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Arsenic Removal from Drinking Water by Oxidation/Filtration and Adsorptive Media U.S. EPA Demonstration Project at Clinton Christian School in Goshen, IN Final Performance Evaluation Report

by

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Sally Gutierrez, Director
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ABSTRACT

This report documents the activities performed for and the results obtained from the arsenic removal treatment technology demonstration project at the Clinton Christian School in Goshen, IN. The objectives of the project were to evaluate the effectiveness of AdEdge Technologies' AD26/E33 media in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 μg/L. Additionally, this project evaluated (1) the reliability of the treatment system, (2) the required system operation and maintenance (O&M) and operator skill levels, and (3) the capital and O&M cost of the technology. The project also characterized the water in the distribution system and process residuals produced by the treatment process.

The 25 gal/min (gpm) AD26/E33 modular arsenic treatment system consisted of two integrated units. The AD26 oxidation/filtration unit consisted of three 13-in × 54-in vessels, each loaded with 2.3 ft^3 of AD26 media. The E33 adsorption unit consisted of two 18-in × 65-in vessels, each loaded with 5.3 ft^3 of E33 media. AD26 media is a manganese dioxide granular mineral commonly used for iron and manganese removal. E33 is an iron-based adsorptive media developed by Bayer AG for arsenic removal.

Operation of the AD26/E33 system began on May 1, 2008, but logging of operational data did not begin until June 6, 2008. 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 performance evaluation study period from June 6, 2008, through June 19, 2009, the system treated approximately 517,000 gal (or 6,522 bed volumes [BV]) of water. (Note that BV was calculated based on 5.3 ft^3 of E33 in each adsorption vessel.) Daily run times averaged 1.9 hr/day when the school was in session or 1.5 hr/day when the school was not in session. The AD26 unit operated at 16.4 gpm (on average), with an equal amount of water flowing through each of the three oxidation/filtration vessels. The E33 unit operated at 16.0 gpm (on average), with 7.7 and 8.3 gpm of water flowing through each of the two adsorption vessels. Based on the flowrates to the E33 unit, empty bed contact times (EBCTs) varied from 4.1 to 7.3 min and averaged 5.0 min. This average EBCT was over 61% higher than the vendor recommended EBCT of 3.1 min for E33 media.

Arsenic concentrations in raw water ranged from 22.2 to 33.4 μg/L and averaged 28.6 μg/L. Soluble As(III) was the predominating arsenic species, with concentrations ranging from 16.3 to 25.6 μg/L and averaging 20.2 μg/L. Upon chlorination, soluble As(III) was oxidized to soluble As(V), which was then adsorbed onto and/or co-precipitated with iron solids. The majority of arsenic (existing mainly in the particulate form) was removed by AD26 media, leaving only 1.2 to 5.0 μg/L (existing mainly as As[V]) to be further removed by E33 media. The system also reduced total iron concentrations from an average of 741 μg/L in raw water to below the method detection limit (MDL) of 25 μg/L. Total manganese concentrations were reduced from an average of 81.5 to <0.1 μg/L.

The AD26 unit was backwashed every 70.3 to 72.1 hr, producing 56,810 gal of wastewater (or 226 gal per vessel per backwash cycle). During the summer months when the school was not in session and the water use rate was low, the system was backwashed manually when the pressure difference across the AD26 vessels rose to approximately 7 psi. The E33 vessels were backwashed every 39 to 44 days, producing 3,450 gal of wastewater. Assuming 10 mg/L of total suspended solid (TSS) in 56,810 gal of backwash wastewater produced in one year, approximately 4.7 lb of solids (including 0.039, 1.5, and 0.21 lb of arsenic, iron, and manganese, respectively) would be discharged annually.

Comparison of the distribution system sampling results before and after the system startup showed a significant decrease in arsenic concentration from an average of 17.6 to 2.8 μg/L. The arsenic concentrations in the distribution system were either similar to or somewhat higher than 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 during the performance evaluation study was related to maintaining a target level of free chlorine residuals. In spite of repeated efforts to increase chlorine doses, free chlorine residuals were often below the Indiana Department of Environmental Management (IDEM)-required level of 0.2 mg/L (as Cl_2).

The capital investment cost for the system was $55,423, including $31,735 for equipment, $11,278 for site engineering, and $12,410 for installation. Using the system's rated capacity of 25 gpm (36,000 gal/day [gpd]), the normalized capital cost was $2,216/gpm ($1.54/gpd).

The O&M cost included the cost for media replacement and disposal, chemical supply, electricity consumption, and labor. Although media replacement did not occur during the demonstration period, the media replacement and disposal cost would represent the majority of the O&M cost and was estimated to be $2,593 for AD26 and $3,951 for E33. The vendor estimated that both media would have a life expectancy of 8.7 yr, which could not be confirmed during the 1-year performance evaluation study.

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ABBREVIATIONS AND ACRONYMS

Δp	differential pressure
AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
As	arsenic
ATS	Aquatic Treatment Systems
bgs	below ground surface
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
GAC	granular activated carbon
GFH	granular ferric hydroxide
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
HIX	hybrid ion exchanger
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IDEM	Indiana Department of Environmental Management
IOCs	inorganic compounds
IR	Iron Removal
IX	ion exchange
LCR	Lead and Copper Rule
lph	liter per hour
MCL	maximum contaminant level
MDL	method detection limit
MEI	Magnesium Elektron, Inc.;
Mg	magnesium
Mn	manganese

ABBREVIATIONS AND ACRONYMS (Continued)

mV	millivolts
Na	sodium
NA	not analyzed
NaOCl	sodium hypochlorite
NRMRL	National Risk Management Research Laboratory
NS	not sampled
NSF	NSF International
NTU	nephelometric turbidity unit
O&M	operation and maintenance
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
P&ID	piping and instrumentation diagram
PO_4	orthophosphate
PLC	programmable logic controller
POU	point-of-use
psi	pounds per square inch
PVC	polyvinyl chloride
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RFP	Request for Proposal
RO	reverse osmosis
RPD	relative percent difference
Sb	antimony
SDWA	Safe Drinking Water Act
SiO_2	silica
SMCL	secondary maximum contaminant level
$SO4^{2-}$	sulfate
SOC	synthetic organic compound
STS	Severn Trent Services
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
VOC	volatile organic compound

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1.0 INTRODUCTION

1.1 Background

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

In October 2001, EPA announced an initiative for additional research and development of cost-effective technologies to help small community water systems (<10,000 customers) meet the new arsenic standard, and to provide technical assistance to operators of small systems to reduce compliance costs. As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, on-site demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems. Shortly thereafter, an announcement was published in the *Federal Register* requesting water utilities interested in participating in Round 1 of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 out of 115 sites to host the demonstration studies.

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

In 2003, EPA initiated Round 2 arsenic technology demonstration projects that were partially funded with Congressional add-on funding to the EPA budget. In June 2003, EPA selected 32 potential demonstration sites. In September 2003, EPA again solicited proposals from engineering firms and vendors for arsenic removal technologies. EPA received 148 technical proposals for the 32 host sites, with each site receiving from two to eight proposals. In April 2004, another technical panel was convened by EPA to review the proposals and provide recommendations to EPA with the number of proposals per site ranging from none (for two sites) to a maximum of four. The final selection of the treatment technology at the sites that received at least one proposal was made, again, through a joint effort by EPA, the state regulators, and the host site. Since then, four sites have withdrawn from the demonstration program, reducing the number of sites to 28.

With additional funding from Congress, EPA selected 10 more sites for demonstration under Round 2a. Somewhat different from the Round 1 and Round 2 selection process, Battelle, under EPA's guidance, issued a Request for Proposal (RFP) on February 14, 2007, to solicit technology proposals from vendors and engineering firms. Upon closing of the RFP on April 13, 2007, Battelle received from 14 vendors a total of 44 proposals, which were reviewed by a three-expert technical review panel convened at EPA on May 2 and 3, 2007. Copies of the proposals and recommendations of the review panel were later provided to and discussed with representatives of the 10 host sites and state regulators in a technology selection meeting held at each host site during April through August 2007. The final selections of the treatment technology were made, again, through a joint effort by EPA, the respective state regulators, and the host sites. A 25-gal/min (gpm) AdEdge AD26/E33 hybrid modular treatment system was selected for demonstration at Clinton Christian School in Goshen, IN.

As of December 2010, 49 of the 50 systems were operational and the performance evaluations of 48 systems were completed.

1.2 Treatment Technologies for Arsenic Removal

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

1.3 Project Objectives

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

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

This report summarizes the performance of the AdEdge system at the Clinton Christian School in Goshen, IN, from May 1, 2008, through June 19, 2009. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and O&M cost.

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

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH (S.U.)
Northeast/Ohio							
Carmel, ME	Carmel Elementary School	RO	Norlen's Water	1,200 gpd	21	<25	7.9
Wales, ME	Springbrook Mobile Home Park	AM (A/I Complex)	ATS	14	38[a]	<25	8.6
Bow, NH	White Rock Water Company	AM (G2)	ADI	70[b]	39	<25	7.7
Goffstown, NH	Orchard Highlands Subdivision	AM (E33)	AdEdge	10	33	<25	6.9
Rollinsford, NH	Rollinsford Water/Sewer District	AM (E33)	AdEdge	100	36[a]	46	8.2
Dummerston, VT	Charette Mobile Home Park	AM (A/I Complex)	ATS	22	30	<25	7.9
Houghton, NY[c]	Town of Caneadea	IR (Macrolite)	Kinetico	550	27[a]	1,806[d]	7.6
Woodstock, CT	Woodstock Middle School	AM (Adsorbsia)	Siemens	17	21	<25	7.7
Pomfret, CT	Seely-Brown Village	AM (ArsenX^{np})	SolmeteX	15	25	<25	7.3
Felton, DE	Town of Felton	C/F (Macrolite)	Kinetico	375	30[a]	48	8.2
Stevensville, MD	Queen Anne's County	AM (E33)	STS	300	19[a]	270[d]	7.3
Conneaut Lake, PA	Conneaut Lake Park	IR (Greensand Plus) with ID	AdEdge	250	28[a]	157[d]	8.0
Newark, OH	Buckeye Lake Head Start Building	AM (ARM 200)	Kinetico	10	15[a]	1,312[d]	7.6
Springfield, OH	Chateau Estates Mobile Home Park	IR & AM (E33)	AdEdge	250[e]	25[a]	1,615[d]	7.3
Great Lakes/Interior Plains							
Brown City, MI	City of Brown City	AM (E33)	STS	640	14[a]	127[d]	7.3
Pentwater, MI	Village of Pentwater	IR (Macrolite) with ID	Kinetico	400	13[a]	466[d]	6.9
Sandusky, MI	City of Sandusky	IR (Aeralater)	Siemens	340[e]	16[a]	1,387[d]	6.9
Delavan, WI	Vintage on the Ponds	IR (Macrolite)	Kinetico	40	20[a]	1,499[d]	7.5
Goshen, IN	Clinton Christian School	IR & AM (E33)	AdEdge	25	29[a]	810[d]	7.4
Fountain City, IN	Northeaster Elementary School	IR (G2)	US Water	60	27[a]	1,547[d]	7.5
Waynesville, IL	Village of Waynesville	IR (Greensand Plus)	Peerless	96	32[a]	2,543[d]	7.1
Geneseo Hills, IL	Geneseo Hills Subdivision	AM (E33)	AdEdge	200	25[a]	248[d]	7.4
Greenville, WI	Town of Greenville	IR (Macrolite)	Kinetico	375	17[a]	7,827[d]	7.3
Climax, MN	City of Climax	IR (Macrolite) with ID	Kinetico	140	39[a]	546[d]	7.4
Sabin, MN	City of Sabin	IR (Macrolite)	Kinetico	250	34[a]	1,470[d]	7.3
Sauk Centre, MN	Big Sauk Lake Mobile Home Park	IR (Macrolite)	Kinetico	20	25[a]	3,078[d]	7.1
Stewart, MN	City of Stewart	IR &AM (E33)	AdEdge	250	42[a]	1,344[d]	7.7
Lidgerwood, ND	City of Lidgerwood	Process Modification	Kinetico	250	146[a]	1,325[d]	7.2
Lead, SD	Terry Trojan Water District	AM (ArsenX^{np})	SolmeteX	75	24	<25	7.3

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

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality As (µg/L)	Fe (µg/L)	pH (S.U.)
Midwest/Southwest							
Willard, UT	Hot Springs Mobile Home Park	IR & AM (Adsorbsia)	Filter Tech	30	15.4[(a)]	332[(d)]	7.5
Arnaudville, LA	United Water Systems	IR (Macrolite)	Kinetico	770[(e)]	35[(a)]	2,068[(d)]	7.0
Alvin, TX	Oak Manor Municipal Utility District	AM (E33)	STS	150	19[(a)]	95	7.8
Bruni, TX	Webb Consolidated Independent School District	AM (E33)	AdEdge	40	56[(a)]	<25	8.0
Wellman, TX	City of Wellman	AM (E33)	AdEdge	100	45	<25	7.7
Anthony, NM	Desert Sands Mutual Domestic Water Consumers Association	AM (E33)	STS	320	23[(a)]	39	7.7
Nambe Pueblo, NM	Nambe Pueblo Tribe	AM (E33)	AdEdge	145	33	<25	8.5
Taos, NM	Town of Taos	AM (E33)	STS	450	14	59	9.5
Rimrock, AZ	Arizona Water Company	AM (E33)	AdEdge	90[(b)]	50	170	7.2
Tohono O'odham Nation, AZ	Tohono O'odham Utility Authority	AM (E33)	AdEdge	50	32	<25	8.2
Valley Vista, AZ	Arizona Water Company	AM (AAFS50/ARM 200)	Kinetico	37	41	<25	7.8
Far West							
Three Forks, MT	City of Three Forks	C/F (Macrolite)	Kinetico	250	64	<25	7.5
Fruitland, ID	City of Fruitland	IX (A300E)	Kinetico	250	44	<25	7.4
Homedale, ID	Sunset Ranch Development	POU RO[(f)]	Kinetico	75 gpd	52	134	7.5
Okanogan, WA	City of Okanogan	C/F (Electromedia-I)	Filtronics	750	18	69[(d)]	8.0
Klamath Falls, OR	Oregon Institute of Technology	POE AM (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)	Siemens	350	39	<25	7.4
Susanville, CA	Richmond School District	AM (A/I Complex)	ATS	12	37[(a)]	125	7.5
Lake Isabella, CA	Upper Bodfish Well CH2-A	AM (HIX)	VEETech	50	35	125	7.5
Tehachapi, CA	Golden Hills Community Service District	AM (Isolux)	MEI	150	15	<25	6.9

AM = adsorptive media process; C/F = coagulation/filtration; HIX = hybrid ion exchanger; IR = iron removal; IR with ID = iron removal with iron addition; IX = ion exchange process; RO = reverse osmosis

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

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

(b) Design flowrate reduced by 50% due to system reconfiguration from parallel to series operation.

(c) Withdrew from program in 2007. Selected originally to replace Village of Lyman, NE site, which withdrew from program in June 2006.

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

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

(f) Including nine residential units.

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

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

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

(a) OIT site at Klamath Falls, OR had three AM systems and eight POU AM units.
(b) Including nine under-the-sink RO units.

2.0 SUMMARY AND CONCLUSIONS

Based on the information collected during the 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:

- Chlorine was effective in oxidizing As(III) and Fe(II) and forming arsenic-laden iron particles.
- AD26 media was capable of removing the arsenic-laden particles formed, reducing arsenic and iron concentrations to <5.0 and <25 μg/L, respectively, presumably via filtration.
- AD26 media was effective in removing both particulate (53%) and soluble manganese (47%), reducing its concentrations from an average of 79.5 μg/L (after chlorination) to 1.1 μg/L.
- Backwashing once every 72 hr was adequate, resulting in no iron particle breakthrough from the AD26 media beds. This backwash frequency allowed an average system run time of 5.7 hr when the school was in session or 4.5 hr when the school was not in session.

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.

Process residuals produced by the technology:

- Residuals produced by the operation of the treatment system consisted of only backwash wastewater.
- Assuming an average of 10 mg/L of total suspended solids (TSS) in 56,810 gal of wastewater produced by backwashing the three AD26 vessels in one year, approximately 4.7 lb of solids would be discharged annually. The solids were composed of 0.039, 1.5, and 0.21 lb of arsenic, iron, and manganese, respectively.

Capital and O&M cost of the technology:

- The unit capital cost was $0.39/1,000 gal of water treated if the system operated at a 100% utilization rate. The system's real unit cost was $10.12/1,000 gal, based on 517,000 gal of water production (i.e., about 4% utilization).

3.0 MATERIALS AND METHODS

3.1 General Project Approach

Following the predemonstration activities summarized in Table 3-1, the performance evaluation study of AdEdge's AD26/E33 arsenic removal system began on May 1, 2008, and ended on June 19, 2009. 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, as described in the Study Plan (Battelle, 2008). The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement. The plant operator recorded unscheduled downtime and repair information on a Repair and Maintenance Log Sheet.

Table 3-1. Predemonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	September 27, 2006
Technology Selection Meeting Held	May 11, 2007
Project Planning Meeting Held	June 13th 2007
Draft Letter of Understanding Issued	June 21, 2007
Final Letter of Understanding Issued	July 3, 2007
Request for Quotation Issued to Vendor	August 13, 2007
Vendor Quotation Received by Battelle	August 31, 2007
Purchase Order Completed and Signed	September 18, 2007
Engineering Package Submitted to IDEM	November 19, 2007
Permit Issued by IDEM	January 10, 2008
Equipment Arrived at Site	February 6, 2008
System Installation and Shakedown Completed	February 27, 2008
Final Study Plan Issued	April 15, 2008
Performance Evaluation Begun	June 6, 2008
Discharge Permit Obtained	September 23, 2008

IDEM = Indiana Department of Environmental Management

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

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

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

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

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

3.2 System O&M and Cost Data Collection

The plant operator performed daily, biweekly, and monthly system O&M and data collection according to instructions provided by the vendor and Battelle. On a regular basis, the plant operator recorded system operational data such as pressure, flowrate, totalizer, and hour meter readings on a System Operation Log Sheet and conducted visual inspections to ensure normal system operations. If any problems occurred, the plant operator contacted the Battelle Study Lead, who determined if the vendor should be contacted for troubleshooting. The plant operator recorded all relevant information, including the problems encountered, course of actions taken, materials and supplies used, and associated cost and labor incurred on the Repair and Maintenance Log Sheet. Occasionally, the plant operator also measured temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and chlorine residuals and recorded the data on an Onsite Water Quality Parameters Log Sheet.

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

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected from the wellheads, across the 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, 2007). The procedure for arsenic speciation is described in Appendix A of the QAPP.

3.3.1 Source Water. During the initial site visit on September 27, 2006, one set of source water samples from Well No. 1 was collected and speciated using an arsenic specitation kit (see Section 3.4.1). 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 water samples across the treatment train once every one to four weeks. In general, sampling alternated between regular and speciation sampling. Regular sampling involved taking samples at the wellhead (IN), after chlorination (AC), after oxidation/filtration vessels (OT), and after adsorption vessels (TT) and having them analyzed for the analytes listed under regular sampling in Table 3-3. Speciation sampling involved collecting and speciating samples at the same four locations onsite and having them analyzed for the analytes listed under speciation sampling in Table 3-3.

3.3.3 Backwash Wastewater and Solids. The plant operator collected backwash wastewater samples from each oxidation/filtration vessel on 10 occasions. Over the duration of backwash for each vessel, a side stream of backwash wastewater 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 1-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.

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

3.3.5 Distribution System Water. Water samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically, the arsenic, lead and copper levels. Prior to the system startup from February 7 to 23, 2008, four sets of baseline distribution system water samples were collected at the bathroom sink, which was one of the Lead and Copper Rule (LCR) locations used by the school for LCR sampling. Following system startup, distribution system sampling continued periodically at the same sampling location.

The plant operator collected the samples following an instruction sheet developed in accordance with the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The date and time of last water usage before samploing and of acutual sample collection were recorded for calculation of stagnation time. All samples were collected from a cold-water faucet that had not been used for at least 6 hr to ensure that stagnant water was sampled.

3.4 Sampling Logistics

3.4.1 Preparation of Arsenic Speciation Kits. The arsenic field speciation method used an anion exchange resin column to separate the soluble arsenic species, As(V) and As(III) (Edwards et al., 1998). Resin columns were prepared in batches at Battelle laboratories in accordance with the procedures detailed in Appendix A of the EPA-endorsed QAPP (Battelle, 2007).

Table 3-3. Sampling Schedule and Analytes

Sample Type	Sample Locations[a]	No. of Samples	Frequency	Analytes	Sampling Date
Source Water	IN	1	Once (during initial site visit)	Onsite: pH, temperature, DO, and ORP Offsite: As (III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), Sb (total and soluble), V (total and soluble), Na, Ca, Mg, Al, Cl, F, NO_3, NO_2, NH_3, SO_4, SiO_2, PO_4, P, turbidity, alkalinity, TDS, and TOC	09/27/06 and 06/17/05
Treatment Plant Water	IN, AC, OT, and TT	4	Speciation sampling	Onsite: pH, temperature, DO, ORP, and/or total and free Cl_2 (except for IN) Offsite: As(III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), Ca, Mg, F, NO_3, NH_3, SO_4, SiO_2, P, turbidity, and alkalinity	6/6/2008[b], 08/20/08, 10/09/08, 11/19/08, 01/08/09, 02/04/09, 03/04/09, 03/31/09, 04/29/09, 06/04/09, 07/01/09, 07/28/09, 09/15/09
			Regular sampling	Onsite: Same as above Offsite: As (total), Fe (total), Mn (total), NH_3, SiO_2, P, turbidity, and alkalinity	06/27/08, 08/13/08, 09/14/08, 11/06/08, 12/09/08, 01/22/09, 02/18/09, 03/19/09, 04/15/09, 05/14/09, 06/10/09
Distribution System Water[c]	Tap in school (DS)	1	Varying	Total As, Fe, Mn, Cu, and Pb, pH, and alkalinity	02/07/08, 02/13/08, 02/21/08, 02/23/08, 06/18/08, 09/14/08, 10/30/08, 11/12/08, 12/18/08, 01/22/09, 03/19/09, 04/15/09, 05/14/09, 06/10/09, 07/28/09, 09/15/09
Backwash Water	Backwash discharge line (BW)	2	Varying	pH, TDS, TSS, turbidity, As (total and soluble), Fe (total and soluble), and Mn (total and soluble)	10/02/08, 12/18/08, 01/22/09, 02/18/09, 03/18/09, 04/15/09, 05/14/09, 06/10/09, 07/28/09, 09/15/09
Backwash Solids	Wastewater container	2	Once	Al, As, Ba, Ca, Cd, Cu, Fe, Mg, Mn, Ni, P, Pb, Si, Zn	12/18/08

(a) Abbreviations in parenthesis corresponding to sample locations shown in Figure 4-6, i.e., AC = after chlorination; BW = backwash discharge line; DS = distribution system; IN = at wellhead; OT = after oxidation/filtration vessels; TT = after adsorption vessels.
(b) Sample taken at IN, OT and TT locations. Sample tap was not yet installed at AC.
(c) Four baseline sampling events taking place in February 2009 before system startup.
DO = dissolved oxygen; ORP = oxidation-reduction potential; TDS = total dissolved solids; TOC = total organic carbon; TSS = total suspended solids

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

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

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

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

3.5 Analytical Procedures

The analytical procedures described in detail in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2007) were followed by Battelle's ICP-MS laboratory and AAL. Laboratory quality assurance/quality control (QA/QC) of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection limits (MDL), and completeness met the criteria established in the QAPP (i.e., relative percent difference [RPD] of 20%, percent recovery of 80 to 120%, and completeness of 80%). The QA data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project.

