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Arsenic Removal from Drinking Water by Coagulation/Filtration U.S. EPA Demonstration Project at Conneaut Lake Park in Conneaut Lake, PA Final Performance Evaluation Report

by

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Sally Gutierrez, Director
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ABSTRACT

This report documents the activities performed and the results obtained from the arsenic removal treatment technology demonstration project at Conneaut Lake Park (the Park) in Conneaut Lake, PA. The main objective of the project was to evaluate the effectiveness of AdEdge Technologies' (AdEdge) coagulation/filtration (C/F) system, using GreensandPlus™ media (branded as AD-GS$^+$ by AdEdge), 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 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.

The community water system (CWS) was supplied primarily by one groundwater well (i.e., Well No. 2) to meet an average daily and a maximum demand of 124,000 and 231,000 gal/day (gpd), respectively. The daily demand changed seasonally with visitors to the park during the summer months. Total arsenic concentrations in source water ranged from 26.8 to 37.3 μg/L and averaged 29.0 μg/L. Soluble As(III) was the predominating arsenic species, with concentrations ranging from 11.3 to 30.8 μg/L and averaging 26.2 μg/L. Total iron concentrations in source water averaged only 188 μg/L with 78% existing in the soluble form. Therefore, iron addition was necessary to facilitate arsenic removal.

The system consisted of three 54-in × 60-in in-parallel, epoxy-lined, carbon steel vessels rated for 100 psi operating pressure. Each vessel contained approximately 6.5 ft^3 of gravel overlain by 39 ft^3 of GreensandPlus™ and 6 ft^3 of anthracite #1 (compared to 11.5, 32, and 16 ft^3 of gravel, GreensandPlus™, and anthracite #1, respectively, by design). GreensandPlus™ is a black, granulated media with a silica sand core coated with manganese dioxide (MnO_2) for iron and manganese removal from drinking water supplies.

The treatment system was designed for a peak flowrate of 250 gal/min (gpm) (83.3 gpm per vessel). Because of the high pressure (i.e., >100 lb/in^2 [psi]) produced by the well pump and to prevent damage to the filtration vessels, the pressure and flowrate were reduced to no greater than 95 psi and 190 gpm (63.3 gpm/vessel) using a Cla-Valve model 49-01 pressure/flow-reducing valve. The reduced flowrate was within the permitted system flowrate of 200 gpm by the Pennsylvania Department of Environmental Protection (DEP) and corresponded to a filtration rate of 4.0 gpm/ft^2 with all three filters online and 5.3 gpm/ft^2 with two filters online and one in backwash.

The pre-existing gas chlorination system was replaced with a liquid sodium hypochlorite (NaOCl) system consisting of a 75-gal day tank and a metering pump that was pulse controlled by a programmable logic control (PLC). Sodium hypochlorite (NaOCl) was injected prior to the pressure/flow-reducing valve to oxidize soluble As(III) to soluble As(V) and maintain a total chlorine residual of 0.3 to 0.5 mg/L (as Cl_2) in the distribution system. Iron was added in the form of ferric chloride ($FeCl_3$) after the pressure/flow-reducing valve and prior to the filtration vessels to supplement natural iron in Well No. 2 water. The addition of iron aided in the formation of arsenic-laden solids, which were filtered by GreensandPlus™ media. The iron addition system consisted of a 75-gal day tank and a metering pump that also was pulse controlled by the PLC.

From December 03, 2009, through the end of the performance evaluation study on December 17, 2010, the treatment system operated for a total of 2,414 hr, treating approximately 20,114,000 gal of water. The average daily run time was 11.9 hr/day when the Park was in operation and 4.3 hr/day when the Park was not in operation. Flowrates through the filtration vessels were 53, 49, and 51 gpm for Vessels A, B, and

C, respectively, based on readings from a flow meter/totalizer installed on each vessel. Average filtration rates for Vessels A, B, and C were 3.3, 3.1, and 3.2 gpm/ft^2, respectively.

Following chlorination and iron addition (with an average dosage of 1.8 mg/L [as Fe]), soluble As(III) concentrations were significantly reduced to 0.2 µg/L while particulate arsenic concentrations were correspondingly increased to 27.8 µg/L. Except for two sampling events where iron was not added due to malfunctioning of the metering pump, removal of arsenic-laden iron particles by the GreensandPlus™ filters was effective, reducing total concentrations to 2.8 µg/L (on average). Iron leakage, however, was observed; concentrations as high as 506 µg/L (or 64 µg/L [on average]) were measured in the filter effluent. The C/F system also reduced total manganese concentrations from 64.3 µg/L (all in the soluble form) in source water to 2.4 µg/L (on average).

Results of a run length study indicated that arsenic breakthrough at 10 µg/L from a filter occurred after 43.5 hr in service. However, iron breakthrough at 300 µg/L occurred much earlier at 26.6 hr. To maintain reasonably good water quality, the filters must be backwashed no less than once every 26 hr. Because the average daily run time was 11.9 hr/day when the Park was in operation and 4.3 hr/day when the Park was not in operation, the filters required backwashing once every 2 to 3 days when the Park was in operation and once every 6 days when the Park was not in operation.

During the performance evaluation study, each of the three filtration vessels was backwashed 85 times (on average). Backwash could be initiated manually or automatically with a time, a throughput, or a differential pressure (Δp) setpoint. Time was chosen as the setpoint during most of system operation. Backwash of a vessel included a 9-min upflow wash and a 1-min downflow rinse both at 184 gpm (on average), producing 1,840 gpm of wastewater per vessel or 5,520 gal per event. Solids produced were 3.5 kg per vessel, consisting of 0.3 to 0.5% (by weight) of arsenic, 36.3 to 37.4% of iron, and 1.3 to 3.3% of manganese. Backwash wastewater produced was discharged into two 4,000-gal holding tanks. After settling for at least 4 hr, the supernatant was recycled to the header of the filtration skid and the sludge after accumulating was discharged to a sewer.

Comparison of the distribution system sampling results before and after system startup showed a decrease in arsenic concentration (i.e., from 10.6 to 5.0 µg/L [on average]). Iron concentrations were elevated after system startup apparently due to iron leakage through the filtration vessels. Iron particles that penetrated through the filters significantly increased arsenic concentrations in two instances. Manganese concentrations were reduced to below the secondary maximum contaminant level (SMCL). Lead and copper levels increased slightly but were significantly lower than the respective action levels.

The capital investment cost for the system was $191,970, including $136,744 for equipment, $21,726 for site engineering, and $33,500 for installation. Using the system's rated capacity of 250 gpm (360,000 gal/day [gpd]), the normalized capital cost was $768/gpm ($0.53/gpd). The O&M cost was $0.48/1,000 gal and only included the cost associated with chemical addition, electricity consumption, and labor.

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FIGURES

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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
Ca	calcium
Cl	chloride
CLJMA	Conneaut Lake Joint Municipal Authority
C/F	coagulation/filtration
CRF	capital recovery factor
CWS	community water system
DBP	disinfection byproduct
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
HDPE	high-density polyethylene
HIX	hybrid ion exchanger
hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IR	iron removal
IX	ion exchange
LCR	Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MEI	Magnesium Elektron, Inc.
Mg	magnesium
Mn	manganese
mV	millivolts

ABBREVIATIONS AND ACRONYMS (Continued)

Na	sodium
NA	not analyzed
NaOCl	sodium hypochlorite
NPDES	National Pollutant Discharge Elimination System
NRMRL	National Risk Management Research Laboratory
NS	not sampled
NSF	NSF International
NTU	nephelometric turbidity unit
O&M	operation and maintenance
OIP	operator interface panel
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
P&ID	piping and instrumentation diagram
PA DEP	Pennsylvania Department of Environmental Protection
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 proposals
RO	reverse osmosis
RPD	relative percent difference
Sb	antimony
SDWA	Safe Drinking Water Act
SiO_2	silica
SMCL	secondary maximum contaminant level
SO_4	sulfate
STS	Severn Trent Services
TDH	total dynamic head
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 subsequently 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 250-gal/min (gpm) coagulation/filtration (C/F) system designed and fabricated by AdEdge Technologies (AdEdge) was selected for demonstration at Conneaut Lake Park in Conneaut Lake, PA. AD-GS$^+$ (GreensandPlus™) was used as the filtration media.

As of May 2011, all 50 systems were operational and the performance evaluations of 49 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), 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 flow rates, 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 treatment system at the Conneaut Lake Park in Conneaut Lake, PA, from December 3, 2009 through, December 17, 2010. The types of data collected include 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 and Sewer District	AM (E33)	AdEdge	100	36[a]	46	8.2
Dummerston, VT	Charette Mobile Home Park	AM (A/I Complex)	ATS	22	30	<25	7.9
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
Buckeye Lake, 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	Northeastern 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
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

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.)
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) Selected originally to replace Village of Lyman, NE site, which withdrew from program in June 2006; withdrew from program in 2007 and replaced with a home system in Lewisburg, OH.

(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

AdEdge's C/F system using AD-GS+ (GeensandPlus™) media has operated at Conneaut Lake Park in Conneaut Lake, PA since December 3, 2009. 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 soluble As(III) and soluble Fe(II), reducing their concentrations from 26.2 to 2.9 μg/L and from 146 to <25 μg/L, respectively (on average), prior to filtration.
- Addition of supplemental iron was effective in converting soluble As(V) to arsenic-laden iron solids, significantly decreasing and increasing respective concentrations (to 2.6 and 27.8 μg/L [on average]) prior to filtration. The average iron dosage of 1.8 mg/L (as Fe) appeared to be adequate.
- GreensandPlus™ media effectively removed arsenic-laden iron solids, reducing arsenic concentrations to <2.8 μg/L (on average). Without iron addition, as much as 15.2 μg/L of total arsenic was measured in the filter effluent with most existing as soluble As(V).
- Iron leakage from the filtration vessels was an issue; concentrations as high as 506 μg/L were measured in one instance (or 64 μg/L [on average]). Based on a run length study, 300 μg/L of iron penetrated through the filtration vessels after 26.6 hr of filter run time. In contrast, arsenic breakthrough at 10 μg/L did not occur until 43.5 hr.
- Chlorine effectively oxidized soluble manganese to, presumably, MnO_2, reducing soluble manganese concentrations from 64.9 to 16.4 μg/L (on average). Manganese was effectively removed by GreensandPlus™, leaving only 2.3 μg/L in the filter effluent.
- To maintain acceptable water quality, the system required backwashing once every 26 hr of system operation. A desired backwash frequency was once every 2 to 3 days when the Park was in operation and once every six days when the Park was not in operation. This is based on an average daily run time of 11.9 hr when the Park was in operation and 4.3 hr when the Park was not in operation.
- The operation of the treatment system significantly lowered arsenic concentrations in the distribution system (from 10.6 to 5.0 μg/L [on average]). Elevated arsenic levels (21.4 and 18.0 μg/L) were observed in two instances; both appeared to be associated with iron leakage (2,758 and 600 μg/L, respectively).
- Lead and copper levels in the distribution system increased slightly from the respective baseline levels, but were significantly lower than the respective action levels.

Required system O&M and operator skill levels:

- The daily demand on the operator was typically 1 hr to visually inspect the system and record operational parameters.
- The operator occasionally had to spend extra time to resolve issues related to backwash wastewater recycling and sludge discharge.

Process residuals produced by the technology:

- Residuals produced by the operation of the treatment system consisted of only backwash wastewater.
- Approximately 1,840 gal of wastewater and 3.5 kg of solids were discharged into two backwash holding tanks during backwash of each filtration vessel. The solids consisted of 0.3 to 0.5% (by weight) of arsenic, 36.3 to 37.4% of iron, and 1.3 to 3.3% of manganese.

Capital and O&M cost of the technology:

- The capital investment for the system was $191,970, including $136,744 (or 71%) for equipment, $21,726 (or 11%) for site engineering, and $33,500 (or 18%) for installation, shakedown, and startup.
- The unit capital cost was $768/gpm (or $0.53 gal/day [gpd]) based on a 250-gpm design capacity.
- The O&M cost was $0.48/1,000 gal, which included the incremental cost for chemicals, electricity and labor.

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 C/F system began on December 3, 2009, and ended on December 17, 2010. 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, 2009). 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 Activities and Completion Dates

Activity	Date
Introductory Meeting Held	10/27/2006
Letter Report Issued	01/23/2007
Technology Selection Meeting Held	07/19/2007
Project Planning Meeting Held	11/15/2007
Draft Letter of Understanding Issued	12/04/2007
Final Letter of Understanding Issued	12/27/2007
Request for Quotation Issued to Vendor	12/28/2008
Vendor Quotation Received by Battelle	01/21/2009
Purchase Order Completed and Signed	04/03/2009
Engineering Package Submitted to PA DEP	06/24/2009
Building Construction Began	07/09/2009
Equipment Arrived at Site	07/31/2009
System Permit Issued by PA DEP	09/03/2009
Building Construction Completed	10/09/2009
System Installation Completed	10/23/2009
System Shakedown Completed	11/06/2009
Study Plan Issued	11/11/2009
Performance Evaluation Began	12/03/2009

PA DEP = Pennsylvania Department of Environmental Protection

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.

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

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

3.2 System O&M and Cost Data Collection

The plant operator performed daily, biweekly, and monthly system O&M and data collection according to instructions provided by the vendor and Battelle. On a 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. During each sampling event, 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 of 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.

Table 3-3. Sampling Schedule and Analytes

Sample Type	Sample Locations[a]	No. of Samples	Frequency	Analytes	Sampling Date
Source Water	Well No. 2	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), Na, Ca, Mg, V, Cl, F, NO_3, NO_2, NH_3, SO_4, SiO_2, PO_4, P, turbidity, alkalinity, TDS, and TOC	10/27/06
Treatment Plant Water (Speciation)	IN, BF, and TT	3	Monthly[b]	Onsite: pH, temperature, DO, ORP, and total and free Cl_2 (except at 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, alkalinity, and TOC	12/03/09, 01/04/10, 01/27/10, 02/24/10, 03/23/10, 04/19/10, 05/17/10, 06/14/10, 07/13/10, 08/09/10, 09/07/10, 10/05/10, 11/02/10, 12/07/10
Treatment Plant Water (Regular)	IN, BF, TA, TB, TC, and TT	6	Monthly[b]	Onsite: pH, temperature, DO, ORP, and total and free Cl_2 (except at IN)[c] Offsite: As (total), Fe (total), Mn (total), NO_3, NH_3, SiO_2, P, turbidity, and alkalinity	12/14/09, 01/07/10, 02/10/10, 03/08/10, 04/05/10, 05/03/10, 06/01/10, 06/28/10, 07/26/10, 08/23/10, 09/20/10
Distribution System Water[d]	Three LCR Locations (DS)	3	Monthly	As (total), Fe (total), Mn (total), Cu, Pb, pH, and alkalinity	12/15/09, 01/08/10, 02/11/10, 03/09/10, 04/06/10, 05/04/10, 06/02/10, 06/28/10, 07/27/10, 08/24/10, 09/21/10
Backwash Water	Backwash Discharge Line (BW)	2	Monthly	As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, TDS, and TSS	01/04/10, 01/27/10, 02/24/10, 03/23/10, 04/19/10, 05/18/10, 06/16/10, 07/12/10, 08/10/10, 09/08/10, 10/06/10
Backwash Solids	Wastewater Sample Container	4	Once	As, Ba, Ca, Fe, Mg, Mn, P, Si	01/27/10

(a) Abbreviations in parenthesis corresponding to sample locations shown in Figure 4-5, i.e., IN = at Wellhead; BF = before filtration; TA/TB/TC = after Vessels A/B/C; TT = after effluent from Vessels A, B, and C combined; BW = backwash discharge line; DS = distribution system.
(b) Alternating between speciation and regular sampling.
(c) Only at IN, BF, and TT.
(d) Four baseline sampling events took place from 09/17/09 through 10/08/09 prior to system startup.
DO = dissolved oxygen; ORP = oxidation/reduction potential; TDS = total dissolved solids; TOC = total organic carbon; TSS = total suspended solids

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected from the wellhead, across the treatment plant, during backwash of the GreensandPlus™ filtration vessels, 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 October 27, 2006, one set of source water samples from Well No. 2 was collected and speciated using an arsenic speciation kit (see Section 3.4.1). The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Analytes for the source water samples are listed in Table 3-3.

3.3.2 Treatment Plant Water. The Battelle Study Plan called for sampling of treatment plant water once every two weeks, with "speciation sampling" performed during the first week of each four-week cycle and "regular sampling" performed during the third week of each four week cycle. Regular sampling involved taking samples at the wellhead (IN), before filtration (BF), and after Vessels A, B, and C (TA, TB, and TC) and having them analyzed for the analytes listed under regular sampling in Table 3-3. Speciation sampling involved collecting and speciating samples at IN, BF, and after effluent from the three filtration vessels combined (TT) and having them analyzed for the analytes listed under speciation sampling in Table 3-3.

During the performance evaluation study, both speciation and regular sampling took place once a month, except for the month of January and June 2010 when speciation and regular sampling, repsectively, were performed twice. In general, sampling alternated between speciation and regular sampling.

3.3.3 Backwash Wastewater and Solids. The plant operator collected backwash wastewater samples from each vessel on 11 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 contents in the container were thoroughly mixed, one aliquot was collected as is and the other filtered with 0.45-μm disc filters. The samples were analyzed for the analytes listed in Table 3-3.

Once during the one-year study period, the contents in the 32-gal plastic container were allowed to settle and the supernatant was carefully siphoned using a piece of plastic tubing to avoid agitating the settled solids in the container. The remaining solids/water mixture was then transferred to a 1-gal plastic jar. After the 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 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 system startup from September 17 through October 8, 2009, four sets of baseline samples were collected from three locations within the distribution system. Following system startup, distribution system water sampling continued on a monthly basis at the same three locations until September 21, 2010, after which it was discontinued.

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 sampling and of actual sample collection were recorded for calculating 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).

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

3.5 Analytical Procedures

The analytical procedures described in detail in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2007) were followed by Battelle 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 Preexisting Treatment System Infrastructure

Conneaut Lake Park (the Park) is a seasonal resort located at 12382 Center Street in Conneaut Lake, PA (Figure 4-1). The existing water treatment plant was built between 1980 and 1989 and is classified as a community water system (CWS). The plant is supplied by two groundwater wells (i.e., Wells No. 1 and No. 2), which are located on a 35-ft × 63-ft corner lot and approximately 1,500 ft from the Park on Route 618. Well No. 2 is the primary well, operating approximately 8 hr/day, while Well No. 1 operates minimally because of its high iron and particulate content. The wells are alternated manually, providing a source capacity no greater than 250 gpm. The Park's water system serves approximately 250 residents with an average daily production of 124,000 gpd and a maximum production of 231,000 gpd. The daily demand changes seasonally with the number of visitors to the Park.

The wells are located in separate well houses approximately 20 ft apart (Figures 4-2 and 4-3). Well No. 1 is 45 ft deep, with a 10-in-diameter steel casing screened from 5 to 45 ft below ground surface (bgs). Well No. 2 is 70 ft deep, consisting of a 16-in-diameter steel casing screened from 5 to 15 ft bgs and a 12-in-diameter steel casing screened from 15 to 70 ft bgs. The static water level in both wells is 3 ft bgs. The PA DEP hydrogeologist determined both wells to be in the same aquifer. Each well is equipped with an 8-in Deminc Vert turbine pump with an 11-stage impeller and a 25-horsepower (hp) motor. Both pumps are rated for 250 gpm at 280 ft of total dynamic head (TDH). Both wells are interlocked with level sensors in a 75,000-gal water tower located at the Park (Figure 4-4). The well control panels are located in Well House No. 1.

Figure 4.1. Conneaut Lake Park Arsenic Demonstration Site

Figure 4-2. Well Houses No. 1 (left) and No. 2 (right) at Conneaut Lake Park

Figure 4-3. Inside of Well Houses No. 1 (left) and No. 2 (right)

Prior to installation of the arsenic removal system, treatment consisted of gas chlorination and silica polyphosphate addition at the wellhead. Chlorine gas was added to the water to reach a target free chlorine residual level of 0.2 mg/L (as Cl_2) and a target total chlorine residual level of 0.5 mg/L (as Cl_2). The chlorinated water then flowed through a 20-in-diameter, 270-ft-long underground pipe loop, which provided approximately 20 min of contact time as required by PA DEP. A silica polyphosphate corrosion inhibitor (Corroban) was added to the water, with a daily usage of approximately 4 lb. The treated water supplied residents near the well houses, but the majority of water was transported via a 4-in-diameter, 800-ft-long transmission line to the 75,000-gal water tower and the Park.

Figure 4-4. 75,000-gal Water Tower at Conneaut Lake Park

Although a public sewer was available at both the well site and the Park, the Conneaut Lake Joint Municipal Authority (CLJMA) was unwilling to accept backwash wastewater generated from the arsenic treatment system. In a letter addressed to the Trustees of Conneaut Lake Park dated January 9, 2009, the CLJMA expressed its concerns over the backwash discharge. The concerns cited included the possibility of exceeding the hydraulic capacity of all pump stations involved with transporting the waste stream to the wastewater treatment plant and the increased load of iron, minerals, and trace metals that could adversely impact the biological treatment process and their National Pollutant Discharge Elimination System (NPDES) permit (which regulates their mandated influent and effluent analyses). A backwash recycling system was therefore considered by the Park to handle the waste.

4.1.1 Source Water Quality.

4.1.1 Source Water Quality. Source water and chlorinated water samples were collected from Well No. 2 and at the end of the chlorination pipe loop, respectively, on October 27, 2006, when Battelle staff traveled to the site to attend an introductory meeting for this demonstration project. Table 4-1 presents analytical results from the October 27, 2006, sampling event and compares them to data provided by EPA and PA DEP. Overall, Battelle's Well No. 2 source water data are comparable to those provided by EPA and PA DEP.

Table 4-1. Source Water Data for Conneaut Lake Park

Parameter	Unit	EPA Data			Battelle Data		PA DEP Data		
		Well No. 1 Raw Water	Well No. 2 Raw Water	Main Shop	Well No. 2 Raw Water	Chlorine Treated-Water	Well No. 1 Raw Water	Well No. 2 Raw Water	Well No. 2 Raw Water
Date		03/01/06			10/27/06		1984		10/14/05
pH	S.U.	NA	NA	NA	8.0	NA	NA	NA	6.8
Temperature	°C	NA	NA	NA	NA	9.9	NA	NA	NA
DO	mg/L	NA	NA	NA	3.1	1.5	NA	NA	NA
ORP	mV	NA	NA	NA	397	600	NA	NA	NA
Total alkalinity[(a)]	mg/L	NA	NA	NA	147	NA	136	132	119
Total hardness[(a)]	mg/L	142	124	130	154	NA	132	114	96
Turbidity	NTU	NA	NA	NA	1.5	NA	NA	NA	NA
TDS	mg/L	NA	NA	NA	170	NA	NA	NA	NA
TOC	mg/L	NA	NA	NA	<1.0	NA	NA	NA	0.7
Nitrate (as N)	mg/L	<0.02	<0.02	<0.02	<0.05	NA	NA	NA	NA
Nitrite (as N)	mg/L	0.05	<0.01	<0.01	<0.05	NA	NA	NA	NA
Ammonia (as N)	mg/L	<0.03	0.14	<0.03	0.14	NA	NA	NA	NA
Chloride	mg/L	NA	NA	NA	14	NA	5	5	60
Fluoride	mg/L	NA	NA	NA	0.2	NA	NA	NA	NA
Sulfate	mg/L	21.1	19.3	20.4	21.0	NA	16	8	20
Silica (as SiO_2)	mg/L	12.8	12.7	12.8	12.7	NA	NA	NA	10.6
Orthophosphate (as PO_4)	mg/L	<0.005	0.009	<0.005	<0.05	NA	NA	NA	NA
P (as PO_4)	mg/L	<0.2	<0.2	<0.2	<0.03	<0.03	NA	NA	0.02
Al (total)	μg/L	<25	<25	<25	NA	NA	NA	NA	NA
As (total)	μg/L	27	28	48	28.4	27.2	24	24	30
As (soluble)	μg/L	NA	NA	NA	28.0	14.5	NA	NA	NA
As (particulate)	μg/L	NA	NA	NA	0.4	12.7	NA	NA	NA
As(III)	μg/L	NA	NA	NA	25.8	NA	NA	NA	NA
As(V)	μg/L	NA	NA	NA	2.2	NA	NA	NA	NA
Fe (total)	μg/L	897	158	648	157	156	650	390	180
Fe (soluble)	μg/L	NA	NA	NA	151	<25	NA	NA	NA
Mn (total)	μg/L	83.1	57.1	76.2	61.0	47.0	130	70	40
Mn (soluble)	μg/L	NA	NA	NA	66.3	1.1	NA	NA	NA
Sb (total)	μg/L	<25	<25	<25	<0.1	<0.1	NA	NA	NA
Sb (soluble)	μg/L	NA	NA	NA	<0.1	<0.1	NA	NA	NA
V (total)	μg/L	NA	NA	NA	0.2	NA	NA	NA	NA
Na (total)	mg/L	13.7	16.2	15.6	15.5	NA	NA	NA	NA
Ca (total)	mg/L	40.9	36.0	37.8	50.0	NA	NA	NA	60.4
Mg (total)	mg/L	9.6	8.2	8.7	7.1	NA	NA	NA	8.7

(a) as $CaCO_3$.
DO = dissolved oxygen; NA = not available; ORP = oxidation/reduction potential; TDS = total dissolved solids; TOC = total organic carbon

Arsenic. Historically, total arsenic concentrations in Well No. 2 source water ranged from 24 to 30 μg/L (Table 4-1). Based on Battelle's October 27, 2006, speciation data, out of 28.4 μg/L of total arsenic, 25.8 μg/L (or 91%) existed as soluble As(III), 2.2 μg/L as soluble As(V), and 0.4 μg/L as particulate arsenic. Soluble As(III) must be oxidized to As(V) using an oxidant, such as chlorine, for more effective removal. No prior information on arsenic speciation is available. Overall, Battelle's and EPA's total arsenic results from Well No. 2 were within the historical range provided by PA DEP.

Iron and Manganese. When selecting the IR or C/F process for arsenic removal, the soluble iron concentration should be at least 20 times the soluble arsenic concentration to achieve effective treatment results (Sorg, 2002). Collectively, iron concentrations in Well No. 2 water ranged from 180 to 390 μg/L. Iron levels in Well No. 1 water were much higher, ranging from 650 to 897 μg/L. Based on Battelle's speciation results, iron existed mainly as soluble iron (151 μg/L or 96%), which was less than six times the soluble arsenic level. Due to low soluble iron concentrations in source water, supplemental iron addition had to be implemented for more effective arsenic removal.

Manganese concentrations in Well No. 2 water ranged from 40 and 70 μg/L, which existed almost entirely in the soluble form. After chlorination, manganese was oxidized to particulate MnO_2, leaving only 1.1 μg/L of soluble manganese in the chlorinated water. Manganese after oxidation may coat on MnO_x-coated media, such as greensand, as observed previously by Knocke et al. (1990) and by Cumming et al. (2009).

Competing Anions. Based on the results shown in Table 4-1, concentrations of silica (12.8 mg/L [as SiO_2] in Well No. 1 water and 10.6 to 12.7 mg/L [as SiO_2] in Well No. 2) and phosphate (below the MDL in Well No. 1 water and as high as 0.02 mg/L [as PO_4] in Well No. 2 water) did not appear to be high enough to impact the treatment process.

Other Water Quality Parameters. Battelle's data indicated a pH of 8.0 for Well No. 2 water, which was within the higher end of the commonly agreed target range of 5.5 to 8.5 for arsenic removal. Concentrations/readings of other parameters analyzed in Well No. 2 water included 96 to 154 mg/L (as $CaCO_3$) for total hardness, 1.5 nephelometric turbidity units (NTU) for turbidity, 170 mg/L for TDS, 5 to 60 mg/L for chloride, 0.2 mg/L for fluoride, and 15.5 to 16.2 mg/L for sodium. All other analytes were below detection limits and/or anticipated to be low enough not to adversely affect the arsenic removal process.

4.1.2 Distribution System. The distribution system has 184 domestic connections in two townships, including 62 in Sadsbury Township and 122 in Summit Township. The majority of these connections are to single family residences, except for three Sadsbury connections to multiple family residences with 13 units. In addition, the Park contains 16 commercial connections serving a high seasonal population of vacationers.

The Park samples water periodically from the distribution system for several parameters: monthly for bacteria; yearly for nitrate; once every 3 years for lead and copper (under the Lead and Copper Rule [LCR]), volatile organic compounds (VOCs), inorganics, and disinfection byproducts (DBPs). Three locations within the distribution system were sampled monthly four times before system startup for baseline data. After system startup, the same three locations were sampled monthly to evaluate the treatment system effects on the distribution system water quality.

4.2 Treatment Process Description

This section provides a general technology description and site-specific details of the AdEdge C/F system installed at Conneaut Lake Park.

4.2.1 Technology Description. AD-26 media was originally intended to be used in AdEdge's C/F system. However, the treatment system was unable to supply the necessary backwash flowrate for effective media expansion due to the flow restriction caused by a 4-in pipe that draws backwash water from the 75,000-gal water tower. A decision was then made to change the source of backwash water and use a media with a lower bulk density. The new source of backwash water was treated water from the two filtration vessels that were not being backwashed. The replacement media selected was GreensandPlus™ (branded as AD-GS+ by AdEdge), which is a black, granulated media with a silica sand core coated with manganese dioxide (MnO_2). Greensand and GreensandPlus™ media are commonly used for iron and manganese removal. The media has NSF International (NSF) Standard 61 approval for use in drinking water applications. Table 4-2 provides physical properties of various filtration media: anthracite #1, AD-GS+ (GreensandPlus™), and AD-26.

