive media developed by Bayer AG, for arsenic removal from drinking water supplies. Table 4-2 presents vendor-provided physical and chemical properties of the media. The SORB 33™ media is delivered in a dry crystalline form and listed by NSF International (NSF) under Standard 61 for use in drinking water applications. The media are provided in both granular and pelletized forms, which have similar physical and chemical properties, except that pellets are 25% denser than granules (i.e., 35 vs. 28 lb/ft^3). The pellet form of the media was used for the Oak Manor MUD facility.

Table 4-2. Physical and Chemical Properties of SORB 33™ Media

Physical Properties	
Parameter	**Values**
Matrix	Iron oxide composite
Physical Form	Dry pellets
Color	Amber
Bulk Density (lb/ft^3)	35
BET Surface Area (m^2/g)	142
Attrition (%)	0.3
Moisture Content (%)	<15 % (by wt.)
Particle Size Distribution (U.S. Standard Mesh)	10 × 35
Crystal Size (Å)	70
Crystal Phase	α – FeOOH
Chemical Analysis	
Constituents	**Weight %**
FeOOH	90.1
CaO	0.27
MgO	1.00
MnO	0.11
SO_3	0.13
Na_2O	0.12
TiO_2	0.11
SiO_2	0.06
Al_2O_3	0.05
P_2O_5	0.02
Cl	0.01

BET = Brunauer, Emmett, and Teller Method
Source: STS

The APU-30S treatment system consists of two adsorption vessels, Vessels A and B, arranged in series (Figure 4-5). When the arsenic concentration in the effluent from the lag vessel approaches 10 µg/L, the spent media in the lead vessel is removed and disposed of. After rebedding, this vessel is switched to the lag position. In general, the series operation better utilizes the media capacity when compared to the parallel operation because the lead vessel may be allowed to exhaust completely prior to changeout.

The piping and valve configuration of the APU-30S system consists of electrically actuated butterfly valves to divert raw water flow into either Vessels A or B depending on which is operating in the lead position. The piping and instrumentation diagrams (P&IDs) presented in Figures 4-6a and 6b use bolded lines to indicate the process flow for series configuration with Vessels A or B, respectively, in the lead position. Table 4-3 presents key system design parameters.

Figure 4-5. APU-30S Arsenic Removal System

The major process components/steps of the APU-30S system are discussed as follows:

- **Intake.** Raw water pumped from the two supply wells (No. 1 and 2) was chlorinated and fed to the treatment system via 3-in steel pipe (Figure 4-1). The well pumps were interlocked with the high and low level sensors in the storage tank (Figure 4-2).
- **Chlorination.** The existing gas chlorination system manufactured by Ecometrics in Silverdale, PA, was used to oxidize As(III), Fe(II), and Mn(II) prior to the adsorption vessels and provide a target total chlorine residual level from 1.5 to 2.0 mg/L (as Cl_2) for disinfection purposes. The chemical feed system consisting of one 150-lb cylinder, a chlorinator unit (sitting on top of the chlorine gas cylinder), and an ejector was located in a secured shed in the close proximity of the treatment system in the fenced area. Figure 4-7 presents composite of pictures of the gas chlorination system. The current chlorine injection point (not pictured) was relocated after the Wells 1 and 2 blending point to >10 ft downstream of the raw water sample tap, after system startup on April 25, 2006 (see Table 4-5). Operation of the chlorine feed system was linked to the well pumps so that gas chlorine was injected only when the wells were on. Chlorine consumption was tracked daily by recording the weight of the chlorine gas cylinder.
- **Adsorption**. The APU-30S system consisted of two 63-in × 86-in adsorption vessels configured in series. The vessels were made of fiberglass reinforced plastic (FRP), rated for 100-psi working pressure, and skid mounted for ease of shipment and installation. According to the original system design, each vessel was to contain 62 ft^3 of media, yielding an empty bed contact time (EBCT) of 3.1 min/vessel at a flowrate of 150 gpm. However, based on STS's onsite measurements on May 17, 2006, Vessels A and B were inadvertently loaded with an uneven amount of media (i.e., 53.6 and 70.3 ft^3 for Vessels A and B, respectively). As such, Vessel A had a slightly shorter EBCT than Vessel B (i.e., 2.7 vs. 3.5 min).

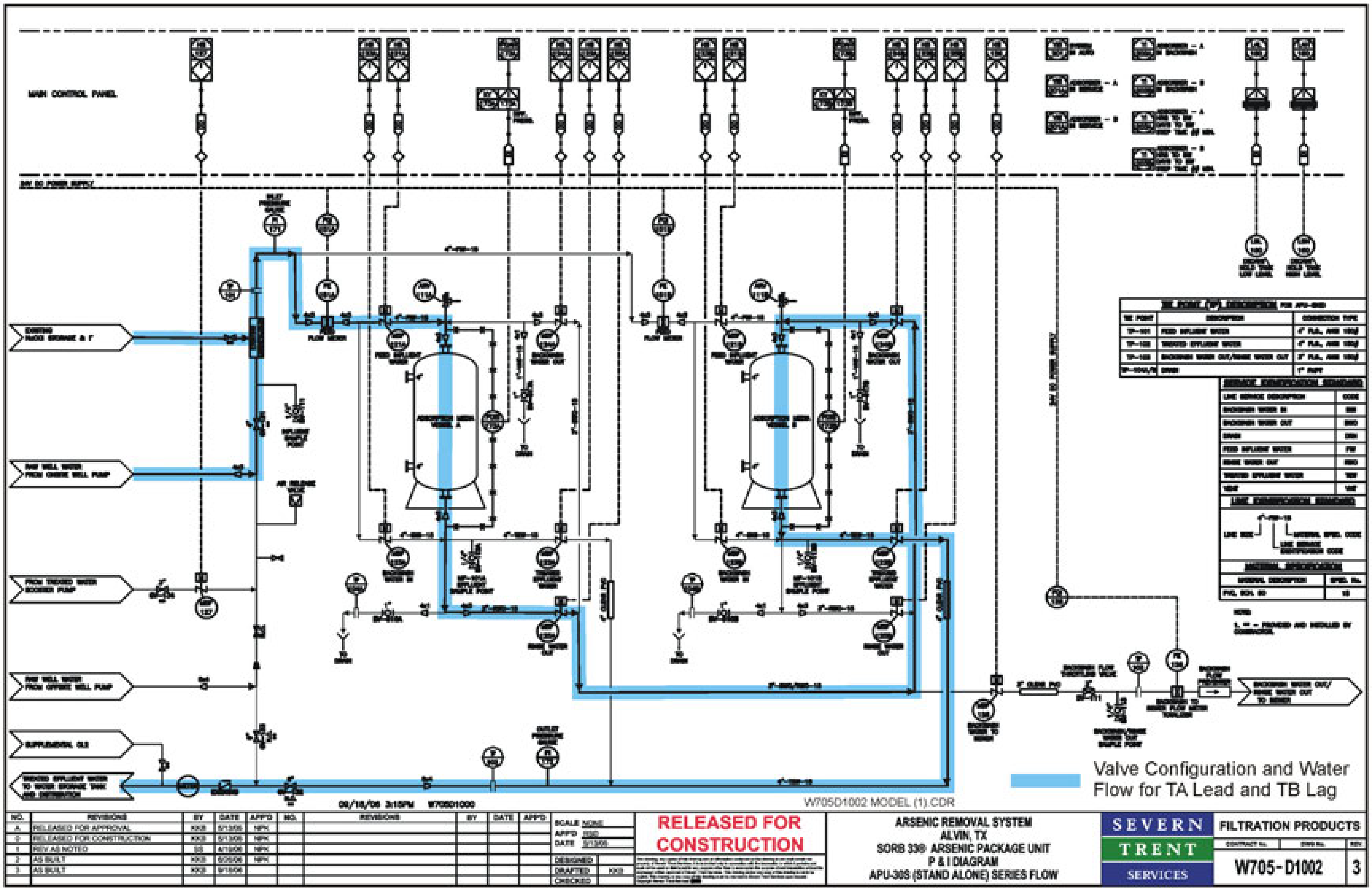


Figure 4-6a. Process Flow Diagram for APU-30S System with Vessel A in Lead Position

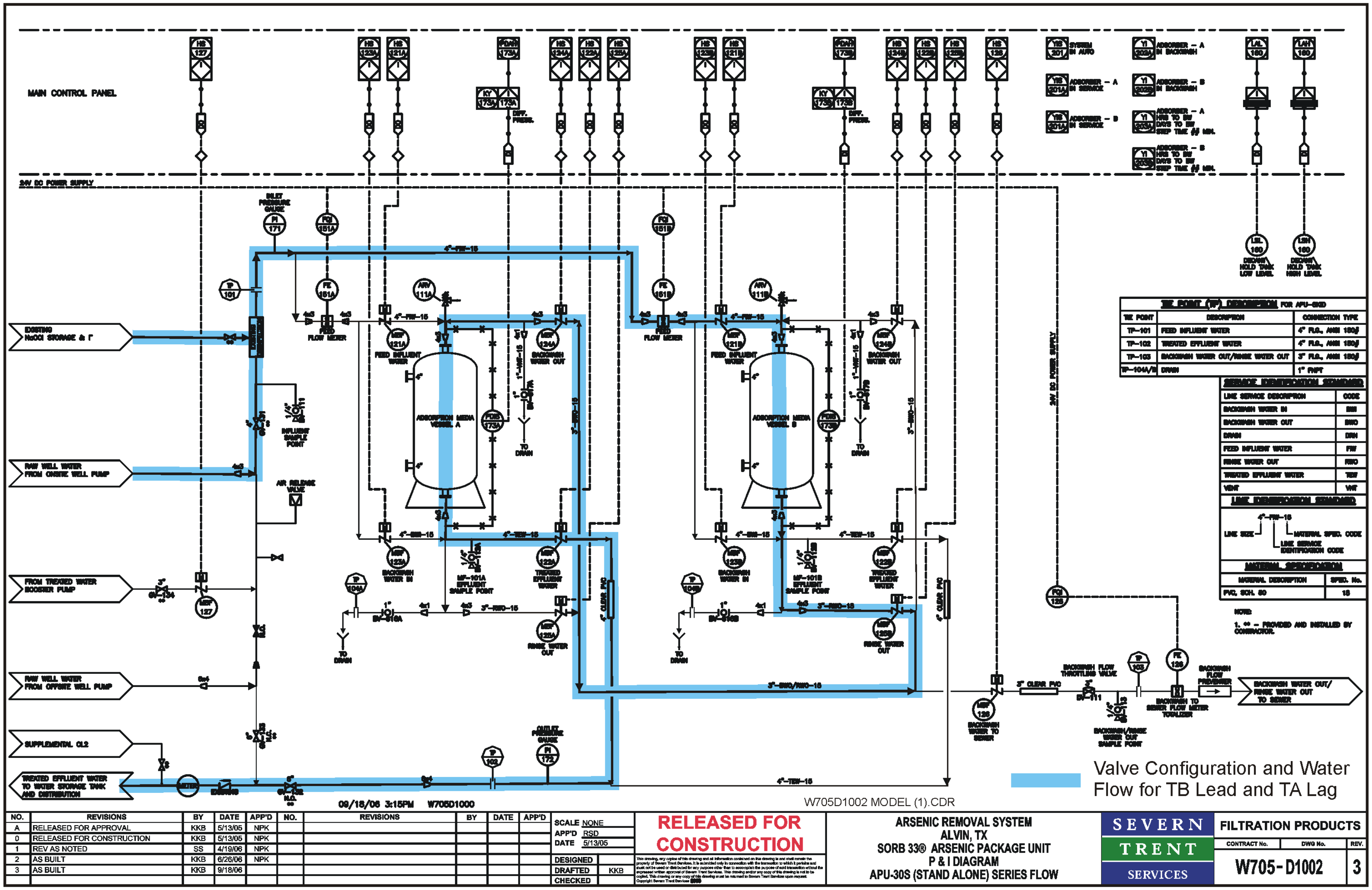


Figure 4-6b. Process Flow Diagram for APU-30S System with Vessel B in Lead Position

Table 4-3. Design Specifications of APU-30S System

Parameter	Value	Remarks
Pretreatment		
Target Total Chlorine Residual (mg/L [as Cl_2])	1.5 to 2.0	Gas chlorine used
Adsorption Vessels		
Vessel Size (in)	63 D × 86 H	–
Cross-Sectional Area (ft^2/vessel)	21.6	–
Number of Vessels	2	–
Configuration	Series	–
Adsorptive Media Bed		
Type of Media	SORB 33™	In pelletized form
Media Quantity (lb)	4,340	
Media Volume (ft^3/vessel)	62	124 ft^3 total
Media Bed Depth (in/vessel)	34	
Service		
Design Flowrate (gpm)	150	–
Hydraulic Loading (gpm/ft^2)	6.9	Based on design flow rate and vessel cross-sectional area of 21.6 ft^2
EBCT (min/vessel)	3.1	6.2 min for both lead and lag vessels
Estimated Throughput to Lead Vessel Changeout (gal)	47,500,000	Based on an influent arsenic concentration of 29 μg/L, a system media volume of 124 ft^3, and an arsenic changeout concentration of 16 μg/L following lead vessel
Estimated Working Capacity (BV)	51,240	Based on total media volume of 124 ft^3
Average Use Rate (gal/day)	74,000	Provided by facility
Estimated Media Life (months)	21	Based on average use rate
Backwash		
Δp Setpoint (psi)	10	–
Flowrate (gpm)	210	
Hydraulic Loading (gpm/ft^2)	9.7	Based on backwash design flow rate and vessel cross-sectional area of 21.6 ft^2
Backwash Frequency (month/backwash)	1	
Backwash Duration (min/vessel)	20	
Downflow rinse Flowrate	210	
Downflow rinse Duration (min/vessel)	10	

Nonetheless, the design EBCT across the system remained unchanged at 6.2 min. The hydraulic loading rate to each adsorption vessel was 6.9 gpm/ft^2.

Each adsorption vessel was interconnected with schedule 80 PVC piping and five electrically actuated butterfly valves, which made up the valve tree as shown in Figure 4-8. In addition to the 10 butterfly valves, the system had two manual diaphragm valves on the backwash line, and six isolation ball valves to divert raw water flow into either vessel, which reversed the lead/lag vessel configuration. Each valve operated independently and the butterfly valves were controlled by a Square D Telemechanique programmable logic controller (PLC) with a Magelis G2220 color touch interface screen.

Figure 4-7. Gas Chlorination System
(Clockwise from the Top: Shed Housing Gas Chlorination System, Gas Cylinder, Chlorine Ejector, and Chlorinator Unit)

- **Backwash.** The vendor recommended that the APU-30S system be backwashed on a regular basis to remove particulates and media fines that accumulated in the media beds. Automatic backwash could be initiated by either a time or a Δp setpoint across each vessel. During a backwash cycle, each vessel was backwashed individually, while the second vessel remained off-line. The vendor recommended backwash flowrate, hydraulic loading, and duration, were 210 gpm, 9.7 gpm/ft^2, and 30 min (including 10 min for downflow rinse), respectively.

  The backwash/downflow rinse flowrates and the amount of wastewater generated were determined by the flowrate and totalizer readings shown on the PLC. The backwash and downflow rinse duration was timed and confirmed by the operator. Backwash and downflow rinse water was mostly supplied by the two supply wells; however, due to their maximum flowrate of 150 gpm, supplemental water had to be drawn from the hydropneumatic pressure tank (Figure 4-9) located just downstream from the adsorption vessels. Backwash and downflow rinse wastewater was sent to a small ditch (Figure 4-10) adjacent to the treatment system and subsequently drained into a roadside ditch.

- **Media Replacement.** Replacement of the media in the lead vessel was scheduled once the arsenic concentration following the lag vessel exceeding 10 µg/L. Once the media in the lead vessel was replaced, flow through the vessels was switched such that the lag vessel was placed into the lead position and the former lead vessel loaded with virgin media was placed in the lag position. A Toxicity Characteristic Leaching Procedure (TCLP) test was conducted on the spent media before disposal to determine whether the media could be considered non-hazardous.

Figure 4-8. APU-30S System Valve Tree and Piping Configuration

Figure 4-9. Valve MB-127 to Supply Additional Treated Water from Hydropneumatic Tank During Backwash

Figure 4-10. Small Ditch for Backwash Wastewater

- **Storage and Distribution.** The treated water was stored in a 24-ft tall, 75,000-gal storage tank located immediately downstream of the APU-30S treatment system. A low-/high-level sensor pair at 13/19.5 ft controlled the on/off of the well pumps. The booster pumps subsequently pressured and temporarily stored water in a 5,000-gal hydropneumatic tank before water entered the distribution system. The booster pumps switched on and off based on the high and low pressure settings at 40 and 60 psi, respectively. The distribution system was constructed primarily of 6-in cast-iron pipe. Piping within individual service hookups consisted primarily of ¾- 1-in PVC and ¾- 1-in galvanized iron.

4.3 Treatment System Installation

4.3.1 System Permitting. A submittal package was sent by Oak Manor MUD to TCEQ on July 8, 2005, requesting an exception from conducting an onsite pilot study as required under Title 30 Texas Administrative Code (30TAC) 290.42(g). The exception request was required by TCEQ prior to the submission of engineering plans for the installation of the arsenic treatment system. The exception submittal included a written description of treatment technology along with a schematic of the system and relevant pilot- and full-scale data. Subsequently, a permit application package including a process flow diagram of the treatment system, mechanical drawings of the treatment equipment, a schematic of the building footprint and equipment layout, was submitted to TCEQ on September 9, 2005. TCEQ granted its approval for the exception request and system permit application on November 21 and December 16, 2005, respectively. A permit was not required to discharge backwash wastewater to a roadside ditch.

4.3.2 Building Construction. A canopy (Figure 4-5) was built to shield the treatment system from direct sunlight exposure. Construction of the concrete pad (Figure 4-11) began on October 6, 2005, and the canopy was completed on November 12, 2005.

Figure 4-11. Construction of Concrete Pad with Storage Tank and Hydropneumatic Tank (in Background)

4.3.3 System Installation, Shakedown, and Startup. The shipment of the APU-30S system arrived at the Oak Manor MUD on September 4, 2005. Upon arrival, STS's subcontractor, Abundant Engineering, off-loaded the system components to a temporary staging area adjacent to the existing treatment facility while the MUD awaited the completion of the concrete pad and issuance of the permit approval. The pelletized media arrived in three super sacks on October 7, 2005. Although each super sack usually has 38 ft^3 of media bringing the total media volume to 114 ft^3, the actual volume of media shipped to the site was 124 ft^3 based on freeboard measurements of the vessels (Section 4.3.4).

Upon receipt of the permit approval on December 16, 2005, Abundant Engineering performed most of the installation work, including connecting the system to the existing inlet and distribution piping. A field engineer from the STS Houston office made three separate trips to the site from January 17 to 19, from March 9 to 10, and on April 5, 2006, to complete system installation and perform system shakedown and startup. System installation, shakedown, and startup were completed on March 9, March 10, and April 25, 2006, respectively.

During the first trip from January 17 to 19, 2006, STS wired the PLC, conducted hydraulic testing on the empty vessels, tested pressure gauges and flowmeters, loaded underbedding gravel and media, measured freeboard heights after backwash, and disinfected the media and the system components with bleach. The hydraulic test was performed at 88 gpm, lower than the design flowrate of 150 gpm. At this flowrate, the inlet and outlet pressure for the treatment system were 14.0 and 6.0 psi, respectively, and the Δp readings across Vessels A and B were 1.2 and 2.0 psi, respectively.

STS recommended a minimum backwash flowrate of 210 gpm (or 9.7 gpm/ft^2), which exceeded the maximum well capacity of 150 gpm. The remedy was to modify the pre-existing plumbing, including the installation of an automatic valve (MB-127), to deliver the treated water from the hydropneumatic tank to supplement the backwash flow. Also, in order to prevent polyphosphate from entering the adsorption vessels to cause adverse effects on arsenic adsorption, the pre-existing polyphosphate addition was relocated downstream of the APU-30S system and, later as discussed below, discontinued due to concerns that polyphosphate in treated water might come in contact with the media during backwash.

STS's field engineer returned to the site from March 9 to 10, 2006, to perform a thorough media backwash with supplemental flow. The backwash flowrates were verified to range from 250 to 270 gpm. Although the polyphosphate addition point had been relocated downstream of the treatment system, concern existed that polyphosphate still could come in contact with the media during backwash. After shutting off polyphosphate addition, backwash and downflow rinse were performed and system shakedown was completed on March 10, 2006. After chlorinating both vessels, the facility took samples for bacteriological testing. Verbal approval to discharge the treated water into the distribution system was granted by TCEQ on March 14, 2006.

Thereafter, the facility attempted to place the system online, but could not due to the production of red/cloudy treated water. After 80,000 to 100,000 gal of water was used for backwash and downflow rinse through both vessels, the facility contacted STS for a return visit.

The STS field engineer returned to the site for the third time on April 5, 2006, to troubleshoot the APU-30S system. Vessels A and B were backwashed at 150 gpm for 30 and 40 min, respectively, followed by 20 min of downflow rinse. Vessel A backwash water cleared after 5 min, and Vessel B soon after. Downflow rinse for Vessels A and B both cleared after 3 min. Only raw water was used during backwash, although polyphosphate addition was discontinued for over a week prior to STS's return visit. After backwash, both adsorption vessels were opened for freeboard measurements and media observations. The results of the measurements and observations are discussed in Section 4.3.4. The vessels were then resealed and the fast rinse through both vessels resumed for about one hour before discharge was directed to the storage tank for distribution. The exact reason as to why the facility was unable to achieve clear water was never determined.

Once all of the activities were completed, polyphosphate addition was restarted downstream of the APU-30S due to complaints of iron in the treated water. On April 17, 2006, the facility shut off the polyphosphate addition again on a permanent basis. The average iron concentration in the treated water remained below the detection limit of 25 µg/L as discussed in Section 4.5.1.

4.3.4 Media Loading. Media loading was performed by STS on January 19, 2006. The super sacks of media were hoisted to the top of the canopy using a boom truck and loaded through a 12-in × 4-in rigid funnel and a roof hatch into the adsorption vessels partially filled with water. A garden hose was used to completely submerge the media, which was allowed to soak for about 4 hr. After the top hat distributor was reinstalled and top piping reconnected, each vessel was backwashed at 150 gpm for approximately 30 min to remove fines. The freeboard over the top of each media bed was then measured three times and the average of each vessel along with the calculated media volume are summarized in Table 4-4.

The freeboard measurements taken from the top of the underbedding gravel to the top of the flange openings before media loading were 65.3 and 66.5 in for Vessels A and B, respectively. The freeboard measurements taken from the top of media beds to the top of the flange openings were 36.5 and 37.5 in for Vessels A and B, respectively. As such, 51.8 and 52.3 ft^3 of media should have been loaded into the vessels. However, the freeboard measurements taken on April 5, 2006 (when STS returned to the site to troubleshoot a facility's complaint concerning red/cloudy water from the adsorption vessels), and on May 17, 2006 (when STS returned to the site to complete the punch-list items identified by Battelle during its system inspections [see Section 4.3.5]), indicated 52.7 to 53.6 ft^3 of media in Vessel A and 69.4 to 70.3 ft^3 in Vessel B. The discrepancy in media volume noted in Vessel B was attributed by the vendor to an uneven distribution of three super sack contents to Vessels A and B and an incorrect freeboard measurement of Vessel B after initial media loading on January 19, 2006. To avoid any confusion, it was decided that the media volumes determined on May 17, 2006 (i.e., 43 and 57% in Vessels A and B) were to be used for all bed volume calculations.

Table 4-4. Freeboard Measurements and Media Volumes in Adsorption Vessels

	Vessel A		Vessel B		
Date	**Depth (in)**	Volume (ft^3)	**Depth (in)**	Volume (ft^3)	**Total Volume (ft^3)**
01/19/06	36.5	51.8	37.5	52.3	104
04/05/06	36.0	52.7	28.0	69.4	122
05/17/06	35.5	53.6	27.5	70.3	124

4.3.5 Punch List Items. Battelle performed system inspection and operator training for sample and data collection on April 24 to 25, 2006. The performance evaluation study officially started on April 25, 2006. Table 4-5 summarizes the punch-list items and corrective actions taken from May 22, 2006, to September 21, 2006. All punch-list items were addressed by STS and/or the facility by September 21, 2006.

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters recorded during the performance evaluation study were tabulated and are attached as Appendix A. Key parameters are summarized in Table 4-6. From April 25, 2006, through April 8, 2008, the system operated daily except for two time periods, i.e., from November 30 through December 16, 2007, and from March 1 to 9, 2008, when the system was shut down for storage tank maintenance and valve repair, respectively. The system operated for a total of 4,628 hr, or an average of 6.7 hr/day (as compared to 8 to 9 hr/day prior to installation of the arsenic treatment system). The 6.7 hr/day operating time represents a daily use rate of about 28%.

Table 4-5. System Inspection Punch-List Items

Item No.	Punch-List Item	Corrective Action(s) Taken	Resolution Date
1	Broken Well 2 totalizer	• Replaced Well 2 totalizer	05/22/06
2	Raw water sample tap incorrectly located (so that only Well 2 water might be sampled [Figure 4-12])	• Used existing chlorine injection point (Figure 4-12) for raw water sampling[(a)] during first three sampling events on 04/25/06, 05/09/06, and 05/23/06 • Relocated raw water sample tap about 0.5 ft after blending point of Wells 1 and 2 (Figure 4-12) and relocated chlorine injection point about 10 ft downstream of the new raw water sample tap for chlorine injection • Relocated raw water sample tap to existing chlorine injection point and continued using relocated chlorine injection point	 05/24/06 05/02/07
3	Broken Vessel A flow meter	• Fixed Vessel A flow meter by removing particles jammed in paddle wheel	05/17/06
4	Inconsistent Vessel B freeboard measurements taken on 01/19/06 and 04/05/06 by vendor (Section 4.3.4)	• Retook freeboard measurements for both Vessels A and B	05/17/06
5	Vessels A and B sample taps (i.e., TA and TB) incorrectly located (so that same water was sampled by both taps).	• Relocated Vessels A and B sample taps (but still at incorrect locations) • Corrected sample tap locations	05/17/06 08/09/06
7	Broken actuator valve 125b (not open for automatic backwash)	• Replaced actuator valve 125b	05/17/06
8	Broken actuator valve 123A (not open for automatic backwash)	• Replaced actuator valve 123A	08/09/06
9	Missing backwash flow meter/totalizer	• Installed a backwash flow meter/totalizer	05/17/06
10	Broken totalizer on treated water line to storage tank	• Replaced totalizer on treated water line	07/10/06
11	Parallel vs. series default settings on PLC	• Investigated PLC default settings, which might not be changed from parallel to series. Power outage will revert system to default setting when left in manual mode [Section 4.3])	05/17/06
12	Block vs. unblock mode	• Held a teleconference with facility representatives, who expressed preference to maintain PLC in unblock mode (i.e., system valves remained open at all times)	05/19/06
13	Missing as-built drawings for APU-30S system	• Provided as-built drawings for APU-30S system	09/21/06
14	Missing as-built site piping and electrical drawings	• Provided as-built site engineering drawings	09/21/06

(a) Raw water samples collected after other treatment plant samples at AC, TA, and TB locations had been taken, chlorine injection had been temporarily discontinued, and chlorine injection point had been thoroughly flushed.

Figure 4-12. Piping, Sample Taps, and Chlorine Injection Point Prior to Treatment System

Table 4-6. Summary of APU-30S System Operation

Operational Parameter	Value/Condition
Duration	04/25/06–04/08/08
Cumulative Operating Time (hr)	4,628
Average Daily Operating Time (hr)	6.7
System Operation – Adsorption	
Total Throughput (gal)[(a)]	35,358,250
Bed Volumes (BV)[(b)]	38,140
Average Daily Demand (gpd)[(c)]	51,393
Average (Range of) Instantaneous Flowrate (gpm)[(d)]	129 (84–151)
Average (Range of) Hydraulic Loading (gpm/ft^2)	6.0 (3.9–7.0)
Average (Range of) System EBCT (min)[(c)]	7.2 (6.1–11.0)
Average (Range of) System Inlet Pressure (psi)	27.9 (18.0–63.0)
Average (Range of) System Outlet Pressure (psi)	7.4 (3.0–27.0)
Average (Range of) Δp across System (psi)	20.8 (12.0-55.0)
Average (Range of) Δp across Vessel A (psi)	7.9 (1.3–15.0)
Average (Range of) Δp across Vessel B (psi)	3.1 (1.0–4.0)
System Operation – Backwash	
Average (Range of) Backwash Flowrate (gpm)[(e)]	207 (173–275)
Average (Range of) Hydraulic Loading (gpm/ft^2)	9.6 (8.0–12.7)
Average (Range of) Backwash Duration (min)	26.0 (20.0–30.0)
Average (Range of) Wastewater Generated (gal/vessel)	5,400 (4,000–6,800)

(a) Based on Vessel A totalizer.
(b) Based on 124 ft^3 of media in both Vessels A and B.
(c) Calculated by dividing total throughput by number of system operating days.
(d) Based on instantaneous readings of Vessel A flow meter/totalizer.
(e) Based on readings of Vessel A totalizer and respective operating time (see Section 4.4.4).
(f) Based on ten backwash events conducted from 07/14/06 to 08/29/07.