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

4.0 RESULTS AND DISCUSSION

4.1 Facility Description and Pre-existing Treatment System Infrastructure

Clinton Christian School is located at 61763 County Road 35 in Goshen, IN. Figure 4-1 shows the location of the school in relation to downtown Goshen, IN. The non-transient, non-community water system at the school supplied water to approximately 130 students and 12 staff members during the academic year. The water system was supplied by a single well, i.e., Well No. 1, which was 4-in in diameter and 166 ft deep. The well was equipped with a Myers 1.5-horsepower (hp) submersible pump set at a depth of 145 ft below ground surface (bgs). Based on the pump curve shown in Figure 4-2, the pump yielded an average production rate of 18 gpm and a maximum production rate of 25 gpm. After installing a totalizer/ flow meter and an hour meter at the wellhead, Hawkins Water Tech, Inc., a local contractor subcontracted to AdEdge, took a series of readings to confirm pump flowrates from August 17 through 24, 2007. Table 4-1 summarizes the results. Instantaneous flowrates recorded from the flow meter ranged from 10.7 to 19.5 gpm and averaged 16.9 gpm, comparable to those (i.e., 7.5 to 20.1 gpm) calculated based on wellhead totalizer and corresponding hour meter readings. These flowrate readings were within the maximum flowrate of 25 gpm while maintaining a wellhead pressure of 20 lb/in^2 (psi). The well turned on and off by a hydopneumatic tank, which was set to operate between 40 and 70 psi. According to the engineering report prepared by LJB Inc., the well had an average daily flow of 1,155 gal/day (gpd) and a weekday average flow of 1,620 gpd (LJB Inc., 2007).

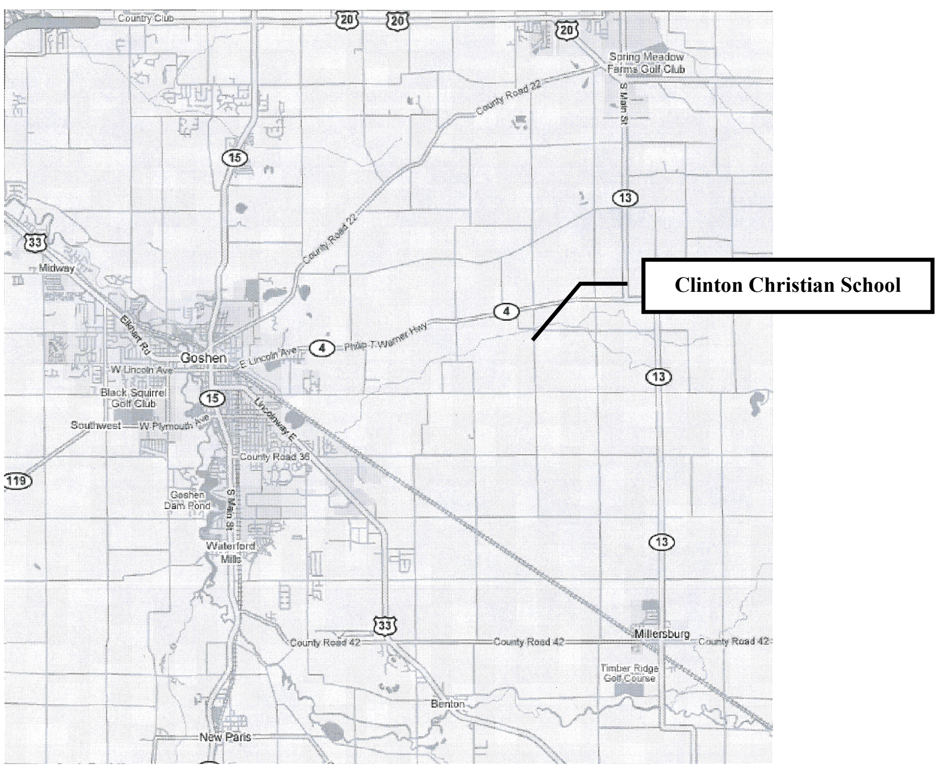


Figure 4.1. Clinton Christian School Location (LJB Inc., 2007)

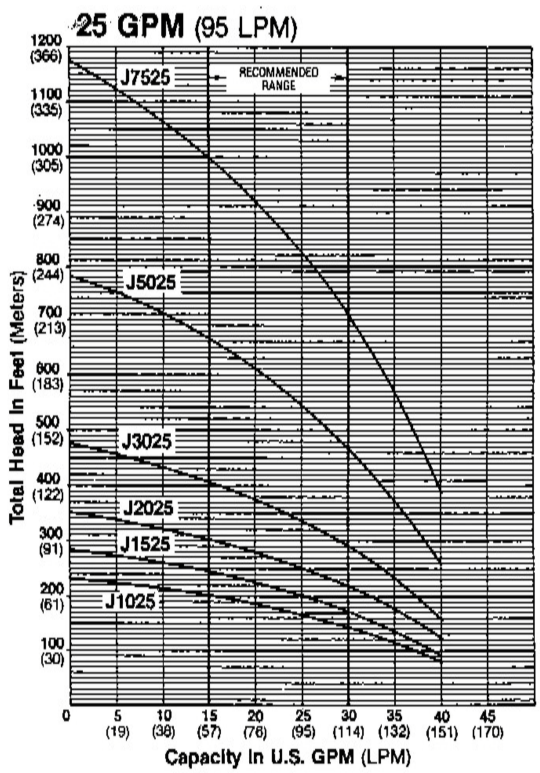


Figure 4-2. Myers Model J1525 Submersible Pump Curve

Table 4-1. Flowrate Data Collected by Hawkins Water Tech, Inc., in August 2007

	Cumulative Totalizer Reading	Cumulative Hour Meter Reading	Calculated Flowrate (gpm)	Instantaneous Flowrate (gpm)	Influent Pressure (psi)
1	2,244	NA	NA	16.8	44.0
2	3,185	NA	NA	10.7	71.0
3	8,960	4.8	20.1	14.6	58.0
4	10,823	6.9	14.8	17.0	54.0
5	13,308	9.7	14.8	18.5	46.0
6	13,647	10.5	7.5	17.8	51.0
7	14,012	10.9	14.8	19.5	49.0
8	14,487	NA	NA	18.9	50.0
9	15,407	1.2	12.9	18.6	48.0

NA = Not Available

Prior to the new boiler room construction and repiping for this project, raw water was piped from the supply well to four 20-gal steel bladder tanks in the school's old boiler room. Figure 4-3 is a photograph of the boiler room that housed the piping and water system equipment. Figure 4-4 is a photograph of the old bladder tanks. Following the bladder tanks, water was divided into two streams, each for cold or hot water distribution. The stream dedicated for hot water distribution was treated with a water softener prior to heating.

Figure 4-3. Pre-existing Boiler Room that Housed Piping and Water System Equipment

Figure 4-4. Pre-existing Water System Bladder Tanks

4.1.1 Source Water Quality. Source water samples were collected on September 27, 2006, when a Battelle staff member traveled with EPA to the site for an introductory meeting for this demonstration project. Table 4-2 presents the analytical results along with the data provided by EPA and Indiana Department of Environmental Management (IDEM). Overall, Battelle's data are comparable to those provided by EPA and IDEM.

Arsenic. Total arsenic concentrations of source water ranged from 21.0 to 28.7 µg/L. Based on the speciation results obtained by Battelle on September 27, 2006, of the 28.7 µg/L total arsenic, 14.7 µg/L existed as As(III) and 11.6 µg/L as As(V). Therefore, chlorination was needed to oxidize As(III) to As(V) for more effective arsenic removal.

Table 4-2. Clinton Christian School Source Water Data

Parameter	Unit	EPA Data		Battelle Data	IDEM Data
Date		05/08/06	09/27/06		06/17/05
pH	S.U.	NA	NA	7.4	NA
Temperature	°C	NA	NA	17.0	NA
DO	mg/L	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA
Total Alkalinity (as $CaCO_3$)	mg/L	273	NA	291	270
Total Hardness (as $CaCO_3$)	mg/L	256	255	255	291
Turbidity	NTU	NA	NA	5.3	NA
Total Dissolved Solids	mg/L	NA	NA	274	NA
Total Organic Carbon	mg/L	NA	NA	<1.0	0.773
Nitrate (as N)	mg/L	0.02	NA	<0.05	NA
Nitrite (as N)	mg/L	<0.01	NA	<0.05	NA
Ammonia (as N)	mg/L	0.2	NA	0.2	NA
Chloride	mg/L	NA	NA	6	2.8
Fluoride	mg/L	NA	NA	0.2	NA
Sulfate	mg/L	2.0	2.1	2.0	5.0
Silica (as SiO_2)	mg/L	18.4	18.0	18.1	18
Orthophosphate (as PO_4)	mg/L	<0.005	NA	<0.1	NA
P (total)	mg/L	<0.2	<0.2	<0.03	0.05
Al (total)	µg/L	<25	<25	NA	NA
As (total)	µg/L	24.0	21.0	28.7	24.2
As (soluble)	µg/L	NA	NA	26.3	NA
As (particulate)	µg/L	NA	NA	2.4	NA
As(III)	µg/L	NA	NA	14.7	9.2
As(V)	µg/L	NA	NA	11.6	15.0
Fe (total)	µg/L	800	807	810	1,300
Fe (soluble)	µg/L	NA	NA	758	NA
Mn (total)	µg/L	90.0	92.4	95.4	92
Mn (soluble)	µg/L	NA	NA	97.4	NA
Sb (total)	µg/L	<25	<25	NA	NA
V (total)	µg/L	NA	NA	<0.1	NA
V (soluble)	µg/L	NA	NA	<0.1	NA
Na (total)	mg/L	8.1	8.1	8.0	NA
Ca (total)	mg/L	65.4	65.7	63.4	NA
Mg (total)	mg/L	22.5	22.2	23.4	NA

IDEM = Indiana Department of Environmental Management; NA = not available

Ammonia. The presence of 0.2 mg/L of NH_3 (as N) in raw water, as shown by the data collected by EPA on May 8, 2006, and by Battelle on September 27, 2006, would consume chlorine especially if breakpoint chlorination was required. The IDEM rule requires at least 0.2 mg/L of free chlorine (as Cl_2) in the treated water. To reach breakpoint, approximately 1.5 mg/L of chlorine (as Cl_2) was needed to react with 0.2 mg/L of NH_3 (as N).

Iron and Manganese. Battelle's speciation results indicated that, out of 810 μg/L of iron measured (which is significantly over the 300-μg/L secondary maximum contaminant level [SMCL]), 758 μg/L (or 94%) existed as soluble iron, which is about 29 times the soluble arsenic level at 26.3 μg/L. EPA's May 8 and September 27, 2006, sampling results also showed 800 and 807 μg/L of total iron in raw water, respectively, which are very close to Battelle's results. The presence of soluble iron in raw water helps remove arsenic once an oxidant, such as chlorine, is introduced to raw water. The use of chlorination prior to AD26 media oxidizes and precipitates iron, enabling removal of arsenic-laden iron solids via filtration through AD26 media. It is important to note that, when using chlorine, total chlorine residuals must be controlled to <1 mg/L (as Cl_2) to minimize any adverse effect on the resin in the softener units, which are located downstream in the new wing of the school building.

Manganese concentrations of 92.4 and 95.4 μg/L obtained on September 27, 2006 by EPA and Battelle, respectively, also exceeded the SMCL of 50 μg/L. Manganese concentrations at these levels could impact performance of adsorptive media.

Competing Anions. Adsorptive media potentially can be affected by competing anions such as silica and phosphate. Based on the results shown in Table 4-2, concentrations of silica (18.0-18.4 mg/L) and phosphate (less than the MDL) in raw water do not appear to be high enough to impact the IR and adsorption process.

Other Water Quality Parameters. Battelle's data indicate a pH value of 7.4, which is within the commonly-agreed target range of 5.5 to 8.5 for arsenic removal via IR and adsorption. Total hardness concentrations ranged from 255 to 291 mg/L (as $CaCO_3$); turbidity was 5.3 nephelometric turbidity unit (NTU); total dissolved solids (TDS) was 274 mg/L; nitrate ranged from less than the MDL to 0.02 mg/L; and sodium ranged from 8.0 to 8.1 mg/L. All other analytes were below MDLs and/or anticipated to be low enough to not adversely affect the arsenic removal process.

4.1.2 Predemonstration Treated Water Quality. As shown in Table 4-3, the treated water quality for samples taken by IDEM was similar to raw water quality except for the slightly lower arsenic levels in treated water. Treated water samples were not collected by Battelle or EPA at the time of source water sampling.

Table 4-3. Clinton Christian School Historic Water Quality Data (1993 to 2006)

Parameter	Unit	Well No. 1								
Sampling Date		09/20/93	10/23/96	05/25/99	03/11/03	05/20/03	03/20/06	05/01/06	07/10/06	10/16/06
Nitrate[(a)]	mg/L	0.1	NS	0.2	NS	0.2	NS	<0.1	NS	NS
Nitrite[(a)]	mg/L	0.1	NS	NS	NS	NS	NS	NS	NS	NS
Fluoride	mg/L	0.26	NS	NS	NS	NS	0.23	NS	NS	NS
Arsenic	μg/L	22.0	21.2	22.3	26.0	NS	20.0	17.0	23.0	20.0
Antimony	μg/L	<5	NS	NS	NS	NS	<5	NS	NS	NS

Source: IDEM
NS = not sampled
(a) as N.

4.1.3 Distribution System. Based on the information provided by the facility, the distribution system material was comprised of galvanized, copper, and polyvinyl chloride (PVC) piping. The pipe material between the supply well and the boiler room was galvanized piping. The pipe material within the boiler room and of the distribution system was copper and PVC, respectively.

For compliance purposes, Clinton Christian School periodically samples water for several parameters. Raw water samples are collected quarterly for arsenic; yearly for nitrate; once every three years for cyanide, volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs). Distribution system water samples are collected once every three years under the LCR; and once every nine years for asbestos.

4.2 Treatment Process Description

This section provides a general technology description and site-specific details on the AD26/E33 modular arsenic removal system for arsenic, iron, and manganese removal.

4.2.1 Technology Description. The AD26/E33 system consisted of three parallel AD26 oxidation/filtration vessels and two parallel E33 adsorption vessels. AD26 was designed to remove iron and manganese prior to E33 arsenic adsorption. Because chlorine was added prior to AD26, some arsenic was removed along with precipitated iron solids via filtration across AD26, leaving remaining soluble As(V) to be further treated by E33.

The treatment system was a fixed-bed, downflow system. Groundwater was pumped from the wellhead and oxidized with chlorine added in the form of liquid sodium hypochlorite (NaOCl). Chlorinated water then flowed through the AD26 vessels, which removed arsenic-laden iron solids and, perhaps, manganese. The filtered water flowed through the E33 vessels where the remaining arsenic, existing primarily as soluble As(V), was removed before entering the distribution system. Both AD26 and E33 vessels needed to be backwashed regularly. The backwash wastewater was filtered through bag filters before being discharged to Rock Run Creek.

4.2.2 AD26 Media. AD26 media is a manganese dioxide granular media that oxidizes and filters out iron and manganese. This process is enhanced by chlorination, which oxidizes and precipitates As(III), Fe(II), and, possibly, Mn(II). Once precipitated, solids are filtered out by the media. After reaching a set differential pressure, solids accumulated in the media beds are removed via backwashing. AD26 media has NSF International (NSF)-61 approval for use in drinking water applications. Table 4-4 provides the physical properties of AD26 media.

4.2.3 E33 Media. Bayoxide E33 is an iron-based adsorptive media developed by Lanxess (formerly Bayer AG) for removal of arsenic from drinking water. E33 media has NSF-61 approval for use in drinking water applications. Table 4-5 provides the physical properties of E33 media.

4.2.4 System Design and Treatment Process The treatment processes at Clinton Christian School included prechlorination, AD26 oxidation/filtration, and E33 adsorption. Figure 4-5 shows the piping and instrumentation diagram (P&ID) of the system. Table 4-6 specifies the key system design parameters of the treatment system. Figure 4-6 presents a process flowchart, along with the sampling/analysis schedule, for the system.

Table 4-4. Properties of AD26 Media

Property	Value
Physical Form and Appearance	Black, dry granular media 
Matrix	Manganese dioxide (>80% active ingredient)
Bulk Density (lb/ft^3)	125
Moisture Content (% by wt.)	< 0.5
Particle Size Distribution (U.S. standard mesh)	20 × 40
Effective Size	0.40
Uniformity Coefficient	1.54
Specific Gravity (g/cm^3)	3.8
Oxidant	NaOCl (12.5%)
Operating pH Range	6–9
Operating Flowrate (gpm)	8–15

Source: AdEdge Technologies, Inc.

Table 4-5. Properties of E33 Media

Property	Value
Physical Form and Appearance	Amber, dry granular media 
Matrix	Iron oxide composite
Bulk Density (lb/ft^3)	28
Moisture Content (%)	<15% by weight
Base Polymer	Macroporous polystyrene
Particle Size Distribution (U.S. standard mesh)	10 × 35
Crystal Size (Å)	70
Crystal Phase	α-FeOOH

Source: Bayer AG

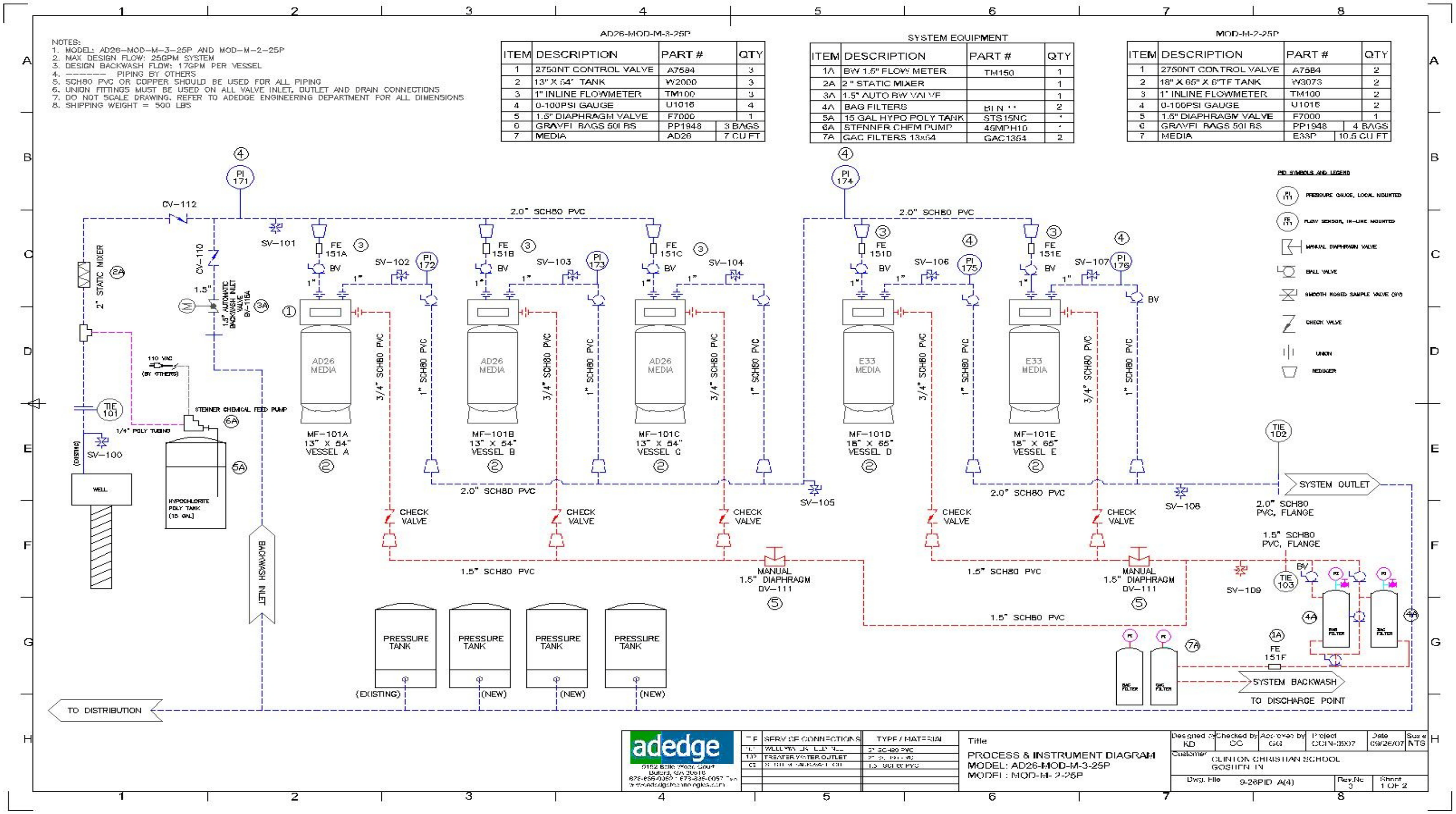


Figure 4-5. P&ID of AD26/E33 Arsenic Removal System at Clinton Christian School

Table 4-6. Design Features of AD26/E33 Arsenic Removal System

Parameter	Value	Remarks
Influent Specifications		
Design Peak Flowrate (gpm)	25	–
Arsenic Concentration (μg/L)	28.7	Based on 09/27/06 source water results
Iron Concentration (μg/L)	810	Based on 09/27/06 source water results
Manganese Concentration (μg/L)	95.4	Based on 09/27/06 source water results
Pretreatment		
NaOCl Strength (%)	12.5	
NaOCl Dosage (mg/L [as Cl_2])	2.4	–
Estimated Chlorine Usage (gph [gpy])	0.03 [13.7]	Based on a design flowrate of 25 gpm, a dosage of 2.4 mg/L (as Cl_2), a NaOCl solution strength of 12.5%, and a daily operating time of 1.3 hr/day
AD26 Oxidation/Filtration Unit		
No. of Vessels	3	–
Configuration	Parallel	–
Vessel Size (in)	13 D × 54 H	–
Vessel Cross-sectional Area (ft^2)	0.9	–
Media Volume (ft^3/tank)	2.3	6.9 ft^3 total media volume in 3 vessels
Media Depth (in)	30	–
Hydraulic Loading Rate (gpm/ft^2)	9.0	Based on 8.3 gpm/tank flowrate
EBCT (min/vessel)	2.1	–
Differential Pressure across Clean Bed (psi/vessel)	3	Vendor specified
Backwash Flowrate (gpm)	18.4	At 20 gpm/ft^2 backwash rate
Backwash Duration (min)	12	–
Fast Rinse Duration (min)	2	At 12 gpm flowrate
Backwash Frequency (day)	2–4	–
E33 Adsorption Unit		
No. of Vessels	2	–
Configuration	Parallel	–
Vessel Size (in)	18 D × 65 H	–
Vessel Cross-sectional Area (ft^2)	1.8	–
Media Volume (ft^3/vessel)	5.25	10.5 ft^3 total media volume in 2 vessels
Media Depth (in)	35	–
Hydraulic Loading Rate (gpm/ft^2)	7.1	Based on 12.5gpm/vessel flowrate
EBCT (min/vessel)	3.1	–
Differential Pressure across Clean Bed (psi/tank)	2–3	Vendor specified
Backwash Flowrate (gpm)	16	At 8.9 gpm/ft^2 backwash rate
Backwash Duration (min)	13	–
Fast Rinse Duration (min)	2	At 11 gpm flowrate
Backwash Frequency (day)	45–60	–
Effluent Specifications		
Arsenic Concentration (μg/L)	<10	–
Iron Concentration (μg/L)	<25	–
Manganese Concentration (μg/L)	<0.1	–
Average Daily Production (gpd)	2,000	Based on average throughput during school year
Daily System Operation (hr/day)	1.3	Based on 25 gpm flowrate
Hydraulic Utilization (%)	5.6	Typical system operation of 1.3 hr/day
Throughput to 10-μg/L As Breakthrough (gal)	6,366,060	Vendor estimate
Throughput for Three AD26 Vessels (BV/day)	38.8	Based on 2,000 gpd water usage
Projected AD26 Media Run Length (BV)	123,763	Based on 6,366,060 gal of throughput and 51.6 gal for 3 vessels
Projected AD26 Media Life (years)	8.7	Based on 38.8 BV treated/day
Throughput for Two E33 Vessels (BV/day)	25.5	Based on 2,000 gpd water usage
Projected E33 Media Run Length to 10-μg/L As Breakthrough (BV)	81,055	Based on 6,366,060 gal to breakthrough and 78.5 gal for 2 tanks
Projected E33 Media Life (years)	8.7	Based on 81,055 BV to breakthrough and 25.5 BV treated/day

