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Arsenic Removal from Drinking Water by Adsorptive Media U.S. EPA Demonstration Project at Chateau Estates Mobile Home Park in Springfield, OH Final Performance Evaluation Report

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Sally Gutierrez, Director
National Risk Management Research Laboratory

ABSTRACT

This report documents the activities performed for and the results obtained from the arsenic removal treatment technology demonstration project at the Chateau Estates Mobile Home Park in Springfield, OH. The objectives of the project are 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, 2) the required system operation and maintenance (O&M) and operator skill levels, and 3) the capital and O&M cost of the technology. The project also characterizes the water in the distribution system and process residuals produced by the treatment process.

The 250 gal/min (gpm) Arsenic Package Unit (APU-250) treatment system consisted of two integrated units referred to as AD-26 oxidation/filtration and AD-33 adsorption systems. The AD-26 pretreatment system was for iron and manganese removal, followed in series by the AD-33 adsorption system for arsenic removal. Both the AD-26 oxidation/filtration and AD-33 adsorption systems were skid-mounted, each comprised of three carbon steel pressure vessels of similar construction and configuration, but of different sizes.

AD-26 media was a manganese dioxide mineral commonly used for oxidation and filtration of iron and manganese. Because chlorine was added prior to the AD-26 system, it helped precipitate soluble iron, oxidize As(III) to As(V), and form arsenic-laden solids, which were then filtered by the AD-26 media. The pretreated water was subsequently polished by the AD-33 media, an iron-based adsorptive media developed by Bayer AG for arsenic removal.

The APU-250 system began regular operation on September 21, 2005. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), process residuals, and capital and O&M cost. Through the demonstration period from September 21, 2005, to September 24, 2006, the system treated approximately 16,873,000 gal (about 19,726 bed volumes) of water with the daily run time ranging from 3.7 to 17.3 hr/day and averaging 9.5 hr/day. The AD-26 system operated at the well pump flowrates with water supplied by two alternating wells at approximately 130 and 90 gpm. The AD-33 system operated on demand from the distribution system, ranging from 9 to 71 gpm and averaging 37 gpm. Because of the low flowrates, long empty bed contact times (EBCT), averaged at 23 min, were experienced by the AD-33 system.

The treatment system reduced the arsenic levels from between 9.5 and 35.4 µg/L (averaged 22.7 µg/L) in raw water to <10 µg/L in the treated water. As(III) was the predominating arsenic species in raw water, ranging from 5.6 to 25.8 µg/L and averaging 16.9 µg/L in both wells. Upon chlorination, As(III) was oxidized to As(V) that, in turn, was attached to the iron solids also formed during chlorination. The majority of arsenic was removed in the particulate form by the AD-26 media, leaving only 0.5 to 2.1 µg/L in solution, existing mainly as As(V), to be further polished by the AD-33 media. The system also reduced total iron concentrations from an average of 1,000 µg/L to less than the method detection limit (MDL) of 25 µg/L, while the total manganese concentrations decreased from an average of 35.6 to 0.1 µg/L.

The AD-26 system was backwashed initially every two days for 15 min with a 2-min service-to-waste rinse, producing approximately 5,640 gal of wastewater per backwash event. During a power outage, the backwash settings were reset to default values, prompting the system to produce almost twice as much wastewater per backwash event. This problem was resolved by manually adjusting the backwash settings, which, after a short time, were further reduced to every three days for 9 min with a 90-sec rinse. Assuming that 83 mg/L of total suspended solid (TSS) was produced in 6,000 gal of backwash wastewater, approximately 4 lb of solids (including 0.02, 1.51, and 0.03 lb of arsenic, iron, and

manganese, respectively) would be discharged during each backwash event. The AD-33 system was backwashed four times during the one year demonstration period.

Comparison of the distribution system sampling results before and after the system startup showed a significant decrease in arsenic concentration (from an average of 23.7 to 1.6 µg/L). The arsenic concentrations in the distribution system were similar to those in the system effluent. Iron and manganese also were significantly reduced in the distribution system. Neither lead nor copper concentrations appeared to have been affected by the operation of the system.

The most significant operational issue observed was related to the chlorine injection system. In spite of repeated efforts to fine tune the chlorine injection system and even reconfigure the system piping to allow the injection to be controlled by well pump flowrates instead of on-demand flowrates, as much as 4 and 3.8 mg/L (as Cl_2) total and free chlorine, respectively, were measured in the treated water, which were significantly higher than the 1.5 and 1 mg/L (as Cl_2) of total and free residuals targeted for the treatment. The problem seems to be resolved by the addition of an inline filter placed just before the chlorine monitor to reduce clogging and coating of the chlorine probe due to iron particulates.

The capital investment cost for the system was $292,252, including $212,826 for equipment, $27,527 for site engineering, and $51,899 for installation. This cost included the cost, paid for by the Park owner, to upgrade the system size from 150 to 250 gpm to meet the Ohio Environmental Protection Agency's (Ohio EPA's) redundancy requirement, upgrade the pressure vessel construction material from fiberglass reinforced plastic (FRP) to carbon steel, and add a chlorine injection and control system. Using the system's rated capacity of 250 gpm (360,000 gal/day [gpd]), the capital cost was $1,170 per gpm of design capacity ($0.81/gpd) and equipment-only cost was $851 per gpm of design capacity ($0.59/gpd).

The O&M cost of $0.33/1000 gal included the incremental cost associated with the oxidation/filtration and adsorption system, such as media replacement and disposal, chemical supply, electricity consumption, and labor. Although media replacement did not occur during the demonstration period, the adsorptive media replacement cost would represent the majority of the O&M cost and was estimated to be $34,230.

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ABBREVIATIONS AND ACRONYMS

Δp	differential pressure
AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
APU	arsenic package unit
As	arsenic
ATS	Aquatic Treatment Systems
BET	Brunauer, Emmett and Teller
bgs	below ground surface
BL	baseline sampling
BV	bed volume
Ca	calcium
Cl	chloride
C/F	coagulation/filtration
CRF	capital recovery factor
DO	dissolved oxygen
EBCT	empty bed contact time
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
FRP	fiberglass reinforced plastic
GFH	granular ferric hydroxide
gpd	gallons per day
gpm	gallons per minute
HIX	hybrid ion exchanger
ICP-MS	inductively coupled plasma-mass spectrometry
i.d.	inner diameter
ID	identification
IX	ion exchange
LCR	Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MEI	Magnesium Elektron, Inc.;
Mg	magnesium
Mn	manganese
mV	millivolts

ABBREVIATIONS AND ACRONYMS (Continued)

Na	sodium
NA	not analyzed
NaOCl	sodium hypochlorite
NRMRL	National Risk Management Research Laboratory
NS	not sampled
O&M	operation and maintenance
Ohio EPA	Ohio Environmental Protection Agency
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
psi	pounds per square inch
PO_4	orthophosphate
PLC	programmable logic controller
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
Sb	antimony
SDWA	Safe Drinking Water Act
SiO_2	silica
SMCL	secondary maximum contaminant level
$SO4^{2-}$	sulfate
SOC	synthetic organic compound
STS	Severn Trent Services
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
VOC	volatile organic compound

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1.0 INTRODUCTION

1.1 Background

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

In October 2001, EPA announced an initiative for additional research and development of cost-effective technologies to help small community water systems (<10,000 customers) meet the new arsenic standard and to provide technical assistance to operators of small systems in order to reduce compliance costs. As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, on-site demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems. Shortly thereafter, an announcement was published in the *Federal Register* requesting water utilities interested in participating in Round 1 of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 out of 115 sites to 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 one to six proposals. In April 2003, an independent technical panel reviewed the proposals and provided its recommendations to EPA on the technologies that it determined were acceptable for the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration project. Using the information provided by the review panel, EPA, in cooperation with the host sites and the drinking water programs of the respective states, selected one technical proposal for each site. As of April 2007, 11 of the 12 systems were operational and the performance evaluation of eight systems was completed.

In 2003, EPA initiated Round 2 arsenic technology demonstration projects that were partially funded with Congressional add-on funding to the EPA budget. In June 2003, EPA selected 32 potential demonstration sites and the community water system in the Chateau Estates Mobile Home Park in Springfield, OH 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), using the Bayoxide E33 media developed by Bayer AG, was selected for demonstration at the Chateau Estates site in September 2004.

1.2 Treatment Technologies for Arsenic Removal

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

1.3 Project Objectives

The objective of the arsenic demonstration program is to conduct 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 Chateau Estates Mobile Home Park in Springfield, OH during the one year demonstration period from September 21, 2005, through September 24, 2006. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and 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
Buckeye Lake, 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)	USFilter	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)	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
		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)	USFilter	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; C/F = coagulation/filtration; GFH = granular ferric hydroxide; HIX = hybrid ion exchanger; IX = ion exchange; RO = reverse osmosis

ATS = Aquatic Treatment Systems; MEI = Magnesium Elektron, Inc.; STS = Severn Trent Services

(a) Arsenic existing mostly as As(III).

(b) Design flowrate reduced by 50% after system was switched from parallel to serial configuration.

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

(d) Replaced Village of Lyman, NE site which withdrew from program in June 2006.

(e) Faculties upgraded Springfield, OH system from 150 to 250 gpm, Sandusky, MI system from 210 to 340 gpm, and Arnaudville, LA system from 385 to 770 gpm.

(f) Including nine residential units.

(g) Including eight under-the-sink units.

2.0 SUMMARY AND CONCLUSIONS

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

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

- Chlorination effectively oxidized As(III) and Fe(II) and formed arsenic-laden particles filterable by the AD-26 media. Via filtration of particles, the AD-26 media alone was capable of reducing total arsenic concentrations to less than 2.5 µg/L, far below the 10-µg/L MCL.
- Without extended contact time, chlorination was effective in precipitating Mn(II), converting 85 to 98% of Mn^{2+} to MnO_2 in nine of the 13 speciation events. This observation was contrary to previously documented findings that, upon chlorination, Mn^{2+} remained in solution for an extended duration due to slow oxidation kinetics (Knocke et al., 1987; Knocke et al., 1990; Condit and Chen, 2006).
- The AD-33 system worked as a polisher, reducing total arsenic concentrations from 2.1 µg/L to less than or equal to 0.5 µg/L (existing mainly as As(V) in the system effluent).
- In spite of repeated efforts, the automatic chlorine monitor/controller failed to control free and total chlorine residuals within the target level of 1.0 mg/L (as Cl_2), leaving as much as 3.8 mg/L (as Cl_2) of free chlorine and 4 mg/L (as Cl_2) of total chlorine at the entry point to the distribution system.

Required system O&M and operator skill levels:

- The daily demand on the operator was typically 20 min to visually inspect the system and record operational parameters.
- The most significant operational issue was related to the chlorine injection system. Many attempts of fine-tuning the system and even reconfiguring the system piping did not seem to resolve the significant high free and total chlorine measured in the treated water.

Process residuals produced by the technology:

- Residuals produced by the operation of the treatment system included backwash wastewater and spent media. Because media was not replaced during this demonstration study, the only residual produced was backwash wastewater.
- The AD-26 system had to be backwashed periodically in order to maintain system operation. The average system run length was increased from 7 to 27 hr (or from two to three days of system operation) during the one year demonstration study, but potentially can be further extended because of low pressure loss (i.e., 2 pounds per square inch [psi]) across the AD-26 vessels.
- The AD-33 system did not require backwashing during the one year demonstration period. The pressure loss across the AD-33 vessels also was insignificant, averaging 2 psi throughout the study period.
- Assuming an average of 83 mg/L of total suspended solids (TSS) in 6,000 gal of wastewater produced by backwashing the three AD-26 vessels, approximately 4 lb of solids would be

discharged during each backwash event. The solids were comprised of 0.5%, 37.8%, and 0.8% of arsenic, iron, and manganese, respectively.

Capital and O&M cost of the technology:

- The unit capital cost was $0.21/1,000 gal if the system operated at 100% utilization rate. The system's real unit cost was $1.64/100 gal, based on 16,873,000 gal of water production (i.e., about 13% utilization). The O&M cost was $0.33/1,000 gal for labor, chemical usage, and electricity consumption.

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 September 21, 2005. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall system performance was evaluated based on its ability to consistently remove arsenic to below the MCL of 10 μg/L through the collection of water samples across the treatment train. The reliability of the system was evaluated by tracking the unscheduled system downtime and the frequency and extent of repair and replacement. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

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

The quantity of aqueous and solid residuals generated was estimated by tracking the volume of backwash water produced during each backwash cycle. Backwash water and solids were sampled and analyzed for chemical characteristics.

Table 3-1. Predemonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	August 5, 2004
Second Introductory Meeting Held	September 9, 2004
Project Planning Meeting Held	October 8, 2004
Draft Letter of Understanding Issued	October 15, 2004
Final Letter of Understanding Issued	November 5, 2004
Request for Quotation Issued to Vendor	November 16, 2004
Vendor Quotation Received	November 29, 2004
Purchase Order Completed and Signed	March 1, 2005
Engineering Plans Submitted to Ohio EPA	June 1, 2005
System Permit Issued by Ohio EPA	July 6, 2005
Building Construction Began	July 15, 2005
Final Letter Report Issued	July 19, 2005
Building Construction Complete	August 15, 2005
APU Unit Shipped and Arrived	August 19, 2005
Final Study Plan Issued	August 30, 2005
System Installation Completed	September 2, 2005
System Shakedown Completed	September 9, 2005
Performance Evaluation Began	September 21, 2005
Performance Evaluation Completed	September 24, 2006

Ohio EPA = Ohio Environmental Protection Agency

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

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

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

3.2 System O&M and Cost Data Collection

The plant operator performed daily, weekly, 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. If any problems occurred, the plant operator contacted the Battelle Study Lead, who determined if the vendor should be contacted for troubleshooting. The plant operator recorded all relevant information, including the problem, course of action taken, materials and supplies used, and associated cost and labor, on a Repair and Maintenance Log Sheet. On a biweekly basis, the plant operator measured several water quality parameters on-site, including temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and total and free chlorine, and recorded the data on an On-Site Water Quality Parameters Log Sheet. The backwash data collected monthly were recorded on a Backwash Log Sheet.

The capital cost for the arsenic removal system consisted of the cost for equipment, site engineering, and system installation. The O&M cost consisted of the cost for chemical usage, electricity consumption, and labor. Consumption of NaOCl was tracked on the Daily System Operation Log Sheet. Electricity consumption was determined by utility bills. Labor for various activities, such as the routine system O&M, troubleshooting and repairs, and demonstration-related work, were tracked using an Operator Labor Hour Log Sheet. The routine system O&M included activities such as completing field logs, replenishing the NaOCl solution, ordering supplies, performing system inspections, and others as recommended by the vendor. The labor for demonstration-related work, including activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead and the vendor, was recorded, but not used for the cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected from the wellheads, across treatment plant, during the oxidation/filtration vessel backwash, and from the distribution system. Table 3-3 presents the sampling schedules and analytes measured during each sampling event. Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2004). The procedure for arsenic speciation is described in Appendix A of the QAPP.

3.3.1 Source Water. During the initial visit to the site, one set of source water samples from the West Well was collected and speciated using an arsenic specitation kit (see Section 3.4.1). A second introductory meeting was held to further discuss the technology selection for the site and a set of source water samples from the East Well was collected and speciated. The sample taps were flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Analytes for the source water samples are listed in Table 3-3.

3.3.2 Treatment Plant Water. During the system performance evaluation study, the plant operator collected samples biweekly. For the first biweekly event, samples were taken at the wellhead (IN), after chlorination (AC), after the oxidation/filtration vessels (OT), and after the adsorption vessels (TT) and analyzed for the analytes listed in Table 3-3 for the monthly (without speciation) treatment plant water. For the second biweekly event, samples were collected and speciated on-site at the same four locations and analyzed for the analytes listed under the monthly (with speciation) treatment plant water list in Table 3-3.

3.3.3 Backwash Water and Solids. Backwash water samples were collected monthly by the plant operator from each oxidation/filtration vessel. Over the duration of backwash for each vessel, a side stream of backwash water was directed from the tap on the backwash water discharge line to a clean, 32-gal plastic container at approximately 1 gpm. After the content in the container was thoroughly mixed, one aliquot was collected as is and the other filtered with 0.45-μm disc filters. The samples were analyzed for analytes listed in Table 3-3.

Once during the one-year study period, the content in the 32-gal plastic container was allowed to settle and the supernatant was carefully siphoned using a piece of plastic tubing to avoid agitation of settled solids in the container. The remaining solids/water mixture was then transferred to a 1-gal plastic jar. After solids in the jar were settled and the supernatant was carefully decanted, one aliquot of the solids/water mixture was air-dried before being acid-digested and analyzed for the metals listed in Table 3-3.

Backwash water and solid samples were collected once from each adsorption vessel using the same procedure applied to the oxidation/filtration vessels. The samples were analyzed for analytes listed in Table 3-3.

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

3.3.5 Distribution System Water. Samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically, the arsenic, lead and copper levels. Prior to the system start-up from April to July 2005, four sets of baseline distribution water samples were collected at three Lead and Copper Rule (LCR) locations within the distribution system, including the Park Clubhouse and Lots 12 and 76 Residences. Following

Table 3-3. Sampling Schedule and Analytes

Sample Type	Sampling Location[a]	No. of Samples	Frequency	Analyte	Sampling Date
Source Water	At Wellhead (IN)	2 (East Well and West Well)	Once at West Well during initial introductory visit and once at East Well during second introductory 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), U (total and soluble), V (total and soluble), Na, Ca, Mg, NH_3, NO_3, NO_2, Cl, F, SO_4, SiO_2, PO_4, TDS, TOC, turbidity, and alkalinity	08/05/04 and 09/09/04
Treatment Plant Water	At Wellhead (IN), after Chlorination (AC), after Oxidation/ Filtration Vessels (OT), after Adsorption Vessels (TT)	4	Monthly (Without speciation)	On-site: pH, temperature, DO, ORP, and Cl_2 (free and total)[c] Off-site: As (total), Fe (total), Mn (total), Ca, Mg, F, NH_3, NO_3, SO_4, SiO_2, P, turbidity, and alkalinity	10/11/05, 11/08/05, 12/12/05, 01/16/06, 02/13/06, 03/13/06, 04/10/06, 05/08/06, 06/13/06, 07/12/06, 08/14/06, 09/11/06
			Monthly (With speciation)	On-site: pH, temperature, DO, ORP, and Cl_2 (free and total)[c] Off-site: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), Ca, Mg, F, NH_3, NO_3, SO_4, SiO_2, P, turbidity, and alkalinity	09/28/05, 10/25/05, 12/05/05, 01/03/06, 02/01/06, 02/28/06, 03/27/06, 04/24/06, 05/22/06, 06/28/06, 07/26/06, 08/30/06, 09/18/06
Distribution Water	Two LCR Locations (including Park Clubhouse and Lot 76 Residence) and One Non-LCR Residence (Lot 16)	3	Monthly[b]	As (total), Fe (total), Mn (total), Cu (total), Pb (total), pH, and alkalinity	Baseline sampling: 04/04/05, 05/03/05, 06/08/05, 07/07/05 Monthly sampling: 10/12/05, 11/15/05, 12/12/05, 01/16/06, 02/13/06, 03/13/06, 04/10/06, 05/08/06, 06/12/06, 07/11/06, 08/14/06, 09/12/06
Backwash Water	Backwash Discharge Line from Each Oxidation/ Filtration Vessel	3	Monthly	As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, TDS, TSS, turbidity	10/13/05, 12/05/05, 01/12/06, 02/02/06, 02/27/06, 03/24/06, 04/20/06, 05/17/06, 06/22/06, 07/13/06, 08/15/06, 09/17/06

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

Sample Type	Sampling Locations[(a)]	No. of Samples	Frequency	Analytes	Sampling Date
Backwash Water	Backwash Discharge Line from Each Adsorption Vessel	3	Once	As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, TDS, TSS, turbidity	02/12/07
Backwash Solids	Backwash Discharge Line from Each Oxidation/ Filtration Vessel	3	Once	Al, Ag, As, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, K, Mg, Mn, Hg, Ni, Pb, Se, Sb, Na, Tl, V, Zn	09/19/06
Backwash Solids	Backwash Discharge Line from Each Adsorption Vessel	3	Once	Al, Ag, As, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, K, Mg, Mn, Hg, Ni, Pb, Se, Sb, Na, Tl, V, Zn	02/12/07

(a) Abbreviations in parentheses corresponding to sample locations shown in Figure 4-5.
(b) Four baseline sampling events performed from April to July 2005 before system became operational.
(c) Taken only at AC, OT, and TT locations.
LCR = Lead and Copper Rule
TDS = total dissolved solids
TSS = total suspended solids

system startup, distribution system sampling continued on a monthly basis at the Park Clubhouse and Lot 76 Residence. Due to availability issues, the Lot 12 Residence was replaced by a non-LCR location at the Lot 16 Residence.

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

3.4 Sampling Logistics

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

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

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

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

Samples for metals analyses were stored at Battelle's inductively coupled plasma-mass spectrometry (ICP-MS) laboratory. Water samples to be analyzed for other parameters by American Analytical Laboratories (AAL) in Columbus, OH, under contract with Battelle, were packed in separate coolers for pickup by AAL couriers. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time, and disposed of properly thereafter.

3.5 Analytical Procedures

The analytical procedures described in detail in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2004) were followed by Battelle ICP-MS and AAL. Laboratory quality assurance/quality control (QA/QC) of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection limits (MDL), and completeness met the criteria established in the QAPP (i.e., relative percent difference [RPD] of 20%, percent recovery of 80 to 120%, and completeness of 80%). The quality assurance (QA) data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project.

Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a VWR Symphony SP90M5 Handheld Multimeter, which was calibrated for pH and DO prior to use following the procedures provided in the user's manual. The ORP probe also was checked for accuracy by measuring the ORP of a standard solution and comparing it to the expected value. The plant operator collected a water sample in a clean, plastic beaker and placed the Symphony SP90M5 probe in the beaker until a stable value was obtained. The plant operator also performed free and total chlorine measurements using Hach chlorine test kits following the user's manual.

4.0 RESULTS AND DISCUSSION

4.1 Facility Description and Preexisting Treatment System Infrastructure

The water treatment system has a total of 226 connections and serves a population of approximately 600 in the Chateau Estates Mobile Home Park Community in Springfield, OH. Source water for the Park is groundwater supplied from two bedrock wells, the West Well and the East Well, located near the pump house (Figure 4-1) at 3454 Folk Ream Road. The West Well produces about 150 gpm and the East Well produces about 90 gpm. Before the installation of the treatment system, only the West Well was in operation. Both wells are 8-in in diameter and were originally installed to a depth of 100 ft below ground surface (bgs). In 2001, the East Well was extended to a depth of 220 ft bgs.

Figure 4-1. Preexisting Treatment Building at Chateau Estates Mobile Home Park

The preexisting water treatment system consisted of chlorination using a 12.5% NaOCl solution and the addition of polyphosphate as a sequestering agent for corrosion and scale control. Figure 4-2 shows the chlorine and polyphosphate storage tanks and chemical metering pumps. Following chlorination and polyphosphate addition, the water was stored in a 2,000-gal hydropneumatic tank (Figure 4-3) prior to entering the distribution system.

Before the installation of the water treatment system, the West Well typically operated for approximately 5 hr/day, producing around 40,000 gal of water based on estimates provided by the facility. To help verify the flowrate of the West Well and the average flowrate to the distribution system from the existing hydropneumatic tank, a flow meter was installed downstream of the hydropneumatic tank in mid-November 2004. Readings from the flow meter and an hour meter (installed in early December 2004) on the West Well pump were collected until the end of February 2005. These readings confirmed that, on average, the West Well pump operated 5.6 hr/day and produced an average of 43,740 gal.

Figure 4-2. Preexisting Chlorine and Polyphosphate Addition Systems

The average flowrate produced by the supply well was calculated based on the volume of water pumped and the time of operation per day; the average flowrate from the supply well was calculated to be 131 gpm, less than the 150-gpm design flowrate assumed for the West Well. The average instantaneous flow reading collected from the hydropnuematic tank to the distribution system was 33 gpm. Figure 4-4 shows the instantaneous flow readings and calculated flowrate from West Well.

4.1.1 Source Water Quality. Source water samples were collected on August 5, 2004, for the West Well and on September 9, 2004, for the East Well. Samples were analyzed for the analytes shown in Table 3-3. The analytical results from source water sampling events are presented in Table 4-1 and compared to data collected by the facility for the EPA demonstration site selection. Historical water quality data at the entry point and from the distribution system were obtained from the Ohio Environmental Protection Agency (Ohio EPA) and the site owner, respectively, and are summarized in Table 4-1.

Total arsenic concentrations in source water (from both wells) ranged from 14.6 to 25.0 µg/L. Based on the water samples collected and analyzed by Battelle, soluble arsenic existed almost entirely as As(III) (24.7 µg/L) in the West Well. Soluble arsenic in the East Well existed as As(III) (6.1 µg/L), As(V) (2.8 µg/L), and particulate As (5.7 µg/L). Total arsenic concentration in the West Well was much higher than that in the East Well (i.e., 24.6 versus 14.6 µg/L). The variations in concentration and species between these two wells were carefully monitored during the course of the demonstration study and are discussed in Section 4.5.1.

