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Arsenic Removal from Drinking Water by Adsorptive Media
U.S. EPA Demonstration Project at Wellman, TX
Six-Month 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 from the first six months of the arsenic removal treatment technology demonstration project in the City of Wellman, TX. The main objective of the project was to evaluate the effectiveness of AdEdge Technologies' AD-33 media in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 μg/L. Additionally, this project evaluates 1) the reliability of the treatment system (Arsenic Package Unit [APU]-100CS-S-2-AVH), 2) the required system operation and maintenance (O&M) and operator skills, and 3) the capital and O&M cost of the technology. The project also characterizes the water in the distribution system and any residuals produced by the treatment process. The types of data collected include system operation, water quality parameters (both across the treatment train and in the distribution system), and capital and O&M cost.

The treatment system consisted of two 48-in-diameter, 72-in-tall carbon steel vessels in parallel configuration, each containing approximately 38 ft^3 of E33 pelletized media, which is an iron-based adsorptive media developed by Bayer AG and marketed under the name of AD-33 by AdEdge. The treatment system was designed for a maximum flowrate of 100 gal/min (gpm) and an empty bed contact time (EBCT) of approximately 5.7 min per vessel.

Over the six-month operational period, the calculated average flowrate was 121 gpm based on the APU system electromagnetic flow meters/totalizers and hour meter. This calculated average flowrate was significantly greater than the design value and pre-existing master totalizer average of 86 gpm. Based on a one-day flowrate test using a portable ultrasonic flow meter, it was determined that the APU system flow meters/totalizers were the least accurate of the meters. Therefore, the master totalizer was used for the purposes of this performance evaluation, and the use of the APU system flow meters/totalizers was discontinued until the sensor's K-factors are adjusted to compensate for the inaccuracy.

The AdEdge treatment system began regular operation on August 10, 2006. Between August 10, 2006, and February 9, 2007, the system operated an average of 4.5 hr/day, treating approximately 4,218,200 gal of water. This volume of treated water was equivalent to about 7,420 bed volumes (BV) based on the 38 ft^3 of media in each adsorption vessel.

Total arsenic concentrations measured in the IN samples varied significantly from 6.0 to 45.9 μg/L. Soluble As(V) was the predominate species, ranging from 11.2 to 41.2 μg/L; soluble As(III) concentrations ranged from 0.4 to 1.6 μg/L. A review of the significant variations measured in the IN samples identified that system operations and sampling techniques were likely contributing to the concentration variations. In fact, the after chlorination sample results provided concentrations in a more realistic range and are believed to me more representative of the true water quality. The total arsenic concentrations in the AC samples ranged from 37.5 to 47.2 μg/L. Soluble As(V) in the AC samples remained predominate, ranging from 38.1 to 43.6 μg/L; soluble As(III) concentrations ranged from 0.7 to 2.0 μg/L.

As of February 6, 2007, total arsenic levels in the treated water following Vessels A and B were 1.2 and 1.8 μg/L, respectively at approximately 7,326 BV. Concentrations of vanadium, phosphate, and silica, which could adversely affect arsenic adsorption by competing with arsenate for adsorption sites, averaged 144 μg/L, <10 μg/L (as P), and 44.5 mg/L (as SiO_2), respectively, in AC samples. Vanadium existed primarily in the soluble form (at 95%) and its concentrations were reduced to <3.2 μg/L in the treated water. Concentrations of iron, manganese, and other ions in raw water were not considered significant enough to impact arsenic removal by the media.

Comparison of the distribution system sampling results before and after operation of the system showed a significant decrease in arsenic concentration (from an average of 38.9 µg/L to an average of 3.3 µg/L). The arsenic concentrations in the distribution system were similar to those in the system effluent. Lead and copper concentrations in the distribution system remained below their respective action level of 15 and 1,300 µg/L and their levels were not adversely affected by the operation of the system.

The capital investment cost of $149,221 included $103,897 for equipment, $25,310 for site engineering, and $20,014 for installation. Using the system's rated capacity of 100 gpm (or 144,000 gal/day [gpd]), the capital cost was $1,492/gpm (or $1.04/gpd) of design capacity. The capital cost also was converted to an annualized cost of $14,085/yr using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-year return period. Assuming that the system operated 24 hours a day, 7 days a week at the system design flowrate of 100 gpm to produce 52,560,000 gal of water per year, the unit capital cost would be $0.27/1,000 gal. Because the system actually operated an average of 4.5 hr/day at an average flowrate less than 90 gpm, during the first 6 months of operation, the approximate annual water production was 8,436,400 gal, and the actual unit capital cost was $1.67/1,000 gal of water.

The O&M cost included only incremental cost associated with the adsorption system, such as media replacement and disposal, chlorine usage, electricity consumption, and labor. Although media replacement did not occur during the first six months of system operation, the media replacement cost would represent the majority of the O&M cost and was estimated to be $30,010 to change out both vessels (including 76 ft^3 AD-33 media and associated labor for media change out and disposal).

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ABBREVIATIONS AND ACRONYMS

Δp	differential pressure
AAL	American Analytical Laboratories
AM	adsorptive media
APU	arsenic package unit
As	arsenic
ATS	Aquatic Treatment System
BET	Brunauer, Emmett, and Teller
BV	bed volume
Ca	calcium
C/F	coagulation/filtration process
Cl	chlorine
CRF	capital recovery factor
Cu	copper
DO	dissolved oxygen
EBCT	empty bed contact time
EPA	U.S. Environmental Protection Agency
F	fluorine
Fe	iron
FRP	fiberglass reinforced plastic
GFH	granular ferric hydroxide
gpd	gallons per day
gpm	gallons per minute
HCl	hydrochloric acid
HDPE	high-density polyethylene
HIX	hybrid ion exchange
Hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IX	ion exchange
LCR	Lead and Copper Rule
LOU	Letter of Understanding
MCL	maximum contaminant level
MDL	method detection limit
MEI	Magnesium Elektron, Inc.
Mg	magnesium
Mn	manganese
mV	millivolts

ABBREVIATIONS AND ACRONYMS (Continued)

Na	sodium
NA	not analyzed
NaOCl	sodium hypochlorite
ND	not detectable
NRMRL	National Risk Management Research Laboratory
NTU	Nephelometric Turbidity Units
O&M	operation and maintenance
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
PLC	programmable logic controller
psi	pounds per square inch
PO_4	orthophosphate
POE	point of entry
POU	point of use
PVC	polyvinyl chloride
QA	quality assurance
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RO	reverse osmosis
RPD	relative percent difference
SDWA	Safe Drinking Water Act
SiO_2	silica
SMCL	secondary maximum contaminant level
SO_4^{2-}	sulfate
STS	Severn Trent Services
TCEQ	Texas Commission on Environmental Quality
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
U	uranium
V	vanadium
VOC	volatile organic compounds
WTW	Wissenschaftlich-Technische-Werkstätten

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Section 1.0: INTRODUCTION

1.1 Background

The Safe Drinking Water Act (SDWA) mandates that the U.S. Environmental Protection Agency (EPA) identify and regulate drinking water contaminants that may have adverse human health effects and that are known or anticipated to occur in public water supply systems. In 1975 under the SDWA, EPA established a maximum contaminant level (MCL) for arsenic at 0.05 mg/L. Amended in 1996, the SDWA required that EPA develop an arsenic research strategy and publish a proposal to revise the arsenic MCL by January 2000. On January 18, 2001, EPA finalized the arsenic MCL at 0.01 mg/L (EPA, 2001). In order to clarify the implementation of the original rule, EPA revised the rule text on March 25, 2003 to express the MCL as 0.010 mg/L (10 µg/L) (EPA, 2003). The final rule 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 cost. 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 sites from a list of 115 sites to be the host sites for the demonstration studies.

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the 17 host sites. EPA received 70 technical proposals for the 17 host sites, with each site receiving from one to six proposals. In April 2003, an independent technical panel reviewed the proposals and provided its recommendations to EPA on the technologies that it determined were acceptable for the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the Round 1 demonstration program. 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 City of Wellman, 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. AdEdge Technologies' (AdEdge) Bayoxide E33 granular media (developed by Bayer AG) was selected for demonstration at the Wellman site. As of May 2008, 38 of the 40 systems were operational, and the performance evaluation of 30 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 systems, two ion exchange (IX) systems, 17 point-of-use (POU) units (including nine under-the-sink reverse osmosis [RO] units at the Sunset Ranch Development site and eight AM units at the OIT site), and one process modification. Table 1-1 summarizes the locations, technologies, vendors, system flowrates, and key source water quality parameters (including arsenic, iron, and pH) at the 40 demonstration sites. An overview of the technology selection and system design for the 12 Round 1 demonstration sites and the associated capital cost is provided in two EPA reports (Wang et al., 2004; Chen et al., 2004), which are posted on the EPA Web site at http://www.epa.gov/ORD/NRMRL/wswrd/dw/arsenic/.

1.3 Project Objectives

The objective of the Round 1 and Round 2 arsenic demonstration program is to conduct full-scale arsenic treatment technology demonstration studies on the removal of arsenic from drinking water supplies. The specific objectives are to:

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

This report summarizes the performance of the AdEdge system at the City of Wellman, TX during the first six-months of operation from August 10, 2006, through February 9, 2007. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and preliminary O&M cost.

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

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH (S.U.)
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 Round 1 and Round 2 Arsenic Removal Demonstration Locations, Technologies, and Source Water Quality (Continued)

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

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

(a) Arsenic existing mostly as As(III).
(b) Design flowrate reduced by 50% due to system reconfiguration from parallel to series operation.
(c) Iron existing mostly as Fe(II).
(d) Replaced Village of Lyman, NE site which withdrew from 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.

Section 2.0: SUMMARY AND CONCLUSIONS

AdEdge's APU-100CS-S-2-AVH treatment system with AD-33 pelletized media was installed and has operated in the City of Wellman, TX since August 10, 2006. Based on the information collected during the first six months of system operation, the following summary and conclusion statements are provided:

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

- AD-33 media was effective at removing soluble As(V). Through the first six months of operation from August 10, 2006, through February 9, 2007, the system treated 4,218,200 gal or 7,420 BV of water, leaving only trace levels, i.e., <1.1 µg/L (on average), in the treated water.
- The arsenic treatment system significantly reduced arsenic concentrations (from 38.9 to 3.3 µg/L, on average) in the distribution system. Impact of the treatment on lead and copper concentrations, however, was less significant, with lead concentrations remaining relatively unchanged from 0.2 to 0.3 µg/L (on average) and copper concentrations decreasing from 115 to 85.0 µg/L (on average).

Required system O&M and operator skill levels:

- The system was easy to operate and maintain. The daily demand on the operator was 15 min after system startup, but progressively decreased to only 3 min by the end of the first six-month period.
- Operation of the system did not require additional skills beyond those necessary to operate the existing water supply equipment, with the exception of the pH adjustment system. The pH adjustment system required additional operator training and safety awareness.

Process residuals produced by the technology:

- The treatment system did not require backwash (because pressure differential [Δp] measured across the media vessels did not reach 10 psi, the Δp set point) or produce any residual media during the first six months of system operation.

Cost-effectiveness of the technology:

- Based on the system's rated capacity of 100 gpm (or 144,000 gpd), the capital cost was $1,492/gpm (or $1.04/gpd) of design capacity.
- Media replacement and subsequent disposal did not occur during the first six months of system operation. The cost to change out two vessels (76 ft^3 AD-33 media) is estimated to be $30,010, which includes the replacement media, spent media disposal, shipping, labor, and travel.

Section 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 AdEdge treatment system began on August 10, 2006. Table 3-2 summarizes the types of data collected and/or considered as part of the technology evaluation process. The overall performance of the system was determined based on its ability to consistently remove arsenic to below the arsenic MCL of 10 µg/L through the collection of water samples across the treatment train, as described in a Performance Evaluation Study Plan (Battelle, 2005). The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

Table 3-1. Predemonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	November 18, 2004
Project Planning Meeting Held	March 22, 2005
Draft Letter of Understanding (LOU) Issued	March 29, 2005
Final Letter of Understanding (LOU) Issued	April 12, 2005
Request for Quotation Issued to Vendor	April 20, 2005
Vendor Quotation Received by Battelle	May 30, 2005
Purchase Order Completed and Signed	June 28, 2005
Engineering Plans Submitted to TCEQ	August 25, 2005
APU System Shipped and Arrived	October 14, 2005
System Permit Issued by TCEQ	February 2, 2006
System Installation Completed	June 20, 2006
System Shakedown Completed	August 9, 2006
Final Study Plan Issued	December 28, 2005
Performance Evaluation Begun	August 10, 2006

TCEQ = Texas Commission on Environmental Quality
APU = arsenic package unit

The required system O&M and operator skill levels were evaluated through quantitative data and qualitative considerations, including the need for pre- and/or post-treatment, level of system automation, extent of preventive maintenance activities, frequency of chemical and/or media handling and inventory, and general knowledge needed for relevant chemical processes and related health and safety practices. The staffing requirements for the system operation were recorded on an Operator Labor Hour Log Sheet.

The cost of the system was evaluated based on the capital cost per gal/min (gpm) (or gal/day [gpd]) of design capacity and the O&M cost per 1,000 gal of water treated. This task requires the tracking of the capital cost for equipment, site engineering, and installation, as well as the O&M cost for media replacement and disposal, chlorine consumption, electrical power usage, and labor. Data on Wellman O&M cost were limited to electricity usage and labor because media replacement did not take place during the first six months of system operation and chlorine consumption was not recorded.

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 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, engineering, and installation -O&M cost for chemical usage, electricity consumption, and labor

3.2 System O&M and Cost Data Collection

The plant operator performed daily, biweekly, and monthly system O&M and data collection according to instructions provided by the vendor and Battelle. On a daily basis, the plant operator recorded system operational data, such as pressure, flowrate, totalizer, and hour meter readings on a Daily System Operation Log Sheet; checked the sodium hypochlorite (NaOCl) level; and conducted visual inspections to ensure normal system operations. In the event of problems, the plant operator contacted the Battelle Study Lead, who determined if the vendor should be contacted for troubleshooting. The plant operator recorded all relevant information, including the problem encountered, course of action taken, materials and supplies used, and associated cost and labor, on the Repair and Maintenance Log Sheet. Every other week, the plant operator measured pH, temperature, dissolved oxygen (DO), and oxidation-reduction potential (ORP), and recorded the data on a Bi-Weekly Water Quality Parameters Log Sheet.

The capital cost for the arsenic removal system consisted of the cost for equipment, site engineering, and system installation. The O&M cost consisted of the cost for media replacement and spent media disposal, chemical and electricity consumption, and labor. Electricity consumption was tracked through the on-site electric meter. Labor for various activities, such as routine system O&M, troubleshooting, and repair and demonstration-related work was tracked using Operator Labor Hour Log Sheets. The routine O&M included activities such as completing field logs, replenishing chemical solutions, ordering supplies, performing system inspections, and others as recommended by the vendor. The demonstration-related labor, 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 performance of the system, samples were collected from the wellhead, across the treatment train, from the backwash discharge line, and from the distribution system. Table 3-3 provides the sampling schedule and analytes for each sampling event. In addition, 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

Table 3-3. Sampling Schedule and Analytes

Sample Type	Sample Locations[a]	No. of Samples	Frequency	Analytes	Collection Date(s)
Source Water	IN	1	Once (during initial site visit)	On-site: pH, temperature, DO, and ORP Off-site: As (total and soluble), As(III) & As(V), Fe (total and soluble), Mn (total and soluble), Sb (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 TOC	11/18/04
Treatment Plant Water	IN, AC, TA, and TB	4	Monthly	On-site[b]: pH, temperature, DO, ORP, and Cl_2 (free and total). Off-site: total As, Fe, Mn, P, and V, SiO_2, turbidity, and alkalinity	08/30/06, 09/20/06, 10/19/06, 11/15/06, 01/03/07, 02/06/07
	IN, AC, and TT	3	Monthly	Same as above plus following: Off-site: As(III) & As(V), Fe (soluble), Mn (soluble), V (soluble), Ca, Mg, F, NO_3, SO_4, and TOC	08/10/06, 09/06/06, 10/02/06, 11/02/06, 11/28/06, 12/14/06, 01/18/07
Backwash Wastewater	Backwash Discharge Line from Each Vessel	2	Monthly or as needed	pH, TDS, TSS, As (total and soluble), Fe (total and soluble), and Mn (total and soluble)	To be determined
Distribution Water	Three residences (including two LCR residences)	3	Monthly	Total As, Fe, Mn, Cu, V (total and soluble) and Pb, pH, and alkalinity	Baseline sampling[c]: 06/22/05, 07/14/05, 08/18/05, 09/14/05 Monthly sampling: 09/06/06, 10/10/06, 11/15/06, 12/14/06, 01/18/07

(a) Abbreviation (IN = at wellhead; AC = after chlorination; TA = after Vessel A; TB = after Vessel B; TT = after Vessels A and B combined) corresponding to sample location in Figure 3-1.

(b) On-site measurements of chlorine not collected at IN.

(c) Sampling events performed before system startup.