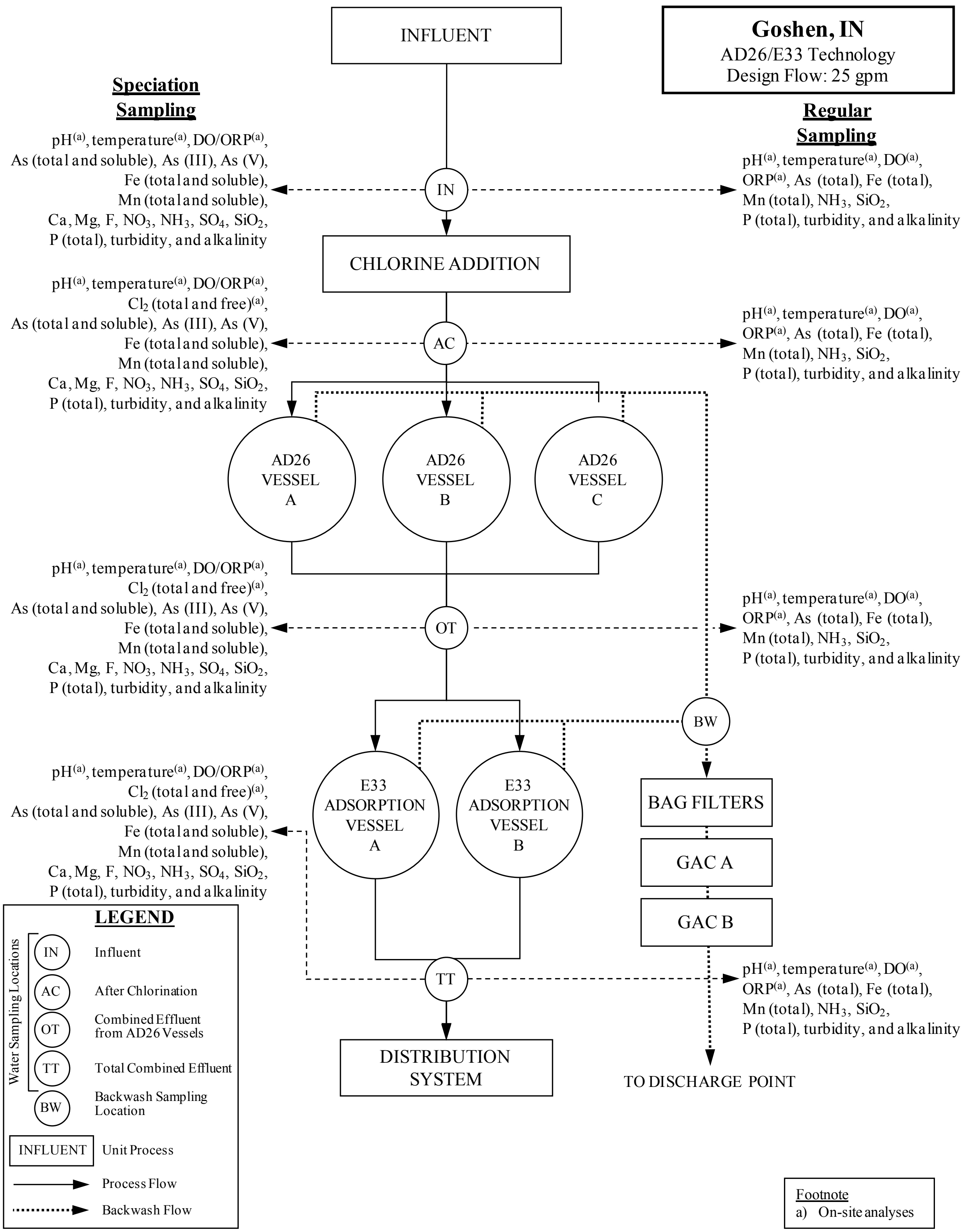


Figure 4-6. Process Flow Diagram

- **Intake** – Raw water pumped from Well No. 1 was fed to the treatment system via a 2-in PVC pipe to a tie-in point, where connection was made to the system piping.

- **Prechlorination/Oxidation** – Chlorine was added prior to the AD26/E33 arsenic treatment system to oxidize As(III) to As(V) and Fe(II) to Fe(III). The chlorine addition system (Figure 4-7) consisted of a Stenner single-head peristaltic pump (Model No. 45 MHP10*45M2) with a maximum capacity of 0.13 gal/hr (gph) or 0.48 L/hr (lph), a chlorine injection tap, a 15-gal polyethylene chemical feed tank (containing a 12.5% NaOCl solution), a 1.5-in in-line mixer, and a control relay box for chlorine pump control. Chlorine addition was synchronized with the well pump.

Figure 4-7. Chlorine Addition System

The chlorine dosage required was estimated to be 2.4 mg/L (of Cl_2) based on concentrations of As(III), Fe(II), Mn(II), and NH_3 in source water. To reach "breakpoint" chlorination, 1.5 mg/L of chlorine (as Cl_2) was needed to react with 0.2 mg/L of NH_3 (as N). An additional 0.7 mg/L of chlorine (as Cl_2) was needed to meet the chlorine demand for reducing species, such as As(III), Fe(II), and Mn(II). Further, the IDEM rule required at least 0.2 mg/L of free chlorine (as Cl_2) in the treated water. The actual target chlorine dosage was determined during system startup and adjusted manually on pump settings. Proper operation of the chlorine feed system was tracked through tank level measurements.

To meet the 0.2 mg/L (as Cl_2) free chlorine requirement, water system operators are required to test for total and free chlorine residuals daily on days when the system is in operation.

The results obtained are recorded on a Monthly Report of Operations, which must be submitted monthly to IDEM's Drinking Water Branch.

To minimize any adverse effect on the resin in the softener units located downstream in the new wing of the school building, the total chlorine residual level must not exceed 1 mg/L (as Cl_2).

- **AD26 Oxidation/Filtration** – The AD26 oxidation/filtration unit consisted of three parallel, 13-in × 54-in composite vessels, each containing 2.3 ft^3 of AD26 media supported by 47 lb of quartz gravel underbedding (with a size distribution of ⅛-in × 1/16-in and a bulk density of 100 lb/ft^3). Three smaller vessels (compared to the dimensions of E33 vessels) were selected to allow enough flow from the pressure tanks to lift the heavy AD26 media during backwash. The quartz gravel was placed over the lower hub and lateral system below the oxidizing media. The vessels had a 4-in threaded opening at the top for loading media and accessing tank intervals. The flow entered the top of the vessels through a 1.5-in diameter header (Figure 4-8). When water reached the tank bottom and screened laterals, it flowed up through a center riser tube back to the top of the valve before exiting the AD26 module.

Figure 4-8. Headers, Fleck Controllers, and Piping/Valves on AD26 Vessels

Based on a design flowrate of 25 gpm, the empty bed contact time (EBCT) for each tank was about 2.1 min and the hydraulic loading rate to each vessel was 9.0 gpm/ft^2. The anticipated pressure drop across each tank for a clean bed was approximately 3 psi. Standard operation had three vessels online running parallel, treating a total flow of 25 gpm. The flow through each vessel was regulated to about 8.3 gpm by an outlet valve after each vessel. Each vessel also had a Fleck 2750 automatic controller with a side-mounted 3200NT timer for setting backwash. The piping used for the system was Schedule 80 PVC.

- **E33 Adsorption** – The E33 adsorption unit consisted of two parallel, 18-in × 65-in composite vessels, each containing 5.25 ft^3 of E33 media supported by 80 lb of quartz gravel underbedding (with a size distribution of ¼-in × ⅛-in and a bulk density of 100 lb/ft). The quartz gravel was placed over the lower hub and lateral system below the adsorption media. The vessels had a 4-in threaded opening at the top for loading media and accessing tank intervals. The flow entered the top of the vessels through a 1.5-in diameter header. When water reached the vessel bottom and screened laterals, it flowed up through a center riser tube back to the top of the valve before exiting the E33 module.

  Based on a design flowrate of 25 gpm, the EBCT for each tank was 3.1 min. The anticipated pressure drop across each train was approximately 2 to 3 psi. Standard operation had two vessels online running parallel, treating a total flow of 25 gpm. The flow through each tank was regulated to about 12.5 gpm by an outlet valve after each vessel. In addition, each vessel had a Fleck 2750 automatic controller with a side-mounted 3200NT timer for setting backwash. The piping used for the unit was Schedule 80 PVC. Figure 4-9 shows Fleck controllers and associated piping/valves connected from AD26 vessels to E33 vessels.

Figure 4-9. Fleck Controllers and Piping/Valves Connected to One AD26 (left) and One E33 (right) Vessel

- **Pressure Tanks** – The treatment system was equipped with three newly installed and one pre-existing 119-gal ProFlo PF119 pressure tanks (Figure 4-10) prior to entering the distribution system. The pressure tanks operated with low- and high-pressure triggers at 40 and 60 psi, respectively, such that when the pressure fell below 40 psi, the well pump was turned on and when the pressure reached 60 psi, the well pump was turned off. In addition to supplying treated water to the distribution system, the pressure tanks also provided needed capacities for backwashing the AD26 and E33 vessels, i.e., 220 gal per AD26 vessel and 208 gal per E33 vessel (see more detailed discussions under Filter Backwash Operation below).

Figure 4-10. ProFlo PF119 Pressure Tanks

- **Filter Backwash Operation** – All AD26 and E33 vessels required backwashing to remove particles and fluff the media beds to minimize channeling. Backwashing was initiated either by pre-setting the time (in days) between backwashes or by manually pressing the recycle button for 3 sec on the 3200NT display. The vendor recommended that the AD26 vessels be backwashed once every 2 to 4 days and the E33 vessels once every 45 to 60 days. Backwashing for each vessel lasted for either 12 (AD26) or 13 min (E33), followed by 2-min of forward rinse. Upon completion, the vessels were put online for normal operation. Table 4-7 summarizes backwash settings and amounts of wastewater generated.

  The three AD26 vessels were backwashed once every 3 days with backwashing of the first vessel initiated at 12 a.m. and the second and third vessels at 1 and 2 a.m., respectively. The 1-hr lag time between two consecutive backwashes allowed the four pressure tanks to be refilled, such that sufficient treated water might be drawn from the pressure tanks during each

Table 4-7. Backwash Settings and Wastewater Production

Parameter	*AD26*	*E33*
Initiating Pressure (psi)	6–7	6–7
Initiating Standby Time (days)	2–4	45–60
Number of Tanks for Backwash	3	2
Hydraulic Loading (gpm/ft^2)	20	9
Backwash Flowrate (gpm)	18.4	16.0
Backwash Duration (min)	12	13
Fast Rinse Flowrate (gpm)	12	11
Fast Rinse Duration (min)	2	2
Wastewater Production (gal/tank)	245	230
Wastewater Production (gal/event)	735	460

backwash. The two E33 vessels were backwashed every 45 days, with backwashing of the first and second vessels initiated at 3 and 4 a.m., respectively. These backwash initiation times were chosen in case that backwashing of the AD26 and E33 vessels occurred on the same day.

During the summer months when school was not in session and the vessels did not require backwashing as frequently, the backwash frequency was set to 99 days, the maximum time allowed. The operator monitored the inlet and outlet pressure of all vessels and manually initiated backwash when differential pressure (Δp) across a vessel had increased to about 6 to 7 psi. If backwash was triggered manually, the backwash standby time to the next backwash event would be reset.

Treated water was used for backwash and fast rinse. A separate backwash line was used to draw treated water from the four pressure tanks to the head of the treatment train for AD26 backwashing. Although treated water was preferred, source water also was used to supplement backwash when pressure in the pressure tanks dropped to below 40 psi. When backwashing the E33 vessels, treated water drawn from the pressure tanks flowed through the AD26 vessels before being used for E33 backwash. If the well pump was triggered during backwash (when pressure in the pressure tanks dropped to below 40 psi), source water was first flowed through (and treated by) the AD26 vessels and then used for E33 backwash.

Wastewater produced from backwash was processed through one 1-µm bag filter assembly to remove arsenic-laden particles and other particulate matter and two granular activated carbon (GAC) tanks to remove chlorine before discharge as required by IDEM (see Figure 4-11). Processed wastewater was temporarily stored in a 1,200-gal holding tank until a discharge permit was received. After receipt of the discharge permit, the wastewater was discharged directly to an 8-in drain line leading to Rock Run Creek approximately 700 ft from the school property. Figure 4-12 shows the location of the backwash discharge line. The totalizer on each AD26 and E33 vessel registered both raw water and backwash water; therefore, the amount of backwash water used was subtracted when determining the total amount of water treated.

- **Media Regeneration/Disposal –** AD26 media is regenerated during chlorination and backwashing. E33 media, when exhausted, is removed from the vessels and disposed of at a sanitary landfill if successfully passing EPA's Toxicity Characteristic Leaching Procedure (TCLP) tests. Virgin media is then loaded into the vessels. Based on the source water data

Figure 4-11. Bag Filter Assembly and GAC Tank

and an average daily throughput of 2,000 gpd, the vendor estimated a media life of 8.7 years for E33, which could not be confirmed during the 1-year performance evaluation study.

4.3 System Installation

AdEdge and Hawkins Water, a subcontractor to AdEdge, completed installation and shakedown of the system on February 27, 2008. The following briefly summarizes system/building installation activities, including permitting, building preparation, system offloading, installation, shakedown, and startup.

4.3.1 Permitting. Design drawings and a process description of the proposed treatment system were submitted to IDEM by LJB Inc. on November 19, 2007. IDEM did not have any review comments and the permit was issued on January 10, 2008.

4.3.2 Building Preparation. The building housing the pre-existing hydropneumatic tanks and water softener was demolished and a new 28 ft × 28 ft boiler room attached to the existing school building (see Figure 4-13) was built to house the new treatment equipment with funds provided by the Indiana State Revolving Fund Loan Program. Piping from the wellhead and to the distribution system was laid to the tie-in points in the building to facilitate system installation and piping connection.

4.3.3 Installation, Shakedown, and Startup. System components were delivered to Hawkins Water during the week of January 28, 2008, and arrived at the school on February 6, 2008. The system was installed during the weeks of February 7 and 14, 2008, with installation completed on February 18, 2008. Installation activities included offloading, placing, and connecting the AD26/E33 system vessels and three new hydropneumatic tanks, connecting the system at the tie-in points, completing

Figure 4-12. Layout of Backwash Discharge Drain Line at Clinton Christian School (LJB Inc., 2007)

Figure 4-13. New Boiler Room Attached to Existing School Building

electrical wiring, and assembling the chlorine injection system. Figure 4-14 shows a photograph of the treatment system.

Upon completion of system installation, the vendor and its subcontractor met on February 25, 2008, to inspect the system and associated piping connections, verify electrical wiring and relays, and perform hydraulic testing before media loading. System shakedown and startup continued on February 26, 2008. Underbedding and 2.3 ft^3 of AD26 were loaded into each of the three AD26 vessels and underbedding and 5.3 ft^3 of E33 were loaded into each of the two E33 vessels. Freeboards above the underbedding and media bed were measured to ensure proper loading of individual media in each vessel. After control heads were reinstalled, the system plumbing was re-pressurized. Each AD26 vessel was then backwashed individually for 50 to 60 min at a maximum flowrate of 18.4 gpm and each E33 vessel was backwashed individually for 50 to 60 min at a maximum flowrate of 16 gpm. Afterwards, the control heads were disassembled to measure the freeboards again.

The treatment system was disinfected by increasing chlorine residual levels at the system outlet to approximately 50 mg/L (as Cl_2). The system was allowed to sit for 24 hr before being flushed of residual chlorine to below 0.5 mg/L (as Cl_2). Bacterial samples were collected by Hawkins Water on March 3 and 4, 2008, and the results received on March 20, 2008, were negative.

The system remained offline while LJB, Inc., under contract with the school, prepared for a construction and a National Pollutant Discharge Elimination System (NPDES) permit for the treatment and discharge of backwash wastewater. The applications were submitted on April 21, 2008. During this time, the school contracted with a drainage contractor to install an 8-in main drainline to discharge backwash wastewater to Rock Run Creek. To allow the system to be operated before the NPDES permit was granted, a holding tank was installed to store backwash wastewater. With the storage tank installed, the system was put online on May 1, 2008.

On June 6, 2008, two Battelle staff members visited the school to inspect the system and provide operator training. Table 4-8 summarizes the punch-list items and corrective actions taken.

Figure 4-14. Treatment System Installed
(From left to right: AD26 Vessels, E33 Vessels, and GAC Vessels; One AD26 Vessel and One Bag Filter Assembly not Shown)

Table 4-8. Punch-List Items and Corrective Actions

Date(s)	Issues/Problems Encountered	Corrective Action Taken	Work Performed by
06/06/08 – 06/18/08	Raw water (IN) sample tap too close to chlorine injection point	IN sample tap moved 10 ft upstream of chlorine injection point	Hawkins Water
06/06/08 – 06/18/08	After chlorination (AC) sample tap not installed as shown on P&ID	AC sample tap installed after chlorine injection point but before 3-way split to AD26 vessels	Hawkins Water
06/06/08 – 06/18/08	Sample tap on AD26 combined effluent line (OT) not installed as shown on P&ID	OT sample tap installed on combined effluent line after AD26 vessels but before 2-way split to E33 vessels	Hawkins Water
06/06/08	Chlorine residuals in distribution system water contained >5.5 mg/L of chlorine (as Cl_2)	Instructions provided for chlorine stock solution preparation and feed pump operation to achieve a 0.30 mg/L (as Cl_2) target residual level	AdEdge
06/06/08 – 06/25/08	Backwash flowrate too low, i.e., 15.4 gpm (or 17 gpm/ft^2) vs. design value of 18.4 gpm (or 20 gpm/ft^2)	Adjusted diaphragm flow control valve (DV111) to achieve a flow of 18 gpm for AD26	AdEdge

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters for the 1-year demonstration study were tabulated and are attached as Appendix A. Table 4-9 summarizes key parameters. The system began to operate on May 1, 2008, but logging of operational data did not begin until June 6, 2008, when two Battelle staff members visited the site to inspect the system and provide operator training. Also, because an hour meter was not installed until June 30, 2008, recording of hour meter readings did not begin until July 16, 2008. From June 30, 2008, through the end of the performance evaluation study on June 19, 2009, the system operated for 621.6 hr. Daily system run times averaged 1.9 hr/day when the school was in session and 1.5 hr/day when the school was not in session. Before installation of the hour meter, the system had operated for 90 hr since May 1, 2008, or 36 hr since June 6, 2008, assuming 1.5 h of daily run time. The total system operating time was estimated to be 712 hr starting from May 1, 2008, or 658 hr starting from June 6, 2008.

From June 6, 2008, through June 19, 2009, the system treated 529,192 gal of water based on readings of the totalizers installed on the influent side of each of the three AD26 vessels, or 517,174 gal based on readings of the totalizers installed on the influent side of each of the two E33 vessels (Table 4-9). Because the flow meters/totalizers were installed at the influent side of the AD26 and E33 vessels, throughput values registered by these totalizers reflect not only the amount of water treated by the AD26/E33 vessels, but also the amount of water used for backwashing A26 and E33 vessels (as read by the AD26 totalizers), or for backwashing E33 vessels (as read by the E33 totalizers). Between June 6, 2008, and June 19, 2009, the two E33 vessels were backwashed seven and eight times, using just over 3,450 gal of water for backwash. Therefore, the 517,174 gal registered by the E33 totalizers was considered the amount of water treated by the E33 vessels and used to calculate the number of bed volumes (BV) treated by the vessels.

Table 4-9. Summary of AD26/E33 System Operation

Operational Parameter	Value/Condition		
Duration	06/06/08–06/19/09		
Well Pump			
Average daily Run Time (hr/day)	1.9	(When school was in session)	
	1.5	(When school was out of session)	
Total Operating Time (hr)	658 (since 06/06/08) or 712 (since 05/01/08)		
AD-26 Oxidation/Filtration Unit			
Throughput (gal)[a]	Vessel	06/06/08–06/19/09	
	A	195,142	
	B	192,775	
	C	141,275	
	Combined	529,192	
Instantaneous Flowrate (gpm)	Vessel	Range	Average
	A	1.8–7.4	5.4
	B	3.0–9.9	5.6
	C	2.9–8.1	5.5
	Combined	8.7–20.3	16.4
Calculated Flowrate (gpm)[b]	Vessel	Range	Average
	A	2.2–9.9[c]	5.1
	B	3.0–10.2[d]	5.3
	C	2.9–10.1[e]	5.1
	Combined	9.3–20.2[f]	15.2

Table 4-9. Summary of AD26/E33 System Operation (Continued)

Operational Parameter	Value/Condition			
Vessel/System Pressure and Δp (psi)	Vessel	Inlet	Outlet	ΔP
	A	54 (46–68)	47 (36–58)	7 (0– 19)
	B	54 (46–68)	47 (38–59)	7 (0– 19)
	C	54 (46–68)	47 (37–59)	7 (1– 19)
E-33 Adsorption Unit				
Throughput (gal)[g]	Vessel	06/06/08–06/19/09		
	D	248,371		
	E	268,803		
	Combined	517,174		
Bed Volume (BV)	6,522			
Instantaneous Flowrate (gpm)	Vessel	Range	Average	
	D	5.1–9.4	7.7	
	E	5.7–10.1	8.3	
	Combined	10.8–19.5[h]	16.0	
Calculated Flowrate (gpm)[b]	Vessel	Range	Average	
	D	3.1–9.1[i]	7.4	
	E	3.4–10.9[j]	6.7	
	Combined	6.5–18.9[k]	12.9	
EBCT (min)[l]	Vessel	Range	Average	
	D	4.2–7.8	5.1	
	E	3.9–7.0	4.8	
	Combined	4.1–7.3	5.0	
Vessel/System Pressure and Δp (psi)	Vessel	Inlet	Outlet	Δp
	D	47 (37–59)	43 (30–58)	4 (1–12)
	E	47 (37–59)	43 (30–59)	4 (0–12)

(a) Including amount of treated and source water used for backwashing AD26 and E33 vessels.
(b) Data calculated by dividing incremental throughput by incremental hour meter readings recorded during July 16, 2008, through June 19, 2009.
(c) Three outliers (0.8, 1.1, and 23.4 gpm) omitted.
(d) Two outliers (1.1 and 24.1 gpm) omitted.
(e) Five outliers (0.7, 1.2, 1.6, 1.6, and 24.3 gpm) omitted.
(f) One outlier (71.7 gpm) omitted.
(g) Including amount of treated and source water used for backwashing E33 vessels.
(h) One outlier (6.4 gpm) omitted
(i) Four outliers (0.6, 13.8, 29.8, and 32.4 gpm) omitted.
(j) Two outliers (15.4 and 36.2 gpm) omitted.
(k) Three outliers (29.2, 37.7, and 68.6 gpm) omitted.
(l) Calculated based on 5.3 ft^3 of media in each adsorption vessel and corresponding instantaneous flowrate readings.