Total iron concentrations in source water ranged from 636 to 1,615 µg/L, which exceed the secondary maximum contaminant level (SMCL) of 300 µg/L. The most recent test results of Battelle showed iron concentrations in the West Well at 1,615 µg/L (existing almost entirely in the soluble form) and in the

Figure 4-3. Preexisting Storage Tank

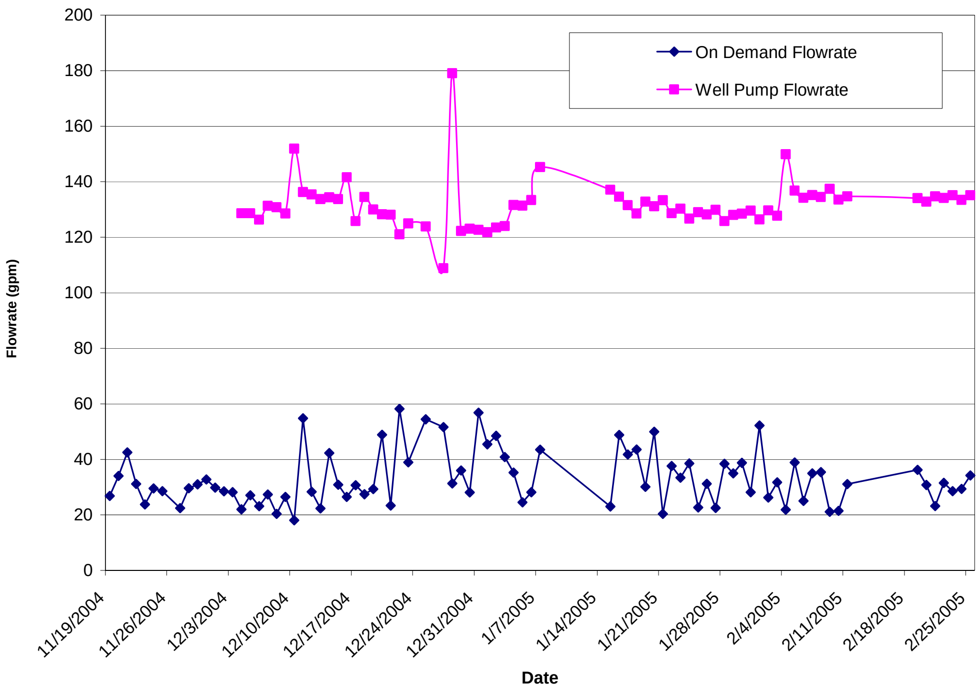


Figure 4-4. West Well Pump Flowrate and On-Demand Flowrate

Table 4-1. Chateau Estates Mobile Home Park Water Quality Data

Parameter	Unit	Facility Data	Battelle Data		Historical Data	
			West Well	East Well	Entry Point	Distribution
Date			08/05/04	09/09/04	1995–2005	1998–2004
Ph		NA	NA	7.3	7.3	NA
Conductivity	μmhos	NA	NA	NA	NA	NA
Temperature	°C	NA	14.5	12.9	NA	NA
DO	mg/L	NA	0.8	3.4	NA	NA
ORP	mv	NA	-88	-25	NA	NA
Total Alkalinity (as CaCO3)	mg/L	NA	319	343	325	NA
Hardness (as $CaCO_3$)	mg/L	256	381	291	NA	NA
Turbidity	NTU	NA	23.0	6.5	1.07–1.4	0.3–17.3
TDS	mg/L	NA	418	372	NA	NA
TOC	mg/L	NA	<1.0	<0.7	NA	NA
Nitrate (as N)	mg/L	NA	<0.04	<0.04	<0.05–0.33	NA
Nitrite (as N)	mg/L	NA	<0.01	<0.01	<0.05	NA
Ammonia (as N)	mg/L	NA	0.24	0.17	NA	NA
Chloride	mg/L	NA	14	1.4	140	NA
Fluoride	mg/L	NA	1.5	0.8	0.85–1.64	NA
Sulfate	mg/L	19.3	27	15	20–33	NA
Silica (as SiO_2)	mg/L	11.3	19.4	17.5	16–18	NA
Orthophosphate (as PO_4)	mg/L	NA	<0.10	<0.10	NA	NA
As(total)	μg/L	25.0	24.6	14.6	15–27.2	4.0–543
As (total soluble)	μg/L	NA	24.3	8.9	NA	NA
As (particulate)	μg/L	NA	0.3	5.7	NA	NA
As(III)	μg/L	NA	24.7	6.1	NA	NA
As(V)	μg/L	NA	<0.1	2.8	NA	NA
Fe (total)	μg/L	1,078	1,615	636	738–2,570	40–44,800
Fe (soluble)	μg/L	NA	1,635	385	NA	NA
Mn (total)	μg/L	35.0	18.5	62.3	<0.02–43	NA
Mn (soluble)	μg/L	NA	18.8	56	NA	NA
U (total)	μg/L	NA	0.9	1.45	NA	NA
U (soluble)	μg/L	NA	0.8	1.6	NA	NA
V (total)	μg/L	NA	0.2	0.41	NA	NA
V (soluble)	μg/L	NA	0.2	0.27	NA	NA
Sb (total)	μg/L	NA	NA	0.30	<4	NA
Na (total)	mg/L	7	11.3	14.8	10–12	NA
Ca (total)	mg/L	68	89	67	68–73	NA
Mg (total)	mg/L	21	39	30	31–33	NA

NA = not analyzed

East Well at 636 μg/L (with 60% existing in the soluble form). The presence of particulate iron in the East Well sample was consistent with the presence of particulate arsenic in the same water. The presence of particulate iron and arsenic in the East Well water, however, needed to be verified during the demonstration study to ensure that these results were not caused by inadvertent aeration of the sample during sampling. Note that the DO and ORP values of the East Well sample were significantly higher than those of the West Well sample.

Manganese concentrations in source water ranged from 18.5 to 62.3 µg/L. The test results of Battelle show manganese concentrations in the West Well at 18.5 µg/L (existing entirely in the soluble form) and in the East Well at 62.3 µg/L (with 90% existing in the soluble form). Based on the relatively high iron and manganese concentrations in source water, the selected vendor proposed to include a pretreatment step for iron and manganese removal prior to arsenic removal.

pH values of source water were consistently around 7.3. Typically, the target pH range for the use of adsorption with iron-based media for arsenic removal is 6.0 to 8.0. The pH value of 7.3 was well within this range; therefore, pH adjustment was not proposed for the arsenic treatment system.

Arsenic adsorption onto iron-based media may be impacted by the presence of competing anions such as silica, sulfate, and phosphate. AD-33 was reportedly affected by silica at levels greater than 40 mg/L, sulfate at levels greater than 150 mg/L, and phosphate at levels greater than 1 mg/L (AdEdge, 2005). The silica levels ranged from 11.3 to 19.4 mg/L, the sulfate levels ranged from 15 to 27 mg/L, and the orthophosphate levels were less than the MDL; therefore, the presence of these anions was not expected to have a significant impact on arsenic adsorption.

Other analyzed water quality parameters showed low concentrations or less than MDLs of ammonia, nitrate, nitrite, fluoride, uranium, vanadium, antimony, and total organic carbon (TOC). The hardness levels ranged from 256 to 381 mg/L, which existed mainly as calcium hardness.

4.1.2 Predemonstration Treated Water Quality. Results of the treated water samples collected at the entry point and from the distribution system from 1995 through 2005 provided by the Ohio EPA and the facility are summarized in Table 4-1. The concentrations of some constituents were considerably higher in the distribution system than those in raw water at the entry point. For example, arsenic concentrations in the distribution system ranged from 4.0 to 543 µg/L (versus 14.6 to 25.0 µg/L in raw water and 15 to 27.2 µg/L at the entry point). Iron concentrations in the distribution system ranged from 40 to 44,800 µg/L (versus 636 to 1,615 µg/L in raw water and 738 to 2,570 µg/L at the entry point). Elevated arsenic and iron concentrations in the distribution system were likely caused by accumulation of particulate matter and/or corrosion products in the distribution system. The facility has been flushing the 11 fire hydrants located throughout the distribution system on a monthly basis.

4.1.3 Distribution System. Based on the information provided by the facility, the water mains within the distribution system are constructed primarily of polyvinyl chloride (PVC) and some copper piping. There also are a few sections of iron pipe installed at the wellhouse at the entry point to the distribution system. The laterals coming off the mains and leading to the individual mobile home units consist of copper and black polyethylene. The piping within the mobile home units is typically PVC, copper, or polybutylene. No lead pipe or lead solder was installed and/or used. Eleven fire hydrants are located throughout the distribution system. Fire hydrants are flushed once a month to remove sediment that builds up in the distribution system.

The LCR samples are collected at five locations every three years. Additional compliance samples include arsenic and iron collected monthly at locations throughout the distribution system and bacteria/total coliform collected monthly. The facility also samples for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), inorganics, nitrate, and radionuclides as directed by the Ohio EPA, typically once every two to three years.

4.2 Treatment Process Description

The treatment system consists of two integrated units referred to as an AD-26 pretreatment system and an AD-33 arsenic package unit (APU) adsorption system. The AD-26 pretreatment system is for iron and manganese removal, followed in series by the APU adsorption system for arsenic removal. The treated water exiting the APU adsorption system is sent to distribution. The preexisting polyphosphate addition system was terminated since it was not needed with the new treatment system.

AD-26 media is a manganese dioxide mineral commonly used for oxidation and filtration of iron and manganese. The media has NSF International Standard 61 approval for use in drinking water applications. Table 4-2 provides physical and chemical properties of the AD-26 media.

Raw water was first treated with chlorine for disinfection and to provide oxidation prior to the AD-26 media. The use of chlorine precipitated soluble iron and converted As(III) to As(V). The As(V) formed was adsorbed onto the precipitated iron solids, which in turn, were filtered out by the AD-26 media.

Following the oxidation/filtration system, the pretreated water was sent to the APU system, which was used as a polishing step. AdEdge's APU arsenic removal system is designed for small systems in the flow range of 10 to 300 gpm. The APU is a fixed bed adsorption system that uses Bayoxide E33 media, an iron-based adsorptive media developed by Bayer AG and marketed as AD-33 by AdEdge.   Table 4-3 presents physical and chemical properties of the AD-33 media. AD-33 is delivered in a dry crystalline form and has NSF International Standard 61 approval for use in drinking water applications. Once reaching its adsorptive capacity, the spent media is removed and disposed of.

Both the AD-26 oxidation/filtration and the APU systems are skid-mounted, each comprised of three carbon steel pressure vessels of similar construction and configuration but of different sizes. Table 4-4 presents the key system design parameters. Figure 4-5 shows the generalized process flow for the system including sampling locations and parameters to be analyzed. Six key process components are discussed as follows:

- **Intake.** Raw water was pumped from two supply wells, West and East Wells, alternating every cycle to the AD-26 oxidation/filtration system.

- **Chlorination.** Prior to the AD-26 oxidation/filtration system, water was chlorinated using a 12.5% liquid NaOCl solution injected to the 4-in PVC line. Chlorine oxidized arsenic and iron and provided a chlorine residual for disinfection. The automatic chlorine injection system was composed of a solenoid driven diaphragm metering pump with a maximum capacity of 2 gal/hr, an in-line chlorine probe, a chlorine monitor/control module equipped with a flow sensor, and a 75-gal polyethylene chemical feed tank with secondary containment. A side-stream of water was directed, via 0.188-in inner diameter (i.d.) poly tubing, from a valve located approximately 12-ft downstream of the chlorine injection point and an inline mixer to the chlorine monitor/controller module. The chlorine injection pump was turned on and off initially by the flow sensor (so that chlorine was injected only when there was on-demand flow flowing through the treatment system and, therefore, the chlorine monitor/controller module), but later by the well pumps (so that chlorine was injected only when a well was on). Further, the feedback from the inline probe to the monitor/controller module relative to a free chlorine set point automatically adjusted the injection rate (in terms of pulses per minute) of the chlorine metering pump. The proper operation of the NaOCl feed system was tracked by the operator through measurements of free and total chlorine across the treatment train and at the entry point. Figure 4-6 is a composite of photographs of the chlorine feed system and its components.

Table 4-2. Physical and Chemical Properties of AD-26 Media[(a)]

Parameter	Value
Matrix	Manganese dioxide mineral (> 80% active ingredient)
Physical Form	Dry granular media
Color	Black
Bulk Density (lbs/ft^3)	120
Moisture Content (%)	< 10 (by weight)
Particle Size Distribution (U.S. Standard mesh)	20 × 40 or 8 × 20
Oxidant	12.5% NaOCl

(a) Provided by AdEdge

Table 4-3. Physical and Chemical Properties of AD-33 Media[(a)]

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

(a) Provided by Bayer AG.
BET = Brunauer, Emmett, and Teller

- **Iron/Manganese Removal.** When a well pump was on, prechlorinated water entered the AD-26 oxidation/filtration system at an average flowrate of 130 gpm (Table 4-4) and exited the system to the three new hydropneumatic tanks. The AD-26 oxidation/filtration system consisted of three 36-in-diameter, 60-in-sidewall high carbon steel pressure vessels configured in parallel. Each vessel was filled with 31 in (19 ft^3) of AD-26 media, which was underlain by 7 in (5 ft^3) of fine underbedding. The free board measurement in

Table 4-4. Design Features of AdEdge Treatment System

Parameter	Value	Remarks
Influent Specifications		
Peak Design Flowrate (gpm)	250	System upsized from 150 gpm at Park Owner's request
West Well Flowrate (gpm)	130	Average flowrate based on totalizer and well pump hour meter readings
East Well Flowrate (gpm)	90	Based on information received from facility
Average Throughput to System (gpd)	40,000	–
Arsenic Concentration (μg/L)	24.6	–
Iron Concentration (μg/L)	1,615	–
Prechlorination		
Chlorine Dosage (mg/L [as Cl_2])	2.5	1.0 mg/L residual chlorine within distribution system
AD-26 – Oxidation/Filtration		
No. of Vessels	3	–
Configuration	Parallel	–
Vessel Size (in)	36 D × 60 H	–
Type of Media	AD-26	Manganese dioxide mineral (See Table 4-2)
Quantity of Media (ft^3/vessel)	19	57 ft^3 total
Flowrate through Each Vessel (gpm)	43	Total flowrate of 130 gpm through AD-26 system
Backwash Flowrate through Each Vessel (gpm)	130	18.4 gpm/ft^2
Backwash Duration (min)	15	Per Vessel
Expected Backwash Frequency (times/week)	3	Actual backwash frequency to be determined during system operation
Estimated AD26 Media Life (yr)	4	Vendor provided estimate
AD-33 Adsorption		
No. of Vessels	3	–
Configuration	Parallel	–
Vessel Size (in)	48 D × 60 H	–
Type of Media	AD-33	Bayoxide E33 (see Table 4-3)
Quantity of Media (ft^3/vessel)	38	114 ft^3 total
Flowrate through Each Vessel (gpm)	on-demand	
EBCT (min/vessel)	25.8	Based on average on-demand flowrate of 33 gpm measured prior to demonstration study (Figure 4-4).
Backwash Flowrate (gpm)	127	10 gpm/ft^2
Backwash Duration (min)	15	Per Vessel
Expected Backwash Frequency (times/60 days)	1	Actual backwash frequency to be determined during system operation
Bed Volumes (BV)/Day	47	Based on throughput of 40,000 gpd, 1 BV = 114 ft^3
Estimated Working Capacity (BV)	83,500	Bed volumes to breakthrough at 10 μg/L based on vendor estimate
Estimated Volume to Breakthrough (gal)	71,200,000	Vendor provided estimate
Estimated AD33 Media Life (yr)	4.9	Estimated frequency of media change-out based on estimated media working capacity of 83,500 BVs and average throughput of 40,000 gpd to system

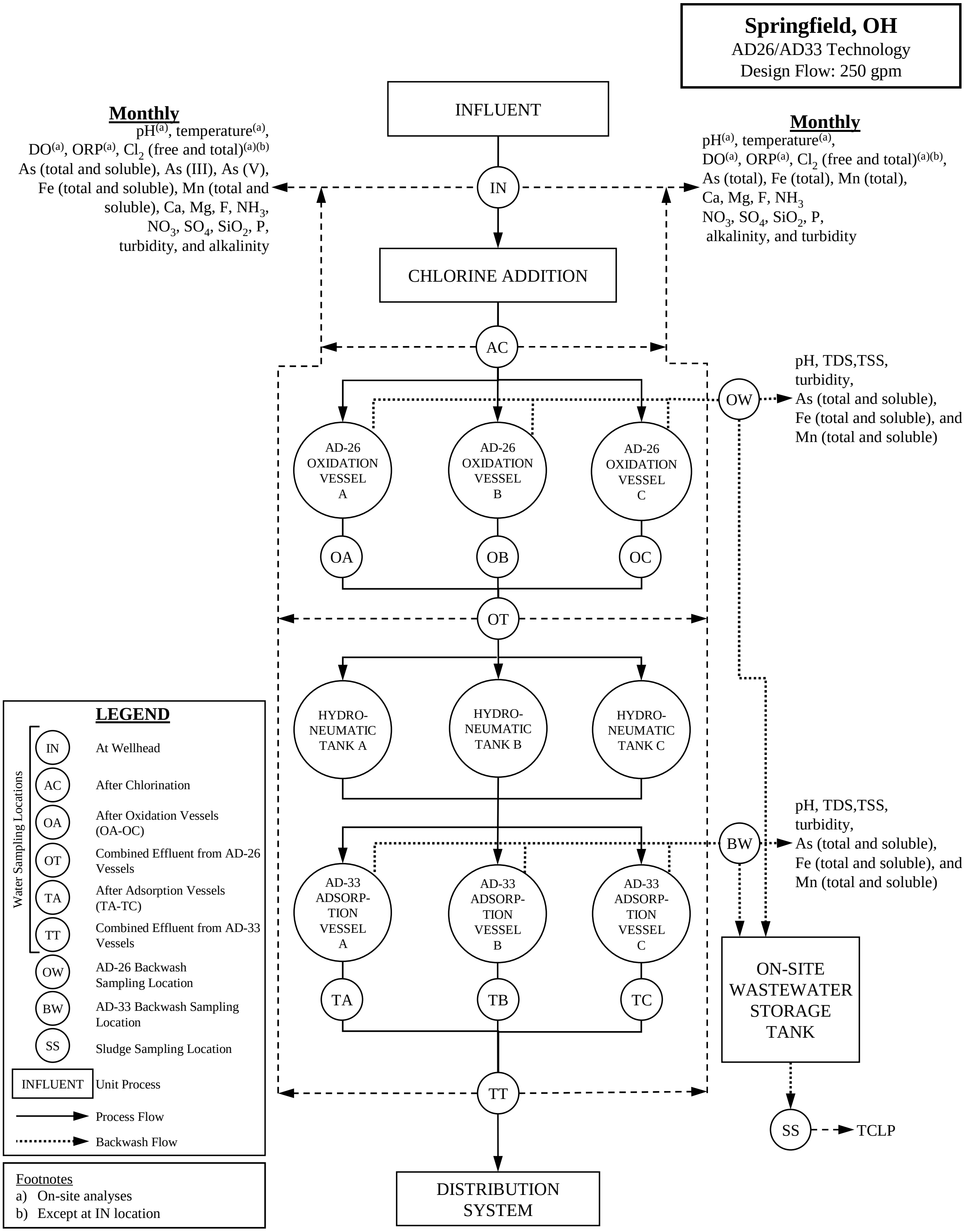


Figure 4-5. Process Flow Diagram and Sampling Locations

Figure 4-6. Chlorine Injection System
(Clockwise from Top: Chlorine Injection Point; Chlorine Monitor/Control Module; Chlorine Injection System; Metering Pump; Chlorine Sensor; Chlorine Monitor/Controller)

the AD-26 vessels was 22 in. The AD-26 system was controlled by electrically actuated butterfly valves and a centralized programmable logic controller (PLC) unit. Figure 4-7 is a photograph of the AD-26 system.

- **Hydropneumatic Tanks.** The filtered water from the AD-26 system entered the three hydropnuematic tanks for storage until needed to meet demand. Each tank had a storage capacity of 528 gal for a total capacity of 1,584 gal. Figure 4-8 is a photograph of the three hydropnuematic tanks.

- **Arsenic Adsorption System.** Upon demand, the water stored in the hydropnuematic tanks flowed through the APU arsenic adsorption system at a varying flowrate. As discussed in Section 4.1, flowrates ranging from 18.1 to 58.2 gpm and averaging 33.0 gpm (Figure 4-4) were recorded from the existing hydropnuematic tank to the distribution system during a predemonstration water demand study. The APU system consisted of three 48-in-diameter, 60-in-sidewall high carbon steel pressure vessels also configured in parallel. Each of the APU vessels contained approximately 38 ft^3 (114 ft^3 total) of AD-33 media. Assuming a flowrate of 33.0 gpm (or 11.0 gpm/vessel), the media empty bed contact time (EBCT) in each vessel would be 25.8 min, which is at least five times higher than that recommended by the vendor. Similar to the AD-26 system, the APU system was controlled by a series of electrically actuated butterfly valves and the PLC unit.

Figure 4-7. AD-26 Treatment System

Figure 4-8. Hydropneumatic Tanks

Figure 4-9 is a photograph of the APU system. Figure 4-10 presents a photograph of the APU control panel.

- **Backwash.** Both the AD-26 and APU systems required backwashing to remove particulates and solids that build up in the media beds. Both systems can be set to initiate backwash automatically based on differential pressure (Δp) measured across the individual pressure vessels, system run time, or volume of water treated. Each vessel was backwashed one at a time using water stored in the hydropnuematic tanks.

  For the AD-26 system that filtered arsenic ladened-iron solids and manganese solids, backwash was performed every two to three days based on a set time. Backwash was adjusted on February 9, 2006, from once every 2 days for 15 min per vessel to once every 3 days for 9 min per vessel, with a 2- or 1.5-min filter-to-waste rinse at a flowrate of 130 gpm. After the adjustment, the total amount of wastewater produced should have been reduced from approximately 6,630 to 4,100 gal for the three vessels although this volume reduction was not observed (see Section 4.4.3).

  The backwash duration for the APU system was 15 min and the backwash flowrate 127 gpm. Each backwash event produced 6,045 gal of wastewater from backwashing the three adsorption vessels. Initially, automatic backwash was disabled to allow for manual backwash; however, the manual setting was reverted back to default for automatic backwash due to a power outage at the end of November 2005. Therefore, the system was automatically backwashed once every 60 days up until September 14, 2006.

  The backwash wastewater produced from both AD-26 and APU systems was collected in two 6,000-gal onsite storage tanks. One a weekly basis, a vacuum truck came to transfer the wastewater from the storage tanks and disposed of it at the Village of North Hampton sewer system. On September 14, 2006, the treatment system was connected to the sewer system.

- **Media replacement.** When the AD-33 adsorptive media exhausts its capacity, the spent media will be removed and disposed of and virgin media loaded into the vessels. Media replacement was not performed during the one year demonstration period. The vendor initially estimated the life of AD-26 media to be 4 yr, but after observation of its performance, extended the media life to 10 yr. The AD-26 media will be replaced when it loses its filtration capabilities.

4.3 System Installation

The installation of the treatment system was completed by LBJ Inc., a subcontractor to AdEdge, on September 2, 2005. The following briefly summarizes some of the system/building installation activities, including permitting, building preparation, system offloading, installation, shake-down, and start-up.

4.3.1 Permitting. Design drawings and a process description of the proposed treatment system were submitted to the Ohio EPA by LBJ, Inc., on May 27, 2005. Ohio EPA's review comments were received on June 21, 2005. The comments were related to redundancy, sampling requirements, disinfection practice, and minimum EBCT. After incorporating the responses to the comments, the plans were resubmitted to Ohio EPA on June 30, 2005. Ohio EPA granted the treatment system permit on July 6, 2005.

Figure 4-9. AD-33 Treatment System

Figure 4-10. System Control Panel

4.3.2 Building Preparation. The building housing the preexisting chlorination and polyphosphate addition systems and the 2,000-gal hydropnuematic tank needed modifications for the planned arsenic treatment system. The necessary additional preparation included removing the ceiling joists, cutting into the floor to install sub-floor piping, removing the 2,000-gal hydropnuematic tank, and pouring a pad for the three new hydropnuematic tanks. The building construction began on July 15, 2005, and was completed on August 15, 2005.

4.3.3 Installation, Shakedown, and Startup. The treatment system arrived at the site on August 10, 2005. The installation activities, which lasted about two weeks, included removing the existing hydropnuematic tank, removing the existing polyphosphate system, offloading and placing the AD-26 oxidation/filtration and AD-33 APU systems and the three new hydropnuematic tanks, connecting system piping at the tie-in points, completing electrical wiring and connections, and assembling the chlorine injection system.

Upon completion of system installation, the media vessels were tested hydraulically before media loading on September 1, 2005. For the APU system, six 100-lb bags of coarse gravel (for a total of 600 lb [or 6 ft^3]), three 100-lb bags of fine gravel (for a total of 300 lb [or 3 ft^3]), and one and one fifth 1,100-lb supersacks of the AD-33 media (for a total of 1,330 lb [or 38 ft^3]) were loaded sequentially into each vessel containing approximately half a tank of water. Figure 4-11 shows a photograph of loading the AD-33 media from a supersack through a hatch on the roof of the building. Each AD-26 vessel was loaded with five 100-lb bags of fine gravel (for a total of 500 lb [or 5 ft^3]) and then approximately 41 55-lb bags of the AD-26 media (for a total of 2,255 lb [or 19 ft^3]) with the vessel containing about half a tank of water. Figure 4-12 is a composite of pictures showing the media bags and loading the underbedding into one of the AD-33 vessels.

Figure 4-11. AD-33 Media Loading

Figure 4-12. AD-33 Media Supersack, AD-26 Media Bags and Loading of Underbedding

After media loading, the vessels were backwashed one at a time to remove media fines. Backwashing continued until the backwash water ran clear. Freeboard measurements were then taken from where the straight side of the tank starts to the top of the media. For the AD-26 oxidation/filtration vessels, the freeboard to the top of the media was measured at 24 to 25 in, which, based on the 55-in freeboard to the top of the underbedding gravel, would yield a bed depth of 30 to 31 in (compared to the design value of 32 in). For the AD-33 adsorption vessels, the freeboard measurements to the top of the media ranged from 24 to 26 in, which, based on the freeboard measurement of 58 in to the top of gravel, would result in a bed depth of 32 to 34 in (compared to the design value of 36 in).

After the media was loaded and backwashed, the vendor and plant operator performed system shakedown and startup work, which included checking system control and interlocking, testing for balanced flows among individual vessels, and adjusting chlorine injection and control. The system was then sanitized with a 12.5% NaOCl according to the Ohio EPA procedure. A water sample was collected for bacteria analysis and the system was bypassed until the results of the bacteria analysis were received.

After the satisfactory results of the bacteria analysis had been forwarded to Ohio EPA, the system was officially put online on September 21, 2005. Battelle conducted a system inspection and provided operator training on data and sample collection on September 28, 2005.

The configuration of the system as it was initially installed allowed water to flow from one of the wells into the three hydropnuematic tanks until demand in the distribution system forced water, after chlorination, to flow through the AD-26 oxidation/filtration and AD-33 adsorption systems. Due to difficulties encountered when attempting to maintain a stable chlorine residual level in the treated water (see discussion in Section 4.4.2), the system was reconfigured on October 26, 2005, to allow the chlorine addition system and the AD-26 oxidation/filtration vessels to locate prior to the hydropnuematic tanks. As such, the chlorine injection pump and the AD-26 system could operate based on the well flowrate of either 130 or 90 gpm (depending on the operating well). Downstream from the hydropnuematic tanks, the AD-33 adsorption system operated on-demand as before. This configuration improved the chlorine feed system for a more steady feed into the head of the treatment system.

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters for the one year demonstration study were tabulated and are attached as Appendix A. Key parameters are summarized in Table 4-5. As discussed in Section 4.3.3, the treatment system operated on-demand from system startup on September 21, 2005, through October 25, 2005. The system piping was then modified so that the chlorine injection system and AD-26 oxidation/filtration system would operate at pump flowrates and the AD-33 adsorption system would operate on-demand as before. During the one year demonstration study from September 21, 2005, through September 24, 2006, the West Well pump ran for a total of 1,995.6 hr with a daily average of 5.5 hr/day (Note: 5.5 hr/day was used to calculate cumulative hours from September 21 through October 21, 2005, during which an hour meter was not available at the well pump), and the East Well pump ran for a total of 1,429 hr with a daily average of 4.0 hr/day (Note: East Well stopped running during October 27 through 31, 2005, due to replacement of the old well piping). The combined daily run times for both wells ranged from 3.7 to 17.3 hr/day and averaged 9.5 hr/day. The operating time of the APU system could not be determined due to the on-demand use of the system; however, after piping retrofit on October 26, 2005, the AD-26 system operated for 3,151 hr based on the well pump hour meters. The system was bypassed for five days from November 29 through December 3, 2005, due to a power outage that caused problems with the control panel (see Section 4.4.5).