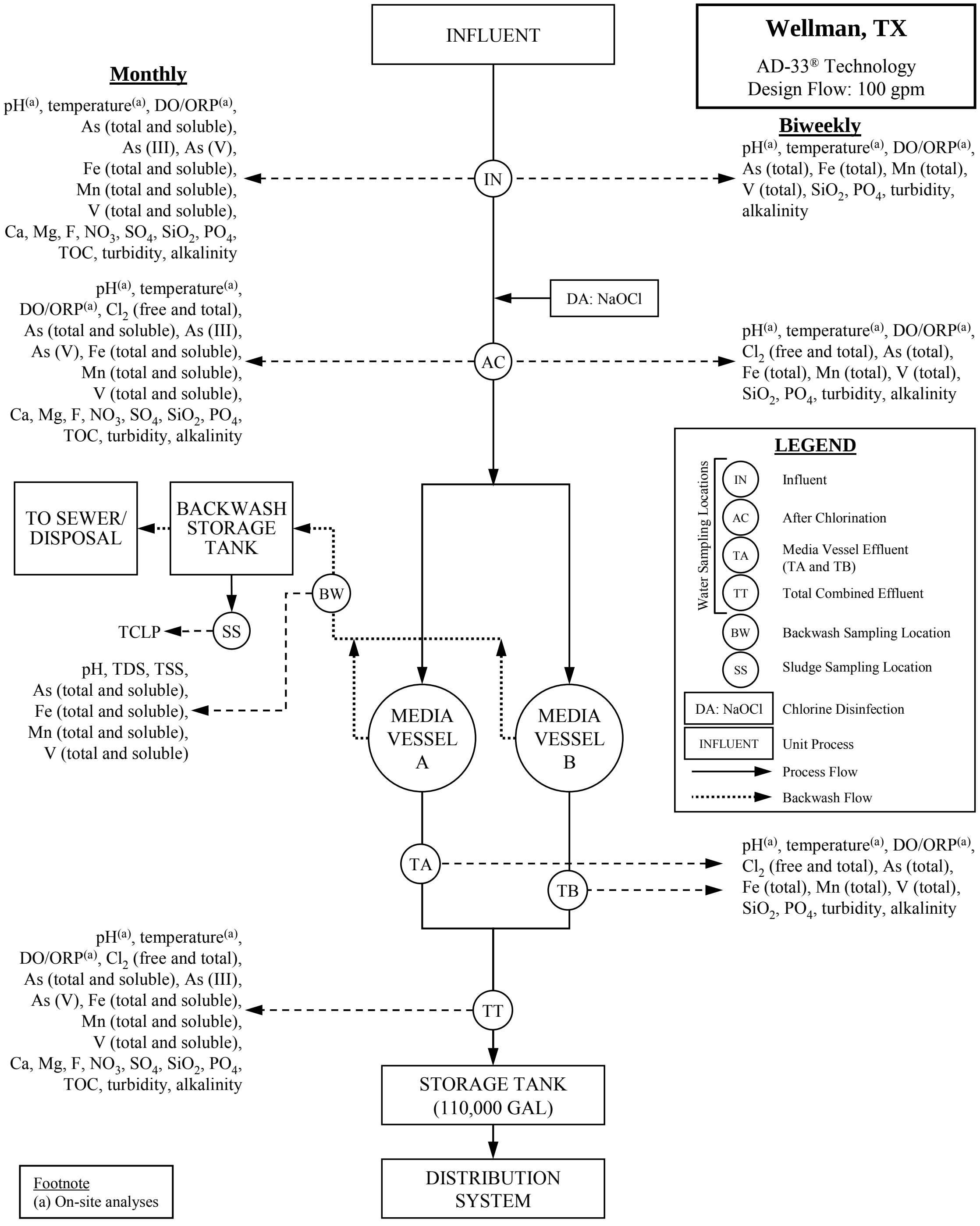

Figure 3-1. Process Flow Diagram and Sampling Schedule and Locations

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 Sample Collection. During the site visit on November 18, 2004, source water samples were collected and speciated using an arsenic speciation kit described in Section 3.4.1. The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Analytes for the source water samples are listed in Table 3-3.

3.3.2 Treatment Plant Water Sample Collection. During the system performance evaluation study, treatment plant water samples were collected every other week for on- and off-site analyses shown in Table 3-3. For the first monthly sampling events, samples were taken at the wellhead (IN), after chlorination (AC), and after Vessels A and B combined (TT) and speciation was performed onsite during these events. For the second sampling monthly events, samples were collected at IN, AC, after Vessel A (TA), and after Vessel B (TB) without onsite speciation.

3.3.3 Backwash Water/Solid Sample Collection. Because the system did not require backwash during the first six months of operation, no backwash residuals were produced. Further, because media replacement did not take place, no spent media samples were collected.

3.3.4 Distribution System Water Sample Collection. Samples were collected from the distribution system by the plant operator to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically, the arsenic, lead, and copper levels. From June to September 2005, prior to the startup of the treatment system, four baseline distribution sampling events were conducted at three locations within the distribution system. Following startup of the arsenic adsorption system, distribution system sampling continued on a monthly basis at the same three locations.

The three locations selected were sample taps within the City of Wellman. Two of the locations had been included in the Lead and Copper Rule (LCR) sampling in the past. The baseline and monthly distribution system samples were collected following an instruction sheet developed according to the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The homeowners recorded the dates and times of last water usage before sampling and the dates and times of sample collection for calculation of stagnation time. All samples were collected from a cold water faucet that had not been used for at least 6 hr to ensure that stagnant water was sampled. Analytes for the baseline and monthly sampling are listed in Table 3-3. Arsenic speciation was not performed for the distribution system water samples.

3.4 Sampling Logistics

All sampling logistics including preparation of arsenic speciation kits and sample coolers, and sample 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, color-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. For example, red, orange, yellow, and blue were used to designate sampling locations for IN, AC, TA, and TB, respectively. The pre-labeled bottles for each sampling location were placed in separate ziplock bags and packed in the cooler.

In addition, all sampling and shipping-related materials, such as latex gloves, sampling instructions, chain-of-custody forms, prepaid addressed FedEx air bills, and bubble wrap, were included. The chain-of-custody forms and FedEx air bills were completed except for the operator's signature and sample dates and times. After preparation, the sample coolers were sent to the facility via FedEx approximately 1 week prior to the scheduled sampling date.

3.4.3 Sample Shipping and Handling. After sample collection, samples for off-site analyses were packed carefully in the original coolers with wet ice and shipped to Battelle. Upon receipt, sample custodians checked sample IDs against the chain-of-custody forms and verfied 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 by Battelle's subcontract laboratories, including American Analytical Laboratories (AAL) in Columbus, OH and Belmont Laboratories in Englewood, OH, were packed in separate coolers at Battelle and picked up by couriers from each laboratory. 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 QAPP (Battelle, 2004) were followed by Battelle's 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., relative percent difference (RPD) of 20%, percent recovery of 80% to 120%, and completeness of 80%. The quality assurance (QA) data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project.

Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a Wissenschaftlich-Technische-Werkstätten (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 400-mL plastic beaker and placed the Multi 340i probe in the beaker until a stable value was obtained. The plant operator also performed free and total chlorine measurements using Hach^{TM} chlorine test kits following the user's manual.

Section 4.0: RESULTS AND DISCUSSION

4.1 Facility Description and Pre-Existing Treatment System Infrastructure

Supplied by five groundwater wells located along U.S. Highway 385, the community water system in the City of Wellman distributes water to approximately 225 community members via 95 service connections. Of the five supply wells, four are located in close proximity to the pre-existing 110,000-gal water tower (Figure 4-1) and underground vault that houses the well manifold (Figure 4-2). The fifth is located approximately 3 miles southwest. The five supply wells range in size from 6 to 8 in, each equipped with a submersible pump of 7 to 15 horsepower (hp). The combined flowrate from the first four wells is estimated to be 50 gpm and the flowrate from the fifth is 40 gpm. Therefore, the total flowrate is approximately 90 gpm. Operating simultaneously 4 to 6 hr at a time, the well pumps are on typically twice per day in the summer and once per day in the winter to meet the average and peak daily demand of about 26,000 and 50,000 gal, respectively. The on/off of the well pumps are controlled by pressure switches in the storage tank set at 40/54 psi. After chlorination with a 12.5% NaOCl solution (injected at the Well 1 manifold as shown in Figure 4-3), water is sent to the water tower for storage and distribution. The target free chlorine residual level in the distribution system is 1.0 mg/L (as Cl_2).

Figure 4-1. Water Tower and Chlorination Shed (Small Grey Structure Left of Truck)

Figure 4-2. Vault Containing Supply Well Manifold, Sampling Tap, and Pre-Existing Master Totalizer

Figure 4-3. Pre-Existing Chlorine Addition System

4.1.1 Source Water Quality. Two sets of source water samples were collected and speciated on November 18, 2004 for on- and off-site analyses. One set was collected from Well No.1 and the other set from the manifold containing water from all five wells after chlorination. The results are presented in Table 4-1 and compared to those taken by the facility for the EPA demonstration site selection.

Table 4-1. Water Quality Data for Wellman, TX

			Battelle Data		
Parameter	**Unit**	**Facility Source Water Data(a)**	**Well No. 1 Source Water**	**Five Wells Combined, Chlorinated**	**TCEQ Treated Water Data**
Date	-	NA	11/18/04		04/27/98–11/10/04
pH	S.U.	7.8	8.2	7.7	7.5
Temperature	°C	NA	15.6	NA	NA
DO	mg/L	NA	6.6	NA	NA
ORP	mV	NA	741	NA	NA
Total Alkalinity (as $CaCO_3$)	mg/L	246; 302*	369	250	246–248
Hardness (as $CaCO_3$)	mg/L	406	442	446	686
Turbidity	NTU	NA	0.6	0.9	NA
TDS	mg/L	NA	1,690	806	823
TOC	mg/L	NA	5.2	3.4	NA
Nitrate (as N)	mg/L	NA	0.6	5.4	5.3–5.6
Nitrite (as N)	mg/L	NA	0.04	<0.01	NA
Ammonia (as N)	mg/L	NA	<0.05	<0.05	NA
Chloride	mg/L	102; 131*	590	75	103–108
Fluoride	mg/L	NA	5.0	5.3	0.6–6.1
Sulfate	mg/L	217; 224*	240	240	241–256
Silica (as SiO_2)	mg/L	19.5*	45.5	45.9	NA
Orthophosphate (as P)	mg/L	0.096*	<0.06	<0.06	NA
As(total)	μg/L	39; 33*	62.0	45.4	16.5–39.3
As (soluble)	μg/L	NA	50.2	NA	NA
As (particulate)	μg/L	NA	11.8	NA	NA
As(III) (soluble)	μg/L	NA	2.8	NA	NA
As(V) (soluble)	μg/L	NA	38.4	NA	NA
Fe (total)	μg/L	24; 55*	<25	<25	<10
Fe (soluble)	μg/L	NA	<25	NA	NA
Mn (total)	μg/L	6; <0.4	1.6	2.0	<2
Mn (soluble)	μg/L	NA	0.4	NA	NA
U (total)	μg/L	NA	10.0	10.1	NA
U (soluble)	μg/L	NA	10.1	NA	NA
V (total)	μg/L	NA	165	145	NA
V (soluble)	μg/L	NA	151	NA	NA
Sb (total)	μg/L	NA	<0.1	<0.1	NA
Sb (soluble)	μg/L	NA	<0.1	NA	NA
Na (total)	mg/L	107; 172*	403	112	140
Ca (total)	mg/L	64; 58*	47.5	50.6	73.7
Mg (total)	mg/L	60; 61*	78.5	77.6	122

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

NA = not analyzed; TCEQ = Texas Commission of Environmental Quality; TDS = total dissolved solids; TOC = total organic carbon; NTU = Nephelometric Turbidity Units; * EPA data

Arsenic. Total arsenic concentrations of source water ranged from 33 to 62 µg/L. Based on the November 18, 2004 sampling results obtained by Battelle, out of 62 µg/L of total arsenic, 11.8 µg/L existed as particulate arsenic and 50.2 µg/L as soluble arsenic. Soluble arsenic comprised 2.8 µg/L of As(III) and 38.4 µg/L of As(V). Therefore, the predominant species is As(V). The existence of As(V) as the predominant species is consistent with the rather oxidizing well condition as reflected by the high DO (i.e., 6.6 mg/L) and ORP (i.e., 741 mV) levels measured during sampling.

Iron and Manganese. Iron concentrations were generally low, ranging from its MDL of 25 µg/L to 55 µg/L. In general, adsorptive media technologies are best suited for sites with relatively low iron levels in source water (i.e., less than 300 µg/L, 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 also were low, ranging from <0.4 to 6 µg/L.

pH. The pH range of 7.7 to 8.2 was at the upper end of the target range of 6.0 to 8.0 for optimal arsenic adsorption onto the AD-33 media. At pH values greater than 8.0 to 8.5, the vendor recommended that pH adjustment be implemented in order to maintain the capacity of the adsorption media. Although pH adjustment was not included in the original system design, a pH adjustment system was later recommended by TCEQ (see Section 4.2).

Competing Anions. Silica, phosphate, and vanadium may compete with arsenic for available adsorptive sites on the AD-33 media. The silica level in the source water sample collected by Battelle was 45.5 mg/L and the orthophosphate level was below detection (<0.06 mg/L). Based on the high silica levels in raw water, the adsorptive capacity of the AD-33 media could potentially be adversely affected. Vanadium concentrations were high, ranging from 145 to 165 µg/L in the source water samples collected by Battelle. Prior studies have indicated that vanadium has an adverse effect on arsenic adsorption. Effects of vanadium on arsenic adsorption will be closely monitored over the course of the demonstration study.

Other Water Quality Parameters. The majority of water quality parameters analyzed in source water were below their respective primary MCLs. Fluoride levels have been measured as high as 5.3 mg/L, exceeding the MCL of 4 mg/L. Total dissolved solids (TDS) and chloride also were observed to exceed their respective SMCLs of 500 mg/L and 250 mg/L, respectively, in at least one source water sample. Total organic carbon (TOC) concentrations also were high, ranging from 3.4 to 5.2 mg/L.

4.1.2 Treated Water Quality. In addition to the source water data, Table 4-1 also presents historic treated water quality data taken by the TCEQ from April 1998 through November 2004. The treated water quality data obtained from TCEQ were similar to the City of Wellman and Battelle test results. Total arsenic concentrations of the treated water ranged from 16.5 to 39.3 µg/L. Although no arsenic speciation data were available for the water following chlorination, it was assumed that arsenic was present as As(V) because of the addition of chlorine. The average pH of the treated water was 7.5. Additional analytes (including several metals and radionuclides) were included in the historical data provided by TCEQ. These data are summarized in Table 4-2.

4.1.3 Distribution System. Based on the information provided by the facility, the mains for the water distribution system in the City of Wellman are constructed of 6-in cast iron. Connections within the distribution system include 3 to 6 in polyvinyl chloride (PVC). Piping within the homes is PVC and copper; neither lead pipe nor lead solder are thought to be present.

Table 4-2. TCEQ Treated Water Quality Data

Parameter	Unit	TCEQ Treated Water Data
Aluminum	μg/L	<20
Antimony	μg/L	<3
Barium	μg/L	28.8
Beryllium	μg/L	<1
Cadmium	μg/L	<1
Chromium	μg/L	<10
Copper	μg/L	6.6
Iron	μg/L	<10
Lead	μg/L	<1
Mercury	μg/L	<0.4
Nickel	μg/L	1.1
Selenium	μg/L	43.2
Silver	μg/L	<10
Thallium	μg/L	<1
Zinc	μg/L	7.1
Gross Alpha	pCi/L	8.8
Gross Beta	pCi/L	15.2
Radium 226	pCi/L	0.3
Radium 228	pCi/L	<1

The three locations selected for distribution sampling before and after the treatment was installed were representative of the distribution system overall. Two of the locations were also part of the city's historic sampling network for the Lead and Copper Rule (LCR). The facility also samples for volatile organic compounds (VOCs), inorganics, nitrate, and radionuclides as directed by the TCEQ, typically once every two to three years.

4.2 Treatment Process Description

The APU marketed by AdEdge is a fixed-bed, down-flow adsorptive media system used for small water systems in the flow range of up to 100 gpm. The system uses Bayoxide E33 media (branded as AD-33 by AdEdge), an iron-based adsorptive media developed by Lanxess (formerly Bayer AG) for the removal of arsenic from drinking water supplies. Table 4-3 presents physical and chemical properties of the AD-33 media. The media, available in both granular and pelletized forms, is delivered in a dry crystalline form and listed by NSF International (NSF) under Standard 61 for use in drinking water applications. The pelletized media, which is slightly denser than its granular counterpart (i.e., 35 vs. 28 lb/ft^3), was used for the demonstration at Wellman.

As groundwater is pumped through the fixed-bed pressure vessels, dissolved arsenic is adsorbed onto the media, thus reducing the dissolved arsenic concentration in the treated water. When the media reaches its capacity (effluent water ≥10 μg/L total As), the spent media is removed and can be disposed of as non-hazardous waste after passing the EPA's Toxicity Characteristic Leaching Procedure (TCLP) test. The media life depends upon the arsenic concentration, the empty bed contact time (EBCT), the mode or variability of operation (on-off), pH, and concentrations of competing ions in source water.

Table 4-3. Physical and Chemical Properties of Bayoxide E33 (or AD-33) Pelletized Media

Physical Properties	
Parameter	**Values**
Matrix	Iron oxide composite
Physical Form	Dry pelletized media
Color	Amber
Bulk Density (lb/ft^3)	35
Bulk Density (g/cm^3)	0.56
BET Surface Area (m^2/g)	142
Attrition (%)	0.3
Moisture Content (%, by wt.)	~5
Particle size distribution (mm)	1.0–1.4 (14×18 mesh)
Crystal size (Å)	70
Crystal phase	α – FeOOH
Chemical Analysis	
Constituents	**Weight %**
FeOOH	90.1
CaO	0.27
SiO_2	0.06
MgO	1.00
Na_2O	0.12
SO_3	0.13
Al_2O_3	0.05
MnO	0.23
TiO_2	0.11
P_2O_5	0.02
Cl	0.01

Data Source: Bayer AG
BET = Brunauer, Emmett, and Teller

Two pretreatment components are installed at the Wellman demonstration site, i.e., chlorination and pH adjustment. Chlorination had already been implemented prior to the demonstration study. Because As(V) was the predominant species and the As(III) concentration was low (i.e., 2.8 µg/L based on November 18, 2004, data), chlorination was used primarily to maintain a chlorine residual in the distribution system. As described in Section 4-1, source water pH ranged from 7.7 to 8.2. A pH adjustment system was required by TCEQ and installed to lower source water pH values to a target of 7.2.