Based on the rationale discussed above, 6,522 BV of water were treated by the E33 unit from June 6, 2008, through June 19, 2009. BV calculations were based on 10.5 ft^3 of media in the two adsorption vessels.

Flowrates through the three AD26 (Figure 4-15) and two E33 vessels (Figure 4-16) were tracked with both instantaneous readings of the flow meters installed at the inlet to the AD26/E33 vessels and calculated values by dividing volume throughputs recorded from respective totalizers by incremental operating times. As shown in Table 4-9, instantaneous readings of each of the three AD26 flow meters averaged 5.4, 5.6, and 5.5 gpm; calculated values for each of these flow meters averaged 5.1, 5.3, and

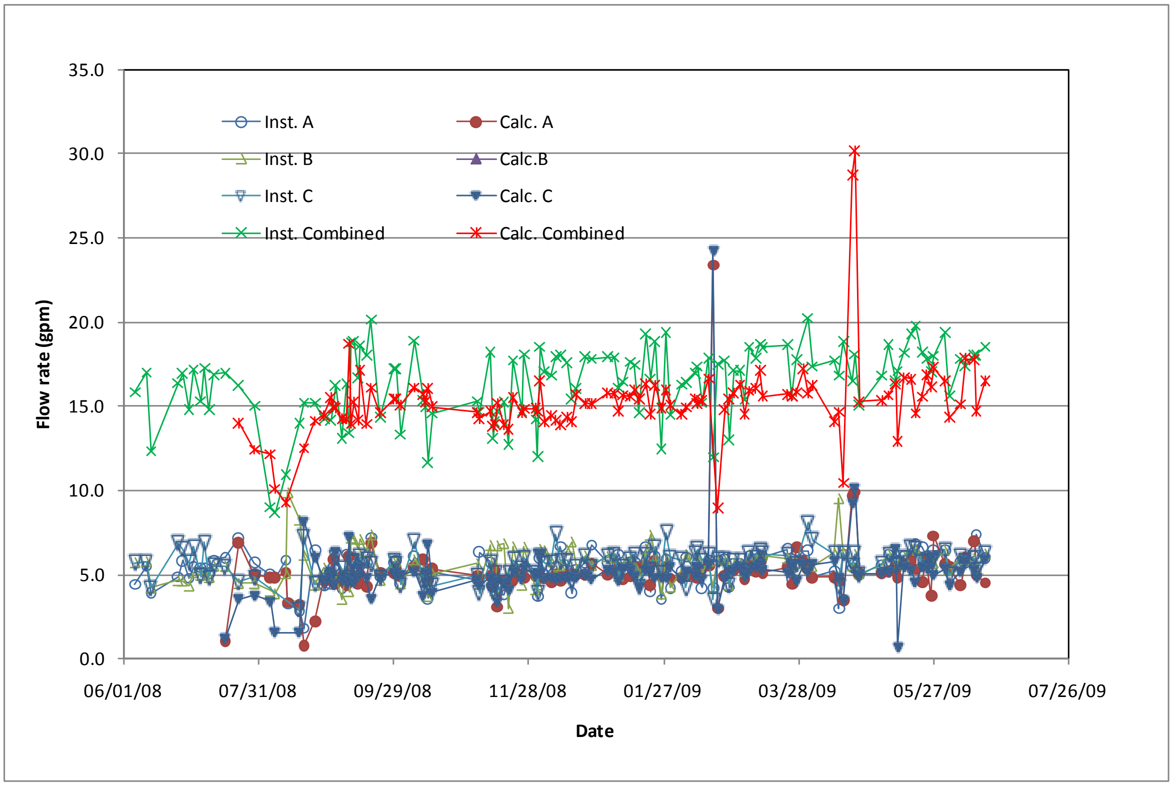


Figure 4-15. Comparison of Instantaneous Flowrate Readings and Calculated Flowrate Values for AD26 Vessels

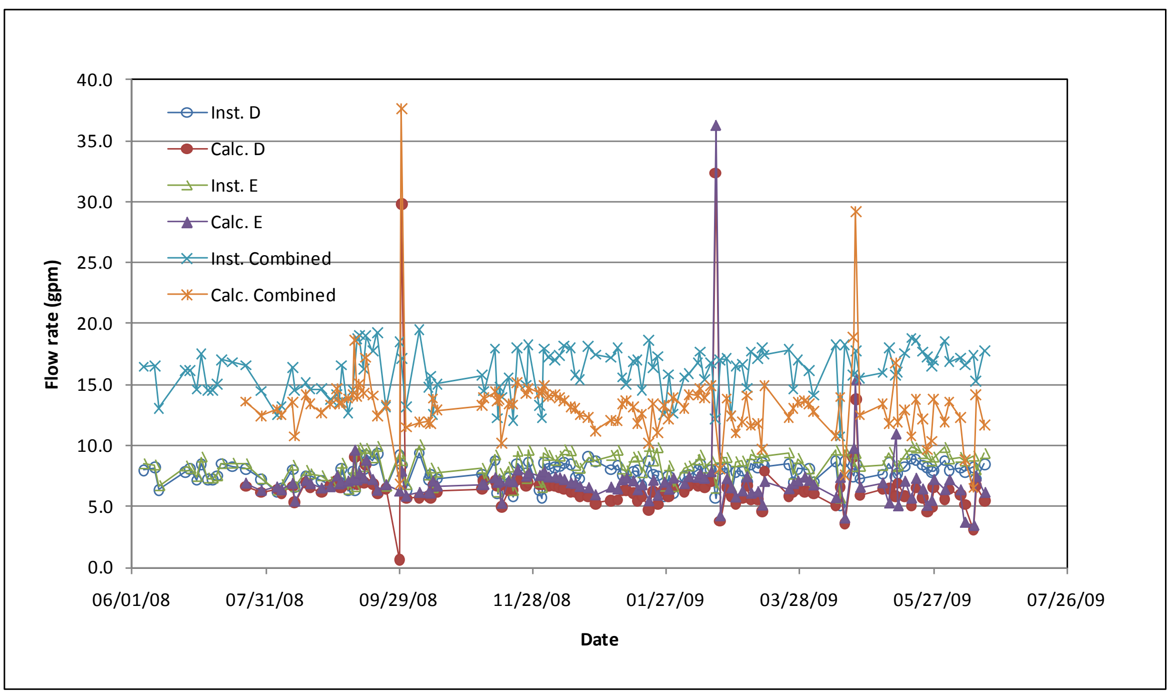


Figure 4-16. Comparison of Instantaneous Flowrate Readings and Calculated Flowrate Values to E33 Vessels

5.1 gpm. While these two sets of flowrate data were comparable to each other, the calculated values appeared to scatter somewhat more than the instantaneous readings (Figure 4-15). Instantaneous readings of each of the two E33 flow meters averaged 7.7 and 8.3 gpm and calculated values averaged 7.4 and 6.7 gpm. The calculated values were more scattered and, again, resulted in lower combined flowrates than the instantaneous readings (i.e., 12.9 gpm vs. 16.0 gpm [for E33 unit] or 16.5 gpm [for AD26 unit]). Thus, only instantaneous readings were used for EBCT calculations.

Based on the flowrates to the individual E33 vessels and the adsorption unit, EBCTs for the individual vessels varied from 3.9 to 7.8 min and averaged 5.0 min; EBCTs for the unit varied from 4.1 to 7.3 min and averaged 5.0 min. This average EBCT is over 61% higher than the vendor-recommended EBCT of 3.1 min for E33 media.

Pressure loss across each AD26 vessel ranged from 0 to 19 psi and averaged 7 psi. The inlet pressure of the AD26 unit ranged from 46 to 68 psi and averaged 54 psi, while the outlet pressure of the AD26 unit ranged from 36 to 59 psi and averaged 47 psi. The average differential pressure for the AD26 unit was 7 psi. Pressure loss across each E33 vessel ranged from 0 to 12 psi and averaged 4 psi. The inlet pressure of the E33 unit ranged from 37 to 59 psi and averaged 47 psi, while the outlet pressure of the E33 unit ranged from 30 to 59 and averaged 43 psi. The average differential pressure for the E33 unit was 4 psi.

4.4.2 Chlorine Injection. As described in Section 4.2, a 12.5% NaOCl solution was used to oxidize As(III) and Fe(II). The chlorine injection system experienced several operational irregularities during the performance evaluation study, as reflected by the variation of free and total chlorine residuals measured at the entry point to the distribution system (Figure 4-17). During the site visit by Battelle staff for system inspections and operator training, chlorine residuals measured in the treated water were higher than the upper limit of a chlorine test kit, i.e., 5.5 mg/L (as Cl_2). At this time, the NaOCl solution in the chlorine feed tank had been diluted 1:1 from the 12.5% NaOCl concentrate and the chlorine pump had been set to 70%. To reduce chlorine residuals in the treated water, the chlorine solution in the feed tank was further diluted for a 3:1 ratio and the chlorine pump setting was reduced to 40%. The chlorine pump setting was further reduced to 30% on June 20, 2008, when the residual chlorine level in the treated water was measured at 2.5 mg/L (as Cl_2). Although a reduction in free chlorine residuals was seen over time to 1.8 mg/L (as Cl_2) by June 27, 2008, chlorine residuals were still above the target level of 0.2 mg/L (as Cl_2) required by IDEM. The pump setting was further reduced to 25% on July 21, 2008 and free chlorine residuals levels were reduced correspondingly to 0.4 mg/L (as Cl_2) by August 13, 2008, to 0.1 mg/L (Cl_2) by September 14, 2008.

Chlorine dosages to the treatment system were carefully monitored by measuring solution levels in the chlorine feed tank. During the performance evaluation study, the average dosage was 4.0 mg/L (as Cl_2), which was about 67% higher than the target dosage of 2.4 mg/L (as Cl_2) as shown in Table 4-6.

Several steps were taken to rectify the problem of having lower-than-the-target level of total and free chlorine residuals in the treated water. These included reducing the total volume of chlorine replenished into the chlorine feed tank and disposing of the remaining chlorine solution in the chlorine feed tank before refilling. Both of these measures were taken because chlorine is known to decompose over time and continually adding fresh chlorine to a decomposed chlorine solution may eventually cause the chlorine dosage to the treatment system to be lower than expected. Despite these measures, chlorine residual levels in the treated water were below the IDEM-required level at times.

4.4.3 Backwash. AD 26 media backwash times, backwash frequencies, and amounts of backwash wastewater produced during the 1-year demonstration study were tabulated and are attached as Appendix C. Table 4-10 summarizes key parameters for both AD26 and E33 media. The three AD26 vessels were backwashed 105, 105, and 103 times, respectively. Among the backwash events, four were performed

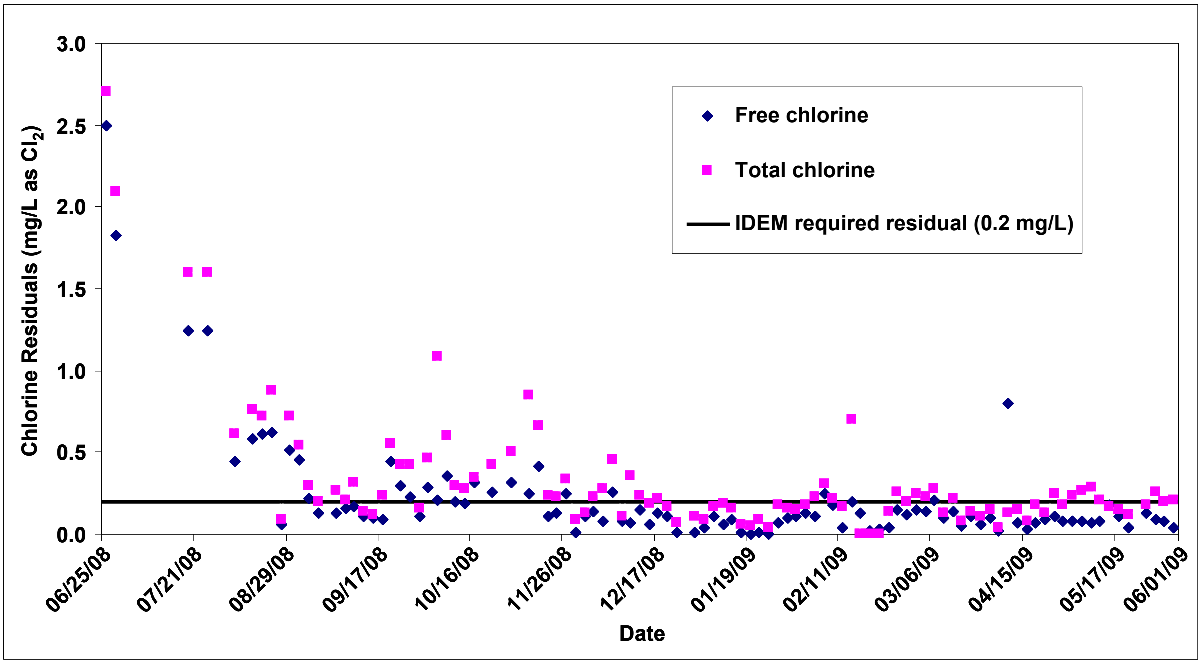


Figure 4-17. Total and Free Chlorine Residuals at Entry Point

manually on each vessel on June 6, 2008 (during Battelle's site visit for system inspections and operator training); July 3 and 4, 2008; and August 20, 2008. Because of the low demand during these summer months when the school was not in session, the backwash frequency was set to every 99 days, the maximum backwash time. The operator manually initiated backwash when the pressure difference across the vessels increased to 7 psi. The backwash frequency was returned to every 72 hr on August 20, 2008, after the school was back in session. The 105, 105, and 103 backwash counts also included (1) 22, 22, and 24 events (denoted by "√" in Table C-1 [Appendix C]) believed to have taken place based on circumstantial evidence (since no field data were collected) such as amounts of wastewater produced during the respective time periods, and (2) 19, 20, and 19 events (shaded in grey in Table C-1) thought to have had incomplete backwash cycles due to clogging of bag filters on the discharge line. Backwash flowrate on one occasion had been reduced to 0 gpm, compared to the design value of 18.4 gpm.

Backwash frequencies (or time elapsed between two consecutive backwash events) ranged from 25 to 94 hr and averaged 70.8 hr for Vessel A, from 31 to 102 hr and averaged 70.3 hr for Vessel B, and from 48 to 96 hr and averaged 72.1 hr for Vessel C. While the average frequencies were very close to the set value of once every 72 hr, actual backwash times varied extensively, deviating significantly from the would-be setting of initiating, at midnight, a backwash event with Vessel A followed by backwashing Vessels B and C at 1 and 2 a.m., respectively. In particular, Vessel A's backwash took place mostly between 11:00 a.m. through 1:00 p.m. from August 2008 to mid-January 2009 (see Table C-1). Since then, adjustments were made to the programmable logic controller (PLC), which changed backwash times to mostly between 11:00 p.m. through 3:00 a.m. For Vessel B, backwash took place mostly at midnight (24 out 79 recorded events [see Table 4-10]) and between 1:00 a.m. through 4:00 a.m. (48 out of 79 recorded events). For Vessel C, backwash occurred mostly between 1:00 a.m. through 4:00 a.m. (60 out of 74 recorded events). As shown in Table C-1, except for a few occasions (most likely due to recording errors), only one vessel was backwashed at a time throughout the entire study period.

Table 4-10. Summary of System Backwash Operations

		AD26 Unit			E33 Unit	
		Vessel A	Vessel B	Vessel C	Vessel D	Vessel E
No. of Backwashes	Manual	4	4	4	2	3
	Automatic[(a,b)]	101	101	99	6	4
Time Elapsed Between Two Consecutive Backwash Events	Range (hr[(c)] or day[(d)])	25–94	31–102	48–96	30–45	35–55
	Average (hr[(c)] or day[(d)])	70.8	70.3	72.1	39.0	43.5
No. of Times Backwashing taking place at	Hour					
	11:00	9	0	0	0	0
	12:00	12	0	1	1	1
	13:00	9	2	0	0	0
	Subtotal	*30*	*2*	*1*	*1*	*1*
	23:00	8	0	0	0	2
	00:00	4	24	2	1	1
	01:00	10	13	16	0	0
	02:00	12	18	13	2	2
	03:00	5	11	18	2	1
	04:00	0	6	13	0	0
	05:00	0	0	4	0	0
	Subtotal	*39*	*72*	*66*	*5*	*6*
	Others	10	5	7	2	0
	Subtotal	*10*	*5*	*7*	*2*	*0*
	Total	79	79	74	8	7
Amount of Wastewater Produced (gal)	Total	56,810			NA	
	Per Vessel per backwash cycle	226			NA	

(a) Including 22, 22, and 24 backwashes, as denoted by "√" in Table C-1, for Vessels A, B, and C, respectively. Although data were lacking, these backwash events most likely had taken place based on circumstantial evidence such as amounts of wastewater produced.
(b) Including 19, 20, and 19 backwashes, as shaded in grey in Table C-1, for Vessels A, B, and C, respectively. Although triggered, these backwashes mostly likely failed to complete because little or no wastewater was produced during these backwash events.
(c) For AD26 unit.
(d) For E33 unit.
NA = not available

Backwashing the three AD26 vessels produced approximately 56,810 gal of wastewater, based on readings of the totalizer installed on the wastewater discharge line between the bag filter assembly and the GAC tanks. Excluding the 62 events that produced little or no backwash wastewater, backwashing one AD26 vessel would produce 226 gal of wastewater, compared to the 245 gal shown in Table 4-7.

Throughout the 1-year performance evaluation study, the two E33 vessels were backwashed eight and seven times. Although set to backwash every 45 days, Vessel D was backwashed every 30 to 45 days (or 39 days [on average]) and Vessel E every 35 to 55 days (or 43.5 days [on average]). Backwash was initiated mostly between 11:00 p.m. through 3:00 a.m., even though it was set to begin for Vessel D at 3:00 a.m. and then for Vessel E at 4:00 a.m. Starting from mid-February 2009, the hour counter since the last backwash would stall and blink at 600 hr just before the time for automatic backwash. The operator reported that the blinking would stop and the hour counter would reset when the vessel was backwashed manually. As a result, manual backwash was performed two and three times for Vessels D and E, respectively.

Because the same totalizer on the waste discharge line was used to track wastewater production from both AD26 and E33 backwashes, the amounts of wastewater produced by the two E33 vessels might not be accurately quantified. Based on the backwash flowrate and backwash duration, backwashing each E33 vessel would produce only 230 gal of wastewater. As such, about 3,450 gal of wastewater would be produced from backwashing the two E33 vessels throughout the performance evaluation study.

4.4.4 Residual Management. Residuals expected by the operation of the system included backwash wastewater, spent bag filters, and spent media. Neither the oxidation/filtration media (AD26) nor the adsorptive media (E33) were replaced during the study period; therefore, the residuals produced were backwash wastewater and spent bag filters. Initially, backwash wastewater was stored in a 1,200-gal storage tank placed in the treatment building (Figure 4-18) before being transferred weekly to a vacuum truck for offsite disposal. On October 2, 2008, the school received the NPDES permit that allowed the wastewater to be discharged via a drain line behind the treatment building to Rock Run Creek. Spent bag filters were disposed of in the municipal trash.

Figure 4-18. Temporary Storage Tank for Backwash Wastewater

4.4.5 System/Operation Reliability and Simplicity. The main operational issues affecting the system were (1) maintaining chlorine residual levels above the IDEM-required 0.2 mg/L (as Cl_2), (2) a short in wiring connected to a motorized ball valve for backwashing Vessel A, and (3) stalling and blinking of the E33 backwash hour counter just before the time for automatic backwash. The issue related to maintaining required chlorine residuals was addressed using the step discussed in Section 4.4.2. The wiring issue that prevented Vessel A from being backwashed was repaired on August 13, 2008, and the problem appeared to not have occurred again. The issue associated with the blinking hour counter was never resolved during the performance evaluation study.

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

Pre- and Post-Treatment Requirements. Pretreatment included chlorination and AD26 treatment. Chlorination oxidized arsenic, iron, and manganese in source water and maintained 0.2 mg/L (as Cl_2) of free chlorine residuals in treated water for disinfection. AD26 filtered arsenic-laden iron and/or manganese solids and oxidized any remaining reduced metals, such as Mn(II). Post-treatment was not needed for this system.

System Automation. The AD26/E33 system included automated controls, which interlocked the well pump alternating on/off controls. The system also was equipped with an automated chlorine feed system, which was set to continually chlorinate raw water. In addition, the system was fitted with automated controls to allow for automatic backwash for both AD26 and E33 vessels.

Operator Skill Requirements. Under normal operating conditions, the skills required to operate the AD26/E33 system were minimal. Operator's duties were to monitor and refill the chlorine tank; change the chlorine pump dial, when necessary, to adjust the dosage; change the backwash setting as water usage changed during the school year, and initiate manual backwash when necessary.

All Indiana public water systems (both community and non-transient/non-community) serving more than 250 people must have a certified operator. Operator certifications are granted by the State of Indiana after passing an exam and maintaining a minimum amount of continuing education hours at professional training events. The number of continuing education hours required depends on the type of distribution and water treatment systems. Operator certifications are classified by the type of systems: for distribution systems they are classified by small, medium, or large (DSS, DSM, DSL); for water treatment systems they are classified from Classes 1 to 6 (WT1 to WT6). A DSS/WT2 certification is required to operator the treatment system at Clinton Christian School.

Preventive Maintenance Activities. The only regularly scheduled maintenance activity required for the operation of the AD26/E33 system was replacing bag filters on the backwash wastewater discharge line. This was done every 3 weeks. Other than that, the operator visited the plant approximately three times a week to record flow, volume, and pressure readings and measure chlorine concentrations.

Chemical/Media Handling and Inventory Requirements. The only chemical required for the system operation was the NaOCl solution used for chlorination. The 75-gal chlorine tank was filled with a diluted NaOCl solution using a 3:1 water to 12.5% NaOCl (as Cl_2) ratio. This was done by adding 8 gal of the chlorine concentrate to 24 gal of water.

4.5 System Performance

The performance of the AD26/E33 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 4-11 summarizes the analytical results of arsenic, iron, and manganese measured at the four sampling locations across the treatment train. Table 4-12 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.