Table 4-2. Physical Properties of Filtration Media

Parameter	Anthracite #1[(a)]	AD-GS+[(b)]	AD-26[(a)]
Physical Form	Dry, crushed	Dry nodular granules	Dry nodular granules
Color	Black	Black	Black
Specific Gravity	1.5–1.6	~2.4	3.8
Bulk Density (g/cm^3)	0.65–0.70	1.36	2.00
Porosity	NA	~0.45	NA
Mesh Size	14 × 30	18 × 60	20 × 40
Effective Size (mm)	0.6–0.8	0.30–0.35	0.40
Uniformity Coefficient	<1.7	<1.6	1.54
pH Range	NA	6.2–8.5	6–9
Maximum Temperature (°C)	NA	NA	NA
Service Loading (gpm/ft^2)	5	2–12	8–12
Backwash Rate (gpm/ft^2)	12–18	≥ 12	18–20

(a) Source: AdEdge Technologies, Inc.
NA = not available

Sodium hypochlorite (NaOCl) and ferric chloride ($FeCl_3$) were injected into source water upstream of the filtration vessels. NaOCl oxidized soluble As(III) to soluble As(V), which was attached to iron solids through co-precipitation and/or adsorption. The iron solids formed were removed from water via filtration by the media. $FeCl_3$ supplemented the natural iron in source water for soluble As(V) removal.

4.2.2 System Design and Treatment Process. The AdEdge C/F system consisted of a NaOCl addition system; a $FeCl_3$ addition system; three in-parallel, epoxy-lined, carbon-steel filtration vessels; a backwash wastewater reclaim system; and associated gauges and sensors to monitor pressure and flowrate. The system also was equipped with a NEMA 4X stainless steel control panel that housed a touch-screen Allen Bradley PanelView Plus 600 operator interface panel (OIP), an Allen Bradley MicroLogix 1500 programmable logic controller (PLC), and an uninterruptible power supply (UPS). The PLC automatically controlled the system by actuating motor operated butterfly valves depending on various inputs and outputs of the system and corresponding PLC setpoints. The system also featured schedule 80 polyvinyl chloride (PVC) solvent-bonded plumbing and all necessary isolation and check valves and sampling ports. As requested by PA DEP, the original gas chlorination system was replaced, due to health and safety concerns, with a new liquid chlorination system using NaOCl for oxidation and disinfection. Because the pressure produced by the well pumps (117 to 120 lb/in^2 [psi]) exceeded the pressure rating of the filtration vessels (100 psi), a pressure and flow reducing valve was installed before the treatment system to prevent damage. The backwash reclaim system was added to recover the liquid fraction of backwash wastewater that the CLJMA was not willing to accept.

The addition of the backwash wastewater reclaim system was the responsibility of the Park as outlined in the Final Letter of Understanding dated December 27, 2007. The Park also was responsible for the liquid NaOCl system since it was part of the original treatment system at Conneaut Lake Park.

Figure 4-5 is a generalized flow diagram of the treatment system, including sampling locations and parameters that were analyzed during the demonstration study. Table 4-3 presents key system design parameters. The major components of the treatment process are discussed as follows:

- **Intake.** Raw water was pumped from Well No. 2 through a 4-in water line with a maximum flowrate of 250 gpm at approximately 120 psi to a pressure- and flow-reducing valve before entering the treatment system.

- **Pre-chlorination.** A liquid NaOCl addition system was used to oxidize As(III), Fe(II), and Mn(II) and maintain a target total chlorine residual level of 0.3 to 0.5 mg/L (as Cl_2) for proper disinfection. The system consisted of a 75-gal day tank containing a 12.5% NaOCl solution and a 0.95 gal/hr (gph) ProMinent gamma/L diaphram metering pump with a self bleeding liquid end that was pulse-controlled by the PLC. Chemical consumption was monitored by measuring the level of the NaOCl solution in the day tank on a daily basis and recording the levels on field log sheets. Figure 4-6 shows the NaOCl and $FeCl_3$ addition systems.

  The chlorine injection point was located upstream of system bypass and the pressure/flow-reducing valve. Chlorine injection was installed prior to the bypass so in the event the system was offline, the Park could still keep the well water disinfected.

- **Pressure and Flow reducing Valve.** Because the three pressure filtration vessels were rated at 100 psi, the pressure and flowrate of the incoming water was reduced from the wellhead levels (120 psi and 250 gpm) to <95 psi and 180 to 190 gpm using a Cla-Val model 49-01 pressure/flow-reducing valve (Figure 4-7). The reduced flowrate was within the 200 gpm flowrate permitted by PA DEP.

- **Ferric Chloride Addition.** Due to the low concentration of soluble iron in Well No. 2 water, $FeCl_3$ was injected after the NaOCl addition point and prior to the filtration vessels to aid in forming arsenic-laden solids. The target iron dosage was 1.5 mg/L (as Fe). The iron addition system consisted of a 75-gal day tank containing a 41% $FeCl_3$ solution and a 1.1 gph ProMinent gamma/L diaphram metering pump that was pulse-controlled by the PLC. Chemical consumption was monitored by measuring the level of the $FeCl_3$ solution in the day tank on a daily basis and recording the levels on field log sheets. After chlorination and iron addition, the water proceeded though a Westfall Model 2850 inline static mixer before entering the filtration vessels.

- **Filtration**. The filtration system consisted of three 54-in × 60-in epoxy-lined carbon-steel vessels configured in parallel. By design, each vessel was to contain 11.5 ft^3 of gravel underbedding overlain by 32 ft^3 of AD-GS$^+$ and 16 ft^3 of anthracite #1. Elliptical man-ways located on the top of each vessel were used for media loading and accessing tank internals. Water traveled to each vessel via 4-in schedule 80 PVC pipe, entered through a flanged opening on the side to the upper distributor, and flowed downward through the media. Filtered water collected by a Schedule 80 PVC slotted hub and lateral assembly proceeded to a 20-in-diameter, 270-ft-long pipe loop that provides 23 min of contact time (based on a 4,400-gal capacity in the pipe loop and a 190-gpm flowrate after pressure/flow reducing). From the loop, the water was sent to a 75,000-gal water tower located approximately 1,000 ft

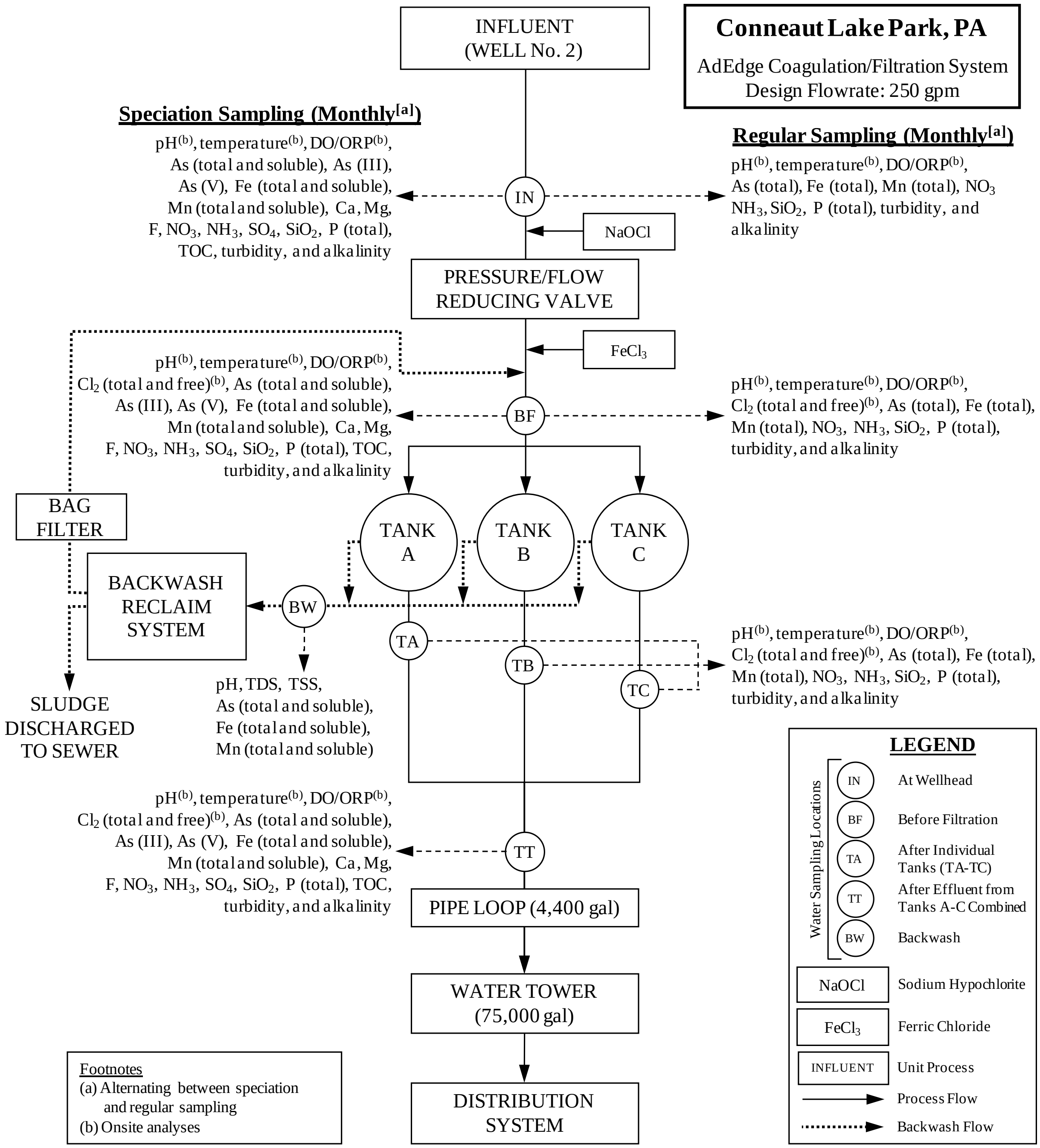


Figure 4-5. Process Flow Diagram with Sampling Schedules and Locations

Table 4-3. Design Features of AdEdge Coagulation/Filtration System

Parameter	Value	Remarks
Pretreatment		
Target Chlorine Dosage (mg/L [as Cl_2])	1.7	Using 12.5% NaOCl
Target Supplemental Iron Dosage (mg/L [as Fe])	1.5	Using 41% $FeCl_3$
Filtration Vessels		
Vessel Size (in)	54 D × 60 H	Epoxy-lined carbon-steel
Cross-sectional Area (ft^2/vessel)	15.9	–
No. of Vessels	3	–
Configuration	Parallel	–
Filtration Media		
Media Type	Anthracite #1 AD-GS+	–
Media Depth (in/vessel)	12 (Anthracite) #1 24 (AD-GS+)	–
Media Volume (ft^3/vessel)	16 (Anthracite) #1 32 (AD-GS+)	–
Underbedding Volume (ft^3/vessel)	11.5	Gravel
Service		
Design Flowrate (gpm)	250	83.3 gpm/vessel
Permitted Flowrate (gpm)	200	66.7 gpm/vessel
Flowrate After Pressure/Flow Reducing (gpm)	190	63.3 gpm/vessel
Filtration Rate (gpm/ft^2)	4.0 5.3	63.3 gpm/vessel with three vessels online; 85.0 gpm/vessel with two vessels online and one in backwash mode
Average use rate (gal/day)	124,000	Based on data received from Park
Backwash		
Differential Pressure Setpoint (psi/vessel)	10	–
Backwash Flowrate (gpm/vessel)	190	–
Backwash Rate (gpm/ft^2)	12	–
Media Bed Expansion (%)	~50	–
Backwash Frequency (frequency/vessel)	Every 2–3 days	Actual backwash frequency to be determined during system operation
Backwash Duration (min/vessel)	9	–
Filter to Waste Rinse Flowrate (gpm/vessel)	190	Based on backwash flowrate and total wastewater production per vessel
Filter to Waste Rinse Duration (min/vessel)	1	–
Wastewater Production (gal/vessel)	1,900	Total wastewater production during backwash and rinse cycle
Backwash Wastewater Reclaim System		
No. of Holding Tanks	2	–
Holding Tank Size (in)	102 D × 125 H	1.5 rating high-density polyethylene (HDPE)
Holding Tank Capacity (gal/tank)	4,000	–
Recycle Flowrate (gpm)	18–20	~10% of service flowrate
Backwash Wastewater Settling Time (hr)	4	–
Time to Complete Recycling (hr)	5	Based on 5,700 gal of wastewater produced from three vessel and 19-gpm recycle flowrate

Figure 4-6. NaOCl and $FeCl_3$ Addition Systems
(NaOCl day tank and pump [left-left side], $FeCl_3$ day tank and pump [left-right side], NaOCl injection point [center], and $FeCl_3$ injection point [right])

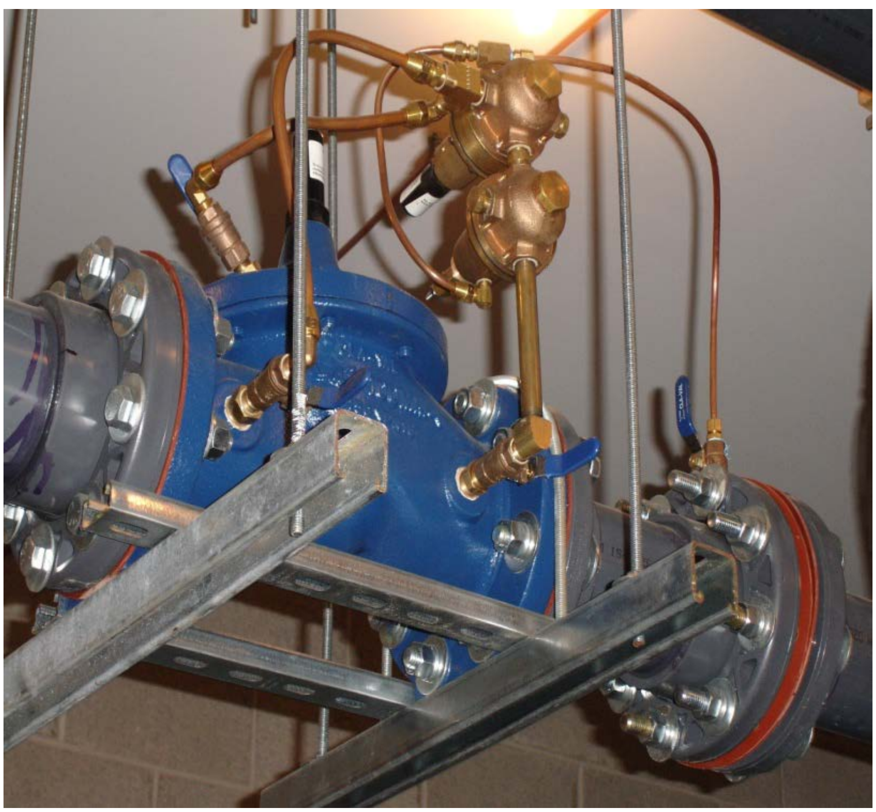


Figure 4-7. Cla-Val Model 49-01 Pressure- and Flow-Reducing Valve

to the southwest. As mentioned above, due to the high pressure generated by the well pump, the incoming pressure and flowrate were reduced to <95 psi and 180 to 190 gpm to avoid vessel damage. The resulting filtration rates were 4.0 gpm/ft^2 when the incoming flowrate was reduced to 190 gpm (or 63.3 gpm/vessel) and 5.3 gpm/ft^2 when the flowrate was reduced to 190 gpm and if only two vessels were online while the third was being backwashed (i.e., 85 gpm/vessel). Figure 4-8 shows the filter vessels and associated piping and valves.

Figure 4-8. Carbon-Steel Filtration Vessels with Associated Piping and Valves

- **Backwash**. Due to accumulation of iron solids in the media, the filter beds needed to be backwashed to remove the solids and fluff the media to minimize channeling. Backwashing can be performed manually or automatically with either time, throughput, or differential pressure (Δp) as the setpoint. The filters were backwashed at approximately 190 gpm, resulting in a backwash rate of 12 gpm/ft^2. During backwash, one filter went into the backwash mode, while the other two remained online. The flow from the two filters that remained online provided the water for the backwash process. The backwash cycle lasted approximately 10 min per vessel, including a 9 min upflow backwash and a 1 min downflow filter-to-waste rinse. All three vessels were backwashed one at a time with a 20 min delay between the end of one backwash and the start of the next, resulting in a backwash event lasting 90 min and generating a total of 5,700 gal of wastewater.
- **Backwash Reclaim System.** Backwash wastewater generated was stored in two 102-in × 125-in high-density polyethylene (HDPE) holding tanks, each having 4,000 gal capacity. The wastewater entered through the top of one of the holding tanks and traveled to the other tank by way of a 1.5-in connector pipe between the tanks, which equalized the levels. Before any wastewater could be recycled back through the treatment system, it was allowed to settle for a

minimum of 4 hr. The supernatant was then pumped from the holding tank via a short length of 1.5-in pipe located on the side of the tank 18 in from the bottom through a polyfelt bag filter (BN-12 2 in stainless steel bag filter) to remove any solids. The filtered water then travelled to the inlet header of the treatment skid, where no more than 10% of the total inlet flow consisted of the recycled water. The reclaim system was propelled by a 1-hp Grundfos Vertical Multistage Centrifugal Pump rated for 18-20 gpm. Disposal of solids that accumulated in the backwash holding tanks was the responsibility of the Park. Figure 4-9 presents a diagram of the backwash reclaim system and Figure 4-10 shows the backwash reclaim system.

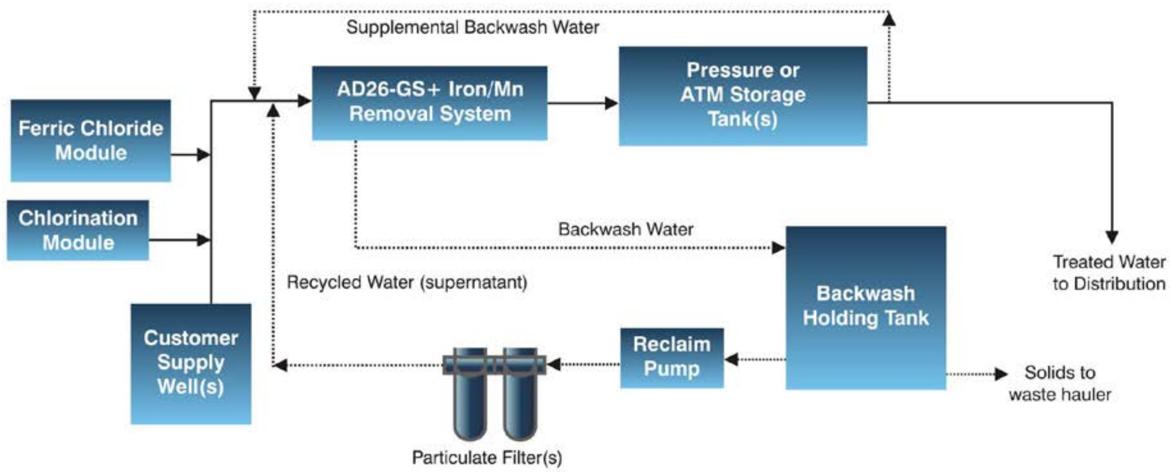


Figure 4-9. Schematic of Backwash Reclaim System

4.3 System Installation

AdEdge completed system installation and shakedown on November 6, 2009. The following briefly summarizes system installation activities, including permitting, building preparation, and system installation, shakedown, and startup.

4.3.1 Permitting. A system engineering package was prepared by AdEdge and its subcontractor, Porter Consulting Engineers, P.C. of Meadville, PA. The package included a system design report with component specifications, treatment system plan and mechanical drawings, and a piping and instrumentation diagram (P&ID). After being certified by a professional engineer registered in the State of Pennsylvania, the package was submitted to PA DEP for review and approval on June 24, 2009. After PA DEP's review comments were addressed, a revised package was submitted, along with a permit application, on August 17, 2009. A water supply construction permit was issued by PA DEP on September 3, 2009, and installation of the system began thereafter.

4.3.2 Building Preparation. A new 20-ft × 38-ft water treatment building was constructed at the site of Well Houses No. 1 and No. 2 (Figure 4-11) to house the treatment and chemical addition systems. The new structure was constructed of 10-in concrete block, with insulated cores, to an interior elevation of 12 ft. The two original small structures were demolished in favor of one large building that enclosed both wells and the entire treatment system. Construction began on July 9, 2009 and was completed by October 9, 2009.

Figure 4-10. Backwash Reclaim System
(Photograph on left: Bag Filter [left], Reclaim Pump [center], and Control Box [right])
(Photograph on right: Backwash Holding Tank)

Figure 4-11. New Treatment Building at Site of Former Well Houses No. 1 and No. 2

4.3.3 Installation, Shakedown, and Startup. The treatment system arrived at the site on July 31, 2009, but installation was delayed until the building to house the system was completed on October 9, 2009. The vendor's subcontractor finished installation of the treatment system on October 23, 2009.

AdEdge and its subcontractor were onsite the week of October 26, 2009 to perform system shakedown and startup. Hydraulic testing and system disinfection using chlorine were performed on October 26, 2009. Bacteria sampling and media loading took place the next day. Before media could be loaded into Vessel C, four lower laterals had to be repaired due to damage to the upper distributor when it fell during shipping. Gravel, GreensandPlus™, and anthracite were loaded sequentially into each vessel and then backwashed to remove media fines. Due to an agreement with CLJMA, only 30,000 gal of water was used for backwash and discharged to the sewer.

Freeboard measurements (Table 4-4) were made during media loading and after backwashing. About 25 in of freeboard was measured in each of the three vessels before backwash; about 26 in of freeboard was measured after backwash. This freeboard should be sufficient for approximately 50% bed expansion as the combined bed depth for GreensandPlus™ and anthracite was about 34 in (on average). Although this average bed depth was very close to the design value of 36 in, the actual depths for GreensandPlus™ and anthracite (i.e., 29.5 and 4.6 in, respectively, assuming a loss of 0.5 in each during backwash) were quite different from the design values of 24 and 12 in, respectively (see Table 4-3). The discrepancies observed probably were caused by the combination of inaccurate freeboard measurements and inaccurate media quantities in media containers.

Table 4-4. Freeboard Measurements and Media Volumes Before and After Backwash

Measurement	Vessel A	Vessel B	Vessel C
To Top of Gravel (in)	60.0	59¾	60¾
Before Backwash			
To Top of GreensandPlus™ (in)	30.0	29⅞	30½
GreensandPlus™ Bed Depth (in)	30.0	29⅞	30¼
Average GreensandPlus™ Bed Depth (in)		30.0	
GreensandPlus™ Volume (ft^3)	39.8	39.6	40.1
Average GreensandPlus™ Volume (ft^3)		39.8	
To Top of Anthracite (in)	25.0	25.0	25¼
Anthracite Bed Depth (in)	5.0	4.9	5¼
Average Anthracite Bed Depth (in)		5.1	
Anthracite Volume (ft^3)	6.6	6.5	7.0
Average Anthracite Volume (ft^3)		6.7	
After Backwash			
To Top of Anthracite (in)	25¾	26.0	26 3/16
Bed Depth Loss (in)	0.75	1.0	0.94
Average Bed Depth Loss (in)		0.9	
Average GreensandPlus™ Bed Depth (in)		29.5[a]	
Average GreensandPlus™ Volume (ft^3)		39.0	
Average Anthracite Bed Depth (in)		4.6[a]	
Average Anthracite Volume (ft^3)		6.0	

(a) Assuming a bed depth loss of 0.5 in.

During PLC testing, a control issue related to the backwash recycle pump and chemical addition pumps was found. Because it could not be addressed by the technician onsite, another site visit was made by a programmer on November 4, 2009. The issue was properly addressed and all components were tested and verified to be working as designed. PA DEP performed a final walkthrough on November 12, 2009, and gave the approval to put the system online on November 16, 2009. Due to a crack in the backwash meter saddle, the system was not put online until November 19, 2009, after a temporary fix was made until the new piece arrived two weeks later.

On December 2 and 3, 2009, two Battelle staff members visited the site to inspect the system and provide sample and data collection training to the operators. During inspection, several installation/operational issues were found. Table 4-5 summarizes punch-list items and corrective actions taken.

Table 4-5. Punch-List Items and Corrective Actions

Dates	Issues/Problems Encountered	Corrective Action Taken	Work Performed by
12/02/09–03/12/10	No hour meters on Well Pump No. 1 and No. 2	An hour meter installed on each well pump	The Park
12/02/09–02/26/10	Leaky air scavenging valve on system inlet line from Well No. 2	Leaky valve repaired	AdEdge Subcontractor
12/02/09–02/26/10	Incorrectly labeled Valve BV-200 on treated effluent line (not matched label shown on PLC)	A new label with correct valve name sent to operator	AdEdge/the Park/
12/02/09–02/16/10	Wrong flow values summed by PLC, making total volume processed since last backwash incorrect	PLC update sent to operator; update installed by operator with guidance from AdEdge	AdEdge/the Park/

4.4 System Operation

4.4.1 Operational Parameters. The performance evaluation study at Conneaut Lake Park began on December 3, 2009 and ended on December 17, 2010. The operational parameters for the one-year study were tabulated and are attached as Appendix A. Key parameters are summarized in Table 4-6. From March 12, 2010, through December 17, 2010, the system operated for 1,988.4 hr. Because the well-pump hour meter was not installed until March 12, 2010, the system operating time could not be tracked during the first three months of system operation. Using an average daily run time of 4.3 hr when the Park was not in operation (see discussion below), 425.7 hr would have been run during that period. Therefore, the total system operating time would have been 2,414 hr. As shown in Figure 4-12, daily system run times fluctuated extensively from 1.6 to 23.2 hr/day and averaged 11.9 hr/day when the Park was in operation (from May 28, 2010 to September 8, 2010) and from 0.1 to 15.6 hr/day and averaged 4.3 hr/day when the Park was not in operation.

During the study period, the system treated 20,114,150 gal of water based on readings of three SeaMetrics electromagnetic insertion flow sensors/totalizers installed on each of the three filtration vessels. Volume throughputs through the three filtration vessels ranged from 6,497,314 to 6,975,153 gal and averaged 6,704,717 gal. The amounts varied in a rather narrow range from -0.9% to 4%, indicating balanced flow.

Flowrates through the three filtration vessels (Figure 4-13) were tracked by both instantaneous readings displayed on the PLC and calculated values by dividing incremental volume throughputs recorded from the PLC by incremental operating times recorded from the well-pump hour meter. As shown in

Table 4-6. Summary of Treatment System Operational Parameters

Operational Parameter	Value/Condition			
Duration	12/03/09–12/17/10			
Average Daily Run Time (hr/day)	11.9 (When Park in operation from 05/28/10–09/08/10) 4.3 (When Park not in operation)			
Total Operating Time (hr)	1,988.4 (03/12/10[a]–12/17/10) 2,414.1 (12/03/09–12/17/10; estimated)			
Throughput (gal)[b]	Vessel	Throughput		
	A	6,975,153		
	B	6,497,314		
	C	6,641,683		
	System	20,114,150		
Instantaneous Flowrate (gpm)/Filtration Rate (gpm/ft^2)	Vessel	Range	Average	
	A	17–92/1.1–5.8	53/3.3	
	B	20–96/1.3–6.0	49/3.1	
	C	10–88/0.6–5.5	51/3.2	
	System	110–186[c]	153	
	Well No. 2	17–194	153	
Calculated Flowrate (gpm)[d]	Vessel	Range	Average	
	A	10.5–98.0[e]	51.3	
	B	15.7–82.5[f]	47.5	
	C	14.2–86.0[g]	48.9	
	System	58.9–200[h]	147	
	Well No. 2	62–252	148	
Operational Pressures (psi)	Vessel	Inlet	Outlet	Δp
	A	82 (80–91)	79 (68–84)	4 (0–15)[i]
	B	81 (77–87)	79 (70–86)	2 (0–10)[j]
	C	81 (78–89)	80 (70–86)	2 (0–10)[k]
	System	81 (60–87)	77 (60–86)	4 (0–20)

(a) Hour meters not installed until 03/11/10.
(b) Including amount of treated water used for backwashing filtration vessels.
(c) Not including one outlier on 02/08/10.
(d) Data calculated by dividing incremental throughput by incremental hour meter readings recorded during 03/12/10 through 12/17/10.
(e) Not including eight outliers as highlighted in red in Appendix A.
(f) Not including six outliers as highlighted in red in Appendix A.
(g) Not including ten outliers as highlighted in red in Appendix A.
(h) Not including eleven outliers as highlighted in red in Appendix A.
(i) Not including three outliers as highlighted in red in Appendix A.
(j) Not including thirteen outliers as highlighted in red in Appendix A.
(k) Not including fifteen outliers as highlighted in red in Appendix A.

Table 4-6, instantaneous flow readings for Vessels A, B, and C averaged 53, 49, and 51 gpm, respectively; calculated flow values averaged 51.3, 47.5, and 48.9 gpm, respectively. Instantaneous system flowrates averaged 153 gpm while calculated system flowrates averaged 147 gpm. Based upon these flowrates, the system operated at approximately 60% of the design capacity of 250 gpm. Due to pressure/flow-reducing, the anticipated flowrate was reduced to approximately 190 gpm and the system operated at approximately 80% of the adjusted flow capacity. While these two sets of flowrate data were comparable to each other, the calculated values appeared to be scattered somewhat more than the instantaneous readings (Figure 4-13). As such, only instantaneous readings were used for filtration rate calculations.