During the one-year study period, the system treated approximately 18,026,000 gal of water based on the readings of the totalizers installed on the effluent side of each of the three AD-26 oxidation/filtration vessels, or 16,873,000 gal based on the readings of the totalizers installed on the effluent side of each of for the three AD-33 adsorption vessels. The combined throughput for the AD-26 system was 6.4% higher than for the AD-33 system. Significantly imbalanced flow was observed among the three AD-26 (Vessels A, B, and C) and three AD-33 vessels (Vessels D, E, and F). Before the totalizers were reset on November 28, 2005, due to a power outage, 17.5, 45.2, and 37.3% of the flow passed through Vessels A, B, and C, respectively. The exceptionally low flow through Vessel A (i.e., 17.5%) was caused mainly by close to zero throughput through that vessel before October 26, 2005, when the AD-26 system operated on-demand. After the totalizer was reset and when the system was operating primarily at pump flowrates, a more even flow was observed, accounting for 29.2, 34.6, and 36.2% through Vessels A, B, and C, respectively. For the AD-33 vessels, 32.2, 38.9, and 28.8% of the flow passed through Vessels D, E, and F, respectively, before the totalizers were reset and 32.2, 39.5, and 28.3% after the totalizers were reset.

Using the 16,873,000 gal throughput for calculations, 19,726 bed volumes (BV) of water were treated by the AD-33 system during the demonstration period. BV calculations were based on 114 ft^3 of media in the adsorption system. The instantaneous on-demand flowrates to the individual adsorption vessels ranged from 3 to 26 gpm with combined flowrates ranging from 9 to 71 gpm and averaging 37 gpm (Figure 4-13). This average on-demand flowrate is nearly the same as that at 33 gpm obtained just before the demonstration study.

Flowrates through the three AD-26 vessels were monitored using individual totalizers/flowmeters installed at the exit side of the vessels. Before the system piping retrofit, instantaneous on-demand flowrate readings taken from the meters ranged from 6 to 28 gpm for Vessels B and C, with combined flowrates ranging from 17 to 52 gpm and averaging 29 gpm (Table 4-5 and Figure 4-14). As noted

Table 4-5. Summary of APU-250 System Operation

Operational Parameter	Value/Condition			
Duration	09/21/05 -09/24/06			
Well Pumps				
Daily Run Time (hr/day)[a]	Well	Range	Average	
	West	0.7 – 11.0	5.5	
	East	0.0 – 7.8	4.0	
	Combined	3.7 – 17.3	9.5	
AD-26 Oxidation/Filtration System				
Time Operated (hr)	3,425			
Throughput (gal)	Vessel	09/21/05 – 11/28/05	11/28/05 – 09/24/06	
	A	514,502	4,400,705	
	B	1,330,884	5,222,773	
	C	1,095,615	5,461,306	
	Combined	2,941,001	15,084,784	
	Total	18,025,785		
Flowrate before Retrofit (gpm)[b]	Vessel	Range	Average	
	A	0	NA	
	B	11 – 28	17	
	C	6 – 24	12	
	Combined	17 – 52	29	
Flowrate after Retrofit (gpm)[b]	Vessel	Range	Average	
	A	14 – 40	29	
	B	17 – 49	35	
	C	18 – 51	36	
	Combined	49 – 140	101	
	Cal. Combined[c]	10 – 165	89	
Vessel/System Pressure and Δp (psi)	Vessel	Inlet	Outlet	ΔP
	A	50 (32 – 70)	46 (33 – 60)	NA
	B	47 (36 – 58)	47 (37 – 58)	NA
	C	48 (28 – 58)	48 (28 – 58)	NA
	System	49 (16 – 60)	46 (33 – 56)	4 (0 – 9)
AD-33 Adsorption System				
Throughput (gal)	Vessel	09/21/05 – 11/28/05	11/28/05 – 09/24/06	
	D	884,259	4,555,985	
	E	1,067,843	5,578,345	
	F	790,679	3,995,554	
	Combined	2,742,781	14,129,884	
	Total	16,872,665		
Bed Volume (BV)	19,726			
Flowrate (gpm)	Vessel	Range	Average	
	D	5 – 23	12	
	E	5 – 26	14	
	F	3 – 22	11	
	Combined	9 – 71	37	
EBCT (min)[d]	Vessel	Range	Average	
	D	12.4 – 56.8	23.9	
	E	10.9 – 56.8	20.3	
	F	12.9 – 94.7	25.8	
	Combined	12.0 – 94.7	23.0	
Vessel/System Pressure and Δp (psi)	Vessel	Inlet	Outlet	ΔP
	D	48 (36 – 60)	52 (31 – 60)	NA
	E	49 (36 – 58)	49 (36 – 58)	NA
	F	48 (32 – 58)	48 (36 – 56)	NA
	System	48 (35 – 56)	48 (35 – 58)	0

(a) From October 26, 2005, through March 26, 2006.
(b) System piping retrofitted on October 26, 2005.
(c) Totalizer readings divided by sum of West Well and East Well hours.
(d) Calculated based on 114 ft^3 of media in adsorption system.

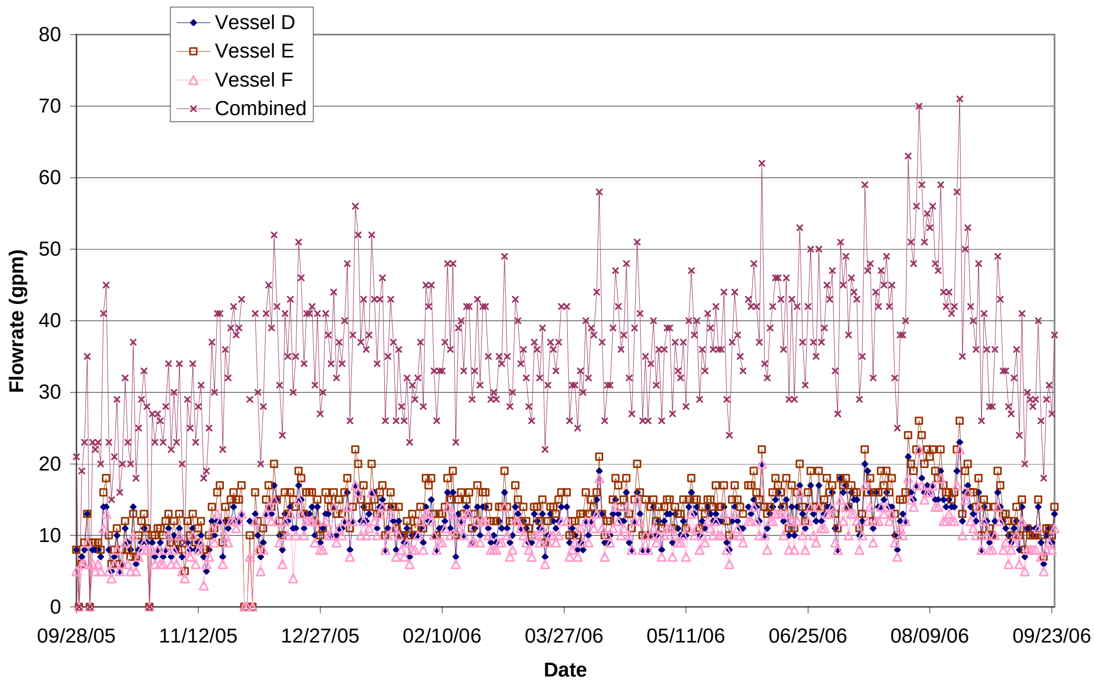


Figure 4-13. AD-33 Adsorption System Flowrates

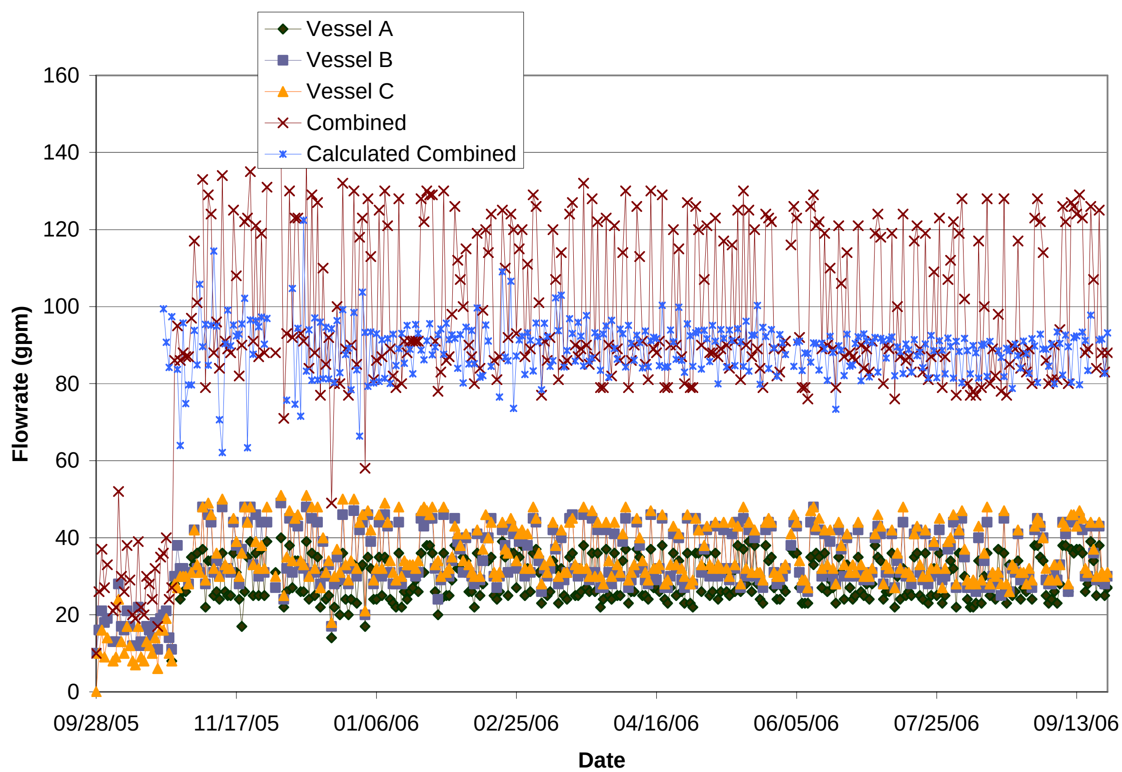


Figure 4-14. AD-26 Oxidation/Filtration System Flowrates

above, little or no flow passed through Vessel A during this time period. After the system piping retrofit, the system operated at the well pump flowrates. The instantaneous flowrate readings taken from the meters ranged from 14 to 51 gpm for the three vessels with combined flowrates ranging from 49 to 140 gpm and averaging 101 gpm. The combined flowrates from the meter readings are compared in Figure 4-14 with the calculated flowrates derived by dividing the combined throughput values by the corresponding operating hours. As expected, the calculated flowrates were less scattered, excluding a few outlier readings, than the instantaneous readings (i.e., 62 to 122 gpm [averaged 89 gpm] versus 49 to 140 gpm [averaged 101 gpm]) due to the different times the readings were recorded. The average flowrate obtained from the meter readings was closer to the operating time-weighted average (i.e., 117 gpm) of the West and East Wells flowrates (i.e., 130 and 90 gpm, respectively).

Based on the flowrates to the individual AD-33 vessels and system, the EBCTs for the individual adsorption vessels varied from 10.9 to 94.7 min and averaged 23.3 min; the EBCTs for the system varied from 12.0 to 94.7 min and averaged 23.0 min. This EBCT is at least five times higher than what normally would be recommended by the vendor for iron-based adsorptive media.

The pressure loss across each AD-26 oxidation/filtration vessel ranged from 0 to 10 psi and averaged 2 psi. The inlet pressure of the AD-26 system ranged from 16 to 60 psi and averaged 49 psi, while the outlet pressure of the AD-26 system ranged from 33 to 56 psi and averaged 46 psi. The average differential pressure for the AD-26 system was 4 psi. The pressure loss across each AD-33 oxidation/filtration vessel ranged from 0 to 8 psi and averaged 2 psi. The inlet pressure of the AD-33 system ranged from 35 to 56 psi and averaged 48 psi, while the outlet pressure of the AD-33 system ranged from 35 to 58 and averaged 48 psi. The average differential pressure for the AD-33 system was 0 psi.

4.4.2 Chlorine Injection. As described in Section 4.2, chlorine was added as an oxidant to oxidize As(III) and Fe(II) using a 12.5% NaOCl solution. The chlorine injection system experienced operational irregularities during most of the demonstration period, as reflected by the wide variation of free and total chlorine residuals measured at the entry point to the distribution system shown in Figure 4-15. After system startup, with a free chlorine set point of 2.5 mg/L (as Cl_2), free and total chlorine residuals varied considerably from 0.34 to 3.49 mg/L and from 0.43 to 3.91 mg/L (as Cl_2), respectively, which, at the time, were thought to have been caused by the fluctuating on-demand flow through the treatment system. The system was, therefore, reconfigured on October 26, 2005, so that the chlorine addition system and the AD-26 system were located before the hydropnuematic tanks and operated based on the well flowrate of either 130 or 90 gpm. Table 4-6 summarizes timelines of the settings and activities associated with the chlorine injection system.

After system reconfiguration, the free chlorine setpoint was maintained at 2.5 mg/L (as Cl_2). Although somewhat improved, the free and total chlorine residuals measured at the entry point continued to scatter, with concentrations ranging from 1.12 to 3.78 mg/L and from 1.81 to 3.99 mg/L (as Cl_2), respectively from October 27, 2005, through January 26, 2006. On November 30, 2005, the free chlorine set point was decreased from 2.5 to 1.8 mg/L (as Cl_2), but the scattering of free and total chlorine residuals continued without significant improvement. On December 20, 2005, modification was made to the setting of pump stroke length in an attempt to reduce chlorine residuals. On January 3, 2006, in an attempt to shorten the response time of the chlorine controller, the chlorine injection system was relocated from the east wall of the well house to approximately 20 ft to the west wall next to the AD-26 vessels and the chlorine injection point so that the length of the polyethylene tubing was reduced from 25 to 30 ft to 5 to 10 ft. On January 6, 2006, the chlorine metering pump was interlocked to the well pumps so that it would operate only when one of the well pumps was on. In addition, on January 6 and 26, 2006, the free chlorine set point was further reduced from 1.8 to 1.5 and then, 1.25 mg/L (as Cl_2). The combination of these efforts caused a somewhat decreasing trend for the chlorine residuals at the entry point, but the residuals continued to scatter significantly between 0.29 and 3.49 mg/L (as Cl_2) for free chlorine and between 0.29 and 3.72 mg/L (as Cl_2) for total chlorine from January 27 through July 28, 2006.

Another potential contributing factor to the erratic free and total chlorine residual readings might be the presence of iron particles in the chlorinated water, which clogged and/or coated the polyethylene tubing leading from the inline mixer to the chlorine monitor/control module and the chlorine probe and flow sensor assemblies. As a result, erroneous measurements might have been made by the chlorine probe, causing incorrect feedback to the chlorine monitor/controller for erratic chlorine injection rates. In an attempt to resolve this issue, an AD2710S iron removal cartridge was installed just before the chlorine monitor/controller and after the polyethylene tubing on July 28, 2006. Due to a significant amount of iron particles removed, the frequency of the cartridge change-out was increased from monthly to approximately twice a month on September 1, 2006. The resulting free and total chlorine residual readings became much less scattered, with concentrations ranging from 0.37 to 2.11 and from 0.56 to 2.88 mg/L (as Cl_2), respectively. The average free chlorine concentration was 1.20 mg/L (as Cl_2), very close to the set value of 1.25 mg/L (as Cl_2). Since then, the plant operator included cleaning of the relevant system components, including the chlorine probe trap, chlorine probe, and flow meter trap, as part of the routine system O&M activities.

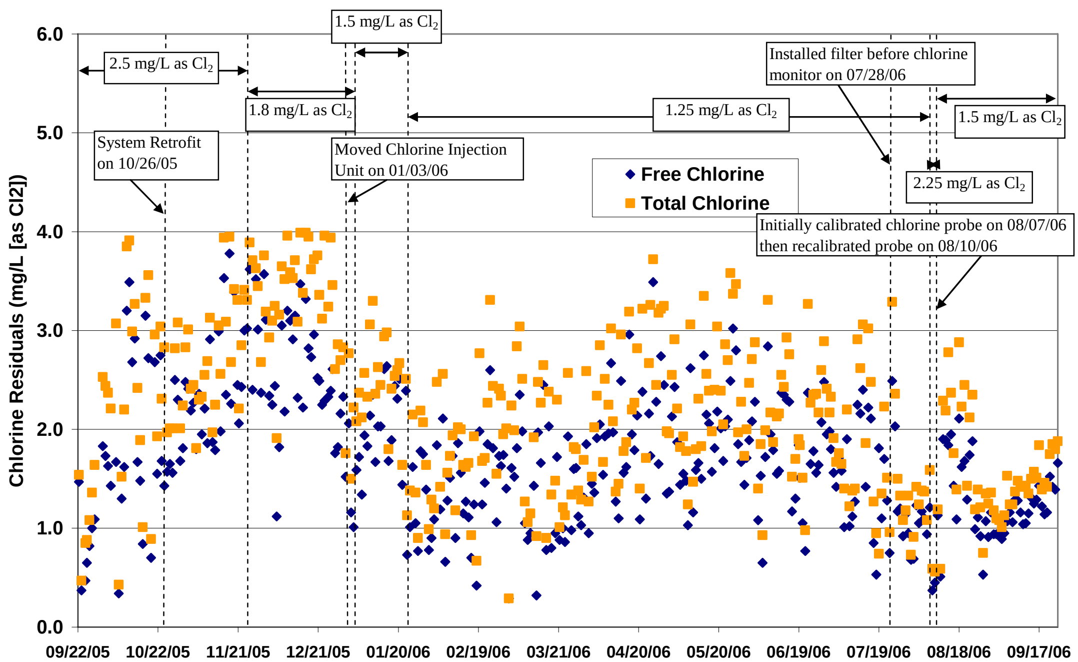


Figure 4-15. Free and Total Chlorine Residuals at Entry Point

The vendor recommended calibration of the chlorine probe every three months. Because it had not been calibrated since system startup, the chlorine probe was recalibrated by the plant operator following the vendor's instructions on August 7, 2006. Due to a miscommunication, the chlorine probe was calibrated with water from the entry point (or the TT sample tap) instead of water from the chlorine probe holder which caused the free and total chlorine concentrations to drop through the treatment train. To correct the drop in chlorine level, the free chlorine set point was increased from 1.25 to 2.25 mg/L (as Cl_2). A call to the vendor was made and the miscommunication was identified. The chlorine probe was then recalibrated

Table 4-6. Settings/Activities Associated with Chlorine Injection System

Operating Period		Free Chlorine Setting[(a)] (mg/L [as Cl_2])	Chlorine Metering Pump on/off Controlled by	Chlorine Metering Pump Stoke Length (%)	Poly Tubing Length[(b)] (ft)	Remarks
From	To					
09/21/05	10/26/05	2.5	Flow Sensor[(c)]	50	25–30	System operational on 09/21/05
10/26/05	11/30/05	2.5	Flow Sensor	50	25–30	System piping retrofitted on 10/26/05
11/30/05	12/20/05	1.8	Flow Sensor	50	25–30	Free chlorine setting reduced to 1.8 mg/L (as Cl_2) on 11/30/05
12/20/05	01/03/06	1.8	Flow Sensor	45	25–30	Stroke length reduced to 45% on 12/20/05
01/03/06	01/06/06	1.8	Flow Sensor	45	5–10	Chlorine injection system relocated on 01/03/06 to help reduce distance of polyethylene tubing and response time of chlorine controller
01/06/06	01/26/06	1.5	Well Pumps	45	5–10	Relay rewired from flow sensor on chlorine monitor/ controller to well pumps and free chlorine setting reduced to 1.5 mg/L (as Cl_2) on 01/06/06
01/26/06	07/28/06	1.25	Well Pumps	45	5–10	Free chlorine setting reduced to 1.25 mg/L (as Cl_2) on 01/26/06
07/28/06	08/08/06	1.25	Well Pumps	45	5-10	Filter installed before chlorine monitor on 07/28/06
08/08/06	08/10/06	2.25	Well Pumps	45	5-10	Chlorine probe recalibrated and free chlorine setting increased to 2.25 mg/L (as Cl_2) due to low chlorine readings in distribution system on 08/08/06
08/10/06	09/24/06	1.5	Well Pumps	45	5-10	Chlorine probe recalibrated and free chlorine setting reduced to 1.5 mg/L (as Cl_2) on 08/10/06

(a) Feedback from chlorine probe to controller that automatically adjusted injection rate (pulse/min) of chlorine metering pump.
(b) Polyethylene tubing that offshot from main water line approximately 12 ft downstream from in-line mixer to chlorine monitor/controller.
(c) Chlorine monitor/controller assembly.

with water from the chlorine probe holder and the free chlorine setpoint was reduced to 1.5 mg/L (as Cl_2) on August 10, 2006. These adjustments made the free and total chlorine readings much steadier, ranging from 0.51 to 2.11 mg/L (as Cl_2) with an average of 1.27 mg/L (as Cl_2) for free chlorine and 0.59 to 2.88 mg/L (as Cl_2) with an average of 1.58 mg/L (as Cl_2) for total chlorine. There seems to be an increasing trend in the free and total chlorine concentrations. The facility is looking into relocating the chlorine monitor/control module from after the chlorination injection point to after the treatment system to reduce the problems associated with the iron build-up.

4.4.3 Backwash. Water stored in the three hydropneumatic tanks after AD-26 treatment was used for backwash. Table 4-7 summarizes the backwash settings and volume of wastewater produced from the three AD-26 oxidation/filtration vessels during the demonstration study. Figure 4-16 plotted the volume of wastewater produced over time. The AD-26 system was backwashed automatically based on a set time. Under the initial settings (i.e., 15 min backwash and 2 min service-to-waste rinse), an average of 5,640 gal, or 85% of the expected volume, was produced from the three vessels during a backwash event. When the Park experienced the power outage on November 28, 2005, the backwash controls apparently were reset so that each vessel would be backwashed for 20 min and rinsed for an extended duration (the vendor reported 25 min but was not sure if it was correct). Consequently, more than twice as much wastewater, i.e., 13,100 gal on average, was produced from each backwash event. The backwash settings were adjusted back to 15 min backwash and 90 sec service-to-waste rinse on January 12, 2006, and the volume of wastewater produced was restored to an average of 5,890 gal per backwash event. Since the backwash water cleared up fairly quickly, it was decided on February 9, 2006, to reduce the backwash duration from 15 to 9 min while the rinse duration remained unchanged. This reduced backwash setting, however, did not result in the expected reduction in wastewater production per backwash event, with the average volume staying at 6,145 gal. Nonetheless, because the backwash frequency also was reduced from every two days to every three days on February 9, 2006, the overall wastewater production was reduced by approximately 33%.

Table 4-7. AD-26 Backwash Settings and Volume of Wastewater Produced

Operating Period		Backwash Settings			Average Volume Produced per Backwash Event		
From	To	Backwash Duration (min)	Fast Rinse Duration (min)	Backwash Frequency (times/wk)	Expected Based on Settings (gal)	Actual (gal)	Remarks
10/26/05	11/28/05	15	2	3	6,630	5,640[(a)]	Piping retrofit completed on 10/26/05; power outage occurred on 11/28/05
12/03/05	01/12/06	20	25	3	17,550	13,100	System operation resumed on 12/03/05; PLC fixed on 01/12/06
01/12/06	02/09/06	15	1.5	3	6,435	5,890	Backwash settings adjusted on 02/09/06
02/09/06	09/24/06	9	1.5	2	4,095	6,145	Demonstration ended 09/24/06

(a) Excluding data from October 28, 2005, October 30, 2005, and November 19, 2005, when abnormally low volumes of wastewater were recorded.

The vendor recommended to backwash the AD-33 adsorption vessels approximately once every 60 days. Automatic backwash could be initiated either by timer or by differential pressure across the vessels. Initially, the backwash setting was placed on manual. After the power outage at the end of November 2005, the setting was reverted back to default, which was once every 60 days. The AD-33 vessels were backwashed four times (February 1, 2006, April 2, 2006, June 1, 2006, and July 31, 2006) during this demonstration study. The backwash settings were for 15 min at approximately 127 gpm (or 10 gpm/ft^2), which produced approximately 5,700 gal for the three APU vessels. The average volume of backwash wastewater produced during the four events was 6,045 gal, slightly above the estimated volume.

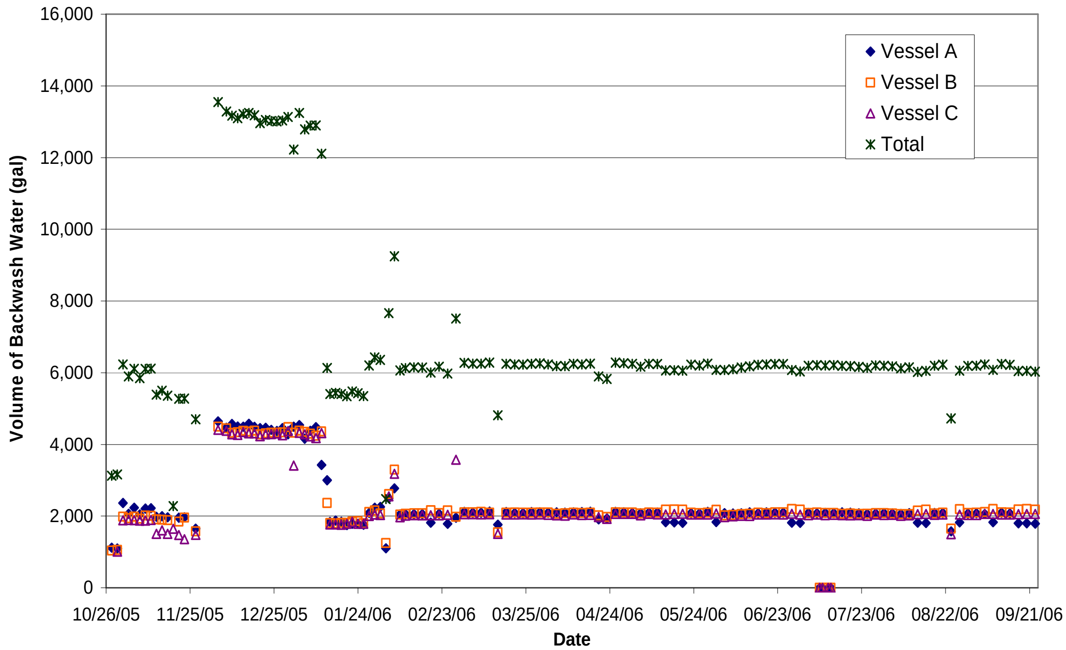


Figure 4-16. Volume of Wastewater Produced When Backwashing AD-26 Vessels

4.4.4 Residual Management. Residuals produced by the operation of the system included backwash water and spent media. Neither the adsorptive media (AD-33) nor the oxidation/filtration media (AD-26) was replaced during the demonstration period; therefore, the only residual produced was backwash wastewater. Initially, the backwash wastewater was stored in two 6,000-gal storage tanks on-site and a vacuum truck hauled the backwash wastewater for off-site disposal at the Village of North Hampton sewer system on a weekly basis. On September 14, 2006, the facility was connected to the sewer system and the backwash wastewater was discharged to the sewer directly.