Table 4-11. 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	22.2	33.4	28.6	3.0
	AC	26[a]	21.9	33.4	28.5	2.8
	OT	27	1.2	5.0	3.6	0.9
	TT	26[b]	<0.1	0.5	-[f]	
As (soluble)	IN	13	21.3	30.1	25.9	3.3
	AC	12[a]	5.2	11.3	7.7	2.0
	OT	13	1.6	4.2	3.3	0.8
	TT	13	<0.1	1.0	-[f]	
As (particulate)	IN	13	0.1	7.2	3.2	2.0
	AC	12[a]	13.7	27.1	21.0	3.7
	OT	13	<0.1	2.9	0.4	0.8
	TT	12[b]	<0.1	<0.1	-[f]	
As (III)	IN	12[c]	16.3	25.6	20.2	2.9
	AC	12[a]	<0.1	0.8	0.4	0.2
	OT	13	<0.1	0.8	0.4	0.2
	TT	13	<0.1	0.8	-[f]	
As (V)	IN	12[c]	2.8	8.8	5.4	1.9
	AC	12[a]	4.8	11.1	7.3	2.0
	OT	13	1.3	3.9	2.9	0.8
	TT	13	<0.1	0.3	-[f]	
Fe (total)	IN	26[d]	560	863	741	75.0
	AC	25[a,d]	559	886	733	73.1
	OT	27	<25	61.1	<25	<25
	TT	26[b]	<25	<25	<25	0.0
Fe (soluble)	IN	11[d,e]	213	887	654	181
	AC	12[a]	<25	156	42.8	51.4
	OT	13	<25	35.5	<25	<25
	TT	13	<25	<25	<25	0.0
Mn (total)	IN	27	58.3	97.5	81.5	8.9
	AC	26[a]	54.2	89.9	79.5	8.6
	OT	27	<0.1	14.4	1.1	2.7
	TT	27	<0.1	1.0	<0.1	0.2
Mn (soluble)	IN	13	57.5	107	82.5	11.7
	AC	11[a,e]	17.5	55.0	38.7	14.4
	OT	13	<0.1	1.6	0.4	0.4
	TT	13	<0.1	0.9	0.1	0.2

(a) AC sample tap installed after first sampling event on 06/06/08.
(b) Outliers for 06/06/08 on total As (4.9 μg/L), particulate As (4.2μg/L), and total Fe (207 μg/L) at TT removed.
(c) Outliers for 10/09/08 on As(III) (8.2 μg/L) and As(V) (20.7 μg/L) at IN removed.
(d) Outliers for 03/31/09 on total Fe (<25 μg/L) and soluble Fe (<25 μg/L) at IN and total Fe (<25 μg/L) at AC removed.
(e) Outliers for 08/20/08 on soluble Fe (260 μg/L) at IN and soluble Mn (2.8 μg/L) at AC removed.
(f) Statistics not provided; see arsenic breakthrough curves.

Table 4-12. Summary of Other Water Quality Parameter Results

Parameter	Sampling Location	Unit	Sample Count[a]	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as $CaCO_3$)	IN	mg/L	26	261	301	277	10.1
	AC	mg/L	25	256	295	277	10.5
	OT	mg/L	26	263	293	276	8.6
	TT	mg/L	26	265	296	276	7.9
Ammonia (as N)	IN	mg/L	26	0.1	0.2	0.1	0.0
	AC	mg/L	25	<0.05	0.1	0.1	0.0
	OT	mg/L	26	<0.05	0.09	<0.05	<0.05
	TT	mg/L	26	<0.05	0.1	<0.05	<0.05
Fluoride	IN	mg/L	12	0.2	0.4	0.3	0.1
	AC	mg/L	11	0.2	0.3	0.3	0.0
	OT	mg/L	12	0.2	0.8	0.3	0.2
	TT	mg/L	12	0.2	0.4	0.3	0.1
Sulfate	IN	mg/L	12	1.9	2.1	2.0	0.1
	AC	mg/L	11	1.8	2.8	2.1	0.3
	OT	mg/L	12	1.9	4.5	2.3	0.7
	TT	mg/L	12	2.0	2.3	2.0	0.1
Nitrate (as N)	IN	mg/L	12	<0.05	0.2	0.1	0.1
	AC	mg/L	11	<0.05	0.2	0.05	0.06
	OT	mg/L	12	<0.05	0.2	0.1	0.1
	TT	mg/L	12	<0.05	0.4	0.1	0.1
Phosphorus (as P)	IN	µg/L	27	<10	33.2	11.1	<10
	AC	µg/L	26	<10	36.3	11.4	<10
	OT	µg/L	27	<10	17.2	<10	<10
	TT	µg/L	26	<10	13.5	<10	<10
Silica (as SiO_2)	IN	mg/L	26	18.1	23.3	20.1	1.1
	AC	mg/L	25	18.1	23.2	20.2	1.2
	OT	mg/L	26	18.0	22.8	19.9	1.0
	TT	mg/L	26	16.3	23.8	19.4	1.6
Turbidity	IN	NTU	26	4.6	10.0	8.3	1.1
	AC	NTU	25	0.4	1.1	0.7	0.2
	OT	NTU	26	<0.1	0.9	0.2	0.3
	TT	NTU	26	<0.1	0.8	0.2	0.2
pH	IN	S.U.	9	7.0	7.6	7.3	0.2
	AC	S.U.	8	7.2	7.5	7.4	0.1
	OT	S.U.	9	7.1	7.5	7.3	0.1
	TT	S.U.	9	7.0	7.4	7.3	0.1
Temperature	IN	°C	8	9.1	17.5	12.6	3.3
	AC	°C	7	9.7	17.8	12.7	3.6
	OT	°C	8	10.6	18.0	13.6	2.9
	TT	°C	8	10.7	17.8	14.4	2.8
Dissolved Oxygen (DO)	IN	mg/L	3[b]	0.9	3.1	2.4	1.3
	AC	mg/L	2[b]	2.4	2.4	2.4	0.0
	OT	mg/L	3[b]	2.3	2.4	2.4	0.1
	TT	mg/L	3[b]	1.5	1.6	1.5	0.1

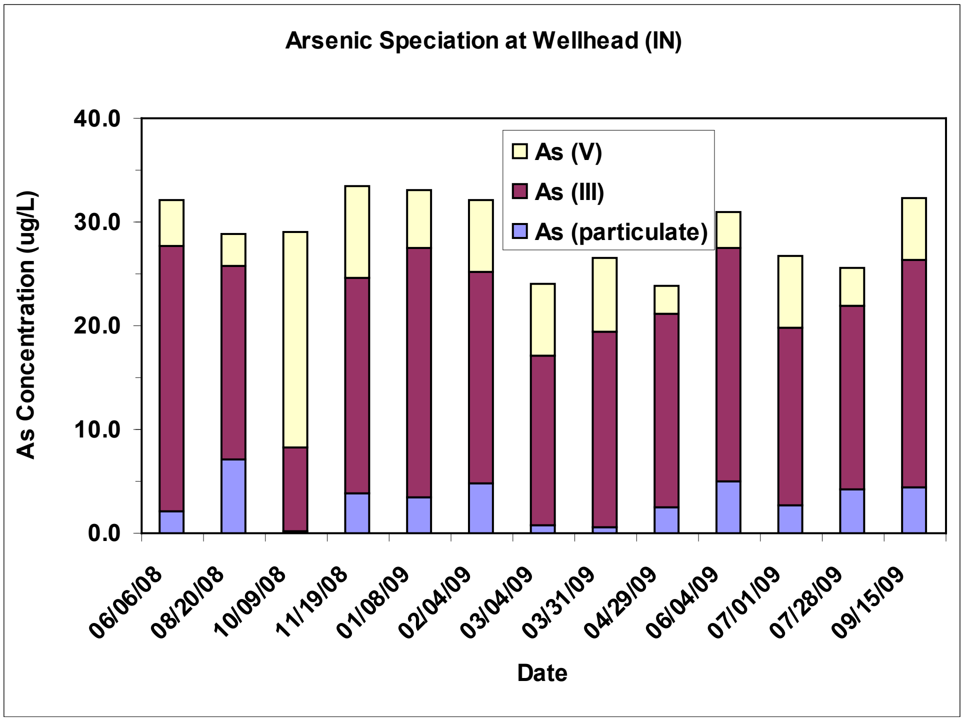
Table 4-12. Summary of Water Quality Parameter Sampling Results (Continued)

Parameter	Sampling Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
ORP	IN	mV	9	41.5	509	324	153
	AC	mV	8	345	886	561	181
	OT	mV	9	354	871	553	171
	TT	mV	9	365	763	538	146
Free Chlorine (as Cl_2)	AC	mg/L	88	0.2	3.6	0.9	0.6
	OT	mg/L	87	0.1	1.4	0.3	0.2
	TT	mg/L	87	0.0	0.8	0.1	0.1
Total Chlorine (as Cl_2)	AC	mg/L	88	0.3	5.1	1.4	0.8
	OT	mg/L	88	0.1	1.9	0.5	0.3
	TT	mg/L	87	0.0	1.1	0.2	0.2
Total Hardness (as $CaCO_3$)	IN	mg/L	12	190	335	263	34.8
	AC	mg/L	11	190	335	263	34.5
	OT	mg/L	12	193	336	270	35.0
	TT	mg/L	12	190	321	271	32.2
Ca Hardness (as $CaCO_3$)	IN	mg/L	12	134	204	164	18.7
	AC	mg/L	11	136	194	163	16.4
	OT	mg/L	12	139	207	169	18.8
	TT	mg/L	12	131	205	169	19.7
Mg Hardness (as $CaCO_3$)	IN	mg/L	12	56.4	186	98.9	29.8
	AC	mg/L	11	53.3	186	98.9	31.8
	OT	mg/L	12	54.3	194	101	32.3
	TT	mg/L	12	52.9	183	102	29.5

(a) AC sample tap installed after first sampling event.
(b) Outliers for 01/08/09 on DO at IN (28.2 mg/L), AC (26.7 mg/L), OT (13.6 mg/L), and TT (14.4 mg/L) removed.

Arsenic. The key parameter for evaluating the effectiveness of the arsenic removal system was the concentration of arsenic in treated water. Water samples were collected on 27 occasions, including three duplicates, with field speciation performed during 13 occasions at IN, AC, OT, and TT sampling locations. Three of the 13 speciation sampling events took place after June 19, 2009, when logging of operation data officially ended. The AC sample tap was installed after the first sampling event so there were only 26 sampling events at the AC location.

Figure 4-19 contains four bar charts showing concentrations of total arsenic, particulate arsenic, As(III), and As(V) at the IN, AC, OT, and TT locations for each of the 13 speciation events. Total arsenic concentrations in raw water ranged from 22.2 to 33.4 μg/L and averaged 28.6 μg/L (Table 4-11). Of the soluble fraction, As(III) was the predominating species, with concentrations ranging from 16.3 to 25.6 μg/L and averaging 20.2 μg/L. Particulate arsenic concentrations were low, averaging 3.2 μg/L. The presence of As(III) as the predominating arsenic species was consistent with the low DO concentrations, averaging 2.4 mg/L (Table 4-12) measured during the performance evaluation study. (Note that only four sets of DO readings were taken during the entire study period, including one showing unrealistically high concentrations across the treatment train [i.e., from 13.6 to 28.2 mg/L on March 4, 2009]). These obviously were the results of erroneous measurements. In fact, the operator had had difficulties in using the VWR Symphony SP90M5 handheld meter with the original and several replacement probes. As a result, the measurements had to be discontinued about halfway through the study. The ORP readings, however, were high, averaging 324 mV in raw water. The higher than expected ORP readings might have been caused by aeration of water during sampling or instrumental errors.



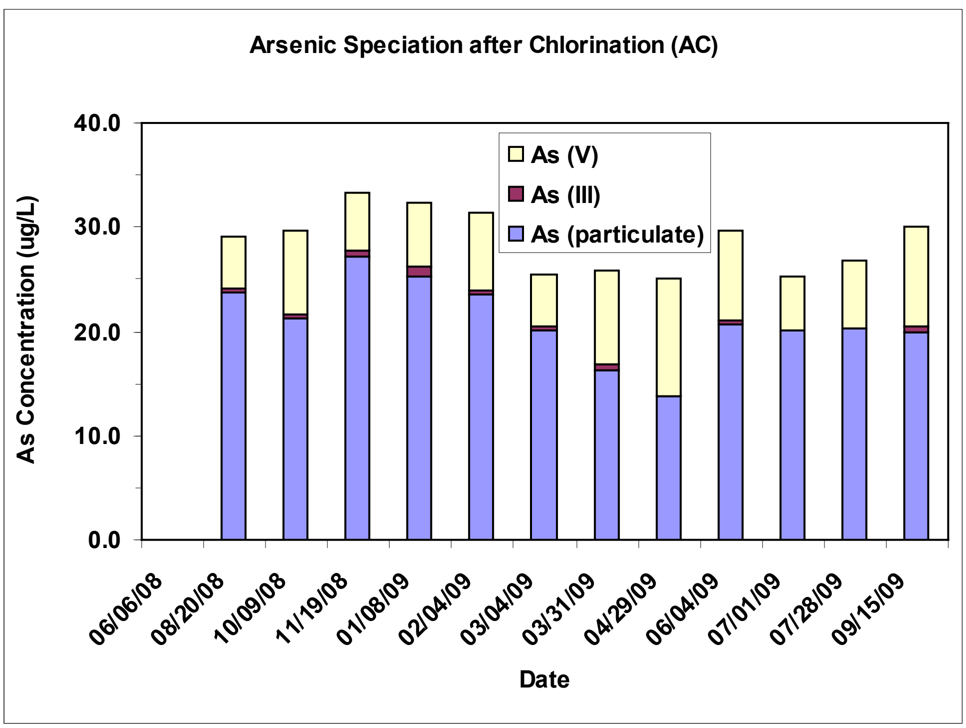
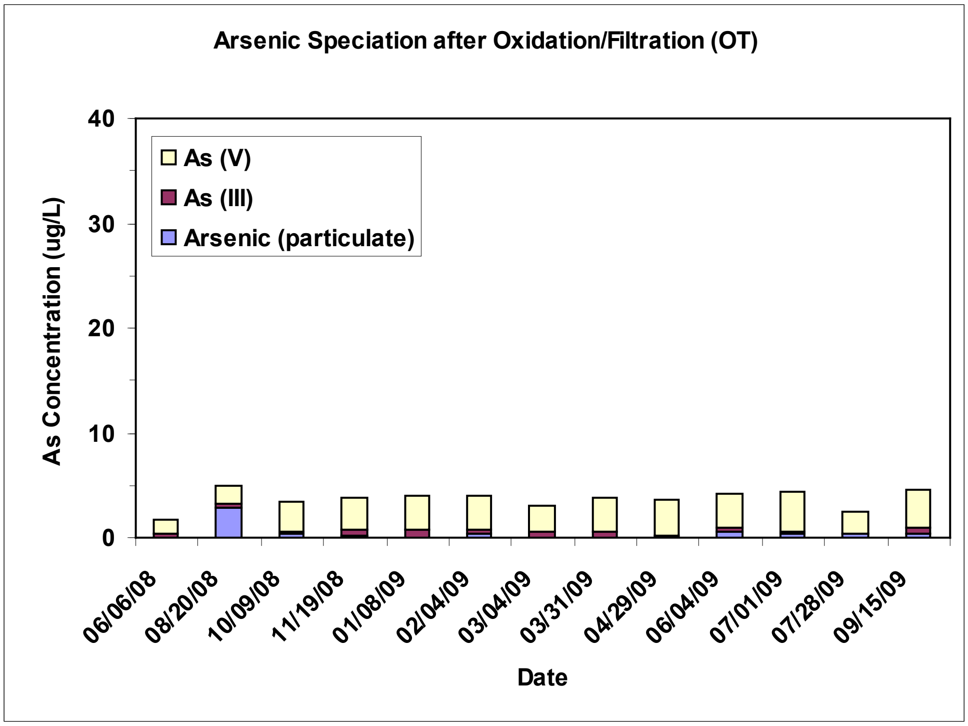


Figure 4-19. Concentrations of Various Arsenic Species at IN, AC, OT and TT Sampling Locations



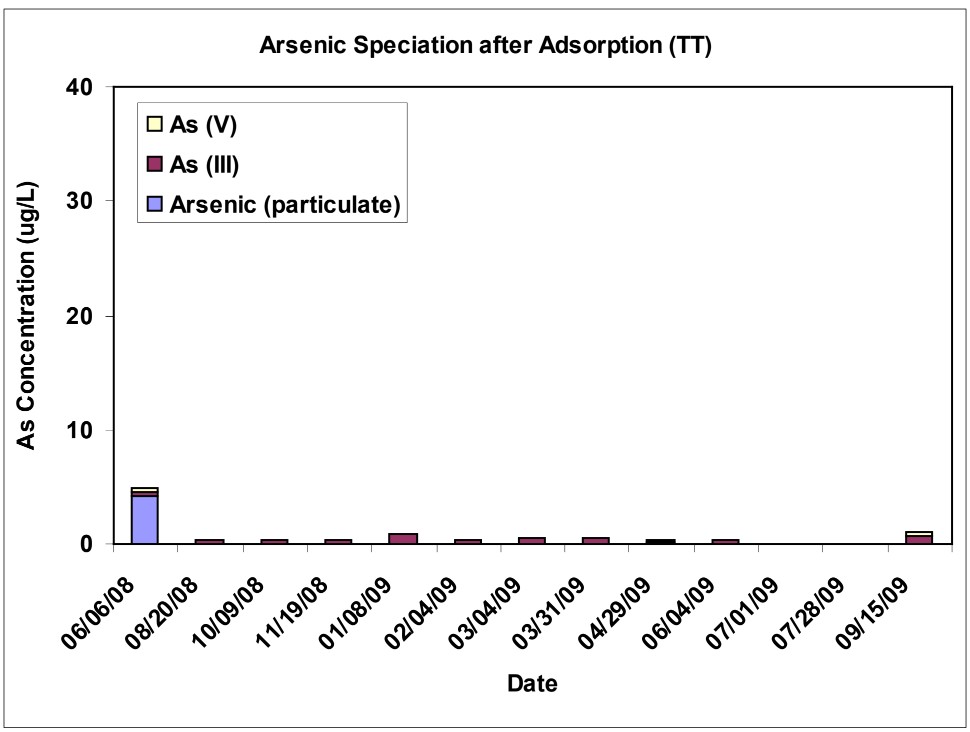


Figure 4-19. Concentrations of Various Arsenic Species at IN, AC, OT and TT Sampling Locations (Continued)

Chlorination oxidized As(III) to As(V), which, in turn, was adsorbed onto and/or co-precipitated with iron solids also formed upon chlorination. This was evidenced by a decrease in soluble arsenic concentration from 25.9 µg/L (on average) in raw water to 7.7 µg/L at the AC location and a corresponding increase in particulate arsenic concentration from 3.2 to 21.0 µg/L. The majority of particulate arsenic was filtered out by the AD26 oxidation/filtration media, leaving only 1.2 to 5.0 µg/L of total arsenic, existing mainly as soluble As(V), to be further removed by E33 adsorptive media. By the end of the performance evaluation study, total arsenic concentrations in treated water after the E33 adsorption vessels were reduced to less than 0.5 µg/L. Figure 4-20 presents arsenic breakthrough curves from the AD26 oxidation/filtration and E33 adsorption units.

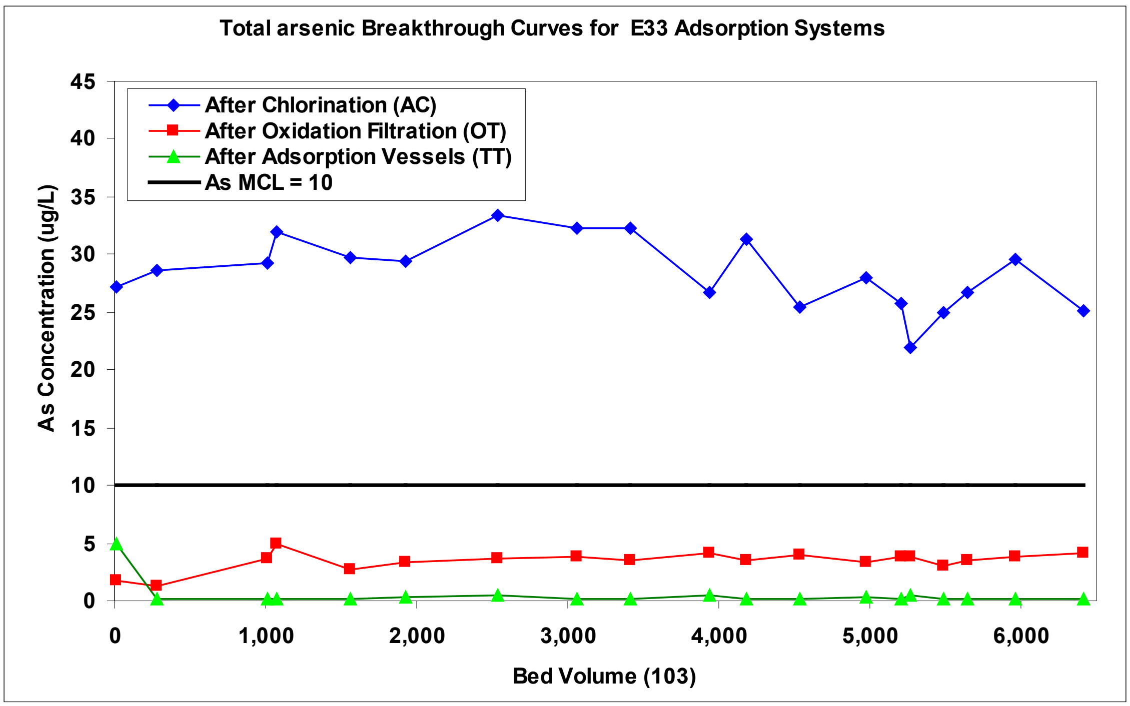


Figure 4-20. Total Arsenic Breakthrough Curves from AD26 and E33 Vessels

Free and total chlorine were monitored at the AC, OT, and TT sampling locations to ensure that the target level of free chlorine residuals (0.2 mg/L [as Cl_2]) was properly maintained. As shown in Table 4-12, free chlorine levels at the AC location ranged from 0.2 to 3.6 mg/L (as Cl_2) and averaged 0.9 mg/L (as Cl_2); total chlorine levels ranged from 0.3 to 5.1 mg/L (as Cl_2) and averaged 1.4 mg/L (as Cl_2). Chlorine residual levels measured at the OT and TT locations were noticeably lower than those at the AC location (i.e., 0.9 vs. 0.3 and 0.1 mg/L [as Cl_2], respectively, for free chlorine and 1.4 vs. 0.5 and 0.2 mg/L [as Cl_2], respectively, for total chlorine), indicating some chlorine demands through the AD26 and E33 vessels. Free chlorine residual levels in the system effluent often were lower than the 0.2 mg/L required by IDEM. Repeated attempts were made to increase the levels of free and total chlorine in the treated water.

After chlorination, DO concentrations remained essentially unchanged; however, ORP readings increased significantly to 561, 553, and 538 mV, on average, at the AC, OT, and TT locations, respectively, despite the fact that the residual levels were low.

Iron. Total iron concentrations at the wellhead ranged from 560 to 863 µg/L and averaged 741 µg/L, existing almost entirely as soluble iron. Following chlorination, soluble iron was precipitated to become iron solids, with its concentration remained essentially unchanged at 733 µg/L (on average). Arsenic-laden iron solids were removed by the AD26 media to the MDL of 25 µg/L. The data indicated that chlorine effectively oxidized soluble iron to form iron solids, which were then effectively filtered by the AD26 oxidation/filtration media. The backwash frequency of once every 3 days appeared to be adequate without having any iron leakage between backwash cycles.

Manganese. Total manganese levels in source water ranged from 58.3 to 97.5 µg/L and averaged 81.5 µg/L, which existed almost entirely in the soluble form. After chlorination, over 53% (on average) of soluble manganese was precipitated to form, presumably, MnO_2 solids, which, along with the unoxidized Mn^{2+}, were removed by the AD26 media to 1.1 µg/L (on average). Total manganese concentrations were further reduced to <0.1 µg/L after the E33 adsorptive media.