During the entire period of the performance evaluation study, the system treated approximately 35,358,250 gal of water, including the 1,223,042 gal already registered by the Vessel A totalizer during system startup. The amount of water treated was equivalent to 38,140 BV, based on 124 ft^3 of media in both vessels. The average daily demand was 51,393 gal, versus 74,000 gal provided by the facility prior to the demonstration study.

The total throughput and flowrates presented in Table 4-6 are based on the electromagnetic flow meter/totalizer installed at the inlet to Vessel A (i.e., lead vessel). Instantaneous flowrate readings from this flow meter ranged from 84 to 151 gpm and averaged 129 gpm, which was 14% lower than the 150 gpm design value. Based on these flowrates, hydraulic loading rates to the adsorption vessels ranged from 3.9 to 7.0 gpm/ft^2 and system EBCTs ranged from 6.1 to 11.0 min. As a result, the average system EBCT was 16 % higher than the design value of 6.2 min.

Flowrates through the treatment system also were tracked by a pre-existing positive displacement totalizer installed on the treated water line, and two pre-existing positive displacement totalizers installed at Wells 1 and 2. Average flowrates were calculated based on readings of the well hour meter and the one electromagnetic and three positive displacement totalizers. As compared in Table 4-7, all calculated average flowrates were consistent with the instantaneous readings of the Vessel A flow meter with a relative difference within 5.4%.

The system throughputs in this report are based on the electromagnetic flow meter/totalizer installed at the inlet to the Vessel A. This flow meter/totalizer was out of order on several occasions and had to be repaired as discussed in Section 4.4.4. Before the flow meter/totalizer was fixed, the system throughput was estimated based on the readings of the two positive displacement totalizers installed at the wellheads. There were two occasions (from April 25 to May 21, 2006, and from November 6 to 18, 2007) when both Vessel A and Well 2 totalizers were not functioning; the system throughput values were estimated for the former occasion based on the average flowrate during the first six months of system operation (i.e., 125 gpm) and respective system operating time, and for the latter occasion based on readings of the effluent totalizer.

Table 4-7. System Instantaneous and Calculated Flowrates

Flowmeter/Totalizer Type and Location	Instantaneous/ Calculated	Flowrate (gpm)		
		Range	Average	% Diff
Electromagnetic Flowmeter, Vessel A Inlet	Instantaneous	84–151	129	-
Electromagnetic Totalizer, Vessel A Inlet	Calculated	66–177	122	-5.4 %
Positive Displacement Totalizers, at Wellheads[(a)]	Calculated	67–172	128	-0.8 %
Positive Displacement Totalizer, on Treated Water Line	Calculated	101–172	131	+1.6 %

(a) Sum of Wells 1 and 2 readings.

The treatment system pressures were monitored at the system inlet and outlet and across the adsorption vessels. Differential pressure (Δp) readings across the system and Vessels A and B are presented in Figure 4-13. Table 4-8 summarizes Δp across Vessels A and B immediately before and after a backwash.

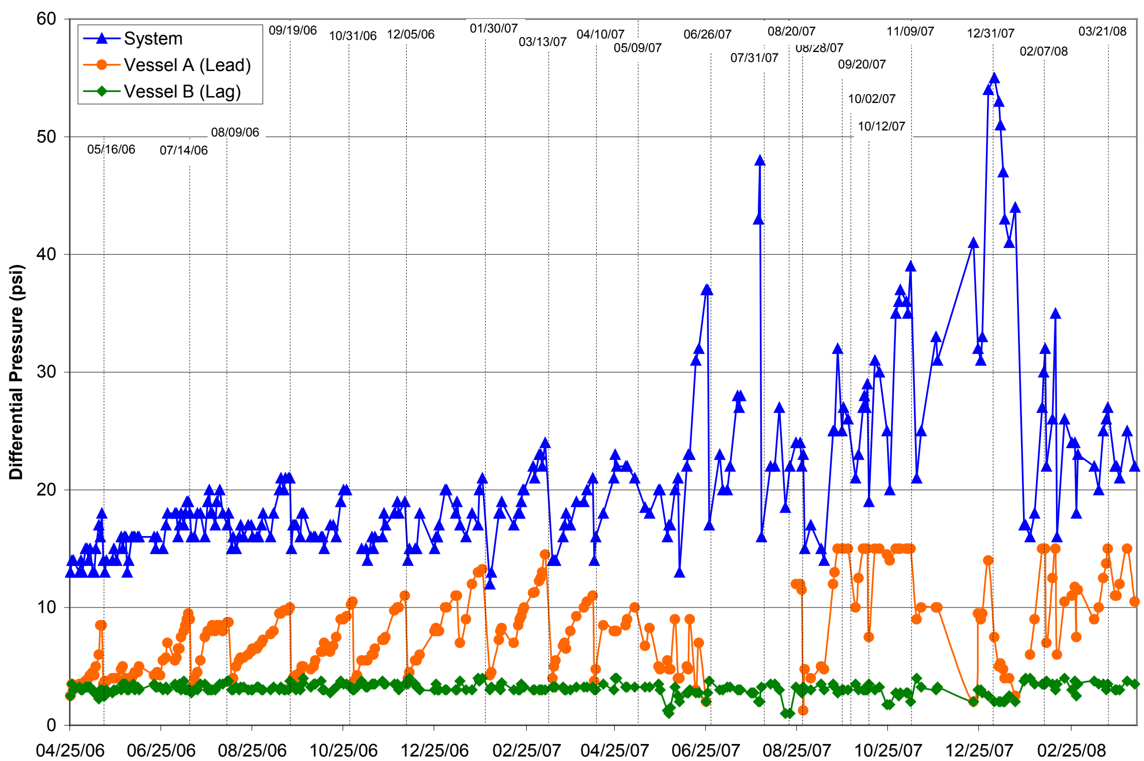


Figure 4-13. Δp Across Treatment System, and Lead and Lag Vessels

As shown in Figure 4-13, Δp readings across the lead vessel (Vessel A) increased steadily after backwashing, indicating accumulation of iron particles and/or media fines. Another backwash was performed when the Δp across Vessel A approached or exceeded 10 psi. During the first year of system operation from April 25, 2006, to April 10, 2007, backwashing was effective in reducing the Δp across the lead vessel to less than 4 psi (Table 4-8). Starting from May 9, 2007, at a throughput around 21,727 BV, backwashing became less and less effective in reducing the Δp. Since then, Vessel A Δp readings after a backwash increased from 6.8 to 15.0 psi.

Table 4-8. Δp Across Vessels A and B Before and After a Backwash Event

No.	Backwash Date	Duration Since Last Backwash (week)	Amount of Water Treated Since Last Backwash (BV)	ΔP across Vessel A before/after Backwash (psi)	ΔP across Vessel B before/after Backwash (psi)
1	05/16/06	NA	NA	8.5/3.5	3.0/2.5
2	07/14/06	8	4,070	9.0/3.3	3.0/2.8
3	08/09/06	4	1,400	8.8/3.8	3.8/3.0
4	09/19/06	6	2,253	10.0/3.3	3.8/3.3
5	10/31/06	6	1,813	11.0/3.8	3.0/3.0
6	12/05/06	5	1,441	11.0/4.0	3.5/3.5
7	01/30/07	8	2,551	13.0/4.3	4.0/3.0
8	03/13/07	6	2,242	15.0/4.0	3.0/3.3
9	04/10/07	4	1,537	11.0/3.8	3.3/3.0
10	05/09/07	4	1,538	10.0/6.8	3.3/3.3
11	06/26/07	7	2,987	NA/NA	2.8/3.8
12	07/31/07	5	1,618	NA/NA	2.0/3.3
13	08/20/07	3	1,253	NA/NA	1.0/3.3
14	08/28/07	1	437	12.0/1.3	2.8/3.3
15	09/20/07	3	1,117	15.0/15.0	3.3/2.8
16	10/02/07	2	636	15.0/10.0	3.0/3.5
17	10/12/07	1	519	7.0/NA	3.5/NA
18	11/09/07	4	1,415	15.0/9.0	2.0/4.0
19	12/31/07	7	1,820	14.0/7.5	2.5/2.0
20	02/07/08	5	1,834	15.0/7.0	3.5/3.8
21	03/21/08	6	1,770	15.0/11.0	3.5/3.0

NA = not available

Gradual accumulation of iron and manganese solids formed after prechlorination and, possibly, media fines were attributed to the less effective backwashing observed during the second year of system operation. In addition, based on trip reports provided by STS, sediments produced from the wells also might have contributed to the observed Δp rise. As shown in Figure 4-13, Δp readings across Vessel B remained low (averaging 3.1 psi) and constant throughout the two-year study period, indicating little or no accumulation of precipitated iron solids or media fines. The data seem to suggest that media fines may not have been the primary contributing factor to less effective backwashing, since both vessels were backwashed when the Δp across the lead vessel approached or exceeded 10 psi.

During the two-year performance evaluation study, 21 backwashes were performed on both vessels, averaging one backwash every five weeks. Both vessels were backwashed even although the Δp across Vessel B remained low. Based on the backwash logs, backwash flowrates ranged from 175 to 275 gpm and averaged 207 gpm, which was very close to the design value of 210 gpm. Each backwash event lasted for approximately 26 min, including backwash and downflow rinse, thereby producing approximately 5,400 gal of wastewater per vessel. Based on the backwash logs, the amount of backwash water produced ranged from 4,000 to 6,800 gal/vessel.

4.4.2 Residual Management. Residuals produced by the operation of the APU-30S system included backwash wastewater and spent media. Backwash wastewater was sent to a small ditch (Figure 4-10) adjacent to the treatment system and subsequently drained into a roadside ditch.

4.4.3 Media Rebedding. As described in Section 4.5.1, arsenic concentrations following the lag vessel first exceeded the MCL on September 12, 2007, after treated approximately 28,700 BV of water (based on 124 ft^3 of media). Since then through the end of the performance study on April 8, 2008, arsenic concentrations measured after the lag vessel fluctuated around 10.0 µg/L, indicating the need for rebedding of the lead vessel.

In April 2008, Battelle contacted STS for media rebedding. An STS technician went to the site to perform media changeout on May 6, 2008, but had to abort the mission due to lack of proper vacuuming equipment to remove the spent media from the lead vessel. During the trip, the STS technician measured the Vessel A freeboard height (i.e., from the flange at the top of the vessel to the media surface) at 49 in, which was 13.5 in more than that measured on May 17, 2006 (Table 4-4), indicating significant media loss over the two year system operation. A spent media sample was collected from the lead vessel and submitted for TCLP analysis.

In July 2008, instead of making a return trip to the site as planned, STS decided not to rebed Vessel A citing the small size of the job. Soon afterwards, Battelle contacted SouthWest Water Company (SWC, Oak Manor MUD's contractor for operating the water utility) to conduct the changeout. A quote for the changeout was received from SWC on July 23, 2008, and the paperwork needed to establish a purchase order for the rebedding service was received from SWC on October 3, 2008.

The media rebedding of Vessel A was conducted by SWC on October 14, 2008, after the system treated approximately 52,400 BV of water (based on 124 ft^3 of media). A vacuum truck was used to remove the spent media and the top portion of the gravel underbedding. Spent media samples were collected at the top (0 to 5 in from the top of the media bed), middle (11 to 15 in from the top of the media bed), and bottom (23 to 27 from the top of the media bed) of the media bed. Vacuum removal of the media was paused at each level to allow for the collection of spent media samples. After the spent media was completely removed, the top 6 in of the gravel underbedding also was removed. Subsequently, 6 in of fresh gravel was loaded on top of the remaining gravel underbedding, followed by virgin media. The freeboard height measured after the media changeout was at the target value of 39 in, based on the design bed volume. Following media changeout, the vessels were switched such that the lag vessel was placed into the lead position and the former lead vessel with the new media was placed in the lag position. Water samples were collected across the treatment system before and after the media changeout and the results are discussed in Section 4.5.1.

4.4.4 Reliability and Simplicity of Operation. There was no downtime for the treatment system during the performance study. However, there were operational irregularities related to the system's Vessel A flowmeter/totalizer, automatic valve 123A, and system default settings.

The Vessel A flowmeter/totalizer stopped functioning on seven separate occasions from April 26 to May 26, 2006; on June 6, 2006; from September 6 to October 3, 2006; from January 15 to March 21, 2007; on April 2 and September 20, 2007, and from October 31 to April 8, 2008; due to wear by either precipitated solids or natural sediments from the wells. The automatic valve 123A failed to open during automatic backwash on July 14, 2006, due to water and humidity accumulating in the valve.

The treatment system was discovered to be in parallel mode instead of series mode during the vendor's visit from May 16 to 17, 2006. The vendor determined that the system was left in manual mode for backwash, which reverted back to its default parallel mode after a power outage. This occurred three times on June 19, September 5, and September 24, 2006, with the lag vessel treating a total of about 20 BV of raw water from the three events. Therefore, leaving the system in manual mode put the system at risk of returning back to its default parallel mode after a power outage. This, in conjunction with the need to accommodate the operator's request for his physical presence during backwash, prompted the vendor to extend the automatic backwash timer setting from 30 to 120 days in the PLC on August 9, 2006. In doing so, the operator could initiate a backwash, as Δp readings were approaching 10 psi, by pushing the manual backwash button on the PLC screen. To alleviate the concerns mentioned above, the following actions were taken: (1) set backwash duration for 20 min and downflow rinse for 10 min, (2) made onsite observations to ensure correct valve positions, and (3) left the manual isolation valve open at all times and allowed the electrically actuated valve, MB-127, to control the supplemental flowrate. Upon completion of the backwash, the operator reset the system back to the automatic mode.

Operational irregularities also were experienced with the master totalizers on Well 2 and the treated water line. The totalizer on Well 2 was broken from April 25 to May 21, 2006, and from November 6 to 18, 2007; while the totalizer on the treated water line was broken from April 25 to July 10, 2006; from August 21 to September 17, 2006; and from February 19 to March 7, 2008.

The system O&M and operator skill requirements are discussed below in relation to pretreatment requirements, levels of system automation, operator skill requirements, preventive maintenance activities, and frequency of chemical/media handling and inventory requirements.

Pre- and Post-Treatment Requirements. Chlorination with the pre-existing gas chlorination system (discussed in Section 4.2 and shown in Figure 4-7) was the only pre-treatment required. The operator monitored the weight of the chlorine gas cylinder and target residual levels the same way as prior to the arsenic demonstration study.

System Automation. For automatic system operation, the treatment system was installed with electronic flow sensors, flow controllers/valves, pressure transmitters/controllers, and a Square D Telemechanique PLC with a Magelis G2220 color touch interface screen. For example, each adsorption vessel was equipped with a flow sensor and totalizer (i.e., electromagnetic flowmeter), five electrically actuated butterfly valves, and a pressure transmitter, all of which were capable of transmitting and receiving electronic signals to and from the PLC. Although the PLC was capable of being interlocked with the well pumps, hydropneumatic pressure tank, and/or the storage tank, the Oak Manor MUD elected not to pursue this option due to additional electrical work required for interlocking.

The treatment system was capable of automatic backwash triggered by either a timer or a Δp setting. It also allowed the operator to override the automatic setpoint by pushing the manual backwash button on the PLC screen. As described earlier, to ensure a proper backwash, the operator initially conducted backwash manually by physically opening/closing the valves. This practice was replaced with "semi-automatic" backwash via the PLC after August 9, 2006.

The system also had six isolation ball valves to reverse the vessel positions from lead to lag and vice versa after each media replacement. Because media replacement occurred rather infrequently, the vessel switching operation was not automated.

In addition to regular O&M, operator's awareness and abilities to detect unusual system performance were necessary when troubleshooting system automation failures. The equipment vendor provided hands-on training and a supplemental operations manual to help increase operator's awareness and abilities to detect and cope with any performance irregularities.

Operator Skill Requirements. Under normal operating conditions, the skill requirements to operate the system were minimal. The operator was on-site typically five times a week and spent about 40 min each day to perform visual inspections and record the system operating parameters on the daily log sheets. Normal operation of the system did not require additional skills beyond those necessary to operate the existing water supply equipment.

The State of Texas requires that an operator for water treatment systems hold at least a TCEQ waterworks operator license. There are four water operator certificate levels, i.e., A, B, C, and D, with Class A being the highest. The certificate levels are based on education, experience, and related training. The operator for the Oak Manor MUD system has a Class C certificate, which requires a high school diploma or equivalent, two years of work experience, and 60 hr of related training (TCEQ, 2007).

Preventive Maintenance Activities. Preventive maintenance tasks included periodic checks of flowmeters and pressure gauges and inspection of system piping and valves. Typically, the operator performed these duties when he was on-site for routine activities.

Chemical Handling and Inventory Requirements. Gas chlorine cylinders were used for prechlorination. The operator ordered chemicals as had been done prior to the installation of the APU-30S system. Typically, four 150-pound cylinders were used per month and the gas chlorine supplier, DXI Industries, refilled the chlorine cylinder onsite.

4.5 System Performance

The performance of the APU-30S system was evaluated based on analyses of water samples collected from the treatment plant, system backwash, and distribution system.

4.5.1 Treatment Plant Sampling. Water samples were collected at four locations through the treatment process: including IN, AC, TA, and TB (Table 3-3). The treatment plant water was sampled on 36 occasions (including the three duplicate sampling events on August 1, 2006; April 4, 2007; and March 13, 2008), with field speciation performed during 14 of the 36 occasions. Field-speciation samples were collected monthly from system startup to October 11, 2006; and switched to bimonthly from November 15, 2006 to October 3, 2007. Field-speciation was discontinued after October 3, 2007.

Table 4-9 provides a summary of analytical results for arsenic, iron, and manganese during the performance evaluation study from May 25, 2006, through April 8, 2008. Table 4-10 summarizes the results of the other water quality parameters. Because the sample tap for the system influent water was installed incorrectly before May 24, 2006 (see Item No. 2 in Table 4-5), the results of the first three sets of "IN" samples were not included in Tables 4-9 and 4-10. In addition, because the "TA" and "TB" samples on May 23, 2006, were collected from wrong sample taps, those results were not included in Tables 4-9 and 4-10, either. Appendix B contains a complete set of analytical results. The results of the water samples collected throughout the treatment plant are discussed below.

Arsenic. Figure 4-14 contains four bar charts showing the concentrations of total As, particulate As, and soluble As(III) and As(V) at the IN, AC, TA, and TB sampling locations for each speciation sampling event. Total arsenic concentrations in raw water ranged from 27.5 to 52.5 µg/L and averaged 40.2 µg/L, with over 94% existing as soluble arsenic. Of the soluble arsenic, As(III) was the predominating species

Table 4-9. Summary of Arsenic, Iron, and Manganese Analytical Results

Parameter	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
As (total)	IN	μg/L	33[(a)]	27.5	52.5	40.2	7.2
	AC	μg/L	36	22.5	41.2	31.6	4.7
	TA	μg/L	35[(b)]	0.2	28.5	-[(c)]	-[(c)]
	TB	μg/L	35[(b)]	<0.1	10.6	-[(c)]	-[(c)]
As (soluble)	IN	μg/L	12[(a)]	25.3	45.1	37.9	6.9
	AC	μg/L	14	19.6	30.5	25.7	3.5
	TA	μg/L	13[(b)]	<0.1	22.1	-[(c)]	-[(c)]
	TB	μg/L	13[(b)]	<0.1	10.8	-[(c)]	-[(c)]
As (particulate)	IN	μg/L	12[(a)]	<0.1	6.9	4.1	2.1
	AC	μg/L	14	2.7	11.6	5.6	2.4
	TA	μg/L	13[(b)]	<0.1	4.8	-[(c)]	-[(c)]
	TB	μg/L	13[(b)]	<0.1	0.6	-[(c)]	-[(c)]
As(III)	IN	μg/L	12[(a)]	17.7	44.1	31.5	8.5
	AC	μg/L	14	<0.1	1.3	0.7	0.4
	TA	μg/L	13[(b)]	<0.1	1.6	-[(c)]	-[(c)]
	TB	μg/L	13[(b)]	<0.1	1.8	-[(c)]	-[(c)]
As(V)	IN	μg/L	12[(a)]	0.2	21.5	6.4	6.6
	AC	μg/L	14	18.2	30.0	25.1	3.6
	TA	μg/L	13[(b)]	<0.1	21.3	-[(c)]	-[(c)]
	TB	μg/L	13[(b)]	<0.1	10.3	-[(c)]	-[(c)]
Fe (total)	IN	μg/L	33[(a)]	<25	145	62.7	36.8
	AC	μg/L	36	<25	169	42.8	33.1
	TA	μg/L	35[(b)]	<25	29	<25	2.8
	TB	μg/L	35[(b)]	12.5	31	13.0	3.1
Fe (soluble)	IN	μg/L	12[(a)]	<25	44	19.0	11.9
	AC	μg/L	14	<25	<25	<25	NA
	TA	μg/L	13[(b)]	<25	<25	<25	NA
	TB	μg/L	13[(b)]	<25	<25	<25	NA
Mn (total)	IN	μg/L	33[(a)]	47.3	66.6	55.1	4.6
	AC	μg/L	36	42.6	57.1	50.6	3.8
	TA	μg/L	35[(b)]	<0.1	9.6	2.2	2.0
	TB	μg/L	35[(b)]	<0.1	0.9	0.3	0.2
Mn (soluble)	IN	μg/L	12[(a)]	48.9	63.4	54.1	4.5
	AC	μg/L	14	<0.1	14.5	1.9	3.7
	TA	μg/L	13[(b)]	<0.1	1.2	0.3	0.4
	TB	μg/L	13[(b)]	<0.1	0.6	0.2	0.2

One-half of detection limit used for samples with concentrations less than detection limit for calculations.
NA = not applicable
(a) Results of "IN" samples collected before May 24, 2006, not included because of use of incorrectly installed sample tap.
(b) Results of "TA" and "TB" samples collected on May 23, 2006, not included because of use of wrong sample taps.
(c) Not meaningful for data related to breakthrough curves; see Figure 4-15.

Table 4-10. Summary of Other Water Quality Sampling Results

Parameter	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as $CaCO_3$)	IN	mg/L	21[(a)]	318	696	375	76.0
	AC	mg/L	24	342	390	366	15.2
	TA	mg/L	23[(b)]	331	404	370	16.2
	TB	mg/L	23[(b)]	331	398	366	15.3
Ammonia (as N)	IN	mg/L	10	0.1	0.2	0.2	0.1
	AC	mg/L	10	<0.05	0.20	0.07	0.06
	TA	mg/L	9	<0.05	0.10	0.03	0.03
	TB	mg/L	9	<0.05	0.10	0.03	0.02
Fluoride	IN	mg/L	10[(a)]	1.1	1.5	1.4	0.1
	AC	mg/L	12	1.2	1.7	1.5	0.1
	TA	mg/L	11[(b)]	1.3	1.7	1.5	0.1
	TB	mg/L	11[(b)]	1.3	1.9	1.5	0.2
Sulfate	IN	mg/L	10[(a)]	0.5	2.0	0.9	0.6
	AC	mg/L	12	1.0	3.0	1.9	0.5
	TA	mg/L	11[(b)]	1.0	2.0	1.8	0.4
	TB	mg/L	11[(b)]	1.0	2.0	1.5	0.5
Nitrate (as N)	IN	mg/L	10[(a)]	<0.05	<0.05	<0.05	NA
	AC	mg/L	12	<0.05	<0.05	<0.05	NA
	TA	mg/L	11[(b)]	<0.05	<0.05	<0.05	NA
	TB	mg/L	11[(b)]	<0.05	<0.05	<0.05	NA
Total P (as P)	IN	μg/L	29[(a)]	25.2	86.7	40.7	11.2
	AC	μg/L	32	20.4	95.0	42.2	11.9
	TA	μg/L	31[(b)]	5.0	76.3	29.1	16.2
	TB	μg/L	31[(b)]	5.0	58.7	17.6	17.0
Silica (as SiO_2)	IN	mg/L	21[(a)]	14.4	16.8	15.3	0.6
	AC	mg/L	24	14.8	16.7	15.7	0.6
	TA	mg/L	23[(b)]	15.2	17.0	15.8	0.5
	TB	mg/L	23[(b)]	12.6	16.8	15.6	0.8
Turbidity	IN	NTU	21[(a)]	0.1	0.9	0.5	0.3
	AC	NTU	24	0.2	1.1	0.5	0.3
	TA	NTU	23[(b)]	0.1	1.3	0.5	0.3
	TB	NTU	23[(b)]	0.1	0.8	0.3	0.2
pH	IN	S.U.	22[(a)]	7.4	8.1	7.8	0.2
	AC	S.U.	25	7.3	7.9	7.6	0.2
	TA	S.U.	24[(b)]	7.5	8.0	7.7	0.1
	TB	S.U.	24[(b)]	7.6	7.9	7.7	0.1
Temperature	IN	°C	22[(a)]	21.5	27.6	23.9	1.7
	AC	°C	25	21.4	33.8	24.3	2.6
	TA	°C	24[(b)]	21.3	32.1	24.2	2.4
	TB	°C	24[(b)]	21.1	30.7	24.1	2.3
Dissolved Oxygen	IN	mg/L	19[(a)]	1.2	2.9	2.0	0.6
	AC	mg/L	22	1.2	2.9	1.8	0.4
	TA	mg/L	21[(b)]	1.3	4.9	2.9	0.9
	TB	mg/L	21[(b)]	1.4	4.3	2.6	0.8
ORP	IN	mV	25[(a)]	189	448	337	76.7
	AC	mV	28	189	687	592	123
	TA	mV	27[(b)]	190	708	576	134
	TB	mV	27[(b)]	190	687	577	137

Table 4-10. Summary of Other Water Quality Sampling Results (Continued)

Parameter	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Free Chlorine (as Cl_2)	AC	mg/L	27	0.3	3.3	2.1	0.8
	TA	mg/L	26[(b)]	0.1	3.2	1.4	0.7
	TB	mg/L	26[(b)]	0.2	2.7	1.3	0.6
Total Chlorine (as Cl_2)	AC	mg/L	27	0.3	3.3	2.2	0.8
	TA	mg/L	26[(b)]	0.2	3.4	1.4	0.7
	TB	mg/L	26[(b)]	0.4	2.8	1.4	0.6
Total Hardness (as $CaCO_3$)	IN	mg/L	10[(a)]	31.0	45.8	39.9	4.7
	AC	mg/L	12	30.0	50.3	42.3	6.1
	TA	mg/L	11[(b)]	31.5	48.7	41.9	4.4
	TB	mg/L	11[(b)]	32.7	47.7	42.9	4.0
Ca Hardness (as $CaCO_3$)	IN	mg/L	10[(a)]	19.1	33.0	27.2	4.0
	AC	mg/L	12	18.0	35.3	28.5	5.3
	TA	mg/L	11[(b)]	19.0	34.2	28.5	3.9
	TB	mg/L	11[(b)]	19.8	33.4	29.1	3.6
Mg Hardness (as $CaCO_3$)	IN	mg/L	10[(a)]	10.4	14.5	12.7	1.1
	AC	mg/L	12	11.9	15.6	13.8	1.3
	TA	mg/L	11[(b)]	11.7	15.6	13.4	1.3
	TB	mg/L	11[(b)]	11.8	16.2	13.8	1.2

One-half of detection limit used for samples with concentrations less than detection limit for calculations.
NA = not applicable
(a) Results of "IN" samples collected before May 24, 2006, not included because of use of incorrectly installed sample tap.
(b) Results of "TA" and "TB" samples collected on May 23, 2006, not included because of use of wrong sample taps.

with its concentrations ranging from 17.7 to 44.1 µg/L and averaging 31.5 µg/L. The remainder of soluble arsenic was As(V) with its concentrations ranging from 0.2 to 21.5 µg/L and averaging 6.4 µg/L. Some particulate arsenic also existed, with its concentrations ranging from <0.1 to 6.9 µg/L and averaging 4.1 µg/L. The average total arsenic concentration (i.e. 40.2 µg/L) measured during the two-year performance evaluation study was approximately 16.5% higher than that measured during the initial site visit on February 16, 2005 (i.e., 34.5 µg/L, Table 4-1).