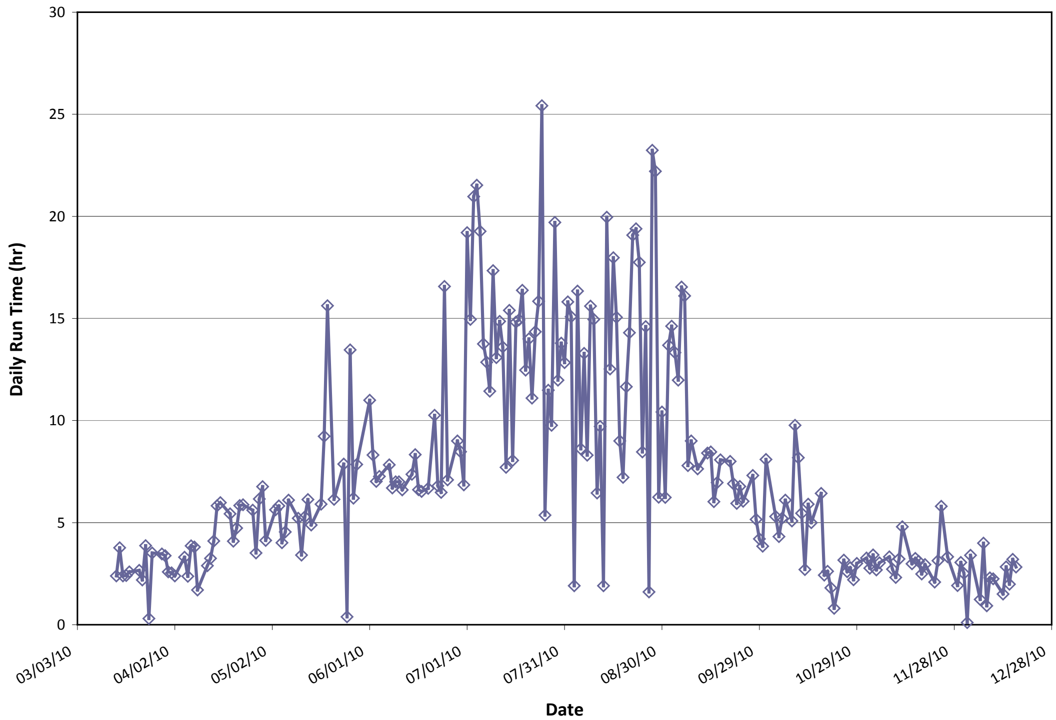


Figure 4-12. Treatment System Daily Operating Times

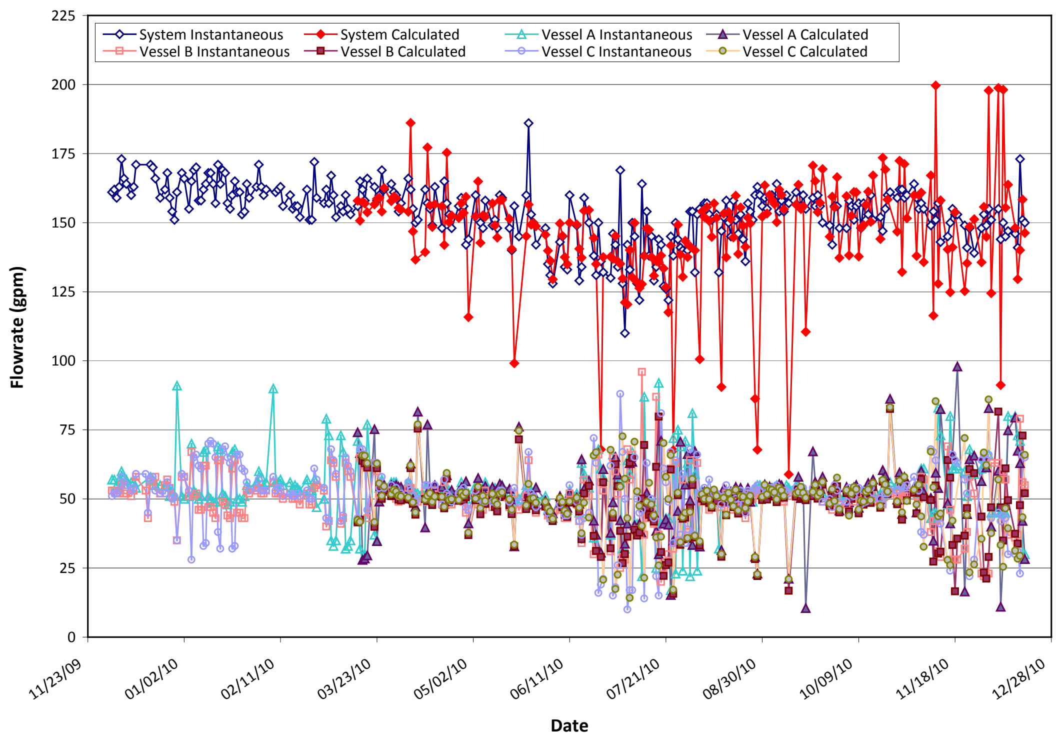


Figure 4-13. Comparison of Instantaneous Flowrate Readings and Calculated Flowrate Values

Based on the instantaneous flowrates to the individual vessels, filtration rates for Vessels A, B, and C ranged from 0.6 to 6.0 gpm/ft^2 and averaged 3.3, 3.1, and 3.2 gpm/ft^2, respectively. These filtration rates were lower than the design value of 4.0 gpm/ft^2 (Table 4-3) with all three vessels online.

Δp across the vessels ranged from 0 to 15 psi and averaged 4 psi for Vessel A and 2 psi for Vessels B and C (Figure 4-14). The system inlet pressure ranged from 60 to 87 psi and averaged 81 psi, while the system outlet pressure ranged from 60 to 86 psi and averaged 77 psi. The average system Δp was 4 psi.

4.4.2 Chlorine Injection. As described in Section 4.2.2, a 12.5% NaOCl solution was used as an oxidant to oxidize As(III) and Fe(II) and a disinfectant for the distribution system. The chlorine injection system was controlled by the PLC and experienced no operational irregularities during the performance evaluation study. The stroke of the injection pump was set to achieve a target dose of 1.7 mg/L (as Cl_2) by the vendor during system startup and remained at that setting for the duration of the study.

Chlorine dosages to the treatment system were carefully monitored by measuring solution levels in the chemical day tank on a daily basis. During the performance evaluation study, the average dosage was 3.5 mg/L (as Cl_2), which was about two times the target dosage of 1.7 mg/L (as Cl_2). Since free and total chlorine residual levels at the TT location were satisfactory, no adjustments were made to pump or PLC settings during the study.

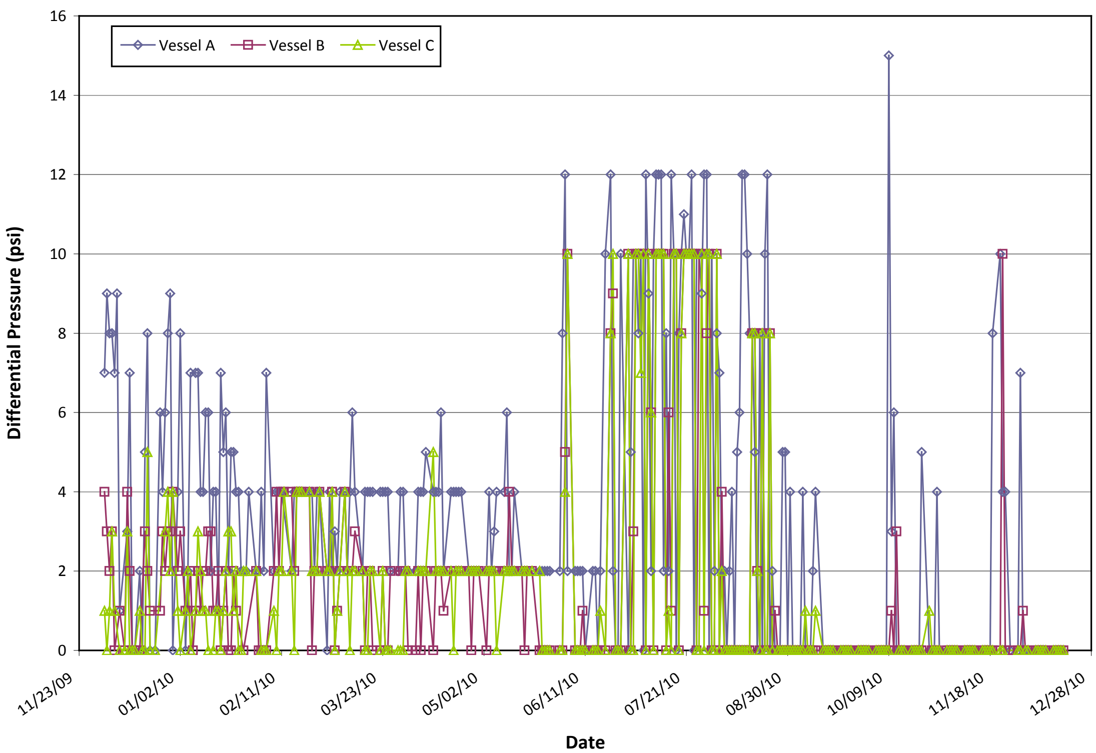


Figure 4-14. Differential Pressures Across Filtration Vessels

4.4.3 Iron Addition. Iron in the form of $FeCl_3$ (41%) was added to source water as a coagulant to remove soluble As(V) through adsorption and/or co-precipitation with iron solids. The stroke of the injection pump was set to achieve a target dose of 1.8 mg/L by the vendor during system startup and remained at that setting for the duration of the study. The iron addition system was controlled by the PLC as described in Section 4.2.2 and functioned properly until August 26, 2010, when the iron addition pump stopped working for unknown reasons. From August 26, 2010, to September 29, 2010, no iron was added to source water, which resulted in arsenic levels higher than the MCL in two sampling events on September 7 and 20, 2010. After undergoing a thorough cleaning by the operator on September 29, 2010, the pump was put back online and experienced no additional operational issues.

Iron dosages to the treatment system were carefully monitored by measuring solution levels in the chemical day tank on a daily basis. During the performance evaluation study, the average dosage was 1.8 mg/L (as Fe), which was very close to the target dosage of 1.5 mg/L (as Fe) as shown in Table 4-3. Since iron levels at the BF and TT location were satisfactory, no adjustments were made to pump or PLC settings during the study.

4.4.4 Backwash and Backwash Reclaim System. Backwash data were tabulated and are attached as Appendix C and summarized in Table 4-7. As mentioned in Section 4.2.2, backwash could be initiated manually or automatically with a time, a throughput (gal), or a Δp setpoint. During system startup, a time was chosen as the setpoint and the PLC was set to initiate backwash for all three vessels once every 6 days. Due to some customer complaints about iron in the treated water and an increased water demand after the Park started its seasonal operation in late May, the backwash frequency was increased to once every 3 days on July 23, 2010. The actual backwash frequency as shown in Table 4-7 was once every 4 to 7 days before June 17, 2010 (about 3 weeks after the Park was open) and once every 1 to 4 days between June 17 and November 17, 2010. Why the backwash frequency did not stay at once every 3 or 6 days, as set, for a large number of backwash events is not known. The 11 manual backwashes initiated by the operator for backwash wastewater sampling and manual recording of backwash counts could contribute, in part, to the irregularities observed. There was no backwash counter displayed in the PLC and there was no throughput countdown on each filtration vessel.

Table 4-7. Summary of System Backwash

Duration[a]	No. of Backwashes (vessel-time)	No. of Days Between Backwashes	Amount of Wastewater Produced (gal)
12/14/09–06/17/10	107	4–7	199,720
06/21/10–11/17/10	140	1–4	256,223
11/23/10–12/16/10	8	4–7	13,199
Total	255[b]		469,142

(a) The Park in operation between 05/28/10 and 09/08/10.
(b) Equivalent to 85 backwash cycles.

Backwashing of the individual vessels also did not necessarily occur in one day. Out of 82 backwash events between December 18, 2009, and November 17, 2010, only 55 events occurred with all three vessels backwashed in one day (see Appendix C). There were times when two vessels were backwashed one day then the third was backwashed the next day, or vice versa. There were times when two or four vessels were backwashed in one day. There also were times when one vessel was backwashed in three consecutive days. These irregularities might be due, in part, to the time when the operator was onsite to record data. However, all backwashes should have taken place in the early morning with each backwash completed in 10 min followed by a 20 min delay and all three backwashes completed in approximately 90 min.

Because the backwash settings had not been modified since late July, the system continued to perform backwashing once every 3 days even after the Park ceased its seasonal operation in early September. The decrease in water demand from the Park resulted in a decrease in daily run time from an average of 11.9 to 4.3 hr/day (see Table 4-6). The decrease in daily run time coupled with backwashing every 3 days allowed the backwash holding tanks to fill up. This was because the volume of wastewater produced from one backwash event could not be completely reclaimed at a flowrate of approximately 18 to 20 gpm by the time the next backwash event started. When the high-level sensor failed during a backwash event on November 4, 2010, the holding tanks overflowed. Therefore, the backwash setpoint was changed again on November 5, 2010, from time to throughput.

The throughput setpoint was based on the findings of a run length study completed by Battelle in July 2010. The results indicated that arsenic breakthrough at 10 µg/L would occur after treating approximately 123,000 gal of water and that iron breakthrough at 300 µg/L (iron secondary maximum contaminant level [SMCL]) would occur after 83,000 gal. Therefore, the volume throughput was set at 65,000 gal for Vessel A, 75,000 gal for Vessel B, and 85,000 gal for Vessel C. The throughputs were staggered from one vessel to the next by 10,000 gal to prevent all vessels from being backwashed at the same time. This volume would allow the two vessels left online to provide enough water for the entire backwash event without going into backwash themselves. Also, under no circumstance could backwash of a vessel be triggered when another vessel had already been in the backwash mode. A lockout in the PLC would delay backwash of the second vessel until backwash of the other vessel was complete.

As shown in Table 4-7, a total of 85 backwash events occurred over the duration of the performance evaluation period, generating 469,142 gal of wastewater based on readings of a SeaMetrics electromagnetic insertion flow sensor/totalizer connected to the PLC. The average amount of wastewater produced per backwash event was 5,520 gal (or 1,840 gal/vessel), compared to the design value of 5,700 gal (or 1,900 gal/vessel). Based on the amount of wastewater produced and the 9-min backwash and 1-min filter-to-waste rinse time, the average flowrate would be 184 gpm. This flowrate is equivalent to a backwash rate of 11.6 gpm/ft^2, which is very close to the design value of 12 gpm/ft^2.

Over the course of the performance evaluation period, a total of 511,915 gal of wastewater was reclaimed by the system based on readings of an inline GPI turbine flowmeter/totalizer located after the bag filter. There was a discrepancy of 42,773 gal between this volume and the total backwash volume generated (i.e., 469,142 gal). The difference was thought to be due to loss of calibration by the GPI turbine flowmeter/totalizer since no water could be introduced into the system between the holding tanks and reclaim tie-in located at the header of the filtration skid.

4.4.5 Residual Management. Residuals include backwash wastewater and spent media. The AD-GS$^+$ media and anthracite were not replaced during the study period; therefore, the only residual produced was backwash wastewater. The backwash wastewater was discharged from the system to two 4,000-gal holding tanks, where solids were allowed to settle for a minimum of 4 hr. After the settling period, the supernatant was recycled back to the header of the filtration skid at approximately 10% of the inlet flowrate (18 to 20 gpm) when the system was operating. Over time, the sludge accumulating in the bottom of the tanks had to be removed to prevent solids from being recycled back into the system and clogging the bag filter. The operator was given special approval by the CLJMA to discharge the sludge to the sanitary sewer on the condition that the date and approximate volume were documented for future billing purposes. The sludge was pumped from the holding tanks to the sewer on five occasions (May 3, June 21, August 2, August 16, and September 22, 2010) during the study period with a combined volume of approximately 15,600 gal.

4.4.6 System/Operation Reliability and Simplicity. There was no downtime for the treatment system during the performance evaluation study. Minor issues were experienced with the iron addition pump, as previously mentioned, along with the bag filter and pressure relief manifold. The bag filter would experience a heavy solids loading whenever the level of the solids in the holding tanks was near the level of the intake pipe (18 in from the bottom of the tank) to the reclaim pump and bag filter. Once the sludge was pumped from the holding tanks, the issue was resolved. A leak in the pressure relief manifold was discovered by the operator on August 2, 2010, which did not affect system operation or performance. The vendor provided the operator with a replacement part and the leak was fixed by August 26, 2010.

A major issue involving the high-level sensor in the holding tanks occurred on November 4, 2010, when the tanks overflowed during backwash. The high-level sensor is a precaution that is intended to abort a backwash if the water level reaches the preset height. To prevent unnecessary backwashes and slow the accumulation of backwash in the tanks, the backwash setpoint was changed from time to throughput. The issue with the high-level sensor had not been properly resolved when the performance evaluation study ended in December 2010.

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

Pre- and Post-Treatment Requirements. Pre-treatment consisted of chlorination and iron addition. Chlorination utilized a 12.5% NaOCl solution to oxidize As(III) and Fe(II), and provide chlorine residuals to the distribution system. In addition to tracking the levels of the NaOCl solution in the day tank, the operator measured chlorine residual concentrations to ensure that residuals existed throughout the treatment train. The addition of iron (as a 41% $FeCl_3$ solution) was required to supplement the low natural iron level in the source water. The iron acted as a coagulant to remove soluble As(V) through adsorption and/or co-precipitation. In addition to tracking the levels of the $FeCl_3$ solution in the day tank, the operator periodically measured iron concentrations at the BF location to verify the correct amount of iron was being added by the pump. Each pump was setup by the vendor during system startup and remained at its original setting throughout the performance evaluation study. Post-treatment was not needed for this system.

System Automation. A low-level sensor in the 75,000 gal water tower triggered the well pump to provide water to the system to be treated. Once the water level in the tower reached the high-level sensor, the well pump shut off. The valve sequences were controlled by an Allen-Bradley (AB) 1500 Micrologix PLC, which also pulse controlled both chemical feed pumps. Each vessel had four electronic actuated butterfly valves controlled by the PLC and two manual isolation butterfly valves. In addition, the system effluent line and backwash line each had a manual throttling valve, which could be used to balance flow. An AB PanelView Plus 600 touch screen interface allowed the operator to monitor system parameters, change system setpoints, and check the status of alarms.

The backwash reclaim system also was controlled by the PLC, which could be used to view recycle flowrates, modify the settling time, and control the recycle pump. Backwash wastewater recycling only occurred when the treatment system was operating and the water in the holding tanks had settled for a minimum of 4 hr. Two manual isolation valves were located on the recycle line with one after the two holding tanks, but before the pump and bag filter and one after the bag filter and right before the tie-in of the recycle line to the inlet line.

Operator Skill Requirements. Under normal operating conditions, the daily demand on the operator was approximately 1 hr. The operator's duties consisted of visually inspecting the system, recording the operational parameters such as flowrates, volumes, and system pressures on field log sheets, and measuring chemical levels in the day tanks. The operator also was responsible for pumping the backwash sludge from the holding tanks to the sewer and occasionally performing minor repairs. After receiving the proper training during system startup, the operator understood the PLC, knew how to use the touch screen, and was able to work with the vendor to troubleshoot problems. The operator's knowledge of the system limitations and typical operational parameters was the key to achieve the system performance objectives. The basis for the operator's skills began with onsite training and a thorough review of the system operations manual; however, increased knowledge and system troubleshooting skills were gained through hands-on operational experience.

All Pennsylvania community and non-transient/non-community public water systems must have a certified operator. Operator certifications are granted by the State of Pennsylvania after passing an exam gaining the necessary experience while working with another operator and maintaining a minimum amount of continuing education hours at professional training events. The number of continuing education hours required depends on the operator's certification and years of experience at that certification level. Operator certifications are classified by the capacity of the system (A to E) and sub-classified by the treatment processes used (1 to 14). The certification of C, E, 8, 9, 12 is required to operate the treatment system at Conneaut Lake Park. The operator held a certification of A, E, 11, 12, 13, 14 certification.

Preventive Maintenance Activities. Preventative maintenance tasks included inspecting the vessels and system piping for leaks and monitoring the levels of NaOCl and $FeCl_3$ in the day tanks to ensure proper chemical usage. Periodically, the operator checked the bag filter on the recycle line for particulate build-up and either cleaned or replaced the filter depending on its condition.

Chemical Handling and Inventory Requirements. Chlorine and iron additions were required for effective arsenic removal. The operator tracked usage of the chemical solutions daily (by measuring solution levels in the day tanks), coordinated supplies, and refilled the day tanks as needed. A 12.5% NaOCl and a 41% $FeCl_3$ solution, both supplied in 15-gal carboys by Barber's Chemicals, were transferred by hand pumps to the respective day tanks and injected without dilution. The stroke settings of the chemical pumps could be adjusted by the operator, if needed.

4.5 System Performance

The performance of the C/F system was evaluated based on analyses of water samples collected across the treatment plant, during the media backwash, and from the distribution system.

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

Arsenic. The key parameter for evaluating the effectiveness of the arsenic treatment system was the concentration of arsenic in the treated water. Treatment plant water samples were collected on 28 occasions, including three sets of duplicate samples taken on February 10, May 3, July 26, 2010, with field speciation performed during 14 occasions at IN, BF, and TT sampling locations.

Figure 4-15 contains three bar charts showing concentrations of soluble As(III), soluble As(V), and particulate arsenic at the IN, BF, and TT locations for each of the 14 speciation events. Total arsenic concentrations in raw water ranged from 26.8 to 37.3 μg/L and averaged 29.0 μg/L, existing almost entirely as soluble arsenic (Table 4-8). Of the soluble fraction, As(III) was the predominating species,

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

Parameter	Sampling Location	Sample Count	Concentration (µg/L) Minimum	Maximum	Average	Standard Deviation
As (total)	IN	28	26.8	37.3	29.0	2.1
	BF	28	24.8	43.2	29.2	3.4
	TA	14	0.7	15.0	3.0	3.8
	TB	13[(a)]	0.8	15.1	2.8	4.1
	TC	14	0.7	15.2	2.8	3.9
	TT	14	0.7	13.5	2.7	3.2
As (soluble)	IN	14	27.3	33.7	29.6	1.6
	BF	14	0.9	21.7	2.9	5.4
	TT	13[(b)]	0.6	14.0	2.3	3.6
As (particulate)	IN	14	<0.1	5.6	0.6	1.5
	BF	14	7.6	42.1	27.8	7.1
	TT	13[(b)]	<0.1	2.2	0.5	0.7
As(III)	IN	14	11.3	30.8	26.2	4.7
	BF	14	<0.1	0.5	0.2	0.1
	TT	13[(b)]	<0.1	0.5	0.2	0.1
As(V)	IN	14	0.2	17.8	3.3	4.5
	BF	14	0.6	21.6	2.6	5.5
	TT	13[(b)]	0.4	13.9	2.1	3.6
Fe (total)	IN	28	128	420	188	55.4
	BF	28	196	3,093	1,866	610
	TA	14	<25	359	77	122
	TB	13[(c)]	<25	506	66	142
	TC	14	<25	463	72	136
	TT	14	<25	226	41	60.0
Fe (soluble)	IN	14	<25	227	146	62.8
	BF	14	<25	<25	<25	-
	TT	13[(b)]	<25	<25	<25	-
Mn (total)	IN	28	54.8	78.0	64.3	6.7
	BF	28	52.1	144	73.2	16.1
	TA	13[(d)]	0.1	11.8	2.2	3.8
	TB	13[(e)]	<0.1	15.5	2.4	4.5
	TC	14	0.1	13.6	2.2	3.9
	TT	14	<0.1	18.4	2.8	5.0
Mn (soluble)	IN	14	56.4	81.9	64.9	7.3
	BF	14	2.0	32.8	16.4	8.8
	TT	12	<0.1	0.7	0.2	0.2

(a) One outlier (i.e., 51.9 µg/L) on 12/14/09 omitted.
(b) Speciation results not available due to reanalysis of 07/13/10 metals sample.
(c) One outlier (i.e., 5,188 µg/L) on 12/14/09 omitted.
(d) One outlier (i.e., 72.1 µg/L) on 12/14/09 omitted.
(e) One outlier (i.e., 1,337 µg/L) on 12/14/09 omitted.

with concentrations ranging from 11.3 to 30.8 µg/L and averaging 26.2 µg/L. Soluble As(V) concentrations were low, ranging from 0.2 to 17.8 µg/L and averaging 3.3 µg/L. Particulate arsenic concentrations also were low, ranging from <0.1 to 5.6 µg/L and averaging 0.6 µg/L. The arsenic concentrations were consistent with those collected previously during source water sampling (Table 4-1).

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

Parameter	Sampling Location	Unit	Sample Count	Concentration Minimum	Concentration Maximum	Concentration Average	Standard Deviation
Alkalinity (as $CaCO_3$)	IN	mg/L	28	138	172	148	8.9
	BF	mg/L	27[(a)]	132	165	143	9.1
	TA	mg/L	14	130	156	140	7.8
	TB	mg/L	14	130	158	141	8.2
	TC	mg/L	14	133	155	141	6.7
	TT	mg/L	14	129	159	142	8.5
Ammonia (as N)	IN	mg/L	28	<0.05	0.2	0.1	0.0
	BF	mg/L	28	<0.05	<0.05	<0.05	-
	TA	mg/L	14	<0.05	<0.05	<0.05	-
	TB	mg/L	14	<0.05	<0.05	<0.05	-
	TC	mg/L	14	<0.05	<0.05	<0.05	-
	TT	mg/L	13[(b)]	<0.05	<0.05	<0.05	-
Fluoride	IN	mg/L	14	0.1	0.2	0.2	0.0
	BF	mg/L	14	0.1	0.2	0.2	0.0
	TT	mg/L	14	0.1	0.3	0.2	0.1
Sulfate	IN	mg/L	14	17.5	24.3	21.0	2.2
	BF	mg/L	14	18.6	25.5	22.0	2.3
	TT	mg/L	14	18.3	32.2	22.6	3.9
Nitrate (as N)	IN	mg/L	28	<0.05	0.1	<0.05	0.0
	BF	mg/L	28	<0.05	0.2	<0.05	0.0
	TA	mg/L	14	<0.05	<0.05	<0.05	-
	TB	mg/L	14	<0.05	0.1	<0.05	0.0
	TC	mg/L	14	<0.05	<0.05	<0.05	-
	TT	mg/L	14	<0.05	<0.05	<0.05	-
Phosphorus (as P)	IN	μg/L	28	<10	<10	<10	-
	BF	μg/L	27[(c)]	<10	12.9	<10	1.5
	TA	μg/L	14	<10	<10	<10	-
	TB	μg/L	13[(d)]	<10	<10	<10	-
	TC	μg/L	14	<10	<10	<10	-
	TT	μg/L	14	<10	<10	<10	-
Silica (as SiO_2)	IN	mg/L	28	12.8	16.2	14.1	0.8
	BF	mg/L	28	12.8	16.4	14.1	0.8
	TA	mg/L	14	12.4	15.1	13.4	0.7
	TB	mg/L	14	12.5	14.2	13.4	0.6
	TC	mg/L	14	12.4	14.9	13.3	0.7
	TT	mg/L	14	12.7	16.4	13.8	0.9
Turbidity	IN	NTU	28	0.5	6.5	1.8	1.5
	BF	NTU	28	0.5	10.0	2.7	2.5
	TA	NTU	14	0.2	5.4	1.3	1.3
	TB	NTU	14	0.2	9.2	1.8	2.5
	TC	NTU	14	0.4	4.0	1.6	1.0
	TT	NTU	14	0.2	1.9	0.8	0.4
TOC	IN	mg/L	14	<1.0	<1.0	<1.0	-
	BF	mg/L	14	<1.0	1.5	<1.0	0.3
	TT	mg/L	14	<1.0	<1.0	<1.0	-
pH	IN	S.U.	19	6.7	8.8	7.8	0.5
	BF	S.U.	19	7.2	9.0	7.8	0.4
	TT	S.U.	19	7.4	8.8	7.9	0.3

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

Parameter	Sampling Location	Unit	Sample Count	Concentration Minimum	Maximum	Average	Standard Deviation
Temperature	IN	°C	16[(e)]	8.5	15.7	12.6	1.9
	BF	°C	17[(e)]	8.3	15.2	12.6	1.7
	TT	°C	17[(e)]	7.9	15.0	12.8	1.8
Dissolved Oxygen (DO)	IN	mg/L	6	1.7	5.8	3.6	1.6
	BF	mg/L	6	1.2	7.6	5.1	2.2
	TT	mg/L	6	1.5	3.6	2.4	0.9
Oxidation-Reduction Potential (ORP)	IN	mV	20	152	482	358	82.3
	BF	mV	20	152	723	535	139
	TT	mV	20	152	707	561	137
Free Chlorine (as Cl_2)	BF	mg/L	19	0.9	3.1	1.6	0.5
	TT	mg/L	19	0.5	1.7	1.2	0.3
Total Chlorine (as Cl_2)	BF	mg/L	19	1.2	4.5	2.0	0.8
	TT	mg/L	19	0.6	2.0	1.4	0.4
Total Hardness (as $CaCO_3$)	IN	mg/L	14	92	166	140	21.0
	BF	mg/L	14	86	175	145	23.4
	TT	mg/L	14	121	171	145	17.8
Ca Hardness (as $CaCO_3$)	IN	mg/L	14	56	126	100	18.5
	BF	mg/L	14	46	128	103	21.8
	TT	mg/L	14	80	126	104	15.4
Mg Hardness (as $CaCO_3$)	IN	mg/L	14	33.5	51	40	5.0
	BF	mg/L	14	34.8	49	42	4.6
	TT	mg/L	14	35.2	46	40	4.3

(a) One outlier (i.e., 43.4 mg/L) on 07/26/10 omitted.
(b) One outlier (i.e., 1.8 mg/L) on 12/03/09 omitted.
(c) One outlier (i.e., 464 µg/L) on 05/03/10 omitted.
(d) One outlier (i.e., 28.0 µg/L) on 12/14/09 omitted.
(e) One outlier (i.e., 25.0 °C) on 04/19/10 omitted.