The arsenic treatment system (specifically referred to as the APU-100CS-S-2-AVH system) consists of two pressure vessels, Vessel A and Vessel B, operating in parallel. The system is located in a newly constructed treatment facility located next to the pre-existing water tower and underground vault along U.S. Highway 385 (Figure 4-4). Table 4-4 presents key system design parameters.

Figure 4-4. Water Treatment Facility in Wellman, TX

The major process components of the arsenic removal system are discussed as follows:

- **Intake.** Raw water is pumped from the five supply wells and fed to the treatment system. Wells 1, 2, 3, and 4 are triggered to operate by a single pressure switch and Well 5, which provides nearly half the water supply, is triggered to operate by a separate pressure switch. The two pressure switches are configured to allow for simultaneous operation of all five wells.

- **Pre-chlorination.** The pre-existing chlorination system, shown in Figure 4-3, was relocated inside the new treatment facility. The system was reconfigured to inject a 12.5% NaOCl solution after the combined raw water sampling location (IN) (as opposed to down Well 1, which was the configuration preceding this demonstration study) but prior to the AC sampling location. The chlorination system was used primarily to provide a target free chlorine residual level of 1.0 mg/L (as Cl_2) for disinfection purposes. The added benefit was to oxidize any As(III) to As(V) prior to the adsorption vessels. Operation of the chlorine feed system was linked to the well pump such that chlorine was injected only when the wells were operating. Chlorine consumption was monitored by the system operator on a weekly basis.

- **pH Adjustment.** A pH adjustment system was installed inside the new treatment facility along with the arsenic treatment system. The pH adjustment system consisted of a solenoid driven diaphragm metering chemical feed pump (ProMinent®, beta/4®), a 50-gal high-density polyethylene (HDPE) chemical feed tank (to store a 31% hydrochloric acid (HCl) solution), tubing to transfer the acid from the tank to the well supply line, an injection valve, an in-line mixer, and a pH probe and monitor (Figure 4-5). The acid injection point was located approximately 10 ft downstream of the raw water sampling location (IN) after the chlorine injection point, but prior to the AC sampling location.

Table 4-4. Design Specifications of AdEdge Arsenic Removal System

Parameter	Value	Remarks
Adsorption Vessels		
Vessel Size (in)	48 D × 72 H	–
Cross-Sectional Area (ft^2/vessel)	12.6	–
No. of Vessels	2	–
Configuration	Parallel	–
AD-33 Adsorption Media		
Media Type	AD-33 (pelletized)	–
Media Volume (ft^3)	76	38 ft^3/vessel (36-in bed depth)
Media Weight (lb)	2,660	1,330 lb/vessel
Service		
Design Flowrate (gpm)	100	50 gpm/vessel
Hydraulic Loading (gpm/ft^2)	4.0	–
EBCT (min)	5.7	–
Estimated Working Capacity (BV)	17,240	Bed volumes to 10 μg/L total As breakthrough from each vessel based on vendor estimate
Estimated Throughput to Breakthrough (gal)	9,800,000	1 BV = 568 gal
Average Use Rate (gal/day)	26,000	Based on 5.4 hr of daily operation at 80 gpm
Estimated Media Life (day)	377 (12.4 months)	Estimated frequency of media change-out based on average throughput to system.
Pre-treatment	HCl	pH Adjustment
	NaOCl	Prechlorination
Backwash		
Pressure Differential Set Point	10 psi	–
Backwash Hydraulic Loading (gpm/ft^2)	9	–
Backwash Frequency (per month)	Once	System was not backwashed within first six months of operation
Backwash Flowrate (gpm)	113	–
Backwash Duration (min/vessel)	20	–
Fast Rinse Flowrate	113	–
Fast Rinse Duration (min/vessel)	1 to 4	–
Wastewater Production (gal/vessel)	2,260	–

- **Adsorption.** The arsenic treatment system consisted of two 48-in diameter, 72-in-tall pressure vessels configured in parallel, each containing 38 ft^3 of pelletized AD-33 media. The vessels were carbon steel construction, skid mounted, and rated for 100-psi working pressure (Figure 4-6). EBCT for this system was 5.7 min in each vessel at a design flowrate of 50 gpm for each vessel (100 gpm total system flow). Hydraulic loading rate to each vessel was approximately 4.0 gpm/ft^2.

  Each pressure vessel was interconnected with schedule 80 PVC piping and five electrically actuated butterfly valves, which made up the valve tree as shown in Figure 4-6. In addition, the system had two manual diaphragm valves on the backwash line and two manual lug-style butterfly valves to divert raw water flow into each vessel. Each valve operated independently and the butterfly valves were controlled by a Square D Telemechanique programmable logic controller (PLC) with a Magelis XBT G2220 color touch interface screen.

Figure 4-5. pH Adjustment System

Figure 4-6. Adsorption System Valve Tree and Piping Configuration

- **Backwash.** The vendor recommended that the APU treatment system be backwashed on a regular basis to remove particulates and media fines that accumulated in the media beds. The system can be backwashed automatically based on differential pressure (Δp) measured across the individual pressure vessels, time of operation, or volume of water treated. The vendor recommended a backwash flowrate of 113 gpm to achieve a backwash hydraulic loading of about 9 gpm/ft^2. Because the incoming flowrate from the supply well is insufficient to provide the necessary flow for backwash, supplemental water is supplied from the treated water storage tank to the head of the system. Each backwash cycle is set to last about 20 min per vessel, generating a total of 4,520 gal for the two tanks. The backwash water produced is pumped to a 5,000-gal polyethylene storage tank located next to the treatment system. From the backwash storage tank, the backwash water is either discharged to a local sewer or collected and used for irrigation purposes. However, due to the minimal pressure drop across the vessels throughout the first six months of system operation, system backwash was never performed. The pressure drop and the arsenic concentrations across the vessels will continue to be monitored and a backwash will be scheduled, if needed, during the next six months of system operation.

- **Media Replacement.** As the total arsenic concentration in the treated water approaches the MCL of 10 μg/L, replacement of the media in the vessels will be scheduled. Based on the estimate provided by the vendor, breakthrough of arsenic is expected after about 17,240 BV of water treated or about 12 months of operation. The spent media will be tested for EPA's TCLP before disposal.

- **Water Storage.** Treated water from the APU system was sent to the existing 110,000-gal water tower located at the site and used to supply treated water to the distribution system (Figure 4-1).

4.3 System Installation

The installation of the APU system was completed by the vendor and its subcontractor on July 20, 2006. The following briefly summarizes some of the pre-demonstration activities, including permitting, building preparation, and system installation, shakedown, and startup.

4.3.1 Permitting. A pre-permit package was submitted to TCEQ by the City of Wellman on July 11, 2005, requesting an exception to use data from an alternative site in lieu of conducting an on-site pilot study as required under 30 TAC §290.42(g). The exception request included a written description of the treatment technology along with a schematic of the system and relevant pilot- and full-scale data. On August 25, 2005, a permit application package including a process flow diagram of the treatment system, mechanical drawings of the treatment equipment, and a schematic of the building footprint and equipment layout was submitted to TCEQ for permit approval. TCEQ granted the exception request on October 31, 2005, and a conditional approval for construction on February 2, 2006. The conditional approval required that the loading rate, media depth, and pH adjustment comply with the requirements outlined in the TCEQ exception request response letter dated October 31, 2005.

A final response to the TCEQ conditional approval was submitted by Oller Engineering, Inc., the engineer of record, on June 26, 2006, ensuring that the system installation would be in accordance to the guidance provided by the TCEQ.

4.3.2 Building Preparation. Construction of a new building to house the planned arsenic treatment system began on January 20, 2006, and was completed on February 6, 2006. The building is a single-story metal structure with concrete flooring, shown in Figure 4-4. Additional preparation required reconfiguration of the chlorination system from the previous treatment facility to the new building.

4.3.3 Installation, Shakedown, and Startup. The treatment system arrived on-site on October 14, 2005. The electrical and plumbing hookups were completed by the vendor's subcontractor, during the week of March 6, 2006. During the week of August 9, 2006, the vendor completed the arsenic treatment system installation and shakedown work, which included hydraulic testing, media loading, and media backwash. Battelle was on-site on August 9, 2006, to inspect the system and provide training to the operator for sampling and data collection. The system officially went online and was put into regular service on August 10, 2006. As a result of the system inspections, a punch-list of items was identified, some of which were quickly resolved and did not affect system operations or data collection, although problems related to the media vessel flow meters could not be resolved immediately and resurfaced throughout the six-month study period. The issues associated with the flow meters are further discussed in Section 4.4.3. Table 4-5 summarizes the items identified and corrective actions taken.

Table 4-5. System Punch-List/Operational Issues and Corrective Action

Item No.	Punch-List/ Operational Issues	Corrective Action(s) Taken	Resolution Date
1	No backwash flow for Vessel A	Malfunctioning actuator on valve BV-014A replaced	8/11/2006
2	Relocate acid and chlorine injection points	Acid and chlorine injection points moved to inside of treatment building prior to treatment system	8/14/2006
3	Install inline mixer after acid and chlorine injection points	Vendor notified but no action taken to date	8/14/2006
4	Install second chlorine injection point after treatment	Vendor supplied 2 additional 4-in PVC saddles to site; no additional action taken to date	8/14/2006
5	Install "IN" sampling point on raw water line in vault	Sample tap installed on combined raw water line in vault	8/14/2006
6	Calibrate and evaluate pressure gauges on system for accuracy	Gauges functioning properly after replacing malfunctioning actuator on valve BV-014A	8/14/2006
7	Replace backwash line sampling port with larger port	Larger sampling port provided to facility	8/14/2006
8	Confirm Vessels A and B flow meters for proper calibration and measurements	Flow coefficients in software checked and correct setting confirmed per factory specifications; Battelle to send portable flow meter to site to verify flow meter reading	8/15/2006 10/9/2006

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters for the first six months of system operation are tabulated and attached as Appendix A with the key parameters summarized in Table 4-6. From August 10, 2006 through February 9, 2007, the system operated for approximately 819 hr, equivalent to 4.5 hr/day and a utilization rate of 19%. Over the six-month period, the APU system treated approximately 5,936,400 gal of water; equivalent to 10,442 BV based on the electromagnetic flow meters/totalizers provided as part of the APU system. In comparison, the master totalizer utilized by the

Table 4-6. Summary of APU-100CS-S-2-AVH System Operation

Operational Parameter	Value/Condition	
Duration	08/10/06–02/09/07	
Cumulative Operating Time (hr)	819	
Average Daily Operating Time (hr)	4.5	
Flow Meter/Totalizer	Electromagnetic(a)	Turbine(b)
Throughput (gal)	5,936,419	4,218,200
Throughput (BV)(c)	10,442	7,420
Average (Range of) Flowrate (gpm)	121 (57–199)(d)	86 (21–161)(d)
Average (Range of) EBCT for System (min)(c)	4.7 (2.9–10.0)	6.6 (3.5–27.1)
Average (Range of) Inlet Pressure (psi)	45.4 (36–53)	
Average (Range of) Outlet Pressure (psi)	45.1 (33–52)	
Average (Range of) Δp across System (psi)	1.4 (0–4)	
Average (Range of) Δp across Vessel A (psi)	0.6 (0–2)	
Average (Range of) Δp across Vessel B (psi)	0.9 (0–8)	

(a) Flow meter installed on each adsorption vessel.
(b) Master flow meter.
(c) Calculated based on 38 ft^3 of media in each vessel.
(d) In calculating the flowrate range, Grubb's Test for Determining Outliers was used to exclude values having <5% probability of occurring.

site prior to the installation of the APU system reported approximately 4,218,200 gal of water treated; equivalent to 7,420 BV. Bed volumes were calculated based on the 38 ft^3 of media in each vessel.

System flowrates were tracked by instantaneous flowrate readings from the electromagnetic flow meter/totalizer on each adsorption vessel, and calculated average flowrate values based on the hour meter and flow totalizer readings from the same electromagnetic flow meters/totalizers. Over the first six months of operation, the calculated average flowrate varied from 57 to 199 gpm and averaged 121 gpm. This calculated average flowrate is significantly greater than the 100-gpm design value and the pre-existing master totalizer average of 86 gpm. In Figure 4-7, the calculated average flowrates of the APU system totalizer and master totalizer are compared over the six month period. It appears the APU system flowrate is consistently greater than the master totalizer flowrate by approximately 41%.

Because of this large discrepancy, a one-day flowrate test was performed on October 9, 2006, using a portable ultrasonic flow meter to establish an alternate reference for evaluating the accuracy of the electromagnetic flow meters/totalizers and turbine master totalizer. Flowrates to the system ranged from 98 to 107 gpm and averaged 101 gpm based on readings from the portable flow meter. Table 4-7 compares the flowrates from the APU system flow meters/totalizers, master totalizer, and portable flow meter over the same period of time. Because the one-day flowrate test results were more comparable with the master totalizer values, the master totalizer was used for the purposes of this performance evaluation.

For consistency and accuracy, the master totalizer readings, provided in Table 4-6, will be reported and utilized throughout the remainder of the report. The inconsistent flowrates between the APU system flow meters/totalizers, master totalizer, and portable flow meter are further examined in Section 4.4.3.

The APU system pressures were monitored at the system inlet and outlet and between both Vessels A and B. Figures 4-8 is a histogram of inlet, outlet, and differential pressures for the system and each vessel over the first six months of system operation. The average pressure differential (Δp) across the system,

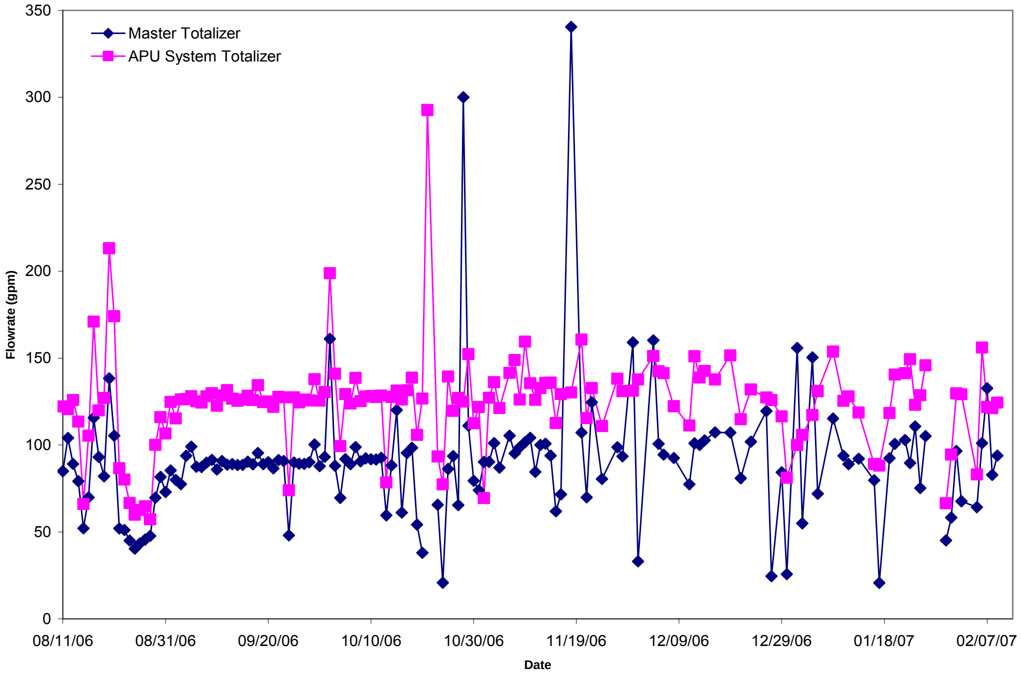

Figure 4-7. Average Flowrate Readings of APU System Totalizer and Master Totalizer

Table 4-7. Flowrates Measured by Various Flow Meters/Totalizers on October 9, 2006

Flow Meter/Totalizer	Type of Flow Meter/Totalizer	Average Flowrate (gpm)	Difference (%)
Master Totalizer	Turbine	92	0
Portable Flow meter	ultrasonic	101	+10
APU System Totalizer	electromagnetic	128	+39

Vessel A, and Vessel B was 1.4, 0.6, and 0.9 psi, respectively and remained relatively low. As such, no pressure increase was observed after 819 hr of system operation. Several pressure spikes were observed; however, none of these spikes caused a significant increase in Δp, i.e. ≥10 psi, across the system or adsorption vessels. As a result, no media backwash was performed during the first six months of system operation.

4.4.2 Residual Management. No residuals were produced during this reporting period because neither backwash nor media replacement was required during the first six months of system operation.

4.4.3 System/Operation Reliability and Simplicity. The only operational irregularity experienced during the first six months of the demonstration study was related to the electromagnetic flow meters/totalizers on the APU treatment system.