Other Water Quality Parameters. Raw water pH values measured at the IN location varied from 7.0 to 7.6. This near neutral pH is desirable for arsenic adsorption onto iron solids. The pH values remained essentially unchanged after the AD26 and E33 vessels. Alkalinity values ranged from 256 to 301 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 except during the last sampling event when the number of parameters analyzed was reduced. Concentrations of total hardness, existing primarily as calcium hardness (about 64%), ranged from 190 to 336 mg/L (as $CaCO_3$), and remained essentially unchanged throughout the treatment train. Sulfate levels were low ranging from 1.8 to 4.5 mg/L and remained constant throughout the treatment train. Silica (as SiO_2) concentrations ranged from 16.3 to 23.8 mg/L and appeared unaffected by the chlorine injection and the AD26 and E33 media. Fluoride results ranged from 0.2 to 0.8 mg/L and did not appear to be affected by the E33 media. Total phosphorous levels ranged from <10 to 36.3 µg/L and were below the MDL of 10 µg/L (as PO_4) during most sampling events. Ammonia concentrations ranged from <0.05 to 0.2 mg/L (as N) and averaged 0.1 mg/L (as N), which would react with 0.76 mg/L of chlorine to reach breakpoint chlorination. Following chlorination, ammonia levels were reduced to below or near the MDL of 0.05 mg/L (as N).

4.5.2 Backwash Wastewater Sampling. Table 4-13 presents the analytical results of backwash wastewater sampling. Backwash wastewater samples were collected 10 times from each of the three AD26 oxidation/filtration vessels. pH values of backwash wastewater ranged from 7.4 to 7.9 and averaged 7.6, which was 0.3 pH units higher than that of E33-treated water. TDS concentrations ranged from 192 to 282 mg/L and averaged 258 mg/L. TSS concentrations ranged from <4 to 28 mg/L and averaged 10 mg/L. The low TSS values measured during backwash of each oxidation/filtration vessel were probably caused by insufficient mixing of solids/water mixtures in the collection container.

As expected, the majority of the total arsenic, iron, and manganese in the backwash wastewater were in the particulate form. Assuming that 10 mg/L of TSS was produced in 56,810 gal of wastewater (Table 4-10), 4.7 lb of solids would be discharged in one year. The solids discharged would be composed of 0.039, 1.5, and 0.21 lb of arsenic, iron, and manganese, respectively, assuming 82 µg/L of particulate arsenic, 3,133 µg/L of particulate iron, and 440 µg/L of particulate manganese in the backwash wastewater.

Table 4-14 presents the results of total metals analysis for one set of backwash solid samples collected on January 12, 2009, and analyzed in duplicate. Iron levels in the solids ranged from 88,199 to 171,489 µg/g and averaged 128,592 µg/g; arsenic levels ranged from 1,010 to 4,452 µg/g and averaged 2,703 µg/g. This yields an Fe:As ratio of 48:1, which is 60% higher than the 30:1 ratio when considering the amounts of iron and arsenic removed by the AD26 vessels (see Table 4-11).

Table 4-13. 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 A										
10/02/08	7.7	250	10	85.6	6.5	79.2	2,197	<25	346	3.1
12/18/08	7.6	280	28	236	10.4	226	8,706	89	855	6.9
01/22/09	7.5	240	<4	46.7	6.2	40.5	1,296	<25	388	7.1
02/18/09	7.4	270	6	NA	NA	NA	NA	NA	NA	NA
03/18/09	7.5	238	7	111	9.4	101	2,914	124	309	7.8
04/15/09	7.7	268	20	202	14.6	187	7,960	359	542	23.8
05/14/09	7.6	258	6	84.9	6.5	78.4	3,472	43	498	5.7
06/10/09	7.6	270	6	34.9	6.4	28.5	1,259	<25	364	4.8
07/28/09	7.6	258	7	9.0	2.5	6.4	1,706	<25	431	5.1
09/15/09	7.6	264	8	119	12.6	106	4,302	174	329	13.7
Oxidation/Filtration Vessel B										
10/02/08	7.7	256	8	69.9	6.4	63.5	1,951	<25	395	3.4
12/18/08	7.5	278	14	112	8.2	104	3,026	42	486	4.5
01/22/09	7.6	254	4	96.9	6.7	90.2	2,386	38.9	500	6.5
02/18/09	7.5	244	6	NA	NA	NA	NA	NA	NA	NA
03/18/09	7.5	252	5	98.5	10.8	87.8	2,706	202	326	13.5
04/15/09	7.6	276	15	93.7	6.9	86.7	3,834	72	387	7.9
05/14/09	7.6	192	9	83.9	6.7	77.2	3,334	48	421	5.9
06/10/09	7.6	258	5	36.7	5.6	31.2	1,408	<25	447	4.1
07/28/09	7.6	272	<4	2.8	2.6	0.2	1,356	<25	426	4.1
09/15/09	7.6	256	11	129	9.7	119	4,573	91	307	9.1
Oxidation/Filtration Vessel C										
10/02/08	7.7	254	8	53.9	6.2	47.7	1,599	<25	383	3.6
12/18/08	7.9	282	10	53.8	5.4	48.4	1,726	<25	559	3.3
01/22/09	7.9	260	20	224	8.5	215	6,567	124	728	11.1
02/18/09	7.5	266	22	NA	NA	NA	NA	NA	NA	NA
03/18/09	7.5	248	5	79.6	8.5	71.0	2,159	98.5	302	6.3
04/15/09	7.6	270	5	122	9.1	113	5,100	183	557	18.8
05/14/09	7.6	266	11	94.9	9.0	85.9	3,706	150	451	12.4
06/10/09	7.6	244	5	34.5	5.3	29.2	1,296	<25	501	4.3
07/28/09	7.6	256	4	11.0	1.3	9.7	1,740	825	548	92.4
09/15/09	7.5	258	13	158	21.3	137	5,570	480	378	31.5

NA = not analyzed
TDS = total dissolved solids
TSS = total suspended solids

When using the metals results presented in Table 4-14, the amounts of arsenic, iron, and manganese discharged could be estimated to be 0.013, 0.60, and 0.19 lb, respectively (compared to 0.039, 1.5, and 0.21 lb, respectively), assuming 10 mg/L of TSS in 56,810 gal of wastewater.

No backwash wastewater or solids sample was collected from sampling of the E33 tanks.

Table 4-14. Oxidation/Filtration Vessels Backwash Solid Sample Total Metal Results

Sample	Unit	Mg	Al	Si	P	Ca	Fe[(a)]	Mn	Ni	Cu	Zn	As[(a)]	Cd	Ba	Pb	µg As/ mg Fe
Vessel AD26-A-Solids-A	µg/g	28,371	4,524	28,664	7,067	149,572	162,312	39,255	88.4	198	381	4,307	5.1	1,581	51.6	26.5
Vessel AD26-A-Solids-B	µg/g	29,932	4,734	31,001	7,490	154,400	171,489	41,145	90.3	211	384	4,452	4.8	1,639	48.4	25.9
Vessel AD26-A-Average	µg/g	29,151	4,629	29,832	7,278	151,986	166,900	40,200	89	205	382	4,379	5	1,610	50	26.2
Vessel AD26-B-Solids-A	µg/g	45,207	5,850	33,136	7,336	173,168	137,990	33,567	104	194	335	2,800	1.2	1,741	49.2	20.3
Vessel AD26-B-Solids-B	µg/g	41,718	5,411	28,601	6,694	175,294	123,185	34,026	102	180	317	2,576	1.2	1,547	46.1	20.9
Vessel AD26-B-Average	µg/g	43,462	5,631	30,869	7,015	174,231	130,587	33,797	103	187	326	2,688	1	1,644	48	20.6
Vessel AD26-C-Solids-A	µg/g	45,927	6,991	21,417	6,572	168,062	88,199	47,890	119	195	334	1,074	1.4	1,458	47.3	12.2
Vessel AD26-C-Solids-B	µg/g	43,750	7,490	25,800	6,454	176,042	88,382	42,270	118	191	338	1,010	1.3	1,514	55.8	11.4
Vessel AD26-C-Average	µg/g	44,838	7,241	23,608	6,513	172,052	88,290	45,080	119	193	336	1,042	1	1,486	52	11.8

Analyzed On 1/12/09.

(a) It is not clear why arsenic and iron concentrations became progressively lower from Vessels A to C.

4.5.3 Distribution System Water Sampling. Prior to the installation/operation of the treatment system, four first draw baseline distribution system water samples were collected from the bathroom sink tap on February 7, 13, 21, and 23, 2008. Following the installation of the treatment system, distribution water sampling continued on a monthly basis except for July and August 2008, February 2009 and August 2009. Table 4-15 presents the results of the distribution system sampling.

Table 4-15. Distribution System Sampling Results

Sampling Event		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
BL1	02/07/08	NA	7.6	273	20.0	323	85.6	0.5	5.5
BL2	02/13/08	7.5	7.5	273	24.1	384	88.5	0.8	2.4
BL3	02/21/08	NA	7.5	271	7.9	<25	82.3	0.2	24.5
BL4	02/23/08	NA	7.5	271	18.4	<25	84.9	0.6	43.0
1	06/18/08	48.0	7.5	277	5.9	134	2.5	10.3	304
2	09/14/08	NA	7.7	270	7.9	30	0.7	<0.1	43.0
3	10/30/08	9.0	7.5	269	0.1	<25	<0.1	<0.1	0.2
4	11/12/08	12.0	7.8	267	0.2	<25	<0.1	0.2	0.7
5	12/18/08	13.0	8.2	270	0.2	<25	<0.1	0.2	0.6
6	01/22/09	NA	7.4	278	0.6	<25	<0.1	1.4	27.0
7	03/19/09	NA	7.3	271	<0.1	<25	<0.1	<0.1	0.4
8	04/15/09	NA	7.6	267	2.4	<25	<0.1	<0.1	3.6
9	05/14/09	NA	7.8	298	0.4	<25	<0.1	<0.1	0.3
10	06/10/09	NA	7.5	280	4.9	66	4.9	<0.1	231
11	07/28/09	NA	7.5	272	1.3	<25	<0.1	<0.1	0.2
12	09/15/09	NA	7.5	267	9.2	68	6.8	6.7	7.1

BL = baseline sampling; NA = not available
Lead action level = 15 µg/L; copper action level = 1.3 mg/L
The unit for analytical parameters is µg/L except for alkalinity (mg/L as $CaCO_3$).

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 7.9 to 24.1 µg/L and averaged 17.6 µg/L. After system startup, arsenic concentrations were reduced to less than 0.1 to 9.2 µg/L (averaged 2.8 µg/L). The baseline iron concentrations ranged from less than the MDL of 25 µg/L to 384 µg/L, and averaged 183 µg/L. After system startup, iron concentrations decreased to less than the MDL of 25 µg/L in all samples except for four at 134, 30, 66 and 68 µg/L. Manganese had a similar trend with baseline concentrations averaging 85.3 µg/L and after-startup concentrations at <0.1 µg/L except for four samples at 2.5, 0.7, 4.9 and 6.8 µg/L on the same dates when the exceptions for iron concentration were observed.

Lead concentrations of all water samples collected before and after the installation of the treatment system were less than 1 µg/L, except for three instances at 10.3, 1.4, and 6.7 µg/L. All of the lead values were, therefore, below the action level of 15 µg/L. Copper concentrations ranged from 0.2 to 304 µg/L across all sampling locations, with no samples exceeding the 1,300 µg/L action level both before and after system startup. The arsenic treatment system did not have an effect on the lead or copper concentration in the distribution system.

Measured pH values ranged from 7.3 to 8.2 and averaged 7.6. Alkalinity levels ranged from 267 to 298 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 tracking of the capital cost for the equipment, site engineering, and installation and the O&M cost for media replacement and disposal, chemical supply, electricity consumption, and labor.

4.6.1 Capital Cost. The capital investment for equipment, site engineering, and installation for the 25-gpm treatment system was $55,423 (Table 4-16). The equipment cost was $31,735 (or 57.3% of the total capital investment). The breakdowns for the 25-gpm system provided by the vendor included $14,251 for the AD26 system, $15,811 for the E33 system, and $1,673 for freight. The cost for each AD26 and E33 vessel was $2,325 and $4,497.50, respectively. The unit cost for AD26 and E33 media was $218 and $265/ft^3, respectively. A prechlorination module and one year of O&M support were $1,978 and $1,320, respectively.

The site engineering cost included the cost for the preparation of a process flow diagram and relevant mechanical drawings of the treatment system, piping, valves, and a backwash discharge line, as well as submission of a permit application package to IDEM for approval. The site engineering cost was $11,278, or 20.3% of the total capital investment. Most of the site engineering cost (i.e., $8,425) went to LJB, Inc., a subcontractor to AdEdge, for labor and travel.

The installation cost included the equipment and labor to unload and install the units, perform piping tie-ins and electrical work, and load and backwash the media. The installation was performed by AdEdge and Hawkins Water, a local contractor subcontracted by AdEdge. The installation cost was $12,410, or 22.4% of the total capital investment.

The capital cost of $55,423 was normalized to the system's rated capacity of 25 gpm (or 36,000 gpd), which results in $2,216/gpm (or $1.54/gpd) of design capacity. The capital cost also was converted to an annualized cost of $5,231/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 25 gpm to produce 36,000 gal/day, the unit capital cost would be $0.39/1,000 gal. During the year long demonstration, the system produced approximately 517,000 gal of water (see Table 4-9); at this reduced rate of usage, the unit capital cost increased to $10.12/1,000 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 4-17. Although media replacement did not occur during the demonstration study, the media replacement cost would represent the majority of the O&M cost. The vendor estimated that the AD26 media would have a life expectancy of 8.7 yr. It was estimated that it would cost $2,593 to replace 6.9 ft^3 of AD26 media in three vessels. At the current water use rate (i.e., 517,000 gal for one year), the system would treat 4,500,000 gal of water in a 8.7-yr period. Therefore, the AD26 media replacement cost would be equivalent to $0.58/1,000 gal of water treated.

It also was estimated that it would cost $3,951 to change out 10.5 ft^3 of E33 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 4-21).

Table 4-16. Capital Investment Cost for AdEdge Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
Three 13-in Diameter AD26 Fiberglass Vessels	1	$6,975	–
AD26 Media (ft^3)	6.9	$1,508	–
Process Valves and Piping	1	$250	–
Instrumentation and Controls	1	$990	–
Totalizer for Backwash Line	1	$430	–
O&M Manuals	3	$800	–
1-year O&M Support	1	$1,320	–
Pre chlorination Module	1	$1,978	
Subtotal		*$14,251*	–
Two 18-in Diameter E33 Fiberglass Vessels	1	$8,995	–
E33 Media (ft^3)	10.5	$2,738	–
Process Valves and Piping	1	$250	–
Instrumentation and Controls	1	$900	–
Additional Sample Taps	2	$210	–
Additional storage (bladder tanks)	3	$2,718	
Subtotal		*$15,811*	–
Shipping		$1,673	
Subtotal		*$1,673*	
Equipment Total	–	**$31,735**	**57.3%**
Engineering Cost			
Vendor Labor	-	$2,853	–
Subcontractor Labor	–	$7,475	–
Subcontractor Travel		$950	–
Engineering Total	–	**$11,278**	**20.3%**
Installation Cost			
Vendor Labor	–	$720	–
Vendor Travel	–	$120	–
Subcontractor Material	–	$5,300	–
Subcontractor Labor	–	$6,270	–
Installation Total	–	**$12,410**	**22.4%**
Total Capital Investment	–	**$55,423**	**100%**

A 12.5% NaOCl solution was used for chlorination. The cost associated with chlorination was approximately $169 during this demonstration study, which translated into a chemical cost of $0.33/1,000 gal of water treated.

Comparison of electrical bills provided by the school prior to system installation and since startup did not indicate any noticeable increase in power consumption by the treatment system. Therefore, electrical cost associated with operation of the AD26/E33 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 1.6 hr/wk. Therefore, the estimated labor cost would be $2.57/1,000 gal of water treated.

Table 4-17. Operation and Maintenance Cost for AdEdge Treatment System

Cost Category	Value	Assumptions
Volume Processed (gal)	517,000	Through June 19, 2009
Media Replacement and Disposal		
AD26 Media Cost ($)	$1,380	Vendor quote
AD26 Media Volume (ft^3)	6.9	To fill three 13-in diameter vessels
Subcontractor Labor Cost ($)	$540	Vendor quote
Freight ($)	$303	Vendor quote
Waste Disposal ($)	$255	Vendor quote
Waste Analysis ($)	$115	Vendor quote
Subtotal ($)	*$2,593*	
AD26 Media Replacement and Disposal cost ($/1,000 gal)	$0.58	Assume 8.7-year media life treating 4,500,000 gal of water
AD33 Media Cost ($)	$2,738	Vendor quote
AD33 Media Volume (ft^3)	10.5	To fill two 18-in diameter vessels
Subcontractor Labor Cost ($)	$540	Vendor quote
Freight ($)	$303	Vendor quote
Waste Disposal ($)	$255	Vendor quote
Waste Analysis ($)	$115	One TCLP test
Subtotal ($)	*$3,951*	
AD-33 Media Replacement and Disposal cost ($/1,000 gal)	See Figure 4-22	
Chemical Usage		
Chemical Cost ($/1,000)	$0.33	Approximately $169 for one year
Electricity		
Electricity Cost ($/1,000 gal)	Negligible	Electrical costs assumed negligible
Labor		
Average Weekly (5 day) Labor (hr)	1.6	20 min/day
Labor cost ($/1,000 gal)	$2.57	Labor rate = $16/hr
Total O&M Cost/1,000 gal	See Figure 4-21	Total O&M cost = $0.58 + E33 adsorptive media replacement cost + $0.33 + $2.57

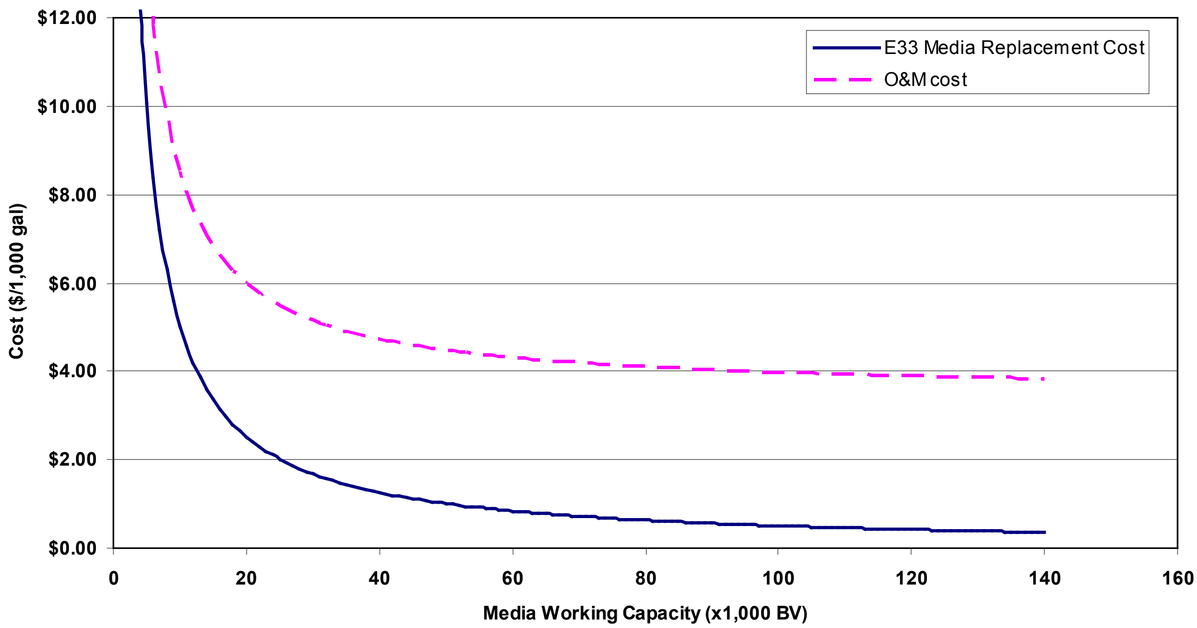


Figure 4-21. Media Replacement Cost Curves for Clinton Christian School System

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APPENDIX A

OPERATIONAL DATA

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

Week No.	Date	Well Pumps		AD26		E33			AD 26		E33
		Operating time[(a)] (hr)	Cumulative hours (hr)	Combined Instantaneous Flowrate[(b)] (gpm)	Combined Calculated Flowrate (gpm)	Combined Instantaneous Flowrate[(b)] (gpm)	Combined Calculated Flowrate (gpm)	Backwash Totalizer Readings (gal)	Inlet Pressure (psi)	Outlet Pressure psi	Outlet Pressure psi
1	06/06/08	NA	NA	17.33	NA	16.67	NA	NA	53	48	43.0
	06/06/08	NA	NA	15.85	NA	16.46	NA	6,299	68	53	46.0
2	06/11/08	NA	NA	17.01	NA	16.55	NA	NA	60	44	40
	06/13/08	NA	NA	12.34	NA	13.05	NA	6,985	60	55	54
4	06/25/08	NA	NA	16.37	NA	16.17	NA	7,210	48	40	36
	06/27/08	NA	NA	16.95	NA	16.17	NA	7,211	50	42	38
5	06/30/08	NA	NA	14.82	NA	14.60	NA	7,211	52	41	38
	07/02/08	NA	NA	17.20	NA	17.51	NA	7,211	52	40	36
	07/05/08	NA	NA	15.29	NA	14.53	NA	NA	50	49	46
6	07/07/08	NA	NA	17.29	NA	14.53	NA	NA	50	49	46
	07/09/08	NA	NA	14.78	NA	15.00	NA	9,214	50	43	40
	07/11/08	NA	NA	16.90	NA	17.02	NA	NA	50	42	38
7	07/16/08	14.8	14.8	16.97	NA	16.82	NA	NA	52	41	38
8	07/22/08	5.7	20.5	16.24	14.01	16.58	13.58	9,409	52	44	40
9	07/29/08	39.9	60.4	15.04	12.41	14.49	12.45	9,409	52	40	38
10	08/05/08	3.1	63.5	9.01	12.16	12.48	13.00	9,409	58	47	44
	08/07/08	1.2	64.7	8.69	10.08	13.25	12	9,410	60	43	38
11	08/12/08	2	66.8	10.94	9.3	16.40	13.55	9,410	52	42	37
	08/13/08	1.0	67.8	NA	NA	14.50	10.77	9,430	63	NA	NA
12	08/18/08	2.7	70.5	14.02	NA	15.12	14.13	9,430	54	38	35
	08/20/08	2.4	72.9	15.21	12.51	14.61	13.40	NA	55	47	44
13	08/25/08	6.7	79.6	15.22	14.14	14.63	12.67	10,320	52	47	42
	08/29/08	9.5	89.1	14.26	14.46	13.77	13.34	11,340	55	48	45
14	09/01/08	2.3	91.4	14.18	15.53	14.19	14.65	11,418	56	53	50
	09/02/08	1.7	93.1	14.88	15.01	13.54	13.43	11,564	52	46	42
	9/3/2008	1.5	94.6	16.26	14.91	16.59	13.56	11,700	52	46	43
	09/06/08	8.8	103.4	13.12	14.25	12.64	13.84	11,949	56	50	47