Following chlorination and iron addition (BF), total arsenic concentrations remained essentially unchanged at 29.2 µg/L (on average). Arsenic, however, existed mostly as particulate arsenic (27.8 µg/L [on average]) with only a small fraction remaining in the soluble form (2.9 µg/L). Of the soluble fraction, 0.2 µg/L (on average) existed as As(III) and 2.6 µg/L as As(V) (on average), indicating effective oxidation of As(III) by chlorine.

The oxidized arsenic was adsorbed onto and/or co-precipitated with iron solids upon chlorination and $FeCl_3$ injection. The solids were filtered out by the GreensandPlus™ media, reducing the average total arsenic concentration to 2.7 µg/L in the combined effluent of the three filtration vessels. Total arsenic concentrations after each vessel ranged from 0.7 to 15.2 µg/L and averaged 3.0, 2.8, and 2.8 µg/L for Vessels A, B, and C, respectively.

As shown in Figure 4-16, total combined arsenic concentrations exceeded the 10 µg/L arsenic MCL once during the 14 speciation sampling events. Effluent samples from the three filtration vessels also exceeded the MCL once during the 14 regular sampling events on September 20, 2010, with 15.0, 15.1, and 15.2 µg/L in Vessels A, B, and C effluent, respectively. None of the exceedances had elevated iron concentrations in the same samples; iron concentrations in all cases were below the MDL of 25 µg/L.

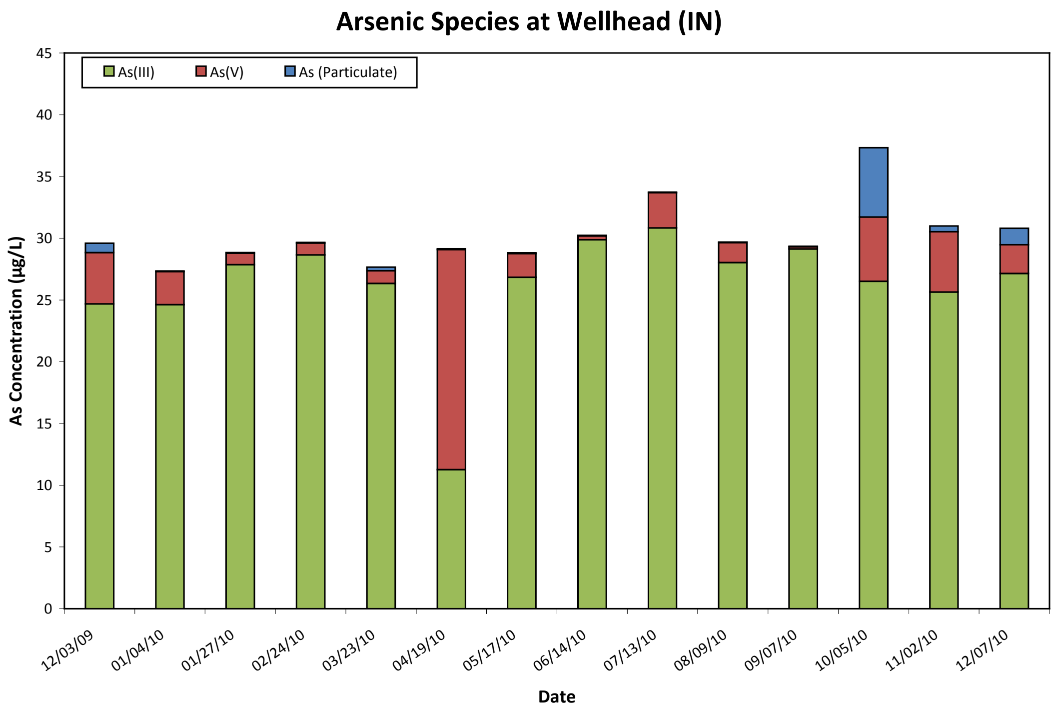
As mentioned above, arsenic existed mostly as soluble As(III) in raw water. This is not consistent with relatively high ORP and DO results measured onsite using a Symphony SP90M5 Handheld Multimeter. As shown in Table 4-9, ORP readings of source water ranged from 152 to 482 mV and averaged 358 mV; DO concentrations ranged from 1.7 to 5.8 mg/L and averaged 3.6 mg/L. These ORP readings and DO concentrations are much higher than those of source waters containing high levels of soluble As(III) at other arsenic demonstration sites. For example, at Big Sauk Lake Mobile Home Park in Sauk Centre, MN, the source water had over 80% of arsenic as soluble As(III) and its ORP readings and DO concentrations averaged -41 mV and 1.2 mg/L, respectively (Shiao et al., 2009). At Climax, MN, arsenic in source water existed almost entirely as soluble As(III) and its ORP readings and DO concentrations averaged -77 mV and 1.7 mg/L, respectively (Condit and Chen, 2006). At Felton, DE, however, the average ORP reading was high at 320 mV even though over 84% of arsenic existed as soluble As(III) (Chen et al., 2010). The average DO concentration at Felton, DE was low at 1.0 mg/L.

What caused high ORP readings and/or DO concentrations at Conneaut Lake Park and Felton is unknown. One contributing factor could be the field handheld meters used, some of which tended to drift over the course of measurements as reported by operators at a number of arsenic demonstration sites. The other possibility could be the effect of surface water from Conneaut Lake, which obviously is more oxidizing than the groundwater underlying the Park.

Iron. Total iron concentrations in source water ranged from 128 to 420 μg/L and averaged 188 μg/L, existing mostly (78% [on average]) as soluble iron. Following chlorination and iron addition, total iron concentration increased significantly, ranging from 196 to 3,093 μg/L and averaging 1,866 μg/L. Low levels of iron at 221 and 196 μg/L were measured on September 7 and 20, 2010, respectively, due to malfunctioning of the metering pump during August 26, 2010, through September 29, 2010. Therefore, no iron was added to source water during this period. The lack of supplemental iron addition caused elevated arsenic levels (from 13.5 to 15.2 μg/L), existing mainly as soluble As(V), in the filter effluent.

Elevated iron levels at the BF location reflected the addition of supplemental iron to source water. The iron dosage on a given date was calculated by subtracting the amount of iron in source water from the amount of iron measured at the BF location. Figure 4-17 plots iron dosages during the study period. Iron dosages ranged from 1.0 to 3.0 mg/L (as Fe) and averaged 1.8 mg/L (as Fe), which is close to the target value of 1.5 mg/L (as Fe) (see Table 4-3) and exactly the same as the estimated dosage (1.8 mg/L [as Fe]) based on solution levels in the day tank.

As expected, iron existed entirely as particulate iron after chlorination. Arsenic-laden iron solids were removed by the GreensandPlus™ media to levels that ranged from <25 to 506 μg/L and averaged 64 μg/L (see Table 4-8). Iron leakage from the filtration vessels appeared to be an issue during some sampling events, including one on March 8, 2010 with concentrations above the 300-μg/L SCML and seven on February 24, March 23, April 19, June 1, June 28, August 9, and August 23, 2010, with concentrations below the SMCL. A filter run length study using Vessel A was then conducted to determine the useful run length before arsenic and iron breakthrough at 10 and 300 μg/L, respectively. Results of the study are discussed in detail in Section 4.5.2. Figure 4-18 shows total iron concentrations across the treatment train.



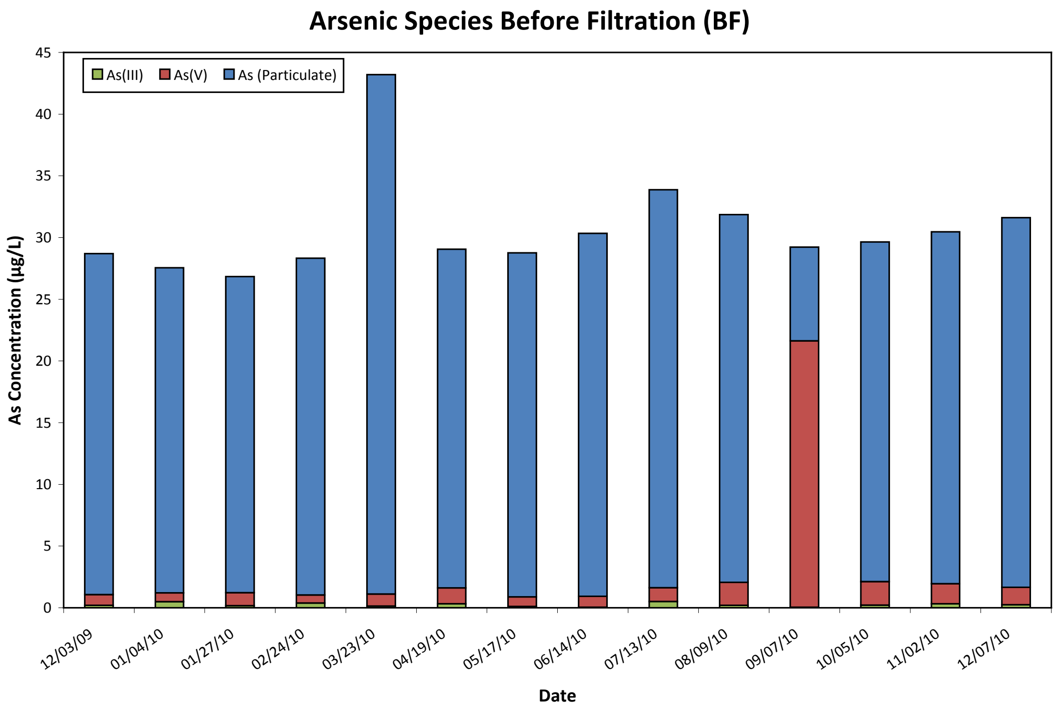


Figure 4-15. Concentrations of Various Arsenic Species at IN, BF, and TT Sampling Locations

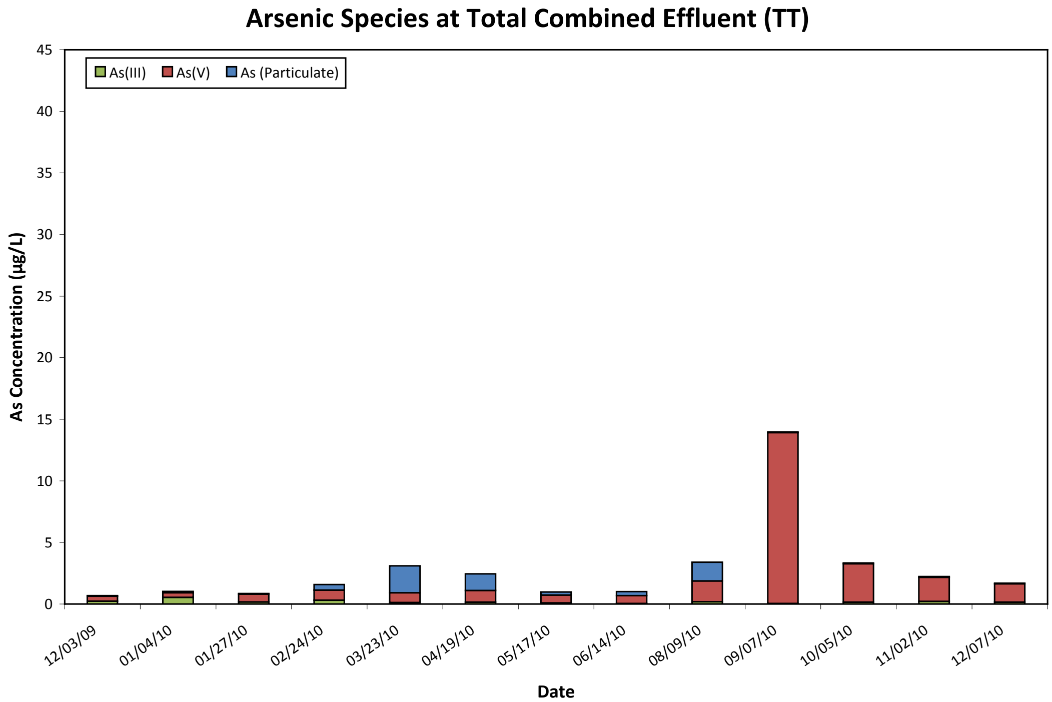


Figure 4-15. Concentrations of Various Arsenic Species at IN, BF, and TT Sampling Locations (Continued)

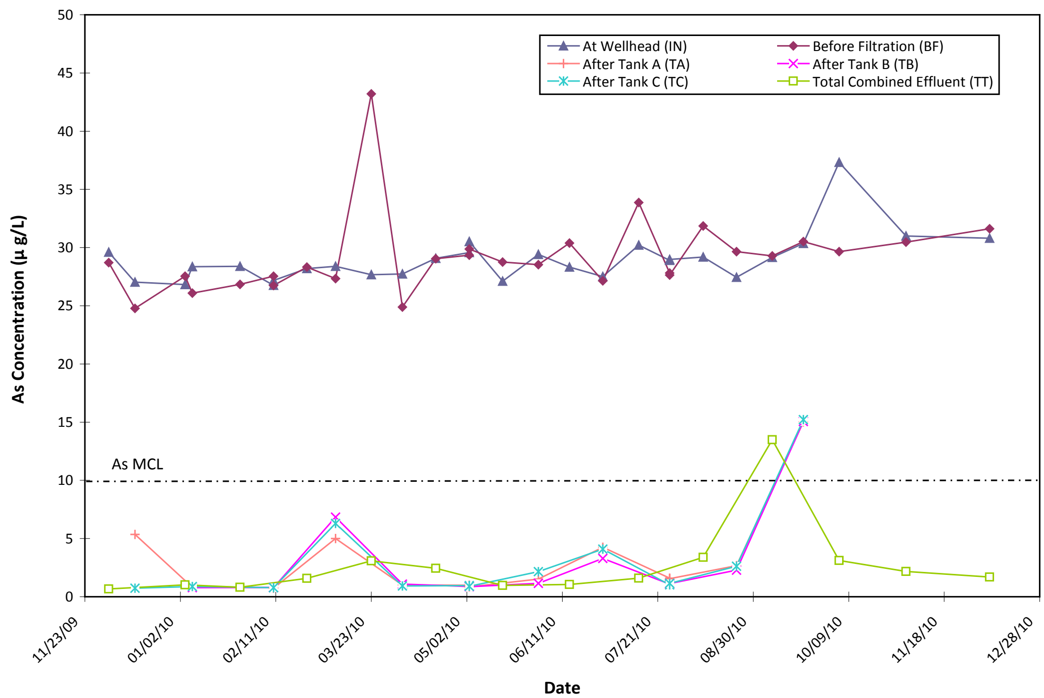


Figure 4-16. Total Arsenic Concentrations Across Treatment Train

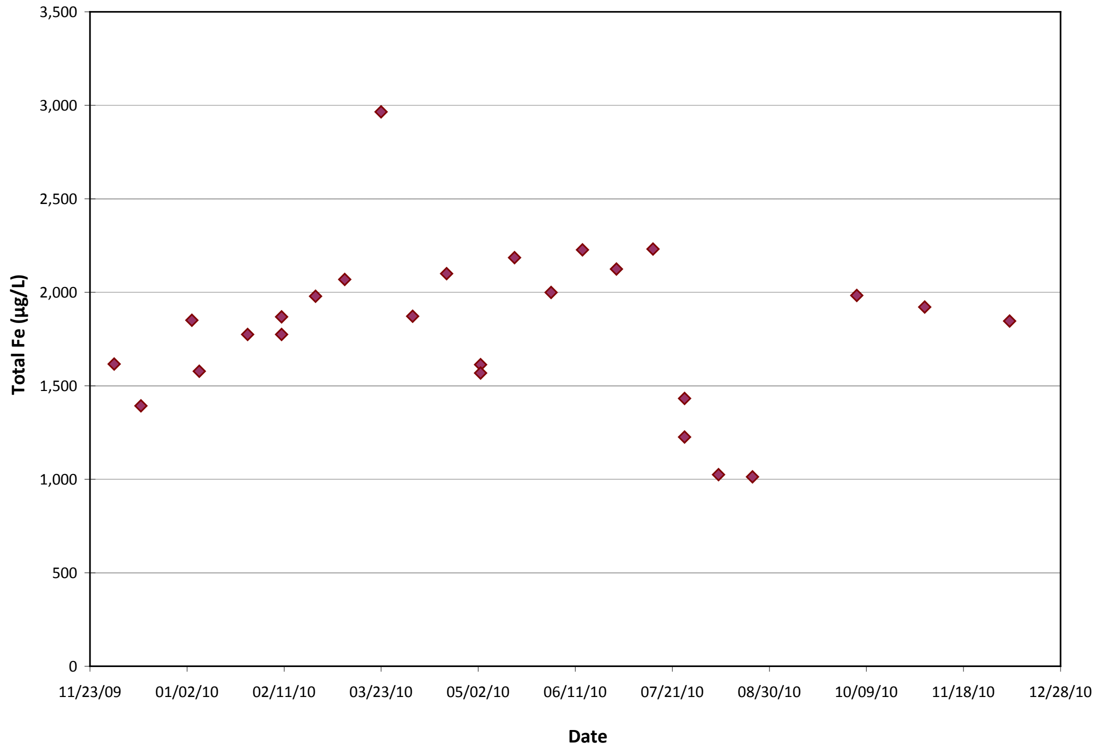


Figure 4-17. Iron Dosages to Source Water

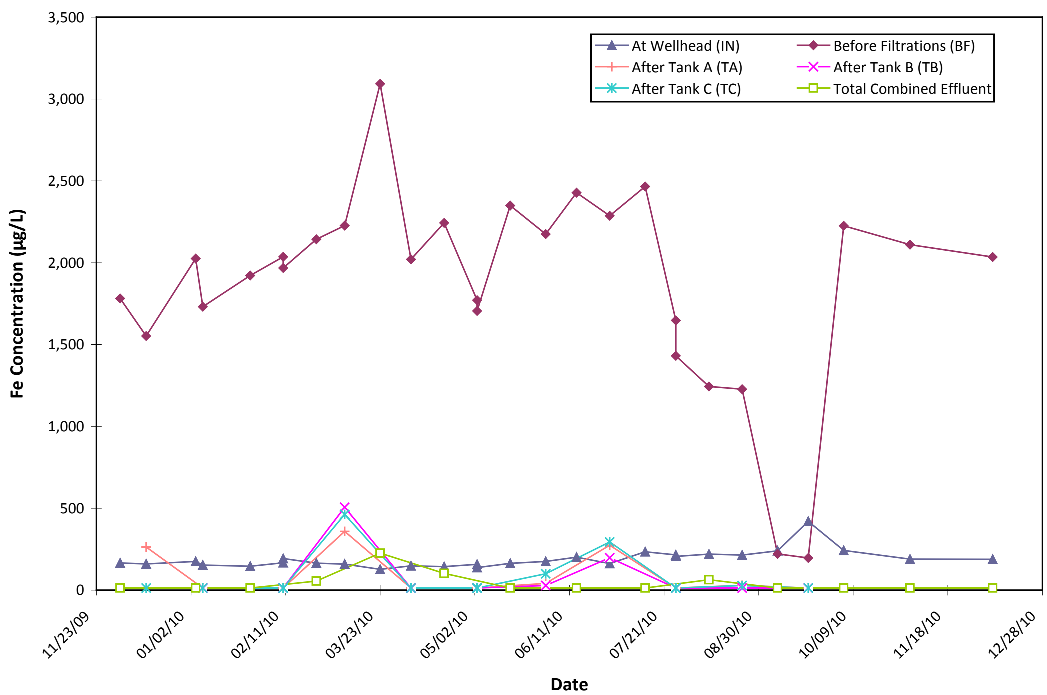


Figure 4-18. Total Iron Concentrations Across Treatment Train

***Manganese*.** Total manganese levels in source water ranged from 54.8 to 78.0 µg/L and averaged 64.3 µg/L, existing entirely in the soluble form. After chlorination, only 16.4 µg/L remained as soluble manganese; the rest was precipitated, presumably, to MnO_2. These results were contrary to those observed at a number of arsenic demonstrations sites, where very little soluble manganese was precipitated by chlorine due to slow kinetics (McCall et al., 2007; Condit and Chen, 2006; Knocke et al., 1990; Knocke et al., 1987).

Total manganese concentrations in the filter effluent ranged from <0.1 to 15.5 µg/L and averaged 2.3 µg/L. Rather complete removal was achieved apparently via filtration of particulate manganese (MnO_2) and possible reactions between soluble manganese (Mn^{2+}) and the GreensandPlus™–MnO_2 media:

$$Mn^{2+} + \text{GreensandPlus–}MnO_2 \rightarrow \text{GreensandPlus–}Mn_2O_3 + MnO_{2(s)}$$

The reduced surface (GreensandPlus–Mn_2O_3) would then be re-oxidized when in contact with chlorine:

$$\text{GreensandPlus–}Mn_2O_3 + OCl^- \rightarrow \text{GreensandPlus–}MnO_2 + Cl^-$$

***Competing Anions*.** As discussed in Section 4.1.1, phosphorus and silica could compete with arsenic for available adsorption sites on iron solids. Phosphorus concentrations were mostly below the MDL of 10 µg/L. Silica concentrations ranged from 12.8 to 16.2 mg/L (as SiO_2) and averaged 14.1 mg/L (as SiO_2); these concentrations remained essentially unchanged across the treatment train. Therefore, the phosphorus and silica effect on arsenic removal should be minimal.

pH. pH values of source water ranged from 6.7 to 8.8 and averaged 7.8. This range was consistent with the pH measurements taken by Battelle during source water sampling on October 27, 2006 (i.e., 8.0 in Table 4-1) and were at the higher end of the commonly agreed upon target range of 5.5 to 8.5 for arsenic removal.

Chlorine. Figure 4-19 presents free and total chlorine residuals measured after chlorination and iron addition (BF) and after the effluent from the three filtration vessels combined (TT). As shown in the figure, data for BF and TT were scattered. Total chlorine residuals at BF ranged from 1.2 to 4.5 mg/L (as Cl_2) and averaged 2.0 mg/L (as Cl_2); free chlorine residuals ranged from 0.9 to 3.1 mg/L (as Cl_2) and averaged 1.6 mg/L (as Cl_2). Total and free chlorine residuals at TT were 0.6 and 0.4 mg/L (as Cl_2), respectively, lower than those at BF, indicating chlorine demand in the filtration vessels. Because only 0.1 mg/L of ammonia (as N) was measured in source water, formation of chloramines was not a concern.

Other Water Quality Parameters. Alkalinity, fluoride, nitrate, sulfate, TOC, and hardness levels were low or below the respective MDLs. They remained relatively constant across the treatment train, indicating that they were not affected by the treatment process (Table 4-9). Turbidity levels averaged 1.8 NTU in source water and increased only slightly to 2.7 NTU (on average) after iron addition. This result was somewhat unexpected because as much as 1.8 mg/L of iron (as Fe) had been added to source water to enhance arsenic removal. Turbidity levels after the filtration vessels ranged 0.2 to 9.2 NTU and averaged 1.4 NTU. Higher turbidity readings did not appear to correlate well with elevated iron and arsenic concentrations in the filter effluent.

4.5.2 Filter Run Length Study. Table 4-10 summarizes results of a filter run length study spanning from July 5 through 13, 2010. After the system was backwashed, filtered (with 0.45 µm disc filters) and unfiltered samples were collected daily from the TA location during normal system operation. By the end of Day 6, the three filtration vessels were backwashed again and sampling continued through Day 8. Daily run time, volume throughput, and Δp were recorded when samples

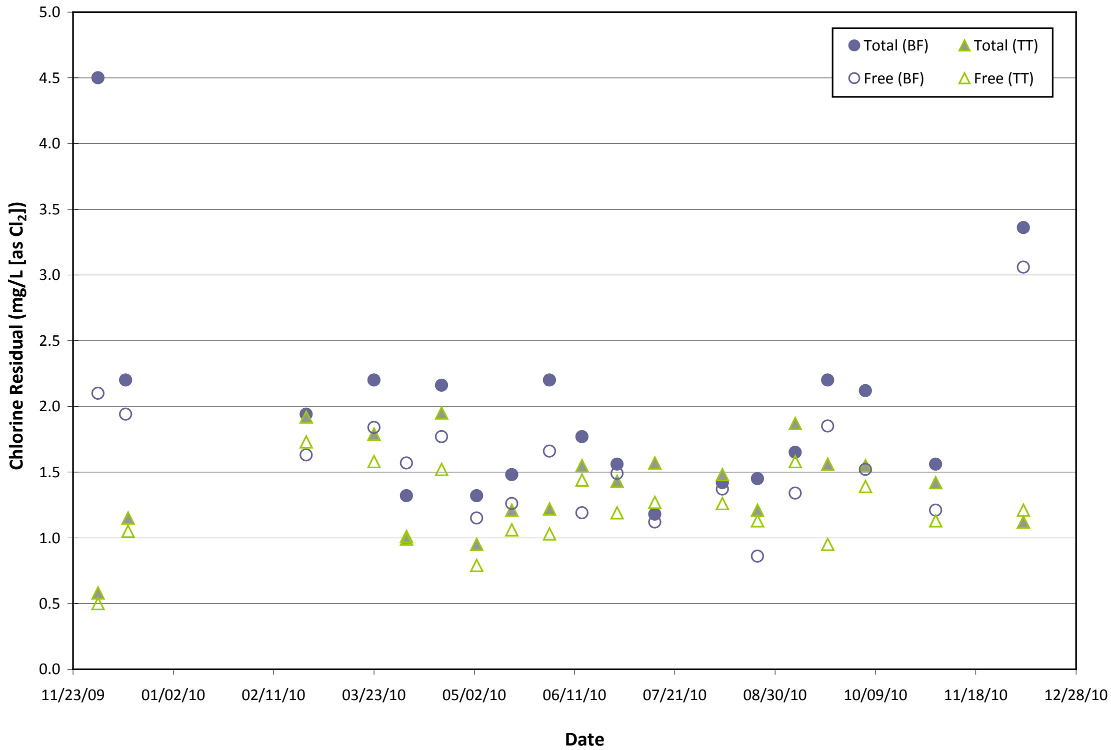


Figure 4-19. Chlorine Residuals Measured at BF and TT Locations

were taken. Both filtered and unfiltered samples were analyzed for arsenic, iron, manganese, and phosphorus. Figure 4-20 plots total and soluble arsenic and iron concentrations and Δp against volume throughput. Figure 4-21 plots total arsenic and total iron concentrations against filter run time.

Table 4-10. Results of Run Length Study

Sampling Date		07/05/10	07/06/10	07/07/10	07/08/10	07/09/10	07/10/10	07/11/10	07/12/10	07/13/10
Day No.		**Day 0**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7[(a)]**	**Day 8[(a)]**
Sampling Location										
Parameter	**Unit**	**TA**	**TA**	**TA**	**TA**	**TA**	**TA**	**TA**	**TA**	**TA**
Operating Time	hr	0	0.3	11.8	23.2	40.6	50.4	65.3	82.6	90.1
Δp	psi	-	5	9	8	10	12	12	12	2
Throughput	gal	0	1,245	47,800	75,222	115,993	140,110	173,457	32,200	55,185
P (as P)	mg/L	-	<10	<10	<10	<10	<10	<10	<10	<10
As (total)	µg/L	-	1.4	1.8	3.7	9.5	11.2	6.5	1.5	1.1
As (soluble)	µg/L	-	1.0	1.1	1.3	1.4	1.3	1.5	1.1	1.0
Fe (total)	µg/L	-	< 25	87	185	774	756	390	33	26
Fe (soluble)	µg/L	-	< 25	31	< 25	< 25	< 25	102	< 25	25
Mn (total)	µg/L	-	0.9	70.1	6.3	22.2	24.2	13.0	2.2	0.7
Mn (soluble)	µg/L	-	0.2	1.4	0.6	0.9	0.7	2.4	0.5	16.1

(a) Results from after backwash occurred at end of Day 6.