Over the first six months of operation, the electromagnetic flow meters/totalizers installed with the APU system had been reporting flowrates significantly greater than the design value and master totalizer

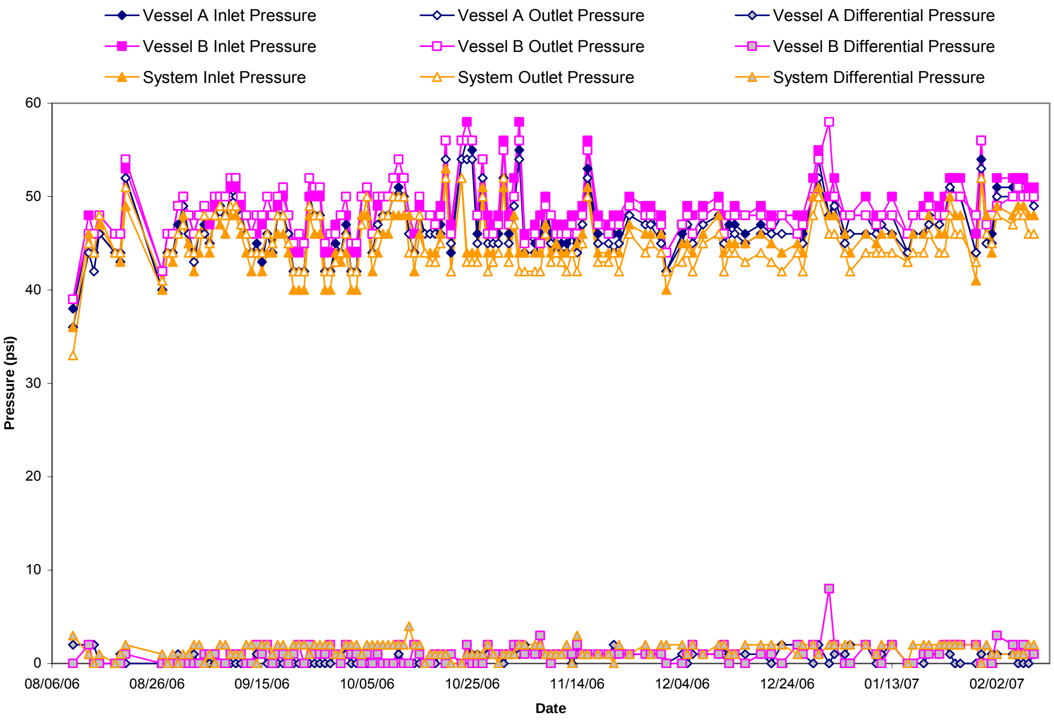

Figure 4-8. Treatment System Operational Pressures

values. Because of this, a one-day flowrate test was performed on October 9, 2006, using a portable ultrasonic flow meter to determine the accuracy of the electromagnetic flow meters/totalizers and turbine master totalizer. The portable flow meter was pre-programmed at Battelle and then sent to the operator along with written instructions specifically prepared for the test.

Each type of totalizer operates differently; hence several different variables could influence the actual flow measurement. The master totalizer is a turbine type flow meter and most often used for water distribution systems. Turbine meters are less accurate than displacement and jet meters, although turbine meters allow for higher flow rates and less pressure loss than displacement type meters. The portable flow meter is an ultrasonic type flow meter, which requires known values to be preset prior to use. The portable flow meter reports an accuracy of ±1 to 3% within a velocity range of ±0.1 m/sec under ideal flow conditions in 4-in plastic piping. The APU flow meter/totalizer is an electromagnetic type flow sensor that is ordered with its fitting and factory calibrated in the fitting prior to shipment. The APU type flow sensor requires a minimum of 10 straight pipe diameters upstream and a minimum of five straight pipe diameters downstream of the flow meters/totalizers. At Wellman, neither upstream nor downstream specifications were met. Upstream from the flow meters/totalizers there should be a minimum of 30-inches of straight pipe and downstream there should be a minimum of 15-in of straight pipe. For both flow meters/totalizers, there are only 21-in upstream and 6-in downstream, a difference of 30% and 60% less than the minimum requirements, respectively.

Based on the one-day flow rate test, it was concluded that the APU system flow sensors are the least accurate of the meters due to the current piping configuration and that results from the master totalizer and portable flow meter are within an acceptable margin of error. Recommendations were made that the master totalizer be used for demonstration purposes and the use of the APU totalizer be discontinued until piping configuration changes are made in compliance with the manufacture’s specifications or until the factory set K-factors are adjusted to compensate for the inaccuracy. Currently, the vendor is working to adjust the K-factors in the system software.

Pre- and Post-Treatment Requirements. Two forms of pre-treatment were required at the Wellman site, chlorination and pH adjustment. A chlorination step provided required chlorine residuals and oxidized As(III) to As(V). Hydrochloric acid was planned to be used to lower the pH value of raw water to a more optimal level in order to maintain effective adsorption by the AD-33 media. However, pH adjustment was not initiated due to safety concerns. Throughout the six-month operational period, the pH values ranged from 7.7 to 8.0 for the IN samples (i.e., raw water) and from 7.5 to 7.7 for the TT samples (i.e., treated water). The average pH values for the IN and TT samples were 7.8 and 7.6, respectively.

The existing chlorination system was relocated into the new water treatment building and reconfigured to inject solution after the combined raw water sampling location (IN) (as opposed to down Well 1) but prior to the AC sampling location. The chlorination system, as discussed in Section 4.2 and shown in Figure 4-3, utilized a 12.5% NaOCl solution to reach a target free residual level of 1.0 mg/L (as Cl_2). The reconfigured chlorination system did not require additional maintenance or skills, other than those required by the previous system. The operator monitored chlorine consumption rates (gal/week) and residual chlorine levels.

System Automation. The system was fitted with automated controls for automatic backwash. Each media vessel was equipped with five electrically actuated butterfly valves, which are controlled by a Square D Telemechanique PLC with a Magelis G2220 color touch interface screen. The automated portion of the system did not require regular O&M; however, operator awareness and an ability to detect unusual system measurements were necessary when troubleshooting system automation failures. The equipment vendor provided hands-on training and a supplemental operations manual to the operator.

Operator Skill Requirements. The operation of the adsorption system demanded a higher level of awareness and attention than the previous system. The system offers increased operational flexibility, which, in turn, requires increased monitoring of system parameters. The operator's knowledge of the system limitations and typical operational parameters are critical in achieving system performance objectives. The operator was on-site typically five times per week and spent approximately 3 to 15 min each day performing visual inspections and recording the system operating parameters on the daily log sheets. Operator training began with on-site training and a thorough review of the system operations manual. However, over the first six months of operation, the operator found increased knowledge and invaluable system troubleshooting skills were gained through hands on operational experience. TCEQ requires that the operator of the treatment system hold at least a Class D TCEQ waterworks operator license. The TCEQ public water system operator certifications are classified by Class D through A. Licensing eligibility requirements are based on education, experience, and related training. The minimum requirements for a Class D license are high school graduate or GED and 20 hr of related training. Licensing requirements incrementally increase with each licensing level, with Class A being the highest requiring the most education, experience, and training.

Preventive Maintenance Activities. Preventive maintenance tasks included periodic checks of flow meters and pressure gauges and inspection of system piping and valves. The pre-chlorination tank and supply lines also were checked for leaks and adequate pressure. Typically, the operator performed these duties when on-site for routine activities.

Chemical/Media Handling and Inventory Requirements. NaOCl was used for pre-chlorination and the operator ordered chemicals as done prior to installation of the treatment system. HCl was intended to be used for pH adjustment, but not incorporated into the water treatment system and, therefore, not handled by the operator.

4.5 System Performance

The performance of the arsenic removal system was evaluated based on analyses of water samples collected from the treatment facility and distribution system.

4.5.1 Treatment Plant Sampling. The treatment plant water was sampled on 15 occasions including two duplicate and seven speciation events; a complete set of the results is included in Appendix B. Table 4-8 summarizes the results for arsenic, iron, manganese, and vanadium across the treatment train. Table 4-9 summarizes the results of other water quality parameters. The results of the water samples collected throughout the treatment train are discussed below.

Arsenic. Figure 4-9 presents the results of seven arsenic speciation events measured at IN, AC, and TT sampling locations. Figure 4-10 illustrates total arsenic concentrations measured across the treatment train as a function of throughput in bed volumes. Total arsenic concentrations in the IN samples varied considerably, ranging from 6.0 to 45.9 μg/L and averaging 27.4 μg/L (Table 4-8). The predominant soluble species was As(V), ranging from 11.2 to 41.2 μg/L and averaging 22.8 μg/L. Low levels of soluble As(III) and particulate As also were present, averaging 0.9 and 2.2 μg/L, respectively. The arsenic concentrations measured in the IN samples during this six-month period are almost one-half of those measured on November 18, 2004 from Well No. 1 (see Table 4-1). A review of the significant variations identified that system operations and sampling techniques were likely contributing to the concentration variations. In fact, the AC sample results provided concentrations in a more realistic range and are believed to me more representative of the true water quality. The total arsenic concentrations in the AC samples ranged from 37.5 to 47.2 μg/L. Soluble As(V) in the AC samples remained predominate, ranging from 38.1 to 43.6 μg/L; soluble As(III) concentrations ranged from 0.7 to 2.0 μg/L.

On 10 occasions, total arsenic concentrations (along with various other analytical parameters) seemingly increased from the wellhead to the after chlorination sampling location. The average total arsenic concentration at the wellhead and after chlorination was 27.4 and 41.9 μg/L, respectively. The average concentration of all other arsenic fractions (i.e., soluble As[III] and As[V] and particulate As) increased proportionally (by approximately 1½ times) after chlorination. Repeat analysis of these samples and discussions with the operator have not revealed an explanation. Several hypotheses have been developed to determine the cause of this inconsistency. One factor that is currently being evaluated is the intermittent operation of the wells and possibility of samples being collected while the system is not operating. The system treats water based on demand and the water is supplied by five wells. Wells 1, 2, 3, and 4 are operated by a single pressure switch and Well 5, which produces nearly half the treated water, is operated by a separate pressure switch. This type of pressure switch configuration could allow some wells to operate longer than others, thereby producing inconsistencies in water quality and analytical results. In fact, in some cases, if one of the pressure switches is delayed, pressure could build in the pipe line and prevent the delayed well pump or pumps from switching on. In an effort to evaluate this possibility, the operator has been instructed to collect samples only while the system is operating and producing the average flow that is expected from all five supply wells. Concentrations measured at the after chlorination sampling location appear to be more representative of the true concentrations.

As shown in Figure 4-9, As(III) levels at the wellhead, after chlorination, and after adsorption were similar at 0.9, 1.1, and 0.9 μg/L, respectively. Because 1.0 and 1.4 mg/L (as Cl_2) of total chlorine were measured at the AC and TT locations, respectively, the presence of As(III) at these locations most likely was due to accuracy of the speciation method. Further, the residual chlorine levels measured at the TT location was similar to those at the AC location, indicating no chlorine consumption by the media.

Table 4-8. Analytical Results for Arsenic, Iron, Manganese, and Vanadium

Parameters	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
As (total)	IN	µg/L	15	6.0	45.9	27.4	13.5
	AC	µg/L	15	37.5	47.2	41.9	3.4
	TA	µg/L	8	0.7	2.0	-(a)	-(a)
	TB	µg/L	8	0.7	2.3	-(a)	-(a)
	TT	µg/L	7	0.4	1.4	-(a)	-(a)
As (soluble)	IN	µg/L	7	12.6	42.0	23.7	12.7
	AC	µg/L	7	38.1	43.6	40.7	2.1
	TT	µg/L	7	0.4	1.4	-(a)	-(a)
As (particulate)	IN	µg/L	7	<0.1	7.2	2.2	2.5
	AC	µg/L	7	<0.1	4.1	2.0	1.6
	TT	µg/L	7	<0.1	0.1	-(a)	-(a)
As (III)	IN	µg/L	7	0.4	1.6	0.9	0.4
	AC	µg/L	7	0.7	2.0	1.1	0.5
	TT	µg/L	7	0.4	1.8	-(a)	-(a)
As (V)	IN	µg/L	7	11.2	41.2	22.8	12.8
	AC	µg/L	7	37.3	42.9	39.6	2.0
	TT	µg/L	7	<0.1	0.3	-(a)	-(a)
Fe (total)	IN	µg/L	15	<25	131	<25	31.8
	AC	µg/L	15	<25	51.9	<25	12.9
	TA	µg/L	8	<25	<25	<25	-
	TB	µg/L	8	<25	<25	<25	-
	TT	µg/L	7	<25	<25	<25	-
Fe (soluble)	IN	µg/L	7	<25	<25	<25	-
	AC	µg/L	7	<25	<25	<25	-
	TT	µg/L	7	<25	<25	<25	-
Mn (total)	IN	µg/L	15	0.2	1.8	0.6	0.4
	AC	µg/L	15	0.1	0.5	0.3	0.1
	TA	µg/L	8	<0.1	0.1	<0.1	0.0
	TB	µg/L	8	<0.1	0.1	<0.1	0.0
	TT	µg/L	7	<0.1	0.2	<0.1	0.1
Mn (soluble)	IN	µg/L	7	0.3	1.2	0.6	0.3
	AC	µg/L	7	0.1	0.7	0.3	0.2
	TT	µg/L	7	<0.1	0.2	<0.1	0.1
V (total)	IN	µg/L	15	17.5	157	86.7	43.0
	AC	µg/L	15	112	168	144	14.0
	TA	µg/L	8	0.7	1.5	-(b)	-(b)
	TB	µg/L	8	0.7	10.8	-(b)	-(b)
	TT	µg/L	7	0.6	3.2	1.7	1.1
V (soluble)	IN	µg/L	7	41.7	154	82.5	45.5
	AC	µg/L	7	134	161	150	10.9
	TT	µg/L	7	0.5	3.8	-(b)	-(b)

One-half of detection limit used for samples with concentrations less than detection limit for calculations.

(a) Statistics not provided; see Figure 4-10 for arsenic breakthrough curves.

(b) Statistics not provided; see Figure 4-11 for vanadium breakthrough curves.

Table 4-9. Summary of Water Quality Parameter Sampling Results

Parameters	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as $CaCO_3$)	IN	mg/L	15	232	301	264	14.7
	AC	mg/L	15	239	272	251	9.9
	TA	mg/L	8	254	270	259	5.3
	TB	mg/L	8	246	276	262	8.7
	TT	mg/L	7	248	265	258	6.1
Fluoride	IN	mg/L	7	0.4	7.6	4.9	2.2
	AC	mg/L	7	3.6	6.8	4.9	1.1
	TT	mg/L	7	4.6	7.0	5.7	0.8
Sulfate	IN	mg/L	7	70.0	318	240	82.7
	AC	mg/L	7	218	470	352	92.5
	TT	mg/L	7	249	380	303	54.7
Nitrate (as N)	IN	mg/L	7	3.5	5.6	4.6	0.7
	AC	mg/L	7	3.5	6.1	4.9	0.9
	TT	mg/L	7	3.9	6.1	4.7	0.7
Phosphorus (as P)	IN	mg/L	15	<10	25.4	<10	5.3
	AC	mg/L	15	<10	<10	<10	-
	TA	mg/L	8	<10	<10	<10	-
	TB	mg/L	8	<10	<10	<10	-
	TT	mg/L	7	<10	<10	<10	-
Silica (as SiO_2)	IN	mg/L	15	42.1	57.6	45.6	3.8
	AC	mg/L	15	42.6	47.5	44.5	1.7
	TA	mg/L	8	41.3	47.2	45.0	1.9
	TB	mg/L	8	42.8	48.5	46.0	2.0
	TT	mg/L	7	24.4	47.6	41.8	7.9
Turbidity	IN	NTU	15	0.2	1.1	0.5	0.3
	AC	NTU	15	0.1	2.4	0.7	0.8
	TA	NTU	8	0.1	1.2	0.5	0.4
	TB	NTU	8	0.1	3.4	0.6	1.1
	TT	NTU	7	0.2	0.6	0.4	0.1
TOC	IN	mg/L	6	1.1	1.3	1.2	0.1
	AC	mg/L	6	1.3	1.5	1.4	0.1
	TT	mg/L	6	1.2	1.4	1.3	0.1
pH	IN	S.U.	7	7.7	8.0	7.8	0.1
	AC	S.U.	7	7.6	7.8	7.7	0.1
	TA	S.U.	1	7.6	7.6	7.6	-
	TB	S.U.	1	7.7	7.7	7.7	-
	TT	S.U.	6	7.5	7.7	7.6	0.1
Temperature	IN	°C	7	8.1	22.3	15.7	5.0
	AC	°C	7	9.8	23.8	15.8	4.9
	TA	°C	1	21.3	21.3	21.3	-
	TB	°C	1	21.0	21.0	21.0	-
	TT	°C	6	10.1	23.8	15.2	5.0
DO	IN	mg/L	6	4.7	6.5	5.7	0.6
	AC	mg/L	6	5.0	6.0	5.6	0.3
	TA	mg/L	1	4.6	4.6	4.6	-
	TB	mg/L	1	5.0	5.0	5.0	-
	TT	mg/L	4	5.2	6.3	5.7	0.5

One-half of detection limit used for samples with concentrations less than detection limit for calculations.

Table 4-9. Summary of Water Quality Parameter Sampling Results (Continued)

Parameters	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
ORP	IN	mV	6	477	535	500	25.6
	AC	mV	6	481	574	529	35.8
	TA	mV	1	475	475	475	-
	TB	mV	1	524	524	524	-
	TT	mV	5	492	659	574	65.2
Free Cl_2	TT	mg/L	2	0.2	0.4	0.3	0.1
Total Cl_2	AC	mg/L	1	1.0	1.0	1.0	-
	TT	mg/L	1	1.4	1.4	1.4	-
Total Hardness (as $CaCO_3$)	IN	mg/L	7	350	604	434	87.3
	AC	mg/L	7	418	668	533	95.0
	TT	mg/L	7	371	557	442	71.5
Ca Hardness (as $CaCO_3$)	IN	mg/L	7	113	155	135	13.5
	AC	mg/L	7	118	161	139	13.4
	TT	mg/L	7	114	164	142	18.1
Mg Hardness (as $CaCO_3$)	IN	mg/L	7	195	474	299	90.0
	AC	mg/L	7	281	507	394	85.6
	TT	mg/L	7	236	401	300	60.4

One-half of detection limit used for samples with concentrations less than detection limit for calculations.