The presence of As(III) as the predominating soluble arsenic species in raw water is consistent with the low DO levels (i.e., 1.2 to 2.9 mg/L Table 4-10) measured during the performance evaluation study and that (i.e., 1.7 mg/L) measured during the November 2, 2004 site visit. ORP readings measured during the performance evaluation study, however, were much higher (i.e., from 189 to 448 mV and averaging 337 mV) than that (i.e., 1 mV) measured during the November 2, 2004 site visit. These high ORP readings were attributed primarily to the use of the handheld meter, which often gave erratic and drifting results at the arsenic removal technology demonstration sites. After prechlorination and adsorption, DO levels remained rather unchanged, averaging 1.8 to 2.9 mg/L. ORP readings increased significantly, as expected, to an average of 576 to 592 mV, due to the presence of chlorine residuals as discussed below.

Prechlorination effectively oxidized As(III) to As(V) and provided required chlorine residuals to the distribution system. As shown in Figure 4-14, all samples collected at the AC location contained mostly As(V) and particulate arsenic. The average As(III) and As(V) concentrations of the AC samples were 0.7 and 25.1 µg/L, respectively (Table 4-9). After chlorination, 98% of the soluble arsenic was present as As(V), compared to only 17% in raw water. The trace levels of As(III) measured were believed to have been caused primarily by the speciation method.

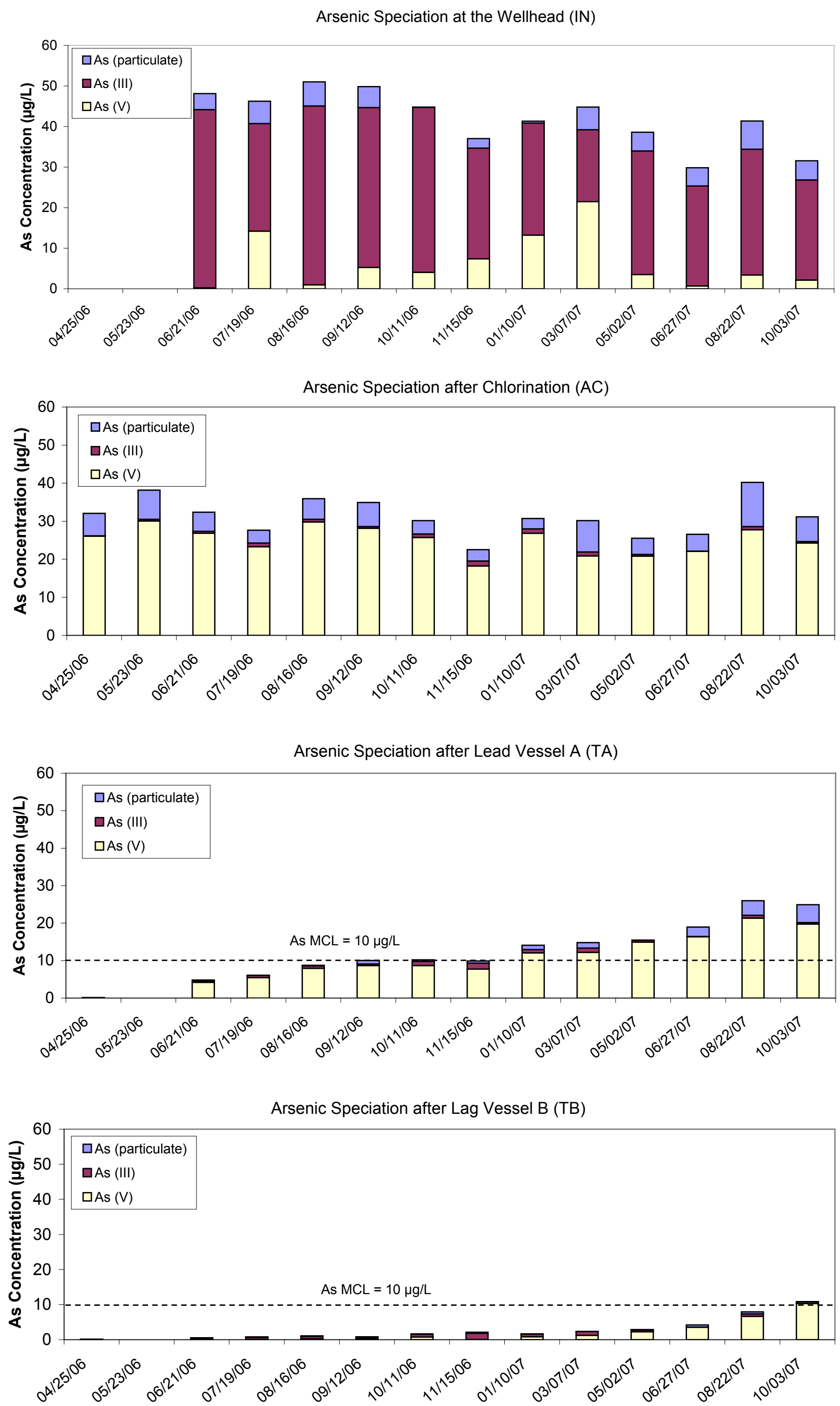


Figure 4-14. Concentrations of Arsenic Species at Influent, After Chlorination, after Lead Vessel, and after Lag Vessel

Free chlorine residuals measured at the AC location ranged from 0.3 to 3.3 mg/L (as Cl_2) and averaged 2.1 mg/L (as Cl_2), which were similar to total chlorine residuals measured in the same samples (Table 4-10). The total chlorine residual levels measured were very close to the target levels of 1.5 to 2.0 mg/L (as Cl_2) set by the facility. The similar levels of total and free chlorine residuals measured suggest the absence of ammonia in raw water, which was confirmed by the low level of ammonia (i.e., 0.1 to 0.2 mg/L [as N]) measured during the later part of the performance evaluation study. Total and free chlorine residuals measured after the lead and lag vessels averaged 1.3 to 1.4 mg/L (as Cl_2), which were lower than those measured at the AC location (i.e., 2.1 mg/L [as Cl_2]). Lower levels of total and free chlorine residuals suggest some chorine demand (i.e., 0.7 mg/L [as Cl_2]) across the lead vessel.

Figure 4-15 presents total arsenic breakthrough curves from the lead and lag vessels, along with total arsenic concentrations in raw water and after prechlorination. The lead vessel removed the majority of arsenic, existing predominately as As(V) because of prechlorination. On September 12, 2006, after treating 9,527,220 gal, or 10,277 BV, of water, arsenic concentrations reached 10.0 µg/L following the lead vessel and 0.8 µg/L following the lag vessel. Arsenic concentrations after the adsorption vessels continued to increase afterwards and reached 10.0 µg/L following the lag vessel the first time on September 12, 2007 after treating 28,736 BV (or 26,638,090 gal) of water. Since then through the end of the performance evaluation study on April 8, 2008, arsenic concentrations measured after the lag vessel fluctuated around 10.0 µg/L, indicating arsenic breakthrough at 10.0 µg/L occurred at the lag vessel after treating approximately 28,700 BV of water. Calculations of bed volumes were based on 124 ft^3 of media in both vessels.

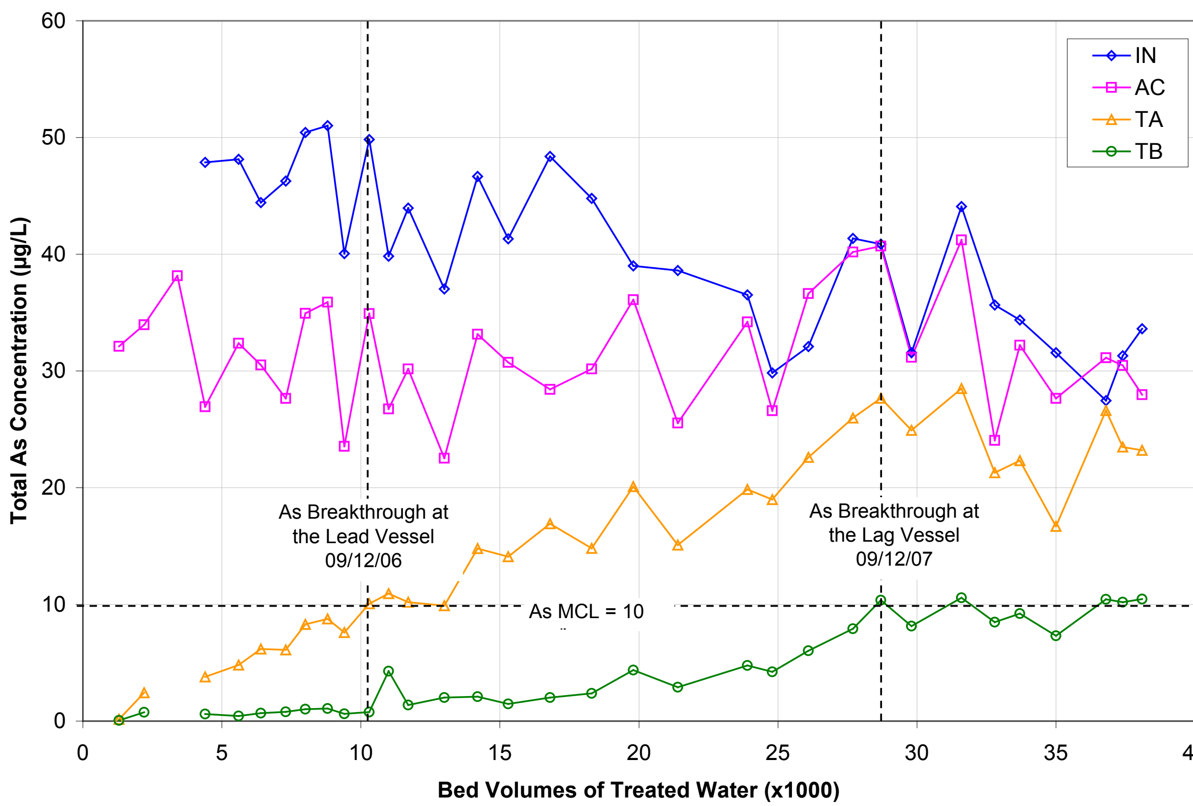


Figure 4-15. Total Arsenic Breakthrough Curves (BV calculated based on 124 ft^3 of media)

At the end of performance evaluation study after treating approximately 38,140 BV (35,358,250 gal) of water, total arsenic concentrations were 23.2 and 10.5 µg/L after the lead and lag vessels, respectively. The concentration after the lead vessel was close to that in the system influent (i.e., 28 µg/L after chlorination), indicating the lead vessel was approaching exhaustion.

The vendor-estimated working capacity for the treatment system was 51,240 BV (Table 4-3), which was based on 29 µg/L of arsenic in the system influent, 124 ft^3 of media in both the lead and lag vessels, and 16 µg/L of arsenic following the lead vessel. As shown in Figure 4-15, the 16- µg/L throughput following the lead vessel occurred at 16,900 BV, which is only one third of the value estimated by the vendor. The lower amount of media in the lead vessel (i.e. 53 ft^3 vs. 62 ft^3) and the higher arsenic concentration in raw water (i.e., 40.3 vs. 29 µg/L) might have contributed, in part, to the lower-than-expected run length observed.

As described in Section 4.4.3, approximately six months after the end of the performance evaluation study, the lead vessel was rebeddede on October 14, 2008. Before the media changeout, water samples were collected across the treatment train. Arsenic concentrations at the system inlet and after the lead and lag vessels were 26.8, 33.4, and 17.5 µg/L, respectively. One week after the media changeout on October 21, 2008, water samples were collected again across the treatment train, with arsenic concentrations measured at 26.2, 15.2, and 2.6 µg/L at the three respective locations. The arsenic concentration in system effluent was reduced significantly from 17.5 to 2.6 µg/L, indicating that media changeout was conducted properly.

Iron. Total iron concentrations in source water ranged from <25 to 145 µg/L and averaged 62.7 µg/L (Table 4-9). Over 70% of iron in source water existed as particulate iron. The source water sample taken during the November 2, 2004, site visit also contained a similar amount of total iron (i.e., 95 µg/L) with over 60% existing as particulate iron. Particulate iron might exist in source water as part of natural sediment or as precipitates caused by inadvertent aeration during sampling. The amounts of DO measured in source water, however, were low, ranging from 1.2 to 2.9 mg/L and averaging 2.0 mg/L as discussed above.

Total iron concentrations following prechlorination were slightly less than those at the IN sampling location, ranging from <25 µg/L to 169 µg/L and averaging 42.8 µg/L. Soluble iron levels at the AC location (based upon the use of 0.45-µm disc filters) were reduced significantly to below the method detection limit of 25 µg/L for all samples, indicating effective oxidation of soluble iron by chlorine. As shown in Figure 4-16, except for one sampling event on January 29, 2008, total iron was removed to below the method detection limit of 25 µg/L by the lead vessel throughout the performance evaluation study. Figure 4-16 shows total iron concentrations versus the amount of water treated across the treatment train.

Manganese. Figure 4-17 shows total manganese concentrations versus the amount of water treated across the treatment train. Total manganese concentrations in source water ranged from 47.3 to 66.6 µg/L and averaged 55.1 µg/L. Manganese existed almost entirely in the soluble form, which was consistent with that found in the source water sample collected during the initial site visit on November 2, 2004 (Table 4-1). After prechlorination, an average of 96.4% of soluble manganese precipitated and formed, presumably, MnO_2 solids. The MnO_2 solids along with unoxidized Mn(II) were removed by the media, causing total manganese concentrations to decrease to 2.2 and 0.3 µg/L following the lead and lag vessels, respectively.

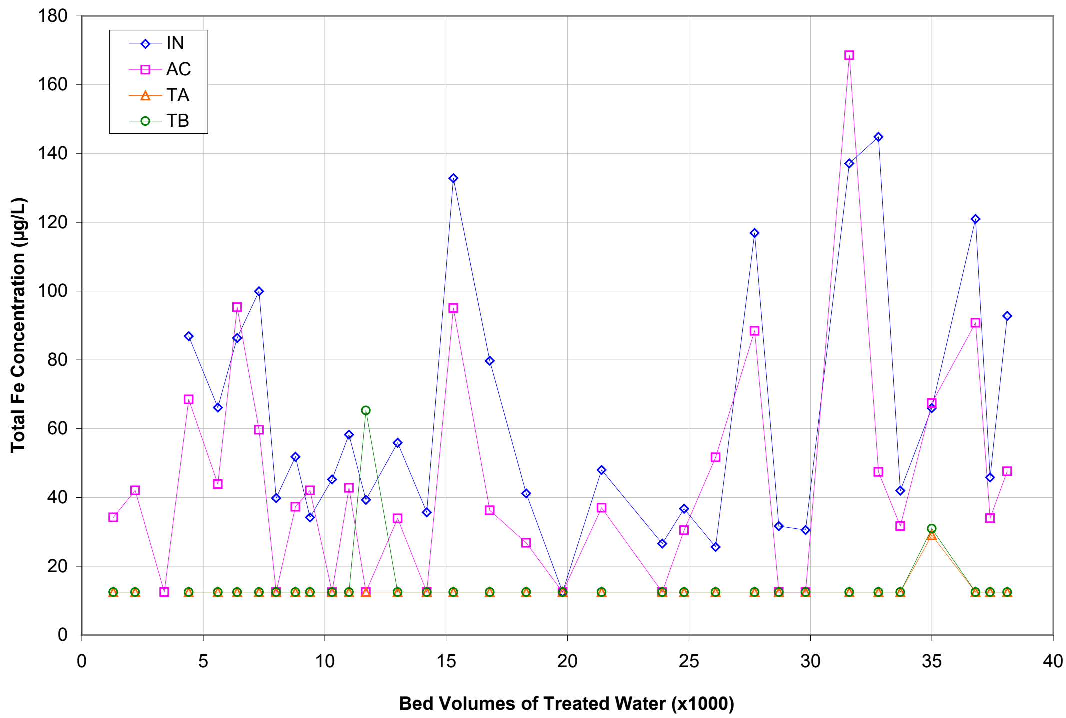


Figure 4-16. Total Iron Concentrations Versus Bed Volumes (BV calculated based on 124 ft^3 of media)

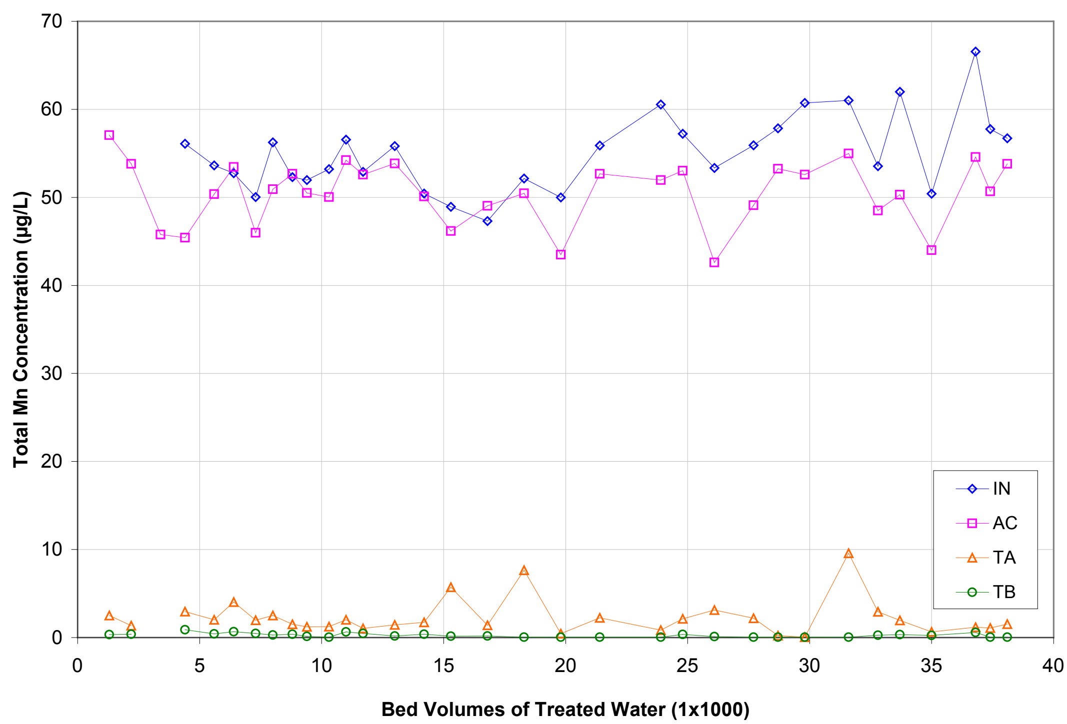


Figure 4-17. Total Manganese Concentrations Versus Bed Volumes (BV calculated based on 124 ft^3 of media)

The high Mn(II) precipitation rate after chlorination at the Oak Manor MUD reflected rapid oxidation kinetics by chlorine, which was contrary to the findings by most researchers who investigated the oxidation of Mn(II) even with some lengths of contact time (Knocke et al, 1987 and 1990; Condit and Chen, 2006). Varying Mn(II) precipitation rates were observed at 11 EPA arsenic removal demonstration sites (Table 4-11), with two sites averaging less than 10% (i.e., Delavan, WI and Bruni, TX), seven sites averaging from 14.6 to 55.0%, and two sites averaging 70 and 93.5% (i.e., Alvin, TX and Springfield, OH). It is not clear why some source waters had slower oxidation kinetics than others. Based on existing literature for Mn(II) oxidation with chlorine, the variables affecting Mn(II) oxidization kinetics might include pH, temperature, and contact time. Mn(II) oxidation rates increased at high pH (i.e., 8.0) and high temperature (Knocke et al., 1987). Table 4-11 did not show clear correlation between pH, temperature, and contact time with precipitation rates (McCall et al., 2007). Out of the 13 sites investigated, the Oak Manor MUD had the highest precipitation rates.

Table 4-11. Amount of Mn(II) Precipitated after Chlorination at 11 Arsenic Removal Demonstration Sites

		Raw Water					After Chlorination	
Demonstration Location	Contact Time (min)	pH (S.U.)	Temperature (°C)	NH_3 (mg/L)	TOC (mg/L)	Avg Mn (Total/Soluble) (µg/L)	Avg Mn (Total/Soluble) (µg/L)	Avg Mn(II) Precipitated (%)
Bruni, TX	None	8.2	25.6	<detect	0.9	5.0/4.7	3.9/3.5	5.8
Anthony, NM	None	7.7	30.0	None	1.6	9.6/8.9	9.8/6.8	23.5
Brown City, MI	None	8	11.6	None	<detect	16.1/15.7	15.0/9.8	31.9
Delavan, WI	2	7.5	13.9	2.9	1.6	19.2/20.1	18.1/17.7	2.7
Sandusky, MI	41	7.2	12.1	0.3	1.5	25.3/26.7	26.0/11.7	55.0
Pentwater, MI	6	8	12.6	0.3	2.0	27.3/28.8	30.1/14.3	52.4
Springfield, OH	None	7.3	16.2	0.2	<detect	35.6/36.3	29.5/8.3	70.0
Alvin, TX	None	7.7	25.6	0.2	0.7	54.4/54.0	51.1/2.8	93.5
Rollinsford, NH	None	7.9	14.2	None	<detect	110/124	101/86.5	14.6
Climax, MN	5	7.6	9.1	None	12.0	135/126	130/73.7	35.9
Sabin, MN	7	7.3	13.0	0.2	1.6	346/378	338/228	32.6

Other Water Quality Parameters. In addition to arsenic, iron, and manganese, other water quality parameters were analyzed and the results are included in Appendix B and summarized in Table 4-10.

Silica and phosphate are known to influence arsenic adsorption with iron-based media. Silica concentrations in source water ranged from 14.4 to 16.8 mg/L with no significant reductions across the treatment train. Total phosphorous concentrations in source water ranged from 25.2 to 86.7 µg/L and averaged 40.7 mg/L. Total phosphorous concentrations were progressively reduced to an average of 29.1 and 17.6 µg/L following the lead and lag vessels, respectively; suggesting that total phosphorus might compete with arsenic for available adsorptive sites.

As shown in Table 4-10, pH values of raw water varied from 7.4 to 8.1 and averaged 7.8. In general, iron-based adsorption media have greater arsenic removal capacities at near or lower than neutral pH values. Alkalinity, reported as $CaCO_3$, ranged from 318 to 389 mg/L and averaged 359 mg/L, not including an outlier for raw samples taken on August 29, 2006. The results indicated that the adsorptive media did not affect the amount of alkalinity in the treated water. Sulfate concentrations were consistently low, averaging 0.9 mg/L in source water and 1.5 to 1.9 mg/L across the treatment train.

Fluoride levels ranged from 1.1 to 1.9 mg/L in all samples and did not appear to have been affected by the SORB 33^{TM} media. Total hardness, existing 68% as calcium hardness and 32% as magnesium hardness, ranged from 31.0 to 45.8 mg/L (as $CaCO_3$), and also remained unchanged throughout the treatment train.

4.5.2 Backwash Wastewater Sampling. Backwash was performed one vessel at a time using a mix of raw water (non-chlorinated) and treated water. Backwash wastewater was sampled 11 times from the sample ports located in the backwash effluent discharge lines from each vessel. The unfiltered samples were analyzed for pH, TDS, TSS, and total arsenic, iron, and manganese. Filtered samples using 0.45-µm disc filters were analyzed for soluble arsenic, iron, and manganese. The analytical results are summarized in Table 4-12. pH values ranged from 7.5 to 8.0, similar to those of source and treated water. TDS levels ranged from 482 to 532 mg/L and averaged 513 mg/L. TSS levels ranged from 80 to 500 mg/L and averaged 307 mg/L for Vessel A, not including an outlier on June 26, 2007. As expected, TSS values were lower for Vessel B, ranging from 5.0 to 150 mg/L and averaging 44 mg/L.

Concentrations of total arsenic in backwash wastewater varied widely from 10.1 to 888 µg/L and averaged 144 µg/L for the lead vessel and from 3.2 to 120 µg/L and averaged 23.7 µg/L for the lag vessel. Concentrations of soluble arsenic were lower, ranging from 13.9 to 37.0 µg/L and averaging 20.3 µg/L for the lead vessel and from 1.5 to 29.1 µg/L and averaging 9.0 µg/L for the lag vessel. Particulate arsenic averaging at 69.6 µg/L might be associated with either iron particles filtered out by the media beds during the service cycles or media fines. As expected, total arsenic concentration was higher (approximately 6 times) in the backwash wastewater from the lead vessel than that from the lag vessel. Concentrations of total iron and manganese ranged from 0.7 to 161.3 mg/L (averaged 19.7 mg/L), and from 0.08 to 15.2 mg/L (averaged 1.8 mg/L), respectively, with over 99.8% existed as particulates.

Table 4-12. Backwash Wastewater Sampling Results

Sampling Event		BW1										BW2									
		Vessel A										Vessel B									
		pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)	pH	TDS	TSS	As (total)	As (soluble)	As(particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)
No.	Date	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
1	07/14/06	7.7	508	366	17.0	15.9	1.1	25,214	<25	3,570	0.2	7.8	532	150	7.7	1.5	6.2	10,739	<25	1,705	0.4
2	08/09/06	7.7	526	116	16.1	14.7	1.4	3,910	<25	162	1.8	7.7	508	5	3.2	2.6	0.6	662	<25	79	0.4
3	09/19/06	7.7	482	400	10.1	13.9	<0.1	22,591	<25	893	0.6	7.7	500	15	5.1	3.0	2.1	1,437	<25	341	0.2
4	10/31/06	7.5	498	225	15.3	15.2	0.1	17,085	<25	737	0.5	7.6	518	25	8.3	4.5	3.9	700	<25	197	0.5
5	12/05/06	7.5	524	80	20.3	16.7	3.6	4,820	<25	311	1.2	7.6	500	30	8.2	5.2	3.0	2,085	<25	131	1.2
6	01/30/07	7.8	488	370	341	37.0	304	38,134	34	2,425	4.9	7.9	532	10	59.0	29.1	29.9	5,982	41	1,101	5.6
7	03/13/07	7.8	522	490	23.6	21.5	2.1	19,881	<25	992	0.7	7.8	516	24	12.8	9.4	3.4	1,450	<25	358	0.8
8	04/10/07	7.9	524	265	22.4	23.0	<0.1	15,412	<25	983	0.7	7.8	498	25	14.1	11.3	2.8	1,352	<25	352	0.3
9	05/09/07	7.7	532	260	25.8	19.2	6.5	13,000	<25	1,158	0.8	7.7	518	30	14.1	3.5	10.6	1,755	451	402	0.6
10	06/26/07	7.8	518	1,130	205	20.2	185	59,138	<25	2,687	1.0	7.8	520	55	8.6	11.5	<0.1	1,631	<25	360	0.8
11	08/29/07	8.0	514	500	888	26.0	862	161,305	<25	15,258	0.4	8.0	518	115	120	17.3	103	25,305	<25	4,482	0.1

TDS = Total Dissolved Solids; TSS = Total Suspended Solids; NA = Not Analyzed

Assuming that 5,400 gal (Table 4-6) of backwash wastewater would be generated from each vessel during each backwash event and that 307 and 44 mg/L of TSS would be produced from Vessels A and B, respectively, approximately 13.8 and 2.0 lb (or 6.3 and 0.9 kg) of solids, respectively, would be discharged every time when Vessels A and B were backwashed. Based on the average particulate metal data in Table 4-12, approximately 2.8 g of arsenic (i.e. 0.04% by weight), 804 g of iron (i.e. 11.2 % by weight), and 71.8 g of manganese (i.e. 1.0 % by weight) were generated from both the lead and lag vessels during each backwash event.

Backwash solid samples were collected on November 1, 2006, from Vessels A and B and analyzed for total metals; the results are presented in Table 4-13. Arsenic, iron, and manganese levels in the solids were averaged 2.0 mg/g (or 0.2% by weight), 291 mg/g (or 29% by weight), and 80.2 mg/g (or 8 % by weight), respectively. These amounts were significantly higher than those based on backwash wastewater metal analysis (i.e. 0.04%, 11.2%, and 1.0%, respectively). Challenges associated with sampling and sample digestion were believed to have contributed to the discrepancies observed. As expected, backwash solids from the lead vessel contained significantly higher percentages of metals, including As, Fe, Mn, Cu, and Zn, indicating removal of metal particulates by the lead vessel.

The particulate iron present in the backwash wastewater might have come from at least two separate sources, i.e., the iron from raw water or media fines. The amount of iron attributable to both sources was estimated using the data of the eleven backwash sampling events conducted from July 14, 2006, to August 29, 2007 (Table 4-12). The amount of iron attributable to the iron removed from raw water was estimated based on the average throughput between backwash events (i.e., 1,588,424 gal based on the throughput data in Table 4-8) and the average total iron concentration (i.e., 62.7 µg/L) in source water during the same period. Assuming complete removal of iron solids by the media beds and complete discharge of iron solids during the backwash events, there would have been 377 g of iron solids, as part of TSS discharged per backwash event, originating from the iron in source water. As discussed above, based on the average TSS measured in backwash wastewater, approximately 7,200 g of solids would be discharged from both Vessels A and B during each backwash event. Therefore, the natural iron level in backwash solids should be approximately 5.2%, which is 17.9% of that calculated based on backwash solids metal analysis (i.e., 29%), indicating that the backwash solids contained a significant amount of media fines.