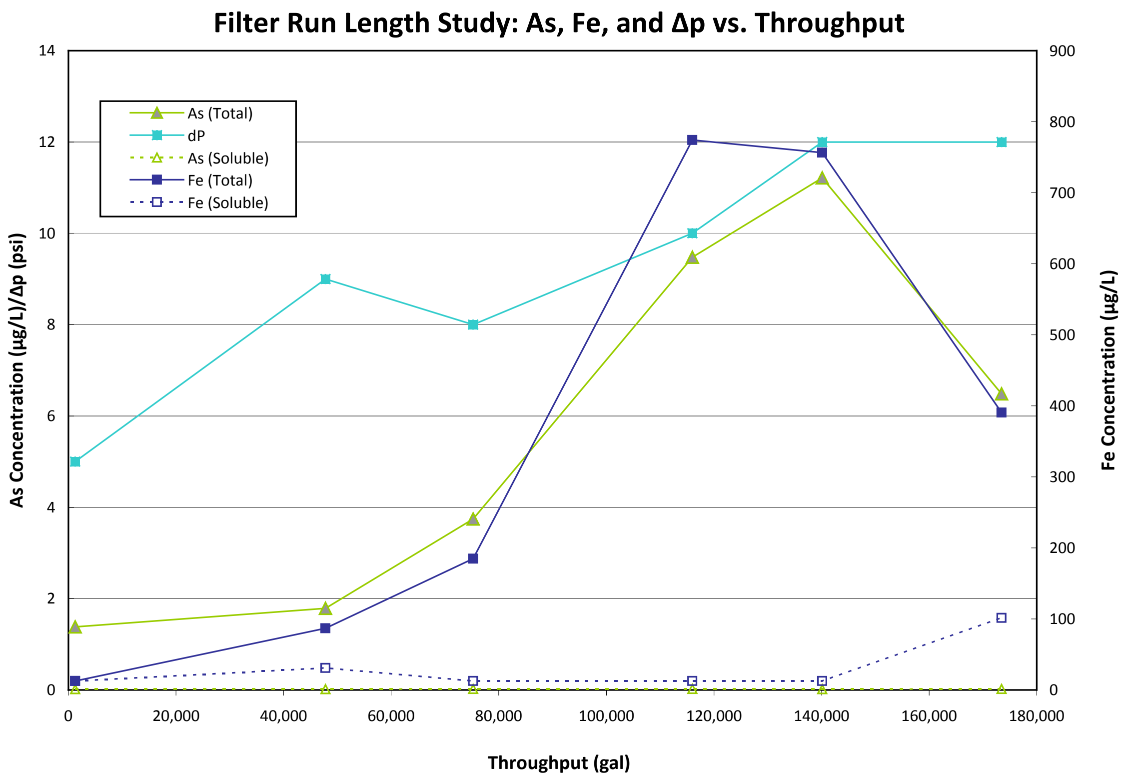


Figure 4-20. Filter Run Length Study Results vs. Throughput

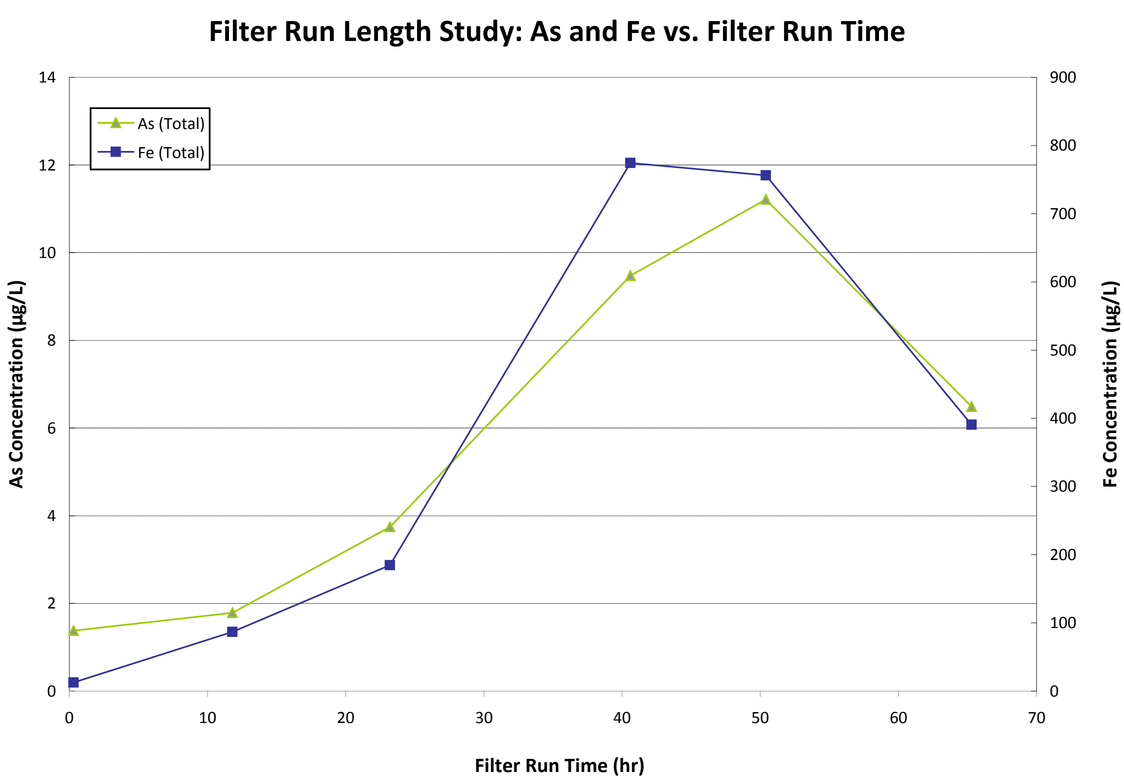


Figure 4-21. Filter Run Length Study Results vs. Filter Run Time

As expected, arsenic and iron in the filter effluent existed primarily in the particulate form. Total arsenic concentrations in the filter effluent increased steadily from 1.4 µg/L at 0.3 hr on Day 1 to 9.5 µg/L at 40.6 hr on Day 4. Based on extrapolation, breakthrough at 10 µg/L would occur at 43.5 hr on Day 5, treating approximately 123,100 gal of water. Total iron concentrations were below the MDL of 25 µg/L at 0.3 hr and increased rather rapidly to 87 and 185 µg/L at 11.8 and 23.2 hr, respectively. By Day 4 at 40.6 hr, the total iron concentration had already increased to 774 µg/L. Therefore, breakthrough at 300 µg/L would occur at 26.6 hr on Day 4, after treating approximately 83,200 gal of water.

To ensure good water quality, the filter run length should be no longer than 26 hr, or 83,000 gal of throughput per filtration vessel, when the Park is in operation. For a 12 and an 8 hr daily run time (the average daily run time is 11.9 hr when the Park is in operation [see Table 4-6]), the system would need a backwash once every 2 and 3 days, respectively. These suggested filter run lengths are based on no higher than 300 µg/L of iron in the treated water. Obviously, if the Park desires to have less iron in the treated water, the filter run length must be further reduced accordingly. The time setpoint starting from July 23, 2010, was once every 3 days.

The samples on Day 6 were taken before backwash by the end of the day. It is not known why the low results were achieved as shown in Table 4-10. Δp increased from a clean-bed level of 5 psi to 12 psi on Day 6. After backwash, Δp remained high at 12 psi at Day 7. There is no plausible reason, other than a recording error, to explain why the Δp remained high.

4.5.3 Backwash Wastewater and Solids Sampling. Table 4-11 presents analytical results of backwash wastewater sampling. Backwash wastewater samples were collected by the operator a total of 11 times from each of the three filtration vessels (except for Vessel C, which was sampled 10 times). pH values of backwash wastewater ranged from 7.3 to 7.9 and averaged 7.6, which was approximately 0.3 pH units lower than that of the treated water. TDS concentrations ranged from 152 to 220 mg/L and averaged 185 mg/L. TSS concentrations ranged from 85 to 1,280 mg/L and averaged 498 mg/L. Concentrations of total arsenic, iron, and manganese ranged from 215 to 3,943 µg/L (averaged 1,581 µg/L), 32,024 to 437,564 µg/L (averaged 180,707 µg/L), and 783 to 16,237 µg/L (averaged 6,335 µg/L), respectively.

As expected, the majority of the total arsenic, iron, and manganese in the backwash wastewater were in particulate form. (Soluble arsenic concentrations in the samples collected on September 8, 2010, were high, ranging from 17.1 to 18.8 µg/L. The reason for these elevated concentration is unknown.) Assuming that 1,840 gal (see Section 4.4.4) of backwash wastewater was produced from each vessel and that 498 mg/L of TSS was produced, approximately 3,469 g (3.5 kg) of solids would be discharged during backwash of each filtration vessel and stored in the two 4,000-gal holding tanks. The solids would be comprised of 11.0 g of arsenic (i.e. 0.3% by weight), 1,258 g of iron (i.e. 36.3 % by weight), and 44.0 g of manganese (i.e. 1.3 % by weight) based on the average particulate metal data presented in Table 4-11.

Solids in backwash wastewater were characterized through collection of backwash solids (Section 3.3.3). Table 4-12 presents analytical results of the solid samples collected on January 27, 2010. Arsenic, iron, and manganese levels in the solids averaged 4,551 µg/g (or 0.5% by weight), 373,734 µg/g (or 37.4% by weight), and 33,168 µg/g (or 3.3 % by weight), respectively. These amounts were comparable to those derived from the backwash wastewater metal analysis (i.e., 0.3%, 36.3%, and 1.3%, respectively).

Table 4-11. Filtration Vessel 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
Filtration Vessel A										
01/04/10	7.8	174	85	302	6.7	295	32,024	369	783	51.6
01/27/10	7.6	176	230	472	2.8	469	108,871	121	1,708	5.5
02/24/10	7.4	180	260	442	2.8	439	102,042	137	1,878	5.2
03/23/10	7.7	174	580	1,692	1.5	1,691	214,299	83	8,643	2.0
04/19/10	7.7	208	810	3,139	1.4	3,138	293,846	46	13,319	1.1
05/18/10	7.7	204	850	1,893	1.2	1,892	229,569	32	8,431	1.4
06/16/10	7.3	202	1,000	2,963	1.4	2,961	264,029	47	12,508	1.7
07/12/10	7.4	220	525	1,535	1.0	1,534	357,290	165	5,367	1.7
08/10/10	7.5	192	650	3,943	2.4	3,940	229,273	<25	11,974	0.8
09/08/10	7.9	192	95	1,283	17.1	1,266	34,481	<25	4,366	3.5
10/06/10	7.6	188	220	1,061	2.9	1,058	96,229	95	2,693	3.7
Filtration Vessel B										
01/04/10	7.7	174	210	451	3.1	448	94,375	129	1,828	3.5
01/27/10	7.7	168	145	357	2.5	355	69,618	114	1,464	3.7
02/24/10	7.6	172	510	1,236	2.3	1,234	193,692	110	6,243	3.9
03/23/10	7.7	174	300	215	1.7	213	117,825	104	1,944	3.0
04/19/10	7.6	210	835	3,863	2.7	3,860	324,397	126	15,482	4.4
05/18/10	7.7	166	810	2,427	2.9	2,424	238,352	155	10,020	6.3
06/16/10	7.3	192	915	1,173	1.7	1,171	437,564	66	5,846	2.2
07/12/10	7.4	194	1,280	3,357	3.6	3,353	332,500	277	14,384	11.4
08/10/10	7.6	194	520	868	2.8	866	191,416	29	4,085	1.6
09/08/10	7.9	182	115	1,238	18.2	1,220	35,598	<25	3,918	5.4
10/06/10	7.6	184	225	1,085	2.9	1,082	95,608	104	2,750	4.2
Filtration Vessel C										
01/04/10(a)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/27/10	7.6	176	160	433	2.9	430	86,792	133	1,345	4.7
02/24/10	7.6	172	310	471	3.4	467	120,994	383	2,229	12.3
03/23/10	7.6	170	345	247	2.3	245	133,835	178	2,417	5.2
04/19/10	7.6	152	665	3,261	1.6	3,259	284,662	44	16,237	1.5
05/18/10	7.7	180	600	2,026	3.4	2,022	203,891	184	7,275	5.8
06/16/10	7.4	196	805	2,683	1.7	2,681	223,185	62	10,334	2.0
07/12/10	7.4	186	1,010	2,555	1.7	2,553	289,080	115	11,199	2.9
08/10/10	7.6	190	550	1,402	3.1	1,398	205,463	40	4,936	2.1
09/08/10	7.9	182	115	1,462	18.8	1,443	42,207	32	4,511	6.6
10/06/10	7.5	186	210	1,048	2.7	1,045	99,612	99	2,589	4.0

NA = not available

(a) Backwash samples not collected from Tank C.

Table 4-12. Backwash Solids Sampling Results

Sample ID	Unit	Mg	P	Si	Ca	Fe	Mn	As	Ba
Vessel A-BW-Solids-1	µg/g	7,556	1,374	13,363	60,053	365,724	39,412	4,518	1,642
Vessel A-BW-Solids-2	µg/g	7,966	1,422	9,936	64,691	395,474	36,158	4,878	1,753
Average	**µg/g**	**7,761**	**1,398**	**11,650**	**62,372**	**380,599**	**37,785**	**4,698**	**1,697**
Vessel B-BW-Solids-1	µg/g	2,871	796	4,322	33,334	270,006	36,406	3,219	1,566
Vessel B-BW-Solids-2	µg/g	2,549	748	3,026	31,751	297,442	40,180	3,591	1,497
Average	**µg/g**	**2,710**	**772**	**3,674**	**32,543**	**283,724**	**38,293**	**3,405**	**1,532**
Vessel C-BW-Solids-1	µg/g	3,729	1,257	4,558	46,980	460,129	22,734	5,600	2,200
Vessel C-BW-Solids-2	µg/g	3,026	1,015	3,276	45,060	453,629	24,116	5,498	1,867
Average	**µg/g**	**3,378**	**1,136**	**3,917**	**46,020**	**456,879**	**23,425**	**5,549**	**2,033**

Collected on 01/27/10.

4.5.4 Distribution System Water Sampling. Prior to system startup, four first-draw baseline samples were collected from three residences (all of which were previously used for LCR sampling) on September 17, September 23, September 29, and October 8, 2009. Following system startup, sampling continued on a monthly basis from December 2009 through September 2010. Table 4-13 presents results of the distribution system sampling.

The most noticeable change in the distribution system water samples since system startup was a decrease in arsenic and manganese concentrations. Baseline arsenic concentrations ranged from 2.8 to 20.7 µg/L and averaged 10.6 µg/L. After system startup, the average arsenic concentration decreased significantly to 5.0 µg/L (on average). Out of the 11 distribution sampling events, two (at DS3 on April 6, 2010, and at DS2 on June 28, 2010) had arsenic concentrations above the 10 µg/L MCL. In both cases, elevated arsenic concentrations (at 21.4 and 18.0 µg/L) were associated with elevated iron concentrations (at 2,758 and 600 µg/L, respectively), indicating iron leakage from and inadequate backwash frequency of the filtration vessels. These elevated concentrations also could come from pipe surfaces.

During the study period, iron leakage from the filtration vessels was observed due to an increase in water demand and inadequte backwash frequency (once every six days), and was reflected by the results of distribution sampling. Baseline iron concentrations ranged from less than the MDL of 25 µg/L to 928 µg/L and averaged 181 µg/L. From system startup through June 2, 2010, iron concentrations increased significantly, ranging from less than the MDL of 25 µg/L to 2,758 µg/L and averaged 458 µg/L. To prevent iron leakage, the backwash frequency was shortened from once every six days to once every three days on July 23, 2010. Since then, iron concentrations were reduced significantly to 230 µg/L (on average).

Baseline manganese concentrations ranged from 0.4 to 212 µg/L, and averaged 62.2 µg/L. After system startup, manganese concentrations were reduced to below the 50 µg/L SMCL (43.5 µg/L [on average]).

Lead and copper concentrations within the distribution system increased slightly from baseline levels, but remained significantly less than their respective action levels of 15 µg/L and 1,300 µg/L. Baseline lead concentrations ranged from less than the MDL of 0.1 µg/L to 4.5 µg/L and averaged 0.6 µg/L, while baseline copper concentrations ranged from 0.3 to 72.6 µg/L and averaged 17.9 µg/L. After system startup, lead and copper levels slightly increased to 1.2 µg/L and 21.2 µg/L (on average), respectively.

Table 4-13. Distribution System Sampling Results

	Location	DS1								DS2								DS3							
	Address	Park Ave–Glancy								Reed Ave–Main Office								Reed Ave–Pasikoski							
	Flushed/ 1st Draw	1st Draw								1st Draw								1st Draw							
No. of Sampling Events	Sampling Date	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu
No.	Date	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
BL1	09/17/09	7.5	7.7	148	5.2	94	37.6	<0.1	0.7	9.5	8.0	140	7.1	53	212	<0.1	3.4	10.5	7.6	148	11.3	67	7.4	<0.1	14.2
BL2	09/23/09	8.3	7.7	139	20.7	928	38.4	0.6	5.8	9.5	7.7	144	14.0	304	129	1.9	72.6	9.5	7.7	141	20.6	398	30.3	0.1	30.3
BL3	09/29/09	5.0	7.8	144	9.5	81	36.2	<0.1	0.3	21.0	7.7	139	9.2	<25	65.5	<0.1	1.6	11.0	7.7	144	12.2	74	10.9	<0.1	30.0
BL4	10/08/09	9.0	7.9	143	8.5	142	22.3	4.5	3.0	21.0	8.0	140	2.8	<25	156	<0.1	1.5	8.0	8.0	145	6.3	<25	0.4	0.2	51.4
1	12/15/09	9.0	7.5	130	8.9	389	44.4	4.6	2.2	10.5	8.0	141	2.7	<25	69.8	0.2	6.3	10.8	8.0	139	8.0	383	7.1	0.2	14.8
2	01/08/10	7.0	8.2	143	2.4	158	45.1	1.9	1.3	12.0	8.0	143	1.9	<25	64.5	<0.1	0.5	8.0	7.9	141	3.4	393	3.4	0.5	17.3
3	02/11/10	7.0	8.1	148	3.1	511	35.0	4.6	2.2	9.0	7.8	139	8.5	296	60.9	3.0	69.7	22.0	7.9	132	4.5	271	3.2	0.2	20.5
4	03/09/10	7.0	7.9	141	1.8	416	35.2	0.2	0.7	21.5	8.0	134	5.4	187	92.8	0.8	15.9	10.5	7.7	141	5.1	1,067	10.6	1.0	16.3
5	04/06/10	NA	7.9	136	4.0	601	48.2	0.1	2.3	NA	7.8	136	3.1	<25	161	<0.1	0.8	11.5	7.7	129	21.4	2,758	32.2	0.2	86.1
6	05/04/10(a)	8.5	7.8	134	2.9	584	17.8	4.0	9.1	21.5	7.6	136	7.1	406	159	1.5	24.7	NA	NA	NA	NA	NA	NA	NA	NA
7	06/02/10	8.5	7.7	136	1.9	399	15.5	2.3	4.8	21.0	7.6	134	1.8	40	83.3	0.2	3.0	9.0	7.6	152	3.1	257	3.8	0.5	18.9
8	06/28/10	8.5	7.6	141	1.2	43	9.0	0.3	1.9	21.5	7.4	145	18.0	600	90.1	8.0	216	10.0	7.6	143	5.8	402	7.5	0.7	36.3
9	07/27/10	8.5	7.7	137	1.8	171	28.4	0.7	5.0	33.5	7.5	155	4.2	62	184	<0.1	1.2	NA	7.6	146	0.8	39	1.8	0.1	28.3
10	08/24/10	8.0	7.8	171	3.4	764	9.1	3.0	23.6	33.5	7.8	156	2.6	251	14.6	<0.1	9.9	9.0	7.7	152	4.3	303	3.3	0.1	22.8
11	09/21/10	8.8	7.9	157	4.6	73	2.1	0.5	2.6	21.5	7.8	157	3.1	<25	49.1	<0.1	3.3	9.0	7.9	153	9.3	35	0.6	0.3	9.3

BL = baseline sampling; NA = not available
lead action level = 15 µg/L; copper action level = 1,300 mg/L
Alkalinity unit mg/L as $CaCO_3$.
(a) Samples not collected from DS3.

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Measured pH values ranged from 7.4 to 8.2 and averaged 7.8. Alkalinity levels ranged from 129 to 184 mg/L (as $CaCO_3$) and averaged 143 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, electricity consumption, and labor.

4.6.1 Capital Cost. The capital investment for equipment, site engineering, and installation for the 250-gpm treatment system was $191,970 (Table 4-14). The equipment cost was $136,744 (or 71% of the total capital investment), which included $36,283 for the three carbon-steel filtration vessels, $13,320 for the AD-GS$^+$ ($138.75/ft^3 or $1.63/lb), $2,244 for anthracite ($46.75/ft^3 or $1.11/lb), $36,283 for process valves and piping, $26,515 for instrumentation and controls, $4,865 for the iron addition system, $3,150 for the chlorine addition system, and $3,950 for shipping.

Table 4-14. Capital Investment Cost

Description	Quantity	Cost	% of Capital Investment
Equipment Cost			
Filtration Vessels	3	$36,283	-
GreensandPlus™ (ft^3)	96	$13,320	-
Anthracite #1 (ft^3)	48	$2,244	
Process Valves and Piping	-	$36,283	-
Instrumentation and Controls	-	$26,515	-
Iron Addition System	1	$4,865	
Chlorine Addition System	1	$3,150	-
O&M Manuals	3	$475	-
Shipping	-	$3,950	-
Miscellaneous Items	-	9,659	
Equipment Total	-	**$136,744**	**71%**
Site Engineering Cost			
Vendor Labor	-	$8,073	
Vendor Travel	-	$3,240	
Subcontractor Labor	-	$9,663	-
PA DEP Review Fees	-	$750	-
Engineering Total	-	**$21,726**	**11%**
Installation Cost			
Vendor Labor for Startup	-	$3,880	-
Vendor Travel for Startup	-	$985	-
Subcontractor Material	-	$16,947	-
Subcontractor Electrical Material/Labor	-	$2,922	-
Subcontractor Labor	-	$8,766	-
Installation Total	-	**$33,500**	**18%**
Total Capital Investment	-	**$191,970**	**100%**

The site engineering cost included the cost for preparation of a process flow diagram and relevant mechanical drawings of the treatment system, piping, and valves, as well as submission of a permit application package to PA DEP for approval. The site engineering cost was $21,726, or 11% of the total capital investment. Site engineering was performed by Porter Consulting Engineers, P.C., a subcontractor to AdEdge.

The installation cost included the equipment and labor to unload and install the system, perform piping tie-ins/electrical connections, load and backwash the media, perform system shakedown and startup, and conduct operator training. The installation was performed by AdEdge and its subcontractor and cost $33,500, or 18% of the total capital investment.

The capital cost of $191,970 was normalized to the system's rated capacity of 250 gpm (or 360,000 gpd), which resulted in $768/gpm (or $0.53 gpd) of design capacity. The capital cost also was converted to an annualized cost of $18,120/year using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-yr return period. Assuming that the system operated 24 hr/day, 7 day/wk at the design flowrate of 250 gpm to produce 131,400,000 gal/year, the unit capital cost would be $0.14/1,000 gal. During the year-long demonstration period, the system produced approximately 20,114,000 gal of water (see Table 4-6); at this reduced rate of usage, the unit capital cost increased to $0.90/1,000 gal.

4.6.2 Operation and Maintenance Cost. The O&M costs included chemical consumption (i.e., $FeCl_3$), electricity consumption, and labor for a combined unit cost of $0.48/1,000 gal as summarized in Table 4-15. Chlorination using NaOCl existed prior to the installation of the treatment system for disinfection purposes. The presence of the system did not affect the use rate of the NaOCl solution. Therefore, the incremental chemical cost of the chlorine was negligible. Iron addition using $FeCl_3$ was calculated to be $0.07/1,000 gal based on 186 gal used to treat approximately 20,114,150 gal of water. Electrical power consumption was calculated based on the difference between the average monthly usage cost from electric bills before and after system startup. The difference in electricity usage was 1,715 KWh, which was an additional $108.37 per month based on a rate of $0.0632/KWh. Therefore, the cost of the electricity was calculated to be $0.06/1,000 gal. The routine, non-demonstration related labor activities consumed approximately 1 hr/day (Section 4.4.6). Based on this time commitment and a labor rate of $22/hr, the labor cost was $0.35/1,000 gal of water treated.

Table 4-15. Operation and Maintenance Cost

Cost Category	Value	Assumptions
Volume Processed (gal)	20,114,150	12/03/09–12/17/10 (379 days)
Chemical Cost		
Ferric Chloride Cost ($/yr)	$1,479	Estimated one-year consumption: 730 gal
Ferric Chloride Cost ($/1,000 gal)	$0.07	Actual consumption: 186 gal
Electricity Cost		
Electricity Cost ($/month)	$108.37	Based on KWh usage at $0.0632 rate
Electricity Cost ($/1,000 gal)	$0.06	Average monthly usage increase of 1,715 KWh
Labor Cost		
Average Weekly Labor (hr)	6.0	1.0 hr/visit, 6.0 visit/week (on average)
Labor Throughout Study (hr)	324	54 weeks from 12/03/09 through 12/17/10
Labor Cost ($)	$7,128	Labor rate = $22.00/hr
Unit Labor Cost ($/1,000 gal)	$0.35	
Total O&M Cost/1,000 gal	$0.48	Sum for chemicals, electricity, and labor

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APPENDIX A

OPERATIONAL DATA

Table A-1. EPA Arsenic Demonstration Project at Conneaut Lake Park, PA - Daily System Operation Log Sheet

Week No.	Day of Week	Date	Time	Supply Well (Well No. 2) Cum. Op Hours (hr)	Well Pump Flowrate (gpm)	Cum. Volume (gal)	Avg Flowrate (gpm)	Vessel A Instant. Flowrate A (gpm)	Cum. Volume A (gal)	Average Flowrate A (gpm)	DP (psi)	Vessel B Instant. Flowrate B (gpm)	Cum. Volume B (gal)	Average Flowrate B (gpm)	DP (psi)	Vessel C Instant. Flowrate C (gpm)	Cum. Volume C (gal)	Average Flowrate C (gpm)	DP (psi)	System Inlet Pressure (psi)	Outlet Pressure (psi)
1	Thur	12/03/09	13:56	NA	163	NA	NA	57	NA	NA	7	53	NA	NA	4	51	NA	NA	1	84	80
	Fri	12/04/09	13:15	NA	162	18,423	NA	57	6,141	NA	9	53	6,141	NA	3	52	6,141	NA	0	85	82
	Sat	12/05/09	4:55	NA	162	34,985	NA	55	12,282	NA	8	52	11,458	NA	2	52	11,245	NA	1	83	81
	Sun	12/06/09	17:00	NA	160	39,327	NA	57	13,736	NA	8	53	12,810	NA	3	53	12,587	NA	3	82	81
2	Mon	12/07/09	13:05	NA	173	85,722	NA	60	30,508	NA	7	55	28,336	NA	0	58	27,921	NA	1	83	82
	Tue	12/08/09	13:05	NA	158	110,103	NA	58	38,593	NA	9	52	35,711	NA	-1	56	35,652	NA	-1	81	80
	Wed	12/09/09	13:21	NA	164	132,996	NA	57	46,398	NA	1	52	42,886	NA	1	55	43,131	NA	0	80	80
	Fri	12/11/09	17:43	NA	165	158,951	NA	56	67,327	NA	-1	51	62,209	NA	0	53	63,089	NA	0	81	80
	Sat	12/12/09	5:18	NA	161	194,463	NA	56	68,051	NA	3	53	62,860	NA	4	54	63,759	NA	3	83	81
	Sun	12/13/09	1:50	NA	172	221,687	NA	54	80,000	NA	7	58	70,184	NA	2	59	71,083	NA	0	82	81
3	Mon	12/14/09	13:22	NA	NA	256,097	NA	NA	104,739	NA	0	NA	104,441	NA	0	NA	NA	NA	0	60	60
	Tue	12/15/09	13:46	NA	NA	279,273	NA	NA	113,935	NA	0	NA	106,537	NA	0	NA	NA	NA	0	87	86
	Thur	12/17/09	13:18	NA	NA	NA	NA	NA	114,635	NA	2	53	107,217	NA	0	59	108,788	NA	1	NA	NA
	Fri	12/18/09	13:45	NA	NA	348,396	NA	NA	118,516	NA	0	43	111,606	NA	-1	45	113,267	NA	0	80	80
	Sat	12/19/09	3:45	NA	170	355,506	NA	58	124,249	NA	5	56	114,638	NA	3	57	116,153	NA	0	83	81
	Sun	12/20/09	4:00	NA	170	377,851	NA	57	132,159	NA	8	55	122,163	NA	2	58	124,032	NA	5	84	81
4	Mon	12/21/09	13:38	NA	161	424,637	NA	55	148,544	NA	0	58	137,673	NA	1	53	140,184	NA	0	80	80
	Wed	12/23/09	19:00	NA	161	475,938	NA	55	165,128	NA	0	52	153,373	NA	-1	52	156,341	NA	0	80	80
	Fri	12/25/09	2:00	NA	162	520,745	NA	55	184,331	NA	6	55	167,203	NA	1	52	169,682	NA	-1	82	80
	Sat	12/26/09	12:00	NA	166	547,716	NA	55	193,089	NA	4	57	176,101	NA	3	56	178,127	NA	-1	82	81
	Sun	12/27/09	10:00	NA	158	594,257	NA	51	208,691	NA	6	54	192,123	NA	2	54	193,704	NA	3	83	80
5	Mon	12/28/09	13:34	NA	154	641,526	NA	53	224,172	NA	8	51	207,828	NA	3	50	209,261	NA	4	80	80
	Tue	12/29/09	13:20	NA	153	665,848	NA	51	232,607	NA	9	49	216,047	NA	3	51	217,509	NA	2	82	80
	Wed	12/30/09	20:40	NA	160	691,285	NA	91	245,532	NA	0	35	222,230	NA	4	35	223,737	NA	4	81	80
	Fri	01/01/10	5:00	NA	167	711,203	NA	51	254,288	NA	4	58	230,715	NA	2	59	231,928	NA	1	82	80
	Sat	01/02/10	8:00	NA	163	761,399	NA	50	268,000	NA	8	58	246,267	NA	3	58	247,536	NA	0	83	80
6	Mon	01/04/10	13:31	NA	154	826,682	NA	51	288,409	NA	0	51	268,186	NA	1	53	267,738	NA	1	80	80
	Tue	01/05/10	13:45	NA	166	844,221	NA	70	295,829	NA	2	67	274,599	NA	1	28	274,013	NA	2	82	80
	Wed	01/06/10	13:03	NA	164	867,932	NA	53	306,037	NA	4	51	284,269	NA	2	65	278,059	NA	0	82	80
	Thur	01/07/10	13:16	NA	163	900,046	NA	52	314,845	NA	-1	52	292,384	NA	0	66	289,051	NA	-1	80	80
	Fri	01/08/10	13:50	NA	157	930,260	NA	50	325,698	NA	7	46	302,465	NA	1	62	302,577	NA	1	82	80
	Sat	01/09/10	11:40	NA	158	952,345	NA	51	332,482	NA	7	46	308,755	NA	2	61	310,848	NA	3	84	80
	Sun	01/10/10	10:30	NA	164	975,509	NA	67	342,084	NA	7	62	317,092	NA	1	33	316,705	NA	2	83	80
7	Mon	01/11/10	13:10	NA	161	996,285	NA	68	350,527	NA	4	62	324,728	NA	2	34	320,822	NA	1	82	80
	Tue	01/12/10	13:15	NA	165	1,018,441	NA	51	359,943	NA	4	47	333,398	NA	2	70	325,463	NA	1	82	80
	Wed	01/13/10	13:06	NA	169	1,031,262	NA	50	366,687	NA	6	47	339,586	NA	3	71	334,989	NA	0	83	80
	Thur	01/14/10	13:30	NA	164	1,064,703	NA	49	373,808	NA	6	45	346,136	NA	3	70	345,125	NA	-1	81	80
	Fri	01/15/10	16:00	NA	158	1,106,112	NA	49	386,272	NA	2	43	357,280	NA	1	65	362,048	NA	0	80	80
	Sat	01/16/10	4:00	NA	168	1,109,712	NA	69	387,587	NA	4	64	358,281	NA	1	38	363,709	NA	1	82	80
	Sun	01/17/10	5:00	NA	164	1,129,986	NA	68	396,149	NA	4	64	366,087	NA	2	32	367,989	NA	1	82	80