The total arsenic breakthrough curves indicate that AD-33 removed arsenic to levels well below the MCL (see Figure 4-10). Through the first six months of operation (August 10, 2006 through February 9, 2007), the system treated 7,420 BV (4,218,200 gal) of water with treated water containing <2.3 µg/L of arsenic. This represents approximately 43% of the media capacity, estimated at 17,240 BV (9,800,000 gal) by the vendor.

Iron, Manganese, and Vanadium. Total iron levels in raw water averaged below the detection limit of 25 µg/L (Table 4-8). However, iron was detected in the first three sampling events at 131, 51.8, and 39.1 µg/L, respectively. Total iron concentrations after chlorination were below the detection limit, except on October 19, 2006, when duplicate results revealed 51.9 and 46.4 µg/L. Iron levels consistently remained below the detection limit in the effluent from the system.

Total manganese levels in raw water ranged from 0.2 to 1.8 µg/L and averaged 0.6 µg/L (Table 4-8). Manganese in system effluent decreased to levels below the detection limit of <0.1 µg/L. Soluble manganese concentrations were similar to total concentrations, averaging 0.6, 0.3, and <0.1 µg/L for IN, AC, and TT locations, respectively.

Total vanadium levels in the IN samples varied significantly ranging from 17.5 to 157 µg/L with 95% existing in the soluble form (Table 4-8). The vanadium concentrations in these samples were almost one-half of those measured from Well No. 1 on November 18, 2004 (see Table 4-1). Figure 4-11 illustrates the vanadium breakthrough curves at sampling locations across the treatment train. Total vanadium concentrations were reduced to <3.2 µg/L.

On eight occasions, total vanadium concentrations (along with various other analytical parameters) seemingly increased from the wellhead to the after chlorination sampling location. The average total vanadium concentrations at the IN and AC samples were 86.7 and 144 µg/L, respectively. The average

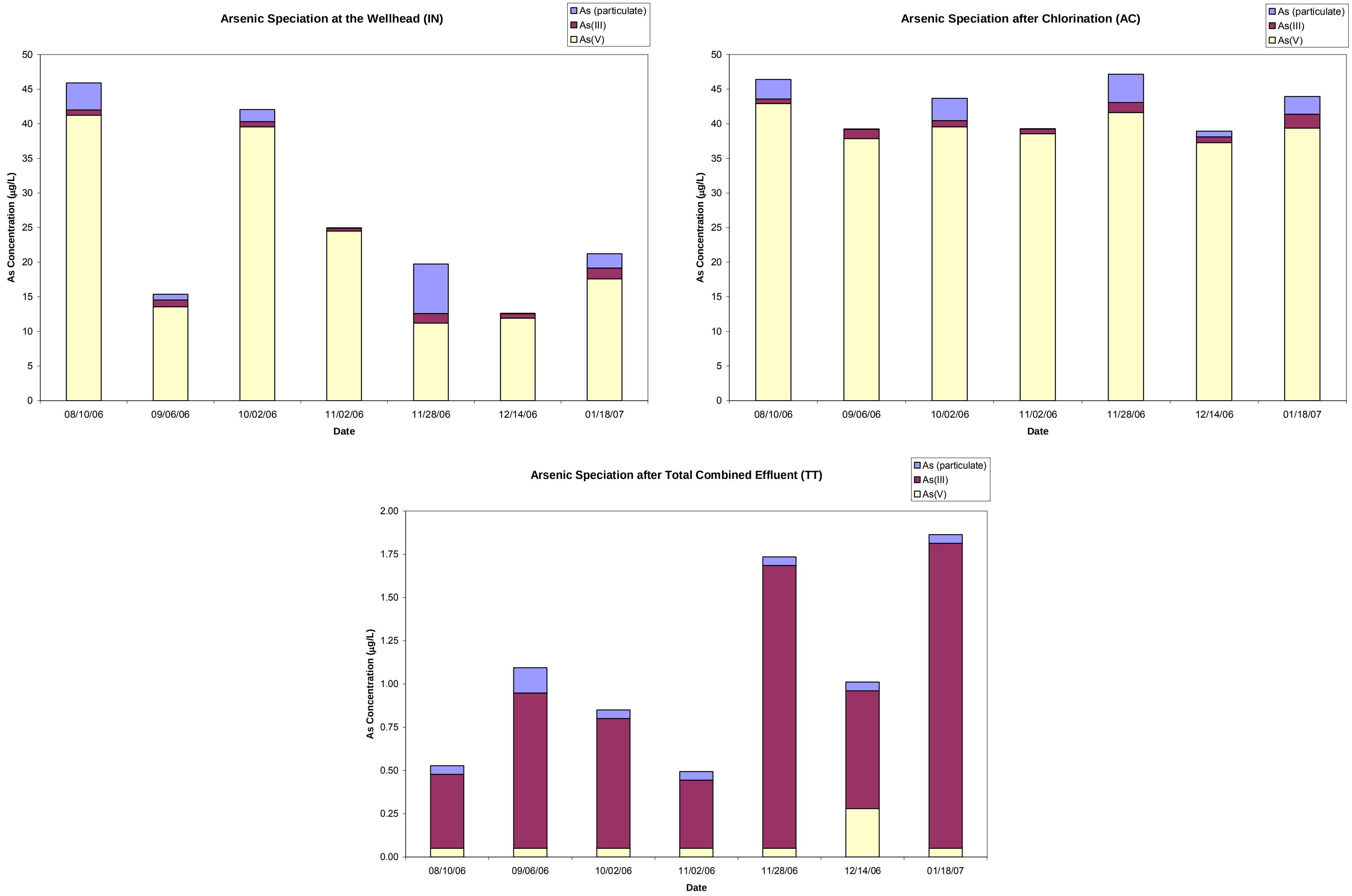

Figure 4-9. Concentrations of Arsenic Species at IN, AC, and TT Sampling Location

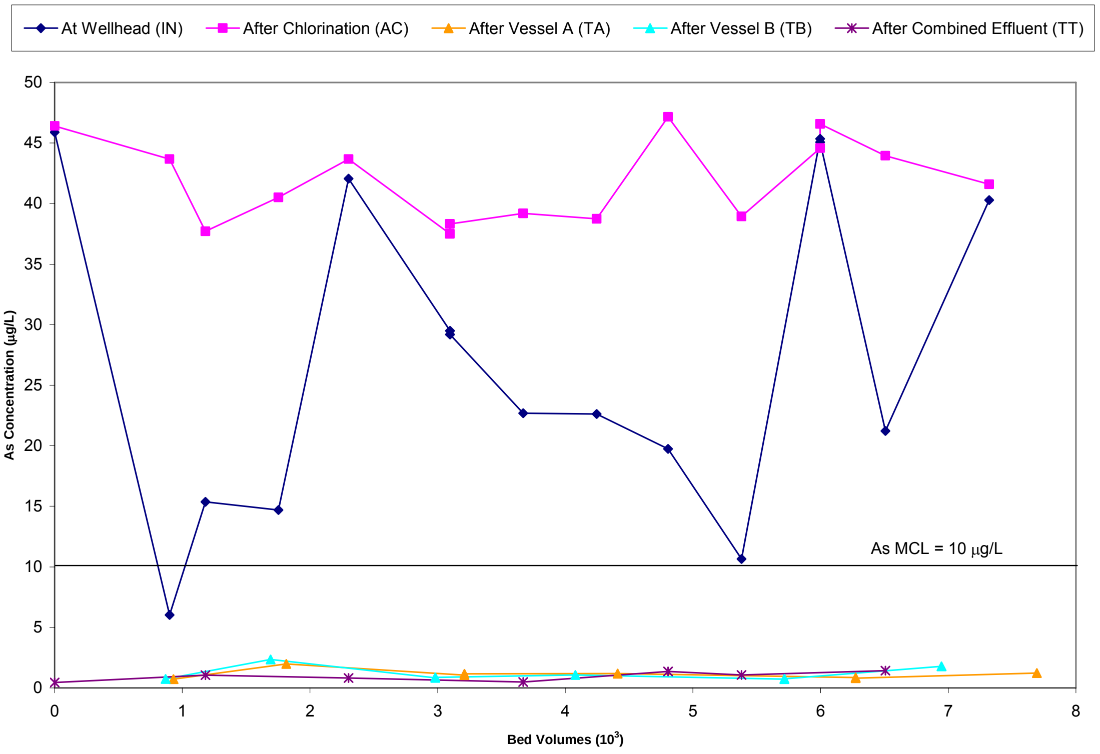

Figure 4-10. Total Arsenic Breakthrough Curves

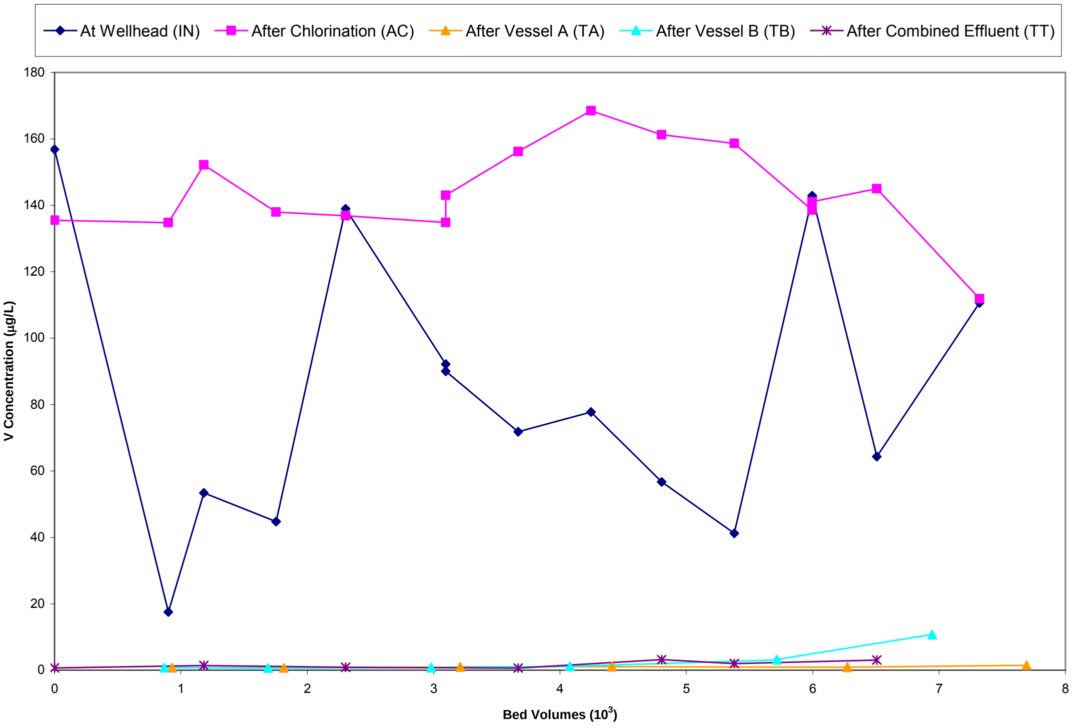

Figure 4-11. Total Vanadium Breakthrough Curves

concentration for soluble vanadium increased proportionally after chlorination. As with the other parameters, repeat analysis and discussion with the operator have not revealed a good explanation. Investigations to determine the cause of this inconsistency are actively being conducted. One possible contributor, as discussed above for arsenic, is inconsistent operations of pressure switches and well pumps that are used to supply water to the APU.

Competing Anions. Phosphate and silica, which can adversely affect arsenic adsorption onto the AD-33 media, were measured at sampling locations across the treatment train. Total phosphorous concentrations remained low throughout the treatment train, averaging <10 μg/L (as P); therefore, it is not expected to affect system performance. Silica concentrations remained relatively constant across the treatment train, ranging from 41.8 to 46.0 mg/L (Table 4-9). Figure 4-12 illustrates the silica breakthrough curves at sampling locations across the treatment train. Some silica was removed during the first 2,000 BV; similar removal by AD-33 media was observed elsewhere during the arsenic demonstration studies (McCall et al., 2007; Williams et al., 2007).

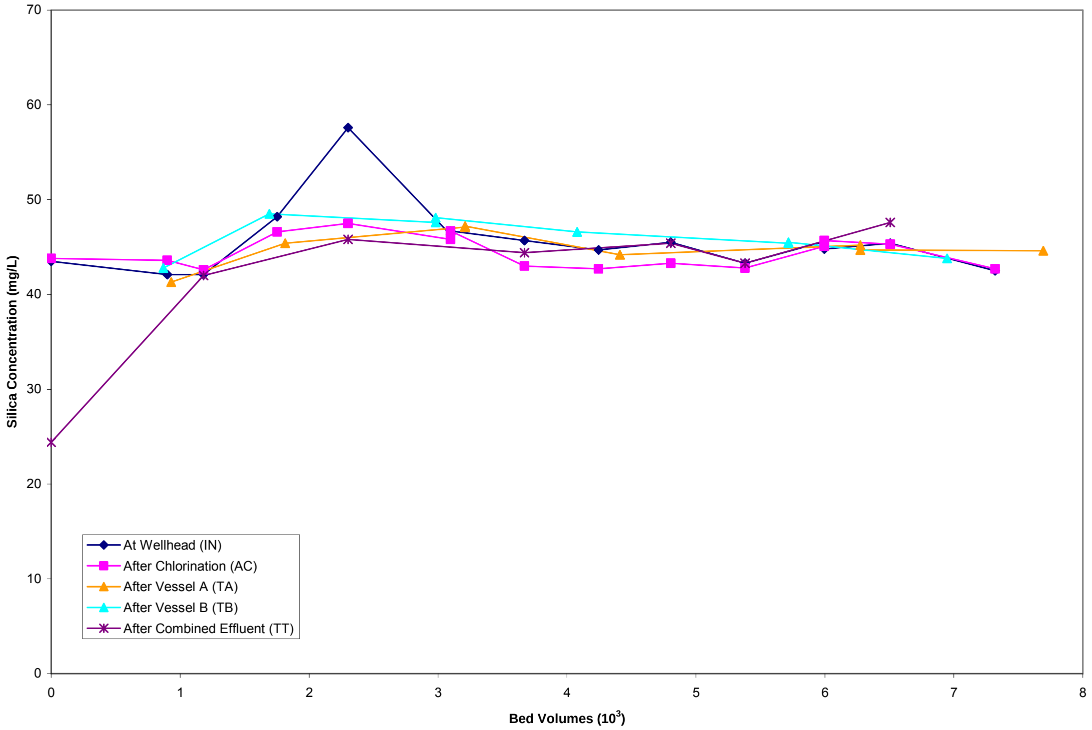

Figure 4-12. Silica (as SiO_2) Breakthrough Curves

Other Water Quality Parameters. As shown in Table 4-9, pH values of raw water ranged from 7.7 to 8.0. After chlorination, pH values ranged from 7.6 to 7.8 and averaged 7.7. This pH range of 7.6 to 7.8 after chlorination, but prior to the adsorption vessels, is lower than that for which pH adjustment should be implemented. As discussed previously, pH adjustment was recommended by TCEQ, but it has not been implemented because of safety concerns.

Alkalinity averaged 264 mg/L (as $CaCO_3$) in raw water and 260 mg/L (as $CaCO_3$) in system effluent. Total hardness ranged from 350 to 604 mg/L (as $CaCO_3$) in raw water and remained stable throughout the treatment train. Fluoride results remained consistent, ranging from 4.9 to 5.7 mg/L, at all sampling locations. DO levels averaged 5.7 mg/L in raw water and remained relatively consistent throughout the treatment train. The results indicated that the AD-33 media did not affect the amount of alkalinity, total hardness, fluoride, and DO in the treated water. ORP readings averaged 500 mV in raw water, but increased to an average of 529 mV after chlorination and 574 mV in the total combined effluent (Table 4-9).

4.5.2 Backwash Water Sampling. Backwash was not performed during the first six-months of operation; however, a backwash is anticipated to occur during the second six-month operation period.

4.5.3 Distribution System Water Sampling. Prior to the installation and operation of the arsenic treatment system, baseline distribution system water samples were collected at 405 7th St., 106 8th St., and 705 Lynn St. on June 22, July 14, August 18, and September 14, 2005. Following installation of the treatment system, distribution water sampling continued on a monthly basis at the same three locations, with samples collected on September 6, October 10, November 15, December 14, 2006, and January 18, 2007. The results of the distribution system sampling are summarized in Table 4-10.

The most significant change in the distribution system water since the system began operation was a decrease in arsenic concentration. Baseline arsenic concentrations ranged from 33.2 to 44.7 µg/L and averaged 38.9 µg/L for all three locations. After treatment began, arsenic concentrations decreased at all three locations (averaging 3.3 µg/L). The first distribution system samples collected on September 6, 2006 contained relatively high arsenic concentrations ranging from 7.0 to 11.4 µg/L. The remaining samples contained lower arsenic concentrations ranging from 1.1 to 2.5 µg/L and averaging 1.6 µg/L, which is similiar to the arsenic conentrations in the system effluent.

After treatment began, lead concentrations ranged from <0.1 to 0.5 µg/L, with no samples exceeding the action level of 15 µg/L. Copper concentrations ranged from 3.0 to 190 µg/L, with no samples exceeding the 1,300 µg/L action level. Overall, operation of the arsenic treatment system did not adversely affect the lead or copper concentrations in the distribution system. Measured pH values averaged 7.6, which is consistent with the average pH values immediately after the adsorption vessels. The average pH values were consistent before and after the treatment system became operational.