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

Week No.	Date	Well Pumps Operating time[(a)] (hr)	Well Pumps Cumulative hours (hr)	AD26 Combined Instantaneous Flowrate[(b)] (gpm)	AD26 Combined Calculated Flowrate (gpm)	E33 Combined Instantaneous Flowrate[(b)] (gpm)	E33 Combined Calculated Flowrate (gpm)	Backwash Totalizer Readings (gal)	AD 26 Inlet Pressure (psi)	AD 26 Outlet Pressure psi	E33 Outlet Pressure psi
15	09/08/08	3.8	107.2	16.32	14.22	14.51	14.14	11,968	56	47	40
	09/09/08	0.3	107.5	13.41	18.72	6.36	18.67	11,970	51	45	41
	09/10/08	4.7	112.2	18.81	13.96	18.77	14.01	11,981	54	44	38
	09/11/08	1.2	113.4	18.85	15.24	19.06	15.08	11,981	51	43	38
	09/13/08	6.1	119.5	16.71	14.14	16.31	14.29	11,994	47	40	36
16	09/14/08	0.4	119.9	18.63	17.12	18.98	17.21	11,994	52	45	43
	09/17/08	5.6	125.5	18.03	13.95	17.75	14.09	11,997	54	40	32
	09/19/08	2.2	127.7	20.16	16.11	19.28	12.45	12,733	58	59	59
17	09/23/08	12.9	140.6	14.34	14.60	13.16	13.26	13,667	54	47	44
18	09/29/08	6.2	146.8	17.25	15.41	18.52	6.87	14,932	48	39	32
	09/30/08	1.5	148.3	17.26	15.41	17.14	37.66	14,932	47	42	38
	10/02/08	2.5	150.8	13.32	15.07	13.14	11.49	14,932	54	50	46
19	10/08/08	6.3	157.1	18.88	16.10	19.46	11.90	17,164	46	39	30
	10/12/08	2.2	159.3	15.36	15.70	14.80	11.95	17,670	50	48	42
20	10/14/08	1.6	164.2	11.66	16.07	12.55	13.83	18,627	62	59	58
	10/16/08	3.7	167.9	14.59	14.96	15.05	12.91	18,627	56	52	48
23	11/05/08	47.5	215.4	15.31	14.65	15.75	13.26	23,257	56	49	46
	11/06/08	2.1	217.5	14.68	14.27	14.47	13.88	23,257	56	49	45
24	11/11/08	11.0	228.5	18.23	14.71	17.96	14.41	23,477	55	46	39
	11/12/08	2.9	231.4	13.10	13.84	12.22	13.63	23,477	56	50	47
	11/13/08	6.6	238.0	14.08	13.95	14.82	13.79	23,487	57	50	47
	11/14/08	0.9	238.9	14.70	15.20	13.98	10.22	23,487	54	47	42
25	11/17/08	23	261.9	15.23	13.88	15.60	13.44	24,361	56	48	45
	11/19/08	6.1	268.0	12.74	13.63	12.06	13.37	24,389	58	52	48
	11/21/08	1.8	269.8	17.73	15.51	18.03	15.18	24,440	56	50	46
26	11/25/08	6.0	275.8	14.74	14.60	14.98	14.22	24,448	56	51	47
	11/26/08	1.8	277.6	18.07	14.85	18.22	14.67	24,448	50	40	38
27	12/01/08	4.1	281.7	14.21	14.88	13.30	14.32	24,460	54	49	45

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

Week No.	Date	Well Pumps Operating time[(a)] (hr)	Well Pumps Cumulative hours (hr)	AD26 Combined Instantaneous Flowrate[(b)] (gpm)	AD26 Combined Calculated Flowrate (gpm)	E33 Combined Instantaneous Flowrate[(b)] (gpm)	E33 Combined Calculated Flowrate (gpm)	Backwash Totalizer Readings (gal)	AD 26 Inlet Pressure (psi)	AD 26 Outlet Pressure psi	E33 Outlet Pressure psi
	12/02/08	1.7	283.4	12.00	14.66	12.25	14.40	24,461	62	59	56
	12/03/08	0.8	284.2	18.53	16.50	17.95	14.87	24,461	52	42	40
	12/05/08	3.5	287.7	17.07	14.06	17.25	14.06	24,461	56	50	45
28	12/08/08	6.2	293.9	16.82	14.45	16.99	14.12	24,461	54	44	40
	12/10/08	6.4	300.3	17.92	14.20	17.40	13.93	24,466	55	46	42
	12/12/08	6.5	306.8	18.04	13.89	18.20	13.69	24,466	54	42	36
29	12/15/08	12.1	318.9	17.58	14.37	17.99	13.14	25,170	54	49	37
	12/17/08	11.9	330.8	15.46	14.09	15.75	13.04	25,813	60	53	49
	12/19/08	3.2	334.0	16.08	15.68	15.39	12.51	26,357	54	48	44
30	12/23/08	4.0	338.0	17.94	15.18	18.12	12.34	26,954	52	42	37
	12/26/08	3.4	341.4	17.80	15.15	17.44	11.19	27,712	52	46	40
31	01/02/08	7.0	348.4	17.93	15.77	17.21	12.09	29,284	53	45	39
32	01/05/09	2.4	350.8	17.90	15.74	17.99	11.98	29,793	56	52	48
	01/07/09	2.9	353.7	16.10	14.74	15.60	13.45	29,963	56	49	45
	01/09/09	3.4	357.1	16.47	15.64	15.03	13.70	30,268	53	45	39
33	01/12/09	3.3	360.4	17.63	15.56	16.90	13.17	30,659	53	47	42
	01/14/09	2.0	362.4	17.46	15.97	17.05	11.83	31,110	54	47	42
	01/16/09	3.3	365.7	14.65	15.42	14.50	12.62	31,608	56	54	50
34	01/19/09	2.1	367.8	19.29	16.30	18.60	10.22	32,332	52	44	38
	01/21/09	10.0	377.8	16.63	14.53	16.37	13.38	32,743	54	49	44
	01/23/09	3.8	381.6	18.85	16.27	17.31	11.07	33,897	53	46	39
35	01/26/09	10.3	391.9	12.44	14.88	12.51	13.32	34,753	62	58	54
	01/28/09	2.1	394.0	19.36	15.99	15.83	12.19	35,171	54	48	43
	01/30/09	4.5	398.5	14.50	15.05	12.62	13.92	35,360	62	57	53
36	02/04/09	16.0	414.5	16.28	14.52	15.58	13.08	36,330	55	50	46
	02/06/09	6.5	421.0	16.45	14.95	15.88	14.18	36,403	54	49	45
37	02/10/09	4.3	425.3	16.99	15.48	16.79	14.09	36,599	54	48	44
	02/11/09	2.1	427.4	17.37	15.16	17.68	14.65	36,599	55	49	44
	02/13/09	2.3	429.7	15.20	15.33	15.44	13.89	36,673	56	50	47

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

Week No.	Date	Well Pumps		AD26		E33			AD 26		E33
		Operating time[a]	Cumulative hours	Combined Instantaneous Flowrate[b]	Combined Calculated Flowrate	Combined Instantaneous Flowrate[b]	Combined Calculated Flowrate	Backwash Totalizer Readings	Inlet Pressure	Outlet Pressure	Outlet Pressure
		(hr)	(hr)	(gpm)	(gpm)	(gpm)	(gpm)	(gal)	(psi)	psi	psi
38	02/16/09	2.0	431.7	17.88	16.64	16.81	14.88	36,718	53	47	41
	02/18/09	0.5	432.2	11.97	71.73	12.17	68.60	36,744	58	54	50
	02/20/09	4.3	436.5	17.52	8.95	17.02	8.04	36,827	54	48	43
39	02/23/09	2.9	439.4	17.73	14.78	17.14	13.87	36,852	55	49	44
	02/25/09	4.4	443.8	13.02	15.43	12.40	12.39	37,563	63	58	56
	02/27/09	2.6	446.4	17.14	15.78	16.52	10.97	38,271	54	49	44
40	03/02/09	2.9	449.3	17.14	16.30	16.62	11.94	38,967	55	49	45
	03/04/09	6.7	456.0	15.39	14.56	14.74	14.12	38,967	56	49	45
	03/06/09	3.2	459.2	18.52	15.93	17.68	11.60	39,640	55	49	44
41	03/09/09	2.6	461.8	17.86	16.04	17.18	11.83	40,297	54	48	43
	03/11/09	1.5	463.3	18.71	17.11	18.00	9.70	40,941	56	53	49
	03/12/09	2.6	465.9	18.49	15.59	17.44	14.92	41,312	54	47	41
43	03/23/09	14.6	480.5	18.65	15.70	17.86	12.32	43,733	51	44	38
	03/25/09	2.6	483.1	15.57	15.61	14.61	13.07	44,058	57	52	49
	03/27/09	1.4	484.5	17.77	15.85	17.02	13.50	44,215	54	NA	NA
44	03/30/09	2.4	486.9	0.00	17.21	NA	13.65	44,771	53	46	40
	04/01/09	3.6	490.5	20.25	15.75	16.14	13.42	45,166	54	46	40
	04/03/09	1.2	491.7	17.36	16.25	14.08	12.78	45,371	54	48	43
46	04/13/09	5.8	496.3	17.72	14.10	18.28	10.80	46,416	52	45	39
	04/15/09	11.6	507.9	16.83	14.66	10.76	13.96	46,444	60	56	53
	04/17/09	8.5	516.4	18.83	10.45	18.26	7.62	47,844	58	47	52
47	04/21/09	1.4	517.8	16.51	28.71	15.74	18.85	48,531	58	54	52
	04/22/09	1.9	519.7	18.09	30.15	17.76	29.21	48,531	54	46	40
	04/24/09	4.6	524.3	15.06	15.26	15.53	12.47	49,201	53	48	42
48	05/04/09	19.7	544.0	16.82	15.35	15.98	13.38	51,189	58	54	50
	05/07/09	5.5	549.5	18.64	15.67	18.00	11.77	NA	53	47	40
	05/10/09	2.7	552.2	16.51	16.35	15.74	16.75	NA	57	48	51
49	05/11/09	0.9	553.1	17.09	12.91	16.02	11.96	52,198	54	48	43
	05/14/09	2.4	555.5	18.18	16.71	17.57	12.88	52,828	54	46	41

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

Week No.	Date	Well Pumps		AD26		E33			AD 26		E33
		Operating time[a]	Cumulative hours	Combined Instantaneous Flowrate[b]	Combined Calculated Flowrate	Combined Instantaneous Flowrate[b]	Combined Calculated Flowrate	Backwash Totalizer Readings	Inlet Pressure	Outlet Pressure	Outlet Pressure
		(hr)	(hr)	(gpm)	(gpm)	(gpm)	(gpm)	(gal)	(psi)	psi	psi
	05/17/09	3.6	559.1	19.31	16.62	18.81	10.73	53,986	53	46	39
50	05/19/09	11.5	570.6	19.78	14.57	18.64	13.82	54,223	48	37	30
	05/22/09	3.8	574.4	18.21	15.58	17.72	12.18	54,933	54	47	41
51	05/24/09	1.7	576.1	17.80	16.87	17.24	9.62	55,600	54	48	43
	05/26/09	1.4	577.5	17.06	16.13	16.56	10.39	56,090	54	48	43
	05/27/09	1.5	579.0	17.99	17.31	16.97	13.79	56,650	54	47	42
52	06/01/09	5.6	584.6	19.37	16.50	18.58	11.96	58,076	52	44	38
	06/03/09	17.1	601.7	15.64	14.35	16.88	13.59	58,298	56	46	41
53	06/08/09	7.9	609.6	17.82	15.12	17.20	12.31	59,576	54	47	42
	06/10/09	1.3	610.9	17.39	17.86	16.58	8.86	60,432	54	48	44
	06/14/09	2.4	613.3	18.06	17.76	17.36	6.51	62,001	54	47	42
54	06/15/09	4.2	617.5	18.06	14.74	15.26	14.17	62,001	56	49	46
	06/19/09	4.1	621.6	18.54	16.53	17.80	11.65	63,109	67	48	44

System started on May 1st 2008
NA = not available
(a) Hour meter was not installed at wellhead at time of system start-up.
(b) AD26C flow meter was replaced on 08/18/08.

APPENDIX B

ANALYTICAL DATA

Table B-1. Analytical Results from Long-Term Sampling at Goshen, IN

Sampling Date		06/06/08			06/27/08				08/13/08				08/20/08			
Sampling Location		IN	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT
Parameter	Unit															
Bed Volume	10^3	-		0.0	-			0.3	-			1.0	-			1.1
Alkalinity (as $CaCO_3$)	mg/L	277	286	280	271	273	271	282	278	276	276	270	279	277	273	286
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	0.1	<0.05	<0.05	NA	NA	NA	NA	0.2	0.1	<0.05	0.1	0.2	<0.05	<0.05	<0.05
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.3	0.3	0.3	-	-	-	-	-	-	-	-	0.2	0.2	0.2	0.2
Sulfate	mg/L	2.1	2.1	2.1	-	-	-	-	-	-	-	-	2.0	1.9	1.9	2.0
Nitrate (as N)	mg/L	<0.05	0.2	<0.05	-	-	-	-	-	-	-	-	0.1	<0.05	<0.05	0.1
Total P (as P)	µg/L	11.4	<10	<10	<10	<10	<10	<10	12.1	10.4	<10	<10	<10	<10	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	20.0	19.6	16.5	18.3	18.1	18.1	16.3	20.0	19.9	19.6	18.0	20.5	20.9	20.2	19.3
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	9.5	<0.1	0.1	8.9	0.5	0.1	0.1	8.3	0.5	0.1	0.1	8.0	0.5	0.1	0.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	7.4	7.5	7.4	7.0	7.5	7.5	7.0	7.4	7.4	7.4	7.3	7.4	7.4	7.4	7.3
Temperature	°C	13.1	13.1	13.1	NA	NA	NA	NA	17.5	17.8	18.0	17.8	17.5	17.8	18.0	17.8
DO	mg/L	0.9	2.3	1.6	NA	NA	NA	NA	3.1	2.4	2.4	1.5	3.1	2.4	2.4	1.5
ORP	mV	278	753	763	509	886	871	655	463	682	523	653	463	682	523	653
Free Chlorine (as Cl_2)	mg/L	-	-	5.5	-	-	-	1.8	-	-	-	0.4	-	-	-	0.6
Total Chlorine (as Cl_2)	mg/L	-	-	5.5	-	-	-	2.1	-	-	-	0.6	-	-	-	0.8
Total Hardness (as $CaCO_3$)	mg/L	300	318	321	-	-	-	-	-	-	-	-	262	256	264	269
Ca Hardness (as $CaCO_3$)	mg/L	204	207	205	-	-	-	-	-	-	-	-	165	167	175	175
Mg Hardness (as $CaCO_3$)	mg/L	95.8	111	116	-	-	-	-	-	-	-	-	97.2	88.7	89.5	93.8
As (total)	µg/L	32.2	1.7	4.9	27.4	27.2	1.2	0.1	28.8	28.6	3.6	0.2	28.9	29.2	4.9	0.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	30.1	1.6	0.6	-	-	-	-	-	-	-	-	21.7	5.4	2.0	0.2
As (particulate)	µg/L	2.1	<0.1	4.2	-	-	-	-	-	-	-	-	7.2	23.7	2.9	<0.1
As (III)	µg/L	25.6	0.4	0.4	-	-	-	-	-	-	-	-	18.6	0.3	0.3	0.3
As (V)	µg/L	4.5	1.3	0.3	-	-	-	-	-	-	-	-	3.1	5.1	1.7	<0.1
Fe (total)	µg/L	851	29	207	770	751	<25	<25	804	781	<25	<25	809	885	61	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	887	<25	<25	-	-	-	-	-	-	-	-	260	<25	<25	<25
Mn (total)	µg/L	97.5	1.0	0.5	87.8	86.8	<0.1	<0.1	85.8	85.5	1.2	0.3	90.1	88.1	14.4	<0.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	107	0.4	<0.1	-	-	-	-	-	-	-	-	88.9	2.8	<0.1	<0.1

NA = not available

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

Sampling Date		09/14/08				10/09/08				11/06/08				11/19/08			
Sampling Location / Parameter	Unit	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT
Bed Volume	10^3	-			1.6	-			1.9[(a)]	-			2.5	-			3.1
Alkalinity (as $CaCO_3$)	mg/L	267	267	267	270	270	275	277	273	274	272	272	265	263	270	263	265
		265	267	270	265	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	0.2	0.1	<0.05	<0.05	0.1	0.1	<0.05	<0.05	0.2	<0.05	<0.05	<0.05	0.2	<0.05	<0.05	<0.05
		0.1	0.1	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	0.3	0.2	0.2	0.2	-	-	-	-	0.2	0.3	0.2	0.3
Sulfate	mg/L	-	-	-	-	2.1	2.1	2.2	2.0	-	-	-	-	1.9	2.0	2.0	2.0
Nitrate (as N)	mg/L	-	-	-	-	<0.05	<0.05	<0.05	<0.05	-	-	-	-	<0.05	<0.05	<0.05	<0.05
Total P (as P)	µg/L	11.7	11.3	<10	<10	12.7	13.3	<10	<10	14.2	15.7	<10	<10	11.2	10.8	<10	<10
		11.3	12.1	<10	<10	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	20.8	20.9	20.3	20.1	20.8	20.2	20.1	20.1	18.7	18.8	18.4	17.9	20.1	20.0	19.9	19.6
		21.0	20.8	20.4	20.0	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	8.8	0.5	0.2	0.1	8.2	0.6	0.1	0.3	9.8	0.5	<0.1	<0.1	8.4	0.7	0.2	<0.1
		8.2	0.5	0.2	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Free Chlorine (as Cl_2)	mg/L	0.0	0.4	0.1	0.1	-	3.6	1.4	0.2[(b)]	-	1.4	0.4	0.3 [(c)]	-	2.1	0.9	0.4
Total Chlorine (as Cl_2)	mg/L	0.1	0.9	0.1	0.1	-	5.1	1.9	1.1	-	1.9	0.6	0.4	-	2.2	1.2	0.7
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	267	278	277	277	-	-	-	-	265	266	263	267
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	169	176	174	175	-	-	-	-	171	170	169	172
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	98.0	102	103	102	-	-	-	-	94.3	95.9	94.2	95.2
As (total)	µg/L	31.9	31.9	2.7	0.2	29.1	29.7	3.4	0.3	28.1	29.4	3.6	0.4	33.4	33.4	3.8	0.2
		31.5	31.9	2.6	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	29.0	8.5	3.1	0.2	-	-	-	-	29.6	6.2	3.6	0.2
As (particulate)	µg/L	-	-	-	-	0.1	21.3	0.4	<0.1	-	-	-	-	3.9	27.1	0.2	<0.1
As (III)	µg/L	-	-	-	-	8.2[(d)]	0.3	0.3	0.3	-	-	-	-	20.8	0.6	0.5	0.3
As (V)	µg/L	-	-	-	-	20.7[(d)]	8.2	2.8	<0.1	-	-	-	-	8.8	5.6	3.0	<0.1
Fe (total)	µg/L	773	748	<25	<25	709	711	<25	<25	667	677	<25	<25	744	717	<25	<25
		763	769	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	724	<25	<25	<25	-	-	-	-	708	<25	<25	<25
Mn (total)	µg/L	81.1	79.8	<0.1	<0.1	76.0	77.0	0.2	<0.1	80.1	81.2	0.2	<0.1	77.6	75.3	0.3	0.2
		80.6	79.9	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	79.5	28.2	0.3	<0.1	-	-	-	-	73.0	17.5	0.2	<0.1

(a) Bed volume from 10/02/08
(b) Free & Total Chlorine from 10/10/08
(c) Free & Total Chlorine from 11/05/08
(d) Samples probably switched by operator
(e) Free & Total Chlorine from 12/10/08
(f) Water quality parameters and chlorine measured on 01/07/09.

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

Sampling Date		12/09/08				01/08/09				01/22/09				02/04/09			
Sampling Location / Parameter	Unit	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT
Bed Volume	10^3		-		3.4[d]		-		4.0		-		4.2		-		4.5
Alkalinity (as $CaCO_3$)	mg/L	271	269	271	273	270	267	267	270	270	270	270	265	277	270	277	274
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	0.1	0.07	<0.05	<0.05	0.2	<0.05	<0.05	0.1	0.1	<0.05	<0.05	<0.05	0.2	0.1	<0.05	<0.05
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	0.2	0.2	0.3	0.3	-	-	-	-	0.4	0.3	0.8	0.4
Sulfate	mg/L	-	-	-	-	1.9	1.9	2.1	2.1	-	-	-	-	2.0	2.0	2.3	2.1
Nitrate (as N)	mg/L	-	-	-	-	<0.05	<0.05	<0.05	<0.05	-	-	-	-	<0.05	0.2	<0.05	<0.05
Total P (as P)	µg/L	15.0	16.0	<10	<10	33.2	36.3	17.2	13.5	13.2	13.0	<10	<10	<10	<10	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	20.0	20.3	19.7	19.8	19.0	18.8	18.9	18.2	19.4	19.1	19.2	18.1	20.6	20.5	20.1	20.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	8.8	0.5	<0.1	<0.1	8.8	0.5	<0.1	<0.1	9.2	0.6	<0.1	<0.1	8.4	1.1	0.9	0.7
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	NA	NA	NA	NA	7.4	7.4	7.3	7.4	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	NA	NA	NA	NA	12.1	11.1	12.5	16.4	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	28.2	26.7	13.6	14.4	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	209	516	635	367	NA	NA	NA	NA	NA	NA	NA	NA
Free Chlorine (as Cl_2)	mg/L	-	0.9	0.2	0.1[e]	-	0.5	0.2	0.0	-	0.9	0.2	0.04[a]	-	1.0	0.3	0.2
Total Chlorine (as Cl_2)	mg/L	-	1.5	0.3	0.1	-	0.9	0.3	0.1	-	0.7	0.2	0.0	-	0.7	0.2	0.1
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	335	332	336	314	-	-	-	-	257	261	268	268
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	149	138	141	131	-	-	-	-	167	169	175	173
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	186	195	194	183	-	-	-	-	90.0	91.6	92.2	95.8
As (total)	µg/L	31.4	32.2	3.5	0.2	33.0	32.3	4.1	0.4	27.0	26.7	3.5	0.2	32.0	31.4	4.0	0.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	29.6	6.9	4.0	0.4	-	-	-	-	27.2	7.8	3.6	0.1
As (particulate)	µg/L	-	-	-	-	3.4	25.4	<0.1	<0.1	-	-	-	-	4.9	23.6	0.5	<0.1
As (III)	µg/L	-	-	-	-	24.2	0.8	0.8	0.8	-	-	-	-	20.4	0.3	0.3	0.3
As (V)	µg/L	-	-	-	-	5.4	6.1	3.2	<0.1	-	-	-	-	6.8	7.5	3.3	<0.1
Fe (total)	µg/L	813	810	<25	<25	580	567	<25	<25	674	670	<25	<25	748	758	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	551	<25	<25	<25	-	-	-	-	767	<25	<25	<25
Mn (total)	µg/L	72.5	71.1	<0.1	<0.1	58.3	54.2	0.2	<0.1	74.9	75.3	0.3	<0.1	82.2	78.5	0.3	<0.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	57.5	17.7	0.2	<0.1	-	-	-	-	82.6	43.5	0.2	<0.1

(a) Chlorine measured on 01/23/09.
(b) Water quality parameters and bed volume taken on 03/23/09.

