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Arsenic Removal from Drinking Water by Iron Removal U.S. EPA Demonstration Project at City of Sandusky, MI Final Performance Evaluation Report

by

Julia M. Valigore
Abraham S.C. Chen
Wendy E. Condit
Lili Wang

Battelle
Columbus, OH 43201-2693

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Thomas J. Sorg
Task Order Manager

Water Supply and Water Resources Division
National Risk Management Research Laboratory
Cincinnati, Ohio 45268

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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Sally Gutierrez, Director
National Risk Management Research Laboratory

ABSTRACT

This report documents the activities performed during and the results obtained from the U.S. Environmental Protection Agency (EPA) arsenic removal technology demonstration project at the City of Sandusky, MI facility. The objectives of the project were to evaluate: 1) the effectiveness of Siemens Water Technologies' Enhanced AERALATER® Type II Arsenic Removal Technology in removing arsenic to meet the maximum contaminant level (MCL) of 10 μg/L, 2) the reliability of the treatment system for use at small water facilities, 3) the required system operation and maintenance (O&M) and operator skill levels, and 4) the capital and O&M cost of the technology. The project also characterized water in the distribution system and residuals generated by the treatment process. The types of data collected included system operation, water quality, process residuals, and capital and O&M cost.

After engineering plan review and approval by the state, the AERALATER® was installed and became operational on June 14, 2006. The fully-automated, packaged system consisted of a 12-ft diameter aluminum detention tank atop a 12-ft diameter, three-cell gravity sand filter plus ancillary equipment including an air distribution grid, an air compressor pack, a blower, two chemical feed systems, a high service pump, sample taps, and associated instrumentation. The filter contained 226 ft^3 of sand and was designed for filtration rates up to 2.5 gpm/ft^2.

During the performance evaluation study, source water had an average pH value of 7.2 and contained fluctuating concentrations of arsenic and iron due, in part, to the use of up to four source water wells. Total arsenic concentrations ranged from 7.3 to 23.5 μg/L and averaged 11.4 μg/L. The predominant soluble species was As(III) with an average concentration of 8.7 μg/L. Total iron concentrations ranged from 236 to 3,214 μg/L and averaged 896 μg/L. Chlorine was used to oxidize As(III) and Fe(II) to form filterable As(V)-laden particles within the detention tank. However, due to the presence of 0.3 mg/L (as N) of ammonia in source water, breakpoint chlorination was not achieved with an average of 2.5 mg/L (as Cl_2) of sodium hypochlorite (NaOCl) applied. The formation of chloramines might have partially inhibited the oxidation of As(III), leaving as much as 3.2 μg/L of As(III) in the treated water. After gravity filtration, total arsenic concentrations ranged from 0.4 to 9.8 μg/L and averaged 2.4 μg/L, consisting of soluble As(III) and As(V). Iron concentrations in the filter effluent were, in most cases, less than the method reporting limit of 25 μg/L; however, occasional elevated concentrations were measured in the range of 99 to 617 μg/L in the filter effluent. The system operated at approximately 163 gal/min (gpm), producing approximately 61,833,000 gal of water through June 22, 2007. The flowrate corresponded to an average detention time of 69 min and an average filtration rate of 1.4 gpm/ft^2, compared to the design values of 40 min and 2.5 gpm/ft^2.

Comparison of the distribution system sampling results before and after system startup demonstrated a considerable decrease in arsenic (i.e., 7.4 to 3.2 μg/L) and iron (i.e., 360 to 35 μg/L). Manganese and lead concentrations did not appear to be affected, but copper concentrations increased from 209 to 473 μg/L after system startup. Alkalinity and pH increased and decreased, respectively, at two locations. Uncertainties of water sources during baseline sampling and changes to the post-treatment chemicals might have impacted the trends.

Filter tank backwash occurred automatically based on a day and time setpoint. Approximately 6,000 gal of wastewater was discharged to the sanitary sewer for each backwash event, totaling 1.0% of the treated water volume when backwashing 2 time/week and 1.6% when backwashing 3 time/week. On average, the backwash wastewater contained 129 mg/L of total suspended solids (TSS), 0.5 mg/L of arsenic, 58 mg/L of iron, and 1.1 mg/L of manganese, with the majority exisiting as particulates. Based on solids

sampling, approximately 3.5 lb of solids were discharged per backwash event, including 0.02 lb of arsenic, 2.90 lb of iron, and 0.06 lb of manganese.

The capital investment for the system was $364,916, including $205,800 for equipment, $27,077 for site engineering, and $132,039 for installation, shakedown, and startup. Using the system's rated capacity of 340 gpm (or 489,600 gal/day [gpd]), the capital cost was $1,073/gpm (or $0.75/gpd). This unit cost does not include the cost of the building to house the treatment system. O&M cost, estimated at $0.50/1,000 gal, included cost for chemical, electricity, and labor.

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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
BV	bed volume(s)
Ca	calcium
C/F	coagulation/filtration
cfm	cubic feet per minute
Cl	chlorine
CRF	capital recovery factor
Cu	copper
DBP	disinfection byproducts
DBPR	Disinfection Byproducts Rule
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
$Fe_2(SO_4)_3$	ferric sulfate
FedEx	Federal Express
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
HAA	haloacetic acid
HIX	hybrid ion exchange
HOA	hand/off/auto
hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IX	ion exchange
LCR	(EPA) Lead and Copper Rule
LOU	Letter of Understanding
MCL	maximum contaminant level
MDEQ	Michigan Department of Environmental Quality
MDL	method detection limit

MEI	Magnesium Elektron, Inc.
Mg	magnesium
µm	micrometer
Mn	manganese
mV	millivolts
Na	sodium
NA	not available/not analyzed
NaOCl	sodium hypochlorite
ND	not detected
NSF	NSF International
NTU	nephlemetric turbidity units
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	phosphorus
Pb	lead
psi	pounds per square inch
PLC	programmable logic controller
PO_4	phosphate
POU	point-of-use
PVC	polyvinyl chloride
QA	quality assurance
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RFQ	request for quotation
RPD	relative percent difference
RO	reverse osmosis
Sb	antimony
SCADA	system control and data acquisition
scfm	standard cubic feet per minute
SDWA	Safe Drinking Water Act
SiO_2	silica
SMCL	secondary maximum contaminant level
SO_4	sulfate
SOC	synthetic organic compound(s)
STS	Severn Trent Services
TDS	total dissolved solids
TDH	total dynamic head
TE	Townley Engineering, LLC.
THM	trihalomethane
TOC	total organic carbon
TSS	total suspended solids

UPS	United Parcel Service
USDA	U.S. Department of Agriculture
V	vanadium
VFD	variable frequency drive
VOC	volatile organic compound(s)

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Section 1.0 INTRODUCTION

1.1 Project Background

The Safe Drinking Water Act (SDWA) mandates that U.S. Environmental Protection Agency (EPA) identify and regulate drinking water contaminants that may have adverse human health effects and that are known or anticipated to occur in public water supply systems. In 1975 under the SDWA, EPA established a maximum contaminant level (MCL) for arsenic at 0.05 mg/L. Amended in 1996, the SDWA required that EPA develop an arsenic research strategy and publish a proposal to revise the arsenic MCL by January 2000. On January 18, 2001, EPA finalized the arsenic MCL at 0.01 mg/L (EPA, 2001). In order to clarify the implementation of the original rule, EPA revised the rule 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 in order to reduce compliance costs. As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, on-site demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems. Shortly thereafter, an announcement was published in the *Federal Register* requesting water utilities interested in participating in Round 1 of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 out of 115 sites to host the demonstration studies.

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the 17 host sites. EPA received 70 technical proposals for the 17 host sites, with each site receiving 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 and the community water system in the City of Sandusky, MI was one of those selected.

In September 2003, EPA, again, solicited proposals from engineering firms and vendors for arsenic removal technologies. EPA received 148 technical proposals for the 32 host sites, with each site receiving from two to eight proposals. In April 2004, another technical panel was convened by EPA to review the proposals and provide recommendations to EPA with the number of proposals per site ranging from none (for two sites) to a maximum of four. The final selection of the treatment technology at the sites that received at least one proposal was made, again, through a joint effort by EPA, the state regulators, and the host site. Since then, four sites have withdrawn from the demonstration program, reducing the number of sites to 28. Siemens Water Technologies' Enhanced AERALATER® Type II Arsenic Removal Technology was selected for demonstration at Sandusky, MI. As of January 2008, 37 of the 40 systems were operational, and the performance evaluation of 26 systems was completed.

1.2 Treatment Technologies for Arsenic Removal

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

1.3 Project Objectives

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

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

This report summarizes the performance of the Siemens' system at the City of Sandusky in Michigan from June 14, 2006, through June 22, 2007. 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 Arsenic Removal Demonstration Sites

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

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

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

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

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

Section 2.0 SUMMARY AND CONCLUSIONS

Siemens Water Technologies' AERALATER® treatment system was installed and operated at the City of Sandusky, MI from June 14, 2006 through June 22, 2007. Based on the information collected during the evaluation study, the following was summarized and concluded relating to the overall project objectives.

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

- The AERALATER® treatment system was capable of reducing arsenic concentrations to below the arsenic MCL. This was achieved at an average filtration rate of 1.4 gpm/ft^2, which was 44% lower than the design value of 2.5 gpm/ft^2.
- An average chlorine dosage of 2.5 mg/L (as Cl_2) was not able to achieve breakpoint chlorination due to the presence of 0.3 mg/L (as N) of ammonia in source water. The formation of chloramines might have partially inhibited the oxidation of As(III), leaving as much as 3.2 µg/L of As(III) in the treated water.
- The filter run time could be as high as 80 hr (or 750,000 gal of throughput) before backwash was required. However, particulate iron breakthrough at levels as high as 617 µg/L was observed on eight weekly sampling occasions.
- Bachwashing at a rate of 7.4 gpm/ft^2 was effective at restoring the gravity filter for subsequent service runs.
- The treatment system was capable of reducing arsenic and iron concentrations in the distribution system. The concentration reductions for arsenic and iron were from 7.4 to 3.2 µg/L and from 360 to 35 µg/L, respectively.

Required system O&M and operator skill levels:

- The treatment system was reliable and easy to operate.
- Very little time was required to operate and maintain the system. The daily demand on the operator was 30 to 45 min to visually inspect the system and record operational parameters. The AERALATER® unit and all ancillary equipment were fully automatic and controlled by a programmable logic controller (PLC).

Characteristics of residuals produced by the technology:

- During system operation, a relatively small amount of wastewater was generated. The amount was equivalent to 1.0 and 1.6% of the volume of water treated based on the backwash frequency of 2 and 3 time/week, respectively.
- Approximately 6,000 gal of wastewater and 3.5 lb of residual solids were produced during each backwash event. The solids discharged to the sanitary sewer included 0.02 lb of arsenic, 2.90 lb of iron, and 0.06 lb of manganese.

Capital and O&M cost of the technology:

- The capital investment for the system was $364,916, including $205,800 for equipment, $27,077 for site engineering, and $132,039 for installation, shakedown, and startup. The building was funded by the City and not included in this cost.
- The unit capital cost was $1,073/gpm (or $0.75/gpd) based on a 340-gpm peak capacity.
- The O&M cost, estimated at $0.50/1,000 gal, included cost for chemical, electricity, and labor.

Section 3.0 MATERIALS AND METHODS

3.1 General Project Approach

Following the predemonstration activities summarized in Table 3-1, the performance evaluation study of the Siemens treatment system began on June 14, 2006. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall system performance was based on its ability to consistently remove arsenic to below the target MCL of 10 μg/L through the collection of water samples across the treatment train. The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement. Any unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

The O&M and operator skill requirements were assessed through quantitative data and qualitative considerations, including the need for pre- and/or post-treatment, level of system automation, extent of preventative maintenance activities, frequency of chemical 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 quantities of aqueous and solid residuals generated were 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 3-1. Predemonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	September 1, 2004
Draft Letter of Understanding (LOU) Issued	October 18, 2004
Final LOU Issued	October 27, 2004
Request for Quotation (RFQ) Issued to Siemens	October, 28, 2004
Siemens' Quotation Received	December 21, 2004
Facility Letter Report Issued	March 1, 2005
RFQ Issued to Townley Engineering	March 29, 2005
Townley Engineering's Quotation Received	April 22, 2005
Purchase Order Established with Siemens	May 20, 2005
Purchase Order Established with Townley Engineering	June 13, 2005
Engineering Package Submitted to MDEQ	August 5, 2005
System Permit Granted by MDEQ	September 7, 2005
Building Construction Permit Granted to City	November 8, 2005
Building Construction Began	November 21, 2005
System Arrived at Facility	February 16, 2006
System Installation Began	February 17, 2006
Performance Evaluation Study Plan Issued	February 28, 2006
Building Construction Completed	March 1, 2006
System Installation Completed	April 6, 2006
System Shakedown Completed	May 5, 2006
Performance Evaluation Began	June 14, 2006
Operator Training Completed by Battelle	June 22, 2006

MDEQ = Michigan Department of Environmental Quality

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

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

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

3.2 System O&M and Cost Data Collection

The plant operator performed daily, weekly, and monthly system O&M and data collection according to instructions provided by the vendor and Battelle. On a daily basis, the plant operator recorded system operational data, such as pressure, flowrate, totalizer, and hour meter readings on a Daily System Operation Log Sheet; checked the sodium hypochlorite (NaOCl) level; and conducted visual inspections to ensure normal system operations. If any problem occurred, the plant operator contacted the Battelle Study Lead, who determined if the vendor should be contacted for troubleshooting. The plant operator recorded all relevant information, including the problem encountered, course of actions taken, materials and supplies used, and associated cost and labor incurred, on a Repair and Maintenance Log Sheet. On a weekly basis, the plant operator measured several water quality parameters on-site, including temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and residual chlorine, and recorded them on a Weekly On-Site Water Quality Parameters Log Sheet. Monthly backwash data also were recorded on a Backwash Log Sheet.

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

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected at the influent, across the treatment plant, during filter backwash, and from the distribution system. The sampling schedules and analytes measured during each sampling event are listed in Table 3-3. In addition, Figure 3-1 presents a flow diagram of the treatment system along with the analytes and schedules at each sampling location. Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2004). The procedure for arsenic speciation is described in Appendix A of the QAPP.

3.3.1 Source Water. During the initial site visit, one set of source water samples was collected and speciated using an arsenic speciation kit (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 plant operator collected samples weekly, on a four-week cycle, for on- and off-site analyses. For the first week of each four-week cycle, samples taken at the inlet (IN), after the detention tank (AD), and after the filter cells (TT), were speciated on-site and analyzed per Table 3-3 for monthly treatment plant water. For the next three weeks, samples were collected at the same three locations and analyzed per Table 3-3 for the weekly treatment plant water.

3.3.3 Backwash Water. Backwash water samples were collected monthly by the plant operator. Connected to the tap on the discharge line, tubing directed a portion of backwash water at approximately 1 gpm into a clean, 32-gal container over the duration of the backwash for each filter cell. After the content in the container was thoroughly mixed, composite samples were collected and/or filtered on-site using 0.45-µm disc filters. Analytes for the backwash samples are listed in Table 3-3.

3.3.4 Distribution System Water. Samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically, the arsenic, lead, and copper levels. Prior to the system startup from February to June 2005, four sets of baseline distribution water samples were collected from two residences and one business within the distribution system. These locations are part of the City's historic sampling network under the EPA Lead and Copper Rule (LCR). Following system startup, distribution system sampling continued on a monthly basis at the same three locations.

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

3.3.5 Residual Solids. Residual solids produced by the treatment process included backwash solids. After the solids in the backwash water containers (Section 3.3.3) had settled and the supernatant was carefully decanted, residual solids samples were collected. A portion of each solid/water mixture was air-dried for metal analyses.

3.4 Sampling Logistics

3.4.1 Preparation of Arsenic Speciation Kits. The arsenic field speciation method uses an anion exchange resin column to separate the soluble arsenic species, As(V) and As(III) (Edwards et al., 1998).

Table 3-3. Sampling Schedule and Analyses

Sample Type	Sample Locations[(a)]	No. of Samples	Frequency	Analytes	Collection Date(s) and Results
Source Water	At Wellhead	1	Once (during initial site visit)	On-site: pH, temperature, DO, and ORP Off-site: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, Cl, F, SO_4, SiO_2, PO_4, NH_3, NO_2, NO_3, TOC, TDS, turbidity, and alkalinity	Table 4-1 (09/01/04)
Treatment Plant Water	IN, AD, TT	3	Weekly	On-site[(b)]: pH, temperature, DO, ORP, Cl_2 (free and total) Off-site: As (total), Fe (total), Mn (total), P (total), SiO_2, turbidity, and alkalinity	Appendix B
			Monthly	Same as above plus following off-site analytes: As (soluble), As(III), As(V), Fe (soluble), Mn (soluble), Ca, Mg, F, NO_3, SO_4, NH_3, and TOC	Appendix B
Backwash Water	BW	3	Monthly	As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, TDS, and TSS	Table 5-5
Distribution Water	Two LCR Residences and One LCR Non-residence	3	Monthly	Total As, Fe, Mn, Cu, and Pb, pH, and alkalinity	Table 5-7
Residual Solids	SS (Backwash Solids from Each Cell)	3	Twice	Total Al, As, Ca, Cd, Cu, Fe, Mg, Mn, Ni, P, Pb, Si, and Zn	Table 5-6

(a) Abbreviation corresponding to sample location in Figure 3-1, i.e., IN = at inlet, AD = after detention, TT = after filter cells, BW = from backwash discharge line; SS = sludge sampling location
(b) On-site measurements of chlorine not collected at IN

Resin columns were prepared in batches at Battelle laboratories according to the procedures detailed in Appendix A of the QAPP (Battelle, 2004).