Alkalinity levels ranged from 254 to 367 mg/L as $CaCO_3$, iron was not detected in any of the samples, and manganese concentrations ranged from <0.1 to 0.3 µg/L. The arsenic treatment system did not appear to affect these water quality parameters in the distribution system.

4.6 System Cost

The system cost is evaluated based on the capital cost per gpm (or gpd) of the design capacity and the O&M cost per 1,000 gal of water treated. The capital cost includes the cost for equipment, site engineering, and installation and the O&M cost includes media replacement and disposal, chemical usage, electrical power use, and labor.

4.6.1 Capital Cost. The capital investment for equipment, site engineering, and installation of the arsenic treatment system was $149,221 (see Table 4-11). The equipment cost was $103,897 (or 70% of the total capital investment), which included $76,254 for the skid-mounted APU-100CS-S-2-AVH unit, $21,280 for the AD-33 media (76 ft^3 to fill two vessels), $2,851 for the pH adjustment system, and $3,512 for shipping.

The engineering cost included the cost for preparing one submittal package for the exception request and permit application and obtaining the required permit in addition to labor and travel (see Section 4.3.1). The engineering cost was $25,310, or 17% of the total capital investment.

Table 4-10. Distribution System Sampling Results

No. of Sampling Events	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
	Sample Type	DS1 LCR								DS2 LCR								DS3 Residence							
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	06/22/05	11.3	7.6	242	40.6	<25	0.3	0.2	62.3	8.8	7.6	242	42.3	<25	0.2	<0.1	73.0	6.5	8.2	242	40.5	<25	0.5	0.3	275
BL2	07/14/05	10.5	7.5	246	39.4	<25	0.9	0.4	67.0	6.4	7.6	251	39.7	<25	0.2	0.4	65.8	7.1	7.6	251	38.5	<25	0.3	0.2	139
BL3	08/18/05	6.5	7.5	242	38.3	<25	0.3	0.3	51.1	8.4	7.5	246	37.9	<25	0.1	0.1	97.2	8.3	7.6	NA(a)	44.7	<25	0.3	0.2	197
BL4	09/14/05	8.5	7.5	264	33.2	<25	<0.1	0.3	67.5	7.8	7.6	264	36.2	<25	0.3	0.1	126	7.4	7.5	264	35.1	<25	<0.1	0.2	153
1	09/06/06	6.5	7.7	263	7.0	<25	<0.1	<0.1	3.0	7.5	7.6	367	11.4	<25	<0.1	<0.1	74.4	7.9	7.8	272	11.4	<25	<0.1	<0.1	72.9
2	10/10/06	9.3	7.6	258	1.4	<25	<0.1	0.4	10.1	6.5	7.6	260	2.4	<25	<0.1	0.0	78.0	7.5	7.7	271	1.8	<25	<0.1	0.3	190
3	11/15/06	6.5	7.5	254	1.1	<25	<0.1	0.5	7.8	8.5	7.5	258	2.1	<25	<0.1	0.2	129	7.3	7.5	258	1.4	<25	0.1	0.3	182
4	12/14/06	6.5	7.6	268	1.1	<25	<0.1	<0.1	5.2	11.0	7.5	262	2.5	<25	0.3	0.5	141	8.1	7.7	266	1.3	<25	0.2	0.2	94.8
5	01/18/07	6.5	7.8	265	2.1	<25	<0.1	<0.1	134	7.8	7.6	272	1.4	<25	0.1	0.2	139	8.2	7.7	272	1.1	<25	<0.1	0.3	13.4

(a) Insufficient sample for analysis due to loss during shipment.
BL = Baseline Sampling; NA = Not Analyzed
Lead action level = 15 µg/L; copper action level = 1.3 mg/L
µg/L as unit for all analytical parameters except for alkalinity (mg/L as $CaCO_3$).

Table 4-11. Capital Investment Cost for APU System

Description	Quantity	Cost	% of Capital Investment
Equipment Cost			
APU Skid-Mounted System (Unit)	1	$76,254	–
AD-33 Media (ft^3)	76	$21,280	–
pH Adjustment System	–	$2,851	–
Shipping	–	$3,512	–
Equipment Total	–	**$103,897**	**70%**
Engineering Cost			
Vendor Material/ Labor/ Travel	–	$11,660	–
Subcontractor Labor/ Travel	–	$13,650	–
Engineering Total	–	**$25,310**	**17%**
Installation Cost			
Vendor Labor/ Travel	–	$6,374	–
Subcontractor Labor/ Travel	–	$13,640	–
Installation Total	–	**$20,014**	**13%**
Total Capital Investment	–	**$149,221**	**100%**

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 $20,014, or 13% of the total capital investment.

The total capital cost of $149,221 was normalized to the system's rated capacity of 100 gpm (144,000 gpd), which resulted in $1,492/gpm ($1.04/gpd) of design capacity. The capital cost also was converted to an annualized cost of $14,085/yr using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-year return period. Assuming that the system operated 24 hours a day, 7 days a week at the system design flowrate of 100 gpm to produce 52,560,000 gal of water per year, the unit capital cost would be $0.27/1,000 gal. Because the system only operated an average of 4.5 hr/day during the first six months of operation, the estimated production for a one year period is approximately 8,436,400 gal of water and the unit capital cost is $1.67/1,000 gal of water.

4.6.2 Operation and Maintenance Cost. The O&M cost includes the cost for such items as media replacement and disposal, chemical usage, electricity consumption, and labor (Table 4-12). Although media replacement did not occur during the first six months of system operation, the media replacement cost would represent the majority of the O&M cost and is estimated to be $30,010 to change out both vessels. This media change-out cost would include the cost for media, freight, labor, travel, spent media analysis, and media disposal fee. This cost was used to estimate the media replacement cost per 1,000 gal of water treated as a function of the projected media run length in bed volumes to 10 μg/L arsenic breakthrough (Figure 4-13).

The chemical cost associated with the operation of the treatment system included the use of hydrochloric acid for pH adjustment and sodium hypochlorite for chlorination. The pH adjustment system was not operated; therefore, no cost has accrued due to acid consumption. Sodium hypochlorite was already being used at the site prior to installation of the APU system for disinfection purposes. The operation of the APU system did not affect the usage of sodium hypochlorite; therefore, the incremental chemical cost for chlorine was negligible and not included in O&M costs.

Electrical bills prior to and after installation showed no indication of an increase in power consumption. Therefore, electrical cost associated with operation of the system was assumed to be negligible.

Under normal operating conditions, routine labor activities to operate and maintain the system consumed 7 min/day, 5 days per week, as noted in Section 4.4.3. Therefore, the estimated labor cost was \$0.14/1,000 gal of water treated.

Table 4-12. Operation and Maintenance Cost for APU-100CS-S-2-AVH System

Cost Category	Value	Assumptions
Volume processed (gal)	4,218,200	Through February 9, 2007
Media Replacement and Disposal Cost		
Media and Underbedding replacement	\$22,420	Vendor quote; \$295/ft^3 for 76 ft^3 (two media vessel)
Shipping	\$983	Vendor quote
Vendor Labor/ Travel	\$3,717	Vendor quote
Subcontractor labor	\$1,890	Vendor quote
Media disposal [including spent media analysis]	\$1,000	Vendor quote
Subtotal	\$30,010	Vendor quote plus spent media analysis
Media replacement and disposal (\$/1,000 gal)	See Figure 4-13	Based upon both vessels media run length at 10-µg/L arsenic breakthrough
Electricity Cost		
Electricity (\$/1,000 gal)	\$0.001	Electrical costs assumed negligible
Labor Cost		
Average weekly labor (min)	35	7 min/day, 5 day/week
Labor (\$/1,000 gal)	\$0.14	Labor rate = \$6.00/hr
Total O&M Cost/1,000 gal	See Figure 4-13	Based upon both vessels media run length at 10-µg/L arsenic breakthrough

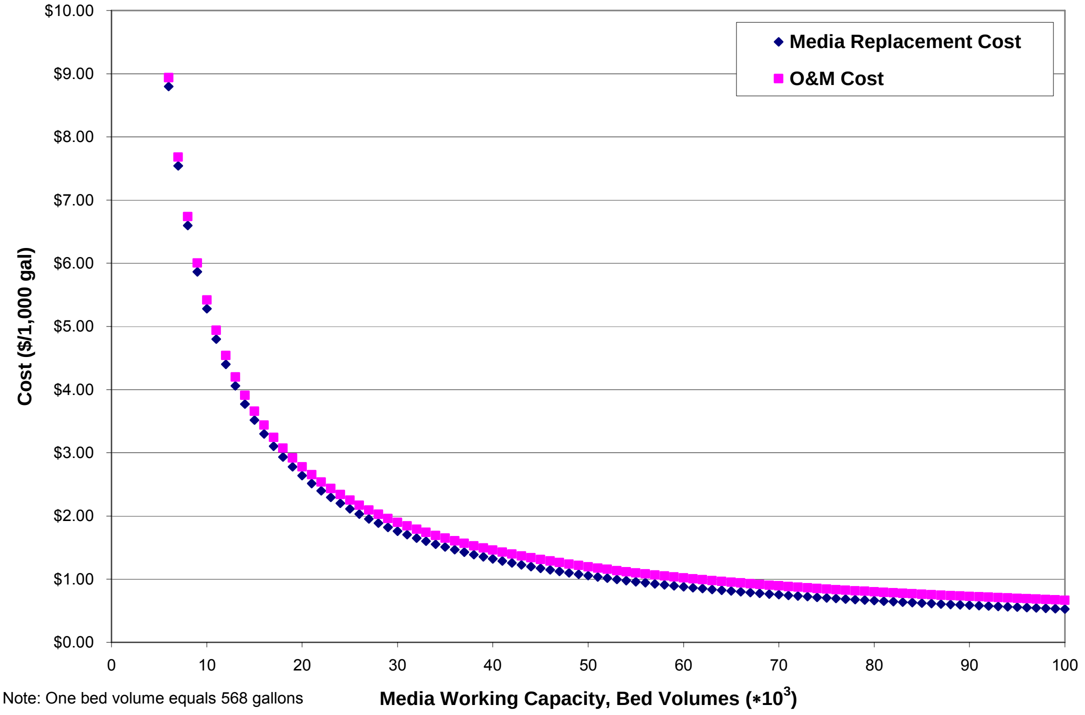

Figure 4-13. Media Replacement and Operation and Maintenance Cost

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APPENDIX A

OPERATIONAL DATA

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

				Master Totalizer Measurements					APU Instrument Panel Measurements									
Week No.	Day of Week	Date	Operational Hours hr	Master Totalizer Meter gal	Daily Treated Volume gal	Cumulative Treated Volume gal	Total Bed Volumes BV	Average Flowrate gpm	APU Totalizer Meter gal	Daily Treated Volume gal	Cumulative Treated Volume gal	Total Bed Volumes BV	Average Flowrate gpm	Average Flowrate A gpm	Average Flowrate B gpm	Inlet Pressure psi	Outlet Pressure psi	Pressure Differential psi
1	Thu	08/10/06	0.0	33,039,400	0	0	0	NA	23,951	0	0	0	NA	NA	NA	36	33	3
	Fri	08/11/06	14.9	33,115,400	76,000	76,000	134	85	133,239	109,288	109,288	192	122	65.4	59.0	8	10	2
	Sat	08/12/06	3.3	33,136,000	20,600	96,600	170	104	157,120	23,881	133,169	234	121	60.5	60.1	0	1	1
	Sun	08/13/06	4.6	33,160,600	24,600	121,200	213	89	191,863	34,743	167,912	295	126	67.6	59.4	46	45	1
2	Mon	08/14/06	5.6	33,187,200	26,600	147,800	260	79	229,992	38,129	206,041	362	113	48.2	64.4	44	44	0
	Tue	08/15/06	8.7	33,214,400	27,200	175,000	308	52	264,499	34,507	240,548	423	66	25.0	41.1	47	48	1
	Wed	08/16/06	4.6	33,233,700	19,300	194,300	342	70	293,575	29,076	269,624	474	105	53.4	51.9	0	0	0
	Thu	08/17/06	3.3	33,256,600	22,900	217,200	382	116	327,434	33,859	303,483	534	171	90.5	80.5	0	0	0
	Fri	08/18/06	2.4	33,270,000	13,400	230,600	406	93	344,691	17,257	320,740	564	120	59.1	59.1	44	44	0
	Sat	08/19/06	6.3	33,301,000	31,000	261,600	460	82	392,696	48,005	368,745	649	127	67.6	60.8	43	44	1
	Sun	08/20/06	3.0	33,325,900	24,900	286,500	504	138	431,068	38,372	407,117	716	213	119.9	90.7	49	51	2
3	Mon	08/21/06(a)	3.4	33,347,400	21,500	308,000	542	105	466,586	35,518	442,635	779	174	105.0	70.4	NA	NA	0
	Tue	08/22/06	6.9	33,368,900	21,500	329,500	580	52	502,488	35,902	478,537	842	87	51.8	34.7	NA	NA	0
	Wed	08/23/06	7.7	33,392,500	23,600	353,100	621	51	539,511	37,023	515,560	907	80	47.3	33.0	NA	NA	0
	Thu	08/24/06	9.4	33,417,900	25,400	378,500	666	45	577,067	37,556	553,116	973	67	33.4	33.1	NA	NA	0
	Fri	08/25/06	9.7	33,441,400	23,500	402,000	707	40	611,907	34,840	587,956	1,034	60	30.2	29.7	NA	NA	0
	Sat	08/26/06	7.9	33,462,000	20,600	422,600	743	43	641,610	29,703	617,659	1,087	63	31.6	31.1	NA	NA	0
	Sun	08/27/06	1.5	33,466,100	4,100	426,700	751	46	647,446	5,836	623,495	1,097	65	32.3	32.5	40	41	1
4	Mon	08/28/06	12.3	33,501,300	35,200	461,900	813	48	689,782	42,336	665,831	1,171	57	29.3	28.0	44	44	0
	Tue	08/29/06	5.0	33,522,200	20,900	482,800	849	70	719,819	30,037	695,868	1,224	100	49.8	33.6	43	44	1
	Wed	08/30/06	5.9	33,551,100	28,900	511,700	900	82	760,881	41,062	736,930	1,296	116	59.7	69.8	46	46	0
	Thu	08/31/06	6.3	33,578,700	27,600	539,300	949	73	801,170	40,289	777,219	1,367	107	55.7	78.2	48	47	1
	Fri	09/01/06	3.3	33,595,600	16,900	556,200	978	85	825,870	24,700	801,919	1,411	125	61.7	10.7	45	44	1
	Sat	09/02/06	5.5	33,622,000	26,400	582,600	1,025	80	863,921	38,051	839,970	1,478	115	59.7	56.4	42	44	2
	Sun	09/03/06	4.6	33,643,400	21,400	604,000	1,062	78	898,784	34,863	874,833	1,539	126	64.0	62.3	44	46	2
5	Mon	09/04/06	3.8	33,664,800	21,400	625,400	1,100	94	927,588	28,804	903,637	1,590	126	64.1	62.2	48	48	0
	Tue	09/05/06	3.6	33,686,200	21,400	646,800	1,138	99	955,246	27,658	931,295	1,638	128	65.4	62.6	44	45	1
	Wed	09/06/06	4.8	33,711,400	25,200	672,000	1,182	87	991,279	36,033	967,328	1,702	125	64.0	61.1	48	48	0
	Thu	09/07/06	4.6	33,735,500	24,100	696,100	1,224	87	1,025,595	34,316	1,001,644	1,762	124	63.4	61.0	47	49	2
	Fri	09/08/06	3.8	33,756,000	20,500	716,600	1,261	90	1,054,775	29,180	1,030,824	1,813	128	65.4	62.6	46	48	2
	Sat	09/09/06	3.9	33,777,400	21,400	738,000	1,298	91	1,085,135	30,360	1,061,184	1,867	130	65.9	63.8	48	49	1
	Sun	09/10/06	3.8	33,797,000	19,600	757,600	1,333	86	1,113,081	27,946	1,089,130	1,916	123	62.3	60.3	48	49	1
6	Mon	09/11/06	4.9	33,823,700	26,700	784,300	1,380	91	1,150,871	37,790	1,126,920	1,982	129	65.1	63.4	46	47	1
	Tue	09/12/06	5.0	33,850,300	26,600	810,900	1,426	89	1,190,365	39,494	1,166,414	2,052	132	70.1	61.5	44	46	2
	Wed	09/13/06	4.4	33,873,800	23,500	834,400	1,468	89	1,223,797	33,432	1,199,846	2,111	127	64.7	62.0	42	44	2
	Thu	09/14/06	4.2	33,896,100	22,300	856,700	1,507	88	1,255,406	31,609	1,231,455	2,166	125	63.9	61.5	44	44	0
	Fri	09/15/06	4.1	33,917,900	21,800	878,500	1,545	89	1,286,453	31,047	1,262,502	2,221	126	64.6	61.6	42	44	2
	Sat	09/16/06	4.5	33,942,300	24,400	902,900	1,588	90	1,321,101	34,648	1,297,150	2,282	128	65.5	62.8	44	46	2
	Sun	09/17/06	4.2	33,964,700	22,400	925,300	1,628	89	1,352,826	31,725	1,328,875	2,338	126	64.5	61.4	44	45	1
7	Mon	09/18/06	4.7	33,991,600	26,900	952,200	1,675	95	1,390,716	37,890	1,366,765	2,404	134	69.1	65.3	46	48	2
	Tue	09/19/06	3.8	34,011,900	20,300	972,500	1,711	89	1,419,142	28,426	1,395,191	2,454	125	64.0	60.7	46	48	2
	Wed	09/20/06	4.4	34,035,700	23,800	996,300	1,753	90	1,452,145	33,003	1,428,194	2,512	125	63.3	61.7	44	45	1
	Thu	09/21/06	3.6	34,054,400	18,700	1,015,000	1,785	87	1,478,474	26,329	1,454,523	2,559	122	62.4	59.4	40	42	2
	Fri	09/22/06	4.8	34,080,700	26,300	1,041,300	1,832	91	1,515,255	36,781	1,491,304	2,623	128	65.2	62.5	40	42	2
	Sat	09/23/06	4.9	34,107,400	26,700	1,068,000	1,879	91	1,552,716	37,461	1,528,765	2,689	127	65.4	62.0	40	42	2
	Sun	09/24/06	13.5	34,146,300	38,900	1,106,900	1,947	48	1,612,618	59,902	1,588,667	2,795	74	42.7	31.2	48	49	1
8	Mon	09/25/06	5.3	34,174,900	28,600	1,135,500	1,997	90	1,653,161	40,543	1,629,210	2,866	127	65.4	62.1	46	48	2
	Tue	09/26/06	4.2	34,197,400	22,500	1,158,000	2,037	89	1,684,529	31,368	1,660,578	2,921	124	63.1	61.3	46	48	2
	Wed	09/27/06	2.3	34,209,700	12,300	1,170,300	2,059	89	1,701,942	17,413	1,677,991	2,952	126	64.9	61.3	40	42	2
	Thu	09/28/06	4.9	34,236,200	26,500	1,196,800	2,105	90	1,738,868	36,926	1,714,917	3,017	126	63.3	62.3	40	42	2
	Fri	09/29/06	4.7	34,264,500	28,300	1,225,100	2,155	100	1,777,720	38,852	1,753,769	3,085	138	69.5	67.5	44	43	1
	Sat	09/30/06	5.6	34,294,000	29,500	1,254,600	2,207	88	1,819,883	42,163	1,795,932	3,159	125	63.5	62.6	43	44	1
	Sun	10/01/06	5.6	34,325,300	31,300	1,285,900	2,262	93	1,863,726	43,843	1,839,775	3,236	130	66.2	64.3	44	46	2