On February 27, 2006, during the system backwash and sample collection, one of the backwash wastewater storage tanks overflowed, due to the fact that there was already water in the storage tank before the backwash was initiated. The incident was reported to Ohio EPA, which requested a copy of the latest analytical data. After reviewing the analytical data, the Ohio EPA deemed that the spill would not adversely affect the environment. The quality of the backwash wastewater is discussed in Section 4.5.2.

4.4.5 System/Operation Reliability and Simplicity. The operational issues related to the chlorine injection system as discussed Section 4.4.2 were the primary factors affecting system/operation reliability and simplicity.

Unscheduled downtime during the demonstration period was caused by a power outage on November 28, 2005; a power surge was created, causing the master and slave chips within the control panel to malfunction. The system was shut down and bypassed from November 28 through December 3, 2005, while the vendor and plant operator tried to troubleshoot and fix the problems. On November 30, 2005, a new set of chips was installed and the system was rebooted. The control panel malfunctioned again and a new set of chips had to be shipped to the Park. On December 1, 2005, the new chips were installed and the system was rebooted. All totalizer readings were reset and the system became operational. However, on December 2, 2005, the control panel malfunctioned in the middle of the night, causing all three vessels to backwash at once. Meanwhile, the system stopped sending water to the distribution system. The vendor went through the steps to correct the problems to no avail, so on December 3, 2005, a new master and slave chips were installed and the control panel became operational.

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

Pre- and Post-Treatment Requirements. The pretreatment included chlorinating source water to oxidize arsenic, iron, and manganese, while maintaining a chlorine residual for disinfection. In addition, the AD-26 media was used to filter arsenic-ladened iron and manganese solids and oxidize any remaining reduced metals, such as Mn(II). Post-treatment was not needed for this system.

System Automation. The APU-250 system included automated controls, which interlocked the well pump alternating on/off controls. The system also was equipped with an automated chlorine feed and control unit, which processed the signal from a chlorine sensor and activated a solenoid that drove the metering pump. In addition, the system was fitted with automated controls to allow for automatic backwash for both the AD-26 and AD-33 vessels. The backwash wastewater storage tanks did not have automation associated with them. Because there were no level sensors installed in the tanks, there was a potential for the tanks to overflow as occurred on February 27, 2006. On September 14, 2006, the backwash line was connected to the sewer system, so the problems associated with the backwash storage tanks were no longer a concern.

Operator Skill Requirements. The skills required to operate the APU-250 system were relatively complex due to the problems associated with the chlorine injection and the power outage that occurred at the site. The operator needed to adjust the dosage of the chlorine, adjust the metering pump, clean the chlorine probe and associated tubing (which would get clogged with iron particulates), calibrate the chlorine probe, change out the filter before the chlorine probe, and change out the master chip within the control panel.

Under normal operating conditions, the operator spent approximately 20 min daily to perform visual inspection and record the system operating parameters on the Daily Field Log Sheets. The operator also performed routine weekly and monthly maintenance according to the users' manual to ensure proper system operation. Normal operation of the system did not appear to require additional skills beyond those necessary to operate the existing water supply equipment.

All Ohio public water systems, both community and nontransient, serving more than 250 people must have a certified operator. Operator certifications are granted by the State of Ohio after passing an exam and maintaining a minimum amount of continuing education hours at professional training events on a biannual basis. Operator certifications are classified by Class I through IV water system operator, Class I and II water distribution operator, Class I through IV wastewater works operator, and Class I and II wastewater collection system operator. Class I is the lowest classification with Class IV being the highest. Chateau Estates has a Class III water system operator.

Preventive Maintenance Activities. Preventive maintenance tasks included such items as periodic checks of flow meters and pressure gauges and inspection of system piping and valves. The chlorine probe needed to be calibrated approximately once every 3 months. During this time, the chlorine feed/control unit would be cleaned out since some system components, such as the chlorine probe trap, chlorine probe, and flow meter trap, tended to build up iron residue. In addition, the polyethylene tubing that provided the side stream to the chlorine monitor/control module was inspected biweekly and replaced, if necessary. The filter cartridge installed just before the chlorine monitor/controller had to be changed out every two weeks. Typically, the operator performed these duties when onsite for routine activities.

Chemical/Media Handling and Inventory Requirements. The only chemical required for the system operation was the NaOCl solution used for chlorination, which was already in use at the site. Every week approximately 15 gal of the 12.5% chlorine solution was added to the 75-gal chlorine tank.

4.5 System Performance

The performance of the APU-250 system was evaluated based on analyses of water samples collected from the treatment plant, the media backwash, and distribution system.

4.5.1 Treatment Plant Sampling. Table 4-8 summarizes the analytical results of arsenic, iron, and manganese measured at the four sampling locations across the treatment train. Table 4-9 summarizes the results of other water quality parameters. Appendix B contains a complete set of analytical results for the demonstration study. The results of the analysis of the water samples collected throughout the treatment plant are discussed below.

Arsenic. The key parameter for evaluating the effectiveness of the arsenic removal system was the concentration of arsenic in the treated water. Water samples were collected on 27 occasions, including two duplicates, with field speciation performed during 13 of the 27 occasions from four sampling locations at IN, AC, OT, and TT.

Figure 4-17 contains four bar charts showing the concentrations of total arsenic, particulate arsenic, As(III), and As(V) at the IN, AC, OT, and TT locations for each speciation event. Total arsenic concentrations in raw water ranged from 9.5 to 35.4 µg/L and averaged 22.7 µg/L (Table 4-8). Of the soluble fraction, As(III) was the predominating species, ranging from 5.6 to 25.8 µg/L and averaging 16.9 µg/L. The particulate arsenic concentrations were low, averaging 2.8 µg/L. The presence of As(III) as the predominating arsenic species was consistent with the low DO concentrations (averaging 2.1 mg/L) measured (Table 4-9). The ORP readings, however, were high, averaging 246 mV. Recall that the ORP readings obtained during the August 5 and September 9, 2004, source water sampling events were -88 mV for the West Well and -25 mV for the East Well. The higher than expected ORP readings might have been caused by aeration of water during sampling.

Similar to the August 5 and September 9, 2004, source water sampling test results, total arsenic concentrations were higher in the West Well than the East Well (26.9 versus 20.2 µg/L on average). Unlike what was observed during these source water sampling events, As(III) was the predominating species in both wells with only 7% of As(V) measured in both the West Well (based on five sets of speciation results) and the East Well (based on eight sets of speciation results). There was no evidence to suggest that there were significant differences in arsenic speciation between the two wells. The presence of elevated particulate arsenic and particulate iron during some of these speciation events and the September 9, 2004, East Well source water sampling (as discussed in Section 4.1.1) most likely was caused by inadvertent aeration of the samples during sampling.

Table 4-8. Summary of Arsenic, Iron, and Manganese Analytical Results

Parameter	Sampling Location	Sample Count	Concentration (µg/L)			Standard Deviation
			Minimum	Maximum	Average	
As (total)	IN	27	9.5	35.4	22.7	5.6
	AC	27	9.4	31.6	23.7	5.0
	OT	27	0.5	2.1	- [(a)]	
	TT	27	<0.1	0.5	- [(a)]	
As (soluble)	IN	13	8.4	25.6	18.5	4.8
	AC	13	1.9	26.2	6.4	7.7
	OT	13	0.5	1.8	- [(a)]	
	TT	13	<0.1	0.4	- [(a)]	
As (particulate)	IN	13	0.7	5.7	2.8	1.8
	AC	13	1.3	28.9	15.2	7.3
	OT	13	<0.1	0.5	- [(a)]	
	TT	13	<0.1	0.2	- [(a)]	
As (III)	IN	13	5.6	25.8	16.9	5.7
	AC	13	<0.1	23.1	2.1	6.3
	OT	13	<0.1	11.6	- [(a)]	
	TT	13	<0.1	0.8	- [(a)]	
As (V)	IN	13	<0.1	6.1	1.7	1.6
	AC	13	<0.1	26.1	4.5	6.6
	OT	13	<0.1	1.4	- [(a)]	
	TT	13	<0.1	<0.1	- [(a)]	
Fe (total)	IN	27	521	2,238	1,102	451
	AC	27	535	1,733	1,171	407
	OT	27	<25	25.3	<25	2.5
	TT	27	<25	<25	<25	-
Fe (soluble)	IN	13	217	1,475	822	408
	AC	13	<25	838	77.7	228
	OT	13	<25	<25	<25	-
	TT	13	<25	<25	<25	-
Mn (total)	IN	27	17.3	82.1	35.6	17.1
	AC	27	16.4	77.3	29.5	13.7
	OT	27	<0.1	0.7	0.2	0.2
	TT	27	<0.1	0.2	0.1	0.04
Mn (soluble)	IN	13	17.9	81.6	36.3	17.5
	AC	13	0.4	39.6	8.3	11.0
	OT	13	<0.1	1.2	0.2	0.3
	TT	13	<0.1	0.5	0.2	0.2

One-half of detection limit used for samples with concentrations less than detection limit for calculations.
Duplicate samples included in calculations.
(a) Statistics not provided; see Figure 4-18 for arsenic breakthrough curves.

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

Parameter	Sampling Location	Unit	Sample Count	Concentration Minimum	Concentration Maximum	Concentration Average	Standard Deviation
Alkalinity (as $CaCO_3$)	IN	mg/L	27	325	371	343	11.4
	AC	mg/L	27	319	370	341	11.6
	OT	mg/L	27	306	365	341	11.1
	TT	mg/L	27	326	365	342	9.3
Ammonia (as N)	IN	mg/L	27	<0.05	0.53	0.21	0.09
	AC	mg/L	27	<0.05	0.26	0.08	0.08
	OT	mg/L	27	<0.05	0.15	0.03	0.02
	TT	mg/L	27	<0.05	<0.05	<0.05	-
Fluoride	IN	mg/L	27	0.8	3.3	1.3	0.4
	AC	mg/L	27	1.1	3.5	1.5	0.5
	OT	mg/L	27	0.9	3.6	1.4	0.5
	TT	mg/L	27	0.8	3.1	1.4	0.4
Sulfate	IN	mg/L	27	14.0	34.0	24.1	5.0
	AC	mg/L	27	12.0	37.0	26.1	6.4
	OT	mg/L	27	13.7	34.0	26.0	3.6
	TT	mg/L	27	22.8	33.0	26.4	2.3
Nitrate (as N)	IN	mg/L	27	<0.05	<0.05	<0.05	-
	AC	mg/L	27	<0.05	0.13	0.03	0.02
	OT	mg/L	27	<0.05	0.20	0.03	0.03
	TT	mg/L	27	<0.05	<0.05	<0.05	-
Total P (as PO_4)	IN	mg/L	26	<0.03	<0.03	<0.03	-
	AC	mg/L	26	<0.03	<0.03	<0.03	-
	OT	mg/L	26	<0.03	<0.03	<0.03	-
	TT	mg/L	26	<0.03	<0.03	<0.03	-
Silica (as SiO_2)	IN	mg/L	27	16.8	20.5	18.4	1.0
	AC	mg/L	27	16.8	20.1	18.5	0.8
	OT	mg/L	27	16.9	19.8	18.2	0.7
	TT	mg/L	27	16.2	18.9	17.9	0.7
Turbidity	IN	NTU	27	0.6	25.0	12.4	7.6
	AC	NTU	27	0.7	26.0	3.2	5.4
	OT	NTU	27	<0.1	0.8	0.4	0.2
	TT	NTU	27	<0.1	1.4	0.5	0.4
pH	IN	S.U.	22	6.9	7.5	7.2	0.2
	AC	S.U.	22	7.0	7.4	7.2	0.1
	OT	S.U.	22	7.1	7.5	7.3	0.1
	TT	S.U.	22	7.0	7.4	7.2	0.1
Temperature	IN	°C	22	10.2	25.0	16.2	3.4
	AC	°C	22	10.2	25.0	15.8	3.0
	OT	°C	22	10.2	25.0	15.8	3.0
	TT	°C	22	10.2	25.0	15.7	3.0
Dissolved Oxygen	IN	mg/L	18	1.1	3.5	2.1	0.7
	AC	mg/L	19	0.9	3.4	2.2	0.6
	OT	mg/L	19	1.2	3.8	2.2	0.7
	TT	mg/L	19	1.0	3.1	2.2	0.6

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

Parameter	Sampling Location	Unit	Sample Count	Concentration Minimum	Maximum	Average	Standard Deviation
ORP	IN	mV	22	-131	435	246	196
	AC	mV	22	-77.6	746	497	231
	OT	mV	22	270	742	588	148
	TT	mV	21	281	718	623	121
Free Chlorine (as Cl_2)	AC	mg/L	10	<0.1	4.0	1.7	1.3
	OT	mg/L	15	0.1	3.1	1.4	0.9
	TT	mg/L	21	0.7	3.2	1.8	0.6
Total Chlorine (as Cl_2)	AC	mg/L	6	0.1	3.2	1.5	1.4
	OT	mg/L	13	0.2	3.5	1.8	0.9
	TT	mg/L	21	0.8	3.8	2.3	0.7
Total Hardness (as $CaCO_3$)	IN	mg/L	27	285	432	341	26.1
	AC	mg/L	27	282	436	344	26.7
	OT	mg/L	27	240	417	343	29.9
	TT	mg/L	27	297	387	346	18.4
Ca Hardness (as $CaCO_3$)	IN	mg/L	27	170	270	206	17.9
	AC	mg/L	27	170	261	206	16.2
	OT	mg/L	27	140	253	205	19.3
	TT	mg/L	27	166	231	207	12.9
Mg Hardness (as $CaCO_3$)	IN	mg/L	27	112	162	135	12.0
	AC	mg/L	27	112	175	138	11.8
	OT	mg/L	27	101	164	137	13.1
	TT	mg/L	27	115	157	139	9.8

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

Chlorination oxidized As(III) to As(V) that, in turn, was attached onto the iron solids also formed upon chlorination. The samples collected downstream of the chlorine injection point at the AC location showed a decrease in soluble arsenic concentration from an average of 18.5 µg/L in source water to an average of 6.4 µg/L after chlorination and a corresponding increase in particulate arsenic concentration from an average of 2.8 µg/L in source water to an average of 15.3 µg/L after chlorination. The majority of particulate arsenic was filtered out by the AD-26 oxidation/filtration media, leaving only 0.5 to 2.1 µg/L of total arsenic, existing mainly as soluble As(V), to be further removed by the AD-33 adsorption vessels. By the end of the demonstration period, total arsenic concentrations in the treated water after the AD-33 adsorption vessels were reduced to less than 0.5 µg/L. Figure 4-18 presents arsenic breakthrough curves from the AD-26 oxidation/filtration and AD-33 adsorption systems.

Free and total chlorine were monitored at the AC, OT, and TT sampling locations to ensure that the target chlorine residual levels were properly maintained. Free chlorine levels at the AC location ranged from <0.1 to 4.0 mg/L (as Cl_2) and averaged 1.7 mg/L (as Cl_2); total chlorine levels ranged from 0.1 to 3.2 mg/L (as Cl_2) and averaged 1.5 mg/L (as Cl_2) (Table 4-9). The residual chlorine levels measured at the OT and TT locations were similar to those measured at the AC location, indicating little or no chlorine

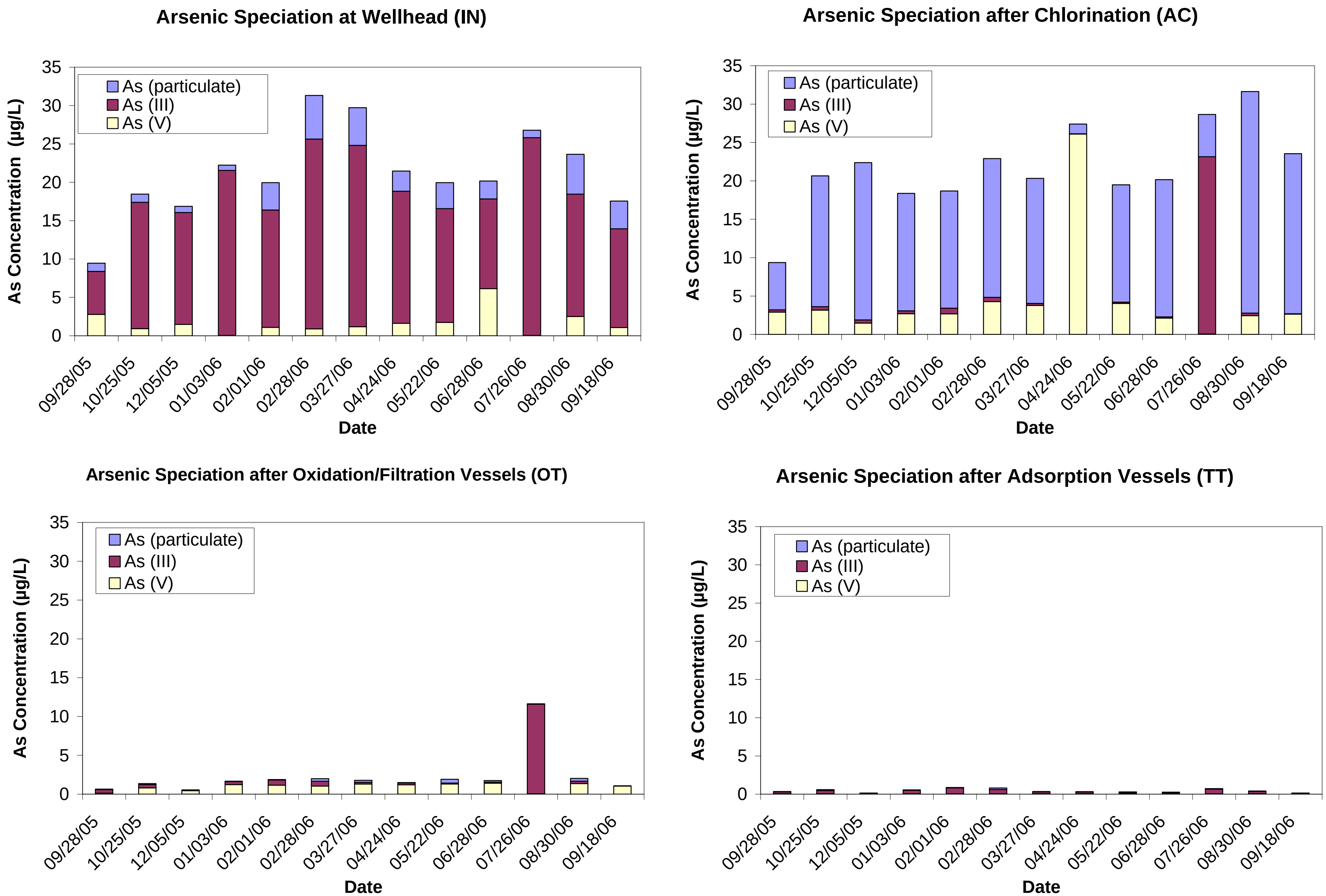


Figure 4-17. Concentrations of Various Arsenic Species at IN, AC, OT and TT Sampling Locations

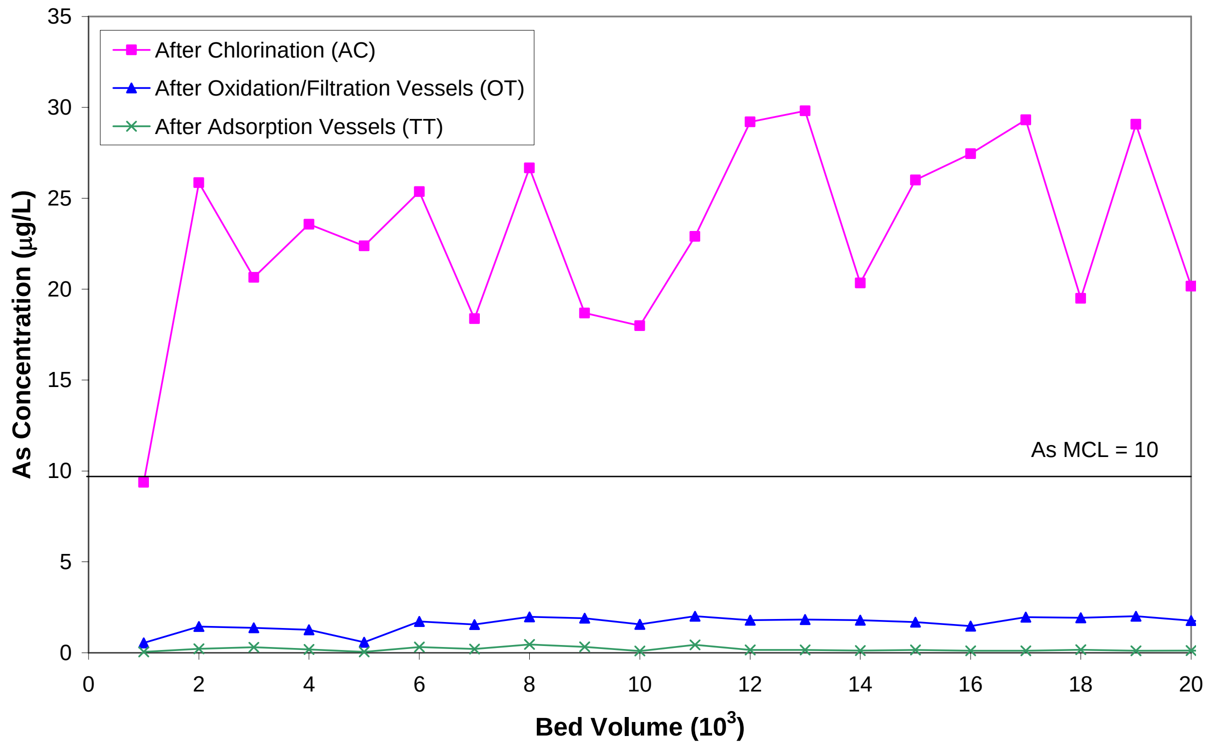


Figure 4-18. Total Arsenic Breakthrough Curves for AD-26 Oxidation/Filtration and AD-33 Adsorption Systems

consumption through the AD-26 and AD-33 vessels. Repeated attempts had been made to reduce the levels of free and total chlorine residuals to the target levels of 1.5 and 1 mg/L (as Cl_2). With the addition of the cartridge filter that was placed just before the chlorine monitor/control module, the chlorine levels appeared to have been under control.

After chlorination, DO concentrations, as expected, remained essentially unchanged; however, ORP readings increased significantly to 497, 588, and 623 mV, on average, at the AC, OT, and TT locations, respectively. The high ORP readings were consistent with the presence of high free chlorine levels, which averaged 1.7 mg/L (as Cl_2) at the AC location, and 1.4 and 1.8 mg/L (as Cl_2) at the OT and TT locations, respectively.

Iron. Total iron concentrations at the wellhead ranged from 521 to 2,238 µg/L and averaged 1,102 µg/L. Iron concentrations following the prechlorination step at the AC location were similar to those at the wellhead, with concentrations ranging from 535 to 1,733 µg/L and averaging 1,171 µg/L. Iron was removed from the treatment train by the AD-26 media with concentrations at the OT sampling point ranging from less than the MDL of 25 µg/L to 25.3 µg/L and less than the MDL of 25µg/L at the TT sample point. Soluble iron levels (based upon 0.45-µm filters) ranged from 217 to 1,475 µg/L at the wellhead. After prechlorination, except for one outlier at 838 µg/L occurring on July 26, 2006, soluble iron levels ranged from less than the MDL of 25 µg/L to 32.8 µg/L. Soluble iron levels were always less than the MDL at the OT and TT sampling locations. The data indicated that chlorine effectively oxidized soluble iron to form iron solids, which were then effectively filtered by the AD-26 oxidation/filtration media. The backwash frequency of once every 3 days appeared to be adequate without having any iron leakage between backwash cycles.

Manganese. The treatment plant water samples were analyzed for total manganese and soluble manganese during speciation sampling. Total manganese levels in source water ranged from 17.3 to 82.1 µg/L and averaged 35.6 µg/L, which existed almost entirely in the soluble form. After prechlorination, over 70% on average, of soluble manganese was precipitated, presumably, to form MnO_2 solids, which, along with unoxidized Mn^{2+}, were removed by the AD-26 media to less than or equal to 0.7 µg/L. Total manganese concentrations were further reduced to 0.2 µg/L after the AD-33 adsorptive media. Note that 0.45 µm disc filters were used to separate solids from the soluble fraction.

It is interesting to note that the amount of Mn^{2+} that precipitated upon chlorination varied quite extensively during the 13 speciation events, with nine events ranging from 85.0 to 98%, two ranging from 48.8 to 57.6%, and the remaining two ranging from 1.1 to 5.8%. The 85 to 98% precipitation rates observed during the nine speciation events reflected rapid oxidation kinetics by chlorine, which were contrary to the findings by most researchers who investigated the oxidation of Mn^{2+} even with some lengths of contact time (Knocke et al., 1987 and 1990; Condit and Chen, 2006). Slow Mn^{2+}oxidation kinetics also were observed at a number of EPA arsenic removal demonstration sites (Table 4-10), where less than 10% Mn^{2+} precipitation rates were observed at two sites (i.e., Delavan, WI and Bruni, TX) and 14.6 to 55.0% observed at seven sites. Alvin, TX, however, had high precipitation rates, averaging 93.5%. It is not clear why precipitation rates varied at the Chateau Estates site and why some raw waters had slower oxidation kinetics than others. The contact time did not seem to correlate directly with the precipitation rate.