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

Sampling Date		02/18/09				03/04/09				03/19/09[b]				03/31/09[a]			
Sampling Location / Parameter	Unit	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT
Bed Volume	10^3		-		4.8		-		5.0		-		5.2[b]		-		5.3
Alkalinity (as $CaCO_3$)	mg/L	287	287	287	283	270	272	270	280	272	272	276	280	285	281	276	281
		-	-	-	-	-	-	-	-	284	284	278	278	-	-	-	-
Ammonia (as N)	mg/L	0.2	0.1	<0.05	<0.05	0.1	<0.05	0.1	<0.05	0.2	0.1	<0.05	0.1	0.1	0.1	<0.05	<0.05
		-	-	-	-	-	-	-	-	0.1	0.1	0.1	0.1	-	-	-	-
Fluoride	mg/L	-	-	-	-	0.2	0.3	0.3	0.3	-	-	-	-	0.3	0.3	0.3	0.3
Sulfate	mg/L	-	-	-	-	1.9	2.8	2.0	2.0	-	-	-	-	2.0	2.1	2.1	2
Nitrate (as N)	mg/L	-	-	-	-	0.2	<0.05	<0.05	<0.05	-	-	-	-	<0.05	0.1	0.2	<0.05
Total P (as P)	µg/L	11.5	12.2	<10	<10	15.3	17.2	<10	<10	12.2	11.4	<10	<10	<10	<10	<10	<10
		-	-	-	-	-	-	-	-	11.5	11.3	<10	<10	-	-	-	-
Silica (as SiO_2)	mg/L	18.5	18.9	18.5	18.0	20.0	20.6	20.0	20.0	19.7	19.8	20.1	20.0	18.1	18.4	18	17.8
		-	-	-	-	-	-	-	-	19.9	19.6	20	19.5	-	-	-	-
Turbidity	NTU	9.0	0.5	<0.1	<0.1	10.0	0.5	<0.1	<0.1	7.7	0.8	0.3	0.3	8.8	0.9	0.5	0.5
		-	-	-	-	-	-	-	-	9.3	0.9	0.4	0.3	-	-	-	-
pH	S.U.	NA	NA	NA	NA	7.2	7.2	7.1	7.1	NA	NA	NA	NA	7.3	7.3	7.3	7.2
Temperature	°C	NA	NA	NA	NA	9.1	9.8	10.6	10.7	NA	NA	NA	NA	10.0	9.7	12.2	14.7
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	41.5	361	414	413	NA	NA	NA	NA	411	523	502	494
Free Chlorine (as Cl_2)	mg/L	-	0.6	0.3	0.1	-	0.8	0.3	0.2	-	0.2	0.1	0.1	-	0.5	0.1	0.0
Total Chlorine (as Cl_2)	mg/L	-	0.6	0.2	0.0	-	1.6	0.4	0.3	-	0.4	0.1	0.1	-	0.7	0.3	0.0
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	190	190	193	190	-	-	-	-	243	249	254	268
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	134	136	138	137	-	-	-	-	147	154	157	168
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	56.4	53.3	54.3	52.9	-	-	-	-	96.1	95.0	97.0	99.7
As (total)	µg/L	25.6	26.6	3.3	0.3	24.0	25.4	3.1	0.2	28.3	28.0	3.8	<0.1	26.5	25.8	3.8	0.4
		-	-	-	-	-	-	-	-	27.0	27.9	4.3	<0.1	-	-	-	-
As (soluble)	µg/L	-	-	-	-	23.3	5.3	3.1	0.2	-	-	-	-	25.9	9.5	3.8	0.3
As (particulate)	µg/L	-	-	-	-	0.7	20.1	<0.1	<0.1	-	-	-	-	0.6	16.3	<0.1	<0.1
As (III)	µg/L	-	-	-	-	16.3	0.5	0.5	0.5	-	-	-	-	18.9	0.6	0.5	0.5
As (V)	µg/L	-	-	-	-	7.0	4.8	2.6	<0.1	-	-	-	-	7.1	8.9	3.3	<0.1
Fe (total)	µg/L	684	683	<25	<25	560	559	<25	<25	769	770	<25	<25	<25	<25	<25	<25
		-	-	-	-	-	-	-	-	746	765	27	<25	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	566	<25	<25	<25	-	-	-	-	<25	<25	<25	<25
Mn (total)	µg/L	70.9	68.9	0.2	<0.1	77.2	75.0	0.6	0.2	84.8	84.1	0.6	<0.1	96.8	89.8	0.8	<0.1
		-	-	-	-	-	-	-	-	83.9	85.1	1.6	<0.1	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	76.7	47.0	0.4	0.1	-	-	-	-	92.5	55.0	0.2	<0.1

(a) Water quality parameters and bed volume taken on 04/01/09.
(b) Water quality parameters taken on 04/17/09.
(c) Water quality parameters taken on 04/24/09.

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

Sampling Date		4/15/09[b]				04/29/09[c]				05/14/09				06/04/09			
Sampling Location / Parameter	Unit	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT
Bed Volume	10^3		-		-		-		-		-		-		-		-
Alkalinity (as $CaCO_3$)	mg/L	261	256	265	267	271	271	271	275	296	293	293	296	282	295	274	280
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	0.1	0.1	<0.05	<0.05	0.1	0.1	<0.05	<0.05	0.1	0.1	<0.05	<0.05	0.1	0.1	<0.05	<0.05
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	0.2	0.3	0.2	0.2	-	-	-	-	0.3	0.3	0.3	0.2
Sulfate	mg/L	-	-	-	-	2.0	2.0	2.0	2.0	-	-	-	-	1.9	1.8	2.0	2.0
Nitrate (as N)	mg/L	-	-	-	-	<0.05	<0.05	<0.05	0.4	-	-	-	-	0.1	<0.05	<0.05	<0.05
Total P (as P)	µg/L	<10	<10	<10	<10	14.9	14.3	<10	<10	12.3	13.8	<10	<10	11.3	11.7	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	20.1	22.5	20	20.8	23.3	23.2	22.8	23.8	21.5	21.6	21.4	21.6	21.1	20.8	20.9	20.7
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	8.0	0.6	0.7	0.2	7.6	0.7	0.8	0.8	7.6	0.4	<0.1	<0.1	8.1	0.5	0.8	0.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	7.6	7.5	7.3	7.4	7.3	7.4	7.3	7.3	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	9.8	9.9	10.8	10.9	11.6	12.5	13.6	14.1	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	212	492	402	479	330	345	354	365	NA	NA	NA	NA	NA	NA	NA	NA
Free Chlorine (as Cl_2)	mg/L	-	0.3	0.1	0.0	-	0.7	0.2	0.1	-	1.0	0.3	0.2	-	NA	NA	NA
Total Chlorine (as Cl_2)	mg/L	-	0.9	0.2	0.1	-	0.8	0.5	0.2	-	0.6	0.2	0.2	-	NA	NA	NA
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	252	263	262	272	-	-	-	-	241	247	256	258
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	154	162	162	171	-	-	-	-	157	163	170	170
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	98.7	101	99.5	101	-	-	-	-	83.7	83.7	86.2	87.6
As (total)	µg/L	22.2	21.9	3.1	<0.1	23.9	25.0	3.5	<0.1	26.4	26.7	3.8	0.2	30.9	29.6	4.2	0.2
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	21.3	11.3	3.6	0.3	-	-	-	-	26.0	8.9	3.7	0.1
As (particulate)	µg/L	-	-	-	-	2.6	13.7	<0.1	<0.1	-	-	-	-	4.9	20.7	0.6	<0.1
As (III)	µg/L	-	-	-	-	18.5	0.2	0.1	0.1	-	-	-	-	22.6	0.3	0.3	0.3
As (V)	µg/L	-	-	-	-	2.8	11.1	3.5	0.2	-	-	-	-	3.3	8.6	3.3	<0.1
Fe (total)	µg/L	643	649	<25	<25	798	810	<25	<25	824	833	<25	<25	754	748	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	213	156	<25	<25	-	-	-	-	724	<25	<25	<25
Mn (total)	µg/L	64.5	64.2	0.8	0.3	87.5	89.9	0.4	<0.1	88.9	88.0	0.3	0.1	89.0	85.3	<0.1	<0.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	85.9	52.0	0.4	<0.1	-	-	-	-	86.1	38.7	<0.1	<0.1

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

Sampling Date		06/10/09				07/01/09				07/28/09				09/15/09			
Sampling Location Parameter	Unit	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT	IN	AC	OT	TT
Bed Volume	10^3	-			-	-			-	-			-	-			-
Alkalinity (as $CaCO_3$)	mg/L	289	293	291	284	301	294	292	283	274	274	272	281	-	-	-	-
		291	293	289	282	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	0.2	0.1	<0.05	<0.05	0.2	0.1	<0.05	<0.05	0.2	0.1	<0.05	<0.05	0.2	0.1	<0.05	<0.05
		0.13	0.08	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	0.2	0.3	0.4	0.2	0.3	0.2	0.2	0.3	-	-	-	-
Sulfate	mg/L	-	-	-	-	1.9	2.1	2.0	2.0	2.1	2.4	4.5	2.3	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	<0.05	<0.05	<0.05	<0.05	0.1	<0.05	<0.05	<0.05	-	-	-	-
Total P (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	12.6	14.7	<10	<10	13.5	11.9	<10	<10
		<10	<10	<10	<10	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	20.6	20.4	20.6	20.5	20.2	20.1	19.9	19.7	20.4	20.4	20.6	18.3	-	-	-	-
		21.1	20.8	20.7	20.5	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	8.5	0.9	0.2	0.2	4.6	0.9	0.1	<0.1	5.9	0.9	0.2	0.4	-	-	-	-
		8.4	0.9	0.2	0.4	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Free Chlorine (as Cl_2)	mg/L	-	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA
Total Chlorine (as Cl_2)	mg/L	-	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	284	287	283	285	263	258	263	262	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	188	194	190	189	167	161	164	161	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	95.4	93.2	92.5	95.8	95.3	96.9	98.2	102	-	-	-	-
As (total)	µg/L	29.3	29.0	4.9	0.2	26.8	25.2	4.4	<0.1	25.6	26.9	2.5	<0.1	32.2	30.1	4.6	0.5
		28.0	29.0	5.0	0.1	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	24.1	5.2	4.0	<0.1	21.5	6.7	2.2	<0.1	27.7	10.3	4.2	1.0
As (particulate)	µg/L	-	-	-	-	2.6	20.0	0.4	<0.1	4.2	20.2	0.4	<0.1	4.5	19.8	0.4	<0.1
As (III)	µg/L	-	-	-	-	17.2	0.2	0.2	<0.1	17.7	<0.1	<0.1	<0.1	21.8	0.8	0.7	0.7
As (V)	µg/L	-	-	-	-	6.9	5.0	3.9	<0.1	3.7	6.6	2.1	<0.1	6.0	9.5	3.6	0.3
Fe (total)	µg/L	755	731	<25	<25	863	740	40	<25	695	717	<25	<25	736	746	<25	<25
		732	725	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	788	39.3	35.5	<25	546	111	<25	<25	724	108	<25	<25
Mn (total)	µg/L	89.0	84.5	2.0	<0.1	74.0	70.1	1.8	0.7	78.2	78.6	0.3	0.2	85.3	84.2	1.1	1.0
		85.0	85.4	2.0	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	74.7	23.7	1.6	0.9	79.6	51.0	0.4	0.2	89.2	51.5	0.3	0.2

APPENDIX C
AD26 MEDIA BACKWASH DATA

Table C-1. Backwash Times, Backwash Frequency, and Amounts of Wastewater Produced During AD26 Backwash

Date	Vessel A		Vessel B		Vessel C		Amounts Wastewater Produced (gal)
	Time Backwashed	No. of Hours from Last Backwash	Time Backwashed	No. of Hours from Last Backwash	Time Backwashed	No. of Hours from Last Backwash	
06/06/08	All three vessels backwash once manually						
07/03/08	All three vessels backwash once manually						
07/04/08	All three vessels backwash once manually						
08/20/08	All three vessels backwash once manually						890
08/25/08	12:00						
08/26/08			01:00		00:00		1,020
08/27/08	12:00	48					
08/28/08							
08/29/08			01:00	72			
08/30/08	12:00	72					78(?)
08/31/08					02:00	98	
09/01/08			01:00	72			
09/02/08	12:00	72					146
09/03/08					03:00	73	136
09/04/08			02:00	73			249(?)
09/05/08	13:00	73					
09/06/08					03:00	72	
09/07/08			02:00	72			19(?)
09/08/08	13:00	72					
09/09/08					03:00	72	2(?)
09/10/08			02:00	72			11(?)
09/11/08							0
09/12/08	13:00	96			03:00	72	13(?)
09/13/08			02:00	72			
09/14/08							0
09/15/08	13:00	72			03:00	72	3(?)
09/16/08			02:00	72			
09/17/08							
09/18/08	13:00	72			03:00	72	736
09/19/08			02:00	72			
09/20/08							934
09/21/08							
09/22/08	11:00	94	00:00	70	01:00	94	
09/23/08							
09/24/08							1,265
09/25/08	√	-	√	-	√	-	
09/26/08							
09/27/08							
09/28/08	13:00	-	02:00	-	03:00	-	
09/29/08							
09/30/08							0
10/01/08	13:00	72	02:00	72	03:00	72	2,232
10/02/08							
10/03/08							
10/04/08	√	-			√	-	
10/05/08			08:00	102			
10/06/08							
10/07/08	22:00	-			12:00	-	
10/08/08			√	-			
10/09/08							506
10/10/08					14:00	74	
10/11/08	14:00	84	13:00	-			
10/12/08	15:00	25					
10/13/08					14:00	72	218
10/14/08			13:00	72			0(?)
10/15/08	00:00	57					
10/16/08							

Table C-1. Backwash Times, Backwash Frequency, and Amounts of Wastewater Produced During AD26 Backwash (Continued)

Date	Vessel A		Vessel B		Vessel C		Amounts Wastewater Produced (gal)
	Time Backwashed	No. of Hours from Last Backwash	Time Backwashed	No. of Hours from Last Backwash	Time Backwashed	No. of Hours from Last Backwash	
10/17/08					√	-	4,630
10/18/08			√	-			
10/19/08	√	-					
10/20/08					√	-	
10/21/08			√	-			
10/22/08	√	-					
10/23/08					√	-	
10/24/08			√	-			
10/25/08	√	-					
10/26/08					√	-	
10/27/08			√	-			
10/28/08	√	-					
10/29/08					√	-	
10/30/08			√	-			
10/31/08	√	-					
11/01/08					√	-	
11/02/08			√	-			
11/03/08	12:00	-					
11/04/08					02:00	-	
11/05/08			01:00	-			
11/06/08	11:00	71					0(?)
11/07/08					√	-	220(?)
11/08/08							
11/09/08	12:00	73					
11/10/08					02:00	-	
11/11/08			00:00	-			
11/12/08	12:00	72					0(?)
11/13/08					02:00	72	10(?)
11/14/08			01:00	73			0(?)
11/15/08	11:00	71					874
11/16/08					01:00	71	
11/17/08			00:00	71			
11/18/08	12:00	73					28(?)
11/19/08					02:00	73	
11/20/08			00:00	72			51
11/21/08	12:00	72					8(?)
11/22/08							
11/23/08			01:00	73			
11/24/08	12:00	72					
11/25/08					02:00	-	
11/26/08			00:00	71			0(?)
11/27/08	√	-					12(?)
11/28/08							
11/29/08			00:00	72			
11/30/08	11:00	-					
12/01/08					01:00	-	
12/02/08			00:00	72			1(?)
12/03/08	11:00	72					0(?)
12/04/08					01:00	72	
12/05/08			00:00	72			
12/06/08	02:00	75			16:00	63	0(?)
12/07/08							
12/08/08	18:00	64	01:00	73			
12/09/08							5(?)
12/10/08					01:00	81	
12/11/08			00:00	71			0(?)
12/12/08	15:00	93					704
12/13/08					00:00	72	
12/14/08			00:00	72			
12/15/08	12:00	69					643

Table C-1. Backwash Times, Backwash Frequency, and Amounts of Wastewater Produced During AD26 Backwash (Continued)

Date	Vessel A		Vessel B		Vessel C		Amounts Wastewater Produced (gal)
	Time Backwashed	No. of Hours from Last Backwash	Time Backwashed	No. of Hours from Last Backwash	Time Backwashed	No. of Hours from Last Backwash	
12/16/08					02:00	74	
12/17/08			01:00	73			
12/18/08	08:00	68	08:00	31	09:00	55	544
12/19/08							
12/20/08	12:00	52					597
12/21/08			01:00	65	02:00	65	
12/22/08							
12/23/08	√	-					
12/24/08			00:00	71	01:00	71	758
12/25/08							
12/26/08	11:00	-					
12/27/08			√	-	√	-	1,572
12/28/08							
12/29/08	√	-					
12/30/08			√	-	√	-	
12/31/08							
01/01/09	11:00	-					
01/02/09			00:00	-	01:00	-	
01/03/09							509
01/04/09	11:00	72					
01/05/09			00:00	72	01:00	72	
01/06/09							170
01/07/09	13:00	74					
01/08/09			00:00	72	01:00	72	305
01/09/09							
01/10/09	13:00	72					391
01/11/09			01:00	73	02:00	73	
01/12/09							
01/13/09	11:00	70	00:00	47			451
01/14/09					01:00	71	
01/15/09	23:00	60	00:00	48			498
01/16/09							
01/17/09					02:00	73	724
01/18/09			01:00	73			
01/19/09	00:00	73					
01/20/09					01:00	71	411
01/21/09			00:00	71			
01/22/09	15:00	87	15:00	39			1,154(?)
01/23/09					02:00	73	
01/24/09	23:00	56					856
01/25/09			00:00	57			
01/26/09					01:00	71	
01/27/09	23:00	72					418
01/28/09			00:00	72			
01/29/09					01:00	72	189
01/30/09	√	-					
01/31/09			√	-			970
02/01/09					√	-	
02/02/09	23:00	-					
02/03/09			00:00	-			
02/04/09					01:00	-	
02/05/09	23:00	72					73(?)
02/06/09			00:00	72			
02/07/09					√	-	196(?)
02/08/09	23:00	72					
02/09/09			00:00	72			
02/10/09					01:00	-	
02/11/09							0
02/12/09	00:00	74	01:00	73			74(?)
02/13/09					02:00	73	
02/14/09	23:00	71					45(?)

Table C-1. Backwash Times, Backwash Frequency, and Amounts of Wastewater Produced During AD26 Backwash (Continued)

Date	Vessel A		Vessel B		Vessel C		Amounts Wastewater Produced (gal)
	Time Backwashed	No. of Hours from Last Backwash	Time Backwashed	No. of Hours from Last Backwash	Time Backwashed	No. of Hours from Last Backwash	
02/15/09			00:00	71			
02/16/09					01:00	71	
02/17/09	23:00	72					269?)
02/18/09			00:00	72	10:00	57	
02/19/09							83(?)
02/20/09							
02/21/09	02:00	75	03:00	75	04:00	66	25(?)
02/22/09							
02/23/09							
02/24/09	01:00	71	02:00	71	03:00	71	711
02/25/09							
02/26/09							708
02/27/09	02:00	73	03:00	73	04:00	73	
02/28/09							696
03/01/09							
03/02/09	01:00	71	02:00	71	03:00	71	
03/03/09							0
03/04/09							
03/05/09	01:00	72	02:00	72	03:00	72	673
03/06/09							
03/07/09							657
03/08/09	01:00	72	02:00	72	03:00	72	
03/09/09							
03/10/09							644
03/11/09	03:00	74	04:00	74	05:00	74	
03/12/09							371(?)
03/13/09							2,421
03/14/09	√	-	√	-	√	-	
03/15/09							
03/16/09		-	√	-	√	-	
03/17/09	√						
03/18/09							
03/19/09			√	-	√	-	
03/20/09	√	-					
03/21/09							
03/22/09			03:00	-	04:00	-	
03/23/09	02:00	-					
03/24/09							325
03/25/09			03:00	72	04:00	72	
03/26/09	02:00	72					157
03/27/09							
03/28/09			03:00	72	04:00	72	556
03/29/09	02:00	72					
03/30/09							
03/31/09			02:00	71	03:00	71	395
04/01/09	01:00	71					
04/02/09							205
04/03/09			03:00	73	04:00	73	
04/04/09	√	-					1,045
04/05/09							
04/06/09			√	-	√	-	
04/07/09	√	-					
04/08/09							
04/09/09			√	-	√	-	
04/10/09	√	-					
04/11/09							
04/12/09			04:00	-	05:00	-	
04/13/09	03:00	-					
04/14/09							28
04/15/09	22:00	-	04:00	72	05:00	72	1,400(?)
04/16/09							

Table C-1. Backwash Times, Backwash Frequency, and Amounts of Wastewater Produced During AD26 Backwash (Continued)

Date	Vessel A		Vessel B		Vessel C		Amounts Wastewater Produced (gal)
	Time Backwashed	No. of Hours from Last Backwash	Time Backwashed	No. of Hours from Last Backwash	Time Backwashed	No. of Hours from Last Backwash	
04/17/09							
04/18/09	√	-	√	-	√	-	687
04/19/09							
04/20/09							
04/21/09	02:00	-	03:00	-	04:00	-	
04/22/09							0
04/23/09	02:00	48	04:00	49	04:00	48	670
04/24/09							
04/25/09							1,988
04/26/09	√	-	√	-	√	-	
04/27/09							
04/28/09							
04/29/09	√	-	√	-	√	-	
04/30/09							
05/01/09							
05/02/09							
05/03/09	02:30	-	03:30	-	04:30	-	
05/04/09							
05/05/09							1,009
05/06/09	14:30	84	15:30	84	16:30	84	
05/07/09							
05/08/09							
05/09/09	03:00	60.5	04:00	60.5	05:00	60.5	
05/10/09							
05/11/09							
05/12/09	02:00	71	03:00	71	04:00	71	
05/13/09							
05/14/09							
05/15/09	03:00	-	√	-	√	-	630
05/16/09							
05/17/09			03:00	-	04:00	-	
05/18/09	02:00	71					1,158(?)
05/19/09							
05/20/09			03:00	72	04:00	72	237(?)
05/21/09	02:00	72					
05/22/09							
05/23/09			03:00	72	04:00	72	667
05/24/09	02:00	72					
05/25/09							490
05/26/09			04:00	73	04:00	72	
05/27/09	03:00	73					560(?)
05/28/09							1,426
05/29/09	√	-	√	-	√	-	
05/30/09							
05/31/09	01:00	-	02:00	-	03:00	-	
06/01/09							222(?)
06/02/09							
06/03/09	01:00	72	02:00	72	03:00	72	
06/04/09							1,278
06/05/09							
06/06/09	01:00	72					
06/07/09			02:00	96	03:00	96	
06/08/09							856
06/09/09	01:00	72					
06/10/09			02:00	72	03:00	72	
06/11/09							1,569
06/12/09	√	-					
06/13/09			02:00	72	03:00	72	
06/14/09	01:00	-					
06/15/09							1,108
06/16/09			√	-	√	-	

Table C-1. Backwash Times, Backwash Frequency, and Amounts of Wastewater Produced During AD26 Backwash (Continued)

	Vessel A		Vessel B		Vessel C		Amounts Wastewater Produced (gal)
Date	Time Backwashed	No. of Hours from Last Backwash	Time Backwashed	No. of Hours from Last Backwash	Time Backwashed	No. of Hours from Last Backwash	
06/17/09	00:00	71					
06/18/09							
06/19/09			01:00	-	02:00	-	

√ = data not available but believed that vessel had been backwashed;
- = hours from last backwash could not be calculated;
(?) = data questionable.