3.4.2 Preparation of Sample Coolers. For each sampling event, a sample cooler was prepared with the appropriate number and type of sample bottles, disc filters, and/or speciation kits. All sample bottles were new and contained appropriate preservatives. Each sample bottle was affixed with a pre-printed, colored-coded label consisting of the sample identification (ID), date and time of sample collection, collector's name, site location, sample destination, analysis required, and preservative. The sample ID consisted of a two-letter code for the demonstration site, the sampling date, a two-letter code

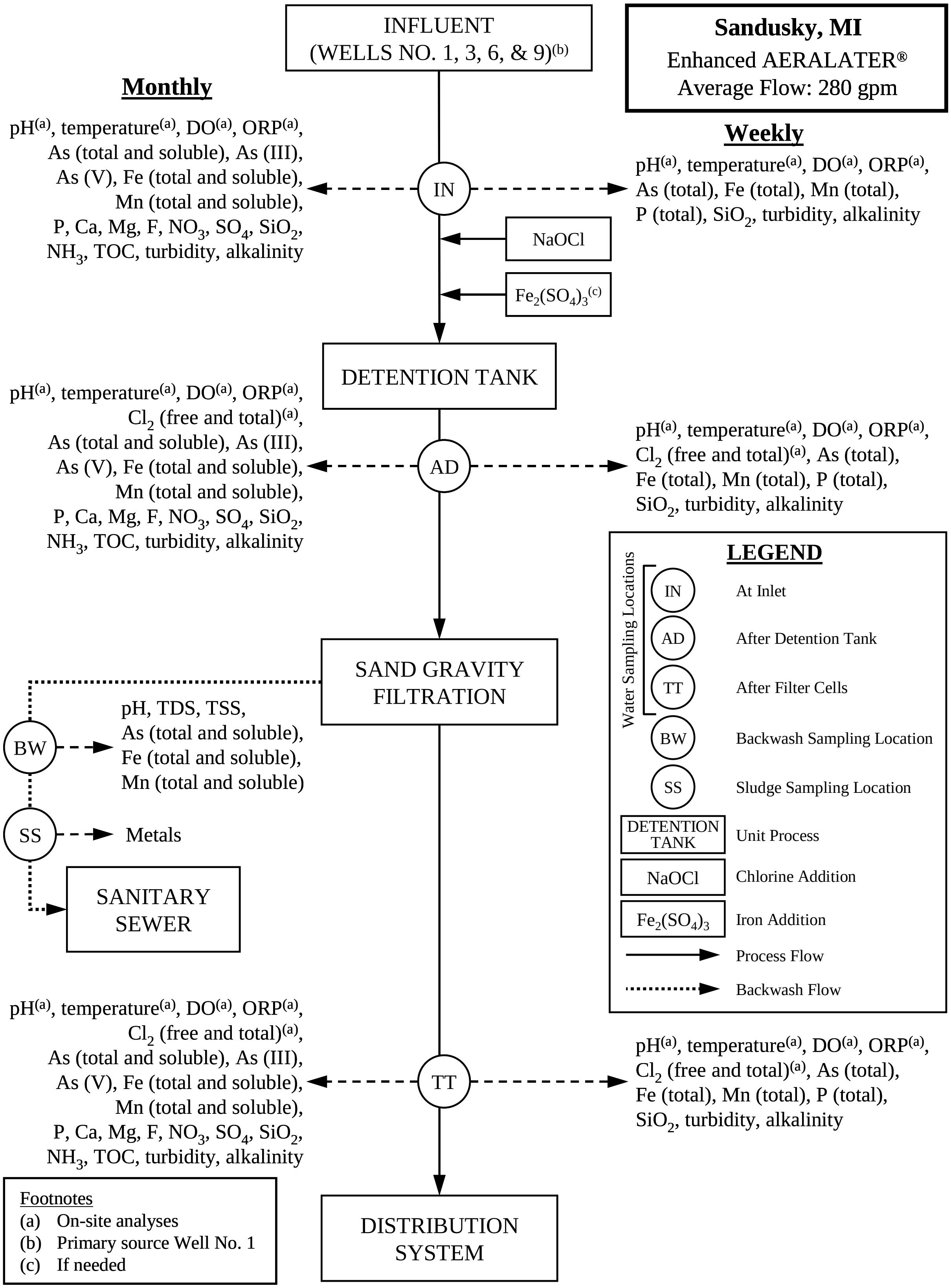

Figure 3-1. Process Flow Diagram and Sampling Schedule and Locations

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 were separated by sampling locations, placed in Ziplock® 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 United Parcel Service (UPS) air bills, and bubble wrap, were included. The chain-of-custody forms and air bills were complete except for the operator's signature and the sample dates and times. After preparation, the sample cooler was sent to the site via FedEx for the following week's sampling event.

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

Samples for metal analyses were stored at Battelle's Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) Laboratory. Samples for other water quality analyses by Battelle's subcontract laboratories, including American Analytical Laboratories (AAL) in Columbus, OH and Belmont Labs in Englewood, OH, were packed in separate coolers and picked up by couriers. The chain-of-custody forms remained with the samples from the time of preparation through collection, analysis, and final disposal. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

3.5 Analytical Procedures

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

Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a handheld field meter, which was calibrated for pH and DO prior to use following the procedures provided in the user's manual. The ORP probe also was checked for accuracy by measuring the ORP of a standard solution and comparing it to the expected value. The plant operator collected a water sample in a clean, plastic beaker and placed the 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.

Section 4.0 DEMONSTRATION SITE AND TECHNOLOGY EVALUATED

4.1 Site Description

4.1.1 Existing Facility. The City of Sandusky has five supply wells (i.e., Wells No. 1, 3, 6, 7, and 9) that have a total capacity of 760 gpm. Because of high iron concentrations (2.5 to 3.0 mg/L), Well No. 3 is seldom used. Prior to the demonstration study, the other four wells (i.e., Wells No. 1, 6, 7, and 9) were used on a monthly, rotating basis. Well No. 1, which was designated for this study, was 10-in in diameter and 136 ft deep. The static water level depth was 30 ft below ground surface (bgs). The submersible pump for Well No. 1 previously operated at 210 gpm at 130 ft of total dynamic head (TDH) to the height of the water tower. A pump test performed in December 2004 indicated that the aquifer was capable of sustaining an increased extraction rate of approximately 280 gpm at a reduced TDH of only 18 ft to the height of the treatment system. A new 15-horsepower (hp) pump, capable of producing 340 gpm, was installed in March 2006 prior to the installation of the arsenic removal system. Servicing with a population of 2,916 people, the water system has a maximum daily capacity of 750,000 gal and an average daily demand of 262,000 gal.

Figure 4-1 shows the existing pump house for Well No. 1 and 300,000-gal water tower, and Figure 4-2 shows the system piping for Well No. 1 with associated valves, flow totalizer, and pressure gauges. Existing water treatment consisted of a NaOCl addition at 3 mg/L (as Cl_2) to reach a target free chlorine residual level of 0.5 to 1.0 mg/L (as Cl_2), and a blended phosphate feed (85% ortho- and 15% poly phosphate) at 4 mg/L as a sequestering agent for iron and for corrosion and scale control. Figure 4-2 shows the 55-gal phosphate and chlorine addition tanks and a scale. The water was pumped to the distribution system and stored in the water tower as shown in Figure 4-1.

Figure 4-1. Pump House for Well No. 1 and Water Tower

Figure 4-2. System Piping and Chlorine and Phosphate Addition Systems

4.1.2 Distribution System and State Sampling Requirements. The distribution system consisted of 4-in and 8-in cast iron and 8-in polyvinyl chloride (PVC) piping, which was added in 2000. The two residences and one non-residence selected for the monthly baseline and distribution system water sampling are impacted by all of the wells in the distribution system and the two residences are part of the City's historic LCR sampling network. Individual service hookups are ¾- and 1-in copper piping.

For compliance purposes, the City had sampled water periodically from the distribution system for several parameters: monthly at two residences for bacterial analysis; yearly at four residences for trihalomethanes (THMs) and haloacetic acids (HAAs) under the EPA Disinfection Byproducts Rule (DBPR); and once every three years at 10 residences for lead and copper under the LCR. Well No. 1 also had been sampled quarterly for arsenic, yearly for partial chemistry (i.e., chloride, fluoride, hardness, nitrate, nitrite, sulfate, sodium, and iron) and volatile organic compounds (VOCs), once every three years for c (SOCs), and once every nine years for metals and radionuclides.

4.1.3 Source Water Quality. Source water samples were collected from Well No. 1 on September 1, 2004. The analytical results are presented in Table 4-1 and compared to the historic data collected by the facility, Battelle (on July 23, 2002), and Michigan Department of Environmental Quality (MDEQ) (from March 7, 2001 through March 15, 2004).

Total arsenic concentrations of source water ranged from 14 to 36 µg/L. Based on Battelle's September 1, 2004 results, total arsenic was 15.8 µg/L, consisting of 13.7 µg/L in the soluble form and 2.1 µg/L in the particulate form. Of the soluble arsenic, 9.7 µg/L (or 60%) existed as As(III) and 4.0 µg/L (or 25%) as As(V). Arsenic speciation performed by Battelle on July 23, 2002, however, showed a total arsenic concentration twice as high with soluble As(III) and As(V) existing almost evenly at 14.9 and 15.3 µg/L, respectively. The variations in arsenic concentration in Well No. 1 water were, therefore, closely

Table 4-1. Well No. 1 Source Water Quality Data

Parameter	Unit	Facility Data	Battelle Data		MDEQ Data
Date		NA	07/23/02	09/01/04	03/07/01 - 03/15/04
pH	S.U.	6.9	NA	6.9/7.2	NA
Temperature	°C	NA	NA	12.9	NA
DO	mg/L	NA	NA	0.5	NA
ORP	mV	NA	NA	-62	NA
Alkalinity (as $CaCO_3$)	mg/L	361*	NA	314	NA
Hardness (as $CaCO_3$)	mg/L	468	NA	525	407-546
Turbidity	NTU	NA	NA	17	NA
TDS	mg/L	NA	NA	736	NA
TOC	mg/L	NA	NA	1.5	NA
Nitrate (as N)	mg/L	NA	NA	<0.04	<0.4
Nitrite (as N)	mg/L	NA	NA	<0.01	<0.05
Ammonia (as N)	mg/L	NA	NA	0.3	NA
Chloride	mg/L	NA	NA	130	71-192
Fluoride	mg/L	NA	NA	0.3	0.5-0.7
Sulfate	mg/L	113*	NA	89.0	95-120
Silica (as SiO_2)	mg/L	16.0*	NA	13.9	NA
Orthophosphate (as P)	mg/L	ND	NA	<0.1	NA
As (total)	µg/L	25.0	30.9	15.8	14-36
As (soluble)	µg/L	NA	30.2	13.7	NA
As (particulate)	µg/L	NA	0.7	2.1	NA
As(III)	µg/L	NA	14.9	9.7	NA
As(V)	µg/L	NA	15.3	4.0	NA
Ca (total)	mg/L	115*	NA	133.6	NA
Fe (total)	µg/L	1,400	1,563	1,387	500-1,700
Fe (soluble)	µg/L	NA	1,212	1,276	NA
Mg (total)	mg/L	44*	NA	46.3	NA
Mn (total)	µg/L	35*	33.6	38.3	NA
Mn (soluble)	µg/L	NA	31.3	37.7	NA
Na (total)	mg/L	43*	NA	109.4	43-106
U (total)	µg/L	NA	NA	0.7	NA
U (soluble)	µg/L	NA	NA	0.6	NA
V (total)	µg/L	NA	NA	1.2	NA
V (soluble)	µg/L	NA	NA	1.1	NA

*EPA sample analysis
TDS = total dissolved solids; TOC = total organic carbon; NA = not analyzed

monitored throughout the course of the demonstration study. Because the treatment process relied upon coprecipitation and adsorption of As(V) with/onto iron solids, prechlorination was required to oxidize As(III) to As(V).

Iron concentrations in source water ranged from 500 to 1,700 µg/L. Manganese concentrations ranged from 33.6 to 38.3 µg/L. Based on the speciation sampling conducted on July 23, 2002 and September 1, 2004, 78 to 92% of iron and 94 to 98% of manganese existed in the soluble form. These results, along with the presence of As(III) at the levels observed, were consistent with the low DO (0.5 mg/L) and ORP (-62 mV) values measured during the September 1, 2004 sampling event. For effective arsenic removal by iron solids, the general recommendations are that the soluble iron concentration is at least 20 times the soluble arsenic concentration (Sorg, 2002), and that the pH values fall within the range of 5.5 to 8.5 (note that improved arsenic removal most likely would occur at the lower end of this pH range). The results obtained on July 23, 2002 and September 1, 2004 indicated soluble iron to soluble arsenic concentration ratios of 40:1 and 93:1, respectively, and a pH range of 6.9 to 7.2. Therefore, no provisions were made for pH adjustment, but an iron addition system was included in case additional iron was required to lower the arsenic level in the treated water.

The September 1, 2004 test results showed that 0.3 mg/L (as N) of ammonia was in raw water. The presence of ammonia will increase the chlorine demand. Addition of chlorine to raw water will oxidize As(III) and other reducing species, such as Fe(II) and Mn(II), and also react with ammonia and organic nitrogen compounds, if any, to form combined chlorine (i.e., mono- and di-chloramines within a pH range of 4.5 to 8.5). In order to attain the target free chlorine residual of 0.5 mg/L (as Cl_2), "breakpoint" chlorination must be achieved. Thus, the theoretical chlorine dosage required would include the following: (1) amount to oxidize As(III), Fe(II), Mn(II), and any other reducing species, which was estimated to be 0.9 mg/L (as Cl_2) (Ghurye and Clifford, 2001), (2) amount to oxidize ammonia and combined chlorine formed during chlorination, which was estimated to be 2.3 mg/L (as Cl_2) (Clark et al., 1977), and (3) amount to provide the target free chlorine residual of 0.5 mg/L (as Cl_2).

With the addition of 3.7 mg/L (as Cl_2) of NaOCl, the potential exists for the formation of disinfection byproducts (DBPs), including THMs and HAAs, due to the presence of approximately 1.5 mg/L of total organic carbon (TOC) in raw water. Factors affecting the DBR formation include type of disinfectant, dosage, contact time, water pH and temperature, and concentration and characteristics of precursors, such as TOC (EPA, 2006). Formation of DBPs is monitored by the State through yearly collection of samples for THM and HAA analyses (Section 4.1.2). Furthermore, chlorine residuals, ammonia, and TOC were monitored during the performance evaluation study.

Other source water quality parameters also were analyzed (Table 4-1); results were mostly comparable to those obtained by the facility and MDEQ. The September 1, 2004 results indicated a high turbidity value of 17 nephlemetric turbidity units (NTU), presumably due to precipitation of iron and other constituents after sampling. The facility added phosphates to source water to sequester iron (Section 4.1.1). The treatment process was expected to greatly reduce turbidity levels through iron removal. Concentrations of orthophosphate, silica, fluoride, vanadium, and uranium were relatively low and not expected to impact the arsenic removal. Total dissolved solids (TDS) and sulfate were measured at 736 and 89 mg/L, respectively, which were not a concern for the treatment process. Hardness levels measured ranged from 407 to 546 mg/L (as $CaCO_3$); some customers of the water system installed point of entry softeners to lower the hardness.

4.1.4 Facility Modifications. Prior to the startup of the EPA-funded AERALATER® (designated as Unit 1), the City installed a second AERALATER® (designated as Unit 2) to meet the State's firm capacity requirements and began a water main project financed by U.S. Department of Agriculture (USDA) Rural Development. The City also installed and tested a generator for backup power to the treatment systems after the building was completed. The two AERALATER® units have a combined capacity of 680 gpm. Via a common header, Wells No. 1 and 3 were connected to the treatment units in May 2006, and Wells No. 6 and 9 were connected in mid-August 2006. Control of these wells (Table 4-2) and monitoring of the AERALATER® systems' operations were facilitated via a system control and data acquisition (SCADA) system at the City's wastewater treatment plant office. The wells' start and stop setpoints were controlled by the established water levels in the storage tanks and could be easily adjusted to change each well's operation. For example, Well No. 1, designated as 'Tower' in Figure 4-3, has the highest water level setpoint at 26 ft, which requires it to operate most often.