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

				Master Totalizer Measurements					APU Instrument Panel Measurements										
Week No.	Day of Week	Date	Operational Hours hr	Master Totalizer Meter gal	Daily Treated Volume gal	Cumulative Treated Volume gal	Total Bed Volumes BV	Average Flowrate gpm	APU Totalizer Meter gal	Daily Treated Volume gal	Cumulative Treated Volume gal	Total Bed Volumes BV	Average Flowrate gpm	Average Flowrate A gpm	Average Flowrate B gpm	Inlet Pressure psi	Outlet Pressure psi	Pressure Differential psi
9	Mon	10/02/06	2.4	34,348,500	23,200	1,309,100	2,303	161	1,892,368	28,642	1,868,417	3,287	199	111.2	87.7	40	42	2
	Tue	10/03/06	5.3	34,376,500	28,000	1,337,100	2,352	88	1,937,203	44,835	1,913,252	3,366	141	72.5	68.5	40	42	2
	Wed	10/04/06	10.9	34,422,000	45,500	1,382,600	2,432	70	2,002,215	65,012	1,978,264	3,480	99	52.7	46.4	48	47	1
	Thu	10/05/06	8.2	34,467,200	45,200	1,427,800	2,512	92	2,065,789	63,574	2,041,838	3,592	129	66.0	63.6	48	50	2
	Fri	10/06/06	3.8	34,487,500	20,300	1,448,100	2,547	89	2,094,019	28,230	2,070,068	3,641	124	63.0	60.8	42	44	2
	Sat	10/07/06	4.5	34,514,200	26,700	1,474,800	2,594	99	2,131,415	37,396	2,107,464	3,707	139	71.1	67.4	44	46	2
	Sun	10/08/06	4.6	34,539,200	25,000	1,499,800	2,638	91	2,165,969	34,554	2,142,018	3,768	125	63.6	61.6	46	48	2
10	Mon	10/09/06	4.8	34,565,800	26,600	1,526,400	2,685	92	2,202,812	36,843	2,178,861	3,833	128	65.0	62.9	46	48	2
	Tue	10/10/06	4.7	34,591,700	25,900	1,552,300	2,731	92	2,238,965	36,153	2,215,014	3,896	128	64.9	63.3	48	50	2
	Wed	10/11/06	4.6	34,617,000	25,300	1,577,600	2,775	92	2,274,199	35,234	2,250,248	3,958	128	64.7	62.9	48	50	2
	Thu	10/12/06	4.1	34,639,800	22,800	1,600,400	2,815	93	2,305,780	31,581	2,281,829	4,014	128	65.1	63.2	48	50	2
	Fri	10/13/06	2.1	34,647,300	7,500	1,607,900	2,828	60	2,315,671	9,891	2,291,720	4,031	79	44.2	35.3	48	44	4
	Sat	10/14/06	4.4	34,670,600	23,300	1,631,200	2,869	88	2,349,386	33,715	2,325,435	4,091	128	64.9	62.4	42	44	2
	Sun	10/15/06	5.3	34,708,800	38,200	1,669,400	2,937	120	2,391,138	41,752	2,367,187	4,164	131	67.0	64.3	46	48	2
11	Mon	10/16/06	4.8	34,726,400	17,600	1,687,000	2,968	61	2,427,468	36,330	2,403,517	4,228	126	63.8	61.4	44	44	0
	Tue	10/17/06	4.4	34,751,600	25,200	1,712,200	3,012	95	2,462,190	34,722	2,438,239	4,289	132	67.7	64.6	44	43	1
	Wed	10/18/06	4.2	34,776,400	24,800	1,737,000	3,056	98	2,497,148	34,958	2,473,197	4,351	139	72.2	67.6	44	43	1
	Thu	10/19/06	7.1	34,799,500	23,100	1,760,100	3,096	54	2,542,188	45,040	2,518,237	4,430	106	54.9	33.3	46	45	1
	Fri	10/20/06	3.9	34,808,400	8,900	1,769,000	3,112	38	2,571,835	29,647	2,547,884	4,482	127	65.1	92.1	53	52	1
	Sat	10/21/06	3.2	34,831,700	23,300	1,792,300	3,153	121	2,575,347	3,512	2,551,396	4,488	18	10.1	8.0	42	42	0
12	Mon	10/23/06	11.5	34,888,800	57,100	1,849,400	3,253	83	2,656,647	81,300	2,632,696	4,631	118	64.8	53.0	52	52	0
	Tue	10/24/06	1.6	34,890,800	2,000	1,851,400	3,257	21	2,664,075	7,428	2,640,124	4,644	77	44.7	32.3	44	43	1
	Wed	10/25/06	5.8	34,920,800	30,000	1,881,400	3,310	86	2,712,601	48,526	2,688,650	4,730	139	72.9	66.5	44	43	1
	Thu	10/26/06	6.3	34,956,200	35,400	1,916,800	3,372	94	2,757,824	45,223	2,733,873	4,809	120	61.2	58.5	44	43	1
	Fri	10/27/06	8.0	34,987,600	31,400	1,948,200	3,427	65	2,818,802	60,978	2,794,851	4,916	127	63.9	63.1	51	50	1
	Sat	10/28/06	1.4	35,012,800	25,200	1,973,400	3,471	300	2,829,299	10,497	2,805,348	4,935	125	64.2	60.6	44	42	2
	Sun	10/29/06	3.9	35,038,800	26,000	1,999,400	3,517	111	2,864,949	35,650	2,840,998	4,998	152	77.6	76.3	44	43	1
13	Mon	10/30/06	5.1	35,063,100	24,300	2,023,700	3,560	79	2,899,391	34,442	2,875,440	5,058	113	58.6	54.8	44	44	0
	Tue	10/31/06	5.7	35,088,400	25,300	2,049,000	3,604	74	2,941,041	41,650	2,917,090	5,131	122	61.6	58.8	51	52	1
	Wed	11/01/06	1.9	35,098,700	10,300	2,059,300	3,622	90	2,948,962	7,921	2,925,011	5,145	69	41.3	28.2	44	43	1
	Thu	11/02/06	5.0	35,125,800	27,100	2,086,400	3,670	90	2,987,116	38,154	2,963,165	5,212	127	65.4	63.2	48	47	1
	Fri	11/03/06	3.1	35,144,600	18,800	2,105,200	3,703	101	3,012,449	25,333	2,988,498	5,257	136	69.6	64.4	44	42	2
	Sat	11/04/06	6.0	35,175,900	31,300	2,136,500	3,758	87	3,056,088	43,639	3,032,137	5,334	121	62.0	59.0	44	42	2
14	Mon	11/06/06	4.7	35,205,600	29,700	2,166,200	3,811	105	3,095,999	39,911	3,072,048	5,404	142	73.0	68.2	44	42	2
	Tue	11/07/06	5.2	35,235,300	29,700	2,195,900	3,863	95	3,142,454	46,455	3,118,503	5,486	149	78.7	70.3	44	42	2
	Wed	11/08/06	5.2	35,266,100	30,800	2,226,700	3,917	99	3,181,806	39,352	3,157,855	5,555	126	65.4	61.1	47	46	1
	Thu	11/09/06	3.0	35,284,400	18,300	2,245,000	3,949	102	3,210,514	28,708	3,186,563	5,605	159	86.7	72.6	44	43	1
	Fri	11/10/06	4.4	35,311,900	27,500	2,272,500	3,998	104	3,246,301	35,787	3,222,350	5,668	136	70.8	64.1	45	44	1
	Sat	11/11/06	5.5	35,339,800	27,900	2,300,400	4,047	85	3,287,855	41,554	3,263,904	5,741	126	66.1	60.3	44	43	1
	Sun	11/12/06	4.8	35,368,600	28,800	2,329,200	4,097	100	3,326,104	38,249	3,302,153	5,809	133	68.9	63.6	44	42	2
15	Mon	11/13/06	4.6	35,396,400	27,800	2,357,000	4,146	101	3,363,546	37,442	3,339,595	5,875	136	70.6	64.9	44	44	0
	Tue	11/14/06	4.4	35,421,200	24,800	2,381,800	4,190	94	3,399,411	35,865	3,375,460	5,938	136	70.9	64.6	45	42	3
	Wed	11/15/06	8.5	35,452,800	31,600	2,413,400	4,245	62	3,456,845	57,434	3,432,894	6,039	113	59.9	53.2	46	45	1
	Thu	11/16/06	7.1	35,483,300	30,500	2,443,900	4,299	72	3,511,902	55,057	3,487,951	6,136	129	65.4	62.9	51	50	1
	Sat	11/18/06	1.4	35,511,900	28,600	2,472,500	4,349	340	3,522,844	10,942	3,498,893	6,155	130	69.5	64.0	44	43	1
16	Mon	11/20/06	9.5	35,573,000	61,100	2,533,600	4,457	107	3,614,399	91,555	3,590,448	6,316	161	86.8	73.9	44	43	1
	Tue	11/21/06	7.2	35,603,200	30,200	2,563,800	4,510	70	3,664,271	49,872	3,640,320	6,404	115	60.4	54.6	44	44	0
	Wed	11/22/06	4.2	35,634,600	31,400	2,595,200	4,565	125	3,697,728	33,457	3,673,777	6,462	133	68.8	64.7	44	42	2
	Fri	11/24/06	7.7	35,671,800	37,200	2,632,400	4,631	81	3,748,951	51,223	3,725,000	6,553	111	59.0	51.7	47	46	1
17	Mon	11/27/06	13.3	35,750,600	78,800	2,711,200	4,769	99	3,859,197	110,246	3,835,246	6,746	138	72.2	66.0	46	44	2
	Tue	11/28/06	3.6	35,770,800	20,200	2,731,400	4,805	94	3,887,493	28,296	3,863,542	6,796	131	68.6	62.8	46	45	1
	Thu	11/30/06	3.5	35,804,200	33,400	2,764,800	4,863	159	3,915,038	27,545	3,891,087	6,845	131	69.9	63.6	46	44	2
	Fri	12/01/06	7.4	35,818,900	14,700	2,779,500	4,889	33	3,976,151	61,113	3,952,200	6,952	138	44.4	40.2	40	42	2

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

				Master Totalizer Measurements					APU Instrument Panel Measurements									
Week No.	Day of Week	Date	Operational Hours	Master Totalizer Meter	Daily Treated Volume	Cumulative Treated Volume	Total Bed Volumes	Average Flowrate	APU Totalizer Meter	Daily Treated Volume	Cumulative Treated Volume	Total Bed Volumes	Average Flowrate	Average Flowrate A	Average Flowrate B	Inlet Pressure	Outlet Pressure	Pressure Differential
			hr	gal	gal	gal	BV	gpm	gal	gal	gal	BV	gpm	gpm	gpm	psi	psi	psi
18	Mon	12/04/06	5.4	35,870,800	51,900	2,831,400	4,981	160	4,025,129	48,978	4,001,178	7,038	151	118.2	104.2	45	43	2
	Tue	12/05/06	4.9	35,900,400	29,600	2,861,000	5,033	101	4,066,994	41,865	4,043,043	7,112	142	76.0	67.7	45	44	1
	Wed	12/06/06	4.5	35,925,900	25,500	2,886,500	5,078	94	4,105,140	38,146	4,081,189	7,179	141	75.4	64.3	44	42	2
	Fri	12/08/06	6.7	35,963,100	37,200	2,923,700	5,143	93	4,154,331	49,191	4,130,380	7,266	122	65.5	56.9	46	45	1
19	Mon	12/11/06	13.5	36,025,800	62,700	2,986,400	5,253	77	4,244,457	90,126	4,220,506	7,424	111	61.4	49.8	48	46	2
	Tue	12/12/06	3.3	36,045,800	20,000	3,006,400	5,288	101	4,274,353	29,896	4,250,402	7,477	151	83.8	69.0	44	42	2
	Wed	12/13/06	4.8	36,074,600	28,800	3,035,200	5,339	100	4,314,337	39,984	4,290,386	7,547	139	74.1	63.6	45	44	1
	Thu	12/14/06	3.8	36,098,000	23,400	3,058,600	5,380	103	4,346,846	32,509	4,322,895	7,604	143	74.5	68.0	45	44	1
	Sat	12/16/06	3.9	36,123,100	25,100	3,083,700	5,424	107	4,379,073	32,227	4,355,122	7,661	138	71.9	65.6	45	43	2
20	Tue	12/19/06	10.0	36,187,400	64,300	3,148,000	5,538	107	4,470,042	90,969	4,446,091	7,821	152	83.6	68.1	46	44	2
	Thu	12/21/06	5.4	36,213,600	26,200	3,174,200	5,584	81	4,507,251	37,209	4,483,300	7,886	115	61.9	53.0	45	43	2
	Sat	12/23/06	5.1	36,244,800	31,200	3,205,400	5,639	102	4,547,606	40,355	4,523,655	7,957	132	70.4	61.1	44	42	2
21	Tue	12/26/06	11.0	36,323,700	78,900	3,284,300	5,777	120	4,631,629	84,023	4,607,678	8,105	127	67.3	60.2	45	44	1
	Wed	12/27/06	5.3	36,331,500	7,800	3,292,100	5,791	25	4,671,645	40,016	4,647,694	8,176	126	65.8	60.0	44	42	2
	Fri	12/29/06	8.4	36,374,000	42,500	3,334,600	5,866	84	4,730,331	58,686	4,706,380	8,279	116	61.7	54.5	50	48	2
	Sat	12/30/06	9.8	36,389,100	15,100	3,349,700	5,892	26	4,778,028	47,697	4,754,077	8,363	81	44.4	37.0	51	50	1
22	Mon	01/01/07	3.7	36,423,700	34,600	3,384,300	5,953	156	4,800,221	22,193	4,776,270	8,402	100	53.3	46.6	48	46	2
	Tue	01/02/07	7.3	36,447,800	24,100	3,408,400	5,996	55	4,846,560	46,339	4,822,609	8,483	106	55.6	50.3	48	46	2
	Thu	01/04/07	3.8	36,482,100	34,300	3,442,700	6,056	150	4,873,274	26,714	4,849,323	8,530	117	59.7	56.3	46	44	2
	Fri	01/05/07	5.1	36,504,100	22,000	3,464,700	6,095	72	4,913,339	40,065	4,889,388	8,601	131	67.9	63.7	44	42	2
23	Mon	01/08/07	8.7	36,564,300	60,200	3,524,900	6,201	115	4,993,595	80,256	4,969,644	8,742	154	83.1	70.6	46	44	2
	Wed	01/10/07	4.9	36,591,900	27,600	3,552,500	6,249	94	5,030,477	36,882	5,006,526	8,807	125	64.8	61.3	45	44	1
	Thu	01/11/07	5.3	36,620,200	28,300	3,580,800	6,299	89	5,071,184	40,707	5,047,233	8,878	128	65.3	62.2	46	44	2
	Sat	01/13/07	6.3	36,655,000	34,800	3,615,600	6,360	92	5,116,058	44,874	5,092,107	8,957	119	61.2	57.0	46	44	2
24	Tue	01/16/07	15.2	36,727,700	72,700	3,688,300	6,488	80	5,197,238	81,180	5,173,287	9,100	89	49.4	39.8	43	43	0
	Wed	01/17/07	8.6	36,738,400	10,700	3,699,000	6,507	21	5,242,721	45,483	5,218,770	9,180	88	49.4	38.6	46	44	2
	Fri	01/19/07	6.2	36,772,800	34,400	3,733,400	6,567	92	5,286,751	44,030	5,262,800	9,258	118	61.2	56.9	46	44	2
	Sat	01/20/07	5.0	36,803,000	30,200	3,763,600	6,620	101	5,328,881	42,130	5,304,930	9,332	140	75.1	65.8	48	46	2
25	Mon	01/22/07	11.4	36,873,400	70,400	3,834,000	6,744	103	5,425,537	96,656	5,401,586	9,502	141	75.6	65.6	46	44	2
	Tue	01/23/07	6.3	36,907,300	33,900	3,867,900	6,804	90	5,481,966	56,429	5,458,015	9,601	149	81.4	69.0	46	44	2
	Wed	01/24/07	4.5	36,937,200	29,900	3,897,800	6,857	111	5,515,194	33,228	5,491,243	9,660	123	63.2	58.2	50	48	2
	Thu	01/25/07	3.7	36,953,900	16,700	3,914,500	6,886	75	5,543,756	28,562	5,519,805	9,710	129	72.7	56.1	48	46	2
	Fri	01/26/07	3.9	36,978,500	24,600	3,939,100	6,929	105	5,577,869	34,113	5,553,918	9,770	146	79.2	66.3	48	46	2
26	Mon	01/29/07	6.3	37,049,000	70,500	4,009,600	7,053	187	5,670,301	92,432	5,646,350	9,932	245	134.3	110.8	41	43	2
	Tue	01/30/07	2.0	37,071,500	22,500	4,032,100	7,093	188	5,703,399	33,098	5,679,448	9,991	276	183.5	89.4	52	52	0
	Wed	01/31/07	1.6	37,077,100	5,600	4,037,700	7,103	58	5,712,463	9,064	5,688,512	10,007	94	66.5	37.0	48	46	2
	Thu	02/01/07	3.4	37,096,800	19,700	4,057,400	7,137	97	5,738,921	26,458	5,714,970	10,053	130	61.6	63.7	44	45	1
	Fri	02/02/07	5.2	37,117,900	21,100	4,078,500	7,174	68	5,779,209	40,288	5,755,258	10,124	129	72.8	57.0	49	48	1
27	Mon	02/05/07	16.7	37,182,300	64,400	4,142,900	7,288	64	5,862,438	83,229	5,838,487	10,270	83	41.7	41.3	48	47	1
	Tue	02/06/07	3.0	37,200,500	18,200	4,161,100	7,320	101	5,890,537	28,099	5,866,586	10,320	156	78.5	77.6	49	48	1
	Wed	02/07/07	2.5	37,220,400	19,900	4,181,000	7,355	133	5,908,806	18,269	5,884,855	10,352	122	62.7	66.3	49	48	1
	Thu	02/08/07	3.4	37,237,300	16,900	4,197,900	7,384	83	5,933,510	24,704	5,909,559	10,395	121	62.0	54.0	48	46	2
	Fri	02/09/07	3.6	37,257,600	20,300	4,218,200	7,420	94	5,960,370	26,860	5,936,419	10,443	124	63.8	60.6	48	46	2