Table 4-10. Amount of Mn^{2+} Precipitated After Chlorination at Ten Arsenic Removal Demonstration Sites

Demonstration Location	Approximate Contact Time	Average Mn in Raw Water (Total/Soluble)	Average Mn after Chlorination (Total/Soluble)	Average Mn^{2+} Precipitated
	(min)	µg/L	µg/L	(%)
Anthony, NM	None	9.6/8.9	9.8/6.8	23.5
Alvin, TX	None	54.0/53.4	50.9/2.8	93.5
Brown City, MI	None	16.1/15.7	15.0/9.8	31.9
Bruni, TX	None	5.0/4.7	3.9/3.5	5.8
Climax, MN	5	135/126	130/73.7	35.9
Delavan, WI	2	19.2/20.1	18.1/17.7	2.7
Pentwater, MI	6	27.3/28.8	30.1/14.3	52.5
Rollinsford, NH	None	110/124	101/86.5	14.6
Sabin, MN	7	346/378	338/228	32.6
Sandusky, MI	41	25.3/26.7	26.0/11.7	55.0

Other Water Quality Parameters. The raw water pH values measured at the IN location varied from 6.9 to 7.5. This near neutral pH is desirable for iron removal and adsorption processes, both of which, in general, have a greater arsenic removal capacity at near or lower than neutral pH values. The pH values remained essentially unchanged after the AD-26 and AD-33 vessels. Alkalinity values ranged from 306 to 371 mg/L (as $CaCO_3$) across the treatment train. The results indicate that the adsorptive media did not affect the amount of alkalinity in water after treatment. The treatment plant samples were analyzed for hardness only when arsenic speciation was performed. Total hardness, existing primarily as calcium hardness (about 60%), ranged from 240 to 436 mg/L (as $CaCO_3$), and also remained constant throughout the treatment train. Sulfate concentrations ranged from 12.0 to 37.0 mg/L, and remained constant throughout the treatment train. Silica (as SiO_2) concentration ranged from 16.2 to 20.5 mg/L, and appeared unaffected by the chlorine injection and the AD-26 and AD-33 media. Fluoride results ranged from 0.8 to 3.6 mg/L and did not appear to be affected by the AD-33 media. Total phosphorous was below the MDL of 0.03 mg/L (as PO_4) for all samples.

4.5.2 Backwash Wastewater Sampling. Backwash was performed using the AD-26 treated water stored in the hydropneumatic tanks for both the AD-26 and AD-33 systems. Unfiltered backwash wastewater samples were analyzed for pH, TDS, TSS, and total arsenic, iron, and manganese. Samples filtered with 0.45-µm disc filters were analyzed for soluble arsenic, iron, and manganese. As shown in Table 4-11, the backwash wastewater from the first oxidation/filtration vessel (OW1), was sampled 12 times, while the second (OW2) and third (OW3) oxidation/filtration vessels, were sampled 11 and eight times, respectively. The pH values of the backwash wastewater were about 0.2 pH units higher than those of the AD-26 treated water, ranging from 7.3 to 7.7. TDS concentrations ranged from 360 to 476 mg/L and averaged 408 mg/L. TSS concentrations ranged from 9 to 262 mg/L and averaged 83.4 mg/L. There were several unusually low TSS values measured during backwash of each oxidation/filtration vessel (including Vessel 1 on September 17, 2006; Vessel 2 on February 2, March 24, and September 17, 2006; and Vessel 3 for March 24, April 20, June 22, and September 17, 2006), which were thought to be the results of sampling errors caused by insufficient mixing of the solids/water mixtures in the backwash wastewater collection containers. Note that lower TSS values also had lower particulate arsenic, iron, and manganese concentrations. As such, these sets of data were not used for further data analyses.

The majority of the total arsenic, iron and manganese in the backwash wastewater were in the particulate form. For example, total arsenic concentrations averaged 456 µg/L while soluble arsenic concentrations averaged only 4.2 µg/L. Total iron levels ranged from 5,257 to 59,656 µg/L, with soluble iron levels ranging from less than the MDL of 25 µg/L to 279 µg/L. Total manganese levels ranged from 127 to 1,357 µg/L, while soluble manganese levels ranged only from 0.4 to 5.2 µg/L.

Assuming that 83 mg/L of TSS (average of all TSS values except for the outliers) was produced in 6,000 gal of backwash wastewater from the vessels, approximately 4.2 lb of solids would be discharged during each AD-26 backwash event. The solids discharged would be composed of 0.02, 1.51, and 0.03 lb of arsenic, iron, and manganese, respectively, assuming 450 µg/L of particulate arsenic, 30,100 µg/L of particulate iron, and 500 µg/L of particulate manganese in the backwash wastewater.

Table 4-12 presents the results of total metals analysis for three backwash solid samples collected on September 17, 2006 and analyzed in triplicate. The iron levels in the solids ranged from 3.78×10^5 to 4.82×10^5 µg/g and the arsenic levels ranged from 5,069 to 6,295 µg/g. This yields an Fe:As ratio of 76:1, which is much higher than the 20:1 ratio as a rule of thumb for effective arsenic removal (EPA, 2001; Sorg, 2002). This 76:1 ratio also equates to 13.2 µg of arsenic per mg of iron solids.

During the demonstration period, each AD-33 adsorption vessels were backwashed four times, generating approximately 6,050 gal of wastewater. Initially the vendor recommended that the AD-33 vessels be backwashed once every 60 days; however, after reviewing the system operation, it was determined that the media would not need to be backwashed on a regular basis and that it would be determined based on system pressures. After the power outage at the end of November 2005, the default setting (which was once every 60 days) was restored, causing a backwash of the AD-33 adsorption vessels on February 1, April 2, June 1, and July 31, 2006.

Table 4-11. Oxidation/Filtration Vessels Backwash Sampling Results

Sampling Event	pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)
Date	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Oxidation/Filtration Vessel 1 (OW1)										
10/13/05	7.7	414	NS	NS	2.7	NS	NS	<25	NS	1.8
12/05/05	7.6	420	156	296	3.2	293	21,366	54	724	3.1
01/12/06	7.7	408	46	238	5.6	232	13,545	161	527	5.0
02/02/06	7.6	412	96	634	4.3	630	57,464	133	1,357	5.2
02/27/06	7.6	384	64	536	4.7	532	30,997	116	486	1.6
03/24/06	7.4	400	92	487	5.6	482	24,432	279	443	4.5
04/20/06	7.4	408	262	1,089	5.0	1,084	59,656	129	487	1.3
05/17/06	7.5	410	86	628	4.8	624	55,409	173	368	3.2
06/22/06	7.4	476	106	699	4.9	694	50,318	55.3	802	1.2
07/13/06	7.3	402	135	814	4.2	810	49,955	56.4	833	2.0
08/15/06	7.4	432	61	410	4.0	406	25,375	104	692	2.3
09/17/06	7.3	402	17	153	3.6	150	10,014	73.4	266	1.9
Oxidation/Filtration Vessel 2 (OW2)										
12/05/05	7.6	378	54	231	3.9	227	15,282	64.7	342	3.3
01/12/06	7.5	360	42	269	4.6	265	15,216	102	556	3.3
02/02/06	7.7	416	22	114	3.2	111	8,226	72.8	183	2.9
02/27/06	7.5	424	64	501	5.3	496	30,131	160	481	2.2
03/24/06	7.3	424	18	133	4.0	129	6,577	170	213	3.0
04/20/06	7.5	386	80	300	3.2	297	15,974	46.8	127	0.4
05/17/06	7.4	402	70	499	4.8	494	44,738	146	253	1.2
06/22/06	7.5	434	52	71.1	2.2	68.9	5,257	<25	133	0.6
07/13/06	7.3	402	35	247	3.3	243	14,818	63.5	273	2.2
08/15/06	7.4	416	67	398	3.0	395	25,461	88.1	653	1.6
09/17/06	7.3	394	9	78.9	3.2	75.7	5,279	84.7	152	2.2
Oxidation/Filtration Vessel 3 (OW3)										
02/27/06	7.5	414	120	853	7.2	846	51,450	226	566	2.5
03/24/06	7.4	408	28	184	4.3	179	9,869	245	202	5.3
04/20/06	7.4	376	26	104	2.7	101	5,237	43.8	51.1	0.5
05/17/06	7.4	398	30	269	3.8	265	20,860	96.0	147	1.0
06/22/06	4.4	418	9	289	2.9	286	21,126	<25	362	0.9
07/13/06	7.3	422	56	210	3.4	207	12,350	64.5	212	2.1
08/15/06	7.4	416	60	344	3.9	340	23,053	205	579	3.0
09/17/06	7.3	384	12	89.0	2.7	86.3	5,920	36.4	168	1.1

NS = not sampled; TDS = total dissolved solids; TSS = total suspended solids
OW2 not sampled on 10/13/05.
OW3 not sampled on 10/13/05, 12/05/05, 01/12/06, or 02/02/06.

Backwash of the AD-33 adsorption vessels was manually activated on February 12, 2007, so that a backwash wastewater sample could be collected from each adsorption vessel. Table 4-13 presents the results of the backwash wastewater analysis. The pH values of the backwash wastewater were about 0.2 pH units higher than those of the AD-33 treated water, ranging from 7.4 to 7.5. TDS concentrations

Table 4-12. Oxidation/Filtration Vessels Backwash Solid Sample Total Metal Results

Sample	Unit	Mg	Al	Si	P	Ca	Fe	Mn	Ni	Cu	Zn	As	Cd	Pb	Fe/As
Vessel OW1-Solids-A	µg/g	13,971	813	179	1,457	69,283	378,975	11,144	13.3	28.0	84.9	5,069	0.36	14.0	74.8
Vessel OW1-Solids-B	µg/g	14,474	916	119	1,446	68,558	379,741	11,100	14.0	28.4	91.8	5,156	0.36	14.7	73.7
Vessel OW1-Solids-C	µg/g	14,964	982	235	1,430	69,783	394,841	11,706	15.2	28.9	89.6	5,175	0.36	15.5	76.3
Vessel OW1 Average	µg/g	14,470	904	178	1,445	69,208	384,519	11,316	14.2	28.4	88.7	5,133	0.36	14.7	74.9
Vessel OW2-Solids-A	µg/g	9,574	752	238	1,096	58,785	434,952	12,374	11.0	20.8	64.8	5,899	0.15	12.9	73.7
Vessel OW2-Solids-B	µg/g	9,422	518	429	1,140	59,433	441,247	11,146	10.9	21.5	60.7	5,951	0.14	11.9	74.1
Vessel OW2-Solids-C	µg/g	9,305	643	431	1,220	60,117	473,494	13,691	11.9	20.4	66.3	6,020	0.18	14.8	78.7
Vessel OW2 Average	µg/g	9,434	637	366	1,152	59,445	449,898	12,404	11.3	20.9	63.9	5,956	0.16	13.2	75.5
Vessel OW3-Solids-A	µg/g	8,306	702	344	1,477	58,252	482,080	15,134	12.1	19.6	71.3	6,295	0.17	11.9	76.6
Vessel OW3-Solids-B	µg/g	8,280	723	373	1,267	59,638	465,394	14,736	12.7	34.4	34.1	6,208	0.19	12.3	75.0
Vessel OW3-Solids-C	µg/g	8,220	662	366	1,254	57,830	465,609	14,421	12.2	19.1	34.5	6,251	0.12	11.7	74.5
Vessel OW3 Average	µg/g	8,268	696	361	1,333	58,573	471,028	14,763	12.3	24.3	46.6	6,251	0.16	12.0	75.4

Table 4-13. Adsorption Vessels Backwash Sampling Results

Sampling Date	pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)
	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Adsorptive Vessel 1 (OW1)										
02/12/07	7.4	380	36	114	2.8	111	12,949	99.6	322	2.2
Adsorptive Vessel 2 (OW2)										
02/12/07	7.5	374	5	13.3	1.9	11.4	1,770	19.3	42.9	1.2
Adsorptive Vessel 3 (OW3)										
02/12/07	7.5	376	24	86.9	2.2	84.6	11,268	56.1	252	1.9

TDS = total dissolved solids; TSS = total suspended solids ranged from 374 to 380 mg/L and averaged 377 mg/L. TSS concentrations ranged from 5 to 36 mg/L and averaged 21.7 mg/L.

Similarly to the AD-26 backwash water sample results, the majority of total arsenic, iron and manganese in the backwash wastewater were in the particulate form. For example, total arsenic concentrations averaged 71.4 µg/L while soluble arsenic concentrations averaged only 2.3 µg/L. Total iron levels ranged from 1,770 to 12,949 µg/L, with soluble iron levels ranging from 19.3 µg/L to 99.6 µg/L. Total manganese levels averaged 206 µg/L, while soluble manganese concentrations averaged 1.8 µg/L.

4.5.3 Distribution System Water Sampling. Prior to the installation/operation of the treatment system, first draw baseline distribution system water samples were collected at three locations (two residences and the mobile park clubhouse) on April 4, May 5, June 8, and July 7, 2005. Following the installation of the treatment system, distribution water sampling continued on a monthly basis. Two of the three locations, i.e., the clubhouse and one residence, remained the same as the baseline, but the residence for the third location was changed on October 12, 2005, to a new residence due to availability. The samples were collected on October 12, November 15, December 12, 2005, January 16, February 13, March 13, April 10, May 8, June 12, July 11, August 14, and September 12, 2006. The results of the distribution system sampling are summarized in Table 4-14.

The most noticeable change in the distribution samples since system startup was a decrease in arsenic, iron, and manganese concentrations. Baseline arsenic concentrations ranged from 9.2 to 68.8 µg/L and averaged 23.7 µg/L for all three locations. After the performance evalution began, arsenic concentrations were reduced to less than 0.1 to 4.5 µg/L (averaged 1.6 µg/L). The baseline iron concentrations ranged from 113 to 5,504 µg/L (averaging 1,359) with the highest concentrations observed in the clubhouse water samples (ranging from 1,423 to 5,504 µg/L). After the treatment system became operational, iron concentrations decreased to less than the MDL of 25 µg/L in all samples except for three at 26.2, 28.1, and 58.3 µg/L. Manganese had a similar trend with baseline concetrations averaging 15.2 µg/L and after startup samples averaging 0.2 µg/L.

Lead concentrations of all water samples collected before and after the installation of the treatment system were less than 2 µg/L, except for three instances at 2.2, 3.6, and 5.2 µg/L. All of the Pb values were, therefore, significantly below the action level of 15 µg/L. Copper concentrations ranged from 0.3 to 1,353 µg/L across all sampling locations, with one sample exceeding the 1,300 µg/L action level during baseline sampling. The arsenic treatment system did not have an effect on the Pb or Cu concentrations in the distribution system.

Measured pH values ranged from 7.3 to 8.0 and averaged 7.5. Alkalinity levels ranged from 198 to 364 mg/L (as $CaCO_3$). The arsenic treatment system did not affect these water quality parameters of the distributed water.

4.6 System Cost

The cost of the treatment system was 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. This required the tracking of the capital cost for the equipment, site engineering, and installation and the O&M cost for media replacement and disposal, chemical supply, electricity consumption, and labor. The park owner decided to upgrade the system from 150 gpm to 250 gpm in response to the Ohio EPA's redundancy requirement and to build additional capacity for future growth of the Park. The additional cost incurred was funded by the park owner and is listed as system upgrades on Table 4-15.

Table 4-14. Distribution System Sampling Results

Sampling Event		DS1								DS2								DS3[a]							
		Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu
No.	Date	Hr	S.U.	mg/L	μg/L	μg/L	μg/L	μg/L	μg/L	hr	S.U.	mg/L	μg/L	μg/L	μg/L	μg/L	μg/L	hr	S.U.	mg/L	μg/L	μg/L	μg/L	μg/L	μg/L
BL1[b]	04/04/05	25.3	7.4	339	68.8	5,504	54.9	0.3	445	8.7	7.4	334	14.8	592	6.6	1.4	48.4	8.3	7.5	334	12.6	257	3.5	3.6	714
BL2	05/03/05	6.1	7.4	355	43.9	3,190	35.2	0.2	191	7.8	7.4	355	13.7	563	7.0	2.2	39.0	10.9	7.3	364	9.2	113	3.0	1.7	1,045
BL3[c]	06/08/05	6.0	7.4	343	33.2	2,232	26.2	0.1	83.3	8.8	7.4	339	10.6	237	3.1	0.1	10.4	NA	7.5	343	12.0	238	4.0	1.2	1,353
BL4	07/07/05	6.2	7.3	352	25.9	1,423	16.4	<0.1	55.4	8.0	7.3	352	27.6	1,769	19.3	5.2	64.9	12.0	7.4	352	12.1	200	3.1	0.7	764
1	10/12/05	7.8	7.4	343	3.6	<25	<0.1	<0.1	9.0	7.8	7.5	352	1.0	<25	<0.1	0.2	5.8	8.3	7.5	352	2.8	<25	0.1	0.3	5.2
2	11/15/05	9.0	7.8	330	4.5	<25	<0.1	<0.1	78.9	7.5	7.5	339	<0.1	<25	<0.1	0.3	28.4	6.5	8.0	198	2.3	<25	<0.1	0.1	95.0
3	12/12/05	6.1	7.5	352	2.1	<25	<0.1	<0.1	29.5	10.9	7.6	343	1.1	<25	<0.1	0.3	39.0	9.0	7.5	348	3.6	<25	0.1	0.3	125
4	01/16/06	6.3	7.3	348	3.6	28.1	0.5	0.3	123	7.3	7.5	356	1.0	<25	0.3	1.6	38.8	6.9	7.5	356	2.2	<25	0.2	1.1	159
5	02/13/06	6.0	7.4	338	2.0	<25	<0.1	0.1	52.5	7.5	7.5	333	0.4	<25	<0.1	0.1	14.9	7.3	7.4	317	2.5	<25	0.1	0.2	45.9
6	03/13/06	7.2	7.5	331	0.8	<25	0.1	0.2	50.3	8.3	7.6	331	0.2	<25	<0.1	0.4	22.9	8.0	7.7	360	2.0	<25	0.2	1.4	123
7	04/10/06	8.0	7.4	332	0.7	<25	0.8	<0.1	11.5	8.3	7.5	340	0.7	<25	<0.1	0.8	28.9	7.8	7.6	328	1.9	58.3	0.4	1.8	125
8	05/08/06	8.6	7.5	333	0.6	<25	0.2	<0.1	0.3	7.7	7.5	333	0.4	<25	0.1	0.3	24.6	8.0	7.6	329	2.0	<25	0.2	0.5	110
9	06/12/06	8.0	7.4	338	1.6	<25	<0.1	0.2	130	9.5	7.4	327	0.2	<25	<0.1	1.9	37.7	9.0	7.4	327	2.1	<25	0.3	0.8	71.2
10	07/11/06	8.1	7.3	339	1.0	<25	0.4	0.6	71.5	9.0	7.4	339	0.3	<25	0.1	1.6	38.4	9.5	7.4	348	2.0	<25	0.2	1.4	93.3
11	08/14/06	8.0	7.4	337	1.0	26.2	0.4	0.3	23.0	10.0	7.4	316	0.3	<25	<0.1	1.8	33.5	9.5	7.4	341	2.6	<25	0.1	1.0	50.8
12	09/12/06	9.6	7.4	344	1.1	<25	<0.1	0.2	91.3	8.0	7.5	350	0.3	<25	<0.1	1.7	28.9	8.7	7.5	350	2.5	<25	<0.1	1.8	118

BL = baseline sampling; NA = not available
Copper action level = 1.3 mg/L; lead action level = 15 μg/L
(a) DS3 samples collected from Lot 12 until 10/12/05.
(b) DS1 collected on 04/03/05.
(c) DS2 collected on 06/09/05.

Table 4-15. Capital Investment Cost for AdEdge Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
Three 42-in Diameter Fiberglass Vessels on Skid (for APU-150)	1 unit	$35,586	–
AD-33 Media	76 ft^3	$21,254	–
Gravel Underbedding	1	$1,125	–
Process Valves and Piping	1	$12,600	–
Instrumentation and Controls	1	$12,075	–
Totalizer for Backwash Line	1	$990	–
O&M Manuals		$720	–
One-Year O&M Support		$2,920	–
Subtotal		*$87,270*	–
Three 30-in Diameter Fiberglass Vessels on Skid (for AD26)	1 unit	$23,400	–
AD26 Media	36 ft^3	$7,866	–
Gravel Underbedding	1	$990	–
Process Valves and Piping	1	$10,800	–
Instrumentation and Controls	1	$10,600	–
Additional Sample Taps	1	$675	–
Subtotal		*$54,331*	–
Freight-AD33 Media	2,430 lb	$600	–
Freight-AD26 Media	4,470 lb	$525	–
Freight-System	12,000 lb	$1,410	–
Subtotal		*$2,535*	–
Upgrades to APU-250 System (Paid by Owner)			–
Additional AD-33 Media	38 ft^3	$10,627	–
Additional AD-26 Media	21 ft^3	$4,588	–
Other Upgrades (Vessels, Hydro Tanks, etc)	1	$53,475	–
Subtotal		*$68,690*	–
Equipment Total	–	**$212,826**	**73**
Engineering Cost			
Vendor Labor	–	$4,534	–
Vendor Travel	–	$2,480	–
Vendor Material	–	$98	–
Subcontractor Labor	–	$14,375	–
Subcontractor Travel		$403	–
Subcontractor Material	–	$564	–
System Upgrade (Paid by Owner)	–	$5,074	–
Engineering Total	–	**$27,527**	**9**
Installation Cost			
Vendor Labor	–	$7,920	–
Vendor Travel	–	$4,200	–
Vendor Material	–	$925	–
Subcontractor Mechanical	–	$9,000	–
Subcontractor Electrical	–	$780	–
Subcontractor Other Labor	–	$4,200	–
System Upgrade (Paid by Owner)	–	$24,874	–
Installation Total	–	**$51,899**	**18**
Total Capital Investment	–	**$292,252**	**100**

4.6.1 Capital Cost. The capital investment for equipment, site engineering, and installation for the 250-gpm treatment system was $292,252. The equipment cost was $212,826 (or 73% of the total capital investment), including $144,136 for the 150-gpm system (funded by EPA) and $68,690 for the system upgrades (funded by the facility). The vendor provided cost breakdowns for the 150-gpm system, which included $87,270 for the skid-mounted APU-150 unit, $54,331 for the skid-mounted AD-26 unit, and $2,535 for freight (as shown in Table 4-15). The APU-150 system included $35,586 for the skid-mounted fiberglass vessels, $21,254 for the AD-33 media ($280/ft^3 or $5.33/lb), $12,600 for process valves and piping, $12,075 for instrumentation and controls, and $5,753 for other materials. The AD-26 system included $23,400 for the skid-mounted AD-26 unit, $7,866 for the AD-26 media ($218.50/ft^3 or $1.75/lb), $10,800 for process valves and piping, $10,600 for instrumentation and controls, and $1,665 for other materials. The $68,690 of equipment upgrades covered the cost of upgrading three 42-in diameter fiberglass reinforced plastic (FRP) vessels to three 48-in diameter steel epoxy vessels for the APU unit and three 30-in diameter FRP vessels to three 36-in diameter steel epoxy vessels for the AD-26 unit, adding 38 ft^3 of AD-33 and 21 ft^3 of AD-26 media, adding three new hydropnuematic tanks, and adding a chlorine injection system including a chlorine monitor/controller module.

The engineering cost included the cost for the preparation of a process flow diagram of the treatment system, mechanical drawings of the treatment equipment, and a schematic of the building footprint and equipment layout to be used as part of the permit application submittal (see Section 4.3.1). The engineering cost was $27,527, which was 9% of the total capital investment.

The installation cost included the equipment and labor to unload and install the skid-mounted units, perform piping tie-ins and electrical work, and load and backwash the media (see Section 4.3.3). The installation was performed by AdEdge and LBJ, Inc., a local contractor subcontracted by AdEdge. The installation cost was $51,899, or 18% of the total capital investment.

The capital cost of $292,252 was normalized to $1,170/gpm ($0.81 gpd) of design capacity using the system's rated capacity of 250 gpm (or 360,000 gpd). The capital cost also was converted to an annualized cost of $27,590/yr using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-yr return period. Assuming that the system operated 24 hr/day, 7 day/wk at the design flowrate of 250 gpm to produce 360,000 gal/day, the unit capital cost would be $0.21/1,000 gal. During the year long demonstration, the system produced 16,873,000 gal of water (see Table 4-5); at this reduced rate of usage, the unit capital cost increased to $1.64/1,000 gal.

4.6.2 Operation and Maintenance Cost. The O&M cost includes media replacement and disposal, chemical supply, electricity, and labor, as summarized in Table 4-16. Although media replacement did not occurred during the demonstration study, the media replacement cost would represent the majority of the O&M cost. The vendor initially estimated that the AD-26 media would have a 4-yr life expectancy, but revised it to a 10-yr life expectancy after reviewing the performance of the media. It is estimated to cost $13,140 for replacement of 57 ft^3 media in three AD-26 vessels. At the current water use rate (i.e., 16,873,000 gal for one year), the system would treat 169 million gal of water in a 10-yr period. Therefore, the AD-26 media replacement cost would be equivalent to $0.08/1,000 gal of water treated.

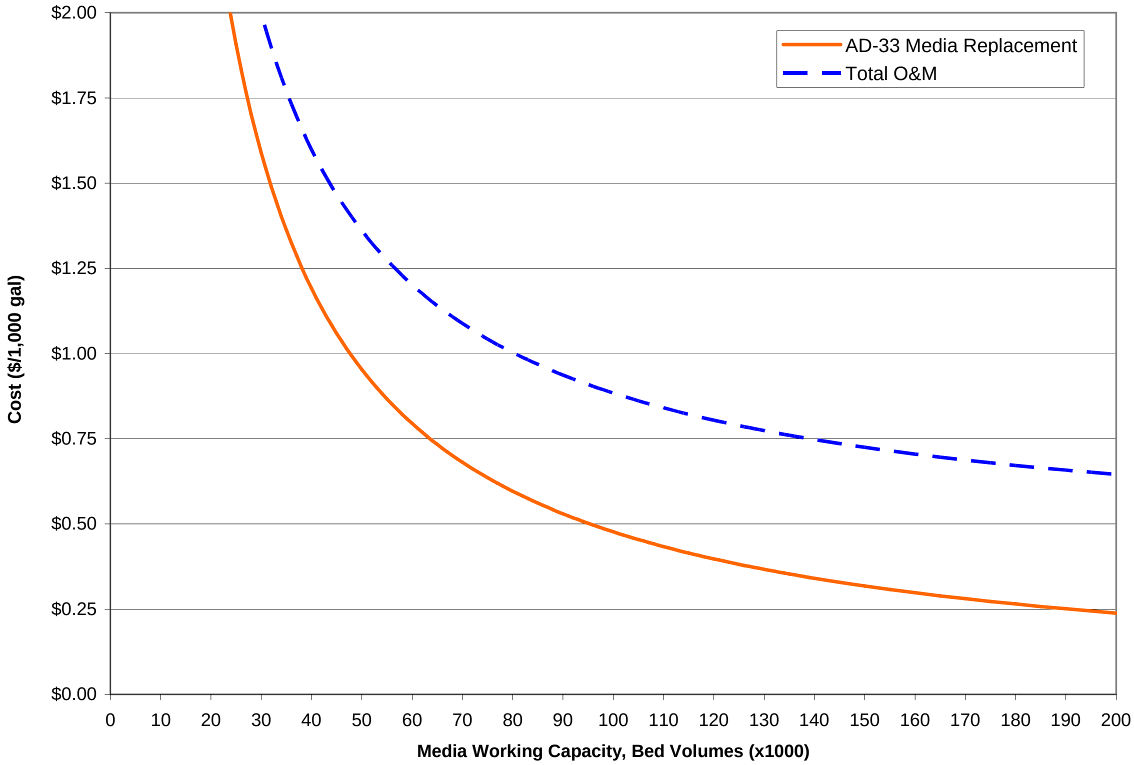
The vendor estimated that the AD-33 media would have a 4.9-yr life expectancy before replacement. It was estimated to cost $34,230 to change out the adsorptive vessels with 114 ft^3 of AD-33 media; that estimate included the cost for media, freight, labor, travel expenses, and media disposal fee. This 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 to the 10-μg/L arsenic breakthrough (Figure 4-19).