Table 4-2. Well Capacities and Control

Well No.	Capacity (gpm)	Lead/Backup
1	340[(a)]	Lead
3	150	Backup
6	150	Backup
9	120	Backup

(a) Well capacity after installation of a new 15-hp pump in March 2006

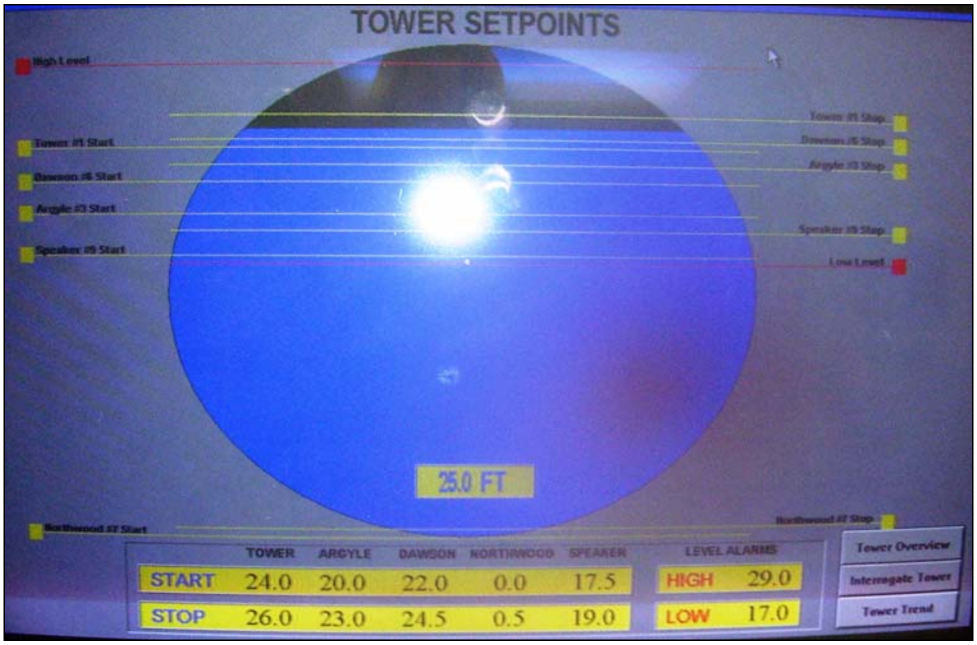

Figure 4-3. Screenshot of Water Tower Setpoints for Well Control

Table 4-3. Wells No. 3, 6, and 9 Source Water Quality Data

Parameter	Unit	Well No. 3	Well No. 6	Well No. 9
Date		07/09/04–10/04/05	03/09/04–10/04/05	03/09/04–10/04/05
Hardness (as $CaCO_3$)	mg/L	620–693	324–351	171–180
Nitrate (as N)	mg/L	<0.4	<0.4	<0.4
Nitrite (as N)	mg/L	<0.05	<0.05	<0.05
Chloride	mg/L	177–197	28–45	8–10
Fluoride	mg/L	0.5	0.7	0.9-1.0
Sulfate	mg/L	131–160	62–64	16–18
As (total)	µg/L	28–43	13–38	12–18
Fe (total)	µg/L	2,500–3,000	500–600	200–400
Na (total)	mg/L	74–105	41–50	25–26

Source: MDEQ

Upon completion of the watermain project, the distribution system consisted of a looped distribution line supplied by Wells No. 1, 3, 6, and 9. The facility used Well No. 1 as the lead well with Wells No. 3, 6, and 9 as backup wells to meet the City's daily demand. Source water data obtained from MDEQ for Wells No. 3, 6, and 9 are summarized in Table 4-3. It appeared that arsenic concentrations of the blended water would still be above 10 µg/L and, therefore, would require treatment through the AERALATER® units. Due to the high iron concentrations in Well No. 3 water when compared to those in Wells No. 6 and 9 water, Well No. 3 was used as the main backup well during this demonstration study.

4.2 Treatment Process Description

Siemens proposed to use a vertical, prepackaged unit, referred to as an Enhanced AERALATER® Type II Arsenic Removal System, to remove iron and arsenic from raw water. Sized at 10-ft diameter for 210 gpm in Siemens' original proposal to EPA, the system was upgraded at the City's request (based on the pump test results discussed in Section 4.1.1) and expenses, to 12-ft diameter for 340 gpm in order to accommodate the City's future expansion. The treatment train included prechlorination/oxidation, coprecipitation/adsorption, and gravity filtration. The filter media was silica sand, which is listed by NSF International (NSF) under Standard 61 for use in drinking water applications. The physical properties of this media are summarized in Table 4-4.

Table 4-4. Physical Properties of Silica Sand Media

Property	Value
Color	Light brown to light red
Effective Size (mm)	0.45–0.55
Uniformity Coefficient	≤1.6
Acid Solubility (%)	< 5
Specific Gravity	>2.5
Bulk Density (lb/ft^3)	100

The AERALATER® treatment system included two chemical feed systems, one detention tank with air diffuser grid, one three-cell gravity filter with aluminum plate underdrains, one blower and motor starter enclosure, one air compressor pack, one aluminum V-notch weir board, one high service pump with variable frequency drive (VFD), sample taps, and associated instrumentation. The main body of the AERALATER® unit was constructed of corrosion-resistant aluminum, and the tank bottom was solvent cleaned prior to undercoat applications. Metal surfaces of all carbon steel, cast iron, and ductile iron pipe, flanges, and fittings greater than 3-in diameter were blast cleaned, coated with 3 to 4 mils of primer, and painted with 4 to 8 mils of epoxy.

The treatment system was fully automated (Section 5.1.4.2) with a wall-mounted control panel that housed a touchscreen operator interface panel (OIP) (Allen Bradley model PanelView 1000), a PLC (Allen Bradley model SLC 5/04), and a modem (U.S. Robotics model V.92). A solenoid panel (Phoenix Contact model UK 5 N) also was included for the manual override of different valves. Figure 4-4 presents the layout and schematic of the AERALATER® unit. Figures 4-5 and 4-6 contain photographs of the system components and control panel and ancillary equipment, respectively. Key system design parameters are listed in Table 4-5. The major steps of the treatment process included:

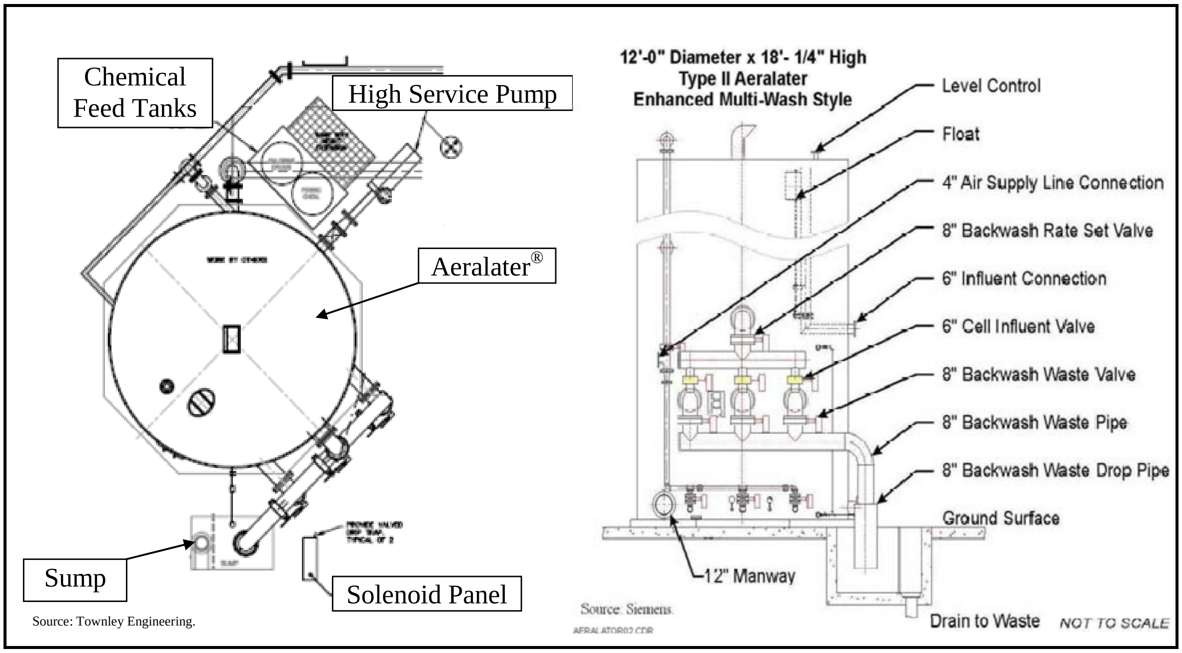

Figure 4-4. Layout and Schematic of Siemens' AERALATER® Unit

Figure 4-5. Treatment System Components

(Clockwise from Left: Inlet Piping from Wells; Air Diffuser Grid within Detention Tank; Influent Piping and Prechlorination Equipment; AERALATER® Unit with Detention Tank Effluent above Gravity Cell Influent; and Discharge Piping with Siphon Breaker to Sump)

Figure 4-6. Control Panel and Ancillary Equipment
(Clockwise from Top Left: Control Panel and VFD; Low Pressure Limit Switch and Head Loss Gauge; High Service Pump; Blower; Compressor; and Solenoid Panel)

- **Intake.** The well pumps were activated and deactivated based on water tower level setpoints. The system primarily treated water from Well No. 1, but also occasionally received water from Wells No. 3, 6, and 9. Influent (and effluent) flowrates and throughput were monitored using Siemens' Sitrans F Magflow flowmeters. The inlet piping from the wells into the building and the combined influent piping to the treatment system is shown in Figure 4-5.

- **Chlorine Addition.** A 12.5% NaOCl solution was injected to oxidize As(III) to As(V) and Fe(II) to Fe(III) in raw water. The chemical feed system included a 0.58-gal/hr (gph) LMI metering pump, a check valve, a 4-function anti-siphon pressure relief valve, suction tubing, a foot valve and a foot valve weight, discharge tubing, an injector check valve, and an LMI 50-gal polyethylene chemical day tank with cover (Figure 4-5). The pump was proportionally paced according to the influent flowrate. One calibration cylinder was included for direct dosage (in gph) measurements. The City also provided a drum scale and eye wash station at its own expense.

- **Iron Addition.** The natural iron in source water was at levels sufficient to effectively remove arsenic through coprecipitation with and adsorption onto the iron solids formed from chlorine addition. Nonetheless, a 0.42-gph LMI metering pump (with flow pacing capabilities), a check valve, a 4-function anti-siphon pressure relief valve, suction tubing, a foot valve and a foot valve weight, discharge tubing, an injector check valve, and an LMI 50-gal polyethylene chemical day tank for ferric sulfate ($Fe_2[SO_4]_3$) solution were available in case supplemental iron addition was required.

Table 4-5. Design Features of the AERALATER® System

Parameter	Value	Remarks
Pretreatment		
Chlorine Addition (mg/L [as Cl_2])	Field Determined	≥0.9 mg/L based on demand for As(III), Fe(II), and Mn(II) (Section 4.1.3)
Supplemental Iron Addition (mg/L)	0	Used only if needed
Detention		
Tank Size (ft)	12 D × 10.8 H	High water level at 9.8 ft
Volume (gal)	11,340	Includes volume of filter freeboard
Detention Time (min)	40	Based on average flowrate of 280 gpm
Filtration		
Filter Size (ft)	12 D × 7.3 H	Three cells in parallel with 1.6 ft underdrain
Filter Freeboard (ft)	3.7	–
Media Depth (ft)	2.0	Silica sand media
Surface Area (ft^2)	113	37.7 ft^2/cell
Media Volume (ft^3)	226	75.3 ft^3/cell
Peak Flowrate (gpm)	340	–
Average Flowrate (gpm)	280	Typically expected
Filtration Rate (gpm/ft^2)	2.5	Based on average flowrate of 280 gpm
Daily Production (gal)	489,600	Based on peak flowrate, 24 hr/day
Hydraulic Utilization (%)	53.5	Based on a daily demand of 262,000 gal
Backwash		
Duration (min)	45	15 min/cell
Flowrate (gpm)	280	–
Hydraulic Loading Rate (gpm/ft^2)	7.4	–
Air Wash (scfm)	75	2.0 scfm/ft^2
Wastewater Production (gal)	12,600	Per backwash for three filter cells
Frequency (gal)	650,000	Based on throughput (or 39 hr of run time)

D = diameter; H = height

- **Detention.** At 280 gpm, 12-ft-diameter by 10.8-ft-tall aluminum detention tank provided over 40 min of contact time to improve the formation of filterable iron flocs. The water level was monitored by a pressure transducer (Rosemount model 2088), which regulated the speed of the high service pump via a VFD (PumpSmart model PS75) connected to the control panel. A high level setpoint prevented overflow of the detention tank by signaling the well pump(s) to shut off. The detention tank had a 6-in inlet connection, an 18-in-diameter access manhole, and an air diffuser below the water surface. The purpose of the air diffuser grid was to further oxidize and mix the chlorinated water. Air supply to the diffuser was provided by a 15-hp, 340-standard-ft^3/min (scfm) positive displacement blower (Unimac model SB4L-15). Figure 4-5 shows photographs of the detention tank and air diffuser grid, and Figure 4-6 shows the VFD and blower.

- **Gravity Filtration.** A 6- and 8-in piping manifold on the front of the unit transferred water from the detention tank to the 12-ft-diameter, 7.3-ft-tall aluminum General Filter MULTIWASH gravity filter with aluminum plate underdrains. Three cells arranged in parallel contained 24 in or 75.3 ft^3 (per cell) of silica sand and provided a total filtration area of 113 ft^2. The filter had a 6-in effluent connection to a 25-hp, centrifugal high service pump (Gould model 3656M [Figure 4-6]) sized for 340 gpm at 130 ft TDH, which pressurized the treated water for distribution. During normal system operation with all three cells in-service, a 280-gpm flowrate provided a filtration rate of 2.5 gpm/ft^2.

- **Backwash.** During the filtration process, solids were collected in the filter cells, resulting in head loss across the filter. Backwash could be initiated manually, semiautomatically, or automatically based on a throughput or a day and time setpoint. A low pressure limit switch (USFilter model 10-in Hg) connected to the underdrain also provided added protection to shut down the high service pump and signal an alarm if a backwash was overdue. An air compressor pack consisting of two 1-hp, 5.0-scfm air compressors (Quincy model QC01006DD [Figure 4-6]) with an alternating starter panel actuated the pneumatic valves (Bray series 92/93) during the backwash sequence. Each filter cell was backwashed in succession with water produced by the other two in-service filter cells and received an air wash from the blower. The resulting wastewater was sent to a backwash waste sump with a V-notch weir board for flowrate indication and then to the sanitary sewer through 8-in-diameter schedule 40 steel piping (Figure 4-5).

4.3 Treatment System Installation

This section provides a summary of the system installation, startup, and shakedown activities and the associated prerequisites including permitting and building construction.

4.3.1 System Permitting. The complete engineering package including civil, architectural, structural, mechanical, and electrical plans for the water treatment plant was prepared according to the Ten States Standards by Townley Engineering, LLC (TE). The plans detailed connections of the AERALATER® systems from the inlet piping and to the City's water distribution and sanitary sewer systems. In addition, system general arrangement, electrical and mechanical drawings, and component specifications were provided by Siemens for inclusion in the package. Extensive communications among Siemens, TE, the City, and Battelle ensured that accurate contract documents existed for proper fabrication and installation of the equipment. Siemens accommodated all necessary adjustments to the standard AERALATER® design, such as system orientation, air piping elevation, and chemical feed equipment. The submittal was certified by a Professional Engineer registered in the State of Michigan and submitted to MDEQ for review and approval on August 5, 2005. After MDEQ's review comments were addressed, the package was resubmitted on August 29, 2005, and a water supply construction permit was issued by MDEQ on September 7, 2005. System fabrication began shortly thereafter.

4.3.2 Building Construction. A building construction permit was issued by Sanilac County on November 8, 2005. After receiving funding from USDA Rural Development on November 16, 2005, the City began and completed its building construction on November 21, 2005 and March 1, 2006, respectively. The 60 ⅔-ft × 31 ▯-ft building provided ample space to house three 12-ft diameter AERALATER® units and included one 12-ft × 42 ⅔-ft annex divided into a generator room and a blower/compressor room. Sidewall and roof peak heights were 19 ▯ and 27 ½ ft, respectively. A section of 16 ⅔-ft-wide removable panel enabled ease of equipment placement and installation. The footing was 52 in deep. The concrete floor in the building was 4 in thick with a 16-in thick reinforced concrete pedestal atop compacted sand backfill beneath the AERALATER® units. A 4 ft × 2 ½ ft × 2 ¾ ft sump (one for each unit) fed two 3,100-gal precast concrete equalization tanks that emptied into the sanitary sewer to facilitate wastewater discharge. Figure 4-7 shows the new treatment plant building. In addition to electrical and plumbing connections, a phone line also was installed to enable the vendor to dial into the modem in the control panel for any troubleshooting.

4.3.3 System Installation, Startup, and Shakedown. The AERALATER® unit and all ancillary equipment were delivered to the site on February 16, 2006, and system installation began following the offloading (Figure 4-8). Two TE subcontractors, Franklin Holwerda Co. in Wyoming, MI, and Blank Electric Co. in Snover, MI, performed all mechanical and electrical work, respectively. Installation work included setting all equipment in place, installing the air diffuser and face piping manifold, hooking up

Figure 4-7. New Treatment Plant Building

Figure 4-8. Equipment Delivery and Unloading

the chemical feed systems, connecting the piping, and painting exposed piping. The issues encountered during system installation are summarized in Table 4-6.

In mid-April 2006, Siemens was on-site for system inspection and O&M training while TE and its subcontractors completed media loading, leak testing, and electrical continuity testing. The vendor added the following parameters/features to the OIP: (1) system run time, (2) volume of wastewater generated during backwash, and (3) blower control status with ability to toggle between operation for aeration and backwash or for backwash only. Startup and shakedown of the AERALATER® unit was completed from May 2 to 5, 2006. The common 8-in effluent PVC pipe for both units burst in mid-May and was replaced by TE and its subcontractors with 8-in ductile iron pipe. Although Well No. 1 was connected to the treatment system in late May 2006, it could not be used until after subsequent bacterial tests passed on June 13, 2006. The performance evaluation study began on June 14, 2006, when water supply by Well No. 1 commenced.

Battelle performed system inspection and training of three operators on sample and data collection from June 21 to 23, 2006. During this time, the replacement blower starter was installed, and the air wash flowrate was set during the course of a backwash by throttling the blower and/or adjusting the air wash rate set valve. Media loss coincided with the air wash flowrate from 40 to 100 scfm with negligible media loss occurring without air wash.