Table A-1. EPA Arsenic Demonstration Project at Conneaut Lake Park, PA - Daily System Operation Log Sheet (Continued)

				Supply Well (Well No. 2)				Vessel A				Vessel B				Vessel C				System	
Week No.	Day of Week	Date	Time	Cum. Op Hours	Well Pump Flowrate	Cum. Volume	Avg Flowrate	Instant. Flowrate A	Cum. Volume A	Average Flowrate A	DP	Instant. Flowrate B	Cum. Volume B	Average Flowrate B	DP	Instant. Flowrate C	Cum. Volume C	Average Flowrate C	DP	Inlet Pressure	Outlet Pressure
				hr	gpm	gal	gpm	gpm	gal	gpm	psi	gpm	gal	gpm	psi	gpm	gal	gpm	psi	psi	psi
8	Mon	01/18/10	13:30	NA	169	1,172,121	NA	52	413,737	NA	1	49	382,443	NA	0	68	376,112	NA	0	82	80
	Tue	01/19/10	13:45	NA	168	1,193,978	NA	51	420,203	NA	7	48	388,429	NA	1	69	384,893	NA	1	83	80
	Wed	01/20/10	13:30	NA	154	1,228,313	NA	48	430,795	NA	5	44	398,229	NA	2	65	399,452	NA	2	82	80
	Thur	01/21/10	13:20	NA	155	1,255,361	NA	49	439,389	NA	6	43	405,914	NA	0	63	410,646	NA	3	83	80
	Fri	01/22/10	13:20	NA	159	1,280,466	NA	67	449,128	NA	2	61	414,552	NA	0	32	416,564	NA	3	82	80
	Sat	01/23/10	3:00	NA	165	1,281,623	NA	68	449,796	NA	5	64	415,171	NA	2	33	416,891	NA	1	83	81
	Sun	01/24/10	2:00	NA	159	1,319,381	NA	50	453,530	NA	5	45	427,838	NA	1	66	427,592	NA	2	82	80
9	Mon	01/25/10	13:15	NA	163	1,344,379	NA	50	471,507	NA	4	45	435,057	NA	-2	66	438,234	NA	0	82	80
	Tue	01/26/10	10:00	NA	153	1,378,064	NA	49	481,649	NA	4	43	443,777	NA	-2	61	451,270	NA	0	82	80
	Wed	01/27/10	13:25	NA	152	1,401,968	NA	51	489,575	NA	2	43	450,940	NA	0	60	460,727	NA	2	80	80
	Thur	01/28/10	13:10	NA	163	1,434,084	NA	55	500,966	NA	2	53	461,129	NA	-2	56	471,436	NA	2	80	80
	Fri	01/29/10	13:11	NA	160	1,458,807	NA	54	509,184	NA	2	52	468,992	NA	-2	53	479,754	NA	-2	81	80
10	Mon	02/01/10	13:20	NA	162	1,525,084	NA	56	532,156	NA	4	53	490,733	NA	2	54	502,199	NA	2	81	80
	Tue	02/02/10	13:10	NA	173	1,552,102	NA	60	541,870	NA	2	54	499,531	NA	0	57	511,071	NA	-2	82	81
	Wed	02/03/10	13:15	NA	164	1,585,652	NA	58	553,652	NA	2	52	510,252	NA	0	53	522,111	NA	0	82	80
	Thur	02/04/10	13:00	NA	163	1,616,587	NA	55	564,502	NA	4	52	520,165	NA	0	53	532,252	NA	0	81	80
	Fri	02/05/10	20:35	NA	164	1,638,985	NA	56	572,141	NA	2	53	527,196	NA	0	53	539,391	NA	0	81	80
11	Mon	02/08/10	13:15	NA	174	1,704,282	NA	90	595,515	NA	7	56	548,268	NA	2	58	560,676	NA	1	83	80
	Tue	02/09/10	13:30	NA	163	1,745,883	NA	56	610,387	NA	2	52	561,997	NA	4	53	574,830	NA	0	82	80
	Wed	02/10/10	13:00	NA	160	1,768,141	NA	56	617,676	NA	4	52	568,827	NA	2	54	581,805	NA	2	82	80
	Thur	02/11/10	13:15	NA	163	1,786,947	NA	57	624,279	NA	4	52	574,896	NA	4	54	588,011	NA	2	83	80
	Fri	02/12/10	13:15	NA	156	1,817,411	NA	55	635,029	NA	-2	50	584,614	NA	4	51	597,991	NA	4	82	80
12	Mon	02/15/10	13:30	NA	160	1,944,617	NA	56	679,931	NA	4	52	625,141	NA	4	52	639,956	NA	2	82	80
	Tue	02/16/10	13:15	NA	155	1,979,035	NA	54	691,881	NA	2	50	636,251	NA	2	51	651,317	NA	0	82	80
	Wed	02/17/10	13:15	NA	156	1,998,741	NA	55	698,754	NA	4	50	642,574	NA	4	51	657,792	NA	4	82	80
	Thur	02/18/10	13:20	NA	156	2,019,021	NA	54	705,860	NA	4	50	649,027	NA	4	52	664,409	NA	4	82	78
	Thur	02/18/10	14:10	NA	NA	2,019,941	NA	NA	706,028	NA	NA	NA	649,212	NA	NA	NA	664,596	NA	NA	NA	NA
	Fri	02/19/10	13:15	NA	154	2,041,204	NA	53	713,708	NA	4	48	656,074	NA	4	51	671,695	NA	4	83	78
13	Mon	02/22/10	13:28	NA	162	2,125,248	NA	57	743,445	NA	4	52	682,602	NA	4	53	699,361	NA	4	82	80
	Tue	02/23/10	12:15	NA	151	2,160,574	NA	53	755,614	NA	4	48	693,465	NA	0	50	710,596	NA	2	80	80
	Wed	02/24/10	13:07	NA	147	2,184,543	NA	53	764,511	NA	4	48	701,340	NA	2	50	718,869	NA	2	82	80
	Thur	02/25/10	13:25	NA	171	2,201,551	NA	57	770,677	NA	2	54	706,914	NA	2	61	724,187	NA	2	82	80
	Fri	02/26/10	13:15	NA	159	2,240,802	NA	47	783,382	NA	4	55	719,942	NA	4	57	737,964	NA	4	83	80
14	Mon	03/01/10	13:10	NA	159	2,300,880	NA	50	801,665	NA	4	53	740,700	NA	2	54	758,795	NA	2	82	79
	Tue	03/02/10	13:13	NA	160	2,331,044	NA	79	815,862	NA	0	40	748,645	NA	2	43	766,689	NA	2	82	79
	Wed	03/03/10	17:00	NA	157	2,353,562	NA	73	826,136	NA	4	42	754,301	NA	4	42	772,253	NA	4	80	80
	Thur	03/04/10	13:00	NA	167	2,374,370	NA	35	836,098	NA	2	64	760,478	NA	0	68	778,048	NA	0	83	83
	Fri	03/05/10	13:10	NA	160	2,400,050	NA	33	841,212	NA	3	63	770,549	NA	1	64	788,450	NA	1	82	80
	Sat	03/06/10	19:10	NA	160	2,434,141	NA	35	848,379	NA	2	58	783,384	NA	2	59	801,712	NA	2	80	80
15	Mon	03/08/10	13:40	NA	155	2,475,502	NA	73	867,817	NA	4	41	794,686	NA	4	42	813,323	NA	4	82	79
	Tue	03/09/10	13:05	NA	153	2,500,129	NA	67	878,929	NA	4	43	801,359	NA	2	44	820,093	NA	2	82	79
	Wed	03/10/10	13:15	NA	152	2,525,380	NA	32	884,812	NA	2	63	811,020	NA	-2	65	829,732	NA	0	82	80
	Thur	03/11/10	13:05	NA	153	2,548,033	NA	33	889,596	NA	4	60	819,849	NA	2	62	838,759	NA	2	81	79
	Fri	03/12/10	13:06	0.3	153	2,570,471	NA	35	894,564	NA	6	58	828,314	NA	3	60	847,420	NA	2	82	79

Table A-1. EPA Arsenic Demonstration Project at Conneaut Lake Park, PA - Daily System Operation Log Sheet (Continued)

				Supply Well (Well No. 2)				Vessel A				Vessel B				Vessel C				System	
Week No.	Day of Week	Date	Time	Cum. Op Hours	Well Pump Flowrate	Cum. Volume	Avg Flowrate	Instant. Flowrate A	Cum. Volume A	Average Flowrate A	DP	Instant. Flowrate B	Cum. Volume B	Average Flowrate B	DP	Instant. Flowrate C	Cum. Volume C	Average Flowrate C	DP	Inlet Pressure	Outlet Pressure
				hr	gpm	gal	gpm	gpm	gal	gpm	psi	gpm	gal	gpm	psi	gpm	gal	gpm	psi	psi	psi
16	Mon	03/15/10	13:25	7.5	153	2,638,283	157	71	926,590	74.1	4	42	846,242	41.5	2	43	865,698	42.3	2	82	73
	Tue	03/16/10	13:00	11.2	165	2,671,740	151	32	941,361	66.5	2	65	855,678	42.5	0	68	874,963	41.7	0	81	80
	Wed	03/17/10	13:05	13.6	148	2,695,023	162	28	945,386	28.0	4	66	864,860	63.8	2	68	884,428	65.7	0	82	78
	Thur	03/18/10	13:00	16.0	154	2,717,187	154	30	949,482	28.4	4	62	873,916	62.9	2	66	893,874	65.6	2	81	73
	Fri	03/19/10	13:05	18.6	165	2,741,153	154	77	954,090	29.5	4	43	883,481	61.3	0	46	903,690	62.9	2	81	80
17	Mon	03/22/10	9:40	26.2	164	2,813,406	158	37	988,388	75.2	4	63	901,667	39.9	0	63	922,630	41.5	0	80	80
	Tue	03/23/10	13:00	28.7	165	2,836,110	151	35	993,591	34.7	4	60	910,836	61.1	2	63	932,054	62.8	2	82	81
	Wed	03/24/10	13:10	32.6	160	2,873,579	160	54	1,005,070	49.1	4	52	923,534	54.3	0	54	945,073	55.6	0	82	80
	Thur	03/25/10	13:05	32.9	165	2,876,275	150	57	1,006,022	52.9	4	54	924,434	50.0	0	58	945,993	51.1	0	81	79
	Fri	03/26/10	13:00	36.4	162	2,910,359	162	55	1,017,566	55.0	4	53	935,564	53.0	2	54	957,455	54.6	0	82	80
18	Mon	03/29/10	21:13	48.0	164	3,020,643	158	56	1,055,847	55.0	2	53	971,079	51.0	-2	55	993,504	51.8	0	80	80
	Tue	03/30/10	14:15	50.4	160	3,043,646	160	56	1,063,710	54.6	2	52	978,510	51.6	2	53	1,001,164	53.2	0	82	80
	Wed	03/31/10	13:28	52.9	159	3,067,031	156	56	1,071,962	55.0	4	50	986,199	51.3	2	54	1,009,062	52.7	0	82	80
	Thur	04/01/10	13:04	55.4	153	3,090,378	156	54	1,080,119	54.4	4	49	993,661	49.7	2	51	1,016,743	51.2	2	81	75
	Fri	04/02/10	13:12	57.8	155	3,112,566	154	54	1,087,945	54.3	2	51	1,000,783	49.5	0	52	1,024,071	50.9	2	82	75
19	Mon	04/05/10	13:06	67.7	163	3,204,719	155	56	1,119,818	53.7	2	54	1,030,371	49.8	0	56	1,054,076	50.5	-2	82	79
	Tue	04/06/10	13:25	70.1	162	3,230,867	182	55	1,128,864	62.8	2	54	1,039,168	61.1	2	53	1,063,032	62.2	2	82	80
	Wed	04/07/10	13:02	73.9	153	3,264,399	147	53	1,140,232	49.9	4	51	1,050,159	48.2	0	51	1,074,156	48.8	2	80	72
	Thur	04/08/10	13:00	77.7	153	3,295,624	137	52	1,151,002	47.2	4	49	1,060,251	44.3	2	49	1,084,441	45.1	2	81	76
	Fri	04/09/10	13:02	79.4	152	3,319,314	232	52	1,159,324	81.6	4	49	1,067,946	75.4	2	50	1,092,294	77.0	2	82	76
20	Mon	04/12/10	8:15	87.5	163	3,396,389	159	54	1,178,609	39.7	5	53	1,092,224	50.0	0	55	1,116,476	49.8	5	80	80
	Tue	04/13/10	13:02	91.4	155	3,428,154	136	53	1,196,603	76.9	4	49	1,103,741	49.2	2	55	1,128,434	51.1	2	81	79
	Wed	04/14/10	13:02	95.5	155	3,466,961	158	53	1,209,900	54.1	4	50	1,116,084	50.2	2	52	1,141,232	52.0	2	82	79
	Thur	04/15/10	13:20	101.4	154	3,520,054	150	51	1,228,228	51.8	4	49	1,132,991	47.8	2	49	1,158,556	48.9	2	82	79
	Fri	04/16/10	13:00	107.3	163	3,574,950	155	55	1,247,656	54.9	6	53	1,151,047	51.0	1	55	1,176,546	50.8	2	81	79
21	Mon	04/19/10	13:00	123.6	17	3,727,571	156	52	1,300,836	54.4	2	48	1,200,700	50.8	2	48	1,226,219	50.8	2	82	76
	Tue	04/20/10	13:04	127.7	166	3,762,438	142	52	1,312,685	48.2	4	56	1,212,160	46.6	2	57	1,237,826	47.2	0	82	80
	Wed	04/21/10	13:25	132.5	157	3,813,085	176	54	1,329,549	58.6	4	51	1,228,686	57.4	2	52	1,254,931	59.4	2	82	79
	Thur	04/22/10	13:15	138.3	150	3,865,250	150	53	1,347,582	51.8	4	49	1,245,646	48.7	2	51	1,272,206	49.6	2	82	76
	Fri	04/23/10	13:20	144.2	147	3,919,404	153	51	1,366,404	53.2	4	48	1,263,152	49.5	2	49	1,289,885	49.9	2	82	74
22	Mon	04/26/10	13:09	161.0	156	4,072,312	152	53	1,419,597	52.8	4	51	1,312,872	49.3	2	52	1,339,891	49.6	2	82	79
	Tue	04/27/10	13:05	164.5	158	4,105,332	157	56	1,430,979	54.2	2	50	1,323,493	50.6	0	53	1,350,871	52.3	2	82	80
	Wed	04/28/10	13:15	170.7	151	4,162,018	152	53	1,450,642	52.9	2	49	1,341,860	49.4	2	54	1,369,945	51.3	2	82	75
	Thur	04/29/10	15:30	178.1	143	4,233,548	161	50	1,475,675	56.4	2	45	1,364,335	50.6	2	47	1,393,174	52.3	2	80	70
	Fri	04/30/10	13:00	181.8	147	4,258,891	114	52	1,484,808	41.1	2	46	1,372,527	36.9	2	46	1,401,566	37.8	2	82	72
23	Mon	05/03/10	13:00	198.7	160	4,413,198	152	55	1,538,189	52.6	2	52	1,422,723	49.5	0	53	1,452,418	50.1	2	82	78
	Tue	05/04/10	13:20	204.6	150	4,471,633	165	53	1,558,576	57.6	2	48	1,441,443	52.9	2	50	1,471,691	54.4	2	82	78
	Wed	05/05/10	13:15	208.6	150	4,505,462	141	53	1,570,950	51.6	4	47	1,452,113	44.5	2	50	1,482,893	46.7	2	82	78
	Thur	05/06/10	13:00	213.1	148	4,547,441	155	53	1,585,333	53.3	2	46	1,465,163	48.3	2	49	1,496,674	51.0	2	82	77
	Fri	05/07/10	13:00	219.2	165	4,602,619	151	56	1,605,333	54.6	3	53	1,482,811	48.2	2	49	1,514,711	49.3	0	82	80
24	Mon	05/10/10	13:45	235.0	149	4,751,557	157	53	1,656,778	54.3	4	47	1,530,991	50.8	2	49	1,563,854	51.8	2	82	78
	Tue	05/11/10	13:00	238.3	152	4,781,059	149	54	1,667,225	52.8	4	48	1,540,310	47.1	2	49	1,573,587	49.2	2	82	76
	Wed	05/12/10	13:05	243.6	149	4,826,903	144	52	1,683,488	51.1	6	46	1,554,767	45.5	4	50	1,588,839	48.0	2	82	76
	Thur	05/13/10	20:48	251.7	159	4,904,190	159	55	1,710,429	55.4	2	52	1,579,386	50.7	2	53	1,614,068	51.9	2	80	80
	Fri	05/14/10	13:02	255.0	159	4,935,217	157	55	1,721,268	54.7	2	51	1,589,519	51.2	2	53	1,624,442	52.4	2	82	80

Table A-1. EPA Arsenic Demonstration Project at Conneaut Lake Park, PA - Daily System Operation Log Sheet (Continued)

Week No.	Day of Week	Date	Time	Supply Well (Well No. 2) Cum. Op Hours	Well Pump Flowrate	Cum. Volume	Avg Flowrate	Vessel A Instant. Flowrate A	Cum. Volume A	Average Flowrate A	DP	Vessel B Instant. Flowrate B	Cum. Volume B	Average Flowrate B	DP	Vessel C Instant. Flowrate C	Cum. Volume C	Average Flowrate C	DP	System Inlet Pressure	Outlet Pressure
				hr	gpm	gal	gpm	gpm	gal	gpm	psi	gpm	gal	gpm	psi	gpm	gal	gpm	psi	psi	psi
25	Mon	05/17/10	13:25	272.8	147	5,097,041	152	52	1,778,590	53.7	4	47	1,640,499	47.7	2	49	1,677,777	49.9	2	82	73
	Tue	05/18/10	13:05	281.9	140	5,173,741	140	49	1,805,797	49.8	2	45	1,664,799	44.5	0	46	1,702,974	46.1	2	82	73
	Wed	05/19/10	13:40	297.9	156	5,268,695	99	50	1,837,317	32.8	2	52	1,696,320	32.8	2	54	1,735,094	33.5	2	82	78
	Fri	05/21/10	13:00	310.0	144	5,430,033	222	50	1,892,611	76.2	2	46	1,748,247	71.5	2	49	1,789,309	74.7	2	82	74
26	Mon	05/24/10	13:00	333.6	161	5,635,649	145	55	1,964,885	51.0	2	51	1,813,809	46.3	0	54	1,856,897	47.7	2	82	80
	Tue	05/25/10	14:00	334.0	194	5,639,266	151	55	1,966,122	51.5	2	64	1,814,999	49.6	0	67	1,858,227	55.4	0	80	77
	Wed	05/26/10	13:00	346.9	153	5,754,930	149	52	2,005,249	50.6	2	49	1,852,653	48.6	0	52	1,896,988	50.1	0	82	75
	Thur	05/27/10	13:00	353.1	155	5,810,468	149	51	2,024,650	52.2	2	48	1,870,326	47.5	0	51	1,915,664	50.2	0	82	75
	Fri	05/28/10	13:10	361.0	141	5,879,750	146	50	2,050,305	54.1	2	45	1,892,092	45.9	0	47	1,938,724	48.6	0	80	72
27	Tue	06/01/10	13:00	404.9	147	NA	NA	51	2,180,455	49.4	2	48	2,016,492	47.2	0	49	2,067,757	49.0	0	80	72
	Wed	06/02/10	13:15	413.3	137	6,335,073	145	46	2,204,532	47.8	2	44	2,039,402	45.5	0	45	2,091,252	46.6	0	80	72
	Thur	06/03/10	13:12	420.3	132	6,392,159	136	45	2,223,929	46.2	8	43	2,058,119	44.6	5	43	2,110,342	45.5	4	80	72
	Fri	06/04/10	13:00	427.5	137	6,448,498	130	43	2,243,274	44.8	12	42	2,076,258	42.0	10	43	2,128,812	42.8	10	80	70
28	Mon	06/07/10	13:00	451.0	142	6,659,315	150	49	2,315,158	51.0	2	46	2,144,390	48.3	0	48	2,199,875	50.4	0	81	73
	Tue	06/08/10	13:00	457.7	145	6,717,539	145	49	2,334,962	49.3	2	47	2,163,298	47.0	0	49	2,219,545	48.9	0	82	73
	Wed	06/09/10	13:00	464.7	137	6,775,609	138	47	2,354,915	47.5	2	43	2,181,902	44.3	0	44	2,238,761	45.8	0	82	73
	Thur	06/10/10	13:00	471.7	135	6,832,281	135	46	2,374,582	46.8	2	43	2,200,171	43.5	1	44	2,257,516	44.7	0	80	72
	Fri	06/11/10	13:00	478.3	161	6,891,558	150	53	2,395,238	52.2	2	52	2,219,454	48.7	0	55	2,276,957	49.1	0	80	80
29	Mon	06/14/10	13:00	500.4	151	7,089,468	149	52	2,462,335	50.6	0	48	2,283,531	48.3	0	49	2,343,790	50.4	0	80	72
	Tue	06/15/10	12:55	508.7	131	7,159,651	141	45	2,486,365	48.3	2	42	2,306,146	45.4	0	42	2,367,120	46.8	0	80	72
	Wed	06/16/10	13:15	515.4	134	7,214,865	137	63	2,512,238	64.4	2	34	2,320,392	35.4	0	37	2,382,222	37.6	0	80	72
	Thur	06/17/10	13:10	521.9	162	7,274,699	153	59	2,533,157	53.6	0	57	2,340,671	52.0	0	43	2,401,194	48.6	1	80	80
	Sat	06/19/10	6:30	533.4	150	7,381,629	155	54	2,572,249	56.7	2	51	2,378,405	54.7	0	45	2,431,014	43.2	0	80	75
30	Mon	06/21/10	13:00	556.7	137	7,583,612	144	36	2,631,115	42.1	10	30	2,429,575	36.6	8	72	2,522,943	65.8	8	80	72
	Tue	06/22/10	13:00	563.5	132	7,638,596	135	37	2,646,227	37.0	12	31	2,442,284	31.1	9	63	2,550,204	66.8	10	80	70
	Wed	06/23/10	13:05	570.0	150	7,764,460	323	68	2,691,766	116.8	2	66	2,482,746	103.7	0	16	2,589,918	101.8	0	80	73
	Thur	06/24/10	14:00	587.2	138	7,834,534	68	61	2,723,236	30.5	0	56	2,512,690	29.0	0	19	2,598,597	8.4	0	80	73
	Fri	06/25/10	13:00	594.0	133	7,890,645	138	58	2,748,042	60.8	0	53	2,535,534	56.0	0	21	2,607,057	20.7	0	80	72
31	Mon	06/28/10	13:00	621.0	132	8,113,530	138	37	2,809,186	37.7	10	31	2,587,583	32.1	10	62	2,716,877	67.8	10	80	72
	Tue	06/29/10	13:05	629.5	147	8,183,618	137	66	2,834,044	48.7	0	65	2,609,618	43.2	0	15	2,739,794	44.9	0	80	75
	Wed	06/30/10	13:15	636.4	141	8,243,511	145	64	2,861,069	65.3	5	60	2,635,502	62.5	3	18	2,746,992	17.4	0	80	73
	Thur	07/01/10	13:15	655.6	134	8,400,264	136	56	2,928,790	58.8	10	52	2,698,465	54.7	10	26	2,773,011	22.6	10	80	70
	Fri	07/02/10	13:00	670.4	142	8,520,184	135	56	2,966,318	42.3	10	25	2,732,610	38.5	10	88	2,821,304	54.4	10	80	72
	Sat	07/03/10	6:10	685.4	129	8,637,143	130	32	2,993,701	30.4	8	29	2,756,680	26.7	10	67	2,886,657	72.6	7	80	70
	Sun	07/04/10	6:15	707.0	109	8,794,010	121	32	3,037,495	33.8	10	28	2,795,636	30.1	10	50	2,960,872	57.3	10	80	70
32	Mon	07/05/10	6:10	726.2	144	8,932,491	120	64	3,084,837	41.1	0	68	2,837,459	36.3	0	10	3,010,443	43.0	0	80	72
	Tue	07/06/10	13:45	744.3	134	9,084,932	140	59	3,153,156	62.9	12	57	2,905,937	63.1	10	17	3,025,814	14.2	10	80	70
	Wed	07/07/10	13:05	756.8	142	9,182,199	130	67	3,200,721	63.4	9	66	2,954,575	64.9	6	17	3,027,248	1.9	6	80	72
	Thur	07/08/10	13:00	768.2	144	9,285,075	150	41	3,228,362	40.4	2	39	2,981,159	38.9	0	65	3,075,578	70.7	0	80	72
	Fri	07/09/10	13:05	785.6	128	9,419,242	129	41	3,269,060	39.0	10	37	3,019,553	36.8	10	50	3,130,621	52.7	10	80	72
	Sat	07/10/10	7:04	795.4	124	9,493,641	127	40	3,293,177	41.0	12	37	3,041,773	37.8	10	45	3,158,541	47.5	10	80	70
	Sun	07/11/10	7:08	810.3	140	9,607,697	128	22	3,326,632	37.4	12	96	3,086,530	50.1	10	46	3,194,541	40.3	10	80	70

Table A-1. EPA Arsenic Demonstration Project at Conneaut Lake Park, PA - Daily System Operation Log Sheet (Continued)