A 12.5% sodium hypochlorite solution was used for chlorination. The cost associated with chlorination was approximately $2,800 during this demonstration study, which translated into a chemical cost of $0.17/1,000 gal of water treated.

Comparison of electrical bills provided by the Park prior to system installation and since startup did not indicate any noticeable increase in power consumption by the treatment system. Therefore, electrical cost associated with operation of the APU-250 system was assumed to be negligible. Under normal operating conditions, routine labor activities to operate and maintain the system consumed 20 min per day, which translates into 2.33 hr/wk, as noted in Section 4.4.6. Therefore, the estimated labor cost is $0.16/1,000 gal of water treated.

Table 4-16. Operation and Maintenance Cost for AdEdge Treatment System

Cost Category	Value	Assumptions
Volume Processed (gal)	16,873,000	Through September 24, 2006
Media Replacement and Disposal		
AD26 Media Unit Cost ($/ft^3)	150	Vendor quote
AD26 Media Volume (ft^3)	57	To fill three 36-in diameter vessels
Underbedding Gravel ($)	1,040	Vendor quote
Subcontractor Labor Cost ($)	1,950	Vendor quote
Freight ($)	705	Vendor quote
Waste Disposal ($)	650	Vendor quote
Waste Analysis ($)	245	Vendor quote
Subtotal ($)	13,140	
AD26 Media Replacement and Disposal cost ($/1,000 gal)	0.08	Assume 10-year media life, treating 169 million gal of water
AD33 Media Unit Cost ($/ft^3)	260	Vendor quote
AD33 Media Volume (ft^3)	114	To fill three 48-in diameter vessels
Underbedding Gravel ($)	1,040	Vendor quote
Subcontractor Labor Cost ($)	1,950	Vendor quote
Freight ($)	705	Vendor quote
Waste Disposal ($)	650	Vendor quote
Waste Analysis ($)	245	One TCLP test
Subtotal ($)	34,230	
AD-33 Media Replacement and Disposal cost ($/1,000 gal)	See Figure 4-19	
Chemical Usage		
Chemical Cost ($/1,000)	0.17	Approximately $2,800 for one year
Electricity		
Electricity Cost ($/1,000 gal)	0.001	Electrical costs assumed negligible
Labor		
Average Weekly Labor (hr)	2.33	20 min/day
Labor cost ($/1,000 gal)	0.16	Labor rate = $21/hr
Total O&M Cost/1,000 gal	See Figure 4-19	Total O&M cost = adsorptive media replacement cost + 0.08 + 0.17 + 0.16



1 BV = 114 cubic feet = 850 gal

Figure 4-19. Media Replacement Cost Curves for Springfield System

5.0 REFERENCES

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APPENDIX A

OPERATIONAL DATA

Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 1 of 11)

Week No.	Date	Hour Meter				Service			Backwash		System Pressure			
		West Well		East Well		AD-26		AD-33	AD-26	AD-33	AD-26		AD-33	
		Daily Op Hours	Cumulative Hours[(a)]	Daily Op Hours	Cumulative Hours[(a)]	Combined Flowrate[(b,c)]	Calculated Combined Flowrate[(d)]	Combined Flowrate[(e)]	Backwash Water Produced	Backwash Water Produced	Inlet Pressure	Outlet Pressure	Inlet Pressure	Outlet Pressure
		hr	hr	hr	hr	gpm	gpm	gpm	gal	gal	psi	psi	psi	psi
2	09/28/05[(b)]	NA	38.5	NA	28.0	10	NA	21	NA	NA	38	38	55	55
	09/29/05	NA	44.0	0.2	28.2	26	NA	NA	NA	NA	52	51	NA	NA
	09/30/05	NA	49.5	3.0	31.2	37	NA	19	NA	NA	39	38	42	42
	10/01/05	NA	55.0	2.7	33.9	27	NA	23	NA	NA	54	52	38	38
	10/02/05	NA	60.5	3.1	37.0	33	NA	35	NA	NA	48	48	50	50
3	10/03/05	NA	66.0	6.6	43.6	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10/04/05	NA	71.5	0.1	43.7	21	NA	23	NA	NA	44	44	38	40
	10/05/05	NA	77.0	2.4	46.1	22	NA	22	NA	NA	40	40	46	48
	10/06/05	NA	82.5	6.9	53.0	52	NA	23	NA	NA	44	46	40	40
	10/07/05	NA	88.0	1.1	54.1	30	NA	20	NA	NA	42	52	44	44
	10/08/05	NA	93.5	1.2	55.3	26	NA	41	NA	NA	42	42	54	54
	10/09/05	NA	99.0	4.3	59.6	38	NA	45	NA	NA	42	38	54	54
4	10/10/05	NA	104.5	4.6	64.2	29	NA	23	NA	NA	42	42	48	50
	10/11/05	NA	110.0	2.9	67.1	20	NA	15	NA	NA	44	44	40	40
	10/12/05	NA	115.5	2.8	69.9	19	NA	21	NA	NA	44	46	44	44
	10/13/05	NA	121.0	2.8	72.7	39	NA	29	NA	NA	54	52	44	44
	10/14/05	NA	126.5	4.2	76.9	22	NA	16	NA	NA	40	40	40	40
	10/15/05	NA	132.0	2.0	78.9	20	NA	20	NA	NA	42	40	40	40
	10/16/05	NA	137.5	3.3	82.2	30	NA	32	NA	NA	42	44	43	43
5	10/17/05	NA	143.0	3.6	85.8	28	NA	23	NA	NA	40	40	50	50
	10/18/05	NA	148.5	3.2	89.0	24	NA	20	NA	NA	44	46	46	46
	10/19/05	NA	154.0	2.7	91.7	32	NA	37	NA	NA	54	52	52	52
	10/20/05	NA	159.5	5.7	97.4	17	NA	18	4,533	NA	48	46	42	44
	10/21/05[(f)]	NA	132.0	NA	101.2	35	NA	25	NA	NA	54	52	44	44
	10/22/05	6.5	138.5	4.5	105.7	36	99	29	4,671	NA	52	50	46	46
	10/23/05	4.6	143.1	3.2	108.9	40	91	33	NA	NA	54	52	46	46
6	10/24/05	3.3	146.4	2.5	111.4	24	84	28	4,683	NA	42	44	50	50
	10/25/05	4.7	151.1	3.2	114.6	27	97	NA	NA	NA	48	48	54	54
	10/26/05[(g)]	2.5	153.6	5.6	120.2	86	30	27	337	NA	52	52	52	52
	10/27/05	6.2	159.8	0.0	120.2	95	84	23	NA	NA	40	40	40	42
	10/28/05	8.5	168.3	0.0	120.2	86	64	27	3,127	NA	50	50	52	52
	10/29/05	7.5	175.8	0.0	120.2	88	96	26	NA	NA	46	46	48	48
	10/30/05	7.1	182.9	0.0	120.2	87	75	23	3,161	NA	52	54	50	48

Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 2 of 11)

Week No.	Date	Hour Meter				Service			Backwash		System Pressure			
		West Well		East Well		AD-26		AD-33	AD-26	AD-33	AD-26		AD-33	
		Daily Op Hours	Cumulative Hours[(a)]	Daily Op Hours	Cumulative Hours[(a)]	Combined Flowrate[(b,c)]	Calculated Combined Flowrate[(d)]	Combined Flowrate[(e)]	Backwash Water Produced	Backwash Water Produced	Inlet Pressure	Outlet Pressure	Inlet Pressure	Outlet Pressure
		hr	hr	hr	hr	gpm	gpm	gpm	gal	gal	psi	psi	psi	psi
7	10/31/05	10.1	193.0	0.5	120.7	87	80	28	653	NA	54	54	52	52
	11/01/05	2.8	195.8	2.6	123.3	97	80	34	6,228	NA	50	50	55	55
	11/02/05	4.0	199.8	2.5	125.8	117	94	22	NA	NA	47	47	48	48
	11/03/05	3.9	203.7	3.3	129.1	101	85	30	5,888	NA	45	45	50	50
	11/04/05	3.9	207.6	2.7	131.8	NA	106	23	NA	NA	53	53	47	47
	11/05/05	3.8	211.4	3.3	135.1	133	90	34	6,106	NA	53	53	45	45
	11/06/05	4.4	215.8	3.0	138.1	79	95	20	NA	NA	47	48	NM	NM
8	11/07/05	4.6	220.4	3.8	141.9	129	85	9	5,846	NA	40	42	40	42
	11/08/05	4.3	224.7	2.8	144.7	124	95	29	NA	NA	54	52	50	52
	11/09/05	4.1	228.8	3.3	148.0	88	114	25	6,100	NA	44	44	44	46
	11/10/05	3.9	232.7	2.5	150.5	96	95	34	NA	NA	52	50	50	52
	11/11/05	4.8	237.5	4.1	154.6	84	71	23	6,116	NA	50	50	52	52
	11/12/05	3.8	241.3	2.7	157.3	134	62	28	NA	NA	50	48	50	50
	11/13/05	5.8	247.1	4.0	161.3	91	90	31	5,389	NA	44	44	48	48
9	11/14/05	3.1	250.2	1.8	163.1	89	99	18	NA	NA	38	38	40	42
	11/15/05	5.3	255.5	3.7	166.8	88	90	19	5,494	NA	52	50	50	50
	11/16/05	3.3	258.8	1.7	168.5	125	95	25	NA	NA	54	50	38	38
	11/17/05	8.0	266.8	7.1	175.6	108	92	37	5,256	NA	38	38	48	50
	11/18/05	3.2	270.0	1.7	177.3	82	93	30	NA	NA	52	48	52	52
	11/19/05	5.5	275.5	3.3	180.6	90	95	41	2,277	NA	40	48	48	50
	11/20/05	7.0	282.5	3.7	184.3	122	102	41	NA	NA	50	48	50	50
10	11/21/05	2.3	284.8	2.0	186.3	123	63	22	5,272	NA	48	48	43	43
	11/22/05	4.5	289.3	2.5	188.8	135	97	36	NA	NA	51	49	44	44
	11/23/05	5.2	294.5	3.2	192.0	91	88	32	5,276	NA	46	45	47	47
	11/24/05	5.3	299.8	2.8	194.8	121	96	39	NA	NA	51	49	43	43
	11/25/05	5.1	304.9	2.8	197.6	87	95	42	219	NA	46	43	48	48
	11/26/05	5.8	310.7	3.1	200.7	119	97	38	NA	NA	51	46	36	36
	11/27/05	6.7	317.4	4.3	205.0	88	90	39	4,700	NA	43	41	48	48
11	11/28/05[(h)]	7.4	324.8	3.4	208.4	131	97	43	NA	NA	46	42	42	44
	11/29/05	2.8	327.6	5.8	214.2	NA	NA	NA	NA	NA	NM	NM	NM	NM
	11/30/05	0.7	328.3	7.4	221.6	NA	NA	NA	NA	NA	NM	NM	NM	NM
	12/01/05	3.7	332.0	2.1	223.7	88	NA	29	NA	NA	41	38	42	42
	12/03/05	12.5	344.5	11.9	235.6	140	NA	41	NA	NA	46	44	54	54
	12/04/05	5.1	349.6	2.9	238.5	71	NA	30	NA	NA	46	44	44	46

Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 3 of 11)

Week No.	Date	Hour Meter				Service			Backwash		System Pressure			
		West Well		East Well		AD-26		AD-33	AD-26	AD-33	AD-26		AD-33	
		Daily Op Hours	Cumulative Hours[a]	Daily Op Hours	Cumulative Hours[a]	Combined Flowrate[b,c]	Calculated Combined Flowrate[d]	Combined Flowrate[e]	Backwash Water Produced	Backwash Water Produced	Inlet Pressure	Outlet Pressure	Inlet Pressure	Outlet Pressure
		hr	hr	hr	hr	gpm	gpm	gpm	gal	gal	psi	psi	psi	psi
12	12/05/05	3.1	352.7	4.1	242.6	93	76	20	13,547	NA	42	40	42	42
	12/06/05	5.5	358.2	3.4	246.0	130	30	28	1,227	NA	48	46	42	42
	12/07/05	5.7	363.9	3.2	249.2	92	105	41	NA	NA	42	33	52	54
	12/08/05	5.8	369.7	4.9	254.1	123	75	45	13,284	NA	52	48	40	40
	12/09/05	6.4	376.1	3.6	257.7	123	94	39	NA	NA	52	48	52	52
	12/10/05	8.2	384.3	5.7	263.4	93	72	52	13,166	NA	44	42	42	47
	12/11/05	4.0	388.3	3.2	266.6	91	122	42	NA	NA	44	40	40	40
13	12/12/05	7.2	395.5	5.9	272.5	138	83	31	13,097	NA	44	40	48	48
	12/13/05	4.3	399.8	2.4	274.9	84	94	24	NA	NA	40	40	35	35
	12/14/05	5.6	405.4	5.0	279.9	129	81	41	13,217	NA	50	47	49	49
	12/15/05	5.5	410.9	3.3	283.2	88	97	35	NA	NA	43	39	48	48
	12/16/05	5.5	416.4	5.2	288.4	127	81	43	13,241	NA	50	49	45	45
	12/17/05	6.0	422.4	3.4	291.8	77	96	30	NA	NA	42	40	43	43
	12/18/05	5.3	427.7	5.2	297.0	110	81	35	13,181	NA	57	54	42	42
14	12/19/05	6.8	434.5	3.7	300.7	85	95	51	NA	NA	48	44	46	48
	12/20/05	6.5	441.0	5.5	306.2	92	81	46	12,959	NA	40	38	42	42
	12/21/05	8.0	449.0	4.0	310.2	49	94	34	NA	NA	44	40	44	44
	12/22/05	5.6	454.6	5.3	315.5	80	80	41	13,048	NA	50	48	52	52
	12/23/05	5.5	460.1	3.2	318.7	100	96	41	NA	NA	42	38	42	42
	12/24/05	9.1	469.2	6.6	325.3	80	83	42	13,019	NA	52	50	52	52
	12/25/05	5.4	474.6	3.0	328.3	132	99	31	NA	NA	48	44	50	50
15	12/26/05	3.7	478.3	3.8	332.1	89	88	41	13,004	NA	42	40	40	40
	12/27/05	5.5	483.8	3.1	335.2	77	89	27	NA	NA	48	48	36	36
	12/28/05	6.1	489.9	5.3	340.5	90	78	30	13,035	NA	42	40	44	46
	12/29/05	5.6	495.5	3.0	343.5	130	98	41	NA	NA	44	38	44	44
	12/30/05	7.4	502.9	4.8	348.3	85	84	38	13,135	NA	46	44	44	44
	12/31/05	9.5	512.4	2.6	350.9	118	66	34	NA	NA	52	46	48	50
	01/01/06	4.2	516.6	7.8	358.7	123	104	44	12,221	NA	50	46	46	48
16	01/02/06	5.3	521.9	3.1	361.8	58	93	32	900	NA	52	47	39	39
	01/03/06	6.0	527.9	6.0	367.8	128	79	37	13,241	NA	39	38	41	41
	01/04/06	6.2	534.1	3.8	371.6	113	93	34	NA	NA	56	55	47	47
	01/05/06	6.3	540.4	6.0	377.6	81	80	40	12,788	NA	56	54	43	43
	01/06/06	6.7	547.1	4.0	381.6	86	93	48	NA	NA	53	49	53	53
	01/07/06	6.0	553.1	6.0	387.6	125	81	26	12,894	NA	43	43	39	39
	01/08/06	7.7	560.8	4.9	392.5	87	91	38	NA	NA	45	42	48	48

Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 4 of 11)

Week No.	Date	Hour Meter				Service			Backwash		System Pressure			
		West Well		East Well		AD-26		AD-33	AD-26	AD-33	AD-26		AD-33	
		Daily Op Hours	Cumulative Hours[(a)]	Daily Op Hours	Cumulative Hours[(a)]	Combined Flowrate[(b,c)]	Calculated Combined Flowrate[(d)]	Combined Flowrate[(e)]	Backwash Water Produced	Backwash Water Produced	Inlet Pressure	Outlet Pressure	Inlet Pressure	Outlet Pressure
		hr	hr	hr	hr	gpm	gpm	gpm	gal	gal	psi	psi	psi	psi
17	01/09/06	7.3	568.1	6.6	399.1	130	81	56	12,898	NA	50	48	52	52
	01/10/06	7.2	575.3	5.1	404.2	121	92	52	NA	NA	52	46	50	50
	01/11/06	4.7	580.0	5.6	409.8	89	80	37	12,106	NA	44	42	48	48
	01/12/06	6.0	586.0	3.9	413.7	82	93	43	NA	NA	54	50	52	52
	01/13/06	5.5	591.5	4.5	418.2	79	85	36	6,133	NA	58	54	52	52
	01/14/06	7.5	599.0	5.5	423.7	128	89	38	5,402	NA	54	50	54	54
	01/15/06	5.5	604.5	3.6	427.3	80	93	52	NA	NA	56	52	52	52
18	01/16/06	3.7	608.2	3.3	430.6	91	85	43	5,434	NA	42	42	40	40
	01/17/06	6.2	614.4	4.3	434.9	88	95	34	NA	NA	48	44	46	48
	01/18/06	6.5	620.9	5.8	440.7	91	89	43	5,406	NA	48	42	50	50
	01/19/06	4.0	624.9	3.3	444.0	91	83	46	NA	NA	54	52	48	48
	01/20/06	4.5	629.4	4.0	448.0	91	95	26	5,343	NA	44	42	48	48
	01/21/06	5.9	635.3	3.8	451.8	91	93	35	NA	NA	58	54	50	50
	01/22/06	7.5	642.8	5.6	457.4	128	89	43	5,476	NA	48	44	40	40
19	01/23/06	3.5	646.3	2.2	459.6	122	86	37	NA	NA	48	42	44	44
	01/24/06	4.0	650.3	3.9	463.5	130	91	26	5,427	NA	42	41	55	58
	01/25/06	5.5	655.8	4.0	467.5	129	96	36	NA	NA	16	42	50	50
	01/26/06	5.1	660.9	4.7	472.2	129	87	28	5,348	NA	52	48	54	56
	01/27/06	4.4	665.3	3.4	475.6	91	89	26	NA	NA	43	41	47	48
	01/28/06	3.8	669.1	3.9	479.5	78	93	32	6,202	NA	46	44	50	50
	01/29/06	5.3	674.4	3.4	482.9	83	94	23	NA	NA	49	47	43	44
20	01/30/06	6.1	680.5	5.3	488.2	130	88	31	6,426	NA	52	48	54	56
	01/31/06	4.5	685.0	3.8	492.0	86	96	29	NA	NA	50	48	48	48
	02/01/06	4.6	689.6	5.5	497.5	87	91	32	6,355	5,752	46	44	48	46
	02/02/06	5.5	695.1	3.3	500.8	98	93	37	NA	NA	50	46	50	52
	02/03/06	5.3	700.4	3.6	504.4	126	92	28	2,473	NA	52	48	54	54
	02/04/06	7.4	707.8	5.1	509.5	112	84	45	7,661	NA	54	52	54	54
	02/05/06	5.3	713.1	3.9	513.4	107	93	42	NA	NA	52	46	50	50
21	02/06/06	6.3	719.4	3.8	517.2	100	80	45	9,244	NA	44	42	44	44
	02/07/06	4.7	724.1	2.9	520.1	115	95	33	NA	NA	54	50	54	54
	02/08/06	6.2	730.3	4.3	524.4	90	85	26	6,060	NA	44	42	42	42
	02/09/06	4.9	735.2	3.4	527.8	87	94	33	NA	NA	46	43	48	48
	02/10/06	5.4	740.6	4.7	532.5	80	85	33	6,125	NA	56	54	54	54
	02/11/06	6.8	747.4	4.6	537.1	119	100	37	NA	NA	50	44	50	50
	02/12/06	4.3	751.7	3.3	540.4	84	82	48	NA	NA	48	42	48	48

Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 5 of 11)

Week No.	Date	Hour Meter				Service			Backwash		System Pressure			
		West Well		East Well		AD-26		AD-33	AD-26	AD-33	AD-26		AD-33	
		Daily Op Hours	Cumulative Hours[a]	Daily Op Hours	Cumulative Hours[a]	Combined Flowrate[b,c]	Calculated Combined Flowrate[d]	Combined Flowrate[e]	Backwash Water Produced	Backwash Water Produced	Inlet Pressure	Outlet Pressure	Inlet Pressure	Outlet Pressure
		hr	hr	hr	hr	gpm	gpm	gpm	gal	gal	psi	psi	psi	psi
22	02/13/06	5.7	757.4	4.3	544.7	99	82	36	6,150	NA	44	43	44	45
	02/14/06	5.3	762.7	3.8	548.5	120	95	48	NA	NA	50	47	56	56
	02/15/06	5.3	768.0	3.9	552.4	114	91	23	NA	NA	56	50	39	39
	02/16/06	5.3	773.3	4.6	557.0	124	84	39	6,144	NA	42	41	50	50
	02/17/06	5.7	779.0	3.7	560.7	86	128	40	NA	NA	45	42	53	54
	02/18/06	4.9	783.9	3.6	564.3	81	54	33	NA	NA	55	53	44	44
	02/19/06	6.5	790.4	4.9	569.2	87	77	42	6,003	NA	47	46	51	51
23	02/20/06	5.3	795.7	3.9	573.1	125	109	42	NA	NA	52	48	52	54
	02/21/06	5.8	801.5	5.1	578.2	110	87	29	NA	NA	54	48	54	54
	02/22/06	5.6	807.1	4.5	582.7	92	86	33	6,167	NA	46	44	48	48
	02/23/06	6.6	813.7	4.8	587.5	124	107	43	NA	NA	52	48	50	50
	02/24/06	5.4	819.1	3.7	591.2	120	74	31	NA	NA	54	48	54	54
	02/25/06	7.7	826.8	5.3	596.5	93	87	42	5,976	NA	44	42	46	44
	02/26/06	6.2	833.0	4.1	600.6	115	91	42	NA	NA	56	52	52	52
24	02/27/06	3.6	836.6	2.4	603.0	120	92	35	NA	NA	52	46	52	52
	02/28/06	5.6	842.2	3.8	606.8	87	82	29	7,507	NA	48	46	48	48
	03/01/06	5.7	847.9	3.8	610.6	111	93	30	NA	NA	58	54	54	54
	03/02/06	4.6	852.5	3.9	614.5	89	91	29	NA	NA	48	46	48	48
	03/03/06	5.1	857.6	4.0	618.5	129	83	35	6,278	NA	50	48	52	52
	03/04/06	5.1	862.7	3.3	621.8	126	96	34	NA	NA	48	44	52	52
	03/05/06	8.1	870.8	5.9	627.7	101	91	49	NA	NA	56	50	52	54
25	03/06/06	2.9	873.7	2.3	630.0	77	78	35	6,250	NA	46	44	46	46
	03/07/06	4.4	878.1	3.7	633.7	91	96	28	NA	NA	46	44	48	48
	03/08/06	4.9	883.0	3.6	637.3	86	92	30	NA	NA	50	48	48	48
	03/09/06	4.3	887.3	4.6	641.9	92	84	43	6,254	NA	46	44	44	44
	03/10/06	6.0	893.3	3.5	645.4	120	86	40	NA	NA	52	48	52	50
	03/11/06	4.8	898.1	5.1	650.5	107	102	34	NA	NA	60	46	48	48
	03/12/06	4.9	903.0	3.8	654.3	81	94	36	6,283	NA	54	50	54	54
26	03/13/06	1.4	904.4	2.3	656.6	114	103	32	NA	NA	56	52	56	54
	03/14/06	6.3	910.7	3.9	660.5	85	84	28	NA	NA	48	44	48	48
	03/15/06	4.5	915.2	4.1	664.6	86	89	26	4,808	NA	46	44	44	44
	03/16/06	4.6	919.8	3.3	667.9	124	97	37	NA	NA	50	48	48	48
	03/17/06	4.4	924.2	3.1	671.0	127	93	36	NA	NA	56	52	52	52
	03/18/06	4.6	928.8	4.2	675.2	90	86	32	6,246	NA	44	40	48	48
	03/19/06	6.7	935.5	5.6	680.8	87	96	39	NA	NA	46	42	44	44

Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 6 of 11)