Table 4-6. Installation Issues Encountered

Issue Encountered	Remarks
Blower received not as specified	• Modifications required to add hand/off/auto (HOA) switches and transformers • Starter and air flow gauge replaced due to malfunction
Low pressure limit switch received not as specified (Figure 4-6)	• Model previously declined by City in lieu of non-mercury model still supplied • Issue never rectified by vendor
Blower piping modification desired by City (Figure 4-9)	• Piping installed according to engineering drawings, however, City opted to add an elevated loop before the 'T' to prevent backflow from detention tank or filter cells to blower • TE advocated change as preventative measure since blower would not be operating full-time as designed because of sufficient oxidation provided via prechlorination
Some equipment missing from original shipment	• Delays in completing installation work experienced • Remaining equipment eventually received on March 30, 2006 (1 ½ months later), and TE then able to finish installation work

Figure 4-9. Blower Piping Modification

Section 5.0 RESULTS AND DISCUSSION

5.1 System Operation

5.1.1 Service Operation. System operational parameters from June 14, 2006, through June 22, 2007, are tabulated and attached as Appendix A. The key parameters are summarized in Table 5-1. During this evaluation study, the EPA-funded AERALATER® system (Unit 1) treated approximately 61,833,000 gal of water. This throughput was 65% of the City's demand, based on flow totalizer readings for Unit 1 and compared to wellhead totalizer readings from the City's water production reports. The remainder of the flow was either treated by Unit 2 or did not require treatment. The daily demands for Unit 1 ranged from 74,000 to 346,000 gal and averaged 166,000 gal (Figure 5-1), equivalent to a utilization rate of 34% over the one-year study period. Well No. 1 was the primary well while Wells No. 3 and 6 also were used (Figure 5-2) due to water tower level setpoints for these wells (Section 4.1.4).

Chlorine addition ranged from 1.3 to 6.7 mg/L (as Cl_2) and averaged 2.5 mg/L (as Cl_2). The dosage was calculated based on daily NaOCl consumption (by weight) and system effluent totalizer readings. This dosage was significantly less than the theoretical dosage of at least 3.7 mg/L required to provide a free chlorine residual of 0.5 mg/L (as Cl_2) as discussed in Section 4.1.3. The implications of this dosage and other confounding data are discussed in Section 5.2.1.5. Iron addition was not required.

The system run time could not be determined because it could only be recorded based on the high service pump run time, which included the high service pump idling time. An incorrect VFD setting caused the pump to idle even when the treatment system was off. After being fixed, the VFD setting had to be changed back to the previous setting because the high service pump was unable to pump under increased pressure from the water tower after the level had been raised to accommodate increased demand. Therefore, system flowrates were tracked only by instantaneous readings on the effluent flow meter, which ranged from 49 to 316 gpm and averaged 163 gpm. This flowrate was significantly lower than the 280-gpm design flowrate (and capacity of Well No. 1), because the influent flow often needed to be split between Units 1 and 2. The corresponding detention time ranged from 36 to 231 min and averaged 69 min, and the corresponding filtration rate ranged from 0.4 to 2.8 gpm/ft^2 and averaged 1.4 gpm/ft^2.

Table 5-1. AERALATER® System Operational Parameters

Parameter	Value
Operational Period	06/14/06–06/22/07
Service Operation	
Throughput (gal)	61,833,000
Average Demand [Range] (gpd)	166,000 [74,000–346,000]
Average Flowrate [Range] (gpm)	163 [49–316]
Average Chlorine Dosage [Range] (mg/L [as Cl_2])	2.5 [1.3–6.7]
Average Detention Time [Range] (min)	69 [36–231]
Average Filtration Rate [Range] (gpm/ft^2)	1.4 [0.4–2.8]
Average Head Loss [Range] (ft H_2O)	1.5 [0.3–2.0]
Backwash Operation	
Frequency (time/week)	2–3
Flowrate (gpm)	280
Hydraulic Loading Rate (gpm/ft^2)	7.4
Duration (min)	21
Wastewater Produced (gal/event)	6,000

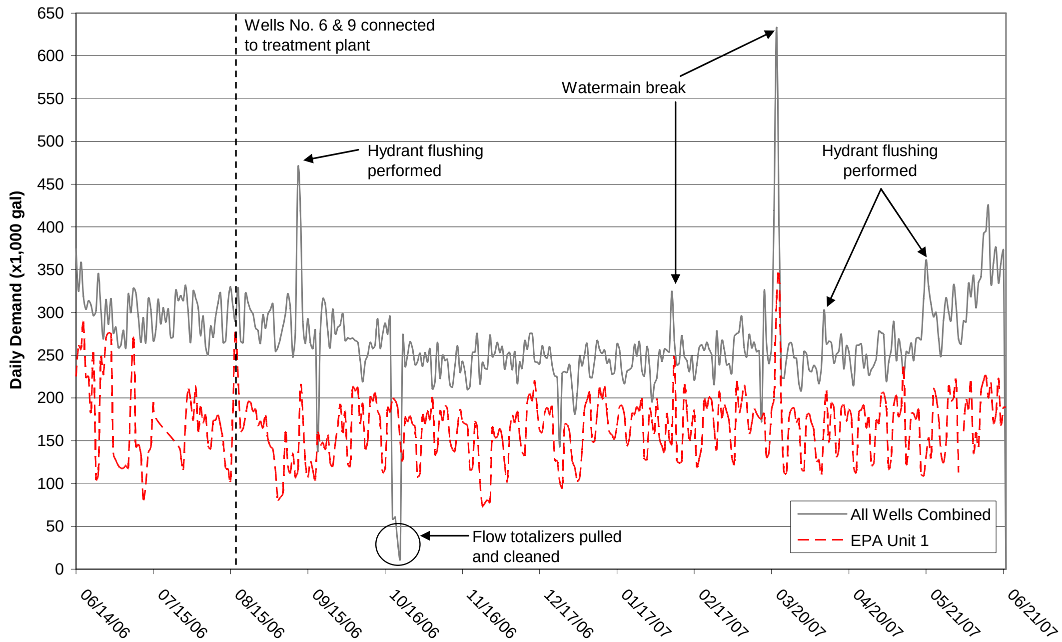

Figure 5-1. Daily Demand of AERALATER® System (Unit 1)

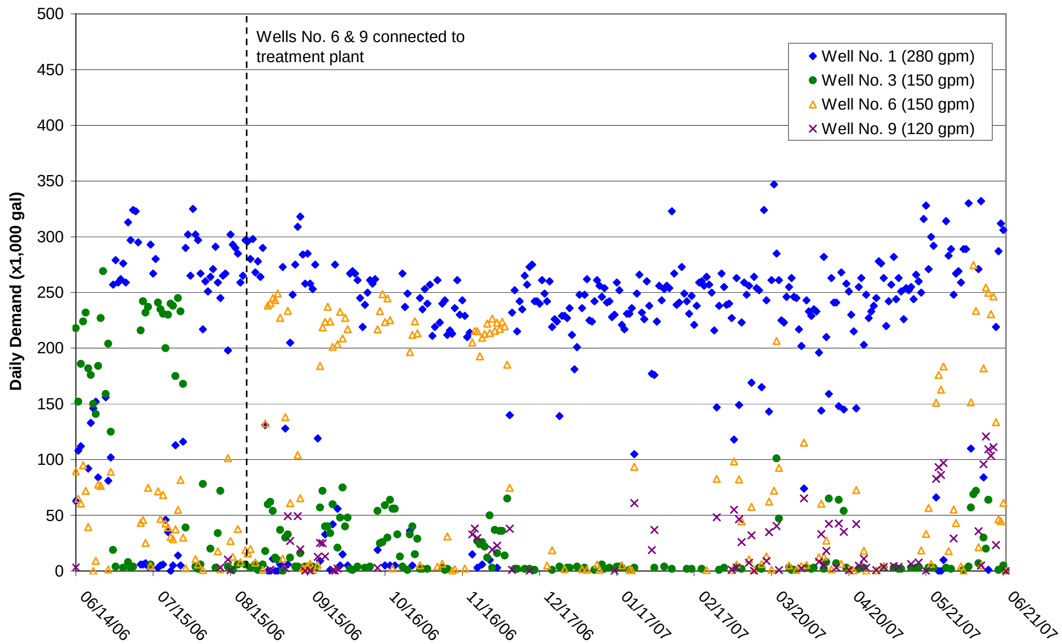

Figure 5-2. Daily Demand of Each Well by Both AERALATER® Units

The range of each of the parameters was inclusive of the respective design value shown in Table 4-5, but varied significantly based on the influent flowrates. Air supply from the blower to the diffuser, originally intended to provide constant aeration to the detention tank, was used only once a week to prevent the diffuser from becoming plugged because the iron in the feed water was oxidized with chlorine. Head loss across the filter varied from 0.3 to 2.0 ft of water (ft of H_2O) and did not increase noticeably between two consecutive backwash cycles.

5.1.2 Backwash Operation. The backwash settings are listed in Table 5-2. Initially, the system was automatically backwashed 3 time/week based on a day and time setpoint of Monday, Wednesday, and Friday mornings (exact time was adjusted periodically from 6:00 to 8:00 a.m.). Instead of using a throughput setting, the facility preferred to use this mode for backwash to ensure that an operator was on-site should any problem arise during backwash. This frequency corresponded to a throughput of 332,000 to 498,000 gal (or a filter run time of 34 to 51 hr [at an average flowrate of 163 gpm]) based on the average daily demand.

The throughput setpoint was temporarily increased to 1,200,000 gal from February 7 to 14, 2007, when a special study on filter run time (or backwash frequency) was performed. The purpose of the study was to determine if the above mentioned 3-time/week backwash frequency was adequate in terms of particulate arsenic and iron breakthrough in between two consecutive backwash events as discussed in Section 5.2.1.2. After the special study, the backwash frequency was reduced to 2 time/week (i.e., Tuesday and Thursday at 8:00 a.m.) on February 16, 2007. This frequency corresponded to a throughput of 498,000 to 664,000 gal and a filter run time of 51 to 68 hr at an average flowrate of 163 gpm based on the average daily demand. The design flowrate of 280 gpm and the design throughput of 650,000 gal (Table 4-5) corresponded to a 39-hr filter run time between two consecutive backwash events. Therefore, the initial backwash frequency agreed with the design filter run time between backwashes, and the revised backwash frequency agreed with the design throughput between backwashes. Manual backwashes also were occasionally initiated for testing and sampling of backwash water and solids (Section 5.2.2).

The backwash flowrate was controlled with a backwash rate set valve located on the face piping manifold. If the influent flowrate was below the 280-gpm setting when backwash was triggered, additional wells would be called upon by the PLC to attain sufficient flow prior to commencing backwash. Water levels in the floor sump also provided visual estimates for backwash flowrate according to heights on the V-notch weir board. The operator indicated that the water level in the sump was usually at or near a specified height corresponding to a flowrate of 280 gpm (or 7.4 gpm/ft^2). Each filter cell was backwashed in succession with water produced by the other two in-service filter cells for 7 min, including 5 min with water only followed by 2 min with air wash at 60 to 70 scfm and water to remove particulates. Approximately 6,000 gal of wastewater was produced during each backwash event, which was less than the design value due to the shorter backwash duration, i.e., 7 vs. 15 min/cell. Backwash appeared adequate to fully restore the filter cells for subsequent filter runs. Section 5.1.3 provides additional information on wastewater management.

Table 5-2. Settings for Backwash Operations

Parameter	Range	Factory Settings	Field Settings 06/14/06	Field Settings 02/16/07
Throughput Trigger (1,000 gal)	100–2,000	650	899[(a)]	1,200
Day and Time Trigger	Any	–	MWF 08:00	TR 08:00
Air Wash Start Delay Timer (sec/cell)	30–300	60	45	45
Backwash Duration (min/cell)	5–30	10	5	5
Backwash Flowrate (gpm)	0–340	NA	280	280
Air Purge Duration (min/cell)	1–50	2	2	2
Air Wash Flowrate (scfm)	0–340	NA	60–70	60–70
Blower Control Status[(b)]	AB or BO	NA	BO	BO

(a) Temporarily increased to 2,000,000 gal for special study from 02/07/07 to 02/14/07
(b) Ability to toggle between operation for aeration and backwash (AB) or backwash only (BO)
NA = not available

5.1.3 Residual Management. The only residual produced by the AERALATER® unit was backwash wastewater and solids. Wastewater from backwash was discharged to the building sump, which emptied to the sanitary sewer. Backwash water discharge was tracked by totalizing the volume of water passing through the influent flow meter during the backwash process. Approximately 855,000 gal of wastewater was generated as a result of this gravity filtration process. By reducing the backwash frequency from 3 to 2 time/week (Section 5.1.2), wastewater production decreased from approximately 1.6 to 1.0% of the treated water production.

5.1.4 Reliability and Simplicity of Operation. No system downtime occurred; however, some difficulties were encountered with the blower (Unimac model SB4L-15) and loss of head gauge (USFilter model), which are shown in Figure 4-6. The air wash provided by the blower occasionally fluctuated outside of the 60 to 70 scfm range. To make adjustments, the operator needed to climb a ladder to reach the set valve located below the 'T' in Figure 4-9. The loss of head gauge, which measures differential pressure (Δp) across the filter, could be improved with the use of a smaller scale (e.g., 0 to 10 ft of H_2O) and/or finer graduations. Five increments from 0 to 32 ft of H_2O with backwash required at about 8 ft of H_2O hinders readability and makes it difficult to monitor increases in head loss especially since readings ranged only from 0.3 to 2.0 ft of H_2O.

5.1.4.1 Pre- and Post-Treatment Requirements. Chlorine addition with a 12.5% NaOCl stock solution was used to oxidize As(III) and Fe(II) and to provide chlorine residuals within the distribution system. The operator tracked the consumption of the solution daily with a drum scale and measured chlorine residuals regularly with a Hach meter. Analytical results indicated that satisfactory arsenic removal was achieved without supplemental iron addition due primarily to the low levels of arsenic in raw water. No post-treatment was required; however, the facility chose to resume blended phosphate (25% ortho- and 75% poly-phosphate) addition in October 2006 for corrosion control.

5.1.4.2 System Automation. The AERALATER® unit was automatically controlled by the PLC in the control panel. The control panel contained a modem and a touchscreen OIP that enabled monitoring of system parameters, toggling the blower status, adjusting backwash setpoints, and checking the alarm status. The OIP was equipped to provide alarms for high service pump or blower failure, low or high detention tank level, backwash requirements (for manual or semiautomatic mode), and low underdrain pressure. Backwash was automatically initiated based on a day and time setpoint; however, it also could be semi-automatically initiated or manually conducted by operating the blower and individual valve function switches on the OIP. The PLC included control loops to ensure that the proper equipment, such as chemical feed and high service pumps, were operating concurrently with the system. In addition, electrode control programming for the level sensors in the detention tank enabled the well pump motor starters, the high service pump VFD, and the water tower's plant demand switch to maintain proper water levels in the detention tank.

5.1.4.3 Operator Skill Requirements. The daily demand on the operator was 30 to 45 min for visual inspection of the system, refilling the chlorine feed tank, and recording of operational parameters, such as volume, flowrate, and chemical usage on field log sheets. In Michigan, operator certifications are classified on a level of 1 (most complex) to 5 (least complex) (MDEQ, 2006). The primary operator was Limited Water Treatment Level 4 (D-4) and Water Distribution Level 3 (S-3) certified. After receiving proper training during system startup, the operator understood the PLC, knew how to use the touch-screen OIP, and was able to work with the vendor to troubleshoot and perform minor on-site repairs.

5.1.4.4 Preventative Maintenance Activities. The vendor recommended routine maintenance activities as provided by the equipment manufacturers to prolong the integrity of the treatment system components within its comprehensive O&M manual (Siemens, 2006). Such tasks included checking and changing lubrication, replacing worn parts, seals, and gaskets, and cleaning instrumentation as prescribed.

5.1.4.5 Chemical Handling and Inventory Requirements. The operator tracked the 12.5% NaOCl usage daily, coordinated the solution supply through Elkhorn Chemical, and refilled the day tank every 1 to 2 weeks. The solution did not require any dilutions and was usually supplied in 30-gal drums. The facility provided an emergency eye wash and shower station for safety measures.

5.2 System Performance

5.2.1 Treatment Plant Sampling. The treatment plant water was sampled on 54 occasions including four duplicate events and 13 speciation events during this evaluation study. Table 5-3 summarizes the analytical results for arsenic, iron, and manganese. Table 5-4 summarizes the results of the other water quality parameters. Appendix B contains a complete set of analytical results. The results of the water samples collected throughout the treatment plant are discussed below.

5.2.1.1 Arsenic. Figure 5-3 shows total arsenic concentrations measured across the treatment train and Figure 5-4 presents the results of 13 speciation events. Total arsenic concentrations in source water fluctuated significantly from 7.3 to 23.5 μg/L, due, in part, to the operation of different wells (i.e., Wells No. 1, 3, 6, and 9) throughout the study. However, even while operation of only one well was confirmed

Table 5-3. Summary of Arsenic, Iron, and Manganese Results

Parameter	Location	Sample Count	Concentration (μg/L)			Standard Deviation
			Minimum	Maximum	Average	
As (total) (Figures 5-3 and 5-4)	IN	54	7.3	23.5	11.4	3.5
	AD	54	7.4	21.6	11.3	3.5
	TT	54	0.4	9.8	2.4	1.8
As (soluble)	IN	13	7.3	18.4	9.8	2.8
	AD	13	1.3	4.5	2.1	0.9
	TT	13	0.9	4.5	1.9	1.0
As (particulate) (Figure 5-4)	IN	13	0.2	8.7	2.2	2.3
	AD	13	6.3	19.5	8.7	3.4
	TT	13	<0.1	0.3	<0.1	0.1
As(III) (Figure 5-4)	IN	13	6.0	18.9	8.7	3.3
	AD	13	<0.1	3.2	0.8	0.9
	TT	13	<0.1	3.2	0.9	0.9
As(V) (Figure 5-4)	IN	13	<0.1	1.8	1.2	0.5
	AD	13	1.0	1.7	1.3	0.2
	TT	13	0.6	1.5	1.0	0.3
Fe (total) (Figure 5-5)	IN	54	236	3,214	896	419
	AD	54	239	1,951	858	291
	TT	54	<25	617	61.0	135
Fe (soluble)	IN	13	610	990	785	112
	AD	13	<25	<25	<25	-
	TT	13	<25	<25	<25	-
Mn (total) (Figures 5-7 and 5-8)	IN	54	21.6	30.6	25.4	1.9
	AD	54	21.1	35.6	25.9	2.4
	TT	54	<0.1	30.8	11.7	8.1
Mn (soluble)	IN	13	23.5	35.6	27.6	3.1
	AD	13	6.3	23.5	15.6	5.9
	TT	13	2.1	20.9	12.4	7.2

One-half of detection limit used for nondetect results and duplicate samples included for calculations.