Week No.	Day of Week	Date	Time	Supply Well (Well No. 2) Cum. Op Hours	Well Pump Flowrate	Cum. Volume	Avg Flowrate	Vessel A Instant. Flowrate A	Cum. Volume A	Average Flowrate A	DP	Vessel B Instant. Flowrate B	Cum. Volume B	Average Flowrate B	DP	Vessel C Instant. Flowrate C	Cum. Volume C	Average Flowrate C	DP	System Inlet Pressure	Outlet Pressure
				hr	gpm	gal	gpm	gpm	gal	gpm	psi	gpm	gal	gpm	psi	gpm	gal	gpm	psi	psi	psi
33	Mon	07/12/10	13:39	827.6	144	9,751,053	138	87	3,375,350	46.9	12	37	3,158,671	69.5	10	14	3,216,778	21.4	10	80	72
	Tue	07/13/10	13:00	835.1	153	9,817,347	147	46	3,398,825	52.2	2	45	3,179,789	46.9	0	63	3,238,778	48.9	0	80	78
	Wed	07/14/10	13:10	850.6	155	9,953,631	147	46	3,442,989	47.5	8	43	3,220,897	44.2	6	49	3,290,665	55.8	1	80	72
	Thur	07/15/10	13:02	858.6	144	10,020,518	139	49	3,465,202	46.3	2	46	3,241,705	43.4	1	50	3,313,684	48.0	0	80	70
	Fri	07/16/10	13:00	873.4	129	10,136,698	131	45	3,505,152	45.0	12	41	3,278,814	41.8	10	43	3,352,808	44.1	10	80	70
	Sat	07/17/10	7:00	884.6	133	10,227,935	136	25	3,530,956	38.4	10	87	3,320,206	61.6	10	22	3,377,034	36.1	10	80	72
	Sun	07/18/10	6:00	900.3	145	10,355,684	136	92	3,559,204	30.0	0	37	3,395,344	79.8	0	15	3,401,425	25.9	0	80	73
34	Mon	07/19/10	13:00	916.4	143	10,489,350	138	41	3,627,831	71.0	8	20	3,425,010	30.7	8	81	3,436,519	36.3	8	80	70
	Tue	07/20/10	13:00	930.4	127	10,601,440	133	41	3,662,325	41.1	10	25	3,443,637	22.2	10	61	3,495,493	70.2	10	80	70
	Wed	07/21/10	13:00	941.5	125	10,685,787	127	43	3,690,702	42.6	11	27	3,461,008	26.1	10	56	3,534,102	58.0	10	80	70
	Thur	07/22/10	13:05	955.9	127	10,787,384	118	43	3,725,853	40.7	10	30	3,484,292	26.9	10	49	3,577,256	49.9	10	80	69
	Fri	07/23/10	13:01	971.7	162	10,921,762	142	17	3,740,292	15.2	10	61	3,541,770	60.6	10	67	3,639,706	65.9	10	80	70
	Sat	07/24/10	7:20	991.1	136	11,000,454	68	72	3,780,840	34.8	12	32	3,560,010	15.7	10	34	3,659,625	17.1	10	80	72
	Sun	07/25/10	7:02	996.4	150	11,123,229	386	23	3,831,503	159.3	0	63	3,595,210	110.7	0	64	3,696,604	116.3	0	80	72
35	Mon	07/26/10	13:45	1011.1	145	11,254,874	149	75	3,871,711	45.6	10	34	3,640,502	51.4	10	35	3,742,685	52.2	0	80	72
	Tue	07/27/10	13:05	1020.6	140	11,333,837	139	69	3,911,987	70.7	10	35	3,659,552	33.4	10	37	3,762,276	34.4	10	80	72
	Wed	07/28/10	13:05	1040.3	138	11,487,900	130	24	3,964,208	44.2	9	57	3,710,178	42.8	1	59	3,813,560	43.4	0	80	72
	Thur	07/29/10	13:08	1052.3	139	11,591,363	144	71	4,003,956	55.2	12	34	3,741,308	43.2	8	34	3,845,931	45.0	10	80	72
	Fri	07/30/10	13:09	1066.1	140	11,705,043	137	63	4,058,767	66.2	12	38	3,770,686	35.5	10	39	3,875,619	35.9	10	80	72
	Sat	07/31/10	8:02	1076.2	154	11,790,688	141	22	4,088,729	49.4	0	64	3,798,943	46.6	0	68	3,903,062	45.3	0	80	72
	Sun	08/01/10	7:06	1091.4	154	11,923,486	146	81	4,119,121	33.3	10	36	3,849,153	55.1	0	37	3,955,232	57.2	0	80	72
36	Mon	08/02/10	13:10	1110.3	132	12,082,246	140	59	4,195,372	67.2	2	36	3,890,048	36.1	10	37	3,996,804	36.7	10	80	72
	Tue	08/03/10	13:02	1112.2	152	12,147,377	571	24	4,215,873	179.8	8	63	3,912,248	194.7	0	66	4,019,357	197.8	0	80	79
	Wed	08/04/10	13:07	1128.6	155	12,246,443	101	52	4,248,127	32.8	7	51	3,944,883	33.2	4	52	4,053,430	34.6	2	80	78
	Thur	08/05/10	13:04	1137.2	154	NA	NA	53	4,275,096	52.3	2	49	3,970,716	50.1	0	52	4,080,097	51.7	0	80	75
	Fri	08/06/10	13:05	1150.5	157	12,448,492	154	52	4,317,208	52.8	2	51	4,009,947	49.2	0	54	4,120,029	50.0	0	80	79
	Sat	08/07/10	7:00	1156.7	158	12,505,255	153	53	4,336,633	52.2	0	51	4,028,727	50.5	0	53	4,139,731	53.0	0	80	75
	Sun	08/08/10	7:00	1172.3	144	12,646,195	151	50	4,385,461	52.2	2	46	4,074,166	48.5	0	57	4,186,407	49.9	0	80	73
37	Mon	08/09/10	13:10	1191.1	152	12,809,684	145	49	4,442,639	50.7	4	50	4,126,982	46.8	0	52	4,239,811	47.3	0	81	78
	Tue	08/10/10	13:20	1197.6	151	12,870,819	157	51	4,462,956	52.1	0	49	4,147,062	51.5	0	52	4,260,633	53.4	0	80	73
	Wed	08/11/10	13:03	1207.2	154	12,958,146	152	52	4,492,547	51.4	5	49	4,175,433	49.3	0	52	4,290,061	51.1	0	80	78
	Thur	08/12/10	13:00	1209.1	151	13,068,308	966	32	4,530,312	331.3	6	49	4,210,904	311.1	0	51	4,326,987	323.9	0	80	76
	Fri	08/13/10	19:40	1234.6	147	13,206,891	91	52	4,578,412	31.4	12	47	4,255,397	29.1	0	48	4,372,947	30.0	0	80	71
	Sat	08/14/10	7:10	1240.6	155	13,262,091	153	51	4,597,782	53.8	12	50	4,273,056	49.1	0	51	4,391,086	50.4	0	80	72
	Sun	08/15/10	7:12	1258.6	160	13,410,473	137	51	4,650,760	49.1	10	52	4,320,655	44.1	0	55	4,438,953	44.3	0	80	74
38	Mon	08/16/10	13:20	1277.5	151	13,584,985	154	51	4,709,274	51.6	8	49	4,377,434	50.1	8	50	4,498,121	52.2	8	80	72
	Tue	08/17/10	13:04	1286.4	145	13,665,658	151	51	4,737,415	52.7	8	46	4,403,498	48.8	8	48	4,524,684	49.7	8	80	70
	Wed	08/18/10	13:00	1293.6	160	13,728,265	145	53	4,759,178	50.4	5	52	4,423,794	47.0	2	53	4,545,135	47.3	2	80	74
	Thur	08/19/10	13:18	1305.4	150	13,841,350	160	52	4,797,666	54.4	0	49	4,460,643	52.0	0	50	4,582,893	53.3	0	80	74
	Fri	08/20/10	13:08	1319.6	145	13,959,489	139	51	4,838,632	48.1	8	47	4,498,747	44.7	8	48	4,621,956	45.8	8	80	72
	Sat	08/21/10	7:15	1334.0	150	14,093,835	155	50	4,885,274	54.0	0	50	4,542,314	50.4	0	53	4,666,087	51.1	0	80	78
	Sun	08/22/10	7:01	1353.2	145	14,265,298	149	49	4,942,431	49.6	10	47	4,598,132	48.5	0	48	4,724,575	50.8	0	80	73

Table A-1. EPA Arsenic Demonstration Project at Conneaut Lake Park, PA - Daily System Operation Log Sheet (Continued)

Week No.	Day of Week	Date	Time	Supply Well (Well No. 2) Cum. Op Hours	Well Pump Flowrate	Cum. Volume	Avg Flowrate	Vessel A Instant. Flowrate A	Cum. Volume A	Average Flowrate A	DP	Vessel B Instant. Flowrate B	Cum. Volume B	Average Flowrate B	DP	Vessel C Instant. Flowrate C	Cum. Volume C	Average Flowrate C	DP	System Inlet Pressure	Outlet Pressure
				hr	gpm	gal	gpm	gpm	gal	gpm	psi	gpm	gal	gpm	psi	gpm	gal	gpm	psi	psi	psi
39	Mon	08/23/10	13:02	1375.4	135	14,453,409	141	48	5,007,868	49.1	12	43	4,658,655	45.4	8	45	4,786,732	46.7	8	80	70
	Tue	08/24/10	13:26	1384.0	157	14,531,750	152	52	5,035,703	53.9	0	52	4,683,898	48.9	0	53	4,811,992	49.0	0	82	80
	Wed	08/25/10	13:06	1398.4	154	14,661,081	150	51	5,078,013	49.0	2	51	4,726,762	49.6	1	52	4,856,146	51.1	-1	80	75
	Thur	08/26/10	13:02	1400.0	152	14,768,608	1,120	49	5,113,262	367.2	0	50	4,762,464	371.9	0	52	4,892,716	380.9	0	80	76
	Fri	08/27/10	13:12	1423.4	160	14,889,718	86	54	5,154,038	29.0	0	52	4,802,086	28.2	0	54	4,933,436	29.0	0	80	78
	Sat	08/28/10	7:02	1439.9	163	14,956,888	68	55	5,176,777	23.0	0	53	4,823,942	22.1	0	55	4,956,008	22.8	0	80	78
	Sun	08/29/10	7:14	1446.2	160	15,114,911	418	55	5,230,407	141.9	5	52	4,875,545	136.5	0	53	5,008,795	139.6	0	80	74
40	Mon	08/30/10	13:10	1459.2	157	15,233,570	152	52	5,270,773	51.8	5	51	4,914,241	49.6	0	53	5,048,399	50.8	0	80	78
	Tue	08/31/10	13:02	1465.4	160	15,294,355	163	53	5,291,333	55.3	0	52	4,934,012	53.1	0	54	5,068,905	55.1	0	80	75
	Wed	09/01/10	13:03	1479.1	155	15,420,455	153	53	5,334,031	51.9	4	50	4,974,940	49.8	-1	52	5,111,341	51.6	0	80	74
	Thur	09/02/10	14:00	1494.3	161	15,566,441	160	53	5,383,695	54.5	0	52	5,022,353	52.0	0	54	5,160,218	53.6	0	79	75
	Fri	09/03/10	13:35	1507.4	159	15,690,810	158	54	5,425,979	53.8	0	52	5,062,641	51.3	0	54	5,202,085	53.3	0	80	79
	Sat	09/04/10	7:37	1516.4	158	15,775,470	157	54	5,454,920	53.6	0	52	5,090,086	50.8	0	52	5,230,359	52.4	0	80	78
	Sun	09/05/10	7:16	1532.7	159	15,922,404	150	55	5,505,265	51.5	0	54	5,137,847	48.8	0	55	5,279,130	49.9	0	80	80
41	Mon	09/06/10	7:07	1548.7	165	16,077,893	162	52	5,558,430	55.4	4	50	5,188,298	52.6	0	52	5,331,003	54.0	1	80	78
	Tue	09/07/10	13:00	1558.4	156	16,171,014	160	54	5,590,375	54.9	0	52	5,218,592	52.1	0	52	5,361,891	53.1	0	80	74
	Wed	09/08/10	13:00	1567.4	160	16,254,640	155	52	5,619,178	53.3	0	49	5,245,830	50.4	0	53	5,389,473	51.1	0	80	78
	Thur	09/09/10	16:45	NA	159	16,342,716	NA	55	5,648,987	NA	0	52	5,277,429	NA	0	53	5,419,168	NA	0	80	80
	Fri	09/10/10	13:08	1582.7	160	16,399,462	62	54	5,668,385	21.1	2	51	5,292,826	16.8	0	52	5,438,404	21.0	1	80	79
42	Mon	09/13/10	13:06	1607.9	159	16,636,341	157	55	5,749,501	53.6	4	52	5,369,751	50.9	-2	54	5,517,027	52.0	0	80	73
	Tue	09/14/10	13:12	1616.4	162	16,719,906	164	52	5,779,074	58.0	0	51	5,396,928	53.3	0	53	5,543,799	52.5	0	80	79
	Wed	09/15/10	13:06	1622.4	158	16,775,688	155	53	5,797,177	50.3	0	51	5,415,051	50.3	0	52	5,563,355	54.3	0	80	78
	Thur	09/16/10	13:14	1629.4	160	16,841,224	156	54	5,819,441	53.0	0	52	5,436,350	50.7	0	54	5,585,271	52.2	0	80	77
	Fri	09/17/10	13:00	1637.4	155	16,914,268	152	52	5,824,484	10.5	0	51	5,460,131	49.5	0	52	5,609,493	50.5	0	80	78
43	Mon	09/20/10	13:00	1661.4	162	17,140,060	157	53	5,921,203	67.2	0	52	5,533,586	51.0	0	54	5,685,108	52.5	0	80	78
	Tue	09/21/10	13:20	1668.4	154	17,209,363	165	53	5,944,804	56.2	0	51	5,556,138	53.7	0	52	5,708,269	55.1	0	80	77
	Wed	09/22/10	13:10	1674.3	160	17,263,832	154	54	5,963,411	52.6	0	52	5,573,873	50.1	0	54	5,726,368	51.1	0	80	76
	Thur	09/23/10	17:56	1682.4	156	17,340,321	157	53	5,989,547	53.7	0	51	5,598,820	51.2	0	52	5,751,818	52.3	0	80	76
	Fri	09/24/10	13:19	1687.3	152	17,389,955	169	52	6,006,539	58.0	0	49	5,614,998	55.2	0	49	5,768,274	56.2	0	80	74
42	Mon	09/27/10	13:30	1709.3	149	17,581,303	145	50	6,071,594	49.3	0	49	5,677,504	47.4	0	50	5,832,053	48.3	0	80	76
	Tue	09/28/10	13:15	1714.4	143	17,630,088	159	49	6,088,073	53.9	0	46	5,693,430	52.0	0	47	5,848,432	53.5	0	80	74
	Wed	09/29/10	13:15	1718.6	160	17,669,312	156	49	6,102,007	55.3	0	52	5,706,300	51.1	0	55	5,860,837	49.2	0	80	80
	Thur	09/30/10	13:00	1722.4	157	17,707,256	166	52	6,114,361	54.2	0	51	5,718,744	54.6	0	53	5,873,986	57.7	0	80	78
	Fri	10/01/10	15:41	1731.4	146	17,781,326	137	51	6,139,102	45.8	0	48	5,743,097	45.1	0	49	5,898,997	46.3	0	80	78
43	Mon	10/04/10	15:45	1747.3	148	17,933,670	160	51	6,190,931	54.3	0	48	5,792,836	52.1	0	49	5,949,691	53.1	0	80	80
	Tue	10/05/10	14:00	1751.3	160	17,966,814	138	52	6,202,636	48.8	0	52	5,803,756	45.5	0	54	5,960,233	43.9	0	80	78
	Wed	10/06/10	13:00	1756.3	156	18,012,547	152	53	6,217,805	50.6	0	50	5,818,756	50.0	0	53	5,975,813	51.9	0	80	78
	Thur	10/07/10	13:00	1762.4	152	18,071,481	161	51	6,237,639	54.2	0	49	5,837,996	52.6	0	51	5,995,690	54.3	0	80	79
	Fri	10/08/10	NA	1768.4	154	18,129,429	161	52	6,257,451	55.0	0	51	5,856,861	52.4	0	53	6,014,964	53.5	0	80	79
	Sat	10/09/10	7:30	1771.4	155	18,154,227	138	53	6,265,871	46.8	0	50	5,864,921	44.8	0	54	6,023,275	46.2	0	80	79
	Sun	10/10/10	7:20	1781.1	149	18,240,455	148	52	6,295,291	50.5	15	48	5,893,033	48.3	1	48	6,051,970	49.3	-1	81	75
44	Mon	10/11/10	13:15	1791.3	157	18,331,730	149	53	6,327,220	52.2	3	51	5,922,381	48.0	0	53	6,081,978	49.0	-1	80	78
	Tue	10/12/10	13:00	1796.7	149	18,382,444	157	53	6,344,359	52.9	6	49	5,938,924	51.1	3	49	6,099,001	52.5	-1	80	76
	Wed	10/13/10	13:00	1799.4	152	18,408,548	161	53	6,353,385	55.7	0	49	5,947,372	52.1	0	51	6,107,649	53.4	0	80	76
	Thur	10/14/10	13:00	1805.3	159	18,461,785	150	54	6,371,889	52.3	0	52	5,964,552	48.5	0	54	6,125,183	49.5	0	80	76
	Fri	10/15/10	13:00	1810.3	161	18,511,895	167	52	6,388,988	57.0	0	49	5,980,838	54.3	0	50	6,141,915	55.8	0	80	75

Table A-1. EPA Arsenic Demonstration Project at Conneaut Lake Park, PA - Daily System Operation Log Sheet (Continued)

				Supply Well (Well No. 2)				Vessel A				Vessel B				Vessel C				System	
Week No.	Day of Week	Date	Time	Cum. Op Hours	Well Pump Flowrate	Cum. Volume	Avg Flowrate	Instant. Flowrate A	Cum. Volume A	Average Flowrate A	DP	Instant. Flowrate B	Cum. Volume B	Average Flowrate B	DP	Instant. Flowrate C	Cum. Volume C	Average Flowrate C	DP	Inlet Pressure	Outlet Pressure
				hr	gpm	gal	gpm	gpm	gal	gpm	psi	gpm	gal	gpm	psi	gpm	gal	gpm	psi	psi	psi
45	Mon	10/18/10	13:00	1829.6	152	18,678,766	144	52	6,446,716	49.9	0	50	6,034,997	46.8	0	50	6,196,891	47.5	0	80	74
	Tue	10/19/10	18:40	1832.6	147	18,709,993	173	51	6,457,589	60.4	0	48	6,045,117	56.2	0	48	6,207,126	56.9	0	80	80
	Wed	10/20/10	13:00	1834.6	158	18,730,298	169	52	6,464,603	58.5	0	51	6,051,784	55.6	0	52	6,213,756	55.3	0	80	79
	Thur	10/21/10	13:00	1836.4	161	18,747,414	158	55	6,470,436	54.0	0	53	6,057,372	51.7	0	52	6,219,441	52.6	0	80	78
	Fri	10/22/10	10:00	1837.1	161	18,757,987	252	56	6,474,057	86.2	0	52	6,060,839	82.5	0	53	6,222,935	83.2	0	82	78
46	Mon	10/25/10	13:00	1847.0	159	18,845,171	147	55	6,503,602	49.7	5	51	6,089,367	48.0	-1	53	6,252,047	49.0	1	81	74
	Tue	10/26/10	13:00	1849.6	162	18,872,067	172	55	6,512,900	59.6	0	52	6,098,135	56.2	0	55	6,260,873	56.6	0	80	78
	Wed	10/27/10	13:00	1852.4	161	18,894,273	132	56	6,520,393	44.6	0	51	6,105,270	42.5	0	55	6,268,449	45.1	0	80	78
	Thur	10/28/10	13:00	1854.6	159	18,916,862	171	54	6,528,045	58.0	0	51	6,112,560	55.2	0	54	6,276,103	58.0	0	80	78
	Fri	10/29/10	13:00	1857.6	161	18,944,154	152	53	6,537,567	52.9	4	52	6,121,468	49.5	-1	55	6,284,963	49.2	0	81	79
47	Mon	11/01/10	13:00	1867.4	163	19,038,168	160	53	6,569,480	54.3	0	53	6,152,207	52.3	0	58	6,316,322	53.3	0	80	79
	Tue	11/02/10	13:15	1870.2	161	19,061,346	138	53	6,577,062	45.1	0	51	6,159,734	44.8	0	55	6,324,390	48.0	0	81	78
	Wed	11/03/10	13:05	1873.6	155	19,093,986	160	52	6,587,804	52.7	0	50	6,170,385	52.2	0	53	6,335,633	55.1	0	80	78
	Thur	11/04/10	13:15	1876.3	157	19,120,042	161	61	6,597,535	60.1	0	58	6,179,641	57.1	0	38	6,342,709	43.7	0	80	78
	Fri	11/05/10	13:00	1879.3	154	19,144,493	136	61	6,606,982	52.5	0	57	6,188,739	50.5	0	37	6,348,592	32.7	0	81	78
48	Mon	11/08/10	13:11	1889.3	150	19,243,706	165	43	6,637,193	50.4	0	38	6,218,491	49.6	0	68	6,388,872	67.1	0	80	78
	Tue	11/09/10	17:25	1892.5	154	19,267,058	122	45	6,643,889	34.9	0	42	6,223,737	27.3	0	67	6,399,278	54.2	0	80	78
	Wed	11/10/10	13:08	1894.4	152	19,289,795	199	45	6,650,662	59.4	0	42	6,229,991	54.9	0	64	6,409,013	85.4	0	81	76
	Thur	11/11/10	13:00	1897.6	157	19,314,391	128	83	6,661,020	53.9	0	31	6,235,796	30.2	0	43	6,417,413	43.8	0	82	78
	Fri	11/12/10	13:00	1902.4	142	19,359,903	158	73	6,684,785	82.5	0	29	6,244,680	30.8	0	41	6,430,290	44.7	0	81	76
49	Mon	11/15/10	13:25	1911.4	145	19,435,707	140	48	6,710,953	48.5	0	69	6,279,265	64.0	0	28	6,445,336	27.9	0	80	78
	Tue	11/16/10	13:05	1914.6	149	19,459,696	125	80	6,718,848	41.1	0	46	6,290,346	57.7	0	24	6,450,333	26.0	0	82	78
	Wed	11/17/10	13:00	1917.7	154	19,485,938	141	61	6,731,069	65.7	0	28	6,296,539	33.3	0	66	6,458,166	42.1	0	81	79
	Thur	11/18/10	18:00	1920.7	153	19,512,180	146	61	6,754,801	131.8	0	28	6,299,513	16.5	0	64	6,459,131	5.4	0	81	79
	Fri	11/19/10	13:33	1923.1	150	19,530,669	128	62	6,768,906	98.0	0	28	6,304,647	35.7	0	63	6,476,964	123.8	0	81	79
50	Mon	11/22/10	14:03	1929.4	147	19,598,004	178	60	6,775,134	16.5	8	32	6,318,522	36.7	0	57	6,504,196	72.0	0	80	80
	Tue	11/23/10	13:00	1932.4	156	19,622,354	135	51	6,783,139	44.5	10	38	6,326,924	46.7	10	52	6,512,149	44.2	0	80	60
	Wed	11/24/10	13:00	1938.2	143	19,674,048	149	68	6,805,523	64.3	4	58	6,348,082	60.8	0	22	6,520,283	23.4	-2	82	78
	Fri	11/26/10	18:25	1945.6	141	19,741,210	151	59	6,834,683	65.7	4	52	6,374,429	59.3	0	28	6,531,936	26.2	-2	82	78
51	Mon	11/29/10	19:00	1951.4	154	19,788,435	136	61	6,854,327	56.4	0	23	6,389,608	43.6	0	64	6,544,320	35.6	0	80	80
	Tue	11/30/10	13:05	1953.7	153	19,809,889	155	65	6,863,379	65.6	0	22	6,392,825	23.3	0	66	6,553,536	66.8	0	80	78
	Wed	12/01/10	13:00	1956.2	150	19,831,641	145	63	6,872,592	61.4	7	22	6,396,005	21.2	1	64	6,562,871	62.2	-1	80	78
	Thur	12/02/10	13:08	1956.3	154	19,832,836	199	66	6,873,089	82.8	0	23	6,396,179	29.0	0	66	6,563,387	86.0	0	82	78
	Fri	12/03/10	13:08	1959.7	152	19,858,201	124	45	6,881,238	39.9	0	63	6,405,750	46.9	0	43	6,571,056	37.6	0	82	80
52	Mon	12/06/10	13:09	1963.4	155	19,902,334	199	47	6,894,585	60.1	0	63	6,423,863	81.6	0	45	6,583,717	57.0	0	82	78
	Tue	12/07/10	13:45	1967.5	143	19,930,766	116	45	6,897,289	11.0	0	57	6,435,404	46.9	0	42	6,591,920	33.3	0	82	76
	Wed	12/08/10	13:10	1968.4	150	19,935,467	87	46	6,904,727	137.7	0	60	6,437,290	34.9	0	44	6,593,292	25.4	0	81	78
	Thur	12/09/10	13:10	1970.7	145	19,956,915	155	45	6,911,323	47.8	0	57	6,445,716	61.1	0	43	6,599,719	46.6	0	82	78
	Fri	12/10/10	18:00	1973.4	147	19,983,545	164	80	6,923,444	74.8	0	37	6,453,744	49.6	0	30	6,606,096	39.4	0	82	78
53	Mon	12/13/10	13:15	1977.6	143	20,020,747	148	80	6,943,458	79.4	0	36	6,463,161	37.4	0	30	6,613,978	31.3	0	82	78
	Tue	12/14/10	13:00	1980.4	141	20,042,526	130	73	6,954,780	67.4	0	37	6,468,846	33.8	0	31	6,618,744	28.4	0	82	78
	Wed	12/15/10	13:12	1982.4	150	20,059,334	140	71	6,962,336	63.0	0	79	6,474,568	47.7	0	23	6,622,269	29.4	0	81	79
	Thur	12/16/10	13:12	1985.6	152	20,090,735	164	29	6,970,409	42.0	0	56	6,488,566	72.9	0	66	6,630,601	43.4	0	82	80
	Fri	12/17/10	13:00	1988.4	151	20,114,282	140	30	6,975,153	28.2	0	55	6,497,314	52.1	0	65	6,641,683	66.0	0	82	79

NA = not available

APPENDIX B

ANALYTICAL DATA

Table B-1. Analytical Results from Long-Term Sampling at Conneaut Lake Park, PA

Sampling Date		12/03/09			12/14/09						01/04/10			01/07/10					
Sampling Location Parameter	Unit	IN	BF	TT	IN	BF	TA	TB	TC	TT	IN	BF	TT	IN	BF	TA	TB	TC	TT
Alkalinity	mg/L[a]	144 -	141 -	137 -	141 -	139 -	137 -	137 -	139 -	- -	152 -	149 -	142 -	146 -	141 -	138 -	138 -	138 -	- -
Ammonia	mg/L	<0.05 -	<0.05 -	1.8 -	0.2 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -	0.1 -	<0.05 -	<0.05 -	0.1 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -
Fluoride	mg/L	0.2	0.2	0.2	-	-	-	-	-	-	0.2	0.2	0.2	-	-	-	-	-	-
Sulfate	mg/L	20.3	18.6	20.6	-	-	-	-	-	-	24.3	23.9	22.9	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -
Total P (as P)	µg/L	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	28.0 -	<10 -	- -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	- -
Silica (as SiO_2)	mg/L	13.7 -	13.8 -	13.4 -	15.0 -	14.8 -	13.9 -	14.2 -	13.7 -	- -	14.8 -	14.7 -	14.3 -	14.4 -	14.5 -	13.8 -	13.9 -	14.0 -	- -
Turbidity	NTU	1.3 -	0.9 -	1.1 -	1.0 -	2.5 -	1.1 -	1.0 -	0.6 -	- -	0.7 -	0.9 -	0.6 -	3.0 -	1.5 -	0.4 -	0.5 -	1.4 -	- -
TOC	mg/L	<1.0	<1.0	<1.0	-	-	-	-	-	-	<1.0	<1.0	<1.0	-	-	-	-	-	-
pH	S.U.	7.9	7.7	7.7	7.3	7.6	-	-	-	7.8	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	-	-	-	NA[c]
Temperature	°C	11.3	11.4	11.5	NA[c]	NA[c]	-	-	-	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	-	-	-	NA[c]
DO	mg/L	2.2	1.2	1.5	NA[b]	NA[b]	-	-	-	NA[b]	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	-	-	-	NA[c]
ORP	mV	419	628	583	298	578	-	-	-	409	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	-	-	-	NA[c]
Free Chlorine (as Cl_2)	mg/L	-	2.1	0.5	-	1.9	-	-	-	1.1	-	NA[c]	NA[c]	-	NA[c]	-	-	-	NA[c]
Total Chlorine (as Cl_2)	mg/L	-	4.5	0.6	-	2.2	-	-	-	1.2	-	NA[c]	NA[c]	-	NA[c]	-	-	-	NA[c]
Total Hardness	mg/L[a]	138	138	138	-	-	-	-	-	-	124	124	128	-	-	-	-	-	-
Ca Hardness	mg/L[a]	100	101	100	-	-	-	-	-	-	88.6	89.6	91.7	-	-	-	-	-	-
Mg Hardness	mg/L[a]	37.5	36.9	37.1	-	-	-	-	-	-	35.2	34.8	36.1	-	-	-	-	-	-
As (total)	µg/L	29.6 -	28.7 -	0.7 -	27.0 -	24.8 -	5.3 -	51.9 -	0.7 -	- -	26.8 -	27.5 -	1.0 -	28.4 -	26.1 -	0.8 -	0.8 -	0.9 -	- -
As (soluble)	µg/L	28.8	1.1	0.6	-	-	-	-	-	-	27.3	1.2	0.9	-	-	-	-	-	-
As (particulate)	µg/L	0.8	27.6	<0.1	-	-	-	-	-	-	<0.1	26.3	0.1	-	-	-	-	-	-
As (III)	µg/L	24.7	0.2	0.2	-	-	-	-	-	-	24.6	0.5	0.5	-	-	-	-	-	-
As (V)	µg/L	4.1	0.9	0.4	-	-	-	-	-	-	2.7	0.7	0.4	-	-	-	-	-	-
Fe (total)	µg/L	166 -	1,782 -	<25 -	160 -	1,553 -	264 -	5,118 -	<25 -	- -	175 -	2,026 -	<25 -	153 -	1,731 -	<25 -	<25 -	<25 -	- -
Fe (soluble)	µg/L	108	<25	<25	-	-	-	-	-	-	165	<25	<25	-	-	-	-	-	-
Mn (total)	µg/L	59.8 -	65.4 -	0.8 -	55.8 -	52.1 -	72.1 -	1,337 -	1.6 -	- -	60.7 -	66.8 -	0.2 -	59.1 -	62.3 -	0.1 -	<0.1 -	<0.1 -	- -
Mn (soluble)	µg/L	59.9	9.3	0.7	-	-	-	-	-	-	59.9	15.9	0.1	-	-	-	-	-	-

(a) As $CaCO_3$.
(b) DO probe calibration error.
(c) Not measured.