Week No.	Date	Hour Meter				Service			Backwash		System Pressure			
		West Well		East Well		AD-26		AD-33	AD-26	AD-33	AD-26		AD-33	
		Daily Op Hours	Cumulative Hours[a]	Daily Op Hours	Cumulative Hours[a]	Combined Flowrate[b,c]	Calculated Combined Flowrate[d]	Combined Flowrate[e]	Backwash Water Produced	Backwash Water Produced	Inlet Pressure	Outlet Pressure	Inlet Pressure	Outlet Pressure
		hr	hr	hr	hr	gpm	gpm	gpm	gal	gal	psi	psi	psi	psi
27	03/20/06	3.6	939.1	2.4	683.2	89	92	22	NA	NA	48	44	48	48
	03/21/06	5.1	944.2	4.0	687.2	132	85	31	6,232	NA	52	50	52	54
	03/22/06	5.7	949.9	4.6	691.8	90	98	37	NA	NA	48	44	46	46
	03/23/06	3.6	953.5	2.8	694.6	85	86	36	NA	NA	48	46	46	46
	03/24/06	5.8	959.3	4.2	698.8	128	87	33	6,222	NA	54	52	50	50
	03/25/06	6.2	965.5	4.3	703.1	87	93	37	NA	NA	48	44	46	46
	03/26/06	5.1	970.6	3.7	706.8	122	92	42	NA	NA	52	46	50	50
28	03/27/06	4.3	974.9	3.4	710.2	79	83	0	6,244	NA	50	48	50	50
	03/28/06	3.7	978.6	2.8	713.0	79	93	42	NA	NA	46	42	46	46
	03/29/06	4.6	983.2	3.9	716.9	123	95	26	NA	NA	52	48	52	52
	03/30/06	5.3	988.5	3.7	720.6	90	82	31	6,257	NA	46	44	46	46
	03/31/06	4.5	993.0	3.5	724.1	82	96	31	NA	NA	52	50	52	52
	04/01/06	4.3	997.3	3.7	727.8	121	89	25	NA	NA	52	46	46	48
	04/02/06	7.3	1,004.6	4.9	732.7	89	86	33	6,230	6,302	44	42	42	42
29	04/03/06	4.5	1,009.1	3.3	736.0	86	94	30	NA	NA	48	46	46	48
	04/04/06	5.2	1,014.3	3.5	739.5	114	93	40	NA	NA	56	52	50	50
	04/05/06	6.9	1,021.2	4.5	744.0	130	84	32	6,185	NA	52	48	56	56
	04/06/06	7.5	1,028.7	6.9	750.9	79	95	39	NA	NA	56	52	54	54
	04/07/06	4.0	1,032.7	2.3	753.2	86	90	38	NA	NA	48	44	46	46
	04/08/06	8.3	1,041.0	5.9	759.1	90	86	44	6,182	NA	48	46	46	46
	04/09/06	6.1	1,047.1	3.8	762.9	126	93	58	NA	NA	50	46	48	48
30	04/10/06	3.8	1,050.9	2.4	765.3	113	91	37	NA	NA	42	50	50	50
	04/11/06	5.6	1,056.5	4.4	769.7	91	84	26	6,247	NA	42	40	44	44
	04/12/06	6.3	1,062.8	4.3	774.0	85	94	31	NA	NA	46	42	42	42
	04/13/06	4.9	1,067.7	3.1	777.1	81	84	31	NA	NA	54	48	48	50
	04/14/06	6.2	1,073.9	3.9	781.0	130	91	39	6,232	NA	46	42	42	42
	04/15/06	5.6	1,079.5	3.4	784.4	89	92	47	NA	NA	54	52	44	44
	04/16/06	6.8	1,086.3	4.5	788.9	88	NA	42	NA	NA	48	42	40	40
31	04/17/06	5.7	1,092.0	4.5	793.4	91	NA	36	6,250	NA	44	42	46	48
	04/18/06	6.1	1,098.1	3.8	797.2	129	100	38	NA	NA	50	46	50	50
	04/19/06	5.8	1,103.9	3.9	801.1	79	84	48	NA	NA	56	52	52	54
	04/20/06	5.8	1,109.7	4.1	805.2	79	84	32	5,896	NA	54	52	54	56
	04/21/06	5.3	1,115.0	3.4	808.6	90	94	27	NA	NA	48	46	48	48
	04/22/06	8.5	1,123.5	5.1	813.7	120	91	39	NA	NA	52	46	48	48
	04/23/06	8.5	1,132.0	5.4	819.1	90	86	51	5,825	NA	46	42	44	44

Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 7 of 11)

Week No.	Date	Hour Meter				Service			Backwash		System Pressure			
		West Well		East Well		AD-26		AD-33	AD-26	AD-33	AD-26		AD-33	
		Daily Op Hours	Cumulative Hours[(a)]	Daily Op Hours	Cumulative Hours[(a)]	Combined Flowrate[(b,c)]	Calculated Combined Flowrate[(d)]	Combined Flowrate[(e)]	Backwash Water Produced	Backwash Water Produced	Inlet Pressure	Outlet Pressure	Inlet Pressure	Outlet Pressure
		hr	hr	hr	hr	gpm	gpm	gpm	gal	gal	psi	psi	psi	psi
32	04/24/06	4.0	1,136.0	2.0	821.1	115	100	41	NA	NA	52	46	48	48
	04/25/06	6.3	1,142.3	3.9	825.0	87	4	26	NA	NA	50	44	44	46
	04/26/06	6.9	1,149.2	4.0	829.0	80	159	35	6,280	NA	56	54	54	54
	04/27/06	4.0	1,153.2	3.0	832.0	127	95	26	NA	NA	48	44	46	46
	04/28/06	4.4	1,157.6	2.9	834.9	79	92	34	NA	NA	56	52	54	54
	04/29/06	5.4	1,163.0	4.1	839.0	79	84	40	6,266	NA	58	56	56	56
	04/30/06	5.8	1,168.8	3.5	842.5	126	93	31	NA	NA	48	42	50	50
33	05/01/06	4.5	1,173.3	3.3	845.8	120	94	36	NA	NA	52	48	52	52
	05/02/06	4.9	1,178.2	4.0	849.8	90	84	26	6,246	NA	44	42	48	48
	05/03/06	4.9	1,183.1	3.1	852.9	107	94	36	NA	NA	50	46	50	52
	05/04/06	4.9	1,188.0	3.3	856.2	121	92	39	NA	NA	52	46	50	50
	05/05/06	7.8	1,195.8	7.1	863.3	88	86	39	6,167	NA	46	44	46	48
	05/06/06	6.7	1,202.5	4.1	867.4	88	95	27	NA	NA	48	46	50	50
	05/07/06	5.3	1,207.8	4.1	871.5	123	91	37	NA	NA	52	46	50	50
34	05/08/06	3.5	1,211.3	2.8	874.3	87	80	33	6,249	NA	46	44	44	44
	05/09/06	5.2	1,216.5	3.4	877.7	89	94	32	NA	NA	48	46	44	44
	05/10/06	5.0	1,221.5	3.4	881.1	117	92	37	NA	NA	48	42	42	44
	05/11/06	5.9	1,227.4	4.1	885.2	90	84	28	6,243	NA	42	42	42	44
	05/12/06	5.1	1,232.5	3.4	888.6	84	94	40	NA	NA	50	48	46	46
	05/13/06	5.0	1,237.5	3.7	892.3	116	91	47	NA	NA	50	44	42	42
	05/14/06	5.8	1,243.3	4.1	896.4	91	85	38	6,060	NA	44	40	46	46
35	05/15/06	5.9	1,249.2	3.6	900.0	125	94	40	NA	NA	52	48	52	52
	05/16/06	6.1	1,255.3	3.5	903.5	81	91	29	NA	NA	48	44	44	44
	05/17/06	4.9	1,260.2	4.6	908.1	130	85	36	6,069	NA	48	46	50	50
	05/18/06	5.3	1,265.5	3.7	911.8	90	96	33	NA	NA	46	42	44	46
	05/19/06	5.4	1,270.9	3.5	915.3	125	83	41	NA	NA	48	44	48	48
	05/20/06	7.7	1,278.6	5.3	920.6	87	93	39	6,058	NA	46	44	46	46
	05/21/06	4.9	1,283.5	3.2	923.8	120	93	36	NA	NA	52	48	50	50
36	05/22/06	4.1	1,287.6	2.8	926.6	89	100	42	NA	NA	46	42	44	42
	05/23/06	5.8	1,293.4	4.5	931.1	84	80	36	6,222	NA	50	48	48	48
	05/24/06	4.5	1,297.9	3.4	934.5	79	95	36	NA	NA	58	54	54	54
	05/25/06	5.7	1,303.6	3.5	938.0	124	92	44	NA	NA	42	40	48	48
	05/26/06	6.8	1,310.4	4.3	942.3	123	84	29	6,201	NA	44	44	42	42
	05/27/06	4.5	1,314.9	2.9	945.2	122	94	24	NA	NA	48	44	44	44
	05/28/06	10.6	1,325.5	6.7	951.9	89	89	37	NA	NA	46	40	42	42

Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 8 of 11)

Week No.	Date	Hour Meter				Service			Backwash		System Pressure			
		West Well		East Well		AD-26		AD-33	AD-26	AD-33	AD-26		AD-33	
		Daily Op Hours	Cumulative Hours[(a)]	Daily Op Hours	Cumulative Hours[(a)]	Combined Flowrate[(b,c)]	Calculated Combined Flowrate[(d)]	Combined Flowrate[(e)]	Backwash Water Produced	Backwash Water Produced	Inlet Pressure	Outlet Pressure	Inlet Pressure	Outlet Pressure
		hr	hr	hr	hr	gpm	gpm	gpm	gal	gal	psi	psi	psi	psi
37	05/29/06	4.2	1,329.7	2.6	954.5	82	82	44	6,250	NA	54	52	52	52
	05/30/06	5.6	1,335.3	2.7	957.2	83	93	38	NA	NA	52	50	50	52
	05/31/06	5.0	1,340.3	3.8	961.0	89	91	35	NA	NA	48	44	46	48
	06/01/06	5.7	1,346.0	4.9	965.9	91	88	33	6,081	5,723	46	44	48	48
	06/03/06	16.3	1,362.3	11.3	977.2	116	90	43	NA	NA	50	46	48	48
	06/04/06	6.9	1,369.2	4.9	982.1	126	84	42	6,074	NA	50	46	52	52
38	06/05/06	4.3	1,373.5	3.3	985.4	123	91	48	NA	NA	52	48	48	48
	06/06/06	7.1	1,380.6	4.9	990.3	92	91	42	NA	NA	54	48	52	52
	06/07/06	7.7	1,388.3	5.1	995.4	79	83	37	6,098	NA	54	54	54	54
	06/08/06	11.0	1,399.3	3.9	999.3	79	88	62	NA	NA	54	50	50	50
	06/09/06	5.8	1,405.1	5.1	1,004.4	76	88	34	NA	NA	60	56	56	56
	06/10/06	8.4	1,413.5	7.2	1,011.6	126	86	32	6,141	NA	52	48	48	48
	06/11/06	5.2	1,418.7	3.0	1,014.6	129	91	39	NA	NA	52	46	46	46
39	06/12/06	4.4	1,423.1	3.4	1,018.0	121	90	42	NA	NA	52	46	50	50
	06/13/06	6.3	1,429.4	6.0	1,024.0	122	84	46	6,176	NA	50	48	50	50
	06/14/06	6.1	1,435.5	4.3	1,028.3	89	90	46	NA	NA	46	42	44	44
	06/15/06	7.3	1,442.8	4.8	1,033.1	119	89	43	NA	NA	50	44	48	48
	06/16/06	6.7	1,449.5	4.6	1,037.7	90	81	36	6,215	NA	44	42	44	44
	06/17/06	7.5	1,457.0	4.8	1,042.5	110	92	46	NA	NA	50	46	48	48
	06/18/06	7.4	1,464.4	3.7	1,046.2	89	88	29	NA	NA	48	44	46	48
40	06/19/06	2.8	1,467.2	1.7	1,047.9	79	73	43	6,229	NA	54	52	52	52
	06/20/06	5.9	1,473.1	3.3	1,051.2	121	90	29	NA	NA	48	52	52	52
	06/21/06	5.8	1,478.9	3.2	1,054.4	106	89	42	NA	NA	54	48	50	50
	06/22/06	5.6	1,484.5	3.4	1,057.8	87	82	53	6,242	NA	44	42	50	50
	06/23/06	5.0	1,489.5	3.5	1,061.3	114	93	37	NA	NA	50	46	44	44
	06/24/06	4.9	1,494.4	3.3	1,064.6	88	85	31	NA	NA	52	46	44	44
	06/25/06	7.3	1,501.7	3.5	1,068.1	87	85	42	6,239	NA	48	46	44	44
41	06/26/06	5.3	1,507.0	2.8	1,070.9	86	90	50	NA	NA	48	44	44	46
	06/27/06	4.7	1,511.7	3.5	1,074.4	121	92	37	NA	NA	52	46	50	50
	06/28/06	4.8	1,516.5	3.5	1,077.9	90	81	35	6,075	NA	44	42	48	48
	06/29/06	5.2	1,521.7	3.3	1,081.2	84	93	50	NA	NA	50	46	48	48
	06/30/06	5.1	1,526.8	3.6	1,084.8	89	91	37	NA	NA	46	44	46	46
	07/01/06	5.6	1,532.4	4.1	1,088.9	83	82	39	6,036	NA	52	48	50	50
	07/02/06	7.4	1,539.8	5.0	1,093.9	91	91	45	NA	NA	46	42	44	44

Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 9 of 11)

Week No.	Date	Hour Meter				Service			Backwash		System Pressure			
		West Well		East Well		AD-26		AD-33	AD-26	AD-33	AD-26		AD-33	
		Daily Op Hours	Cumulative Hours[(a)]	Daily Op Hours	Cumulative Hours[(a)]	Combined Flowrate[(b,c)]	Calculated Combined Flowrate[(d)]	Combined Flowrate[(e)]	Backwash Water Produced	Backwash Water Produced	Inlet Pressure	Outlet Pressure	Inlet Pressure	Outlet Pressure
		hr	hr	hr	hr	gpm	gpm	gpm	gal	gal	psi	psi	psi	psi
42	07/03/06	3.1	1,542.9	2.5	1,096.4	119	92	43	NA	NA	52	46	44	44
	07/04/06	5.6	1,548.5	6.0	1,102.4	124	83	47	6,197	NA	56	52	52	52
	07/05/06	4.1	1,552.6	2.6	1,105.0	118	92	33	NA	NA	50	44	46	46
	07/06/06	4.7	1,557.3	4.1	1,109.1	80	91	27	NA	NA	56	56	54	54
	07/07/06	5.5	1,562.8	5.5	1,114.6	90	87	51	6,214	NA	48	46	44	44
	07/08/06	6.5	1,569.3	3.5	1,118.1	89	91	45	NA	NA	46	42	42	42
	07/09/06	5.4	1,574.7	3.1	1,121.2	119	92	49	NA	NA	52	46	44	44
43	07/10/06	7.4	1,582.1	5.4	1,126.6	76	82	38	6,199	NA	48	48	42	42
	07/11/06	5.2	1,587.3	2.7	1,129.3	100	90	46	NA	NA	48	44	48	48
	07/12/06	5.4	1,592.7	3.1	1,132.4	87	88	44	NA	NA	46	42	44	44
	07/13/06	5.7	1,598.4	4.0	1,136.4	124	83	43	6,210	NA	48	46	48	48
	07/14/06	7.1	1,605.5	4.0	1,140.4	86	90	29	NA	NA	48	46	48	48
	07/15/06	6.5	1,612.0	4.7	1,145.1	87	89	35	NA	NA	48	44	46	46
	07/16/06	7.6	1,619.6	5.0	1,150.1	83	83	59	6,191	NA	46	42	42	42
44	07/17/06	4.8	1,624.4	3.9	1,154.0	117	91	47	NA	NA	50	44	46	44
	07/18/06	4.5	1,628.9	2.7	1,156.7	121	87	48	NA	NA	50	42	44	44
	07/19/06	5.7	1,634.6	4.5	1,161.2	89	88	32	6,185	NA	50	48	48	48
	07/20/06	6.7	1,641.3	4.0	1,165.2	83	84	44	NA	NA	50	46	46	46
	07/21/06	6.1	1,647.4	4.5	1,169.7	119	90	42	NA	NA	50	44	48	48
	07/22/06	6.4	1,653.8	4.5	1,174.2	81	81	47	6,158	NA	52	48	50	50
	07/23/06	5.2	1,659.0	3.2	1,177.4	87	93	45	NA	NA	46	42	44	46
45	07/24/06	7.5	1,666.5	3.6	1,181.0	109	89	49	NA	NA	54	48	52	52
	07/25/06	6.1	1,672.6	4.7	1,185.7	88	82	42	6,136	NA	44	42	44	44
	07/26/06	6.3	1,678.9	3.8	1,189.5	123	91	45	NA	NA	50	46	48	48
	07/27/06	5.2	1,684.1	3.7	1,193.2	79	89	32	NA	NA	56	52	52	52
	07/28/06	5.7	1,689.8	3.9	1,197.1	87	83	25	6,198	NA	46	42	46	48
	07/29/06	5.6	1,695.4	3.5	1,200.6	107	92	38	NA	NA	56	54	52	52
	07/30/06	6.1	1,701.5	3.8	1,204.4	112	90	38	NA	NA	50	44	56	56
46	07/31/06	7.0	1,708.5	5.5	1,209.9	122	81	40	6,196	6,402	48	44	48	48
	08/01/06	6.1	1,714.6	3.8	1,213.7	77	91	63	NA	NA	56	52	54	52
	08/02/06	7.3	1,721.9	4.3	1,218.0	119	88	51	NA	NA	58	52	54	54
	08/03/06	4.9	1,726.8	3.5	1,221.5	128	80	48	6,180	NA	50	46	48	48
	08/04/06	6.4	1,733.2	4.9	1,226.4	102	92	56	NA	NA	52	48	48	48
	08/05/06	6.7	1,739.9	4.6	1,231.0	80	89	70	NA	NA	48	44	44	44
	08/06/06	6.8	1,746.7	5.2	1,236.2	77	83	59	6,119	NA	56	56	56	56

Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 10 of 11)

Week No.	Date	Hour Meter				Service			Backwash		System Pressure			
		West Well		East Well		AD-26		AD-33	AD-26	AD-33	AD-26		AD-33	
		Daily Op Hours	Cumulative Hours[(a)]	Daily Op Hours	Cumulative Hours[(a)]	Combined Flowrate[(b,c)]	Calculated Combined Flowrate[(d)]	Combined Flowrate[(e)]	Backwash Water Produced	Backwash Water Produced	Inlet Pressure	Outlet Pressure	Inlet Pressure	Outlet Pressure
		hr	hr	hr	hr	gpm	gpm	gpm	gal	gal	psi	psi	psi	psi
47	08/07/06	6.5	1,753.2	3.7	1,239.9	78	90	51	NA	NA	56	52	52	52
	08/08/06	5.8	1,759.0	4.0	1,243.9	77	88	55	NA	NA	56	52	54	54
	08/09/06	6.6	1,765.6	5.0	1,248.9	117	81	53	6,150	NA	48	44	48	48
	08/10/06	6.0	1,771.6	3.7	1,252.6	79	90	56	NA	NA	56	52	54	54
	08/11/06	5.2	1,776.8	4.2	1,256.8	100	90	48	NA	NA	54	52	52	52
	08/12/06	6.2	1,783.0	4.5	1,261.3	128	82	47	6,024	NA	48	44	48	48
	08/13/06	5.9	1,788.9	4.4	1,265.7	80	91	59	NA	NA	50	46	48	46
48	08/14/06	6.0	1,794.9	4.9	1,270.6	89	10	44	NA	NA	52	48	48	44
	08/15/06	6.0	1,800.9	4.3	1,274.9	82	165	42	6,048	NA	50	48	48	48
	08/16/06	6.6	1,807.5	4.7	1,279.6	98	89	44	NA	NA	46	42	46	44
	08/17/06	5.6	1,813.1	4.6	1,284.2	78	87	41	NA	NA	48	52	52	52
	08/18/06	5.1	1,818.2	4.2	1,288.4	128	82	42	6,197	NA	48	44	50	50
	08/19/06	6.0	1,824.2	3.9	1,292.3	77	89	58	NA	NA	56	52	52	50
	08/20/06	5.3	1,829.5	3.7	1,296.0	85	89	71	NA	NA	60	54	54	54
49	08/21/06	5.6	1,835.1	4.9	1,300.9	90	79	35	6,222	NA	46	44	46	46
	08/22/06	6.2	1,841.3	3.5	1,304.4	89	90	50	NA	NA	44	42	42	42
	08/23/06	5.7	1,847.0	4.3	1,308.7	117	87	53	NA	NA	50	46	48	48
	08/24/06	4.6	1,851.6	4.9	1,313.6	84	84	42	4,721	NA	48	46	48	48
	08/25/06	5.3	1,856.9	3.5	1,317.1	88	91	40	NA	NA	44	42	44	44
	08/26/06	6.2	1,863.1	4.6	1,321.7	83	88	36	NA	NA	50	48	48	48
	08/27/06	5.9	1,869.0	4.9	1,326.6	89	83	48	6,054	NA	44	42	44	42
50	08/28/06	3.8	1,872.8	3.0	1,329.6	80	92	26	NA	NA	52	50	54	54
	08/29/06	4.7	1,877.5	3.2	1,332.8	123	90	41	NA	NA	58	54	54	54
	08/30/06	5.1	1,882.6	3.9	1,336.7	128	80	36	6,190	NA	50	48	50	50
	08/31/06	5.0	1,887.6	3.7	1,340.4	122	93	28	NA	NA	50	44	46	46
	09/01/06	4.7	1,892.3	3.6	1,344.0	114	89	28	NA	NA	52	44	48	48
	09/02/06	5.7	1,898.0	4.8	1,348.8	86	89	36	6,195	NA	46	42	46	46
	09/03/06	3.9	1,901.9	2.8	1,351.6	80	85	49	NA	NA	54	50	50	50
51	09/04/06	5.0	1,906.9	3.9	1,355.5	81	90	43	NA	NA	60	54	54	54
	09/05/06	5.1	1,912.0	4.0	1,359.5	90	80	33	6,228	NA	46	44	42	42
	09/06/06	4.1	1,916.1	2.9	1,362.4	81	93	33	NA	NA	54	52	52	52
	09/07/06	3.9	1,920.0	3.2	1,365.6	94	90	28	NA	NA	58	54	48	48
	09/08/06	4.7	1,924.7	5.7	1,371.3	126	82	27	6,081	NA	50	46	48	48
	09/09/06	5.1	1,929.8	3.8	1,375.1	122	93	32	NA	NA	50	44	48	48
	09/10/06	3.8	1,933.6	3.3	1,378.4	80	90	36	NA	NA	52	48	50	50

Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 11 of 11)

Week No.	Date	Hour Meter				Service			Backwash		System Pressure			
		West Well		East Well		AD-26		AD-33	AD-26	AD-33	AD-26		AD-33	
		Daily Op Hours	Cumulative Hours[(a)]	Daily Op Hours	Cumulative Hours[(a)]	Combined Flowrate[(b,c)]	Calculated Combined Flowrate[(d)]	Combined Flowrate[(e)]	Backwash Water Produced	Backwash Water Produced	Inlet Pressure	Outlet Pressure	Inlet Pressure	Outlet Pressure
		hr	hr	hr	hr	gpm	gpm	gpm	gal	gal	psi	psi	psi	psi
52	09/11/06	4.5	1,938.1	3.8	1,382.2	127	80	24	6,243	NA	48	46	50	52
	09/12/06	4.3	1,942.4	3.1	1,385.3	126	92	41	NA	NA	48	46	46	46
	09/13/06	3.8	1,946.2	2.8	1,388.1	124	92	20	NA	NA	52	48	52	52
	09/14/06	4.4	1,950.6	3.5	1,391.6	129	80	30	6,215	NA	48	46	48	48
	09/15/06	4.2	1,954.8	3.1	1,394.7	123	93	29	NA	NA	48	46	50	50
	09/16/06	5.9	1,960.7	5.0	1,399.7	88	91	28	NA	NA	48	44	46	46
	09/17/06	4.9	1,965.6	3.9	1,403.6	89	83	29	6,042	NA	44	42	46	46
53	09/18/06	2.3	1,967.9	1.6	1,405.2	126	98	40	NA	NA	50	46	50	50
	09/19/06	4.0	1,971.9	4.0	1,409.2	107	24	26	NA	NA	54	50	54	54
	09/20/06	4.8	1,976.7	3.5	1,412.7	84	142	18	6,052	NA	48	46	50	50
	09/21/06	4.4	1,981.1	3.3	1,416.0	125	91	29	NA	NA	50	44	48	48
	09/22/06	4.4	1,985.5	4.1	1,420.1	88	92	31	NA	NA	46	42	44	46
	09/23/06	4.6	1,990.1	4.3	1,424.4	83	83	27	6,027	NA	44	42	46	46
	09/24/06	5.5	1,995.6	4.8	1,429.2	88	93	38	NA	NA	46	42	44	44

Note: System started on September 21, 2005 at 5:00 pm, but operational readings not taken until September 28, 2005.
(a) In instances where readings not taken per hour meters, average used to calculate cumulative hours (5.5 hr for West Well and 4.0 hr for East Well)
(b) Oxidation/Filtration Vessel A not in service between September 28 to October 23, 2005.
(c) Sum of flowrate readings on each of three AD-26 vessels.
(d) Totalizer readings divided by sum of West Well and East Well hours.
(e) Sum of flowrate readings of each of three AD-33 vessels.
(f) Hour meter on East Well switched to West Well and a new hour meter installed on East Well on October 21, 2005.
(g) Since October 26, 2005 AD-26 system operated at pump flowrates and AD-33 system continued to operate on-demand.
(h) System by-passed between November 28 (8 a.m.) and 29, 2005 due to power outage/surge. System back online on November 30, 2005.
NA = Not Available

APPENDIX B

ANALYTICAL DATA

Table B-1. Analytical Results from Long-Term Sampling at Springfield, OH (Page 1 of 7)

Sampling Date		09/28/05 - East				10/11/05[b] - East				10/25/05 - East				11/08/05 - East			
Sampling Location		IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT
Parameter	Unit																
Bed Volume	BV	-	-	-	0.5	-	-	-	1.1	-	-	-	1.7	-	-	-	2.2
Alkalinity (as $CaCO_3$)	mg/L	361	370	365	365	352	356	352	348	343	330	339	334	352	343	352	343
Ammonia (as N)	mg/L	0.3	0.2	<0.05	<0.05	0.2	<0.05	<0.05	<0.05	0.2	<0.05	<0.05	<0.05	0.2	<0.05	<0.05	<0.05
Fluoride	mg/L	1.2	1.2	1.3	1.5	1.3	1.3	1.4	1.4	1.1	1.4	1.2	1.2	1.3	1.5	1.4	1.4
Sulfate	mg/L	14.0	13.8	13.7	23.0	17.9	20.1	23.0	23.0	20.0	12.0	25.0	26.0	20.8	29.9	25.0	25.9
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Orthophosphate (as PO_4)[a]	mg/L	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as PO_4)	mg/L	-	-	-	-	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Silica (as SiO_2)	mg/L	18.3	18.8	19.2	17.3	17.5	17.1	16.9	16.2	17.1	17.2	17.2	16.7	17.6	18.1	17.6	17.0
Turbidity	NTU	5.9	1.4	<0.1	<0.1	6.6	0.7	<0.1	0.1	7.6	1.0	<0.1	0.1	7.9	0.9	<0.1	<0.1
pH	S.U.	7.4	7.4	7.3	7.4	7.2	7.2	7.1	7.1	7.3	7.4	7.4	7.3	-	-	-	-
Temperature	°C	23.1	17.6	17.1	18.0	21.4	21.1	20.8	20.4	25.0	25.0	25.0	25.0	-	-	-	-
DO	mg/L	1.1	1.8	1.4	1.6	1.3	1.4	1.6	1.6	1.9	1.5	1.5	1.2	-	-	-	-
ORP	mV	107	746	728	718	232	624	627	566	102	734	712	713	-	-	-	-
Free Chlorine (as Cl_2)	mg/L	-	-	-	1.1	-	1.4	1.1	3.2	-	-	2.1	1.3	-	-	-	-
Total Chlorine (as Cl_2)	mg/L	-	-	-	1.6	-	1.8	-	3.3	-	-	2.2	1.9	-	-	-	-
Total Hardness (as $CaCO_3$)	mg/L	285	282	287	297	339	343	334	340	344	337	353	343	333	349	345	359
Ca Hardness (as $CaCO_3$)	mg/L	170	170	171	166	205	202	198	203	210	205	214	208	212	212	215	222
Mg Hardness (as $CaCO_3$)	mg/L	115	112	116	131	134	141	135	137	134	131	139	135	121	137	130	138
As (total)	µg/L	9.5	9.4	0.5	<0.1	19.4	25.9	1.4	0.2	18.5	20.6	1.4	0.3	16.7	23.6	1.3	0.2
As (soluble)	µg/L	8.4	3.2	0.6	<0.1	-	-	-	-	17.4	3.6	1.2	0.2	-	-	-	-
As (particulate)	µg/L	1.1	6.2	<0.1	<0.1	-	-	-	-	1.1	17.0	0.1	0.1	-	-	-	-
As (III)	µg/L	5.6	0.3	0.5	0.2	-	-	-	-	16.5	0.4	0.4	0.4	-	-	-	-
As (V)	µg/L	2.8	2.9	0.1	<0.1	-	-	-	-	0.9	3.2	0.8	<0.1	-	-	-	-
Fe (total)	µg/L	549	535	<25	<25	521	1,283	<25	<25	614	800	<25	<25	671	1,595	<25	<25
Fe (soluble)	µg/L	390	<25	<25	<25	-	-	-	-	519	<25	<25	<25	-	-	-	-
Mn (total)	µg/L	77.0	77.3	<0.1	<0.1	82.1	32.7	<0.1	<0.1	62.1	47.3	0.2	0.1	54.3	18.3	0.4	<0.1
Mn (soluble)	µg/L	81.6	39.6	<0.1	<0.1	-	-	-	-	58.8	7.1	0.4	0.5	-	-	-	-

IN = at Wellhead; AC = after chlorination; OT = after oxidation/filtration vessels; TT = after adsorption vessels

(a) Due to holding time issues, stopped sampling for orthophosphate and started sampling for total phosphorous.