Table 5-4. Summary of Other Water Quality Parameter Results

Parameter	Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as $CaCO_3$)	IN	mg/L	54	293	350	319	13.3
	AD	mg/L	54	295	350	320	12.3
	TT	mg/L	54	293	346	320	12.9
Ammonia (as N)	IN	mg/L	13	0.1	0.5	0.3	0.1
	AD	mg/L	13	0.1	0.4	0.2	0.1
	TT	mg/L	13	0.1	0.4	0.2	0.1
Fluoride	IN	mg/L	13	0.4	3.4	0.9	0.8
	AD	mg/L	13	0.5	1.8	0.8	0.4
	TT	mg/L	13	0.5	1.9	0.8	0.4
Sulfate	IN	mg/L	13	80	105	96	7.3
	AD	mg/L	13	89	107	97	5.8
	TT	mg/L	13	76	118	97	9.7
Nitrate (as N)	IN	mg/L	13	<0.05	<0.05	<0.05	-
	AD	mg/L	13	<0.05	0.07	<0.05	0.0
	TT	mg/L	13	<0.05	<0.05	<0.05	-
Phosphorus (as P)	IN	μg/L	54	<10	27.0	<10	4.1
	AD	μg/L	54	<10	29.7	<10	4.2
	TT	μg/L	54	<10	25.4	<10	3.1
Silica (as SiO_2)	IN	mg/L	54	11.2	13.5	12.0	0.5
	AD	mg/L	54	11.2	13.9	12.0	0.5
	TT	mg/L	54	10.0	13.8	11.8	0.6
Turbidity	IN	NTU	54	2.1	17.0	10.9	3.1
	AD	NTU	54	0.5	9.9	1.6	1.4
	TT	NTU	54	<0.1	3.4	0.7	0.6
TOC	IN	mg/L	12	<1.0	1.3	<1.0	0.3
	AD	mg/L	12	<1.0	1.3	1.0	0.3
	TT	mg/L	12	<1.0	1.1	<1.0	0.3
pH	IN	S.U.	50	6.4	7.7	7.2	0.2
	AD	S.U.	50	7.0	7.7	7.2	0.1
	TT	S.U.	50	7.1	7.6	7.2	0.1
Temperature	IN	°C	50	9.7	13.3	11.9	0.6
	AD	°C	50	10.2	13.1	11.4	0.5
	TT	°C	50	10.2	16.2	11.7	0.9
DO	IN	mg/L	50	0.8	3.7	1.7	0.6
	AD	mg/L	50	1.3	4.2	2.7	0.6
	TT	mg/L	50	1.3	5.6	2.6	0.7
ORP	IN	mV	49[a]	248	406	303	32.5
	AD	mV	50	284	552	364	71.8
	TT	mV	50	274	566	351	83.5
Free Chlorine (as Cl_2) (Figure 5-8)	AD	mg/L	50	0.1	2.3	0.5	0.5
	TT	mg/L	50	0.1	3.1	0.6	0.7
Total Chlorine (as Cl_2) (Figure 5-8)	AD	mg/L	47	1.1	4.6	2.8	0.8
	TT	mg/L	47	1.2	4.7	2.7	0.9
Total Hardness (as $CaCO_3$)	IN	mg/L	13	328	436	387	30.5
	AD	mg/L	13	330	431	392	29.1
	TT	mg/L	13	331	432	395	27.4

Table 5-4. Summary of Other Water Quality Parameter Results (Continued)

Parameter	Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Ca Hardness (as $CaCO_3$)	IN	mg/L	13	196	300	259	29.8
	AD	mg/L	13	198	297	261	28.5
	TT	mg/L	13	198	295	263	29.4
Mg Hardness (as $CaCO_3$)	IN	mg/L	13	112	142	128	9.3
	AD	mg/L	13	121	148	130	7.9
	TT	mg/L	13	119	141	132	7.5

(a) One outlier (i.e., 2.6 mV on 08/08/06) omitted
One-half of detection limit used for nondetect results and duplicate samples included for calculations.

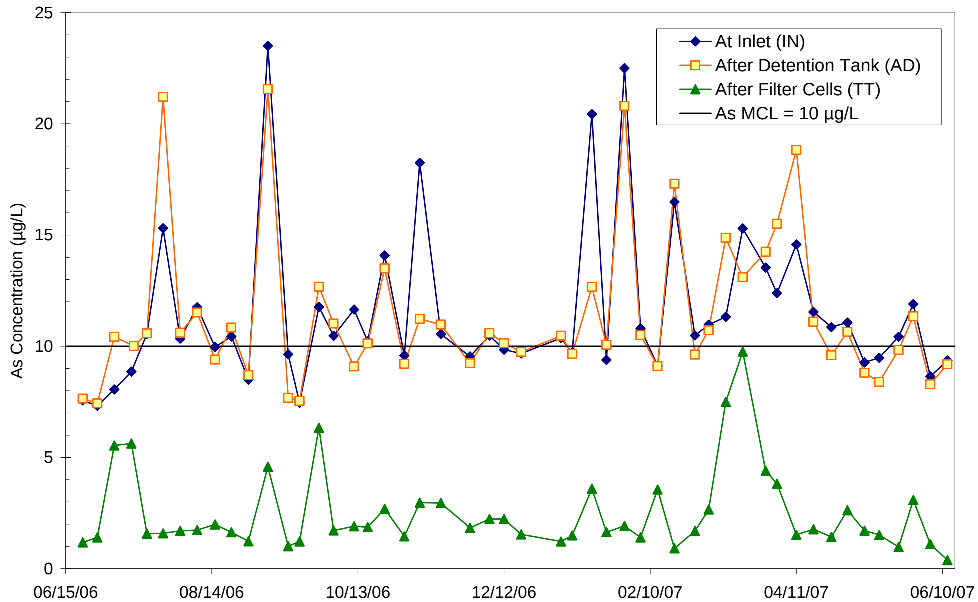

Figure 5-3. Total Arsenic Concentrations Across Treatment Train

over several weeks, no discernable trends were apparent. Source water arsenic concentrations ranged from 7.3 to 23.5 µg/L and averaged 11.4 µg/L with 2.2 µg/L existing in the particulate form and 9.8 µg/L in the soluble form. The soluble arsenic consisted of 8.7 µg/L of As(III), the predominant arsenic species, and 1.2 µg/L of As(V). The range of total arsenic concentrations measured during this one-year study period was lower than that of previous results for Well No. 1 (Table 4-1).

Following the detention tank, the average total arsenic concentration remained the same at 11.3 µg/L with 8.7 µg/L existing in the particulate form and 2.1 µg/L in the soluble form (including 0.8 µg/L of As[III] and 1.3 µg/L of As[V]). The decrease in As(III) and increase in particulate arsenic after prechlorination and detention indicated oxidation of As(III) and subsequent coprecipitation/adsorption of As(V) with/onto the iron solids also formed upon chlorination. As much as 3.2 µg/L of As(III), however, was observed following detention, indicating incomplete oxidation caused, presumably, by the presence of ammonia. As(III) most likely was oxidized initially by free chlorine before free chlorine reacted with ammonia to form chloramines (Frank and Clifford, 1986). Ghurye and Clifford (2001) reported that only limited As(III) oxidation occurred due to the presence of monochloramine formed *in situ*.

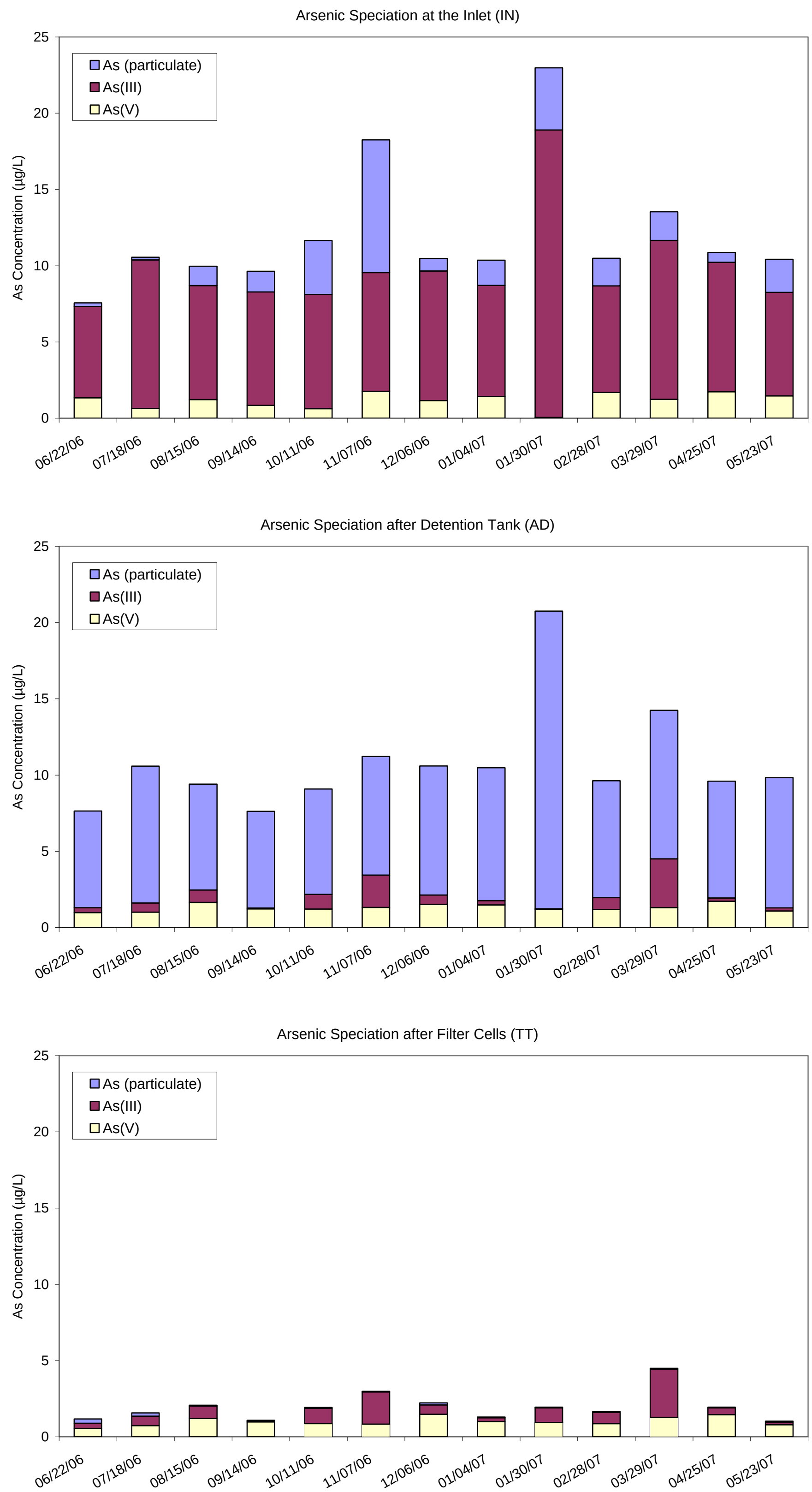

Figure 5-4. Arsenic Speciation Results at Inlet (IN), After Detention Tank (AD), and after Filter Cells (TT)

Total arsenic concentrations after gravity filtration ranged from 0.4 to 9.8 µg/L and averaged 2.4 µg/L. Based on average influent results, the ratio of soluble iron to soluble arsenic was 80:1, which was more than adequate compared to the rule of thumb ratio of 20:1 for effective arsenic removal.

5.2.1.2 Iron. Figure 5-5 presents total iron concentrations measured across the treatment train. Similarly to arsenic concentrations, source water iron concentrations also fluctuated significantly, ranging from 236 to 3,214 µg/L. Total iron concentrations in source water averaged 896 µg/L, existing primarily in the soluble form with an average concentration of 785 µg/L. Maximum iron concentrations coincided with maximum arsenic concentrations and were seen in Well No. 1 water. According to historical results presented in Table 4-3, highest arsenic and iron concentrations were expected in Well No. 3 water. Well No. 6 water contained the lowest iron concentrations, which were lower than historical ranges. Well No. 9 water, however, might have even lower concentrations, but samples were not collected during periods of its operation. Even at lower-than-expected influent iron concentrations, arsenic removal was not impacted due mainly to the relatively low levels of arsenic observed in source water.

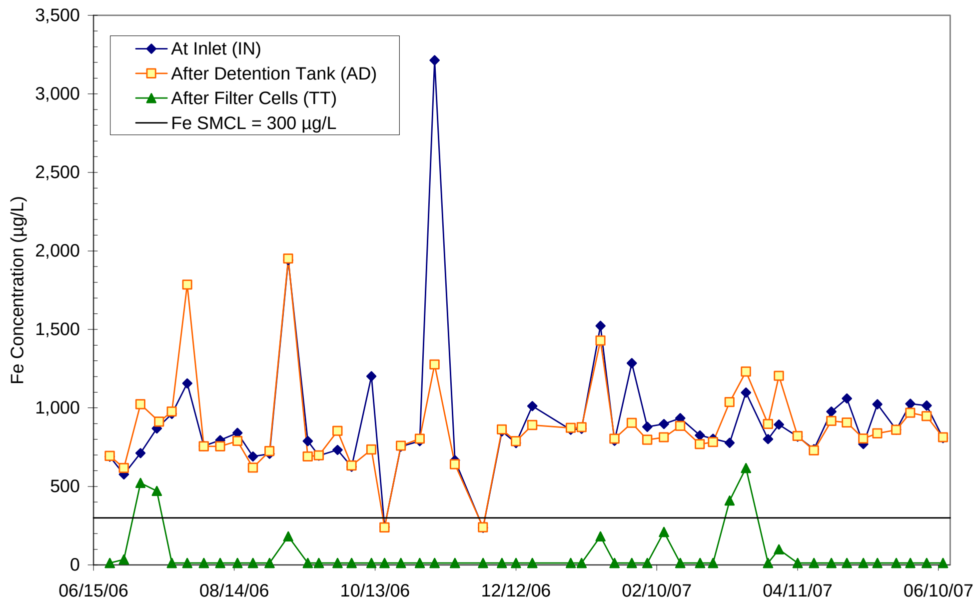

Figure 5-5. Total Iron Concentrations Across Treatment Train

The treated water contained low iron concentrations, mostly below the method reporting limit of 25 µg/L. Considerable breakthrough of iron occurred on eight occasions with concentrations ranging from 99 to 617 µg/L. Four of these occasions had concentrations above the 300-µg/L secondary maximum contaminant level (SMCL). All soluble iron concentrations were <25 µg/L after chlorine addition, detention, and filtration. The presence of chloramines apparently did not affect complete oxidation of Fe(II).

As part of a special study, an extended filter run was conducted from February 7 to 14, 2007, to determine the extent of particulate arsenic and iron breakthrough during the run. Nine samples were collected in 113 hr (Figure 5-6) as 1,139,000 gal of water was treated. Except for two samples taken at 97.1 and 98.7 hr, concentrations of arsenic and iron in the filter effluent, including the one taken at 113 hr just before the end of the run, were consistently below 3 and 90 µg/L, respectively. Further, six of the nine samples,

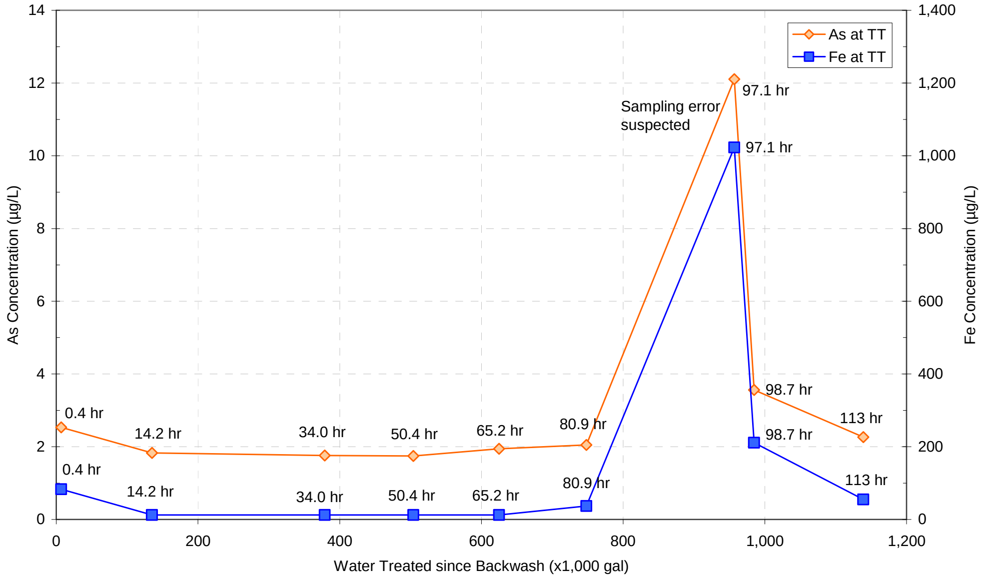

Figure 5-6. Total Arsenic and Iron Concentrations During Special Study

including the one taken at 113 hr, had iron concentration either near or below the method reporting limit of 25 µg/L. The anomalous results for the sample collected at 97.1 hr were thought to have been caused by a sampling error because the results were more characteristic of source water than treated water. Regardless of the anomaly, the filter cells were able to operate for at least 80 hr or 750,000 gal of throughput without having significant arsenic and iron breakthrough. These results confirmed that the backwash frequency could be reduced to once every 498,000 to 664,000 gal or 51 to 68 hr as discussed in Section 5.1.2.