Table B-1. Analytical Results from Long-Term Sampling at Conneaut Lake Park, PA (Continued)

Sampling Date		01/27/10			02/10/10						02/24/10			03/08/10					
Sampling Location Parameter	Unit	IN	BF	TT	IN	BF	TA	TB	TC	TT	IN	BF	TT	IN	BF	TA	TB	TC	TT
Alkalinity	mg/L(a)	138 -	134 -	129 -	159 148	143 139	139 139	143 139	143 136	- -	155 -	135 -	139 -	146 -	148 -	141 -	136 -	141 -	- -
Ammonia	mg/L	0.1 -	<0.05 -	<0.05 -	0.1 0.1	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	- -	0.2 -	<0.05 -	<0.05 -	0.1 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -
Fluoride	mg/L	0.2	0.2	0.2	-	-	-	-	-	-	0.2	0.2	0.3	-	-	-	-	-	-
Sulfate	mg/L	18.2	18.6	18.3	-	-	-	-	-	-	17.5	19.3	18.7	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05 -	<0.05 -	<0.05 -	<0.05 0.1	0.2 <0.05	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	- -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -
Total P (as P)	µg/L	<10 -	<10 -	<10 -	<10 <10	<10 <10	<10 <10	<10 <10	<10 <10	- -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	- -
Silica (as SiO_2)	mg/L	14.9 -	14.9 -	14.4 -	14.2 13.9	13.7 14.0	13.5 13.6	13.4 13.7	13.5 13.5	- -	13.9 -	13.7 -	13.1 -	13.2 -	13.3 -	12.6 -	12.6 -	12.4 -	- -
Turbidity	NTU	4.4 -	4.4 -	1.0 -	4.5 6.5	10.0 8.6	1.7 5.4	9.2 5.1	2.6 4.0	- -	1.2 -	1.5 -	0.8 -	1.5 -	3.0 -	2.0 -	1.7 -	2.0 -	- -
TOC	mg/L	<1.0	<1.0	<1.0	-	-	-	-	-	-	<1.0	<1.0	<1.0	-	-	-	-	-	-
pH	S.U.	NA(c)	NA(c)	NA(c)	7.6	7.7	-	-	-	7.7	7.9	7.6	8.1	NA(c)	NA(c)	-	-	-	NA(c)
Temperature	°C	NA(c)	NA(c)	NA(c)	8.5	8.3	-	-	-	7.9	11.0	10.9	10.6	NA(c)	NA(c)	-	-	-	NA(c)
DO	mg/L	NA(c)	NA(c)	NA(c)	5.1	6.1	-	-	-	3.4	5.8	7.6	3.6	NA(c)	NA(c)	-	-	-	NA(c)
ORP	mV	NA(c)	NA(c)	NA(c)	448	513	-	-	-	707	320	675	689	NA(c)	NA(c)	-	-	-	NA(c)
Free Chlorine (as Cl_2)	mg/L	-	NA(c)	NA(c)	-	NA(c)	-	-	-	NA(c)	-	1.6	1.7	-	NA(c)	-	-	-	NA(c)
Total Chlorine (as Cl_2)	mg/L	-	NA(c)	NA(c)	-	NA(c)	-	-	-	NA(c)	-	1.9	1.9	-	NA(c)	-	-	-	NA(c)
Total Hardness	mg/L(a)	114	130	127	-	-	-	-	-	-	144	148	140	-	-	-	-	-	-
Ca Hardness	mg/L(a)	80.7	90.7	89.0	-	-	-	-	-	-	103	107	100	-	-	-	-	-	-
Mg Hardness	mg/L(a)	33.5	39.6	38.5	-	-	-	-	-	-	40.8	41.6	39.7	-	-	-	-	-	-
As (total)	µg/L	28.4 -	26.8 -	0.8 -	26.8 27.2	27.5 26.7	0.8 0.7	0.8 0.8	0.8 0.8	- -	28.2 -	28.3 -	1.6 -	28.4 -	27.3 -	5.0 -	6.8 -	6.3 -	- -
As (soluble)	µg/L	28.8	1.2	0.8	-	-	-	-	-	-	29.6	1.0	1.1	-	-	-	-	-	-
As (particulate)	µg/L	<0.1	25.6	<0.1	-	-	-	-	-	-	<0.1	27.3	0.4	-	-	-	-	-	-
As (III)	µg/L	27.9	0.2	0.2	-	-	-	-	-	-	28.7	0.4	0.3	-	-	-	-	-	-
As (V)	µg/L	0.9	1.1	0.6	-	-	-	-	-	-	1.0	0.6	0.8	-	-	-	-	-	-
Fe (total)	µg/L	146 -	1,921 -	<25 -	167 193	2,036 1,968	<25 <25	<25 <25	<25 <25	- -	164 -	2,143 -	55 -	158 -	2,227 -	359 -	506 -	463 -	- -
Fe (soluble)	µg/L	141	<25	<25	-	-	-	-	-	-	137	<25	<25	-	-	-	-	-	-
Mn (total)	µg/L	59.9 -	72.2 -	0.2 -	58.0 60.4	66.9 59.9	0.3 0.2	0.2 0.2	0.2 0.2	- -	61.6 -	71.0 -	3.6 -	58.3 -	56.7 -	11.8 -	15.5 -	13.6 -	- -
Mn (soluble)	µg/L	60.5	13.8	0.1	-	-	-	-	-	-	60.8	13.6	0.6	-	-	-	-	-	-

(a) As $CaCO_3$.
(b) DO probe calibration error.
(c) Not measured.

Table B-1. Analytical Results from Long-Term Sampling at Conneaut Lake Park, PA (Continued)

Sampling Date		03/23/10			04/05/10						04/19/10			05/03/10					
Sampling Location		IN	BF	TT	IN	BF	TA	TB	TC	TT	IN	BF	TT	IN	BF	TA	TB	TC	TT
Parameter	Unit																		
Alkalinity	mg/L[a]	142 -	137 -	137 -	138 -	133 -	131 -	142 -	133 -	- -	144 -	141 -	139 -	141 143	134 132	130 130	134 134	136 134	- -
Ammonia	mg/L	0.1 -	<0.05 -	<0.05 -	0.1 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -	0.1 -	<0.05 -	<0.05 -	0.1 0.1	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	- -
Fluoride	mg/L	0.2	0.2	0.2	-	-	-	-	-	-	0.2	0.2	0.2	-	-	-	-	-	-
Sulfate	mg/L	19.3	19.9	18.7	-	-	-	-	-	-	20.5	20.7	21.7	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -	<0.05 -	<0.05 -	<0.05 -	<0.05 <0.05	<0.05 0.1	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	- -
Total P (as P)	µg/L	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	- -	<10 -	<10 -	<10 -	<10 <10	464 12.9	<10 <10	<10 <10	<10 <10	- -
Silica (as SiO_2)	mg/L	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	- -	14.6 -	14.0 -	13.9 -	13.0 13.1	13.2 13.1	12.5 12.4	12.5 12.5	12.6 12.6	- -
Turbidity	NTU	0.5 -	2.8 -	0.7 -	3.6 -	4.2 -	1.2 -	1.2 -	0.7 -	- -	0.9 -	1.1 -	0.7 -	1.0 1.9	2.2 2.2	0.4 1.2	2.5 1.1	2.4 1.7	- -
TOC	mg/L	<1.0	<1.0	<1.0	-	-	-	-	-	-	<1.0	<1.0	<1.0	-	-	-	-	-	-
pH	S.U.	8.1	7.5	7.7	8.0	7.8	-	-	-	7.7	7.0	7.4	7.6	6.7	7.2	-	-	-	7.2
Temperature	°C	11.8	12.0	12.0	13.1	13.1	-	-	-	13.9	25.0	25.0	25.0	14.9	13.1	-	-	-	13.1
DO	mg/L	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	-	-	-	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	-	-	-	NA[b]
ORP	mV	482	706	435	419	661	-	-	-	665	261	675	476	420	627	-	-	-	627
Free Chlorine (as Cl_2)	mg/L	-	1.8	1.6	-	1.6	-	-	-	1.0	-	1.8	1.5	-	1.2	-	-	-	1.2
Total Chlorine (as Cl_2)	mg/L	-	2.2	1.8	-	1.3	-	-	-	1.0	-	2.2	2.0	-	1.3	-	-	-	1.3
Total Hardness	mg/L[a]	125	134	129	-	-	-	-	-	-	92.3	86.2	121	-	-	-	-	-	-
Ca Hardness	mg/L[a]	90.5	95.3	92.5	-	-	-	-	-	-	56.0	45.8	86.1	-	-	-	-	-	-
Mg Hardness	mg/L[a]	34.1	38.7	36.1	-	-	-	-	-	-	36.4	40.4	35.2	-	-	-	-	-	-
As (total)	µg/L	27.7 -	43.2 -	3.1 -	27.7 -	24.9 -	1.0 -	1.1 -	0.9 -	- -	29.1 -	29.1 -	2.4 -	29.6 30.5	29.3 29.9	1.0 0.8	0.9 0.9	1.0 0.9	- -
As (soluble)	µg/L	27.4	1.1	0.9	-	-	-	-	-	-	29.1	1.6	1.1	-	-	-	-	-	-
As (particulate)	µg/L	0.3	42.1	2.2	-	-	-	-	-	-	<0.1	27.4	1.3	-	-	-	-	-	-
As (III)	µg/L	26.4	0.1	0.1	-	-	-	-	-	-	11.3	0.3	0.2	-	-	-	-	-	-
As (V)	µg/L	1.0	1.0	0.8	-	-	-	-	-	-	17.8	1.3	0.9	-	-	-	-	-	-
Fe (total)	µg/L	128 -	3,093 -	226 -	149 -	2,020 -	<25 -	<25 -	<25 -	- -	143 -	2,243 -	103 -	158 137	1,771 1,705	<25 <25	<25 <25	<25 <25	- -
Fe (soluble)	µg/L	<25	<25	<25	-	-	-	-	-	-	49	<25	<25	-	-	-	-	-	-
Mn (total)	µg/L	60.7 -	144 -	18.4 -	58.7 -	64.5 -	0.2 -	6.6 -	0.9 -	- -	61.7 -	72.8 -	7.6 -	54.8 58.2	60.7 62.4	2.8 0.3	<0.1 0.1	0.6 0.1	- -
Mn (soluble)	µg/L	56.4	2.0	0.2	-	-	-	-	-	-	59.9	3.0	0.2	-	-	-	-	-	-

(a) As $CaCO_3$.
(b) DO probe calibration error.

Table B-1. Analytical Results from Long-Term Sampling at Conneaut Lake Park, PA (Continued)

Sampling Date		05/17/10			06/01/10						06/14/10			06/28/10					
Sampling Location Parameter	Unit	IN	BF	TT	IN	BF	TA	TB	TC	TT	IN	BF	TT	IN	BF	TA	TB	TC	TT
Alkalinity	mg/L[a]	139 -	134 -	134 -	145 -	141 -	141 -	130 -	136 -	- -	150 -	147 -	140 -	138 -	141 -	134 -	138 -	138 -	- -
Ammonia	mg/L	0.1 -	<0.05 -	<0.05 -	0.1 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -	0.2 -	<0.05 -	<0.05 -	0.1 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -
Fluoride	mg/L	0.1	0.1	0.1	-	-	-	-	-	-	0.1	0.2	0.1	-	-	-	-	-	-
Sulfate	mg/L	19.7	21.4	19.3	-	-	-	-	-	-	21.4	21.8	23.2	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05 -	<0.05 -	<0.05 -	<0.05 -	0.14 -	<0.05 -	0.05 -	<0.05 -	- -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -
Total P (as P)	µg/L	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	- -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	- -
Silica (as SiO_2)	mg/L	13.9 -	14.1 -	13.6 -	14.5 -	15.3 -	13.9 -	14.2 -	14.0 -	- -	14.3 -	14.4 -	14.0 -	13.9 -	13.9 -	13.2 -	13.3 -	13.2 -	- -
Turbidity	NTU	1.4 -	1.8 -	1.3 -	1.6 -	2.1 -	1.1 -	0.8 -	1.2 -	- -	0.6 -	1.6 -	0.4 -	0.5 -	1.3 -	0.6 -	0.5 -	0.7 -	- -
TOC	mg/L	<1.0	1.5	<1.0	-	-	-	-	-	-	<1.0	<1.0	<1.0	-	-	-	-	-	-
pH	S.U.	7.8	7.7	7.6	8.1	7.9	-	-	-	7.8	7.6	7.7	7.7	8.1	7.3	-	-	-	7.8
Temperature	°C	11.9	12.4	12.5	15.7	15.0	-	-	-	15.0	14.8	13.8	14.4	15.0	14.7	-	-	-	14.9
DO	mg/L	NA[b]	NA[b]	NA[b]	2.8	5.5	-	-	-	2.5	3.9	6.0	2.0	1.7	4.2	-	-	-	1.6
ORP	mV	440	488	638	416	457	-	-	-	634	367	411	541	325	437	-	-	-	677
Free Chlorine (as Cl_2)	mg/L	-	1.3	1.1	-	1.7	-	-	-	1.0	-	1.2	1.4	-	1.5	-	-	-	1.2
Total Chlorine (as Cl_2)	mg/L	-	1.5	1.2	-	2.2	-	-	-	1.2	-	1.8	1.6	-	1.6	-	-	-	1.4
Total Hardness	mg/L[a]	156	175	170	-	-	-	-	-	-	166	163	163	-	-	-	-	-	-
Ca Hardness	mg/L[a]	113	128	124	-	-	-	-	-	-	120	118	117	-	-	-	-	-	-
Mg Hardness	mg/L[a]	42.5	47.5	46.2	-	-	-	-	-	-	46.4	45.3	45.8	-	-	-	-	-	-
As (total)	µg/L	27.1 -	28.8 -	1.0 -	29.4 -	28.5 -	1.5 -	1.2 -	2.2 -	- -	28.3 -	30.4 -	1.1 -	27.5 -	27.1 -	4.3 -	3.3 -	4.1 -	- -
As (soluble)	µg/L	28.8	0.9	0.7	-	-	-	-	-	-	30.2	1.0	0.7	-	-	-	-	-	-
As (particulate)	µg/L	<0.1	27.9	0.3	-	-	-	-	-	-	<0.1	29.4	0.3	-	-	-	-	-	-
As (III)	µg/L	26.8	0.1	0.1	-	-	-	-	-	-	29.9	<0.1	<0.1	-	-	-	-	-	-
As (V)	µg/L	1.9	0.8	0.6	-	-	-	-	-	-	0.3	0.9	0.6	-	-	-	-	-	-
Fe (total)	µg/L	164 -	2,349 -	<25 -	175 -	2,175 -	41 -	28 -	101 -	- -	201 -	2,428 -	<25 -	162 -	2,287 -	274 -	197 -	294 -	- -
Fe (soluble)	µg/L	154	<25	<25	-	-	-	-	-	-	185	<25	<25	-	-	-	-	-	-
Mn (total)	µg/L	58.7 -	75.7 -	1.4 -	65.8 -	76.6 -	1.2 -	1.0 -	2.8 -	- -	74.8 -	83.7 -	1.3 -	60.6 -	67.5 -	8.9 -	5.7 -	8.0 -	- -
Mn (soluble)	µg/L	57.7	17.1	0.3	-	-	-	-	-	-	73.6	22.2	0.1	-	-	-	-	-	-

(a) As $CaCO_3$.
(b) DO probe calibration error.

Table B-1. Analytical Results from Long-Term Sampling at Conneaut Lake Park, PA (Continued)

Sampling Date		07/13/10			07/26/10						08/09/10			08/23/10					
Sampling Location / Parameter	Unit	IN	BF	TT	IN	BF	TA	TB	TC	TT	IN	BF	TT	IN	BF	TA	TB	TC	TT
Alkalinity	mg/L(a)	169 -	136 -	136 -	153 146	43.8 144	139 146	144 146	146 144	- -	138 -	153 -	149 -	153 -	156 -	156 -	158 -	153 -	- -
Ammonia	mg/L	0.1 -	0.05 -	0.05 -	0.1 0.1	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	- -	0.1 -	<0.05 -	<0.05 -	0.1 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -
Fluoride	mg/L	0.1	0.1	0.1	-	-	-	-	-	-	0.1	0.1	0.1	-	-	-	-	-	-
Sulfate	mg/L	22.8	23.8	32.2	-	-	-	-	-	-	22.4	22.7	22.1	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05 -	<0.05 -	<0.05 -	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	- -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -
Total P (as P)	µg/L	<10 -	<10 -	<10 -	<10 <10	<10 <10	<10 <10	<10 <10	<10 <10	- -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	- -
Silica (as SiO_2)	mg/L	13.4 -	13.4 -	13.9 -	13.5 13.6	13.1 13.2	13.4 12.8	13.3 12.7	13.0 12.9	- -	15.0 -	14.9 -	14.2 -	14.8 -	14.7 -	15.1 -	14.2 -	14.9 -	- -
Turbidity	NTU	1.1 -	1.3 -	0.8 -	1.0 1.0	0.8 0.8	0.3 0.2	0.3 0.2	0.5 0.4	- -	1.4 -	0.9 -	0.5 -	1.6 -	1.1 -	0.6 -	0.7 -	2.6 -	- -
TOC	mg/L	<1.0	<1.0	<1.0	-	-	-	-	-	-	<1.0	<1.0	<1.0	-	-	-	-	-	-
pH	S.U.	7.8	7.8	7.7	NA(a)	NA(a)	-	-	-	NA(a)	7.1	7.6	7.9	7.9	8.0	-	-	-	8.0
Temperature	°C	13.4	14.0	13.6	NA(a)	NA(a)	-	-	-	NA(a)	NA(c)	15.2	14.1	12.6	11.8	-	-	-	12.8
DO	mg/L	NA(b)	NA(b)	NA(b)	NA(a)	NA(a)	-	-	-	NA(a)	NA(b)	NA(b)	NA(b)	NA(b)	NA(b)	-	-	-	NA(b)
ORP	mV	257	466	527	NA(a)	NA(a)	-	-	-	NA(a)	152	152	152	352	424	-	-	-	593
Free Chlorine (as Cl_2)	mg/L	-	1.1	1.3	-	NA(a)	-	-	-	NA(a)	-	1.4	1.3	-	0.9	-	-	-	1.1
Total Chlorine (as Cl_2)	mg/L	-	1.2	1.6	-	NA(a)	-	-	-	NA(a)	-	1.4	1.5	-	1.5	-	-	-	1.2
Total Hardness	mg/L(a)	163	174	171	-	-	-	-	-	-	153	162	161	-	-	-	-	-	-
Ca Hardness	mg/L(a)	118	126	125	-	-	-	-	-	-	108	116	115	-	-	-	-	-	-
Mg Hardness	mg/L(a)	44.3	47.6	45.1	-	-	-	-	-	-	45.1	46.1	46.1	-	-	-	-	-	-
As (total)	µg/L	30.2 -	33.9 -	1.6 -	28.9 29.0	27.8 27.6	1.6 1.6	1.1 1.1	1.0 1.2	- -	29.2 -	31.9 -	3.4 -	27.4 -	29.7 -	2.7 -	2.3 -	2.6 -	- -
As (soluble)	µg/L	33.7	1.6	NA	-	-	-	-	-	-	29.6	2.1	1.9	-	-	-	-	-	-
As (particulate)	µg/L	<0.1	32.3	NA	-	-	-	-	-	-	<0.1	29.8	1.5	-	-	-	-	-	-
As (III)	µg/L	30.8	0.5	NA	-	-	-	-	-	-	28.0	0.2	0.2	-	-	-	-	-	-
As (V)	µg/L	2.9	1.1	NA	-	-	-	-	-	-	1.6	1.9	1.7	-	-	-	-	-	-
Fe (total)	µg/L	234 -	2,466 -	<25 -	215 206	1,647 1,431	<25 <25	<25 <25	<25 <25	- -	219 -	1,244 -	63 -	214 -	1,227 -	30 -	<25 -	28 -	- -
Fe (soluble)	µg/L	227	<25	NA(h)	-	-	-	-	-	-	171	<25	<25	-	-	-	-	-	-
Mn (total)	µg/L	73.8 -	84.5 -	0.8 -	72.2 72.6	75.4 77.3	0.2 0.2	0.2 0.3	0.2 0.3	- -	73.4 -	78.8 -	4.4 -	72.7 -	78.3 -	2.0 -	0.6 -	2.0 -	- -
Mn (soluble)	µg/L	70.2	24.3	NA(h)	-	-	-	-	-	-	71.1	7.7	0.3	-	-	-	-	-	-

(a) As $CaCO_3$.
(b) DO probe calibration error.
(c) Not measured.

Table B-1. Analytical Results from Long-Term Sampling at Conneaut Lake Park, PA (Continued)

Sampling Date		09/07/10[c]			09/20/10[c]						10/05/10			11/02/10			12/07/10[d]		
Sampling Location Parameter	Unit	IN	BF	TT	IN	BF	TA	TB	TC	TT	IN	BF	TT	IN	BF	TT	IN	BF	TT
Alkalinity	mg/L[a]	158 -	158 -	156 -	153 -	156 -	156 -	158 -	153 -	- -	172 -	165 -	159 -	148 -	150 -	150 -	141 -	139 -	143 -
Ammonia	mg/L	0.1 -	<0.05 -	<0.05 -	0.1 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -	0.1 -	<0.05 -	<0.05 -	0.1 -	<0.05 -	<0.05 -	0.1 -	<0.05 -	<0.05 -
Fluoride	mg/L	0.1	0.1	0.1	-	-	-	-	-	-	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.2
Sulfate	mg/L	23.3	25.5	29.2	-	-	-	-	-	-	21.4	23.5	23.1	24.3	23.6	22.9	18.8	24.8	22.8
Nitrate (as N)	mg/L	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	- -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -	<0.05 -
Total P (as P)	µg/L	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	- -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -
Silica (as SiO_2)	mg/L	16.2 -	16.4 -	16.4 -	12.8 -	12.8 -	12.8 -	13.4 -	12.9 -	- -	13.4 -	14.7 -	12.8 -	13.5 -	13.5 -	12.7 -	13.4 -	13.6 -	13.2 -
Turbidity	NTU	0.9 -	0.5 -	0.2 -	1.1 -	2.3 -	1.9 -	0.8 -	1.1 -	- -	0.8 -	4.5 -	0.3 -	1.2 -	1.6 -	0.9 -	3.6 -	8.9 -	1.9 -
TOC	mg/L	< 1.0	< 1.0	< 1.0	-	-	-	-	-	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
pH	S.U.	8.3	8.3	8.4	8.8	9.0	-	-	-	8.8	8.3	8.4	8.3	8.2	8.3	8.0	NA[e]	NA[e]	NA[e]
Temperature	°C	11.9	12.8	13.2	12.5	12.1	-	-	-	12.5	11.4	11.5	12.3	11.6	11.5	11.6	NA[e]	NA[e]	NA[e]
DO	mg/L	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	-	-	-	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]
ORP	mV	290	441	397	421	475	-	-	-	488	330	500	649	313	663	652	425	723	688
Free Chlorine (as Cl_2)	mg/L	-	1.3	1.6	-	1.9	-	-	-	0.8	-	1.5	1.4	-	1.2	1.1	-	3.1	1.2
Total Chlorine (as Cl_2)	mg/L	-	1.7	1.9	-	2.2	-	-	-	1.6	-	2.1	1.6	-	1.6	1.4	-	3.4	1.1
Total Hardness	mg/L[a]	136	133	125	-	-	-	-	-	-	164	163	163	145	150	150	147	147	143
Ca Hardness	mg/L[a]	85.2	83.8	79.7	-	-	-	-	-	-	126	126	126	104	108	109	107	109	105
Mg Hardness	mg/L[a]	50.7	49.2	45.5	-	-	-	-	-	-	38.4	37.3	36.9	40.5	41.0	40.6	39.7	38.1	38.2
As (total)	µg/L	29.2 -	29.3 -	13.5 -	30.4 -	30.5 -	15.0 -	15.1 -	15.2 -	- -	37.3 -	29.6 -	3.1 -	31.0 -	30.5 -	2.2 -	30.8 -	31.6 -	1.7 -
As (soluble)	µg/L	29.3	21.7	14.0	-	-	-	-	-	-	31.7	2.1	3.3	30.5	2.0	2.2	29.5	1.7	1.6
As (particulate)	µg/L	<0.1	7.6	<0.1	-	-	-	-	-	-	5.6	27.5	<0.1	0.5	28.5	<0.1	1.3	30.0	<0.1
As (III)	µg/L	29.1	<0.1	<0.1	-	-	-	-	-	-	26.5	0.2	0.1	25.6	0.3	0.2	27.1	0.2	0.2
As (V)	µg/L	0.2	21.6	13.9	-	-	-	-	-	-	5.2	1.9	3.1	4.9	1.6	2.0	2.3	1.4	1.5
Fe (total)	µg/L	240 -	221 -	<25 -	420 -	196 -	<25 -	<25 -	<25 -	- -	243 -	2,226 -	<25 -	190 -	2,111 -	<25 -	188 -	2,035 -	<25 -
Fe (soluble)	µg/L	224	<25	<25	-	-	-	-	-	-	221	<25	<25	104	<25	<25	148	<25	<25
Mn (total)	µg/L	71.5 -	72.0 -	<0.1 -	68.8 -	71.4 -	0.4 -	0.4 -	0.4 -	- -	78.0 -	86.9 -	0.4 -	64.2 -	73.6 -	0.2 -	65.0 -	71.5 -	0.1 -
Mn (soluble)	µg/L	69.1	21.6	<0.1	-	-	-	-	-	-	81.9	23.3	0.3	63.2	23.1	0.1	64.3	32.8	<0.1

(a) As $CaCO_3$.
(b) DO probe calibration error.
(c) $FeCl_3$ addition not functioning properly.
(d) All non-metal samples except TOC collected on 12/06/10.
(e) pH probe calibration error

APPENDIX C

BACKWASH DATA

Table C-1. Backwash Data for Conneaut Lake Park, PA

Backwash Date(s)	No. of Vessels Backwashed	No. of Days Between Backwashes	Amount of Wastewater Produced (gal)	Remarks
12/14/09	6	Unknown	10,943	
12/18/09–12/19/09	1,2	Unknown	1,878;3,788	
12/25/09	3	6–7	5,691	
12/30/09–01/01/10	1,2	5–6	1,872;3,797	
01/05/10–01/06/10	2,1	5–6	3,748;1,899	Backwash on 01/04/10
01/10/10–01/12/10	2,1	4–6	3,756;1,882	
01/16/10–01/18/10	2,1	4–6	3,738;1,869	
01/22/10–01/24/10	2,1	4–6	3,745;1,892	
01/28/10	3	4	5,664	Backwash on 01/27/10
02/02/10	3	5	5,650	
02/08/10	3	6	5,670	
02/15/10	3	6?	5,729	
02/22/10	3	6?	5,721	
02/25/10–02/26/10	2,2	3–4	3,920;3,884	Backwash on 02/24/10
03/02/10–03/04/10	1,2	4–6	1,848;3,638	
03/04/10–03/19/10	6	Unknown	11,029	6 vessels backwashed in specified duration
03/19/10–03/22/10	1,2	Unknown	1,844;3,689	Backwash on 03/23/10
03/24/10	3	2	5,618	
03/29/10	3	5	5,611	
04/05/10	3	6?	5,585	
04/12/10	3	6–7	5,578	
04/16/10	3	6	5,535	
04/20/10	3	4	5,556	Backwash on 04/19/10
04/26/10	3	6?	5,533	
05/03/10	3	5–6?	5,572	
05/07/10	3	5–6?	5,515	
05/13/10	3	6	5,507	
05/19/10	3	6	5,533	Backwash on 05/18/10
05/24/10	3	5?	5,508	
06/01/10	3	6?	5,496	
06/07/10	3	6?	5,488	
06/11/10	3	4	5,466	
06/17/10	4	6	7,659	Backwash on 06/16/10
06/21/10	1	3–4	1,793	
06/23/10	2	2	3,582	
06/28/10–06/29/10	1,2	3	1,781;3,648	
07/02/10-07/05/10	1,2	3	1,786;3,575	
07/07/10–07/08/10	2,1	2–3	3,071;1,875	
07/11/10–07/12/10	1,1	3–4	1,792;1,753	Backwash on 07/12/10
07/13/10	3	1	5,446	
07/17/10–07/19/10	1,1,1	4	1,769;1,753;1,779	
07/23/10–07/24/10	2,1	4	3,539;2,429	
07/25/10–07/26/10	2,1	3	3,042;1,820	
07/28/10–07/29/10	2,1	3	3,631;1,826	
07/31/10–08/01/10	2,1	3	3,622;1,815	
08/03/10	2	3	3,653	

Table C-1. Backwash Data for Conneaut Lake Park, PA (Continued)

Backwash Date(s)	No. of Vessels Backwashed	No. of Days Between Backwashes	Amount of Wastewater Produced (gal)	Remarks
08/04/10	3	1	5,536	
08/06/10	3	2	5,588	
08/09/10	3	3	5,497	
08/11/10	2	2	3,981	Backwash on 08/10/10
08/12/10	3	1	5,526	
08/16/10	3	4	5,469	
08/18/10	3	2	5,477	
08/21/10	3	3	5,463	
08/24/10	3	3	5,428	
08/27/10	3	3	5,529	
08/30/10	3	3	5,526	
09/02/10	3	3	5,524	
09/05/10	3	3	5,505	
09/08/10	3	3	5,525	
09/09/10	2	1	3,573	
09/13/10	3	4	5,529	
09/14/10	3	3	5,522	
09/17/10	3	2–3	5,513	
09/20/10	3	3	5,483	
09/23/10	3	3	5,496	
09/27/10	3	3	5,518	
09/29/10	3	3	5,533	
10/04/10	3	3–4	5,465	
10/06/10	3	3–4	5,521	Backwash on 10/06/10
10/07/10	2	1	3,286	
10/08/10	3	2	5,494	
10/11/10	3	3	5,533	
10/14/10	3	3	5,550	
10/18/10	3	3	5,542	
10/20/10	3	3	5,548	
10/25/10	3	3	5,567	
10/26/10	3	3	5,526	
10/29/10	3	3	5,561	
11/01/10	3	3	5,553	
11/04/10	2	3	3,702	
11/08/10	1	3	2,732	
11/11/10	1	3	1,685	
11/15/10–11/17/10	1,1,1	3–4	1,706;1,687;2.045	
11/23/10–11/24/10	1,1	6	1,791;1,606	
11/29/10	2	5	3,249	
12/03/10	1	4	1,654	
12/10/10	1	7	1,631	
12/15/10–12/16/10	1,1	5–6	1,643;1,625	
Total	247		469,142	1,900 gal/vessel