Table 4-13. Backwash Solids Total Metal Results (µg/g)

Analyte	Mg	Al	Si	P	Ca	Fe	Mn	Ni	Cu	Zn	As	Cd	Pb
Vessel A	2,563	1,422	295	5,746	22,747	437,784	108,632	99	331	5,275	3,266	<0.1	46
Vessel B	6,219	1,551	728	1,964	31,798	144,335	51,676	53	197	1,095	825	1	50

Note: Average compositions calculated from triplicate analyses.

4.5.3 Spent Media Sampling. Spent media samples were collected from the lead vessel on May 6, 2008, for TCLP analysis and on October 14, 2008, for metals analysis (Section 3.3.4). The results from TCLP analysis indicated that the media was non-hazardous and could be disposed of at a sanitary landfill.

The ICP-MS results of the spent media samples are presented in Table 4-14. The average arsenic loading on the spent media was 3.5 mg/g of dry media. The adsorptive capacity also was calculated by dividing the arsenic mass represented by the area between the influent (IN) and the lead vessel effluent (TA) curves, as shown in Figure 4-15 by the amount of dry media in each vessel. Assuming no media loss, the dry weight of the media, i.e., 1,595 lb/vessel, was calculated based on a wet weight of 1,876 lb (i.e., 53,6 ft^3 of media at 35 lb/ft^3) and a maximum moisture content of 15% (Table 4-2). Using this approach, the arsenic loading on the media would be 4.7 mg/g of dry media. Assuming that arsenic loading measured at the top of the media bed was representative of the media throughout the bed (because the lead vessel was approaching saturation as shown in Figure 4-15), ICP-MS analysis would have recovered approximately 74.5% of the arsenic removed during the adsorption run.

Table 4-14. Spent Media Total Metal Analysis

Analyte (μg/g)		Mg	Si	P	Ca	Fe	Mn	As	Ba
Vessel A (Top)	Run 1	1,920	6,907	2,143	5,418	526,004	11,047	3,451	783
	Run 2	1,992	6,845	2,215	5,557	548,413	11,073	3,478	782
	Ave.	1,956	6,875	2,179	5,487	537,208	11,059	3,464	783

As shown in Table 4-14, the spent media contained mostly iron at 537 mg/g (as Fe) or 854 mg/g (as FeOOH) on the media, which is close to the 90.1% (by weight) value specified by the STS for the virgin media (Table 4-3).

4.5.4 Distribution System Water Sampling. Distribution system water samples were collected to determine if water treated by the arsenic removal system would impact the lead, copper, and arsenic levels and other water chemistry in the distribution system. Prior to system startup, baseline distribution system water samples were collected on March 16, April 20, May 18, and June 14, 2005. Since system startup, distribution system water sampling continued monthly at the same three locations until April 4, 2007. The results are presented in Table 4-15.

The main differences observed between the baseline samples and samples collected after system startup were decreases in arsenic and manganese concentrations at each of the three sampling locations. Arsenic concentrations were reduced from a pre-startup level of 38.2 μg/L (on average) to 2.6 μg/L after startup. Manganese concentrations were reduced from a pre-startup level of 41.8 μg/L (on average) to 1.5 μg/L after startup. Iron concentrations measured in the distribution system were low both before and after system startup (except for two outliers at DS1 and DS3 on May 18, 2005 during the baseline sampling), with the majority of the samples being <25 μg/L. In general, the iron levels measured in the distribution system water mirrored those in the system effluent. Manganese levels measured in the distribution system water were slightly higher than those in the system effluent results (i.e., 1.5 vs. 0.3 μg/L [on average]).

Arsenic concentrations measured in the distribution system water were compared to those measured in the plant effluent. As shown in Figure 4-18, prior to reaching 10,000 BV of throughput, arsenic concentrations in the distribution system water were higher than those in the plant effluent. Afterwards, arsenic concentrations were at levels similar to those of the plant effluent. These results suggest initial redissolution and/or resuspendsion of arsenic previously accumulated in the distribution system. After that, arsenic concentrations in the distribution system water essentially mirrored those of the plant effluent.

Measured pH values ranged from 7.6 to 8.2, and alkalinity levels ranged from 347 to 410 mg/L (as $CaCO_3$); no discernable trends were observed after system startup. Lead levels ranged from <0.1 to 2 μg/L (exclusing one data point at 7.9 μg/L for DS1 on May 17, 2006), which were less than the action level of 15 μg/L. The average lead level was 0.6 μg/L both in the baseline samples and the samples taken after system startup. Copper concentrations ranged from 14.9 to 862 μg/L, with no samples exceeding the 1,300 μg/L action level. The average copper level was 153 μg/L in the baseline samples and 157 μg/L in the samples taken after system startup. Copper concentrations at DS1 were much higher than those at DS2 and DS3 (i.e., 400 μg/L, on average, at DS1 compared to 29.5 μg/L at DS2 and 42.4 μg/L at DS3). The operator reported that DS1 had older distribution piping. Both lead and copper concentrations in the distribution system appeared to have not been affected by the operation of the arsenic treatment system.

Table 4-15. Distribution Water Sampling Results

No. of Sampling Events		DS1								DS2								DS3							
	Address	95 Oak Trail								61 Shady Oak Drive								7 Kenny Court							
	Sample Type	Non-LCR								Non-LCR								LCR							
	Flushed / 1st Draw	1st Draw								1st Draw								1st Draw							
	Sampling Date	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
No.	Date	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
BL1	03/16/05[(a)]	10.0	8.2	379	27.8	<25	40.6	0.6	32.2	6.4	8.1	366	29.6	49	68.3	0.6	20.1	12.0	7.9	379	29.8	<25	34.9	0.3	32.6
BL2	04/20/05[(a)]	12.0	7.6	369	32.4	<25	32.7	0.8	18.4	Homeowner Not Available								11.8	7.7	368	30.9	<25	19.7	0.1	81.7
BL3	05/18/05	8.6	7.4	379	92.8	815	60.5	0.5	435	8.6	7.7	379	33.0	26	38.3	0.6	59.1	8.0	7.5	357	50.3	268	34.7	0.7	36.5
BL4	06/14/05[(b)]	11.0	7.7	361	32.4	<25	36.9	0.4	862	7.0	7.7	365	29.6	25	50.9	1.3	28.6	12.0	7.8	356	31.2	<25	42.2	0.8	74.0
1	05/17/06[(c)]	11.0	7.9	363	16.5	<25	17.4	7.9	187	NA	8.0	363	3.0	<25	1.1	0.5	29.4	NA	7.9	347	3.9	<25	1.4	0.2	25.9
2	06/07/06	10.0	7.8	363	1.9	<25	0.3	0.1	624	6.9	7.9	355	2.4	<25	1.3	0.1	36.8	8.5	7.8	359	2.8	<25	3.8	0.5	23.3
3	07/19/06[(d)]	9.0	7.8	353	1.8	<25	0.4	0.3	465	8.0	7.9	361	2.0	<25	2.5	0.6	27.3	8.0	7.8	357	2.1	<25	1.5	0.4	32.4
4	08/15/06	10.3	7.7	358	1.4	<25	0.5	0.4	496	6.0	7.9	350	1.6	<25	1.2	0.4	51.3	8.0	7.8	358	2.0	<25	1.7	0.5	41.3
5	09/13/06	9.8	8.0	379	1.2	<25	0.3	0.6	383	7.0	7.9	388	1.3	<25	3.0	0.2	18.5	8.0	7.9	398	1.4	<25	0.2	0.3	18.7
6	10/10/06	9.3	7.9	385	1.6	<25	0.7	0.6	520	8.2	7.9	387	2.0	<25	1.7	0.6	14.9	10.0	7.8	382	2.0	<25	0.4	0.5	44.6
7	11/21/06	9.0	7.8	387	1.6	<25	0.3	0.5	500	5.5	7.7	391	1.7	<25	1.2	1.7	24.3	7.8	7.7	396	2.3	<25	0.6	0.8	104
8	12/13/06	9.0	7.8	368	1.8	<25	0.5	<0.1	369	8.0	7.8	368	1.7	<25	1.3	2.0	23.0	>6.0	7.8	368	1.8	<25	1.1	<0.1	61.2
9	01/10/07	9.0	8.0	402	1.4	<25	0.1	0.3	280	6.3	8.0	396	1.4	<25	0.3	0.1	16.0	11.0	8.0	410	1.5	<25	0.5	1.0	37.5
10	02/07/07[(e)]	10.0	8.1	376	2.4	<25	0.7	0.6	366	6.5	8.1	386	2.3	<25	0.7	0.8	49.8	7.8	8.0	386	2.7	<25	1.2	0.3	28.3
11	03/07/07	9.0	8.1	378	3.0	<25	<0.1	0.6	292	7.3	8.1	373	2.5	<25	0.2	0.6	39.7	7.8	8.0	373	2.6	<25	0.1	0.9	47.0
12	04/04/07	NA	8.0	366	3.6	<25	0.6	0.7	320	NA	8.1	368	3.6	<25	0.6	1.3	23.1	NA	8.0	371	3.3	<25	0.5	1.4	44.1
Average		9.6	7.9	373	3.2	<25	2.0	1.1	400	7.0	7.9	374	2.1	<25	1.3	0.7	29.5	8.5	7.9	375	2.4	<25	1.1	0.6	42.4

NS = not sampled; NA = not analyzed; BL = Baseline Sampling
(a) DS1 and DS2 sampled at different locations as discussed in Section 3.3.5.
(b) DS1 sampled on 06/13/05.
(c) DS3 sampled on 05/18/06.
(d) DS2 sampled on 07/25/06.
(e) DS2 Sampled on 02/08/07.

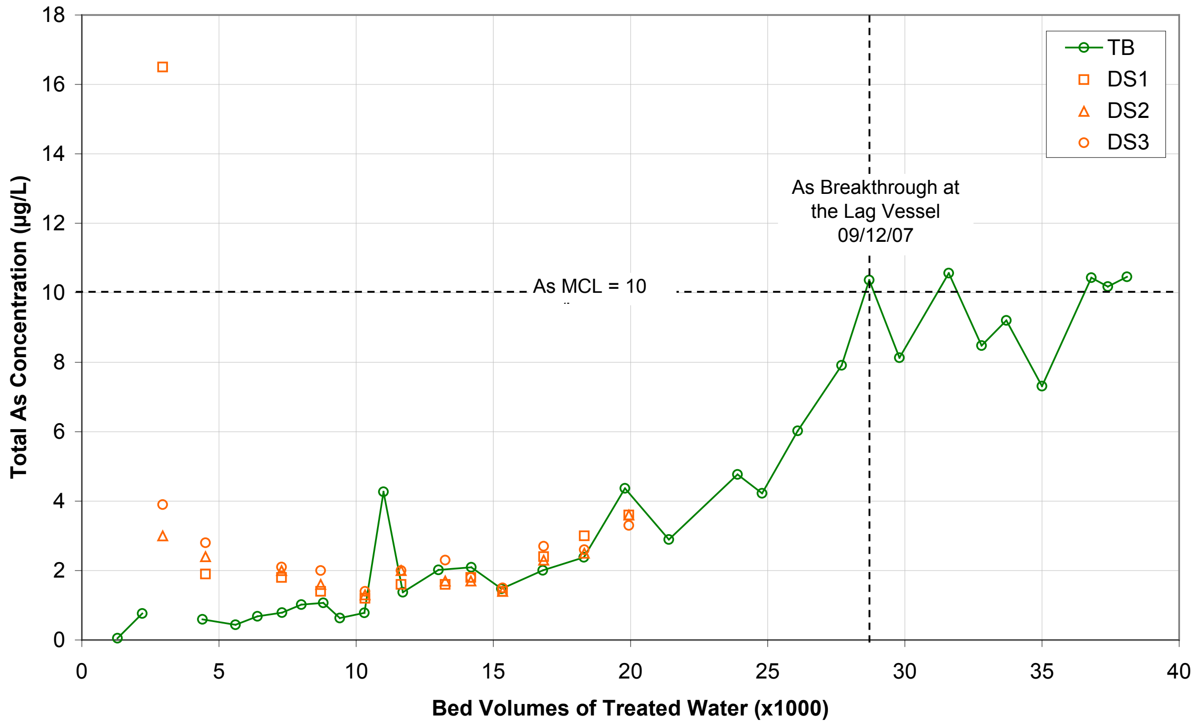


Figure 4-18. Comparsion of Total Arsenic Concentrations in Distribution System Water and Treatment System Effluent (BV based on 124 ft^3 of media)

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 task required tracking capital cost for the equipment, site engineering, and installation and the O&M cost for media replacement and disposal, replacement parts, chemical supply, electricity consumption, and labor.

4.6.1 Capital Cost. The capital investment for equipment, site engineering, and installation of the treatment system was $179,750 (see Table 4-16). The equipment cost was $124,103 (or 69% of the total capital investment), which included $86,642 for the skid-mounted APU-30S unit, $18,858 for the SORB 33™ media ($152/$ft^3$ or $4.35/lb to fill two vessels), $8,393 for shipping, and $10,211 for labor.

The engineering cost included the cost for preparing a submittal package for the exception request to system piloting and a follow-up permit application to TCEQ by Oak Manor MUD. The permit submittal package was prepared by SCL Engineering, the District's Engineer (see Section 4.3.1). The engineering cost was $14,000, or 8% of the total capital investment.

The installation cost included the equipment and labor to unload and install the skid-mounted unit, perform piping tie-ins and electrical work, load and backwash the media, perform system shakedown and startup, and conduct operator training. The installation cost was $41,647, or 23% of the total capital investment.

The total capital cost of $179,750 was normalized to the system's rated capacity of 150 gpm (216,000 gpd), which resulted in $1,198/gpm (or $0.83/gpd) of design capacity. The capital cost also was converted to an annualized cost of $16,967/yr using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-year return period (Chen et al., 2004). Assuming that the system operated 24 hours a day, 7 days a week, at the system design flowrate of 150 gpm to produce 78,624,000 gal of water per year, the unit capital cost would be $0.22/1,000 gal. Because the system operated an average of 6.7 hr/day at 129 gpm (see Table 4-6), producing 18,928,170 gal of water per year, the unit capital cost increased to $0.90/1,000 gal at this reduced rate of use.

Table 4-16. Capital Investment for Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment			
APU-30S Skid Mounted System	1	$86,642	–
SORB 33™ Media	124 ft^3	$18,858	–
Shipping	–	$8,393	–
Vendor Labor	–	$10,211	–
Equipment Total	–	**$124,103**	**69%**
Engineering			
Subcontractor Labor/Travel	–	$14,000	–
Engineering Total	–	**$14,000**	**8%**
Installation			
Subcontractor Labor	–	$28,750	–
Vendor Labor	–	$4,913	–
Vendor Travel	–	$7,984	–
Installation Total	–	**$41,647**	**23%**
Total Capital Investment	–	**$179,750**	**100%**

4.6.2 Operation and Maintenance Cost. The O&M cost included the cost for such items as media replacement and disposal, electricity, chemical, and labor (Table 4-17). The media replacement and disposal cost was $12,680, including cost for the replacement media for the lead vessel, freight, labor, equipment, and media disposal. This cost was used to calculate the media replacement cost per 1,000 gal of water treated as a function of total throughput at10-µg/L arsenic breakthrough from the lag vessel.

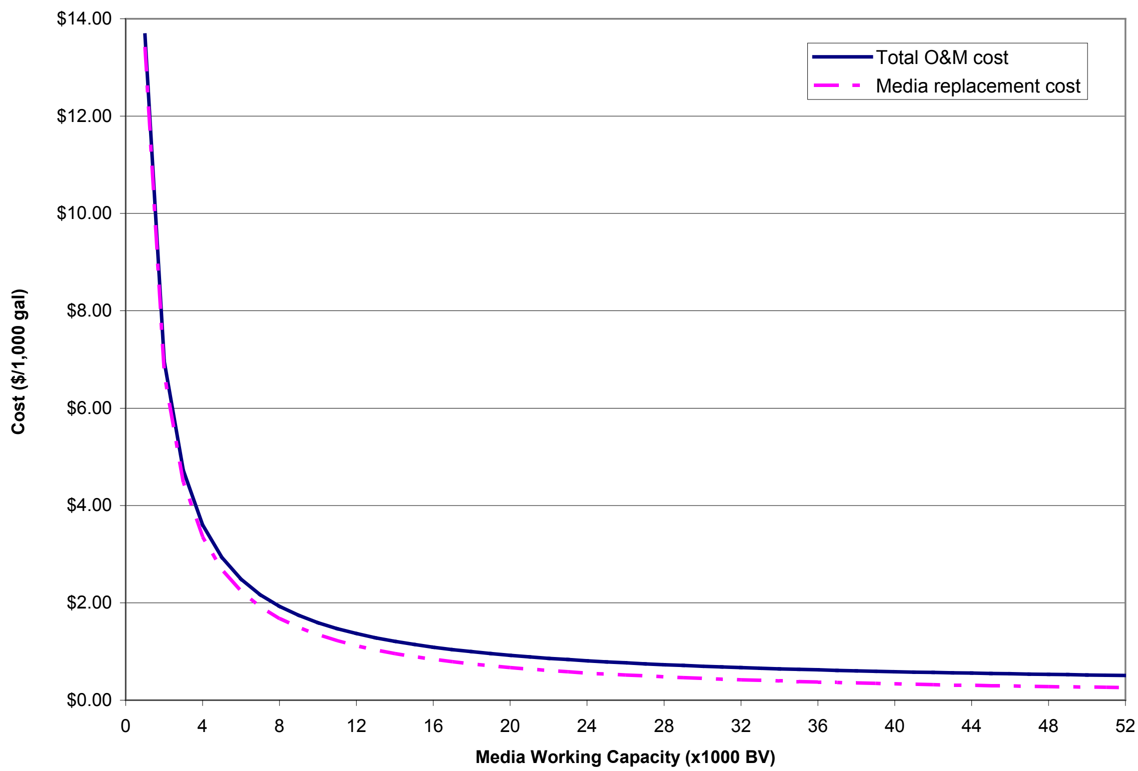
Comparison of electrical bills supplied by the utility prior to system installation and since startup did not indicate a noticeable increase in power consumption. Therefore, electrical cost associated with operation of the system was assumed to be negligible.

The chemical cost associated with the operation of the treatment system included chlorine addition prior to the adsorption vessels. This treatment step was in use at the site prior to installation of the treatment system. The treatment system did not have a significant effect on the chlorine gas usage based on the data collected during the performance evaluation study. Therefore, the incremental chemical cost for the treatment system was negligible.

Under normal operating conditions, routine labor activities to operate and maintain the system consumed an average of 40.0 min/day. Therefore, the estimated labor cost was $0.25/1,000 gal of water treated based on this time commitment and a labor rate of $19.50/hr.

Table 4-17. O&M Cost for APU-30S System

Cost Category	Value	Remarks
Media Replacement and Disposal		
Media Replacement ($)	$7,940	48 ft^3 (in lead vessel)
Shipping ($)	$240	–
Subcontractor Labor ($)	$1,000	–
Media Disposal ($)	$1,500	–
Equipment	$2,000	–
Subtotal	$12,680	–
Media Replacement and Disposal ($/1,000 gal)	See Figure 4-19	Based upon media run length at 10 µg/L arsenic breakthrough at lag vessel
Chemical Usage		
Chemical Cost ($)	$0.00	No additional chemicals required
Electricity		
Electricity ($/1,000 gal)	$0.00	Electrical costs assumed negligible
Labor Cost		
Average Weekly Labor (hr/year)	243	40 min/day
Labor ($/1,000 gal)	$0.25	- Labor rate of $19.50/hr - Annual throughput of 18,928,170 gal
Total O&M Cost/1,000 gal	See Figure 4-19	–



Note: One bed volume equals to 124 ft^3 (or 927 gal) for both Vessels A and B

Figure 4-19. Media Replacement and O&M Cost for APU-30S System

5.0 REFERENCES

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APPENDIX A

OPERATIONAL DATA

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

Week	Date	Op Time	Well 1 Totalizer	Well 1 Average Flow	Well 2 Totalizer	Well 2 Average Flow	Vessel A Instant Flowrate	Vessel A Totalizer	Vessel A Calculated Flowrate	Cum total Throughput	Cum total Bed Volume	Vessel A ΔP	Vessel B ΔP	System ΔP	Effluent Totalizer	Effluent Calculated Flowrate
		hr	kgal	gpm	kgal	gpm	gpm	gal	gpm	gal	BV	psi	psi	psig	gal	gpm
1	04/25/06[a,c]	NA	1,244	47	NM	NA	off	1,223,042	NA	1,199,097	1,294	2.50	2.50	13.0	NM	NA
	04/26/06[b]	8.5	1,268	47	NM	NA	NM	NM	NA	1,262,847	1,362	3.50	3.50	14.0	NM	NA
	04/27/06	6.5	1,283	38	NM	NA	NM	NM	NA	1,311,597	1,415	3.00	3.00	14.0	NM	NA
	04/28/06	8.4	1,309	52	NM	NA	off	NM	NA	1,374,597	1,483	off	off	NA	NM	NA
	04/29/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	04/30/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
2	05/01/06	21.7	1,369	46	NM	NA	NM	NM	NA	1,537,346	1,658	3.50	3.25	13.0	NM	NA
	05/02/06	4.5	1,381	44	NM	NA	NM	NM	NA	1,571,096	1,695	3.50	3.00	14.0	NM	NA
	05/03/06	8.6	1,405	47	NM	NA	NM	NM	NA	1,635,596	1,764	3.50	3.00	13.0	NM	NA
	05/04/06	7.4	1,425	45	NM	NA	off	NM	NA	1,691,096	1,824	off	off	NA	NM	NA
	05/05/06	11.2	1,455	45	NM	NA	NM	NM	NA	1,775,097	1,915	3.75	3.25	15.0	NM	NA
	05/06/06	5.9	1,469	NA	NM	NA	NM	NM	NA	1,819,347	1,963	3.75	3.25	15.0	NM	NA
	05/07/06	6.9	1,491	NA	NM	NA	NM	NM	NA	1,871,097	2,018	4.00	3.25	14.0	NM	NA
3	05/08/06	9.8	1,518	46	NM	NA	NM	NM	NA	1,944,597	2,098	4.25	3.25	15.0	NM	NA
	05/09/06	7.7	1,539	45	NM	NA	off	NM	NA	2,002,347	2,160	off	off	NA	NM	NA
	05/10/06	7.5	1,559	44	NM	NA	NM	NM	NA	2,058,597	2,221	4.50	3.00	13.0	NM	NA
	05/11/06	10.0	1,587	47	NM	NA	NM	NM	NA	2,133,597	2,302	4.25	2.75	13.0	NM	NA
	05/12/06	9.3	1,612	45	NM	NA	NM	NM	NA	2,203,347	2,377	5.00	2.75	15.0	NM	NA
	05/13/06	8.4	1,639	NA	NM	NA	off	NM	NA	2,266,347	2,445	off	off	NA	NM	NA
	05/14/06	10.8	1,678	NA	NM	NA	NM	NM	NA	2,347,347	2,532	6.00	2.25	17.0	NM	NA
4	05/15/06	28.4	1,740	36	NM	NA	NM	NM	NA	2,560,347	2,762	8.50	3.00	16.0	NM	NA
	05/16/06	14.8	1,779	44	NM	NA	NM	NM	NA	2,671,347	2,882	8.50	3.00	18.0	NM	NA
	05/17/06	9.2	1,803	43	NM	NA	NM	NM	NA	2,734,847	2,950	3.50	2.50	14.0	NM	NA
	05/18/06	10.0	1,830	45	NM	NA	NM	NM	NA	2,809,847	3,031	3.75	2.50	13.0	NM	NA
	05/19/06	7.0	1,850	48	NM	NA	NM	NM	NA	2,862,347	3,088	3.75	3.00	14.0	NM	NA
	05/20/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	05/21/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
5	05/22/06	31.1	1,935	46	858	NA	off	NM	NA	3,095,597	3,339	off	off	NA	NM	NA
	05/23/06	10.6	1,964	46	911	83	NM	NM	NA	3,177,597	3,428	4.00	2.75	14.0	NM	NA
	05/24/06	8.2	1,986	45	951	81	NM	NM	NA	3,239,597	3,495	4.00	3.00	15.0	NM	NA
	05/25/06	12.6	2,022	48	1,014	83	off	NM	NA	3,338,597	3,602	off	off	NA	NM	NA
	05/26/06	7.7	2,042	43	1,052	82	NM	NM	NA	3,396,597	3,664	4.00	3.00	14.0	NM	NA
	05/27/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	05/28/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
6	05/29/06	34.2	2,137	46	1,222	83	138	1,931,776	129	3,661,597	3,950	4.75	3.00	16.0	NM	NA
	05/30/06	10.7	2,165	44	1,274	81	139	2,015,209	130	3,745,030	4,040	5.00	3.50	15.0	NM	NA
	05/31/06	6.8	2,182	42	1,292	44	147	2,063,789	119	3,793,610	4,092	3.75	3.50	16.0	NM	NA
	06/01/06	5.1	2,198	52	1,318	85	NM	2,107,017	141	3,836,838	4,139	4.00	3.50	16.0	NM	NA
	06/02/06	7.5	2,218	44	1,358	89	139	2,150,150	96	3,879,971	4,186	3.50	3.00	13.0	NM	NA
	06/03/06	6.1	2,233	41	1,389	85	141	2,200,785	138	3,930,606	4,240	3.75	3.00	14.0	NM	NA
	06/04/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
7	06/05/06	13.8	2,273	48	1,461	87	NM	2,310,687	133	4,040,508	4,359	4.00	3.25	16.0	NM	NA
	06/06/06[b]	8.5	2,297	47	1,505	86	NM	NM	133	4,108,508	4,432	4.25	3.50	16.0	NM	NA
	06/07/06	8.9	2,322	47	1,550	84	141	2,386,445	131	4,178,508	4,508	4.50	3.00	16.0	NM	NA
	06/08/06	9.7	2,348	45	1,599	84	off	2,464,677	134	4,256,740	4,592	off	off	NA	NM	NA
	06/09/06	7.0	2,367	45	1,637	90	147	2,523,294	140	4,315,357	4,655	4.50	3.25	16.0	NM	NA
	06/10/06	9.7	2,390	40	1,684	81	141	2,603,680	138	4,395,743	4,742	5.00	3.00	16.0	NM	NA
	06/11/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
8	06/12/06[d]	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/13/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/14/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/15/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/16/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/17/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/18/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
9	06/19/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/20/06	85.3	2,626	46	2,081	78	147	3,304,162	137	5,096,225	5,498	4.25	3.50	16.0	NM	NA
	06/21/06	6.8	2,646	49	2,121	98	139	3,368,383	157	5,160,446	5,567	4.25	3.25	15.0	NM	NA
	06/22/06	5.9	2,659	37	2,148	76	141	3,411,585	122	5,203,648	5,613	4.50	3.25	16.0	NM	NA
	06/23/06	7.2	2,681	51	2,188	93	off	3,472,230	140	5,264,293	5,679	off	off	NA	NM	NA
	06/24/06	5.4	2,696	46	2,214	80	137	3,517,645	140	5,309,708	5,728	4.25	3.25	NA	NM	NA
	06/25/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA

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

Week	Date	Op Time	Well 1 Totalizer	Well 1 Average Flow	Well 2 Totalizer	Well 2 Average Flow	Vessel A Instant Flowrate	Vessel A Totalizer	Vessel A Calculated Flowrate	Cum total Throughput	Cum total Bed Volume	Vessel A ΔP	Vessel B ΔP	System ΔP	Effluent Totalizer	Effluent Calculated Flowrate
		hr	kgal	gpm	kgal	gpm	gpm	gal	gpm	gal	BV	psi	psi	psig	gal	gpm
10	06/26/06	15.0	2,737	46	2,291	86	144	3,644,307	141	5,436,370	5,864	5.50	3.00	15.0	NM	NA
	06/27/06	8.6	2,761	47	2,335	85	off	3,713,347	134	5,505,410	5,939	off	off	NA	NM	NA
	06/28/06	10.3	2,789	45	2,387	84	140	3,798,059	137	5,590,122	6,030	5.75	3.25	17.0	NM	NA
	06/29/06	7.9	2,810	44	2,427	84	137	3,861,720	134	5,653,783	6,099	7.00	3.00	18.0	NM	NA
	06/30/06	8.9	2,834	45	2,471	82	off	3,932,777	133	5,724,840	6,176	off	off	NA	NM	NA
	07/01/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	07/02/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
11	07/03/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	07/04/06	26.1	2,900	42	2,598	81	134	4,112,690	115	5,904,753	6,370	5.50	3.50	18.0	NM	NA
	07/05/06	8.7	2,923	44	2,643	86	136	4,184,622	138	5,976,685	6,447	5.75	3.25	18.0	NM	NA
	07/06/06	6.6	2,942	48	2,676	83	140	4,238,853	137	6,030,916	6,506	6.50	3.25	16.0	NM	NA
	07/07/06	5.6	2,957	45	2,705	86	139	4,284,523	136	6,076,586	6,555	6.50	3.50	17.0	NM	NA
	07/08/06	7.5	2,975	40	2,741	80	139	4,341,954	128	6,134,017	6,617	7.50	3.00	18.0	NM	NA
	07/09/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
12	07/10/06	14.4	3,016	47	2,817	88	133	4,463,729	141	6,255,792	6,748	8.00	3.75	17.0	NM	NA
	07/11/06	4.4	3,028	45	2,839	83	144	4,498,496	132	6,290,559	6,786	8.50	3.00	18.0	429,000	NA
	07/12/06	7.3	3,046	41	2,876	84	137	4,532,646	78	6,324,709	6,823	9.00	3.00	19.0	489,000	137
	07/13/06	8.2	3,069	47	2,918	85	138	4,599,386	136	6,391,449	6,895	9.50	3.00	19.0	557,000	138
	07/14/06	7.1	3,088	45	2,956	89	131	4,652,797	125	6,444,860	6,952	9.00	3.00	18.0	617,000	141
	07/15/06	6.9	3,107	46	2,989	80	138	4,708,628	122	6,495,191	7,007	3.25	2.75	16.0	663,000	111
	07/16/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
13	07/17/06	16.7	3,153	46	3,075	86	138	4,842,012	133	6,628,575	7,151	4.00	3.00	16.0	811,000	148
	07/18/06	8.7	3,177	46	3,122	90	off	4,913,506	137	6,700,069	7,228	off	off	NA	878,000	128
	07/19/06	6.0	3,191	39	3,154	89	141	4,961,891	134	6,748,454	7,280	4.50	3.00	18.0	929,000	142
	07/20/06	6.2	3,209	48	3,183	78	off	5,007,671	123	6,794,234	7,329	off	off	NA	977,000	129
	07/21/06	4.0	3,221	50	3,207	100	134	5,044,209	152	6,830,772	7,369	5.50	3.50	18.0	1,016,000	163
	07/22/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	07/23/06	13.5	3,258	46	3,277	86	off	5,152,592	134	6,939,155	7,486	off	off	NA	1,129,000	140
14	07/24/06	5.7	3,273	44	3,306	85	135	5,197,865	132	6,984,428	7,534	7.50	3.50	16.0	1,177,000	140
	07/25/06	6.2	3,290	46	3,339	89	off	5,247,778	134	7,034,341	7,588	off	off	NA	1,229,000	140
	07/26/06	5.7	3,305	44	3,368	85	137	5,293,620	134	7,080,183	7,638	8.00	3.00	19.0	1,277,000	140
	07/27/06	4.2	3,316	44	3,390	87	136	5,326,234	129	7,112,797	7,673	8.00	3.00	20.0	1,312,000	139
	07/28/06	6.5	3,335	49	3,425	90	127	5,379,462	136	7,166,025	7,730	8.00	3.00	18.0	1,369,000	146
	07/29/06	5.6	3,349	42	3,456	92	132	5,423,999	133	7,210,562	7,778	8.50	3.00	18.0	1,419,000	149
	07/30/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
15	07/31/06	14.3	3,387	44	3,525	80	130	5,527,735	121	7,314,298	7,890	8.00	3.00	17.0	1,530,000	129
	08/01/06	8.3	3,410	46	3,568	86	132	5,587,260	120	7,373,823	7,955	8.50	3.25	19.0	1,599,000	139
	08/02/06	6.7	3,428	45	3,603	87	off	5,635,693	120	7,422,256	8,007	off	off	NA	1,656,000	142
	08/03/06	6.1	3,444	44	3,635	87	141	5,679,966	121	7,466,529	8,055	8.50	3.50	20.0	1,707,000	139
	08/04/06	8.2	3,467	47	3,677	85	off	5,739,258	121	7,525,821	8,118	off	off	NA	1,776,000	140
	08/05/06	3.4	3,476	44	3,694	83	122	5,763,379	118	7,549,942	8,144	8.00	3.50	18.0	1,804,000	137
	08/06/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
16	08/07/06	14.6	3,515	45	3,770	87	off	5,869,392	121	7,655,955	8,259	off	off	NA	1,926,000	139
	08/08/06	6.1	3,531	44	3,801	85	131	5,913,936	122	7,700,499	8,307	8.75	3.75	17.0	1,977,000	139
	08/09/06	5.7	3,546	44	3,831	88	133	5,955,885	123	7,742,448	8,352	8.75	3.75	18.0	2,025,000	140
	08/10/06	10.0	3,574	47	3,883	87	off	6,028,701	103	7,804,454	8,419	off	off	NA	2,100,000	125
	08/11/06	5.3	3,588	44	3,912	91	129	6,068,951	127	7,844,704	8,462	3.75	3.00	15.0	2,146,000	145
	08/12/06	5.4	3,602	43	3,941	90	126	6,109,366	125	7,885,119	8,506	4.00	3.00	16.0	2,192,000	142
	08/13/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
17	08/14/06	17.8	3,652	47	4,034	87	126	6,241,936	124	8,017,689	8,649	5.00	3.25	15.0	2,343,000	141
	08/15/06	7.4	3,672	45	4,073	88	off	6,297,782	126	8,073,535	8,709	off	off	NA	2,406,000	142
	08/16/06	7.3	3,690	41	4,109	82	125	6,350,079	119	8,125,832	8,766	5.50	3.00	16.0	2,464,000	132
	08/17/06	6.9	3,710	48	4,147	92	129	6,404,035	130	8,179,788	8,824	5.75	3.25	17.0	2,522,000	140
	08/18/06	10.1	3,738	46	4,199	86	off	6,479,813	125	8,255,566	8,906	off	off	NA	2,610,000	145
	08/19/06	6.3	3,756	48	4,236	98	130	6,531,033	121	8,301,286	8,955	5.75	3.24	16.0	2,672,000	164
	08/20/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
18	08/21/06[(c)]	15.3	3,795	42	4,312	83	off	6,640,748	120	8,411,001	9,073	off	off	NA	NM	NA
	08/22/06	6.1	3,812	46	4,344	87	126	6,686,472	125	8,456,725	9,123	6.00	3.00	17.0	NM	NA
	08/23/06	7.9	3,834	46	4,385	86	off	6,743,842	121	8,514,095	9,185	off	off	NA	NM	NA
	08/24/06	4.7	3,846	43	4,410	89	128	6,778,677	124	8,548,930	9,222	6.25	3.00	17.0	NM	NA
	08/25/06	6.5	3,864	46	4,444	87	122	6,826,067	122	8,596,320	9,273	6.50	3.00	16.0	NM	NA
	08/26/06	5.8	3,879	43	4,475	89	126	6,868,299	106	8,633,052	9,313	6.25	3.00	NA	NM	NA
	08/27/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA

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

Week	Date	Op Time	Well 1 Totalizer	Well 1 Average Flow	Well 2 Totalizer	Well 2 Average Flow	Vessel A Instant Flowrate	Vessel A Totalizer	Vessel A Calculated Flowrate	Cum total Throughput	Cum total Bed Volume	Vessel A ΔP	Vessel B ΔP	System ΔP	Effluent Totalizer	Effluent Calculated Flowrate
		hr	kgal	gpm	kgal	gpm	gpm	gal	gpm	gal	BV	psi	psi	psig	gal	gpm
19	08/28/06	9.5	3,905	46	4,525	88	124	6,938,879	124	8,703,632	9,389	6.50	3.25	16.0	NM	NA
	08/29/06	4.9	3,918	44	4,551	88	133	6,972,660	115	8,737,413	9,425	6.75	3.25	16.0	NM	NA
	08/30/06	7.9	3,940	46	4,593	89	off	7,030,197	121	8,794,950	9,488	off	off	NA	NM	NA
	08/31/06	5.3	3,954	44	4,620	85	117	7,068,971	122	8,833,724	9,529	7.00	3.00	17.0	NM	NA
	09/01/06	6.9	3,972	43	4,657	89	128	7,119,467	122	8,884,220	9,584	7.25	3.00	18.0	NM	NA
	09/02/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	09/03/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
20	09/04/06[(d)]	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	09/05/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	09/06/06[(b)]	40.1	4,080	45	4,863	86	NM	NM	NA	9,198,220	9,923	7.75	3.00	16.0	NM	NA
	09/07/06	11.1	4,109	44	4,919	84	off	NM	NA	9,283,220	10,014	off	off	NA	NM	NA
	09/08/06	7.6	4,129	44	4,957	83	NM	NM	NA	9,341,220	10,077	8.00	3.25	18.0	NM	NA
	09/09/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	09/10/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
21	09/11/06	19.2	4,180	44	5,057	87	off	NM	NA	9,492,220	10,240	off	off	NA	NM	NA
	09/12/06	4.5	4,192	44	5,080	85	NM	NM	NA	9,527,220	10,277	9.50	3.00	20.0	NM	NA
	09/13/06	5.0	4,206	47	5,106	87	NM	NM	NA	9,567,220	10,321	9.50	3.25	21.0	NM	NA
	09/14/06	7.4	4,225	43	5,145	88	off	NM	NA	9,625,220	10,383	off	off	NA	NM	NA
	09/15/06	4.0	4,236	46	5,167	92	NM	NM	NA	9,658,220	10,419	9.75	3.00	20.0	NM	NA
	09/16/06	7.1	4,253	40	5,202	82	NM	NM	NA	9,710,220	10,475	9.75	3.00	21.0	NM	NA
	09/17/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
22	09/18/06	10.6	4,282	46	5,256	85	NM	NM	NA	9,793,220	10,564	9.75	3.00	21.0	3,074,000	NA
	09/19/06	4.7	4,295	46	5,281	89	NM	NM	NA	9,831,220	10,605	10.00	3.75	21.0	3,109,000	124
	09/20/06	7.3	4,315	46	5,321	91	NM	NM	NA	9,891,220	10,670	3.25	3.25	15.0	3,166,000	130
	09/21/06	4.5	4,328	48	5,345	89	NM	NM	NA	9,928,220	10,710	4.00	3.50	17.0	3,205,000	144
	09/22/06	5.7	4,343	44	5,376	91	NM	NM	NA	9,974,220	10,760	4.00	3.25	17.0	3,252,000	137
	09/23/06	7.0	4,362	45	5,415	93	NM	NM	NA	10,032,220	10,822	4.25	3.00	17.0	3,308,000	133
	09/24/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
23	09/25/06	12.3	4,398	49	5,480	88	off	NM	NA	10,133,220	10,931	off	off	NA	3,418,000	149
	09/26/06	4.0	4,408	42	5,503	96	NM	NM	NA	10,166,220	10,967	4.50	3.00	16.0	3,454,000	150
	09/27/06	3.7	4,419	50	5,522	86	NM	NM	NA	10,196,220	10,999	5.00	3.50	18.0	3,483,000	131
	09/28/06	6.7	4,437	45	5,559	92	NM	NM	NA	10,251,220	11,058	5.00	4.00	18.0	3,539,000	139
	09/29/06	2.7	4,444	43	5,573	86	off	NM	NA	10,272,220	11,081	off	off	NA	3,562,000	142
	09/30/06	NA	NM	NA	NM	NA	off	NM	NA	NA	NA	off	off	NA	NM	NA
	10/01/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
24	10/02/06	18.0	4,497	49	5,678	97	off	NM	NA	10,430,220	11,252	off	off	NA	3,724,000	150
	10/03/06	5.2	4,511	45	5,708	96	NM	NM	NA	10,474,220	11,299	4.75	3.25	16.0	3,770,000	147
	10/04/06	3.0	4,520	50	5,725	94	off	7,793,016	NA	10,500,220	11,327	off	off	NA	3,796,000	144
	10/05/06	5.2	4,534	45	5,753	90	142	7,834,501	133	10,541,705	11,372	5.00	3.50	16.0	3,840,000	141
	10/06/06	6.1	4,550	44	5,785	87	138	7,880,991	127	10,588,195	11,422	5.50	3.50	16.0	3,891,000	139
	10/07/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	10/08/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
25	10/09/06	20.6	4,606	45	5,895	89	off	8,039,652	128	10,746,856	11,593	off	off	NA	4,064,000	140
	10/10/06	4.8	4,619	45	5,922	94	133	8,077,869	133	10,785,073	11,634	6.25	3.75	16.0	4,105,000	142
	10/11/06	4.4	4,631	45	5,946	91	131	8,113,039	133	10,820,243	11,672	6.25	3.00	16.0	4,142,000	140
	10/12/06	5.7	4,646	44	5,976	88	133	8,156,598	127	10,863,802	11,719	7.00	3.00	15.0	4,189,000	137
	10/13/06	3.1	4,655	48	5,993	91	off	8,180,153	127	10,887,357	11,745	off	off	NA	4,215,000	140
	10/14/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	10/15/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
26	10/16/06	17.0	4,700	44	6,084	89	121	8,309,040	126	11,016,244	11,884	6.25	2.75	17.0	4,362,000	144
	10/17/06	3.1	4,708	43	6,101	91	off	8,332,174	124	11,039,378	11,909	off	off	NA	4,377,000	NA
	10/18/06	4.6	4,721	47	6,126	91	128	8,366,560	125	11,073,764	11,946	6.75	3.00	17.0	4,395,000	NA
	10/19/06	4.6	4,733	43	6,151	91	off	8,400,428	123	11,107,632	11,982	off	off	NA	4,428,000	120
	10/20/06	4.5	4,745	44	6,176	93	133	8,433,876	124	11,141,080	12,018	7.50	3.25	16.0	4,460,000	119
	10/21/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	10/22/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
27	10/23/06	14.9	4,784	44	6,255	88	123	8,540,793	120	11,247,997	12,134	9.00	3.75	19.0	4,573,000	126
	10/24/06	4.8	4,797	45	6,281	90	off	8,572,904	111	11,280,108	12,168	off	off	NA	4,611,000	132
	10/25/06	4.6	4,809	43	6,305	87	126	8,605,761	119	11,312,965	12,204	9.00	3.50	20.0	4,650,000	141
	10/26/06	4.5	4,821	44	6,330	93	off	8,636,099	112	11,343,303	12,237	off	off	NA	4,688,000	141
	10/27/06	4.9	4,834	44	6,355	85	118	8,669,044	112	11,376,248	12,272	9.25	3.50	20.0	4,728,000	136
	10/28/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	10/29/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA

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

Week	Date	Op Time	Well 1 Totalizer	Well 1 Average Flow	Well 2 Totalizer	Well 2 Average Flow	Vessel A Instant Flowrate	Vessel A Totalizer	Vessel A Calculated Flowrate	Cum total Throughput	Cum total Bed Volume	Vessel A ΔP	Vessel B ΔP	System ΔP	Effluent Totalizer	Effluent Calculated Flowrate
		hr	kgal	gpm	kgal	gpm	gpm	gal	gpm	gal	BV	psi	psi	psig	gal	gpm
	10/30/06	16.5	4,877	43	6,443	89	113	8,777,005	109	11,484,209	12,389	10.25	3.25	NM	4,867,000	140
	10/31/06	6.0	4,893	44	6,474	86	off	8,804,665	77	11,511,869	12,418	10.50	3.00	off	4,915,000	133
	11/01/06	5.5	4,908	45	6,505	94	123	8,831,308	68	11,534,293	12,443	3.75	3.00	NM	4,955,000	121
28	11/02/06	2.8	4,916	48	6,521	95	off	8,861,118	177	11,564,103	12,475	off	off	off	4,978,000	137
	11/03/06	5.9	4,932	45	6,554	93	131	8,906,557	128	11,609,542	12,524	4.25	3.25	NM	5,028,000	141
	11/04/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	11/05/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	11/06/06	13.8	4,969	45	6,629	91	127	9,011,500	127	11,714,485	12,637	5.50	3.75	15.0	5,146,000	143
	11/07/06	5.0	4,983	47	6,656	90	off	9,048,578	124	11,751,563	12,677	off	off	NA	5,189,000	143
	11/08/06	4.7	4,996	46	6,682	92	off	9,084,251	126	11,787,236	12,715	off	off	NA	5,229,000	142
29	11/09/06	4.5	5,008	44	6,707	93	130	9,126,133	155	11,829,118	12,761	5.50	3.25	15.0	5,269,000	148
	11/10/06	5.4	5,022	43	6,745	117	123	9,160,760	107	11,863,745	12,798	5.50	3.25	14.0	5,315,000	142
	11/11/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	11/12/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	11/13/06	14.9	5,062	45	6,818	82	130	9,274,788	128	11,977,773	12,921	6.00	3.50	16.0	5,445,000	145
	11/14/06	4.5	5,075	48	6,842	89	129	9,307,581	121	12,010,566	12,956	6.00	3.50	15.0	5,481,000	133
	11/15/06	4.8	5,087	42	6,868	90	131	9,344,528	128	12,047,513	12,996	6.50	3.50	16.0	5,522,000	142
30	11/16/06	4.9	5,099	41	6,892	82	off	9,377,930	114	12,080,915	13,032	off	off	NA	5,567,000	153
	11/17/06	4.5	5,113	52	6,919	100	off	9,414,780	136	12,117,765	13,072	off	off	NA	5,602,000	130
	11/18/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	11/19/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	11/20/06	16.8	5,157	44	7,010	90	129	9,541,056	125	12,244,041	13,208	7.25	3.75	16.0	5,747,000	144
	11/21/06	5.1	5,171	46	7,037	88	132	9,579,089	124	12,282,074	13,249	7.25	3.50	18.0	5,788,000	134
	11/22/06	5.4	5,185	43	7,065	86	134	9,617,440	118	12,320,425	13,291	7.50	3.50	17.0	5,831,000	133
31	11/23/06	8.8	5,208	44	7,112	89	off	9,683,133	124	12,386,118	13,362	off	off	NA	5,907,000	144
	11/24/06	10.0	5,236	47	7,164	87	off	9,755,880	121	12,458,865	13,440	off	off	NA	5,990,000	138
	11/25/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	11/26/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	11/27/06	17.5	5,282	44	7,257	89	off	9,879,410	118	12,582,395	13,573	off	off	NA	6,137,000	140
	11/28/06	3.3	5,290	40	7,276	96	128	9,909,334	151	12,612,319	13,606	9.75	3.50	18.0	6,169,000	162
	11/29/06	4.5	5,302	44	7,298	81	off	9,940,895	117	12,643,880	13,640	off	off	NA	6,202,000	122
32	11/30/06	4.9	5,315	44	7,324	88	127	9,980,119	133	12,683,104	13,682	10.00	3.50	19.0	6,243,000	139
	12/01/06	8.4	5,336	42	7,368	87	121	10,037,765	114	12,740,750	13,744	10.00	3.00	18.0	6,313,000	139
	12/02/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/03/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/04/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/05/06	19.6	5,388	44	7,471	88	139	10,143,913	90	12,846,898	13,859	11.00	3.50	19.0	6,475,000	138
	12/06/06	8.0	5,410	46	7,516	94	off	10,202,219	111	12,900,304	13,916	off	off	NA	6,537,000	129
33	12/07/06	2.6	5,417	45	7,530	90	129	10,221,707	125	12,919,792	13,937	4.00	3.50	14.0	6,560,000	147
	12/08/06	4.8	5,430	45	7,556	90	135	10,240,607	66	12,938,692	13,958	4.50	4.00	15.0	6,601,000	142
	12/09/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/10/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/11/06	15.6	5,473	46	7,642	92	off	10,356,802	124	13,054,887	14,083	off	off	NA	6,736,000	144
	12/12/06	5.6	5,487	42	7,673	92	129	10,399,393	127	13,097,478	14,129	5.50	3.50	15.0	6,785,000	146
	12/13/06	6.9	5,506	46	7,710	89	133	10,450,383	123	13,148,468	14,184	5.50	3.25	15.0	6,844,000	143
34	12/14/06	2.5	5,512	40	7,724	93	off	10,469,096	125	13,167,181	14,204	off	off	NA	6,865,000	140
	12/15/06	5.6	5,528	48	7,755	92	125	10,512,331	129	13,210,416	14,251	6.00	3.00	18.0	6,914,000	146
	12/16/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/17/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/18/06[(d)]	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/19/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/20/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
35	12/21/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/22/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/23/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/24/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/25/06	55.9	5,677	44	8,027	81	118	10,905,508	117	13,603,593	14,675	8.00	3.00	15.0	7,386,000	141
	12/26/06	3.7	5,687	45	8,047	90	126	10,931,651	118	13,629,736	14,703	8.25	3.50	16.0	7,421,000	158
	12/27/06	7.9	5,708	44	8,089	89	113	10,988,360	120	13,686,445	14,764	8.00	3.00	16.0	7,487,000	139
36	12/28/06	3.0	5,716	44	8,105	89	123	11,009,551	118	13,707,636	14,787	8.00	3.00	17.0	7,512,000	139
	12/29/06	5.1	5,730	46	8,132	88	off	11,045,572	118	13,743,657	14,826	off	off	NA	7,555,000	141
	12/30/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/31/06	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA

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

Week	Date	Op Time	Well 1 Totalizer	Well 1 Average Flow	Well 2 Totalizer	Well 2 Average Flow	Vessel A Instant Flowrate	Vessel A Totalizer	Vessel A Calculated Flowrate	Cum total Throughput	Cum total Bed Volume	Vessel A ΔP	Vessel B ΔP	System ΔP	Effluent Totalizer	Effluent Calculated Flowrate
		hr	kgal	gpm	kgal	gpm	gpm	gal	gpm	gal	BV	psi	psi	psig	gal	gpm
37	01/01/07	17.5	5,775	43	8,226	90	115	11,171,274	120	13,869,359	14,962	10.00	3.00	20.0	7,703,000	141
	01/02/07	4.7	5,787	43	8,250	85	116	11,203,438	114	13,901,523	14,996	10.00	3.00	20.0	7,741,000	135
	01/03/07	4.5	5,799	44	8,274	89	off	11,216,062	NA	13,937,523	15,035	off	off	NA	7,779,000	141
	01/04/07	5.3	5,813	44	8,301	85	off	11,252,654	115	13,974,115	15,075	off	off	NA	7,822,000	135
	01/05/07	5.1	5,827	46	8,329	92	off	11,288,819	118	14,010,280	15,114	off	off	NA	7,865,000	141
	01/06/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	01/07/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
38	01/08/07	17.8	5,873	43	8,423	88	122	11,412,750	116	14,134,211	15,247	11.00	3.00	18.0	8,014,000	140
	01/09/07	5.9	5,888	42	8,454	88	114	11,452,700	113	14,174,161	15,290	11.00	3.00	19.0	8,061,000	133
	01/10/07	6.6	5,905	43	8,487	83	off	11,495,550	108	14,217,011	15,337	off	off	NA	8,114,000	134
	01/11/07	2.6	5,912	45	8,502	96	117	11,513,999	118	14,235,460	15,356	7.00	3.75	17.0	8,137,000	147
	01/12/07	8.2	5,933	43	8,546	89	off	11,568,711	111	14,290,172	15,416	off	off	NA	8,205,000	138
	01/13/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	01/14/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
39	01/15/07[(b)]	18.5	5,982	44	8,614	61	NM	NM	NA	14,407,172	15,542	9.00	3.00	16.0	8,361,000	141
	01/16/07	8.1	6,003	43	8,656	86	off	NM	NA	14,470,172	15,610	off	off	NA	8,426,000	134
	01/17/07	6.5	6,020	44	8,689	85	off	NM	NA	14,520,172	15,664	off	off	NA	8,479,000	136
	01/18/07	6.5	6,037	44	8,723	87	off	NM	NA	14,571,172	15,719	off	off	NA	8,531,000	133
	01/19/07	7.4	6,055	41	8,761	86	NM	NM	NA	14,627,172	15,779	12.00	3.00	18.0	8,590,000	133
	01/20/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	01/21/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
40	01/22/07	22.1	6,111	42	8,871	83	off	NM	NA	14,793,172	15,958	off	off	NA	8,764,000	131
	01/23/07	6.5	6,127	41	8,904	85	NM	NM	NA	14,842,172	16,011	13.00	4.00	17.0	8,811,000	121
	01/24/07	6.0	6,142	42	8,934	83	NM	NM	NA	14,887,172	16,060	13.00	3.75	20.0	8,862,000	142
	01/25/07	7.4	6,161	43	8,970	81	off	NM	NA	14,942,172	16,119	off	off	NA	8,919,000	128
	01/26/07	6.9	6,178	41	9,003	80	NM	NM	NA	14,992,172	16,173	13.25	4.00	21.0	8,972,000	128
	01/27/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	01/28/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
41	01/29/07	23.3	6,234	40	9,113	79	off	NM	NA	15,158,172	16,352	off	off	NA	9,147,000	125
	01/30/07	7.6	6,252	39	9,149	79	off	NM	NA	15,212,172	16,410	off	off	NA	9,204,000	125
	01/31/07	7.6	6,271	42	9,185	79	NM	NM	NA	15,261,345	16,463	4.25	3.00	12.0	9,260,000	123
	02/01/07	3.0	6,280	50	9,200	83	NM	NM	NA	15,285,345	16,489	4.50	3.25	13.0	9,283,000	128
	02/02/07	9.8	6,307	46	9,255	94	off	NM	NA	15,367,345	16,578	off	off	NA	9,368,000	145
	02/03/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	02/04/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
42	02/05/07	17.9	6,354	44	9,350	88	off	NM	NA	15,509,345	16,731	off	off	NA	9,517,000	139
	02/06/07	6.2	6,371	46	9,383	89	NM	NM	NA	15,559,345	16,785	7.25	3.25	18.0	9,568,000	137
	02/07/07	5.9	6,385	40	9,414	88	NM	NM	NA	15,604,345	16,833	8.00	3.00	18.0	9,618,000	141
	02/08/07	5.4	6,400	46	9,443	90	NM	NM	NA	15,648,345	16,881	8.25	3.60	19.0	9,662,000	136
	02/09/07	7.1	6,419	45	9,481	89	off	NM	NA	15,705,345	16,942	off	off	NA	9,722,000	141
	02/10/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	02/11/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
43	02/12/07	18.8	6,468	43	9,580	88	off	NM	NA	15,853,345	17,102	off	off	NA	9,878,000	138
	02/13/07	5.7	6,483	44	9,611	91	off	NM	NA	15,899,345	17,151	off	off	NA	9,926,000	140
	02/14/07	5.6	6,497	42	9,640	86	off	NM	NA	15,942,345	17,198	off	off	NA	9,972,000	137
	02/15/07	5.4	6,512	46	9,669	90	off	NM	NA	15,986,345	17,245	off	off	NA	10,017,000	139
	02/16/07	6.1	6,528	44	9,703	93	NM	NM	NA	16,036,345	17,299	7.00	3.00	17.0	10,066,000	134
	02/17/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	02/18/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
44	02/19/07	17.9	6,575	44	9,797	88	NM	NM	NA	16,177,345	17,451	8.50	3.00	18.0	10,217,000	141
	02/20/07	5.0	6,588	43	9,823	87	NM	NM	NA	16,216,345	17,493	9.00	3.00	18.0	10,258,000	137
	02/21/07	4.6	6,599	40	9,842	69	NM	NM	NA	16,246,345	17,526	9.25	3.50	19.0	10,295,000	134
	02/22/07	7.5	6,619	44	9,872	67	NM	NM	NA	16,296,345	17,580	9.75	3.25	20.0	10,358,000	140
	02/23/07	3.7	6,629	45	9,891	86	NM	NM	NA	16,325,345	17,611	10.00	3.25	20.0	10,388,000	135
	02/24/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	02/25/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
45	02/26/07	20.4	6,681	42	9,997	87	off	NM	NA	16,483,345	17,781	off	off	NA	10,554,000	136
	02/27/07	6.0	6,697	44	10,028	86	off	NM	NA	16,530,345	17,832	off	off	NA	10,602,000	133
	02/28/07	6.1	6,713	44	10,060	87	off	NM	NA	16,578,345	17,884	off	off	NA	10,652,000	137
	03/01/07	5.3	6,726	41	10,087	85	NM	NM	NA	16,618,345	17,927	11.25	3.00	22.0	10,697,000	142
	03/02/07	9.0	6,749	43	10,132	83	NM	NM	NA	16,686,345	18,000	11.30	3.00	21.0	10,767,000	130
	03/03/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	03/04/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA

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

Week	Date	Op Time	Well 1 Totalizer	Well 1 Average Flow	Well 2 Totalizer	Well 2 Average Flow	Vessel A Instant Flowrate	Vessel A Totalizer	Vessel A Calculated Flowrate	Cum total Throughput	Cum total Bed Volume	Vessel A ΔP	Vessel B ΔP	System ΔP	Effluent Totalizer	Effluent Calculated Flowrate
		hr	kgal	gpm	kgal	gpm	gpm	gal	gpm	gal	BV	psi	psi	psig	gal	gpm
46	03/05/07	24.3	6,811	43	10,255	84	NM	NM	NA	16,871,345	18,200	12.25	3.00	23.0	10,960,000	132
	03/06/07	8.7	6,832	40	10,297	80	NM	NM	NA	16,934,345	18,268	12.50	3.00	23.0	11,028,000	130
	03/07/07	6.2	6,855	62	10,319	59	NM	NM	NA	16,979,345	18,316	13.00	3.00	22.0	11,077,000	132
	03/08/07	6.5	6,864	23	10,361	108	off	NM	NA	17,030,345	18,371	off	off	NA	11,128,000	131
	03/09/07	5.1	6,878	46	10,387	85	NM	NM	NA	17,070,345	18,415	14.50	3.00	24.0	11,168,000	131
	03/10/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	03/11/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
47	03/12/07	23.2	6,939	44	10,500	81	NM	NM	NA	17,244,345	18,602	off	off	NA	11,347,000	129
	03/13/07	6.3	6,954	40	10,531	82	off	NM	NA	17,290,345	18,652	off	off	NA	11,395,000	127
	03/14/07	5.0	6,964	33	10,559	93	NM	NM	NA	17,322,545	18,687	4.00	3.25	14.0	11,432,000	123
	03/15/07	6.2	6,980	43	10,593	91	NM	NM	NA	17,372,545	18,741	5.00	3.25	14.0	11,479,000	126
	03/16/07	5.3	6,994	44	10,622	91	NM	NM	NA	17,415,545	18,787	5.50	3.25	14.0	11,523,000	138
	03/17/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	03/18/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
48	03/19/07	20.6	7,049	44	10,731	88	off	NM	NA	17,579,545	18,964	off	off	NA	11,690,000	135
	03/20/07	6.3	7,070	56	10,765	90	off	NM	NA	17,634,545	19,023	off	off	NA	11,742,000	138
	03/21/07	6.0	7,081	31	10,796	86	NM	NM	NA	17,676,545	19,069	6.75	3.25	16.0	11,790,000	133
	03/22/07	6.0	7,096	42	10,829	92	151	12,208,714	NA	17,724,545	19,120	7.00	3.00	17.0	11,839,000	136
	03/23/07	6.5	7,114	46	10,864	90	133	12,261,234	135	17,777,065	19,177	6.50	3.00	18.0	11,894,000	141
	03/24/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	03/25/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
49	03/26/07	21.0	7,169	44	10,976	89	136	12,431,523	135	17,947,354	19,361	8.00	3.00	17.0	12,067,000	137
	03/27/07	6.4	7,186	44	11,010	89	off	12,482,936	134	17,998,767	19,416	off	off	NA	12,119,000	135
	03/28/07	6.6	7,202	40	11,044	86	off	12,535,977	134	18,051,808	19,473	off	off	NA	12,172,000	134
	03/29/07	6.2	7,219	46	11,077	89	off	12,573,640	101	18,089,471	19,514	off	off	NA	12,222,000	134
	03/30/07	5.5	7,233	42	11,108	94	147	12,607,263	102	18,123,094	19,550	9.25	3.25	19.0	12,266,000	133
	03/31/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	04/01/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
50	04/02/07[b]	20.1	7,285	43	11,213	87	off	NM	NA	18,280,094	19,720	off	off	NA	12,427,000	133
	04/03/07	6.0	7,301	44	11,244	86	off	12,607,264	NA	18,327,094	19,770	off	off	NA	12,473,000	128
	04/04/07	7.1	7,318	40	11,281	87	127	12,665,447	137	18,385,277	19,833	10.00	3.25	19.0	12,530,000	134
	04/05/07	6.4	7,336	47	11,315	89	off	12,717,676	136	18,437,506	19,889	off	off	NA	12,580,000	130
	04/06/07	6.1	7,351	41	11,346	85	133	12,766,714	134	18,486,544	19,942	10.50	3.25	20.0	12,627,000	128
	04/07/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	04/08/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
51	04/09/07	22.3	7,409	43	11,463	87	off	12,945,850	134	18,665,680	20,136	off	off	NA	12,797,000	127
	04/10/07	6.4	7,425	42	11,494	81	138	12,995,265	129	18,715,095	20,189	11.00	3.25	21.0	12,844,000	122
	04/11/07	8.1	7,446	43	11,539	93	136	13,057,666	117	18,771,996	20,250	3.75	3.00	14.0	12,903,000	121
	04/12/07	7.2	7,465	44	11,578	90	133	13,115,840	135	18,830,170	20,313	4.75	3.00	16.0	12,957,000	125
	04/13/07	6.5	7,482	44	11,612	87	off	13,167,287	132	18,881,617	20,369	off	off	NA	13,008,000	131
	04/14/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	04/15/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
52	04/16/07	18.6	7,530	43	11,711	89	off	13,316,668	134	19,030,998	20,530	off	off	NA	13,153,000	130
	04/17/07	5.7	7,545	44	11,741	88	NM	13,363,396	137	19,077,726	20,580	8.50	3.50	18.0	13,197,000	129
	04/18/07	6.1	7,561	44	11,774	90	off	13,412,627	135	19,126,957	20,633	off	off	NA	13,245,000	131
	04/19/07	5.5	7,576	45	11,804	91	off	13,457,323	135	19,171,653	20,681	off	off	NA	13,288,000	130
	04/20/07	6.1	7,592	44	11,836	87	off	13,507,175	136	19,221,505	20,735	off	off	NA	13,336,000	131
	04/21/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	04/22/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
53	04/23/07	18.7	7,640	43	11,935	88	off	13,659,664	136	19,373,994	20,900	off	off	NA	13,480,000	128
	04/24/07	5.5	7,654	42	11,965	91	141	13,705,116	138	19,419,446	20,949	8.00	3.00	21.0	13,523,000	130
	04/25/07	6.2	7,670	43	11,997	86	141	13,756,759	139	19,471,089	21,004	8.00	4.00	23.0	13,571,000	129
	04/26/07	5.2	7,685	48	12,025	90	142	13,799,149	136	19,513,479	21,050	8.00	4.00	22.0	13,611,000	128
	04/27/07	6.9	7,702	41	12,062	89	off	13,854,073	133	19,568,403	21,109	off	off	NA	13,662,000	123
	04/28/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	04/29/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
54	04/30/07	18.5	7,749	42	12,159	87	off	13,997,104	129	19,711,434	21,264	off	off	NA	13,804,000	128
	05/01/07	5.9	7,765	45	12,191	90	off	14,045,011	135	19,759,341	21,315	off	off	NA	13,851,000	133
	05/02/07	6.1	7,780	41	12,222	85	134	14,093,324	132	19,807,654	21,367	8.50	3.25	22.0	13,897,000	126
	05/03/07	6.6	7,799	48	12,257	88	127	14,146,364	134	19,860,694	21,425	9.00	3.25	22.0	13,949,000	131
	05/04/07	5.7	7,813	41	12,288	91	off	14,189,364	126	19,903,694	21,471	off	off	NA	13,993,000	129
	05/05/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	05/06/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA

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

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

Week	Date	Op Time	Well 1 Totalizer	Well 1 Average Flow	Well 2 Totalizer	Well 2 Average Flow	Vessel A Instant Flowrate	Vessel A Totalizer	Vessel A Calculated Flowrate	Cum total Throughput	Cum total Bed Volume	Vessel A ΔP	Vessel B ΔP	System ΔP	Effluent Totalizer	Effluent Calculated Flowrate
		hr	kgal	gpm	kgal	gpm	gpm	gal	gpm	gal	BV	psi	psi	psig	gal	gpm
55	05/07/07	19.2	7,862	43	12,370	71	off	14,340,963	132	20,055,293	21,635	off	off	NA	14,140,000	128
	05/08/07	6.7	7,879	42	12,405	87	139	14,393,684	131	20,108,014	21,691	10.00	3.25	21.0	14,191,000	127
	05/09/07	4.2	7,889	40	12,426	83	off	14,427,039	132	20,141,369	21,727	off	off	NA	14,222,000	123
	05/10/07	9.6	7,916	47	12,480	94	off	14,502,307	142	20,223,435	21,816	off	off	NA	14,293,000	123
	05/11/07	6.1	7,932	44	12,513	90	off	14,551,446	134	20,272,574	21,869	off	off	NA	14,341,000	131
	05/12/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	05/13/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
56	05/14/07	21.0	7,987	44	12,626	90	off	14,720,824	134	20,441,952	22,052	off	off	NA	14,504,000	129
	05/15/07	6.1	8,003	44	12,658	87	133	14,770,196	135	20,491,324	22,105	6.75	3.25	18.5	14,550,000	126
	05/16/07	7.3	8,023	46	12,697	89	off	14,828,617	133	20,549,745	22,168	off	off	NA	14,606,000	128
	05/17/07	9.1	8,046	42	12,745	88	off	14,900,999	133	20,622,127	22,246	off	off	NA	14,675,000	126
	05/18/07	7.0	8,065	45	12,782	88	137	14,956,630	132	20,677,758	22,306	8.25	3.25	18.0	14,727,000	124
	05/19/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	05/20/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
57	05/21/07	29.3	8,140	43	12,917	77	off	15,185,220	130	20,906,348	22,553	off	off	NA	14,943,000	123
	05/22/07	9.8	8,165	43	12,967	85	off	15,262,796	132	20,983,924	22,636	off	off	NA	15,015,000	122
	05/23/07	6.6	8,182	43	13,001	86	off	15,314,845	131	21,035,973	22,693	off	off	NA	15,064,000	124
	05/24/07	6.5	8,198	41	13,034	85	137	15,366,779	133	21,087,907	22,749	5.00	3.50	20.0	15,112,000	123
	05/25/07	6.6	8,215	43	13,069	88	129	15,419,480	133	21,140,608	22,805	4.75	3.00	20.0	15,162,000	126
	05/26/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	05/27/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
58	05/28/07	19.9	8,265	NA	13,172	86	off	15,574,914	130	21,296,042	22,973	off	off	NA	15,310,000	124
	05/29/07[(e)]	11.1	NM	NA	13,231	89	off	15,634,344	89	21,355,472	23,037	off	off	NA	15,369,000	NA
	05/30/07	7.7	NM	NA	13,271	87	97	15,675,075	88	21,396,203	23,081	5.50	1.25	16.0	15,410,000	NA
	05/31/07	11.1	NM	NA	13,330	89	89	15,735,097	90	21,456,225	23,146	4.75	1.00	17.0	15,469,000	NA
	06/01/07	4.7	8,265	NA	13,355	89	94	15,760,259	89	21,481,387	23,173	4.75	1.50	17.0	15,494,000	NA
	06/02/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/03/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
59	06/04/07	23.0	8,315	36	13,472	85	138	15,916,287	113	21,637,415	23,341	9.00	3.25	20.0	15,655,000	117
	06/05/07	7.4	8,334	43	13,510	86	off	15,966,792	114	21,687,920	23,396	off	off	NA	15,711,000	126
	06/06/07	17.4	8,376	40	13,587	74	133	16,071,075	100	21,792,203	23,508	4.00	2.50	21.0	15,827,000	111
	06/07/07	8.5	8,400	47	13,636	96	NM	16,133,400	122	21,854,528	23,576	4.00	2.00	13.0	15,884,000	112
	06/08/07	8.9	8,418	34	13,689	99	off	16,203,380	131	21,924,508	23,651	off	off	NA	15,951,000	125
	06/09/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/10/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
60	06/11/07	21.8	8,482	49	13,818	99	off	16,384,253	138	22,105,381	23,846	off	off	NA	16,114,000	125
	06/12/07	10.1	8,512	50	13,876	96	136	16,476,644	152	22,197,772	23,946	5.00	2.75	22.0	16,200,000	142
	06/13/07	5.8	8,528	46	13,909	95	134	16,525,897	142	22,247,025	23,999	4.75	2.75	23.0	16,248,000	138
	06/14/07	9.7	8,553	43	13,948	67	127	16,599,937	127	22,321,065	24,079	9.00	3.00	23.0	16,321,000	125
	06/15/07	11.9	8,582	41	14,003	77	off	16,688,715	124	22,409,843	24,175	off	off	NA	16,408,000	122
	06/16/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/17/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
61	06/18/07[(f)]	18.1	8,628	42	14,095	85	127	16,807,883	110	22,529,011	24,303	3.00	2.75	31.0	16,545,000	126
	06/19/07	4.0	8,637	38	14,113	75	off	16,835,554	115	22,556,682	24,333	off	off	NA	16,573,000	117
	06/20/07	9.3	8,660	41	14,159	82	123	16,906,650	127	22,627,778	24,410	7.00	2.75	32.0	16,646,000	130
	06/21/07	8.6	8,682	43	14,202	83	off	16,972,763	128	22,693,891	24,481	off	off	NA	16,715,000	134
	06/22/07	6.5	8,700	46	14,234	82	off	17,023,646	130	22,744,774	24,536	off	off	NA	16,767,000	133
	06/23/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/24/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
62	06/25/07	21.3	8,758	45	14,315	64	109	17,153,970	102	22,875,098	24,676	2.00	2.00	37.0	16,939,000	135
	06/26/07[(g)]	4.6	8,769	40	14,336	77	117	17,189,009	128	22,910,137	24,714	NM	2.75	37.0	16,976,000	135
	06/27/07	6.3	8,784	39	14,369	87	126	17,193,979	NA	22,958,137	24,766	NM	3.75	17.0	17,017,000	108
	06/28/07	8.8	8,806	42	14,413	83	off	17,195,169	NA	23,024,137	24,837	NM	off	NA	17,084,000	127
	06/29/07	6.5	8,822	41	14,447	87	off	17,245,048	128	23,074,016	24,891	NM	off	NA	17,140,000	144
	06/30/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	07/01/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
63	07/02/07	21.0	8,874	41	14,553	84	off	17,397,355	121	23,226,323	25,055	NM	off	NA	17,295,000	123
	07/03/07	7.0	8,890	38	14,586	79	off	17,446,997	118	23,275,965	25,109	NM	off	NA	17,357,000	148
	07/04/07	3.5	8,900	48	14,607	101	150	17,479,613	158	23,308,581	25,144	NM	3.00	23.0	17,378,000	101
	07/05/07	7.9	8,920	42	14,648	86	off	17,540,551	129	23,369,519	25,210	NM	off	NA	17,441,000	133
	07/06/07	4.0	8,930	42	14,670	92	134	17,572,300	133	23,401,268	25,244	NM	3.00	20.0	17,474,000	138
	07/07/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	07/08/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA

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

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

Week	Date	Op Time	Well 1 Totalizer	Well 1 Average Flow	Well 2 Totalizer	Well 2 Average Flow	Vessel A Instant Flowrate	Vessel A Totalizer	Vessel A Calculated Flowrate	Cum total Throughput	Cum total Bed Volume	Vessel A ΔP	Vessel B ΔP	System ΔP	Effluent Totalizer	Effluent Calculated Flowrate
		hr	kgal	gpm	kgal	gpm	gpm	gal	gpm	gal	BV	psi	psi	psig	gal	gpm
55	05/07/07	19.2	7,862	43	12,370	71	off	14,340,963	132	20,055,293	21,635	off	off	NA	14,140,000	128
	05/08/07	6.7	7,879	42	12,405	87	139	14,393,684	131	20,108,014	21,691	10.00	3.25	21.0	14,191,000	127
	05/09/07	4.2	7,889	40	12,426	83	off	14,427,039	132	20,141,369	21,727	off	off	NA	14,222,000	123
	05/10/07	9.6	7,916	47	12,480	94	off	14,502,307	142	20,223,435	21,816	off	off	NA	14,293,000	123
	05/11/07	6.1	7,932	44	12,513	90	off	14,551,446	134	20,272,574	21,869	off	off	NA	14,341,000	131
	05/12/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	05/13/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
56	05/14/07	21.0	7,987	44	12,626	90	off	14,720,824	134	20,441,952	22,052	off	off	NA	14,504,000	129
	05/15/07	6.1	8,003	44	12,658	87	133	14,770,196	135	20,491,324	22,105	6.75	3.25	18.5	14,550,000	126
	05/16/07	7.3	8,023	46	12,697	89	off	14,828,617	133	20,549,745	22,168	off	off	NA	14,606,000	128
	05/17/07	9.1	8,046	42	12,745	88	off	14,900,999	133	20,622,127	22,246	off	off	NA	14,675,000	126
	05/18/07	7.0	8,065	45	12,782	88	137	14,956,630	132	20,677,758	22,306	8.25	3.25	18.0	14,727,000	124
	05/19/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	05/20/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
57	05/21/07	29.3	8,140	43	12,917	77	off	15,185,220	130	20,906,348	22,553	off	off	NA	14,943,000	123
	05/22/07	9.8	8,165	43	12,967	85	off	15,262,796	132	20,983,924	22,636	off	off	NA	15,015,000	122
	05/23/07	6.6	8,182	43	13,001	86	off	15,314,845	131	21,035,973	22,693	off	off	NA	15,064,000	124
	05/24/07	6.5	8,198	41	13,034	85	137	15,366,779	133	21,087,907	22,749	5.00	3.50	20.0	15,112,000	123
	05/25/07	6.6	8,215	43	13,069	88	129	15,419,480	133	21,140,608	22,805	4.75	3.00	20.0	15,162,000	126
	05/26/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	05/27/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
58	05/28/07	19.9	8,265	NA	13,172	86	off	15,574,914	130	21,296,042	22,973	off	off	NA	15,310,000	124
	05/29/07[e]	11.1	NM	NA	13,231	89	off	15,634,344	89	21,355,472	23,037	off	off	NA	15,369,000	NA
	05/30/07	7.7	NM	NA	13,271	87	97	15,675,075	88	21,396,203	23,081	5.50	1.25	16.0	15,410,000	NA
	05/31/07	11.1	NM	NA	13,330	89	89	15,735,097	90	21,456,225	23,146	4.75	1.00	17.0	15,469,000	NA
	06/01/07	4.7	8,265	NA	13,355	89	94	15,760,259	89	21,481,387	23,173	4.75	1.50	17.0	15,494,000	NA
	06/02/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/03/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
59	06/04/07	23.0	8,315	36	13,472	85	138	15,916,287	113	21,637,415	23,341	9.00	3.25	20.0	15,655,000	117
	06/05/07	7.4	8,334	43	13,510	86	off	15,966,792	114	21,687,920	23,396	off	off	NA	15,711,000	126
	06/06/07	17.4	8,376	40	13,587	74	133	16,071,075	100	21,792,203	23,508	4.00	2.50	21.0	15,827,000	111
	06/07/07	8.5	8,400	47	13,636	96	NM	16,133,400	122	21,854,528	23,576	4.00	2.00	13.0	15,884,000	112
	06/08/07	8.9	8,418	34	13,689	99	off	16,203,380	131	21,924,508	23,651	off	off	NA	15,951,000	125
	06/09/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/10/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
60	06/11/07	21.8	8,482	49	13,818	99	off	16,384,253	138	22,105,381	23,846	off	off	NA	16,114,000	125
	06/12/07	10.1	8,512	50	13,876	96	136	16,476,644	152	22,197,772	23,946	5.00	2.75	22.0	16,200,000	142
	06/13/07	5.8	8,528	46	13,909	95	134	16,525,897	142	22,247,025	23,999	4.75	2.75	23.0	16,248,000	138
	06/14/07	9.7	8,553	43	13,948	67	127	16,599,937	127	22,321,065	24,079	9.00	3.00	23.0	16,321,000	125
	06/15/07	11.9	8,582	41	14,003	77	off	16,688,715	124	22,409,843	24,175	off	off	NA	16,408,000	122
	06/16/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/17/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
61	06/18/07[f]	18.1	8,628	42	14,095	85	127	16,807,883	110	22,529,011	24,303	3.00	2.75	31.0	16,545,000	126
	06/19/07	4.0	8,637	38	14,113	75	off	16,835,554	115	22,556,682	24,333	off	off	NA	16,573,000	117
	06/20/07	9.3	8,660	41	14,159	82	123	16,906,650	127	22,627,778	24,410	7.00	2.75	32.0	16,646,000	130
	06/21/07	8.6	8,682	43	14,202	83	off	16,972,763	128	22,693,891	24,481	off	off	NA	16,715,000	134
	06/22/07	6.5	8,700	46	14,234	82	off	17,023,646	130	22,744,774	24,536	off	off	NA	16,767,000	133
	06/23/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	06/24/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
62	06/25/07	21.3	8,758	45	14,315	64	109	17,153,970	102	22,875,098	24,676	2.00	2.00	37.0	16,939,000	135
	06/26/07[g]	4.6	8,769	40	14,336	77	117	17,189,009	128	22,910,137	24,714	NM	2.75	37.0	16,976,000	135
	06/27/07	6.3	8,784	39	14,369	87	126	17,193,979	NA	22,958,137	24,766	NM	3.75	17.0	17,017,000	108
	06/28/07	8.8	8,806	42	14,413	83	off	17,195,169	NA	23,024,137	24,837	NM	off	NA	17,084,000	127
	06/29/07	6.5	8,822	41	14,447	87	off	17,245,048	128	23,074,016	24,891	NM	off	NA	17,140,000	144
	06/30/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	07/01/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
63	07/02/07	21.0	8,874	41	14,553	84	off	17,397,355	121	23,226,323	25,055	NM	off	NA	17,295,000	123
	07/03/07	7.0	8,890	38	14,586	79	off	17,446,997	118	23,275,965	25,109	NM	off	NA	17,357,000	148
	07/04/07	3.5	8,900	48	14,607	101	150	17,479,613	158	23,308,581	25,144	NM	3.00	23.0	17,378,000	101
	07/05/07	7.9	8,920	42	14,648	86	off	17,540,551	129	23,369,519	25,210	NM	off	NA	17,441,000	133
	07/06/07	4.0	8,930	42	14,670	92	134	17,572,300	133	23,401,268	25,244	NM	3.00	20.0	17,474,000	138
	07/07/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	07/08/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA

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

Week	Date	Op Time	Well 1 Totalizer	Well 1 Average Flow	Well 2 Totalizer	Well 2 Average Flow	Vessel A Instant Flowrate	Vessel A Totalizer	Vessel A Calculated Flowrate	Cum total Throughput	Cum total Bed Volume	Vessel A ΔP	Vessel B ΔP	System ΔP	Effluent Totalizer	Effluent Calculated Flowrate
		hr	kgal	gpm	kgal	gpm	gpm	gal	gpm	gal	BV	psi	psi	psig	gal	gpm
64	07/09/07	16.5	8,984	54	14,746	77	131	17,712,225	141	23,541,193	25,395	NM	3.25	20.0	17,639,000	166
	07/10/07	3.4	8,996	59	14,754	39	off	17,746,641	169	23,575,609	25,432	NM	off	NA	17,674,000	172
	07/11/07	6.2	9,013	46	14,784	81	127	17,792,127	123	23,621,095	25,481	NM	3.25	22.0	17,728,000	146
	07/12/07	3.6	9,025	56	14,799	69	off	17,814,176	102	23,643,144	25,505	NM	off	NA	17,763,000	162
	07/13/07	8.8	9,047	42	14,844	85	off	17,868,274	102	23,697,242	25,563	NM	off	NA	17,832,000	131
	07/14/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	07/15/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
65	07/16/07	20.6	9,096	40	14,944	81	121	17,988,299	97	23,817,267	25,693	NM	3.00	28.0	17,981,000	121
	07/17/07	6.0	9,110	39	14,973	80	119	18,030,076	NA	23,859,044	25,738	NM	3.00	27.0	18,025,000	122
	07/18/07	5.8	9,125	43	15,002	83	126	18,071,817	119	23,900,785	25,783	NM	3.00	28.0	18,068,000	123
	07/19/07	8.0	9,145	42	15,041	81	off	18,105,859	71	23,934,827	25,820	NM	off	NA	18,128,000	125
	07/20/07	7.0	9,161	38	15,073	76	off	18,151,511	109	23,980,479	25,869	NM	off	NA	18,177,000	117
	07/21/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	07/22/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
66	07/23/07	21.3	9,209	38	15,169	75	off	18,288,678	107	24,117,646	26,017	NM	off	NA	18,323,000	114
	07/24/07	6.2	9,220	30	15,200	83	off	18,333,928	122	24,162,896	26,066	NM	off	NA	18,371,000	129
	07/25/07	6.8	9,240	49	15,230	73	122	18,378,456	109	24,207,424	26,114	NM	2.75	NA	18,417,000	112
	07/26/07	4.4	9,251	42	15,253	87	129	18,408,857	115	24,237,825	26,147	NM	2.75	NA	18,451,000	129
	07/27/07	5.6	9,264	39	15,280	80	119	18,446,970	113	24,275,938	26,188	NM	2.75	NA	18,492,000	122
	07/28/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	07/29/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
67	07/30/07	26.3	9,320	36	15,388	68	104	18,552,090	67	24,381,058	26,301	NM	2.00	43.0	18,656,000	104
	07/31/07	5.2	9,331	35	15,407	61	96	18,581,014	93	24,409,982	26,332	NM	2.00	48.0	18,688,000	102
	08/01/07	8.0	9,351	42	15,449	87	129	18,638,733	120	24,467,701	26,394	NM	3.25	16.0	18,746,000	121
	08/02/07	9.4	9,372	37	15,490	73	off	18,695,213	100	24,524,181	26,455	NM	off	NA	18,807,000	108
	08/03/07	7.2	9,387	35	15,522	74	off	18,739,904	103	24,568,872	26,504	NM	off	NA	18,854,000	109
	08/04/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	08/05/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
68	08/06/07	26.3	9,440	34	15,629	68	off	18,889,796	95	24,718,764	26,665	NM	off	NA	19,013,000	101
	08/07/07	NA	9,453	42	15,656	87	128	18,928,797	125	24,757,765	26,707	NM	3.50	22.0	19,054,000	NA
	08/08/07	10.8	9,480	42	15,711	85	off	19,009,365	124	24,838,333	26,794	NM	off	NA	19,136,000	127
	08/09/07	9.4	9,505	44	15,760	87	off	19,077,285	120	24,906,253	26,868	NM	off	NA	19,209,000	129
	08/10/07	7.2	9,523	42	15,796	83	NM	19,130,022	122	24,958,990	26,924	NM	3.50	22.0	19,263,000	125
	08/11/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	08/12/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
69	08/13/07	25.7	9,587	42	15,866	45	117	19,315,766	120	25,144,734	27,125	NM	3.00	27.0	19,456,000	125
	08/14/07	9.1	9,610	42	15,880	26	off	19,378,550	115	25,207,518	27,193	NM	off	NA	19,523,000	123
	08/15/07	11.2	9,638	42	15,935	82	114	19,458,124	118	25,287,092	27,278	NM	off	NA	19,608,000	126
	08/16/07	7.6	9,653	33	15,973	83	off	19,507,750	109	25,336,718	27,332	NM	off	NA	19,661,000	116
	08/17/07[(e)]	8.0	NM	NA	16,014	85	89	19,547,970	84	25,376,938	27,375	NM	1.00	18.5	19,704,000	NA
	08/18/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	08/19/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
70	08/20/07	40.9	9,653	NA	16,212	81	84	19,742,141	79	25,571,109	27,585	NM	1.00	22.0	19,911,000	NA
	08/21/07	10.3	9,675	36	16,259	76	off	19,806,769	105	25,635,737	27,655	NM	off	NA	19,980,000	112
	08/22/07	8.1	9,695	41	16,299	82	off	19,863,941	118	25,692,909	27,716	NM	off	NA	20,041,000	126
	08/23/07	7.1	9,713	42	16,333	80	off	19,892,841	68	25,721,809	27,747	NM	off	NA	20,094,000	124
	08/24/07	6.9	9,730	41	16,369	87	130	19,941,561	118	25,770,529	27,800	12.00	3.25	24.0	20,146,000	126
	08/25/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	08/26/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
71	08/27/07	22.9	9,798	49	16,488	87	119	20,099,035	115	25,928,003	27,970	12.00	3.00	24.0	20,310,000	119
	08/28/07	7.0	9,807	21	16,525	88	124	20,147,646	116	25,976,614	28,022	11.50	2.75	22.0	20,363,000	126
	08/29/07	5.7	9,821	41	16,554	85	119	20,187,584	117	26,016,552	28,065	1.25	3.25	23.0	20,404,000	120
	08/30/07	6.0	9,838	47	16,587	92	128	20,228,747	114	26,057,715	28,110	4.75	3.00	15.0	20,444,000	111
	08/31/07	7.4	9,858	45	16,628	92	off	20,282,897	122	26,111,865	28,168	off	off	NA	20,503,000	133
	09/01/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	09/02/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
72	09/03/07	19.0	9,909	45	16,735	94	125	20,405,246	107	26,234,214	28,300	4.00	3.00	17.0	20,647,000	126
	09/04/07	5.9	9,926	48	16,768	93	off	20,447,587	120	26,276,555	28,346	off	off	NA	20,692,000	127
	09/05/07	5.6	9,941	45	16,799	92	off	20,488,515	122	26,317,483	28,390	off	off	NA	20,735,000	128
	09/06/07	5.5	9,956	45	16,830	94	off	20,529,216	123	26,358,184	28,434	off	off	NA	20,779,000	133
	09/07/07	5.6	9,971	45	16,862	95	off	20,571,012	124	26,399,980	28,479	off	off	NA	20,827,000	143
	09/08/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	09/09/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA

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

Week	Date	Op Time	Well 1 Totalizer	Well 1 Average Flow	Well 2 Totalizer	Well 2 Average Flow	Vessel A Instant Flowrate	Vessel A Totalizer	Vessel A Calculated Flowrate	Cum total Throughput	Cum total Bed Volume	Vessel A ΔP	Vessel B ΔP	System ΔP	Effluent Totalizer	Effluent Calculated Flowrate
		hr	kgal	gpm	kgal	gpm	gpm	gal	gpm	gal	BV	psi	psi	psig	gal	gpm
	09/10/07	20.1	10,025	45	16,974	93	133	20,718,270	122	26,547,238	28,638	5.00	3.50	15.0	20,979,000	126
	09/11/07	6.6	10,043	45	17,011	93	off	20,766,487	122	26,595,455	28,690	off	off	NA	21,030,000	129
	09/12/07	5.8	10,058	43	17,044	95	129	20,809,124	123	26,638,092	28,736	4.75	3.00	14.0	21,075,000	129
73	09/13/07	6.4	10,076	47	17,079	91	off	20,857,474	126	26,686,442	28,788	off	off	NA	21,127,000	135
	09/14/07	5.7	10,076	NA	17,112	96	off	20,907,902	147	26,736,870	28,842	off	off	NA	21,160,000	NA
	09/15/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	09/16/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	09/17/07	22.7	10,124	35	17,233	89	off	21,046,413	102	26,875,381	28,992	off	off	NA	21,329,000	124
	09/18/07	6.0	10,139	42	17,265	89	135	21,090,970	124	26,919,938	29,040	12.00	3.50	25.0	21,374,000	125
	09/19/07	4.1	10,150	45	17,286	85	134	21,120,539	120	26,949,507	29,072	13.00	3.25	25.0	21,406,000	130
74	09/20/07[(b)]	8.3	10,170	40	17,328	84	off	NM	NA	27,011,507	29,139	off	off	NA	21,468,000	124
	09/21/07	7.1	10,187	40	17,361	77	129	21,137,614	NA	27,061,507	29,193	15.00	2.75	32.0	21,518,000	117
	09/22/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	09/23/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	09/24/07	27.7	10,255	41	17,494	80	124	21,329,721	116	27,253,614	29,400	15.00	3.00	25.0	21,712,000	117
	09/25/07	5.5	10,269	42	17,521	82	127	21,369,613	121	27,293,506	29,443	15.00	3.00	27.0	21,752,000	121
	09/26/07	4.0	10,280	46	17,541	83	off	21,398,946	122	27,322,839	29,474	off	off	NA	21,787,000	146
75	09/27/07	8.4	10,300	40	17,555	28	off	21,460,204	122	27,384,097	29,541	off	off	NA	21,843,000	111
	09/28/07	4.7	10,312	43	17,578	82	122	21,496,344	128	27,420,237	29,580	15.00	3.00	26.0	21,878,000	124
	09/29/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	09/30/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	10/01/07	19.0	10,359	41	17,673	83	off	21,627,930	115	27,551,823	29,721	off	off	NA	22,017,000	122
	10/02/07	8.6	10,380	41	17,715	81	off	21,677,835	97	27,601,728	29,775	off	off	NA	22,079,000	120
	10/03/07	4.3	10,391	43	17,738	89	137	21,712,004	132	27,635,897	29,812	10.00	3.50	21.0	22,110,000	120
76	10/04/07	7.7	10,411	43	17,778	87	off	21,770,053	126	27,693,946	29,875	off	off	NA	22,168,000	126
	10/05/07	6.0	10,426	42	17,810	89	130	21,816,109	128	27,740,002	29,924	12.50	3.00	23.0	22,214,000	128
	10/06/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	10/07/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	10/08/07	20.2	10,477	42	17,912	84	133	21,967,949	125	27,891,842	30,088	15.00	3.00	27.0	22,365,000	125
	10/09/07	5.7	10,490	38	17,937	73	131	22,007,388	115	27,931,281	30,131	15.00	3.00	28.0	22,405,000	117
	10/10/07	4.8	10,503	45	17,965	97	135	22,046,595	136	27,970,488	30,173	15.00	3.00	27.0	22,443,000	132
77	10/11/07	6.0	10,518	42	17,995	83	129	22,090,796	123	28,014,689	30,221	15.00	3.00	29.0	22,486,000	119
	10/12/07	8.8	10,540	42	18,038	81	133	22,159,015	129	28,082,908	30,294	7.50	3.50	19.0	22,550,000	121
	10/13/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	10/14/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	10/15/07	20.6	10,592	42	18,142	84	off	22,313,599	125	28,237,492	30,461	off	off	NA	22,702,000	123
	10/16/07	5.7	10,605	38	18,171	85	126	22,355,656	123	28,279,549	30,507	15.00	3.00	31.0	22,742,000	117
	10/17/07	7.1	10,626	49	18,205	80	off	22,407,506	122	28,331,399	30,562	off	off	NA	22,793,000	120
78	10/18/07	5.8	10,636	29	18,235	86	off	22,451,268	126	28,375,161	30,610	off	off	NA	22,835,000	121
	10/19/07	6.3	10,653	45	18,266	82	129	22,497,196	122	28,421,089	30,659	15.00	3.25	30.0	22,882,000	124
	10/20/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	10/21/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	10/22/07	19.5	10,698	38	18,361	81	off	22,619,311	104	28,543,204	30,791	off	off	NA	23,023,000	121
	10/23/07	9.0	10,715	31	18,404	80	off	22,677,133	107	28,601,026	30,853	off	off	NA	23,079,000	104
	10/24/07	3.9	10,723	34	18,422	77	97	22,697,575	87	28,621,468	30,875	14.50	1.75	25.0	23,105,000	NA
79	10/25/07[(e)]	5.5	10,726	9	18,460	115	off	22,738,447	124	28,662,340	30,919	off	off	NA	23,146,000	124
	10/26/07	10.5	10,726	NA	18,505	71	94	22,783,100	71	28,706,993	30,968	14.00	1.75	20.0	23,191,000	NA
	10/27/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	10/28/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	10/29/07	25.8	10,777	33	18,624	77	off	22,950,872	108	28,874,765	31,149	off	off	NA	23,360,000	109
	10/30/07	5.0	10,789	40	18,647	77	128	22,985,353	115	28,909,246	31,186	15.00	2.75	35.0	23,395,000	117
	10/31/07[(b)]	9.1	10,809	37	18,687	73	off	NM	NA	28,969,246	31,251	off	off	NA	23,460,000	119
80	11/01/07	4.5	10,819	37	18,708	78	124	NM	NA	29,000,246	31,284	15.00	2.50	36.0	23,493,000	122
	11/02/07	6.2	10,833	38	18,735	73	123	NM	NA	29,041,246	31,328	15.00	2.75	37.0	23,537,000	118
	11/03/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	11/04/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	11/05/07	27.0	10,896	39	18,850	71	off	NM	NA	29,219,246	31,520	off	off	NA	23,722,000	114
	11/06/07[(h)]	7.2	10,910	32	NM	NA	115	NM	NA	29,267,246	31,572	15.00	2.75	36.0	23,770,000	111
	11/07/07	5.5	10,922	36	NM	NA	109	NM	NA	29,305,246	31,613	15.00	2.75	35.0	23,808,000	115
81	11/08/07	5.3	10,933	35	NM	NA	off	NM	NA	29,342,246	31,653	off	off	NA	23,845,000	116
	11/09/07	7.4	10,949	36	NM	NA	107	NM	NA	29,394,246	31,709	15.00	2.00	39.0	23,897,000	117
	11/10/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	11/11/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA

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

Week	Date	Op Time	Well 1 Totalizer	Well 1 Average Flow	Well 2 Totalizer	Well 2 Average Flow	Vessel A Instant Flowrate	Vessel A Totalizer	Vessel A Calculated Flowrate	Cum total Throughput	Cum total Bed Volume	Vessel A ΔP	Vessel B ΔP	System ΔP	Effluent Totalizer	Effluent Calculated Flowrate
		hr	kgal	gpm	kgal	gpm	gpm	gal	gpm	gal	BV	psi	psi	psig	gal	gpm
82	11/12/07	22.1	11,009	45	NM	NA	off	NM	NA	29,574,246	31,903	off	off	NA	24,077,000	136
	11/13/07	8.6	11,031	43	NM	NA	119	NM	NA	29,647,246	31,982	9.00	4.00	21.0	24,150,000	141
	11/14/07	5.5	11,046	45	NM	NA	off	NM	NA	29,695,246	32,034	off	off	NA	24,198,000	145
	11/15/07	5.8	11,061	43	NM	NA	off	NM	NA	29,744,246	32,087	off	off	NA	24,247,000	141
	11/16/07	6.5	11,076	38	NM	NA	121	NM	NA	29,814,246	32,162	10.00	3.25	25.0	24,302,000	141
	11/17/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	11/18/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
83	11/19/07	18.5	11,123	42	19,183	NA	off	NM	NA	29,967,246	32,327	off	off	NA	24,455,000	138
	11/20/07	5.8	11,138	43	19,214	89	off	NM	NA	30,013,246	32,377	off	off	NA	24,503,000	138
	11/21/07	3.9	11,148	43	19,234	85	off	NM	NA	30,043,246	32,409	off	off	NA	24,535,000	137
	11/22/07	10.0	11,172	40	19,283	82	off	NM	NA	30,116,246	32,488	off	off	NA	24,613,000	130
	11/23/07	6.7	11,188	40	19,316	82	off	NM	NA	30,165,246	32,541	off	off	NA	24,665,000	129
	11/24/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	11/25/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
84	11/26/07	18.8	11,232	39	19,407	81	NM	NM	NA	30,300,246	32,686	10.00	3.00	33.0	24,808,000	127
	11/27/07	8.2	11,252	41	19,447	81	129	NM	NA	30,360,246	32,751	10.00	3.25	31.0	24,872,000	130
	11/28/07	6.4	11,267	39	19,477	78	off	NM	NA	30,405,246	32,800	off	off	NA	24,920,000	125
	11/29/07	5.0	11,279	40	19,503	87	off	NM	NA	30,443,246	32,841	off	off	NA	24,960,000	133
	11/30/07															
	12/01/07															
	12/02/07															
85	12/03/07															
	12/04/07															
	12/05/07															
	12/06/07															
	12/07/07															
	12/08/07	System out of service and being bypassed because storage tank is being maintained														
	12/09/07															
86	12/10/07															
	12/11/07															
	12/12/07															
	12/13/07															
	12/14/07															
	12/15/07															
	12/16/07															
87	12/17/07	0.0	11,558	35	20,065	70	off	NM	NA	30,443,246	32,841	off	off	NA	25,065,000	NA
	12/18/07	4.4	11,568	38	20,089	91	off	NM	NA	30,477,246	32,877	off	off	NA	25,065,000	NA
	12/19/07	9.9	11,591	39	20,130	69	off	NM	NA	30,541,246	32,946	off	off	NA	25,136,000	120
	12/20/07	7.1	11,607	38	20,161	73	off	NM	NA	30,588,246	32,997	off	off	NA	25,186,000	117
	12/21/07	5.6	11,617	30	20,182	63	103	NM	NA	30,619,246	33,030	2.00	2.00	41.0	25,224,000	113
	12/22/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/23/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
88	12/24/07	18.1	11,661	41	20,271	82	119	NM	NA	30,752,246	33,174	9.50	3.00	32.0	25,346,000	112
	12/25/07	10.4	11,680	30	20,321	80	off	NM	NA	30,821,246	33,248	off	off	NA	25,419,000	117
	12/26/07	4.4	11,696	61	20,343	83	122	NM	NA	30,859,246	33,289	9.00	3.00	31.0	25,449,000	114
	12/27/07	6.6	11,712	40	20,375	81	118	NM	NA	30,907,246	33,341	9.50	2.75	33.0	25,493,000	111
	12/28/07	4.7	11,726	50	20,402	96	off	NM	NA	30,948,246	33,385	off	off	NA	25,530,000	131
	12/29/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	12/30/07	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
89	12/31/07	21.8	11,771	34	20,490	67	118	NM	NA	31,081,246	33,529	14.00	2.50	54.0	25,663,000	102
	01/01/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	01/02/08	15.9	11,809	40	20,568	82	off	NM	NA	31,197,246	33,654	off	off	NA	25,781,000	124
	01/03/08	5.7	11,823	41	20,596	82	off	NM	NA	31,239,246	33,699	off	off	NA	25,822,000	120
	01/04/08	7.5	11,834	24	20,626	67	116	NM	NA	31,280,246	33,744	7.50	2.00	55.0	25,868,000	102
	01/05/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	01/06/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
90	01/07/08	27.3	11,892	35	20,719	57	115	NM	NA	31,431,246	33,906	5.00	2.00	53.0	26,015,000	NA
	01/08/08	7.6	11,907	33	20,750	68	111	NM	NA	31,477,246	33,956	5.25	2.00	51.0	26,057,000	NA
	01/09/08	6.8	11,922	37	20,777	66	off	NM	NA	31,519,246	34,001	off	off	NA	26,096,000	NA
	01/10/08	7.6	11,937	33	20,810	72	113	NM	NA	31,567,246	34,053	4.75	2.00	47.0	26,141,000	NA
	01/11/08	6.7	11,953	40	20,839	72	109	NM	NA	31,612,246	34,102	4.00	2.00	43.0	26,182,000	102
	01/12/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	01/13/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA

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

Week	Date	Op Time	Well 1 Totalizer	Well 1 Average Flow	Well 2 Totalizer	Well 2 Average Flow	Vessel A Instant Flowrate	Vessel A Totalizer	Vessel A Calculated Flowrate	Cum total Throughput	Cum total Bed Volume	Vessel A ΔP	Vessel B ΔP	System ΔP	Effluent Totalizer	Effluent Calculated Flowrate
		hr	kgal	gpm	kgal	gpm	gpm	gal	gpm	gal	BV	psi	psi	psig	gal	gpm
91	01/14/08	21.5	12,001	37	20,932	72	109	NM	NA	31,753,246	34,254	4.00	2.50	41.0	26,310,000	NA
	01/15/08	6.2	12,015	38	20,960	75	off	NM	NA	31,795,246	34,299	off	off	NA	26,349,000	105
	01/16/08	6.4	12,030	39	20,988	73	off	NM	NA	31,838,246	34,345	off	off	NA	26,389,000	104
	01/17/08	6.4	12,042	31	21,018	78	off	NM	NA	31,880,246	34,391	off	off	NA	26,432,000	112
	01/18/08	8.9	12,063	39	21,053	66	NM	NM	NA	31,936,246	34,451	2.50	2.00	44.0	26,468,000	NA
	01/19/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	01/20/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
92	01/21/08	17.0	12,109	45	21,152	97	off	NM	NA	32,081,246	34,608	off	off	NA	26,563,000	NA
	01/22/08	3.4	12,118	44	21,173	103	137	NM	NA	32,111,246	34,640	NM	NM	17.0	26,588,000	123
	01/23/08	6.6	12,136	45	21,211	96	off	NM	NA	32,167,246	34,700	off	off	NA	26,636,000	121
	01/24/08	2.6	12,143	45	21,226	96	134	NM	NA	32,189,246	34,724	NM	3.75	17.0	26,656,000	128
	01/25/08	5.0	12,158	50	21,256	100	135	NM	NA	32,234,246	34,773	NM	4.00	17.0	26,691,000	117
	01/26/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	01/27/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
93	01/28/08	16.5	12,203	45	21,355	100	144	NM	NA	32,378,246	34,928	6.00	4.00	16.0	26,808,000	118
	01/29/08	5.4	12,215	37	21,382	83	off	NM	NA	32,417,246	34,970	off	off	NA	26,848,000	123
	01/30/08	2.4	12,222	49	21,397	104	off	NM	NA	32,439,246	34,994	off	off	NA	26,864,000	111
	01/31/08	6.2	12,234	32	21,433	97	138	NM	NA	32,487,246	35,046	9.00	3.50	18.0	26,915,000	137
	02/01/08	5.7	12,254	58	21,464	91	off	NM	NA	32,538,246	35,101	off	off	NA	26,945,000	NA
	02/02/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	02/03/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
94	02/04/08	16.6	12,297	43	21,555	91	off	NM	NA	32,672,246	35,245	off	off	NA	27,074,000	130
	02/05/08	5.0	12,309	40	21,582	90	130	NM	NA	32,711,246	35,287	15.00	3.50	27.0	27,117,000	143
	02/06/08	5.4	12,321	37	21,609	83	132	NM	NA	32,750,246	35,329	15.00	3.50	30.0	27,153,000	111
	02/07/08	3.9	12,332	47	21,629	85	128	NM	NA	32,781,246	35,363	15.00	3.50	32.0	27,158,000	NA
	02/08/08	7.1	12,346	33	21,665	85	136	NM	NA	32,831,246	35,417	7.00	3.75	22.0	27,184,000	NA
	02/09/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	02/10/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
95	02/11/08	18.5	12,398	47	21,767	92	off	NM	NA	32,985,246	35,583	off	off	NA	27,226,000	NA
	02/12/08	5.3	12,411	41	21,795	88	134	NM	NA	33,026,246	35,627	12.50	3.50	26.0	27,259,000	104
	02/13/08	8.3	12,432	42	21,838	86	off	NM	NA	33,090,246	35,696	off	off	NA	27,287,000	NA
	02/14/08	5.7	12,446	41	21,866	82	119	NM	NA	33,132,246	35,741	15.00	3.00	35.0	27,320,000	NA
	02/15/08	5.3	12,460	44	21,897	97	142	NM	NA	33,177,246	35,790	6.00	3.50	16.0	27,340,000	NA
	02/16/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	02/17/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
96	02/18/08	16.6	12,504	44	21,990	93	off	NM	NA	33,314,246	35,938	off	off	NA	27,412,000	NA
	02/19/08[c]	5.7	12,519	44	22,021	91	off	NM	NA	33,360,246	35,987	off	off	NA	NM	NA
	02/20/08	5.3	12,532	41	22,049	88	140	NM	NA	33,401,246	36,032	10.50	4.00	26.0	NM	NA
	02/21/08	5.6	12,547	45	22,079	89	off	NM	NA	33,446,246	36,080	off	off	NA	NM	NA
	02/22/08	5.3	12,560	41	22,107	88	off	NM	NA	33,487,246	36,124	off	off	NA	NM	NA
	02/23/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	02/24/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
97	02/25/08	19.5	12,610	43	22,211	89	129	NM	NA	33,641,246	36,290	11.00	3.00	24.0	NM	NA
	02/26/08	6.4	12,627	44	22,240	76	off	NM	NA	33,687,246	36,340	off	off	NA	NM	NA
	02/27/08	3.3	12,636	45	22,265	126	144	NM	NA	33,721,246	36,377	11.75	3.75	24.0	NM	NA
	02/28/08	21.4	12,696	47	22,391	98	127	NM	NA	33,907,246	36,577	7.50	2.50	18.0	NM	NA
	02/29/08	10.4	12,726	48	22,440	79	131	NM	NA	33,986,246	36,663	11.50	3.50	23.0	NM	NA
	03/01/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	03/02/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
98	03/03/08															
	03/04/08															
	03/05/08	System was shutdown week of 03/03/08 due to valve issues														
	03/06/08															
	03/07/08															
	03/08/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	03/09/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
99	03/10/08	0.0	12,881	46	22,757	94	off	NM	NA	33,986,246	36,663	off	off	NA	535,000	
	03/11/08	3.1	12,889	43	22,776	102	148	NM	NA	34,013,246	36,692	9.00	3.75	22.0	565,000	161
	03/12/08	4.6	12,902	47	22,789	47	off	NM	NA	34,039,246	36,720	off	off	NA	604,000	141
	03/13/08	6.9	12,920	43	22,829	97	off	NM	NA	34,097,246	36,782	off	off	NA	665,000	147
	03/14/08	4.9	12,933	44	22,856	92	139	NM	NA	34,137,246	36,826	10.00	3.50	20.0	708,000	146
	03/15/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	03/16/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA

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

Week	Date	Op Time	Well 1 Totalizer	Well 1 Average Flow	Well 2 Totalizer	Well 2 Average Flow	Vessel A Instant Flowrate	Vessel A Totalizer	Vessel A Calculated Flowrate	Cum total Throughput	Cum total Bed Volume	Vessel A ΔP	Vessel B ΔP	System ΔP	Effluent Totalizer	Effluent Calculated Flowrate
		hr	kgal	gpm	kgal	gpm	gpm	gal	gpm	gal	BV	psi	psi	psig	gal	gpm
100	03/17/08	14.9	12,976	48	22,938	92	141	NM	NA	34,262,246	36,960	12.50	3.50	25.0	835,000	142
	03/18/08	5.4	12,986	31	22,967	90	off	NM	NA	34,301,246	37,002	off	off	NA	879,000	136
	03/19/08	6.9	13,004	43	23,005	92	139	NM	NA	34,357,246	37,063	13.75	3.00	26.0	937,000	140
	03/20/08	5.8	13,018	40	23,036	89	NM	NM	NA	34,402,246	37,111	15.00	3.50	27.0	985,000	138
	03/21/08	3.7	13,018	0	23,056	90	off	NM	NA	34,422,246	37,133	off	off	NA	1,015,000	135
	03/22/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	03/23/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
101	03/24/08	20.9	13,083	52	23,173	93	off	NM	NA	34,604,246	37,329	off	off	NA	1,192,000	141
	03/25/08	5.0	13,096	43	23,201	93	143	NM	NA	34,645,246	37,374	11.00	3.00	22.0	1,235,000	143
	03/26/08	5.6	13,111	45	23,232	92	142	NM	NA	34,691,246	37,423	11.00	3.00	22.0	1,283,000	143
	03/27/08	7.0	13,129	43	23,269	88	off	NM	NA	34,746,246	37,482	off	off	NA	1,341,000	138
	03/28/08	3.2	13,137	42	23,287	94	145	NM	NA	34,772,246	37,511	12.00	3.00	21.0	1,368,000	141
	03/29/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	03/30/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
102	03/31/08	20.9	13,191	43	23,399	89	off	NM	NA	34,938,246	37,690	off	off	NA	1,542,000	139
	04/01/08	5.8	13,209	52	23,430	89	off	NM	NA	34,987,246	37,742	off	off	NA	1,590,000	138
	04/02/08	5.7	13,220	32	23,460	88	139	NM	NA	35,028,246	37,787	15.00	3.75	25.0	1,638,000	140
	04/03/08	6.4	13,236	42	23,494	89	off	NM	NA	35,078,246	37,841	off	off	NA	1,690,000	135
	04/04/08	6.4	13,252	42	23,527	86	off	NM	NA	35,127,246	37,893	off	off	NA	1,739,000	128
	04/05/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
	04/06/08	NA	NM	NA	NM	NA	NM	NM	NA	NA	NA	NM	NM	NA	NM	NA
103	04/07/08	21.1	13,308	44	23,646	94	140	NM	NA	35,302,246	38,082	10.50	3.50	22.0	1,920,000	143
	04/08/08	7.0	13,326	43	23,684	90	off	NM	NA	35,358,246	38,143	off	off	NA	1,979,000	140

(a) Well 2 totalizer broken from 04/25/06 to 05/21/06. Throughput and BV estimated based on average flowrate of 125 gpm and respective operating time.

(b) Vessel A flowmeter and totalizer broken from 04/26/06 to 05/26/06, on 06/06/06, from 09/06/06 to 10/03/06, from 01/15/07 to 03/21/07,on 04/02/07, on 09/20/07, and from 10/31/07 to 04/08/08. Throughput and BV estimated based on Wells 1 and 2 totalizers.

(c) Totalizer on treated water line broken from 04/25/06 to 07/10/06, from 08/21/06 to 09/17/06, and from 02/19/08 to 03/07/08.

(d) No operational data taken from 06/12/06 to 06/19/06, from 09/04/06 to 09/05/06, and from 12/18/06 to 12/22/06.

(e) Well 1 totalizer broken from 05/29/07 to 05/31/07, on 08/17/07, and from 10/25/07 to 10/26/07.

(f) Hour meter broken from 06/18/07 to 08/06/07; operational hours estimated by dividing total volume from Wells 1 and 2 by flowrate readings from Vessel A flowmeter/totalizer.

(g) Tank A pressure readings questionable from 06/26/07 to 08/23/07.

(h) Well 2 totalizer broken from 04/25/06 to 05/21/06. Throughput and BV estimated based on readings of effluent totalizer.

NA = not available.

NM = not measured.

off = well pumps not running when operator was onsite taking operational data.

APPENDIX B

ANALYTICAL DATA

Table B-1. Analytical Results from Long-Term Sampling, Alvin, TX

Sampling Date		04/25/06[a, b]				05/09/06[a, b]				05/23/06[c, d]				06/06/06[b]			
Sampling Location / Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10^3	-	-	1.3		-	-	2.2		-	-	3.4		-	-	4.4	
Alkalinity (as $CaCO_3$)	mg/L	361	366	370	370	347	372	363	355	355	347	351	355	346	342	367	363
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	1.2	1.4	1.3	1.3	-	-	-	-	1.3	1.3	1.3	1.4	-	-	-	-
Sulfate	mg/L	1	2	2	2	-	-	-	-	2	2	1	2	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	-	-	-	-	<0.05	<0.05	<0.05	<0.05	-	-	-	-
Total P (as P)	µg/L	48.5	42.6	<10	<10	48.2	46.0	10.0	<10	34.4	34.3	46.6	48.0	51.5	43.4	18.9	<10
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	15.2	15.7	15.4	15.3	17.0	14.8	16.4	12.6	15.6	16.6	16.0	16.1	15.4	16.2	16.4	16.5
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	0.6	0.3	0.5	0.4	0.3	0.4	0.2	0.2	0.8	0.3	0.2	0.2	0.3	0.5	1.2	0.5
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	7.9	7.6	7.7	7.6	7.9	7.7	8.0	7.9	8.0	7.5	7.7	7.8	7.8	7.3	7.7	7.6
Temperature	°C	27.7	28.1	28.3	27.9	32.8	33.8	32.1	30.7	25.0	25.0	25.0	25.0	27.6	27.2	27.0	27.2
DO	mg/L	3.0	1.9	2.8	2.0	2.8	1.8	3.5	2.8	1.5	1.7	1.7	1.2	1.6	1.2	4.2	3.5
ORP	mV	217	605	619	628	254	548	292	464	321	407	360	377	365	556	510	397
Free Chlorine	mg/L	<0.02	1.8	1.5	1.5	-	0.3	0.5	0.2	-	0.7	0.8	0.9	-	0.5	0.1	0.4
Total Chlorine	mg/L	<0.1	1.8	1.5	1.6	-	0.3	0.7	0.5	-	0.7	0.8	1.0	-	0.6	0.2	0.5
Total Hardness (as $CaCO_3$)	mg/L	44.9	44.4	43.8	44.1	-	-	-	-	31.0	30.0	28.4	25.9	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	32.7	32.2	32.0	32.3	-	-	-	-	18.8	18.0	17.0	15.7	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	12.3	12.2	11.8	11.8	-	-	-	-	12.3	12.0	11.3	10.2	-	-	-	-
As (total)	µg/L	30.2	32.1	0.2	<0.1	34.6	34.0	2.4	0.8	34.7	38.1	29.6	27.7	47.9	26.9	3.8	0.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	27.4	26.2	<0.1	<0.1	-	-	-	-	32.6	30.5	28.5	29.7	-	-	-	-
As (particulate)	µg/L	2.9	5.9	<0.1	<0.1	-	-	-	-	2.1	7.6	1.1	<0.1	-	-	-	-
As (III)	µg/L	21.9	<0.1	<0.1	<0.1	-	-	-	-	29.5	0.5	26.2	0.6	-	-	-	-
As (V)	µg/L	5.5	26.1	<0.1	<0.1	-	-	-	-	3.1	30.0	2.3	29.1	-	-	-	-
Fe (total)	µg/L	72	34	<25	<25	66	42	<25	<25	60	<25	46	<25	87	69	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	43	<25	<25	<25	-	-	-	-	<25	<25	<25	<25	-	-	-	-
Mn (total)	µg/L	61.3	57.1	2.5	0.3	59.2	53.8	1.3	0.4	52.3	45.8	50.9	44.8	56.1	45.4	2.9	0.9
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	61.0	14.5	1.2	<0.1	-	-	-	-	51.8	1.4	51.3	1.9	-	-	-	-

(a) Due to lack of combined IN sample tap, IN sample taken at Cl_2 injection point after Cl_2 injection turned off and thus no residual Cl_2 detected.