5.2.1.3 Manganese. Figure 5-7 presents total manganese concentrations measured across the treatment train. Total manganese concentrations in source water ranged from 21.6 to 30.6 µg/L and averaged 25.4 µg/L, which existed entirely in the soluble form. After chlorine addition and detention, total manganese concentrations remained essentially unchanged although over 40% (on average) turned into particulates. The particulates formed were completely removed by the filter, leaving 11.7 µg/L soluble manganese in the filter effluent.

Careful examination of the manganese results revealed that the amounts of particulate manganese formed and then removed by the filter followed rather closely with the amounts of total chlorine residuals in the treated water. Higher total chlorine residuals apparently led to faster oxidation kinetics for Mn(II), enabling more particulates to be formed and then removed by the filter. The manganese removal rates were close to or over 90% in 10 occasions with corresponding total chlorine residuals at approximately 3 to 4.5 mg/L (as Cl_2), and close to or less than 30% in 11 occasions with corresponding total chlorine residuals at approximately 1.5 to 2.0 mg/L (as Cl_2). At 3 to 4.5 mg/L (as Cl_2), some free chlorine might have become available to react with Mn(II) even with the presence of ammonia (see discussion in Section 5.2.1.5). Conversely, at 1.5 to 2.0 mg/L (as Cl_2), residuals were present only as chloramines, which were not effective in oxidizing Mn(II). Even in the absence of ammonia, previous studies have shown that incomplete oxidation of Mn(II) occurred using free chlorine at pH values less than 8.5 (Knocke et al., 1987 and 1990; Condit and Chen, 2006). Filtration media (such as sand and Macrolite®) removed manganese only if it was present as filterable particles; any soluble and unfilterable solids, such as colloidal particles, would be left untreated in the filter effluent.

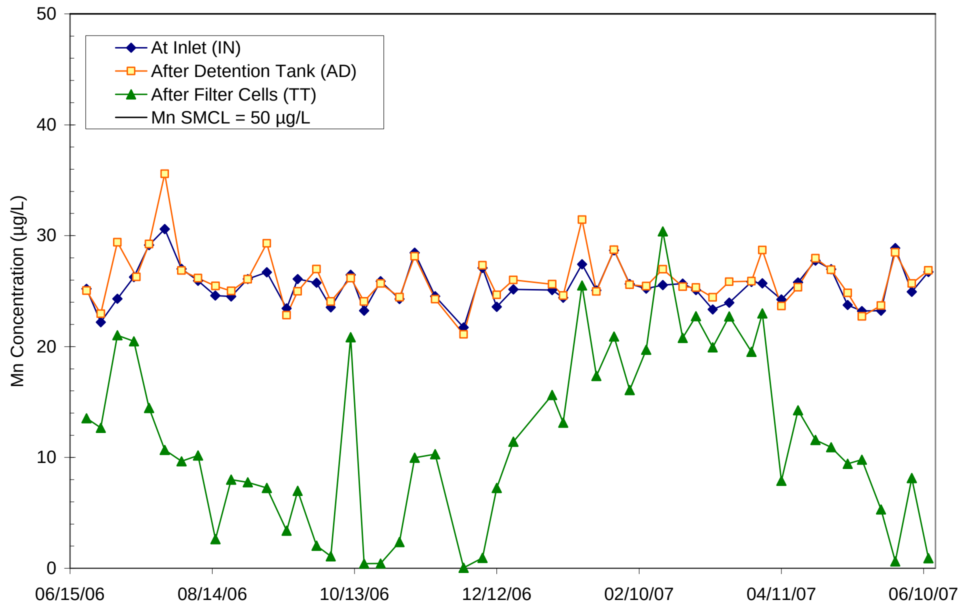

Figure 5-7. Total Manganese Concentrations Across Treatment Train

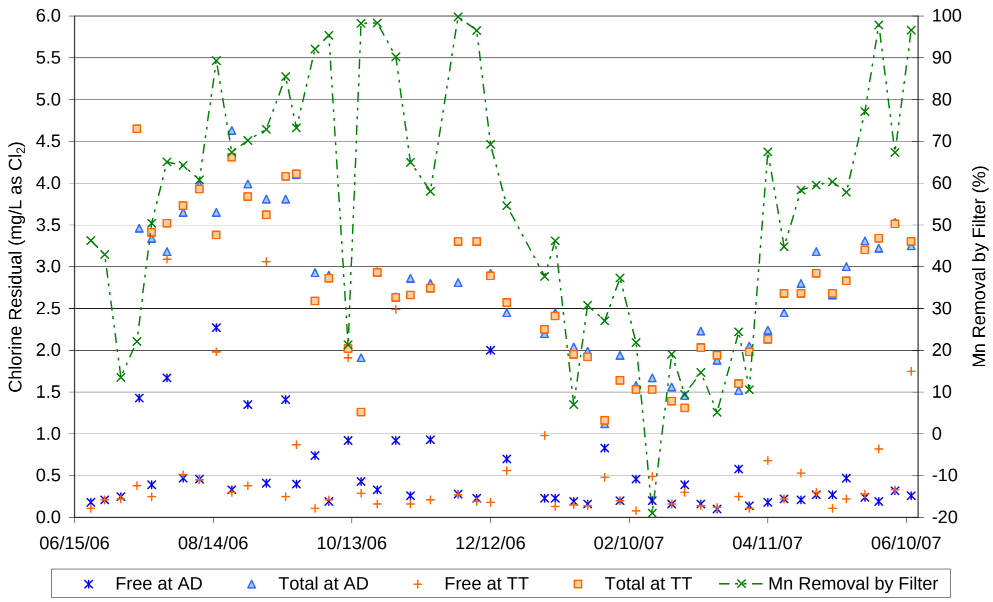

Figure 5-8. Chlorine Residuals and Manganese Removal

5.2.1.4 pH, DO, and ORP. pH values of source water ranged from 6.4 to 7.7 and averaged 7.2. This range was comparable to those obtained by Battelle during sampling of Well No. 1 water on September 1, 2004 (i.e., 6.9 and 7.2 [Table 4-1]). Average DO levels at the inlet were relatively low at 1.7 mg/L, and then increased slightly to 2.7 mg/L after the detention tank. Although the air diffuser grid was used only once a week to prevent plugging, some aeration did occur as raw water entered the detention tank. As a result of chlorine addition and some aeration, average ORP levels increased from 303 mV in source water to 364 mV after the detention tank. DO and ORP readings in source water were much higher than those measured by Battelle on September 1, 2004 (i.e., 0.5 mg/L and -62 mV, respectively). Some source water samples might have been partially aerated during sampling.

5.2.1.5 Chlorine and Ammonia. Ammonia concentrations ranged from 0.1 to 0.5 mg/L (as N) across the treatment train and averaged 0.3 mg/L (as N) at the inlet and 0.2 mg/L (as N) after detention and after filtration. Judging by the amount of total chlorine residuals measured after detention and after filtration (see discussion below), ammonia should have been completely oxidized. The reporting limit for ammonia was 0.1 mg/L (as N), which was very close to the average amount (i.e., 0.2 mg/L) measured after chlorine addition and filtration.

Free and total chlorine residuals measured after the detention tank and after the filter cells are presented in Figure 5-8. As shown in the figure, data for total and, especially, free chlorine residuals were widely scattered from 1.1 to 4.7 (2.7 on average) and from 0.1 to 3.1 (0.5 on average) mg/L (as Cl_2), respectively. Because only 2.5 mg/L (as Cl_2) of NaOCl (on average) had been added to raw water (Section 5.1.1), it suggested that the concentrations measured might have been somewhat higher than the actual concentrations.

Considering that 2.5 mg/L (as Cl_2) of NaOCl was applied to raw water, 0.5 mg/L (as Cl_2) would have reacted with As(III), Fe(II), and Mn(II) based on the average amounts (i.e., 8.7, 785, and 27.6 µg/L, respectively) present in raw water (Table 5-3), and 2.0 mg/L (as Cl_2) would have reacted with 0.3 mg/L (as N) of ammonia to form 2.0 mg/L (as Cl_2) of combined chlorine. As such, no free chlorine residuals should have been formed. This seems to be supported by the majority of free chlorine data, which showed no more than a few tenths of mg/L (as Cl_2) and were very close to the MDL of 0.1 mg/L (as Cl_2).

5.2.1.6 Other Water Quality Parameters. Alkalinity, fluoride, sulfate, nitrate, phosphorus, silica, TOC, temperature, and hardness levels remained consistent across the treatment train and were not affected by the treatment process (Table 5-4). Average turbidity decreased from 10.9 to 0.7 NTU with treatment via the removal of particulates.

5.2.2 Backwash Water and Solids Sampling. Table 5-5 presents the analytical results of the backwash water samples along with the minimum, average, and maximum of each parameter for all three cells combined. The pH, TDS, and total suspended solids (TSS) values of backwash water ranged from 6.7 to 7.8, from 664 to 784 mg/L, and from 52 to 232 mg/L, respectively. The average pH value of backwash water (i.e., 7.6) was somewhat higher than that across the treatment train (i.e., 7.2). Concentrations of total arsenic, iron, and manganese averaged 0.5, 58, and 1.1 mg/L, respectively, with the majority exisiting as particulate. Applying the average iron, manganese, and arsenic results, approximately 2.92 lb of iron, 0.05 lb of manganese, and 0.02 lb of arsenic would have been produced and discharged in 6,000 gal of backwash wastewater during each backwash cycle.

Solids loading to the sanitary sewer system was further monitored through collection of backwash solids (Section 3.3.5). The analytical results of solid samples collected in October 2006 and May 2007 are presented in Table 5-6. Based on an average TSS concentration of 129 mg/L in backwash wastewater, approximately 3.5 lb of solids were produced per backwash. The iron, manganese, and arsenic compositions of 2.90 lb, 0.06 lb, and 0.02 lb, respectively, agreed well with the results derived from the water quality data. The calcium composition also was noteworthy at 0.42 lb or 12% of the total solids mass.

5.2.3 Distribution System Water Sampling. Table 5-7 summarizes the results of the distribution system samples. During the baseline sampling, the City was predominantly operating Wells No. 1, 6, 7, and 9 to meet its demand. Blended phosphate (85% ortho- and 15% poly-phosphate) also was added at 4 mg/L at the wellheads for iron sequestration and corrosion control. Once the wells were connected to

Table 5-5. Backwash Water Results

Sampling Event		Cell 1										Cell 2										Cell 3									
		pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)	pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)	pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)
No.	Date	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
1	06/28/06	7.7	718	232	702	3.1	699	199,191	48.7	1,355	16.2	7.6	742	190	524	3.3	521	72,171	77.2	1,003	17.1	7.6	714	172	485	3.3	482	77,198	80.3	932	17.0
2	07/26/06	7.5	756	156	420	2.2	418	53,399	<25	1,023	15.2	7.5	784	128	400	2.2	398	49,488	<25	946	11.0	7.5	770	88	326	2.1	324	39,039	<25	750	13.8
3	08/29/06	7.5	718	58	244	2.4	241	27,856	85.6	648	11.5	7.6	728	62	245	2.5	242	27,144	105	649	10.8	7.6	748	52	237	2.5	235	26,205	81.4	630	11.9
4	09/27/06	7.6	748	74	293	6.9	286	28,795	97.1	798	12.7	7.6	708	86	290	6.7	283	28,746	96.4	822	8.2	7.6	756	84	316	7.0	309	30,684	86.6	878	7.0
5	10/25/06	7.5	726	84	393	3.9	390	42,151	80.8	905	9.5	7.6	700	88	419	4.0	415	45,934	102	950	10.4	7.5	694	84	356	3.5	352	42,651	85.1	829	8.0
6	12/11/06	7.4	700	114	449	3.4	446	45,637	45.8	914	9.7	7.5	672	102	515	3.6	512	50,148	52.2	1,016	8.4	7.5	674	104	447	4.1	443	43,409	114	840	10.1
7	01/10/07	7.7	692	100	289	4.3	285	41,672	100	709	15.8	7.7	664	130	353	3.3	350	55,730	132	961	15.1	7.7	664	95	425	4.5	420	51,120	71.0	819	12.1
8	02/07/07	7.6	690	82	357	3.2	354	39,704	126	600	22.0	7.7	670	88	368	3.2	365	41,991	127	650	19.6	7.7	686	88	356	2.9	353	41,788	97.3	668	21.4
9	03/13/07	7.7	702	174	692	4.1	688	75,045	115	1,053	17.4	7.7	698	162	605	4.1	601	69,880	132	978	16.5	7.7	700	176	764	3.7	761	60,171	99.6	1,033	17.0
10	04/17/07	7.7	718	190	676	1.8	674	75,742	158	1,761	16.1	7.7	716	176	678	2.0	676	71,556	196	1,654	15.7	7.7	716	144	550	1.7	549	58,974	164	1,337	15.0
11	05/15/07	7.7	708	200	773	2.8	770	104,489	69.4	1,761	16.8	7.7	718	170	648	2.3	646	87,826	44.4	1,433	16.9	6.7	718	190	683	2.5	681	87,216	77.0	1,516	9.8
12	06/12/07	7.8	714	195	681	0.7	680	74,181	<25	2,043	1.7	7.7	680	180	628	1.0	627.0	68,945	<25	1,871	2.8	7.7	680	150	534	0.9	533	60,372	<25	1,648	2.8
Cells Combined		Minimum										Average										Maximum									
		6.7	664	52	237	0.7	235	26,205	<25	600	1.7	7.6	711	129	476	3.2	472	58,229	83.9	1,066	12.9	7.8	784	232	773	7.0	770	199,191	196	2,043	22.0

Table 5-6. Backwash Solids Results

Date: Filter	Mg	Al	Si	P	Ca	Fe	Mn	Ni	Cu	Zn	As	Cd	Pb	Ba
	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
10/25/06: Cell 1	6,430	1,258	225	1,267	89,293	449,254	10,172	9.4	22.5	203	3,792	<0.1	4.2	NA
10/25/06: Cell 2	5,550	1,205	330	1,299	66,304	465,579	9,861	11.1	19.0	198	3,779	<0.1	4.5	NA
10/25/06: Cell 3	6,225	1,168	197	1,260	68,137	435,348	9,353	8.3	49.7	243	3,505	<0.1	5.6	NA
Average	6,068	1,210	251	1,275	74,578	450,060	9,795	9.6	30.4	215	3,692	<0.1	4.8	NA
05/15/07: Cell 1	5,783	NA	307	973	55,766	443,670	7,735	NA	NA	NA	3,397	NA	NA	619
05/15/07: Cell 2	5,986	NA	370	882	54,850	445,184	7,570	NA	NA	NA	3,364	NA	NA	624
05/15/07: Cell 3	5,444	NA	155	902	57,620	450,860	7,981	NA	NA	NA	3,438	NA	NA	632
Average	5,738	NA	277	919	56,079	446,571	7,762	NA	NA	NA	3,399	NA	NA	625

NA = not available

Table 5-7. Distribution System Sampling Results

Sampling Event		DS1								DS2[a]								DS3[b]							
		LCR Residence								LCR Non-residence								LCR Residence							
		1st Draw								1st Draw								1st Draw							
		Stagnation Time	pH	Alkalinity (as $CaCO_3$)	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity (as $CaCO_3$)	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity (as $CaCO_3$)	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	02/23/05	10.5	7.5	270	6.3	168	9.4	0.3	113	8.5	7.9	225	8.8	149	3.2	0.4	272	7.0	7.8	225	9.0	63.3	4.3	0.7	224
BL2	03/22/05	8.5	7.8	333	5.0	587	14.9	0.9	152	11.8	7.7	311	6.5	235	13.8	0.2	159	7.0	7.5	320	8.2	138	5.5	1.1	265
BL3	04/26/05	8.8	7.2	326	7.7	534	19.7	5.6	57.3	14.8	7.4	330	8.2	530	27.7	0.5	253	8.0	7.5	286	6.6	186	3.6	2.2	349
BL4	06/01/05	9.0	7.2	312	9.5	1214	21.7	3.2	193	14.3	7.4	321	7.0	424	21.3	0.4	262	7.0	7.7	223	5.5	92.1	2.5	0.8	213
Baseline Average		-	7.4	310	7.1	626	16.4	2.5	129	-	7.6	297	7.6	335	16.5	0.4	236	-	7.7	264	7.3	120	4.0	1.2	263
1	07/13/06[c,d]	8.0	7.4	306	2.5	128	16.5	1.2	910	13.1	7.3	310	2.8	158	19.4	0.2	453	8.0	7.3	314	2.0	<25	16.0	1.0	491
2	08/08/06[d]	8.3	7.5	302	3.7	<25	13.9	1.0	418	14.5	7.5	302	3.6	<25	15.8	0.5	382	7.8	7.5	298	3.6	<25	15.3	1.1	473
3	09/06/06[d]	9.3	7.4	331	2.6	<25	5.1	0.1	406	14.6	7.4	335	2.8	<25	4.8	<0.1	324	7.8	7.3	326	2.8	<25	11.0	0.3	355
4	10/31/06	22.0	7.3	335	2.6	<25	4.1	<0.1	922	12.8	7.3	346	2.5	<25	5.4	<0.1	520	8.0	7.2	333	3.1	<25	0.5	0.1	275
5	11/29/06	9.0	7.3	314	3.1	<25	6.4	0.3	840	14.1	7.2	342	3.3	<25	4.9	0.1	505	7.0	7.4	320	4.0	<25	0.5	0.2	384
6	12/19/06	9.0	7.2	331	3.4	<25	4.2	<0.1	661	14.0	7.3	329	3.4	<25	7.8	<0.1	417	7.0	7.2	333	4.0	<25	0.2	0.2	299
7	01/18/07	7.3	7.5	339	3.2	<25	5.7	<0.1	758	14.1	7.4	328	2.8	<25	13.0	<0.1	499	8.0	7.5	322	3.9	<25	0.4	0.1	458
8	02/14/07[e]	7.0	7.4	320	6.0	268	8.7	1.3	877	10.5	7.4	320	5.5	142	12.1	0.3	330	7.5	7.4	322	4.0	<25	7.0	0.7	524
9	03/14/07	8.0	7.5	337	3.2	<25	15.5	<0.1	421	15.0	7.4	330	2.3	<25	3.4	0.6	414	7.5	7.5	335	3.5	<25	12.3	<0.1	152
10	04/11/07	8.3	7.4	324	3.0	<25	8.2	<0.1	633	10.5	7.4	324	3.7	<25	5.2	<0.1	235	7.0	7.4	324	2.6	<25	18.0	0.5	559
11	05/09/07	7.8	7.4	317	4.9	<25	6.7	<0.1	222	14.5	7.4	314	4.0	49.0	9.2	0.1	515	7.0	7.5	321	3.9	145	4.7	1.5	464
12	06/13/07	8.0	7.5	320	1.5	<25	1.3	<0.1	507	14.6	7.5	313	1.8	<25	1.2	<0.1	177	6.5	7.5	309	1.4	<25	3.8	<0.1	261
Average		-	7.4	323	3.3	43.4	8.0	0.4	631	-	7.4	324	3.2	38.4	8.5	0.2	398	-	7.4	321	3.2	<25	7.5	0.5	391

(a) BL1 collected from different location with water softener present
(b) Water softener present at this location
(c) Fe and As treatment plant results also elevated for 07/12/06 possibly due to inadequate backwash
(d) No phosphate addition to treated water exiting treatment plant
(e) Elevated As and Fe possibly due to extended filter run length for special breakthrough study
Note: lead action level = 15 µg/L; copper action level = 1.3 mg/L; BL = baseline sampling; NA = not available

the treatment plant and treatment commenced in June 2006, Well No. 1 was primarily used without phosphate addition. Beginning in October 2006, post-treatment using blended phosphate (25% ortho- and 75% poly-phosphate) resumed for corrosion control at 1 to 2 mg/L.