(b) Water quality measurements taken on 10/18/05.

Table B-1. Analytical Results from Long-Term Sampling at Springfield, OH (Page 2 of 7)

Sampling Date		12/05/05 - East				12/12/05[a] - West				01/03/06 - East				01/16/06 - West			
Sampling Location		IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT
Parameter	Unit																
Bed Volume	BV	-	-	-	3.2	-	-	-	3.6	-	-	-	4.9	-	-	-	5.7
Alkalinity (as $CaCO_3$)	mg/L	343	339	339	339	338	343	348	339	339	339	334	339	343	352	352	348
Ammonia (as N)	mg/L	0.2	0.2	<0.05	<0.05	0.2	<0.05	<0.05	<0.05	0.2	<0.05	<0.05	<0.05	0.2	<0.05	<0.05	<0.05
Fluoride	mg/L	0.8	1.1	1.1	1.2	1.4	1.4	1.3	1.3	1.2	1.2	1.3	1.3	1.4	1.4	1.2	1.2
Sulfate	mg/L	17.1	24.5	21.6	22.8	30.1	30.3	25.0	25.7	22.0	22.0	27.0	27.0	29.5	29.6	25.2	23.9
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total P (as PO_4)	mg/L	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Silica (as SiO_2)	mg/L	18.1	19.0	18.3	18.3	19.7	19.7	18.9	18.7	18.8	17.9	18.0	18.2	19.4	19.2	18.2	18.9
Turbidity	NTU	7.0	1.1	<0.1	0.1	24.0	1.5	0.8	0.4	9.2	1.0	0.5	0.7	24.0	1.1	0.1	0.2
Ph	S.U.	7.5	7.4	7.4	7.3	7.4	7.4	7.4	7.4	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.1
Temperature	°C	10.2	10.2	10.2	10.2	14.4	14.2	14.2	14.1	15.7	15.7	15.7	15.6	17.1	16.7	16.5	16.3
DO	mg/L	NA	0.9	1.2	1.0	1.5	1.9	1.9	2.3	1.3	2.5	2.1	2.6	2.7	2.7	2.8	2.7
ORP	mV	145	148	394	468	132	689	681	684	5	691	679	689	-131	110	395	475
Free Chlorine (as Cl_2)	mg/L	-	-	3.1	1.5	-	-	-	2.7	-	2.3	1.1	1.8	-	2.1	0.4	1.7
Total Chlorine (as Cl_2)	mg/L	-	-	3.5	2.0	-	-	-	3.8	-	2.8	1.6	2.2	-	3.2	1.8	1.8
Total Hardness (as $CaCO_3$)	mg/L	322	325	240	347	331	326	323	320	357	345	348	354	344	349	351	349
Ca Hardness (as $CaCO_3$)	mg/L	195	189	140	194	202	202	203	205	214	215	202	207	209	211	214	214
Mg Hardness (as $CaCO_3$)	mg/L	126	136	101	153	129	124	120	115	143	131	146	147	134	139	137	135
As (total)	µg/L	16.9	22.4	0.6	<0.1	24.5	25.4	1.7	0.3	21.9	18.4	1.6	0.2	27.0	26.7	2.0	0.5
As (soluble)	µg/L	16.0	1.9	0.5	<0.1	-	-	-	-	21.2	3.1	1.6	0.2	-	-	-	-
As (particulate)	µg/L	0.8	20.5	<0.1	<0.1	-	-	-	-	0.7	15.3	<0.1	<0.1	-	-	-	-
As (III)	µg/L	14.6	0.4	<0.1	<0.1	-	-	-	-	21.5	0.4	0.4	0.5	-	-	-	-
As (V)	µg/L	1.5	1.5	0.4	<0.1	-	-	-	-	<0.1	2.7	1.2	<0.1	-	-	-	-
Fe (total)	µg/L	773	1,386	25	<25	1,587	1,546	<25	<25	1,260	802	<25	<25	1,595	1,538	<25	<25
Fe (soluble)	µg/L	658	<25	<25	<25	-	-	-	-	933	<25	<25	<25	-	-	-	-
Mn (total)	µg/L	42.8	20.0	<0.1	<0.1	19.6	19.6	0.4	<0.1	24.7	36.3	<0.1	<0.1	17.9	17.4	0.2	<0.1
Mn (soluble)	µg/L	43.5	0.4	<0.1	<0.1	-	-	-	-	24.4	3.8	0.3	0.2	-	-	-	-

IN = at Wellhead; AC = after chlorination; OT = after oxidation/filtration vessels; TT = after adsorption vessels
(a) Water quality measurements recorded on 12/16/05.

Table B-1. Analytical Results from Long-Term Sampling at Springfield, OH (Page 3 of 7)

Sampling Date		02/01/06[a] - East				02/13/06 - West				02/28/06[b] - West			
Sampling Location		IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT
Parameter	Unit												
Bed Volume	BV	-	-	-	6.6	-	-	-	7.3	-	-	-	8.1
Alkalinity (as $CaCO_3$)	mg/L	348	343	335	343	338	342	338	338	329	350	338	338
Ammonia (as N)	mg/L	0.2	0.2	<0.05	<0.05	0.1	0.2	<0.05	<0.05	0.2	<0.05	<0.05	<0.05
Fluoride	mg/L	1.1	1.1	1.3	1.3	1.3	1.1	1.2	1.2	1.5	1.3	1.5	1.4
Sulfate	mg/L	22.0	22.0	24.0	25.0	28.0	20.0	23.0	25.0	33.0	23.0	27.0	26.0
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total P (as PO_4)	mg/L	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Silica (as SiO_2)	mg/L	18.5	18.3	18.5	18.5	19.1	17.6	18.5	18.1	19.9	17.9	18.5	17.7
Turbidity	NTU	11.0	1.2	0.3	0.2	25.0	2.0	0.6	0.6	25.0	1.2	0.5	0.6
Ph	S.U.	7.2	7.3	7.2	7.2	7.1	7.0	7.1	7.1	7.2	7.2	7.2	7.1
Temperature	°C	17.8	17.6	17.4	17.3	16.6	16.0	15.8	15.7	13.6	13.9	14.0	14.1
DO	mg/L	1.7	1.5	2.0	2.6	1.8	2.1	2.7	2.3	2.6	2.6	3.0	2.4
ORP	mV	228	653	341	393	-90	-78	600	619	-84	304	270	281
Free Chlorine (as Cl_2)	mg/L	-	-	0.6	1.4	-	2.4	1.7	1.2	-	2.5	0.3	0.7
Total Chlorine (as Cl_2)	mg/L	-	-	0.6	1.6	-	-	2.3	1.7	-	-	0.9	0.8
Total Hardness (as $CaCO_3$)	mg/L	321	323	347	305	360	349	357	360	365	341	349	348
Ca Hardness (as $CaCO_3$)	mg/L	201	197	194	183	208	210	213	212	215	208	207	209
Mg Hardness (as $CaCO_3$)	mg/L	120	126	153	121	152	139	144	148	150	134	141	139
As (total)	µg/L	20.0	18.7	1.9	0.3	30.8	18.0	1.6	0.1	31.3	22.9	2.0	0.4
As (soluble)	µg/L	16.4	3.4	1.8	0.4	-	-	-	-	25.6	4.8	1.7	0.2
As (particulate)	µg/L	3.6	15.3	<0.1	<0.1	-	-	-	-	5.7	18.1	0.3	0.2
As (III)	µg/L	15.3	0.7	0.7	0.8	-	-	-	-	24.7	0.6	0.6	0.6
As (V)	µg/L	1.1	2.7	1.2	<0.1	-	-	-	-	0.9	4.3	1.0	<0.1
Fe (total)	µg/L	650	660	<25	<25	1573	728	<25	<25	1484	703	<25	<25
Fe (soluble)	µg/L	563	<25	<25	<25	-	-	-	-	1463	<25	<25	<25
Mn (total)	µg/L	34.4	34.2	0.2	<0.1	18.9	39.0	0.2	<0.1	18.2	34.9	<0.1	<0.1
Mn (soluble)	µg/L	36.6	2.2	<0.1	<0.1	-	-	-	-	18.8	3.2	<0.1	<0.1

IN = at Wellhead; AC = after chlorination; OT = after oxidation/filtration vessels; TT = after adsorption vessels

(a) Water quality measurements recorded on 01/30/06.

(b) On-site water quality parameters taken on 02/27/06.

Table B-1. Analytical Results from Long-Term Sampling at Springfield, OH (Page 4 of 7)

Sampling Date		03/13/06 - East				03/27/06[(a)] - West				04/10/06 - East			
Sampling Location		IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT
Parameter	Unit												
Bed Volume	BV	-	-	-	8.9	-	-	-	9.6	-	-	-	10.4
Alkalinity (as $CaCO_3$)	mg/L	351/335	331/331	331/335	339/ 343	340	323	328	336	328	319	336	328
Ammonia (as N)	mg/L	<0.05/<0.05	<0.05/<0.05	<0.05/<0.05	<0.05/<0.05	0.3	<0.05	<0.05	<0.05	0.3	<0.05	<0.05	<0.05
Fluoride	mg/L	1.3/1.3	1.5/1.6	1.5/1.6	1.4/1.4	1.3	1.6	1.4	1.4	1.3	1.4	1.3	1.3
Sulfate	mg/L	22.8/22.4	32.5/33.1	30.7/29.2	27.5/27.6	23.0	33.0	28.0	27.0	22.0	33.0	27.0	28.0
Nitrate (as N)	mg/L	<0.05/<0.05	<0.05/<0.05	<0.05/<0.05	<0.05/<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total P (as PO_4)	mg/L	<0.01/<0.01	<0.01/<0.01	<0.01/<0.01	<0.01/<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silica (as SiO_2)	mg/L	17.3/17.0	18.8/18.7	17.8/17.4	17.8/17.4	18.7	18.3	18.7	18.8	17.7	18.6	17.7	17.6
Turbidity	NTU	11.0/11.0	4.3/14.0	0.8/0.7	1.4/1.1	2.6	26.0	0.4	0.4	15.0	1.1	0.5	0.4
Ph	S.U.	7.3	7.4	7.5	7.2	7.2	7.3	7.3	7.3	7.2	7.3	7.3	7.3
Temperature	°C	15.7	15.4	15.4	15.5	14.3	14.0	14.3	13.6	13.8	14.2	13.7	13.9
DO	mg/L	-	-	-	-	2.2	1.9	2.7	2.2	2.1	2.1	1.5	1.6
ORP	mV	193	489	347	-	396	313	658	684	414	734	742	694
Free Chlorine (as Cl_2)	mg/L	-	0.3	1.6	2.0	-	4.0	0.9	1.9	-	0.0	0.1	2.0
Total Chlorine (as Cl_2)	mg/L	-	0.7	2.5	2.5	-	-	-	2.3	-	0.1	0.2	2.1
Total Hardness (as $CaCO_3$)	mg/L	329/336	342/346	349/344	345/339	339	328	346	344	308	324	323	332
Ca Hardness (as $CaCO_3$)	mg/L	206/210	204/208	210/211	211/209	196	197	206	205	196	199	201	205
Mg Hardness (as $CaCO_3$)	mg/L	123/126	138/138	139/133	134/130	143	131	140	139	112	126	122	127
As (total)	µg/L	20.9/21.8	29.2/29.8	1.8/1.8	0.2/0.2	29.7	20.3	1.8	0.1	20.5	26.0	1.7	0.2
As (soluble)	µg/L	-	-	-	-	24.8	4.0	1.5	<0.1	-	-	-	-
As (particulate)	µg/L	-	-	-	-	4.9	16.3	0.2	<0.1	-	-	-	-
As (III)	µg/L	-	-	-	-	23.6	0.3	0.2	0.2	-	-	-	-
As (V)	µg/L	-	-	-	-	1.2	3.8	1.3	<0.1	-	-	-	-
Fe (total)	µg/L	829/896	1561/1564	<25/<25	<25/<25	1892	903	<25	<25	1058	1733	<25	<25
Fe (soluble)	µg/L	-	-	-	-	1475	<25	<25	<25	-	-	-	-
Mn (total)	µg/L	35.4/34.7	17.6/17.3	0.2/0.2	<0.1/<0.1	20.0	33.8	0.3	0.2	46.6	21.0	0.1	<0.1
Mn (soluble)	µg/L	-	-	-	-	20.8	2.9	0.1	<0.1	-	-	-	-

IN = at Wellhead; AC = after chlorination; OT = after oxidation/filtration vessels; TT = after adsorption vessels
(a) On-site water quality parameters taken on 04/04/06.

Table B-1. Analytical Results from Long-Term Sampling at Springfield, OH (Page 5 of 7)

Sampling Date		04/24/06 - West				05/08/06 - East				05/22/06 - East				06/13/06[(a)] - West			
Sampling Location		IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT
Parameter	Unit																
Bed Volume	BV	-	-	-	11.2	-	-	-	11.9	-	-	-	12.7	-	-	-	14.1
Alkalinity (as $CaCO_3$)	mg/L	357	348	348	353	326	335	306	326	326	335	306	326	327	322	331	327
Ammonia (as N)	mg/L	0.2	<0.05	0.2	<0.05	0.2	<0.05	<0.05	<0.05	0.2	<0.05	<0.05	<0.05	0.2	<0.05	<0.05	<0.05
Fluoride	mg/L	1.3	1.9	1.5	1.7	1.1	1.2	1.3	1.2	1.1	1.2	1.3	1.2	1.4	1.3	1.2	1.3
Sulfate	mg/L	23.0	31.0	28.0	28.0	23.0	23.0	27.0	29.0	23.0	23.0	27.0	29.0	34.0	33.0	28.0	28.0
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total P (as PO_4)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03	<0.01	<0.01
Silica (as SiO_2)	mg/L	18.5	18.2	18.2	17.8	18.8	19.4	18.9	18.6	18.8	19.4	18.9	18.6	20.5	20.1	19.2	18.9
Turbidity	NTU	9.3	1.1	0.2	0.2	7.2	0.8	0.4	0.7	7.2	0.8	0.4	0.7	24.6	1.1	0.4	0.6
Ph	S.U.	7.3	7.3	7.5	7.3	7.1	7.3	7.3	7.3	7.2	7.4	7.4	7.4	6.9	7.2	7.1	7.1
Temperature	°C	14.3	14.1	14.2	13.8	13.6	13.6	13.6	13.6	13.8	13.6	13.6	13.7	14.6	14.3	14.0	14.2
DO	mg/L	3.5	2.9	2.4	2.6	1.7	2.9	2.7	2.7	3.4	3.4	3.8	3.1	2.3	2.1	1.7	1.8
ORP	mV	422	422	681	702	419	559	722	654	435	722	699	709	414	620	525	593
Free Chlorine (as Cl_2)	mg/L	-	-	-	1.7	-	-	-	1.0	-	-	1.6	2.0	-	-	-	2.4
Total Chlorine (as Cl_2)	mg/L	-	-	-	3.3	-	-	-	1.2	-	-	1.9	2.9	-	-	-	2.6
Total Hardness (as $CaCO_3$)	mg/L	347	344	344	351	432	436	417	387	319	325	335	349	355	354	346	341
Ca Hardness (as $CaCO_3$)	mg/L	215	207	211	216	270	261	253	230	188	191	194	205	210	210	208	205
Mg Hardness (as $CaCO_3$)	mg/L	133	137	133	136	162	175	164	157	131	134	141	144	145	144	138	136
As (total)	µg/L	21.5	27.4	1.5	0.1	21.3	29.3	2.0	0.1	20.0	19.5	1.9	0.2	29.5	29.1	2.0	0.1
As (soluble)	µg/L	18.8	26.2	1.4	<0.1	-	-	-	-	16.6	4.2	1.4	0.0	-	-	-	-
As (particulate)	µg/L	2.6	1.3	0.1	0.1	-	-	-	-	3.4	15.3	0.5	0.1	-	-	-	-
As (III)	µg/L	17.2	<0.1	0.2	0.2	-	-	-	-	14.8	0.1	0.1	0.1	-	-	-	-
As (V)	µg/L	1.6	26.1	1.2	<0.1	-	-	-	-	1.7	4.0	1.3	<0.1	-	-	-	-
Fe (total)	µg/L	1113	1627	<25	<25	1020	1599	<25	<25	697	675	<25	<25	1565	1504	<25	<25
Fe (soluble)	µg/L	988	2.5	<25	<25	-	-	-	-	613	<25	<25	<25	-	-	-	-
Mn (total)	µg/L	32.2	18.9	<0.1	<0.1	37.7	18.7	0.2	<0.1	32.7	32.1	0.1	<0.1	17.3	16.8	0.1	<0.1
Mn (soluble)	µg/L	32.2	17.8	<0.1	<0.1	-	-	-	-	33.4	1.0	<0.1	<0.1	-	-	-	-

IN = at Wellhead; AC = after chlorination; OT = after oxidation/filtration vessels; TT = after adsorption vessels
(a) On-site water quality parameters taken on 06/12/06.

Table B-1. Analytical Results from Long-Term Sampling at Springfield, OH (Page 6 of 7)

Sampling Date		06/28/06 - West				07/12/06[(a)] - East				07/26/06 - East			
Sampling Location		IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT
Parameter	Unit												
Bed Volume	BV	-	-	-	14.9	-	-	-	15.7	-	-	-	16.5
Alkalinity (as $CaCO_3$)	mg/L	348	344	339	335	345/345	345/350	350/345	337/341	325	333	346	346
Ammonia (as N)	mg/L	0.2	0.1	<0.05	<0.05	0.1/0.2	<0.05/0.2	<0.05/<0.05	<0.05/<0.05	0.2	0.2	<0.05	<0.05
Fluoride	mg/L	0.9	1.2	1.2	1.0	1.7/1.1	1.7/1.2	0.9/1.2	0.8/1.0	1.4	1.3	1.6	1.4
Sulfate	mg/L	23.0	22.0	27.0	25.0	23.0/23.0	24.0/23.0	23.0/26.0	27.0/23.0	31.0	22.0	25.0	25.0
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05/<0.05	<0.05/<0.05	<0.05/<0.05	<0.05/<0.05	<0.05	<0.05	<0.05	<0.05
Total P (as PO_4)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01/<0.01	<0.01/<0.01	<0.01/<0.01	<0.01/<0.01	<0.01	<0.01	<0.01	<0.01
Silica (as SiO_2)	mg/L	19.7	19.4	19.8	18.2	18.9/18.0	18.2/18.7	18.1/17.9	18.3/18.0	19.4	19.3	18.4	17.6
Turbidity	NTU	8.7	7.3	0.5	1.1	0.6/9.8	2.0/7.2	0.4/0.4	0.9/1.2	24.0	1.8	0.2	0.5
Ph	S.U.	7.1	7.2	7.3	7.4	7.0	7.1	7.1	7.2	7.0	7.1	7.2	7.0
Temperature	°C	17.8	16.4	17.6	17.4	15.8	16.1	15.8	15.4	17.1	17.8	17.5	17.7
DO	mg/L	3.1	2.6	3.0	2.9	1.6	2.3	2.2	2.1	-	-	-	-
ORP	mV	434	461	506	676	410	430	674	706	375	422	568	669
Free Chlorine (as Cl_2)	mg/L	-	-	-	2.5	-	-	-	2.3	-	0.2	1.5	2.2
Total Chlorine (as Cl_2)	mg/L	-	-	-	2.9	-	-	-	2.9	-	0.2	1.6	2.7
Total Hardness (as $CaCO_3$)	mg/L	343	358	361	348	342/329	333/336	335/337	340/345	322	331	332	346
Ca Hardness (as $CaCO_3$)	mg/L	195	208	203	195	208/200	203/204	204/206	205/208	187	193	199	207
Mg Hardness (as $CaCO_3$)	mg/L	148	150	158	153	133/129	129/131	131/131	136/137	135	138	133	139
As (total)	µg/L	20.2	20.2	1.8	0.1	19.8/20.2	23.0/19.5	1.6/2.0	<0.1/<0.1	26.0	26.2	1.6	0.1
As (soluble)	µg/L	17.8	2.3	1.6	<0.1	-	-	-	-	25.1	20.7	1.6	0.2
As (particulate)	µg/L	2.3	17.9	0.2	<0.1	-	-	-	-	1.0	5.5	<0.1	<0.1
As (III)	µg/L	11.7	0.2	0.2	0.2	-	-	-	-	25.8	23.1	11.5	0.6
As (V)	µg/L	6.1	2.1	1.4	<0.1	-	-	-	-	<0.1	<0.1	<0.1	<0.1
Fe (total)	µg/L	981	1133	<25	<25	822/893	737/739	<25/<25	<25/<25	1451	1455	<25	<25
Fe (soluble)	µg/L	773	<25	<25	<25	-	-	-	-	1393	838	<25	<25
Mn (total)	µg/L	35.2	34.9	0.5	0.2	36.1/34.8	38.3/35.3	0.2/0.7	<0.1/<0.1	17.6	17.6	<0.1	<0.1
Mn (soluble)	µg/L	34.3	2.6	0.3	0.2	-	-	-	-	17.8	17.4	0.2	0.5

IN = at Wellhead; AC = after chlorination; OT = after oxidation/filtration vessels; TT = after adsorption vessels
(a) On-site water quality parameters taken on 07/11/06.

Table B-1. Analytical Results from Long-Term Sampling at Springfield, OH (Page 7 of 7)

Sampling Date		08/14/06 - West				08/30/06 - East				09/11/06 - East				09/18/06 - East			
Sampling Location / Parameter	Unit	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT
Bed Volume	BV	-	-	-	17.7	-	-	-	18.5	-	-	-	19.1	-	-	-	19.4
Alkalinity (as $CaCO_3$)	mg/L	341	341	337	337	371	355	350	357	350	352	348	350	358	349	352	359
Ammonia (as N)	mg/L	0.3	<0.05	<0.05	<0.05	0.5	0.3	<0.05	<0.05	0.2	<0.05	<0.05	<0.05	0.2	0.1	<0.05	<0.05
Fluoride	mg/L	3.3	3.5	3.6	3.1	1.5	1.8	1.7	1.7	1.3	1.3	1.5	1.6	1.3	1.6	1.5	1.5
Sulfate	mg/L	33.0	23.0	24.0	26.0	26.0	37.0	34.0	33.0	23.0	23.0	28.0	30.0	23.0	33.0	30.0	28.0
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total P (as PO_4)	mg/L	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Silica (as SiO_2)	mg/L	18.1	17.7	17.7	17.7	17.7	17.9	17.3	17.4	16.8	16.8	17.6	17.0	18.7	19.3	18.8	18.4
Turbidity	NTU	23.0	1.1	0.3	0.5	7.6	1.5	0.3	0.7	11.0	1.2	0.3	0.4	6.5	1.2	0.3	0.6
Ph	S.U.	6.9	7.1	7.2	7.2	-	-	-	-	7.0	7.1	7.2	7.3	-	-	-	-
Temperature	°C	17.5	16.5	16.1	16.2	-	-	-	-	14.1	14.3	14.3	14.4	-	-	-	-
DO	mg/L	-	-	-	-	-	-	-	-	1.9	2.1	2.4	2.8	-	-	-	-
ORP	mV	433	742	718	716	-	-	-	-	416	395	663	665	-	-	-	-
Free Chlorine (as Cl_2)	mg/L	-	-	2.7	1.8	-	-	-	1.2	-	2.3	1.8	1.0	-	-	-	-
Total Chlorine (as Cl_2)	mg/L	-	-	2.7	2.4	-	-	-	1.4	-	-	1.8	1.4	-	-	-	-
Total Hardness (as $CaCO_3$)	mg/L	358	366	361	369	359	384	373	366	365	378	371	370	318	342	348	345
Ca Hardness (as $CaCO_3$)	mg/L	205	217	210	213	224	234	226	222	232	225	232	231	185	195	204	204
Mg Hardness (as $CaCO_3$)	mg/L	153	149	151	156	135	150	147	144	132	153	139	139	132	147	144	141
As (total)	µg/L	28.0	21.2	2.1	0.2	23.7	31.6	2.0	0.2	35.4	31.4	2.0	0.1	17.6	23.6	1.1	<0.1
As (soluble)	µg/L	-	-	-	-	18.5	2.8	1.7	0.2	-	-	-	-	14.0	2.7	1.1	<0.1
As (particulate)	µg/L	-	-	-	-	5.2	28.9	0.4	<0.1	-	-	-	-	3.6	20.8	<0.1	<0.1
As (III)	µg/L	-	-	-	-	16.0	0.3	0.3	0.3	-	-	-	-	12.9	<0.1	<0.1	<0.1
As (V)	µg/L	-	-	-	-	2.5	2.5	1.4	<0.1	-	-	-	-	1.1	2.6	1.0	<0.1
Fe (total)	µg/L	1485	776	<25	<25	807	1679	<25	<25	2238	922	<25	<25	742	1430	<25	<25
Fe (soluble)	µg/L	-	-	-	-	703	32.8	<25	<25	-	-	-	-	217	25.2	<25	<25
Mn (total)	µg/L	18.5	39.1	0.3	<0.1	36.6	18.4	0.1	<0.1	39.0	42.8	0.2	<0.1	32.6	16.4	<0.1	<0.1
Mn (soluble)	µg/L	-	-	-	-	36.5	7.8	1.2	0.2	-	-	-	-	32.9	1.9	0.2	0.2

IN = at Wellhead; AC = after chlorination; OT = after oxidation/filtration vessels; TT = after adsorption vessels