(b) Due to incorrect location of TA sample tap, effluent TA and TB samples taken from tank's 1-inch drain line.

(c) TA and TB sample taps relocated on 05/17/06

(d) IN sample tap relocated on 05/24/06.

Table B-1. Analytical Results from Long-Term Sampling, Alvin, TX (Continued)

Sampling Date		06/21/06[a, b]				7/5/2006				7/19/2006				08/01/06[k]			
Sampling Location / Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10^3	-	-	5.6		-	-	6.4		-	-	7.3		-	-	8.0	
Alkalinity (as $CaCO_3$)	mg/L	338	359	371	359	339	352	352	356	340	353	349	353	344	349	357	362
		-	-	-	-	-	-	-	-	-	-	-	-	341	350	354	350
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	1.2	1.2	1.3	1.4	-	-	-	-	1.4	1.4	1.7	1.9	-	-	-	-
Sulfate	mg/L	<1	2	2	1	-	-	-	-	<1	1	1	1	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	-	-	-	-	<0.05	<0.05	<0.05	<0.05	-	-	-	-
Total P (as P)	µg/L	44.5	45.9	13.6	<10	37.8	40.2	12.4	<10	25.2	20.4	<10	<10	35.5	28.9	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-	31.9	33.0	<10	<10
Silica (as SiO_2)	mg/L	14.4	14.8	15.3	15.2	15.4	16.3	16.0	15.8	15.1	15.2	15.8	15.6	15.5	16.4	17.0	16.5
		-	-	-	-	-	-	-	-	-	-	-	-	15.9	16.3	16.1	16.8
Turbidity	NTU	0.6	0.6	0.5	0.5	0.5	0.5	0.2	0.1	0.1	0.5	0.2	0.1	0.2	0.3	0.3	0.2
		-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.3	0.2	0.2
pH	S.U.	7.6	7.6	7.7	7.8	7.5	7.4	7.8	7.7	7.6	7.6	7.9	7.7	7.8	7.6	7.9	7.8
Temperature	°C	25.8	25.6	24.6	24.5	24.5	24.5	24.3	24.4	24.7	23.9	23.4	23.8	26.0	24.7	25.1	24.8
DO	mg/L	2.1	2.0	3.9	3.2	1.8	1.7	3.3	3.1	1.7	2.3	4.9	4.0	1.4	1.7	3.7	2.9
ORP	mV	302	622	568	477	430	667	461	621	437	459	596	631	345	655	644	652
Free Chlorine	mg/L	-	3.0	1.1	1.1	-	3.2	1.8	1.8	-	1.9	1.5	1.8	-	2.3	1.4	0.9
Total Chlorine	mg/L	-	2.9	1.3	1.2	-	2.5	1.7	1.7	-	2.2	1.6	1.9	-	2.4	1.4	1.0
Total Hardness (as $CaCO_3$)	mg/L	42.5	45.9	44.1	44.5	-	-	-	-	31.1	32.0	31.5	32.7	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	28.7	30.8	29.6	29.9	-	-	-	-	19.1	19.3	19.0	19.8	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	13.8	15.1	14.5	14.6	-	-	-	-	12.1	12.7	12.5	13.0	-	-	-	-
As (total)	µg/L	48.1	32.4	4.8	0.4	44.4	30.5	6.2	0.7	46.3	27.6	6.1	0.8	50.4	34.9	8.3	1.0
		-	-	-	-	-	-	-	-	-	-	-	-	52.5	33.6	7.9	1.1
As (soluble)	µg/L	44.2	27.3	4.6	0.4	-	-	-	-	40.7	24.3	6.1	0.7	-	-	-	-
As (particulate)	µg/L	4.0	5.0	0.2	<0.1	-	-	-	-	5.5	3.4	<0.1	0.1	-	-	-	-
As (III)	µg/L	43.9	0.5	0.4	0.4	-	-	-	-	26.5	1.0	0.6	0.6	-	-	-	-
As (V)	µg/L	0.2	26.9	4.2	<0.1	-	-	-	-	14.2	23.3	5.5	0.1	-	-	-	-
Fe (total)	µg/L	66	44	<25	<25	86	95	<25	<25	100	60	<25	<25	40	<25	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	40	<25	<25	<25
Fe (soluble)	µg/L	<25	<25	<25	<25	-	-	-	-	<25	<25	<25	<25	-	-	-	-
Mn (total)	µg/L	53.6	50.4	2.0	0.4	52.7	53.5	4.0	0.7	50.0	46.0	2.0	0.5	56.2	50.9	2.5	0.3
		-	-	-	-	-	-	-	-	-	-	-	-	53.5	53.2	1.7	0.2
Mn (soluble)	µg/L	52.2	1.1	0.9	0.4	-	-	-	-	49.5	<0.1	0.3	0.1	-	-	-	-

(a) TA and TB taken at each vessel's 1-inch drain line.

(b) Additional samples for TA and TB taken at sample taps located at panel.

Table B-1. Analytical Results from Long-Term Sampling, Alvin, TX (Continued)

Sampling Date		08/16/06[a]				08/29/06				09/12/06				09/27/06[b]			
Sampling Location / Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10^3	-	-	8.8		-	-	9.4		-	-	10.3		-	-	11.0	
Alkalinity (as $CaCO_3$)	mg/L	318 -	343 -	331 -	331 -	696[d] -	384 -	381 -	366 -	352 -	362 -	362 -	362 -	354 -	382 -	388 -	382 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	1.4	1.4	1.5	1.4	-	-	-	-	1.4	1.4	1.4	1.4	-	-	-	-
Sulfate	mg/L	<1	1	2	1	-	-	-	-	<1	2	2	2	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	0.2	-	-	-	-	<0.05	<0.05	<0.05	<0.05	-	-	-	-
Total P (as P)	µg/L	36.2 -	39.2 -	15.9 -	<10 -	50.2 -	53.9 -	33.0 -	<10 -	38.7 -	42.8 -	24.6 -	<10 -	86.7 -	95.0 -	76.3 -	58.7 -
Silica (as SiO_2)	mg/L	15.4 -	15.7 -	15.6 -	16.0 -	14.7 -	15.2 -	15.6 -	15.2 -	15.3 -	15.3 -	15.7 -	15.8 -	14.8 -	15.7 -	16.1 -	15.5 -
Turbidity	NTU	0.2 -	0.3 -	0.2 -	0.1 -	0.2 -	0.3 -	0.1 -	0.3 -	0.2 -	0.3 -	0.1 -	0.2 -	0.3 -	0.2 -	0.2 -	0.1 -
pH	S.U.	7.8	7.6	7.6	7.7	7.6	7.5	7.6	7.7	7.7	7.5	7.6	7.6	7.7	7.5	7.6	7.7
Temperature	°C	24.3	23.9	24.1	24.1	25.6	25.2	25.0	24.8	23.4	23.1	23.1	23.1	22.8	22.3	22.1	21.7
DO	mg/L	1.2	1.5	1.8	1.5	1.4	1.7	2.2	2.9	1.5	2.0	1.7	1.5	NA	NA	NA	NA
ORP	mV	369	655	651	668	423	660	655	655	303	655	639	646	390	660	659	658
Free Chlorine	mg/L	-	2.5	1.8	1.8	-	2.2	1.7	1.5	-	2.6	1.7	1.6	-	2.9	1.7	1.2
Total Chlorine	mg/L	-	2.6	1.9	2.0	-	2.1	1.5	1.6	-	2.9	1.7	1.8	-	3.1	2.0	1.4
Total Hardness (as $CaCO_3$)	mg/L	37.4	42.5	40.5	42.9	-	-	-	-	37.8	40.7	41.2	41.5	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	25.1	29.0	27.8	29.4	-	-	-	-	25.2	26.9	27.2	27.4	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	12.3	13.5	12.7	13.5	-	-	-	-	12.7	13.7	14.0	14.1	-	-	-	-
As (total)	µg/L	51.0 -	35.9 -	8.8 -	1.1 -	40.1 -	23.5 -	7.6 -	0.6 -	49.8 -	34.9 -	10.0 -	0.8 -	39.8 -	26.7 -	10.9 -	4.3 -
As (soluble)	µg/L	45.1	30.5	8.6	0.9	-	-	-	-	44.7	28.6	9.1	0.8	-	-	-	-
As (particulate)	µg/L	5.9	5.4	0.1	0.2	-	-	-	-	5.1	6.3	0.9	<0.1	-	-	-	-
As (III)	µg/L	44.1	0.7	0.7	0.6	-	-	-	-	39.4	0.4	0.4	0.4	-	-	-	-
As (V)	µg/L	1.0	29.8	8.0	0.2	-	-	-	-	5.3	28.1	8.7	0.3	-	-	-	-
Fe (total)	µg/L	52 -	37 -	<25 -	<25 -	34 -	42 -	<25 -	<25 -	45 -	<25 -	<25 -	<25 -	58 -	43 -	<25 -	<25 -
Fe (soluble)	µg/L	38	<25	<25	<25	-	-	-	-	<25	<25	<25	<25	-	-	-	-
Mn (total)	µg/L	52.3 -	52.7 -	1.5 -	0.4 -	52.0 -	50.5 -	1.2 -	0.1 -	53.2 -	50.0 -	1.3 -	<0.1 -	56.6 -	54.2 -	2.0 -	0.6 -
Mn (soluble)	µg/L	54.9	0.8	0.2	0.1	-	-	-	-	52.8	0.7	<0.1	<0.1	-	-	-	-

(a) TA and TB sample taps relocated on 08/09/06. Samples no longer taken after each tank's 1-in drainline.

(b) DO readings not taken due to error messages from field meter.

Table B-1. Analytical Results from Long-Term Sampling, Alvin, TX (Continued)

Sampling Date		10/11/06[a]				11/15/06				12/13/06				01/10/07			
Sampling Location / Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10^3	-	-	11.7		-	-	13.0		-	-	14.2		-	-	15.3	
Alkalinity (as $CaCO_3$)	mg/L	371 -	390 -	399 -	392 -	368 -	381 -	404 -	398 -	350 -	360 -	372 -	364 -	382 -	380 -	384 -	392 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.5[c]	-	-	-	-	1.5	1.6	1.6	1.5
Sulfate	mg/L	<1	2	2	2	1	2	2	2	-	-	-	-	<1	2	1	1
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	<0.05	<0.05	<0.05	<0.05
Total P (as P)	µg/L	28.1 -	39.3 -	19.9 -	<10 -	28.0 -	32.7 -	18.2 -	<10 -	26.9 -	34.8 -	31.3 -	<10 -	43.6 -	42.5 -	27.7 -	<10 -
Silica (as SiO_2)	mg/L	15.9 -	16.0 -	15.3 -	16.5 -	15.9 -	15.7 -	15.8 -	15.1 -	14.7 -	15.2 -	15.3 -	15.4 -	15.5 -	15.5 -	15.7 -	15.7 -
Turbidity	NTU	0.8[h] -	0.8[h] -	0.4 -	0.4 -	0.3 -	0.4 -	0.3 -	0.2 -	0.4 -	0.6 -	0.8[d] -	0.8[d] -	0.6 -	0.9 -	0.6 -	0.3 -
pH	S.U.	7.7	7.5	7.6	7.6	7.7	7.5	7.5	7.6	7.4	7.4	7.5	7.6	7.8	7.6	7.6	7.6
Temperature	°C	23.1	22.8	22.8	22.5	21.9	22.0	22.4	22.4	22.3	22.6	22.5	22.2	21.7	21.7	22.0	22.2
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	317	675	665	672	448	641	628	643	189	189	190	190	339	679	684	642
Free Chlorine	mg/L	-	3.3	1.8	1.7	-	2.0	1.1	1.4	-	2.8	1.6	1.6	-	3.2	2.8	2.7
Total Chlorine	mg/L	-	3.1	1.9	2.0	-	2.2	1.1	1.5	-	3.2	1.7	1.8	-	3.3	2.9	2.8
Total Hardness (as $CaCO_3$)	mg/L	39.6	45.6	45.4	46.6	35.8	39.9	39.8	40.3	-	-	-	-	39.6	41.7	40.2	42.6
Ca Hardness (as $CaCO_3$)	mg/L	26.3	30.0	29.8	30.4	25.4	28.1	28.1	28.2	-	-	-	-	26.4	27.3	26.1	27.9
Mg Hardness (as $CaCO_3$)	mg/L	13.4	15.6	15.6	16.2	10.4	11.9	11.7	12.1	-	-	-	-	13.2	14.4	14.1	14.6
As (total)	µg/L	44.0 -	30.2 -	10.2 -	1.4 -	37.0 -	22.5 -	9.9 -	2.0 -	46.7 -	33.1 -	14.8 -	2.1 -	41.3 -	30.7 -	14.1 -	1.5 -
As (soluble)	µg/L	44.7	26.6	9.8	1.5	34.7	19.6	9.3	1.7	-	-	-	-	40.9	28.0	12.9	1.6
As (particulate)	µg/L	<0.1	3.5	0.4	<0.1	2.3	3.0	0.5	0.3	-	-	-	-	0.4	2.7	1.2	<0.1
As (III)	µg/L	40.7	0.9	1.1	0.8	27.3	1.3	1.6	1.8	-	-	-	-	27.6	1.2	0.9	0.7
As (V)	µg/L	4.1	25.7	8.7	0.8	7.4	18.2	7.7	<0.1	-	-	-	-	13.2	26.8	12.1	0.9
Fe (total)	µg/L	39 -	<25 -	<25 -	<25[b] -	56 -	34 -	<25 -	<25 -	36 -	<25 -	<25 -	<25 -	133 -	95 -	<25 -	<25 -
Fe (soluble)	µg/L	<25	<25	<25	<25	33	<25	<25	<25	-	-	-	-	44	<25	<25	<25
Mn (total)	µg/L	52.9 -	52.6 -	1.0 -	0.5 -	55.8 -	53.9 -	1.4 -	0.2 -	50.4 -	50.1 -	1.7 -	0.4 -	48.9 -	46.2 -	5.7 -	0.2 -
Mn (soluble)	µg/L	55.6	0.9	0.2	0.2	54.4	1.4	0.6	0.1	-	-	-	-	48.9	1.7	0.2	0.5

(a) Sampling reduced to bimonthly.

(b) Reanalyzed by the laboratory, orgininally 63.5 µg/L.

(c) Reanalyzed by laboratory out of hold time, originally 2.6 mg/L.

(d) Elevated levels remained the same after it was checked by the laboratory.

Table B-1. Analytical Results from Long-Term Sampling, Alvin, TX (Continued)

Sampling Date		02/06/07				03/07/07				04/04/07[b]				05/02/07[c]			
Sampling Location / Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10^3	-	-	16.8		-	-	18.3		-	-	19.8		-	-	21.4	
Alkalinity (as $CaCO_3$)	mg/L	372 -	383 -	374 -	383 -	366 -	383 -	378 -	371 -	364 371	364 354	364 366	359 366	389 [378] -	388 -	381 -	374 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	1.5	1.5	1.5	1.5	-	-	-	-	1.1 [1.2]	1.5	1.6	1.4
Sulfate	mg/L	-	-	-	-	1	2	2	2	-	-	-	-	2 [1]	3	2	1
Nitrate (as N)	mg/L	-	-	-	-	<0.05	<0.05	<0.05	<0.05	-	-	-	-	<0.05 [<0.05]	<0.05	<0.05	<0.05
Total P (as P)	µg/L	36.5 -	43.2 -	33.3 -	<10 -	40.6 -	44.8 -	33.2 -	<10 -	43.7 41.6	41.1 39.5	40.5 39.9	16.6 16.6	34.6 [43.5] -	44.3 -	34.5 -	14.9 -
Silica (as SiO_2)	mg/L	15.0 -	15.9 -	15.3 -	15.5 -	14.7 -	15.6 -	15.9 -	15.2 -	15.3 15.5	14.9 15.4	15.2 15.2	15.3 15.2	15.5 [16.5] -	16.7 -	16.9 -	16.4 -
Turbidity	NTU	0.8 -	0.6 -	0.4 -	0.6 -	0.8 -	1.1 -	1.3 -	0.7 -	0.4 0.5	0.3 0.3	0.7 0.4	0.4 0.1	1.2 [0.9] -	0.7 -	0.9 -	0.6 -
pH	S.U.	8.0	7.7	7.7	7.7	7.8	7.5	7.7	7.6	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	21.5	21.4	21.3	21.1	25.2	25.8	25.5	23.7	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	2.4	2.0	3.2	2.7	1.7	1.7	2.6	3.3	1.3	1.7	1.6	1.5	1.7	1.6	2.9	2.7
ORP	mV	328	655	673	675	210	681	670	679	254	687	670	674	251	673	637	663
Free Chlorine	mg/L	-	2.1	1.6	1.5	-	2.9	1.2	1.3	-	2.7	1.2	1.2	-	1.6	0.8	1.0
Total Chlorine	mg/L	-	2.2	1.7	1.6	-	3.0	1.3	1.5	-	2.7	1.3	1.3	-	1.6	0.9	1.1
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	45.3	50.3	48.7	47.7	-	-	-	-	43.2 [44.4]	48.0	40.9	44.0
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	33.0	35.3	34.2	33.4	-	-	-	-	31.1 [30.9]	32.8	28.2	30.7
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	12.3	15.0	14.6	14.4	-	-	-	-	12.1 [13.5]	15.2	12.7	13.3
As (total)	µg/L	48.4 -	28.4 -	16.9 -	2.0 -	44.8 -	30.2 -	14.8 -	2.4 -	39.0 39.4	36.1 35.6	20.1 19.9	4.4 4.4	38.6 [36.9] -	25.5 -	15.1 -	2.9 -
As (soluble)	µg/L	-	-	-	-	39.2	21.9	13.3	2.3	-	-	-	-	34.0 [30.5]	21.3	15.4	2.7
As (particulate)	µg/L	-	-	-	-	5.6	8.2	1.5	<0.1	-	-	-	-	4.6 [6.4]	4.3	<0.1	0.2
As (III)	µg/L	-	-	-	-	17.7[a]	1.0	1.1	1.1	-	-	-	-	30.5 [24.1]	0.4	0.5	0.4
As (V)	µg/L	-	-	-	-	21.5[a]	20.9	12.2	1.2	-	-	-	-	3.5 [6.4]	20.8	15.0	2.3
Fe (total)	µg/L	80 -	36 -	<25 -	<25 -	41 -	27 -	<25 -	<25 -	<25 <25	<25 <25	<25 <25	<25 <25	48 [197] -	37 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	<25	<25	<25	<25	-	-	-	-	25.3 [<25]	<25	<25	<25
Mn (total)	µg/L	47.3 -	49.1 -	1.4 -	0.2 -	52.2 -	50.5 -	7.6 -	<0.1 -	50.0 49.9	43.5 43.7	0.5 0.4	<0.1 <0.1	55.9 [58.1] -	52.7 -	2.3 -	<0.1 -
Mn (soluble)	µg/L	-	-	-	-	50.9	1.3	<0.1	<0.1	-	-	-	-	49.3 [55.6]	0.7	<0.1	<0.1

(a) Samples were rerun but showed similar results.

(b) Starting 04/04/07, IN sample taken at original chlorine injection point further downstream of the Well 1 and 2 blending point.

(c) Samples taken at orginal sample point on 05/09/07. [Sample taken at relocated sample tap on 05/02/07].

Table B-1. Analytical Results from Long-Term Sampling, Alvin, TX (Continued)

Sampling Date		06/12/07				06/27/07				07/25/07[a]				08/22/07			
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10^3	-	-	23.9		-	-	24.8		-	-	26.1		-	-	27.7	
Alkalinity (as $CaCO_3$)	mg/L	387	363	366	356	377	370	377	365	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	1.5	1.7	1.6	1.6	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	2	2	2	2	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-
Total P (as P)	μg/L	36.5	35.1	37.6	26.2	37.3	35.6	27.0	17.6	41.9	38.1	36.8	25.9	41.7	45.6	42.1	32.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	16.8	16.2	15.9	16.1	16.1	15.9	16.1	15.7	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	0.8	1.0	0.7	0.6	0.5	0.3	0.4	0.3	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	NA	NA	NA	NA	8.1	7.9	7.9	7.9	NA	NA	NA	NA	8.1	7.8	7.9	7.9
Temperature	°C	NA	NA	NA	NA	22.7	22.7	22.9	23.0	NA	NA	NA	NA	25.4	25.3	25.2	25.1
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.2	1.7	3.0	2.0
ORP	mV	NA	NA	NA	NA	265	546	531	567	NA	NA	NA	NA	239	538	549	367
Free Chlorine	mg/L	-	NA	NA	NA	-	1.4	0.7	0.9	-	NA	NA	NA	-	2.2	0.8	0.6
Total Chlorine	mg/L	-	NA	NA	NA	-	1.6	0.8	1.0	-	NA	NA	NA	-	2.2	0.8	0.6
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	45.8	47.1	44.6	44.7	-	-	-	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	31.3	32.8	31.1	31.0	-	-	-	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	14.5	14.3	13.6	13.7	-	-	-	-	-	-	-	-
As (total)	μg/L	36.5	34.2	19.8	4.8	29.8	26.6	19.0	4.2	32.1	36.6	22.6	6.0	41.4	40.2	26.0	7.9
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	μg/L	-	-	-	-	25.3	22.2	16.5	3.6	-	-	-	-	34.4	28.6	22.1	7.3
As (particulate)	μg/L	-	-	-	-	4.5	4.4	2.5	0.6	-	-	-	-	6.9	11.6	3.9	0.6
As (III)	μg/L	-	-	-	-	24.6	<0.1	<0.1	<0.1	-	-	-	-	31.0	0.8	0.8	0.7
As (V)	μg/L	-	-	-	-	0.7	22.1	16.4	3.5	-	-	-	-	3.4	27.8	21.3	6.7
Fe (total)	μg/L	27	<25	<25	<25	37	30	<25	<25	26	52	<25	<25	117	88	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	μg/L	-	-	-	-	<25	<25	<25	<25	-	-	-	-	<25	<25	<25	<25
Mn (total)	μg/L	60.6	52.0	0.8	<0.1	57.2	53.0	2.1	0.3	53.3	42.6	3.1	0.1	55.9	49.1	2.2	<0.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	μg/L	-	-	-	-	60.0	1.9	0.2	0.1	-	-	-	-	56.9	0.4	<0.1	0.6

(a) Starting July 2007, analytes reduced to As, Fe, Mn, and P. Speciation samples are conducted every other month.

Table B-1. Analytical Results from Long-Term Sampling, Alvin, TX (Continued)

Sampling Date		09/12/07[a, b]				10/03/07				11/06/07[c]				11/27/07			
Sampling Location / Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10^3	-	-	28.7		-	-	29.8		-	-	31.6		-	-	32.8	
Alkalinity (as $CaCO_3$)	mg/L	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Ammonia (as N)	mg/L	0.2	0.2	-	-	0.2	<0.05	<0.05	<0.05	0.2	<0.05	<0.05	<0.05	0.2	0.1	<0.05	<0.05
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	46.5 -	47.3 -	52.9 -	52.6 -	30.5 -	32.5 -	32.6 -	29.7 -	44.9 -	47.3 -	44.8 -	43.4 -	42.5 -	50.5 -	43.9 -	38.4 -
Silica (as SiO_2)	mg/L	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Turbidity	NTU	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
pH	S.U.	8.0	7.9	7.9	7.9	8.0	7.7	7.7	7.7	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	23.9	23.8	23.8	23.7	22.1	22.1	22.4	22.3	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	2.5	1.2	1.3	1.4	2.7	1.6	2.7	3.1	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	394	272	265	257	245	652	641	656	NA	NA	NA	NA	NA	NA	NA	NA
Free Chlorine	mg/L	-	NA	NA	NA	-	2.2	1.2	1.4	-	NA	NA	NA	-	NA	NA	NA
Total Chlorine	mg/L	-	NA	NA	NA	-	2.2	1.3	1.3	-	NA	NA	NA	-	NA	NA	NA
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L	40.9 -	40.7 -	27.7 -	10.4 -	31.6 -	31.2 -	24.9 -	8.1 -	44.1 -	41.2 -	28.5 -	10.6 -	35.6 -	24.1 -	21.3 -	8.5 -
As (soluble)	µg/L	-	-	-	-	26.9	24.6	20.1	10.8	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	4.7	6.5	4.8	<0.1	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	24.7	0.4	0.4	0.5	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	2.2	24.3	19.8	10.3	-	-	-	-	-	-	-	-
Fe (total)	µg/L	32 -	<25 -	<25 -	<25 -	31 -	<25 -	<25 -	<25 -	137 -	169 -	<25 -	<25 -	145 -	47 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	<25	<25	<25	<25	-	-	-	-	-	-	-	-
Mn (total)	µg/L	57.8 -	53.3 -	0.2 -	<0.1 -	60.7 -	52.6 -	<0.1 -	<0.1 -	61.0 -	55.0 -	9.6 -	<0.1 -	53.5 -	48.5 -	2.9 -	0.3 -
Mn (soluble)	µg/L	-	-	-	-	63.4	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-

(a) One time sampling event for ammonia at IN and AC.

(b) Chlorine addition was switched to post-chlorination (instead of pre-chlorination) two weeks prior, by mistake.

(c) Starting Nov 2007, sampling frequency increased to biweekly due to lag vessel total As > 10 ug/L in Sept. Analytes are total As, Fe, Mn, total P, and NH_3.

Table B-1. Analytical Results from Long-Term Sampling, Alvin, TX (Continued)

Sampling Date		01/02/08				01/29/08				03/13/08				03/25/08				04/08/08			
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10^3	-	-	33.7		-	-	35.0		-	-	36.8		-	-	37.4		-	-	38.1	
Alkalinity (as $CaCO_3$)	mg/L	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Ammonia (as N)	mg/L	0.2	<0.05	<0.05	<0.05	0.2	0.1	0.1	0.1	0.1 0.1	<0.05 0.1	<0.05 <0.05	<0.05 <0.05	0.1	<0.05	<0.05	<0.05	0.1	<0.05	<0.05	<0.05
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	40.0 -	39.6 -	36.1 -	39.1 -	48.9 -	51.8 -	43.9 -	48.8 -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Silica (as SiO_2)	mg/L	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Turbidity	NTU	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
pH	S.U.	NA	NA	NA	NA	8.0	7.8	7.9	7.9	NA	NA	NA	NA	8.0	7.8	7.8	7.8	7.9	7.7	7.7	7.7
Temperature	°C	NA	NA	NA	NA	23.8	23.8	23.6	27.6	NA	NA	NA	NA	21.5	21.4	21.4	21.3	25.0	25.0	25.0	25.0
DO	mg/L	NA	NA	NA	NA	2.5	2.4	2.5	2.2	2.9	2.9	4.1	4.3	2.7	2.2	2.8	2.0	2.8	2.0	2.2	1.9
ORP	mV	NA	NA	NA	NA	416	642	483	454	366	593	605	603	395	657	660	653	414	660	708	687
Free Chlorine	mg/L	-	NA	NA	NA	-	2.2	0.7	0.4	-	0.8	0.7	0.8	-	1.5	1.0	0.9	-	1.9	3.2	2.5
Total Chlorine	mg/L	-	NA	NA	NA	-	2.3	0.7	0.4	-	1.0	0.7	0.8	-	1.6	1.2	1.1	-	1.9	3.4	2.6
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L	34.4 -	32.2 -	22.3 -	9.2 -	31.6 -	27.6 -	16.7 -	7.3 -	27.5 27.5	31.1 31.4	26.6 25.8	10.4 10.4	31.3 -	30.5 -	23.5 -	10.2 -	33.6 -	28.0 -	23.2 -	10.5 -
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	42 -	32 -	<25 -	<25 -	66 -	67 -	29 -	31 -	121 86	91 51	<25 <25	<25 <25	46 -	34 -	<25 -	<25 -	93 -	48 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	62.0 -	50.3 -	2.0 -	0.3 -	50.4 -	44.0 -	0.7 -	0.2 -	66.6 64.9	54.6 55.4	1.2 1.1	0.6 0.6	57.8 -	50.7 -	1.1 -	<0.1 -	56.7 -	53.8 -	1.5 -	<0.1 -
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-