Average arsenic concentrations improved from 7.1 to 7.6 μg/L at baseline to 3.2 to 3.3 μg/L after the system startup and similarly for average iron concentrations from 120 to 626 μg/L to <25 to 43.4 μg/L at the three locations. Alkalinity and pH increased and decreased, respectively, at DS2 and DS3 compared to baseline levels. Lead and manganese concentrations did not show any apparent trends; average copper concentrations increased from 129 to 263 μg/L to 391 to 631 μg/L. Explanations for this increase are not apparent due to uncertainties of water sources during baseline sampling and changes to the post-treatment chemicals. The water in the distribution system was comparable to that of the treatment system effluent for arsenic and iron, so the treatment system appeared to have beneficial effects on these parameters since they decreased significantly.

5.3 Building and System Cost

5.3.1 Building Cost. A 60 ⅔-ft × 31 □-ft building with sidewall and roof peak heights of 19 □ and 27 ½ ft, respectively, was constructed by the City to house the treatment system and provide space for two additional systems to meet the State's firm capacity requirements and the City's future expansion needs (Section 4.3.2). The total cost for the building construction, site improvements (including sanitary sewer service and holding tanks), water system telemetry, well connections (to the treatment systems) and improvements, and Unit 2 installation, was $663,654, which reflects some price escalation resulting from the aftermath of hurricane Katrina. This cost was not included in the capital cost or used to evaluate the system cost because the work was outside of the scope of this demonstration project and funded separately by the City.

5.3.2 System Cost. The system cost was evaluated based on the capital cost per gpm (or gpd) of design capacity and the O&M cost per 1,000 gal of water treated. The total capital investment cost for the AERALATER® unit was $364,916 consisting of $330,374 (from EPA) for the proposed 10-ft diameter unit plus $34,542 (from the City) for upgrade to the 12-ft diameter unit (Table 5-8). The equipment cost of $205,800 (or 56% of the total) included cost for the detention tank and three-cell filter, process valves and piping, 157 ft^3 of sand, two chemical feed systems, an air diffuser grid and other ancillary equipment, instrumentation and controls, labor, and freight. The system warranty was also included in the cost, which covered repair and replacement of any defective components for one year after system startup.

The engineering cost covered the cost for preparing the required system permit application submittal, including system general arrangement, electrical and mechanical drawings, component specifications, connections to the entry piping and the City's water distribution and sanitary sewer systems, and obtaining the required approval from MDEQ. The engineering cost of $27,077 was 7% of the total capital investment.

The installation, shakedown, and startup cost covered the labor and materials required to unload, install, paint, and test the system for proper operation. All installation activities were performed by Franklin Holwerda Co. and Blank Electric Co., both subcontracted to TE. All startup and shakedown activities were performed by Siemens, TE, and TE's subcontractors with the operator's assistance. The installation, startup, and shakedown cost of $132,039 was 36% of the total capital investment.

The total capital cost of $364,916 was normalized to $1,073/gpm ($0.75/gpd) of design capacity using the system's rated capacity of 340 gpm (or 489,600 gpd). The capital cost also was converted to a unit cost of $0.19/1,000 gal using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate, a 20-yr return period, and full-time system operation at the rated capacity. Since the system produced only 60,292,000 gal of water during the first year, the total unit cost increased to $0.57/1,000 gal.

Table 5-8. Capital Investment for Siemens' AERALATER® System

Description	Cost	% of Capital Investment Cost
Equipment		
Detention Tank and Filter Cells	$64,100	–
Process Valves, Piping, and Air Diffuser Grid	$13,431	–
Silica Sand Media (157 ft^3)	$883	–
Instrumentation and Controls	$44,882	–
High Service Pump, Compressor Pack, and Blower	$11,435	–
Chemical Feed Systems	$2,314	–
Sample Taps and Totalizers/Meters	$1,571	–
Siemens' Labor	$34,978	–
Freight	$6,460	–
Equipment Surcharge for Upgrade	$25,746	–
Subtotal	**$205,800**	**56%**
Engineering		
Siemens' Labor	$11,077	–
TE's Labor	$16,000	–
Subtotal	**$27,077**	**7%**
Installation, Shakedown, and Startup		
Installation Material	$15,120	–
TE's Labor for Installation	$24,126	–
Subcontractor Labor for Installation	$66,380	–
Installation Surcharge for Upgrade	$8,796	–
Siemens' Labor and Travel for Shakedown/Startup	$17,617	–
Subtotal	**$132,039**	**36%**
Total Cost for 12-ft Diameter System		
10-ft Diameter System	$330,374	91%
Upgrade to 12-ft Diameter System	$34,542	9%
Capital Investment Total	**$364,916**	**100%**

5.3.3 O&M Cost. O&M cost included chemical, electricity, and labor for a combined unit cost of $0.50/1,000 gal (Table 5-9). No cost was incurred for repairs because the system was under warranty. The only chemical requirement for treatment was NaOCl addition, which cost $0.04/1,000 gal. The electricity cost of $1,943/month or $0.39/1,000 gal was calculated based on the average monthly cost from electric bills after building construction and system startup. This cost included an incremental cost of $1,136/month or $0.24/1,000 gal compared to the consumption prior to the facility improvements. The routine, non-demonstration related labor activities consumed 30 to 45 min/day (Section 5.1.4.3). Based on this time commitment and a labor rate of $18/hr, the labor cost was $0.07/1,000 gal of water treated.

Table 5-9. O&M Cost for Siemens' AERALATER® System

Category	Value	Remarks
System Throughput (1,000 gal)	61,833	From 06/14/06 through 06/22/07
Chemical Usage		
NaOCl Cost ($/1,000 gal)	$0.04	No incremental consumption
Electricity Consumption		
Electricity Cost ($/month)	$1,943.00	Average after system startup including building heating and lighting
Electricity Cost ($/1,000 gal)	$0.39	
Labor		
Labor (hr/week)	4.5	30 to 45 min/day, 7 day/week
Labor Cost ($/1,000 gal)	$0.07	Labor rate = $18/hr
Total O&M Cost ($/1,000 gal)	$0.50	-

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APPENDIX A

OPERATIONAL DATA

US EPA Arsenic Demonstration Project at Sandusky, MI - Daily System Operation

Week No.	Date	Time	12.5% Cl_2 Usage lb	Inlet Flow: Flow rate gpm	Inlet Flow: Meter kgal	Inlet Flow: Daily Flow kgal	Effluent Flow: Flow rate gpm	Effluent Flow: Meter kgal	Effluent Flow: Daily Flow kgal	Effluent Flow: Cum. Flow kgal	Head Loss ft H2O	Backwash: Elapsed Volume kgal	Backwash: Cum. Volume kgal	Backwash: Kgal/ event kgal
	06/14/06	7:00	25	185	4386	225	139	4451	225	225	1.5	365	71.7	NA
	06/15/06	7:00	28	260	4643	257	312	4712	261	486	1.5	251	NR	NA
1	06/16/06	7:00	26	261	4895	252	311	4969	257	743	2.0	507	77.6	NA
	06/17/06	7:00	NA	182	5179	284	164	5258	289	1032	1.5	276	NR	NA
	06/18/06	7:00	27	185	5398	219	141	5482	224	1256	1.5	500	83.4	NA
	06/19/06	7:00	29	186	5621	223	223	5708	226	1482	1.5	76	89.4	6.0
	06/20/06	7:00	20	187	5804	183	232	5891	183	1665	1.5	172	NR	NA
	06/21/06	7:00	28	188	6050	246	242	6143	252	1917	1.5	424	NR	NA
2	06/22/06	7:00	11	267	6152	102	283	6248	105	2022	1.5	88	101.9	NA
	06/23/06	7:00	12	0	6261	109	0	6359	111	2133	NA	20	107.9	6.0
	06/24/06	7:00	NA	189	6506	245	236	6606	247	2380	1.5	238	NR	NA
	06/25/06	7:00	28	190	6727	221	131	6833	227	2607	1.5	464	NR	NA
	06/26/06	7:01	35	266	6992	265	316	7103	270	2877	1.5	NR	107.9	NA
	06/27/06	6:57	35	0	7262	270	0	7379	276	3153	NA	638	113.9	6.0
	06/28/06	6:49	37	264	7531	269	301	7654	275	3428	1.5	363	113.9	NA
3	06/29/06	7:02	19	240	7668	137	0	7790	136	3564	NA	809	125.5	11.6
	06/30/06	7:06	19	0	7792	124	0	7917	127	3691	NA	682	125.5	NA
	07/01/06	7:11	20	136	7913	121	137	8038	121	3812	1.4	780	131.4	5.9
	07/02/06	7:10	18	0	8028	115	0	8156	118	3930	NA	662	131.4	NA
	07/03/06	7:00	19	0	8144	116	0	8274	118	4048	NA	355	131.4	NA
	07/04/06	7:00	25	0	8263	119	0	8395	121	4169	NA	778	137.3	5.9
	07/05/06	7:00	21	131	8379	116	121	8513	118	4287	1.5	660	137.3	NA
4	07/06/06	7:00	22	0	8517	138	235	8652	139	4426	1.5	769	143.1	5.8
	07/07/06	7:00	21	0	8650	133	0	8788	136	4562	NA	632	143.1	NA
	07/08/06	7:00	NA	118	8792	142	127	8931	143	4705	1.3	756	148.9	5.8
	07/09/06	7:00	27	0	8934	142	0	9077	146	4851	NA	610	148.9	NA
	07/10/06	7:15	26	0	9065	131	0	9211	134	4985	NA	476	148.9	NA
	07/11/06	7:00	22	76	9149	84	0	9293	82	5067	NA	817	154.8	5.9
	07/12/06	7:00	24	76	9246	97	0	9392	99	5166	NA	718	154.8	NA
5	07/13/06	7:00	30	191	9381	135	296	9528	136	5302	1.5	767	160.6	5.8
	07/14/06	7:00	26	185	9522	141	268	9671	143	5445	1.5	624	160.6	NA
	07/15/06	7:00	29	188	9712	190	116	9865	194	5639	1.3	709	166.4	5.8
	07/16/06	7:00	25	0	9884	172	0	41	176	5815	NA	533	166.4	NA
	07/17/06	7:13	33	187	10802	NA	218	14183	NA	NA	1.6	NA	166.4	NA
	07/18/06	7:00	39	187	11043	241	122	14419	NA	NA	1.5	669	172.3	5.9
	07/19/06	6:57	40	188	11280	237	264	14087	NA	NA	1.7	432	172.3	NA
6	07/20/06	6:57	44	184	11516	236	238	14316	NA	NA	1.5	680	178.1	5.8
	07/21/06	7:01	NA	75	11623	107	110	14560	NA	NA	1.5	573	178.1	NA
	07/22/06	6:39	32	75	11734	111	75	14818	NA	NA	1.4	799	183.9	5.8
	07/23/06	6:48	30	75	11830	96	0	15059	NA	NA	NA	704	183.9	NA
	07/24/06	7:00	30	92	1156	NA	110	1336	NA	7110	1.5	601	183.9	NA
	07/25/06	7:00	35	90	1299	143	56	1480	144	7254	1.4	767	189.9	6.0
	07/26/06	7:00	35	94	1429	130	110	1613	133	7387	1.5	634	189.9	NA
7	07/27/06	7:00	31	239	1545	116	0	1729	116	7503	NA	790	195.6	5.7
	07/28/06	7:00	36	115	1717	172	117	1904	175	7678	1.4	615	195.6	NA
	07/29/06	7:00	38	0	1923	206	0	2114	210	7888	NA	705	201.4	5.8
	07/30/06	7:00	37	0	2116	193	0	2311	197	8085	NA	508	201.4	NA
	07/31/06	7:00	31	281	2286	170	306	2485	174	8259	1.5	334	201.4	NA
	08/01/06	7:03	40	178	2496	210	236	2699	214	8473	1.5	699	207.2	5.8
	08/02/06	7:06	32	213	2667	171	273	2860	161	8634	1.5	761	213.0	5.8
8	08/03/06	7:04	37	198	2854	187	0	3050	190	8824	NA	722	219.0	6.0
	08/04/06	6:56	32	0	3020	166	0	3221	171	8995	NA	551	219.0	NA
	08/05/06	7:12	35	0	3198	178	0	3401	180	9175	NA	727	224.8	5.8
	08/06/06	7:14	28	152	3340	142	153	3545	144	9319	1.5	583	224.8	NA
	08/07/06	7:00	28	152	3477	137	202	3686	141	9460	1.5	442	224.8	NA
	08/08/06	7:00	34	0	3647	170	0	3859	173	9633	NA	734	230.0	5.2
	08/09/06	7:00	34	175	3818	171	108	4033	174	9807	1.5	560	230.0	NA
9	08/10/06	7:00	36	178	3995	177	151	4213	180	9987	1.5	730	236.0	6.0
	08/11/06	7:00	35	0	4158	163	0	4380	167	10154	NA	563	236.0	NA
	08/12/06	7:00	26	0	4308	150	0	4530	150	10304	NA	754	242.0	6.0
	08/13/06	7:00	37	120	4423	115	200	4648	118	10422	1.5	636	242.0	NA