(a) Totalizer A and B values are the average of readings taken on 08/20/06 and 08/22/06, respectively

NA = not available

Bed volume = 38 ft^3 or 284 gallons (equivalent to the volume of media in one vessel)

Highlighted cells indicate calculated values.

APPENDIX B

ANALYTICAL DATA

Table B-1. Analytical Results from Treatment Plant Sampling at Wellman, TX

Sampling Date		08/10/06			08/30/06				09/06/06			09/20/06(b)				10/02/06(c)		
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB	IN	AC	TT
Bed Volume (d)	10^3	-	-	NA	-	-	0.9	0.9	-	-	1.2	-	-	1.8	1.7	-	-	2.3
Alkalinity (as $CaCO_3$)	mg/L	232 -	248 -	248 -	266 -	255 -	255 -	266 -	265 -	254 -	265 -	255 -	239 -	255 -	261 -	301 -	258 -	258 -
Fluoride	mg/L	5.0(a)	6.8	7.0	-	-	-	-	6.0	4.9	6.0	-	-	-	-	0.4	5.8	5.6
Sulfate	mg/L	245	305(a)	302(a)	-	-	-	-	244	218	249	-	-	-	-	70	260	265
Nitrate (as N)	mg/L	5.2	4.3	4.1	-	-	-	-	4.0	3.5	3.9	-	-	-	-	3.5	4.3	4.6
Total P (as P)	µg/L	25.4 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -
Silica (as SiO_2)	mg/L	43.5 -	43.8 -	24.4 -	42.1 -	43.6 -	41.3 -	42.8 -	42.1 -	42.6 -	42.0 -	48.2 -	46.6 -	45.4 -	48.5 -	57.6 -	47.5 -	45.8 -
Turbidity	NTU	1.1 -	0.3 -	0.2 -	0.4 -	0.2 -	0.2 -	0.1 -	0.3 -	0.2 -	0.4 -	0.3 -	0.3 -	0.1 -	0.1 -	0.7 -	0.1 -	0.5 -
TOC	mg/L	-	-	-	-	-	-	-	1.3	1.3	1.2	-	-	-	-	1.3	1.3	1.3
pH	S.U.	7.7	7.7	7.5	NA	NA	NA	NA	NA	NA	NA	7.7	7.7	7.6	7.7	7.9	7.6	7.6
Temperature	°C	22.3	23.8	23.8	NA	NA	NA	NA	NA	NA	NA	20.0	20.0	21.3	21.0	18.9	17.0	17.0
DO	mg/L	5.4	5.8	-	NA	NA	NA	NA	NA	NA	NA	4.7	5.0	4.6	5.0	6.2	5.6	5.5
ORP	mV	178	352	271	NA	NA	NA	NA	NA	NA	NA	483	569	475	524	500	574	585
Free Chlorine (as Cl_2)	mg/L	-	NA	NA	-	NA	NA	NA	-	NA	NA	-	NA	NA	NA	-	NA	NA
Total Chlorine (as Cl_2)	mg/L	-	NA	NA	-	NA	NA	NA	-	NA	NA	-	NA	NA	NA	-	NA	NA
Total Hardness (as $CaCO_3$)	mg/L	604	422	415	-	-	-	-	387	521	395	-	-	-	-	410	418	434
Ca Hardness (as $CaCO_3$)	mg/L	130	131	133	-	-	-	-	128	136	130	-	-	-	-	134	137	140
Mg Hardness (as $CaCO_3$)	mg/L	474	291	282	-	-	-	-	258	385	265	-	-	-	-	277	281	295
As (total)	µg/L	45.9 -	46.4 -	0.4 -	6.0 -	43.7 -	0.7 -	0.7 -	15.4 -	37.7 -	1.1 -	14.7 -	40.5 -	2.0 -	2.3 -	42.1 -	43.7 -	0.8 -
As (soluble)	µg/L	42.0	43.6	0.4	-	-	-	-	14.6	39.2	0.9	-	-	-	-	40.3	40.5	0.7
As (particulate)	µg/L	3.9	2.8	<0.1	-	-	-	-	0.8	<0.1	0.1	-	-	-	-	1.7	3.2	<0.1
As (III)	µg/L	0.8	0.7	0.4	-	-	-	-	1.0	1.4	0.9	-	-	-	-	0.7	0.9	0.8
As (V)	µg/L	41.2	42.9	<0.1	-	-	-	-	13.6	37.9	<0.1	-	-	-	-	39.6	39.6	<0.1
Fe (total)	µg/L	131 -	<25 -	<25 -	52 -	<25 -	<25 -	<25 -	39 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -
Fe (soluble)	µg/L	<25	<25	<25	-	-	-	-	<25	<25	<25	-	-	-	-	<25	<25	<25
Mn (total)	µg/L	1.8 -	0.2 -	0.1 -	0.6 -	0.5 -	<0.1 -	<0.1 -	0.6 -	0.3 -	0.2 -	0.8 -	0.3 -	0.1 -	0.1 -	0.3 -	0.2 -	<0.1 -
Mn (soluble)	µg/L	0.8	0.3	0.2	-	-	-	-	0.4	0.3	0.2	-	-	-	-	0.3	0.2	<0.1
V (total)	µg/L	157 -	136 -	0.7 -	17.5 -	135 -	0.8 -	0.8 -	53.4 -	152 -	1.4 -	44.7 -	138 -	0.7 -	0.7 -	139 -	137 -	0.9 -
V (soluble)	µg/L	154	134	0.5	-	-	-	-	51.8	154	1.1	-	-	-	-	138	143	1.0

(a) Parameter analyzed outside of hold time. (b) Water quality measurements taken on 09/27/06. (c) Water quality measurements taken on 10/10/06. (d) Bed volumes calculated from Master Totalizer readings.

IN = at wellhead; AC = after chlorination and pH adjustment; TA = after vessel A; TB = after vessel B; TT = total combined effluent.

NA = not available.

Table B-1. Analytical Results from Treatment Plant Sampling at Wellman, TX (Continued)

Sampling Date		10/19/06				11/02/06			11/15/06				11/28/06			12/14/06		
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB	IN	AC	TT	IN	AC	TT
Bed Volume$^{(d)}$	10^3	-	-	3.2	3.0	-	-	3.7	-	-	4.4	4.1	-	-	4.8	-	-	5.4
Alkalinity (as $CaCO_3$)	mg/L	256 258	240 244	260 260	260 258	267 -	246 -	261 -	258 -	246 -	254 -	246 -	259 -	245 -	259 -	258 -	243 -	252 -
Fluoride	mg/L	-	-	-	-	4.6	3.6	4.6	-	-	-	-	7.6	4.4	6.2	5.1	3.8	4.8
Sulfate	mg/L	-	-	-	-	221	427	272	-	-	-	-	308	470	379	318	400	380
Nitrate (as N)	mg/L	-	-	-	-	4.2	5.3	4.6	-	-	-	-	5.6	6.1	6.1	4.8	5.2	4.4
Total P (as P)	µg/L	<10 <10	<10 <10	<10 <10	<10 <10	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -
Silica (as SiO_2)	mg/L	46.3 46.7	45.8 46.7	47.1 47.2	47.6 48.1	45.7 -	43.0 -	44.4 -	44.7 -	42.7 -	44.2 -	46.6 -	45.5 -	43.3 -	45.4 -	43.3 -	42.8 -	43.3 -
Turbidity	NTU	0.4 0.2	0.3 0.3	0.2 0.2	0.2 0.2	0.8 -	0.2 -	0.3 -	0.5 -	1.0 -	0.6 -	3.4 -	0.9 -	0.9 -	0.2 -	0.5 -	1.6 -	0.4 -
TOC	mg/L	-	-	-	-	1.1	1.5	1.2	-	-	-	-	1.1	1.5	1.4	1.3	1.5	1.4
pH	S.U.	NA	NA	NA	NA	7.9	7.7	7.7	NA	NA	NA	NA	7.8	7.7	7.6	7.9	7.8	7.6
Temperature	°C	NA	NA	NA	NA	13.1	11.5	11.2	NA	NA	NA	NA	15.2	15.6	15.9	12.4	13.1	13.4
DO	mg/L	NA	NA	NA	NA	57.1	59.8	63.0	NA	NA	NA	NA	6.5	5.8	5.9	5.7	5.6	5.2
ORP	mV	NA	NA	NA	NA	477	522	603	NA	NA	NA	NA	479	481	492	529	514	529
Free Chlorine (as Cl_2)	mg/L	-	NA	NA	NA	-	NA	0.4	-	NA	NA	NA	-	NA	0.2	-	NA	NA
Total Chlorine (as Cl_2)	mg/L	-	NA	NA	NA	-	NA	NA	-	NA	NA	NA	-	NA	NA	-	NA	1.4
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	350	668	395	-	-	-	-	423	608	527	489	593	557
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	155	161	159	-	-	-	-	147	148	164	136	143	155
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	195	507	236	-	-	-	-	276	460	364	353	450	401
As (total)	µg/L	29.5 29.2	37.5 38.3	1.0 1.2	0.8 0.9	22.7 -	39.2 -	0.5 -	22.6 -	38.7 -	1.2 -	1.1 -	19.7 -	47.2 -	1.4 -	10.7 -	38.9 -	1.1 -
As (soluble)	µg/L	-	-	-	-	24.9	39.2	0.4	-	-	-	-	12.6	43.1	1.4	12.6	38.1	1.0
As (particulate)	µg/L	-	-	-	-	<0.1	<0.1	<0.1	-	-	-	-	7.2	4.1	<0.1	<0.1	0.8	<0.1
As (III)	µg/L	-	-	-	-	0.4	0.7	0.4	-	-	-	-	1.4	1.4	1.6	0.7	0.8	0.7
As (V)	µg/L	-	-	-	-	24.5	38.6	<0.1	-	-	-	-	11.2	41.6	<0.1	11.9	37.3	0.3
Fe (total)	µg/L	<25 <25	52 46	<25 <25	<25 <25	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	<25	<25	<25	-	-	-	-	<25	<25	<25	<25	<25	<25
Mn (total)	µg/L	0.7 0.6	0.2 0.2	<0.1 <0.1	<0.1 0.1	0.6 -	0.3 -	<0.1 -	1.0 -	0.2 -	<0.1 -	<0.1 -	0.8 -	0.1 -	<0.1 -	0.5 -	0.4 -	<0.1 -
Mn (soluble)	µg/L	-	-	-	-	0.5	0.3	<0.1	-	-	-	-	1.2	0.1	<0.1	0.5	0.4	<0.1
V (total)	µg/L	92.1 90.0	135 143	0.9 1.0	0.8 0.8	71.8 -	156 -	0.6 -	77.7 -	168 -	1.0 -	1.1 -	56.7 -	161 -	3.2 -	41.2 -	159 -	2.0 -
V (soluble)	µg/L	-	-	-	-	82.1	161	0.5	-	-	-	-	41.7	160	3.7	47.7	160	1.9

IN = at wellhead; AC = after chlorination and pH adjustment; TA = after vessel A; TB = after vessel B; TT = total combined effluent. . (d) Bed volumes calculated from Master Totalizer readings.
NA = not available.

Table B-1. Analytical Results from Treatment Plant Sampling at Wellman, TX (Continued)

Sampling Date		01/03/07				01/18/07			02/06/07			
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB
Bed Volume(c)	10^3	-	-	NA(a)	NA(a)	-	-	NA(a)	-	-	7.7	6.9
Alkalinity (as CaCO_3)	mg/L	268 268	272 270	270 258	262 276	263 -	248 -	263 -	281 -	256 -	263 -	268 -
Fluoride	mg/L	-	-	-	-	5.7	4.7	5.5	-	-	-	-
Sulfate	mg/L	-	-	-	-	272	381	273	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	4.8	5.5	4.9	-	-	-	-
Total P (as P)	µg/L	<10 <10	<10 <10	<10 <10	<10 <10	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -
Silica (as SiO_2)	mg/L	45.6 44.8	45.1 45.7	45.2 44.7	45.4 45.5	45.4 -	45.3 -	47.6 -	42.5 -	42.7 -	44.6 -	43.8 -
Turbidity	NTU	0.5 0.5	2.3 2.4	1.1 1.2	0.3 0.3	0.4 -	0.6 -	0.6 -	0.2 -	0.1 -	0.3 -	0.2 -
TOC	mg/L	-	-	-	-	1.2	1.5	1.2	-	-	-	-
pH	S.U.	NA	NA	NA	NA	8.0	7.8	7.7	NA	NA	NA	NA
Temperature	°C	NA	NA	NA	NA	8.1	9.8	10.1	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA(b)	NA(b)	NA(b)	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	535	512	659	NA	NA	NA	NA
Free Chlorine (as Cl_2)	mg/L	-	NA	NA	NA	-	NA	NA	-	NA	NA	NA
Total Chlorine (as Cl_2)	mg/L	-	NA	NA	NA	-	1.0	NA	-	NA	NA	NA
Total Hardness (as CaCO_3)	mg/L	-	-	-	-	372	503	371	-	-	-	-
Ca Hardness (as CaCO_3)	mg/L	-	-	-	-	113	118	114	-	-	-	-
Mg Hardness (as CaCO_3)	mg/L	-	-	-	-	259	385	257	-	-	-	-
As (total)	µg/L	45.4 45.1	44.6 46.6	0.8 0.8	0.7 0.8	21.2 -	44.0 -	1.4 -	40.3 -	41.6 -	1.2 -	1.8 -
As (soluble)	µg/L	-	-	-	-	19.2	41.4	1.4	-	-	-	-
As (particulate)	µg/L	-	-	-	-	2.1	2.6	<0.1	-	-	-	-
As (III)	µg/L	-	-	-	-	1.6	2.0	1.8	-	-	-	-
As (V)	µg/L	-	-	-	-	17.6	39.4	<0.1	-	-	-	-
Fe (total)	µg/L	<25 <25	<25 <25	<25 <25	<25 <25	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	<25	<25	<25	-	-	-	-
Mn (total)	µg/L	0.3 0.2	0.2 0.2	<0.1 <0.1	<0.1 <0.1	0.4 -	0.5 -	<0.1 -	0.3 -	0.3 -	<0.1 -	<0.1 -
Mn (soluble)	µg/L	-	-	-	-	0.6	0.7	<0.1	-	-	-	-
V (total)	µg/L	142 143	139 141	0.9 0.9	3.1 3.2	64.3 -	145 -	3.1 -	111 -	112 -	1.5 -	10.8 -
V (soluble)	µg/L	-	-	-	-	62.2	142	3.8	-	-	-	-

(a) Operational data not taken. (b) DO probe not operational. (c) Bed volumes calculated from Master Totalizer readings.
IN = at wellhead; AC = after chlorination and pH adjustment; TA = after vessel A; TB = after vessel B; TT = total combined effluent.
NA = not available.