US EPA Arsenic Demonstration Project at Sandusky, MI - Daily System Operation

Week No.	Date	Time	12.5% Cl_2 Usage lb	Inlet Flow Flow rate gpm	Inlet Flow Meter kgal	Inlet Flow Daily Flow kgal	Effluent Flow Flow rate gpm	Effluent Flow Meter kgal	Effluent Flow Daily Flow kgal	Effluent Flow Cum. Flow kgal	Head Loss ft H2O	Backwash Elapsed Volume kgal	Backwash Cum. Volume kgal	Backwash Kgal/ event kgal
10	08/14/06	7:00	29	121	4539	116	211	4765	117	10539	1.5	519	242.2	NA
	08/15/06	7:00	29	0	4640	101	0	4867	102	10641	NA	804	248.0	5.8
	08/16/06	7:00	38	0	4823	183	0	5052	185	10826	NA	768	253.8	5.8
	08/17/06	7:15	52	270	5095	272	314	5329	277	11103	1.5	645	259.7	5.9
	08/18/06	7:00	42	224	5533	438	192	5296	NA	NA	1.5	441	259.7	NA
	08/19/06	7:00	42	0	5730	197	0	5490	161	11264	NA	712	265.5	5.8
	08/20/06	7:00	35	170	5898	168	0	5654	164	11428	NA	544	265.5	NA
11	08/21/06	7:00	37	0	5817	NA	0	6065	NA	11839	NA	377	265.5	NA
	08/22/06	7:00	43	169	6018	201	234	6260	195	12034	1.5	708	271.4	5.9
	08/23/06	7:00	41	0	6201	183	0	6455	195	12229	NA	513	271.4	NA
	08/24/06	7:10	42	172	6383	182	154	6639	184	12413	1.5	721	277.2	5.8
	08/25/06	7:09	41	171	6566	183	177	6826	187	12600	1.5	534	277.2	NA
	08/26/06	6:43	37	0	6732	166	0	6994	168	12768	NA	739	283.1	5.9
	08/27/06	6:30	40	171	6902	170	256	7167	173	12941	1.6	566	283.1	NA
12	08/28/06	7:13	38	168	7064	162	0	7332	165	13106	NA	401	283.1	NA
	08/29/06	7:14	39	170	7512	NA	153	7512	180	13286	1.5	720	288.9	5.8
	08/30/06	7:18	40	91	7392	NA	89	7664	152	13438	1.5	754	294.8	5.9
	08/31/06	7:12	40	76	7534	142	89	7807	143	13581	1.4	611	294.8	NA
	09/01/06	6:49	39	76	7671	137	0	7947	140	13721	NA	471	294.8	NA
	09/02/06	7:02	42	60	7787	116	180	8063	116	13837	1.5	789	300.6	5.8
	09/03/06	6:45	38	60	7868	81	0	8144	81	13918	NA	708	300.6	NA
13	09/04/06	7:15	37	61	7952	84	172	8228	84	14002	1.5	624	300.6	NA
	09/05/06	7:00	38	0	8042	90	0	8317	89	14091	NA	812	306.5	5.9
	09/06/06	7:00	36	0	8199	157	0	8477	160	14251	NA	652	306.5	NA
	09/07/06	7:00	33	225	8319	120	260	8598	121	14372	1.5	778	312.4	5.9
	09/08/06	7:00	36	160	8430	111	225	8710	112	14484	1.4	895	318.2	5.8
	09/09/06	7:00	34	118	8561	131	0	8845	135	14619	NA	760	318.2	NA
	09/10/06	7:00	27	119	8667	106	206	8952	107	14726	1.5	653	318.2	NA
14	09/11/06	7:00	30	117	8783	116	220	9068	116	14842	1.5	897	324.1	5.9
	09/12/06	7:00	40	117	8993	210	171	9282	214	15056	1.5	683	324.1	NA
	09/13/06	7:00	39	116	9172	179	198	9462	180	15236	1.5	898	329.9	5.8
	09/14/06	7:00	31	116	9295	123	231	9587	125	15361	1.5	772	329.9	NA
	09/15/06	7:00	29	117	9402	107	0	9694	107	15468	NA	898	335.8	5.9
	09/16/06	7:00	32	0	9526	124	0	9820	126	15594	NA	772	335.8	NA
	09/17/06	7:00	28	0	9639	113	0	9935	115	15709	NA	657	335.8	NA
15	09/18/06	7:00	24	117	9744	105	219	40	105	15814	1.5	896	341.7	5.9
	09/19/06	7:15	26	162	9901	157	279	199	159	15973	1.5	899	344.4	2.7
	09/20/06	7:05	25	87	44	143	120	344	145	16118	1.5	896	347.6	3.2
	09/21/06	7:00	13	0	190	146	0	492	148	16266	NA	775	349.5	1.9
	09/22/06	7:00	23	74	325	135	181	632	140	16406	1.5	635	349.5	NA
	09/23/06	7:00	21	79	482	157	102	789	157	16563	1.5	772	355.3	5.8
	09/24/06	7:00	22	79	607	125	93	913	124	16687	1.5	648	355.3	NA
16	09/25/06	7:00	34	283	721	114	0	1033	120	16807	NA	528	355.3	NA
	09/26/06	7:00	33	170	867	146	241	1179	146	16953	1.5	753	361.2	5.9
	09/27/06	7:00	36	284	1030	163	0	1346	167	17120	NA	586	366.1	4.9
	09/28/06	7:10	40	97	1220	190	106	1539	193	17313	1.5	706	367.3	1.2
	09/29/06	7:00	40	158	1376	156	136	1698	159	17472	1.5	547	367.3	NA
	09/30/06	7:00	40	80	1559	183	0	1882	184	17656	NA	899	379.3	12.0
	10/01/06	7:00	34	80	1679	120	91	2005	123	17779	1.5	776	379.3	NA
17	10/02/06	7:00	32	160	1798	119	0	2125	120	17899	NA	897	385.2	5.9
	10/03/06	7:00	31	0	2006	208	0	2338	213	18112	NA	684	385.2	NA
	10/04/06	7:00	30	0	2210	204	0	2546	208	18320	NA	899	391.1	5.9
	10/05/06	7:00	30	260	2419	209	307	2758	212	18532	1.5	687	391.1	NA
	10/06/06	7:00	27	0	2584	165	0	2928	170	18702	NA	899	396.9	5.8
	10/07/06	7:00	27	0	2775	191	0	3121	193	18895	NA	706	396.9	NA
	10/08/06	7:00	22	177	2913	138	87	3262	141	19036	0.3	565	396.9	NA
18	10/09/06	7:00	25	170	3060	147	112	3412	150	19186	1.5	898	402.9	6.0
	10/10/06	7:11	27	173	3258	198	248	3613	201	19387	1.5	697	402.9	NA
	10/11/06	7:07	30	167	3451	193	224	3809	196	19583	1.4	896	408.8	5.9
	10/12/06	7:14	30	173	3651	200	105	4015	206	19789	1.5	691	408.8	NA
	10/13/06	7:12	29	144	3833	182	159	4200	185	19974	1.5	506	408.8	NA
	10/14/06	6:59	35	78	4007	174	179	4376	176	20150	1.5	734	414.6	5.8
	10/15/06	6:50	31	78	4117	110	126	4489	113	20263	0.0	622	414.6	NA

US EPA Arsenic Demonstration Project at Sandusky, MI - Daily System Operation

Week No.	Date	Time	12.5% Cl_2 Usage lb	Inlet Flow: Flow rate gpm	Inlet Flow: Meter kgal	Inlet Flow: Daily Flow kgal	Effluent Flow: Flow rate gpm	Effluent Flow: Meter kgal	Effluent Flow: Daily Flow kgal	Effluent Flow: Cum. Flow kgal	Head Loss ft H2O	Backwash: Elapsed Volume kgal	Backwash: Cum. Volume kgal	Backwash: Kgal/ event kgal
19	10/16/06	7:00	30	95	4234	117	136	4607	118	20381	1.5	504	414.6	NA
	10/17/06	7:00	34	95	4418	184	91	4796	189	20570	0.8	719	420.6	6.0
	10/18/06	7:00	36	158	4598	180	105	4979	183	20753	1.3	536	420.6	NA
	10/19/06	7:00	37	97	4792	194	106	5178	199	20952	1.3	710	426.5	5.9
	10/20/06	7:00	35	97	4985	193	133	5375	197	21149	1.3	513	426.5	NA
	10/21/06	7:00	35	95	5170	185	0	5564	189	21338	NA	716	432.3	5.8
	10/22/06	7:00	33	95	5316	146	0	5713	149	21487	NA	567	432.3	NA
20	10/23/06	7:00	29	96	5441	125	102	5840	127	21614	0.7	440	432.3	NA
	10/24/06	7:00	31	0	5615	174	0	6017	177	21791	NA	728	438.3	6.0
	10/25/06	7:00	29	147	5784	169	49	6189	172	21963	0.7	556	438.3	NA
	10/26/06	7:00	30	149	5961	177	208	6368	179	22142	1.5	732	444.2	5.9
	10/27/06	7:00	32	80	6126	165	77	6537	169	22311	0.8	564	444.2	NA
	10/28/06	7:00	36	80	6289	163	87	6703	166	22477	0.7	741	450.0	5.8
	10/29/06	7:00	30	81	6395	106	83	6811	108	22585	0.7	633	450.0	NA
21	10/30/06	7:03	29	282	6505	110	0	6923	112	22697	NA	521	452.0	2.0
	10/31/06	7:11	31	264	6684	179	245	7103	180	22877	1.5	919	456.0	4.0
	11/01/06	6:52	28	257	6849	165	225	7273	170	23047	1.5	549	456.0	NA
	11/02/06	7:08	32	258	7032	183	170	7458	185	23232	1.5	716	461.9	5.9
	11/03/06	6:56	28	151	7203	171	80	7633	175	23407	1.5	541	461.9	NA
	11/04/06	7:06	31	0	7400	197	0	7833	200	23607	NA	699	467.0	5.1
	11/05/06	7:07	23	0	7531	131	0	7967	134	23741	NA	565	467.0	NA
22	11/06/06	7:00	24	171	7669	138	176	8108	141	23882	1.5	424	467.7	0.7
	11/07/06	7:08	31	143	7849	180	151	8293	185	24067	1.5	728	473.7	6.0
	11/08/06	7:02	27	304	8018	169	229	8466	173	24240	0.3	555	473.7	NA
	11/09/06	7:03	29	170	8206	188	174	8657	191	24431	1.5	722	479.6	5.9
	11/10/06	7:16	29	160	8390	184	185	8844	187	24618	1.5	534	479.6	NA
	11/11/06	7:15	25	0	8539	149	0	8995	151	24769	NA	756	485.5	5.9
	11/12/06	7:04	26	173	8676	137	175	9135	140	24909	1.5	616	485.5	NA
23	11/13/06	7:00	24	174	8811	135	180	9273	138	25047	1.5	478	485.5	NA
	11/14/06	7:00	28	0	8973	162	0	9438	165	25212	NA	744	491.4	5.9
	11/15/06	7:00	29	0	9155	182	0	9625	187	25399	NA	557	491.4	NA
	11/16/06	7:00	27	173	9327	172	181	9798	173	25572	1.5	726	497.4	6.0
	11/17/06	7:00	26	151	9492	165	152	9968	170	25742	1.5	556	497.4	NA
	11/18/06	7:00	26	0	9658	166	0	136	168	25910	NA	743	503.3	5.9
	11/19/06	7:00	22	0	9772	114	0	252	116	26026	NA	627	503.3	NA
24	11/20/06	7:00	22	0	9887	115	0	370	118	26144	NA	509	503.3	NA
	11/21/06	7:00	33	98	57	170	106	542	172	26316	1.4	731	509.2	5.9
	11/22/06	7:00	32	79	77	20	78	707	165	26481	1.4	566	509.2	NA
	11/23/06	7:00	28	61	322	245	0	811	104	26585	NA	798	515.2	6.0
	11/24/06	6:46	21	60	396	74	76	885	74	26659	1.4	724	515.2	NA
	11/25/06	7:04	24	62	476	80	87	962	77	26736	1.4	826	521.0	5.8
	11/26/06	7:00	24	61	555	79	0	1043	81	26817	NA	745	521.0	NA
25	11/27/06	7:15	24	60	634	79	80	1121	78	26895	1.4	667	521.0	NA
	11/28/06	7:05	30	189	795	161	192	1286	165	27060	1.4	738	521.0	NA
	11/29/06	7:11	32	78	947	152	82	1440	154	27214	1.4	584	527.0	6.0
	11/30/06	7:05	29	83	1101	154	79	1595	155	27369	1.4	751	532.9	5.9
	12/01/06	7:12	32	80	1261	160	98	1759	164	27533	1.4	587	532.9	NA
	12/02/06	7:16	34	82	1413	152	89	1911	152	27685	1.4	754	538.8	5.9
	12/03/06	7:11	31	80	1533	120	82	2034	123	27808	1.4	631	538.8	NA
26	12/04/06	7:00	28	80	1634	101	70	2137	103	27911	1.5	528	538.8	NA
	12/05/06	7:00	31	82	1793	159	83	2298	161	28072	1.5	367	538.8	NA
	12/06/06	7:02	28	269	1969	176	278	2478	180	28252	1.6	187	538.8	NA
	12/07/06	7:04	27	154	2139	170	160	2649	171	28423	1.5	736	544.7	5.9
	12/08/06	7:22	28	0	2320	181	0	2834	185	28608	NA	551	544.7	NA
	12/09/06	7:00	25	0	2476	156	0	2990	156	28764	NA	742	550.6	5.9
	12/10/06	7:00	24	0	2609	133	0	3127	137	28901	NA	606	550.6	NA
27	12/11/06	6:51	23	155	2739	130	154	3260	133	29034	1.5	473	550.6	NA
	12/12/06	6:58	31	154	2931	192	157	3455	195	29229	1.5	722	556.6	6.0
	12/13/06	7:00	30	177	3132	201	176	3660	205	29434	1.5	517	556.6	NA
	12/14/06	6:59	32	0	3327	195	0	3857	197	29631	NA	718	562.5	5.9
	12/15/06	6:55	33	182	3543	216	189	4077	220	29851	1.5	498	562.5	NA
	12/16/06	6:38	28	186	3727	184	195	4263	186	30037	1.5	730	568.4	5.9
	12/17/06	6:36	26	185	3889	162	190	4425	162	30199	1.5	568	568.4	NA

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	12/18/06	6:49	24	0	4041	152	0	4585	160	30359	NA	408	568.4	NA
	12/19/06	6:55	29	0	4222	181	0	4768	183	30542	NA	716	574.4	6.0
	12/20/06	7:03	28	276	4408	186	281	4957	189	30731	1.5	527	574.4	NA
28	12/21/06	6:55	30	0	4586	178	0	5138	181	30912	NA	734	580.4	6.0
	12/22/06	6:45	31	0	4773	187	0	5328	190	31102	NA	544	580.4	NA
	12/23/06	6:43	23	0	4898	125	0	5455	127	31229	NA	779	586.3	5.9
	12/24/06	6:30	23	155	5022	124	161	5582	127	31356	1.5	652	586.3	NA
	12/25/06	6:40	18	159	5123	101	165	5685	103	31459	1.5	549	586.3	NA
	12/26/06	6:50	18	0	5217	94	0	5780	95	31554	NA	818	592.2	5.9
	12/27/06	6:50	24	0	5384	167	0	5949	169	31723	NA	649	592.2	NA
29	12/28/06	6:45	26	0	5551	167	0	6118	169	31892	NA	736	598.2	6.0
	12/29/06	7:00	25	0	5708	157	0	6278	160	32052	NA	576	598.2	NA
	12/30/06	6:50	24	0	5834	126	0	6405	127	32179	NA	776	604.1	5.9
	12/31/06	6:30	21	0	5949	115	0	6524	119	32298	NA	657	604.1	NA
	01/01/07	5:41	18	158	6050	101	165	6627	103	32401	1.5	554	604.1	NA
	01/02/07	5:50	18	0	6155	105	0	6733	106	32507	NA	807	610.1	6.0
	01/03/07	6:11	25	0	6291	136	0	6872	139	32646	NA	668	610.1	NA
30	01/04/07	5:44	28	0	6477	186	0	7060	188	32834	NA	724	616.0	5.9
	01/05/07	5:48	27	0	6670	193	0	7257	197	33031	NA	527	616.0	NA
	01/06/07	5:50	30	0	6874	204	0	7463	206	33237	NA	709	621.9	5.9
	01/07/07	5:51	22	0	7020	146	0	7613	150	33387	NA	559	621.9	NA
	01/08/07	5:30	22	0	7166	146	0	7762	149	33536	NA	410	621.9	NA
	01/09/07	5:25	27	0	7343	177	0	7942	180	33716	NA	739	627.9	6.0
	01/10/07	5:42	29	0	7552	209	0	8154	212	33928	NA	527	627.9	NA
31	01/11/07	5:25	28	185	7748	196	188	8352	198	34126	1.5	717	633.8	5.9
	01/12/07	6:35	26	186	7957	209	193	8566	214	34340	1.5	503	633.8	NA
	01/13/07	5:28	28	0	8136	179	0	8748	182	34522	NA	732	639.7	5.9
	01/14/07	5:40	23	0	8293	157	81	8908	160	34682	NA	572	639.7	NA
	01/15/07	8:40	24	185	8448	155	183	9065	157	34839	1.4	897	645.7	6.0
	01/16/07	7:30	23	274	8597	149	278	9217	152	34991	1.5	745	645.7	NA
	01/17/07	5:30	22	156	8761	164	159	9385	168	35159	1.5	577	645.7	NA
32	01/18/07	5:30	25	0	8949	188	0	9575	190	35349	NA	743	651.7	6.0
	01/19/07	7:41	26	159	9137	188	167	9766	191	35540	1.5	552	651.7	NA
	01/20/07	6:00	24	0	9314	177	0	9946	180	35720	NA	723	657.6	5.9
	01/21/07	5:30	20	0	9456	142	0	91	145	35865	NA	578	657.6	NA
	01/22/07	7:40	21	187	9607	151	192	245	154	36019	1.5	423	657.6	NA
	01/23/07	7:20	22	191	9786	179	193	427	182	36201	1.5	721	663.6	6.0
	01/24/07	6:53	22	158	9964	178	158	608	181	36382	1.5	540	663.6	NA
33	01/25/07	7:03	24	277	152	188	279	798	190	36572	1.5	727	669.5	5.9
	01/26/07	7:47	23	155	334	182	128	983	185	36757	1.3	541	669.5	NA
	01/27/07	8:12	26	178	529	195	136	1183	200	36957	1.3	703	675.5	6.0
	01/28/07	8:00	12	165	656	127	124	1312	129	37086	1.4	573	675.5	NA
	01/29/07	7:18	21	156	781	125	157	1440	128	37214	1.5	445	675.5	NA
	01/30/07	7:45	21	175	965	184	127	1627	187	37401	1.5	722	681.5	6.0
	01/31/07	6:51	20	155	1138	173	107	1802	175	37576	0.3	547	681.5	NA
34	02/01/07	7:00	17	157	1294	156	147	1960	158	37734	1.5	660	687.4	5.9
	02/02/07	6:45	21	151	1489	195	152	2159	199	37933	1.5	461	687.4	NA
	02/03/07	6:30	20	155	1640	151	159	2312	153	38086	1.5	666	693.3	5.9
	02/04/07	6:30	18	0	1781	141	0	2456	144	38230	NA	522	693.3	NA
	02/05/07	7:00	18	155	1914	133	166	2593	137	38367	1.5	385	693.3	NA
	02/06/07	7:00	20	154	2095	181	150	2775	182	38549	1.5	632	699.3	6.0
	02/07/07	6:45	18	156	2242	147	160	2926	151	38700	1.5	481	699.3	NA
35	02/08/07	6:45	18	160	2386	144	150	3072	146	38846	1.5	1864	705.3	6.0
	02/09/07	6:45	27	119	2630	244	128	3321	249	39095	1.5	1615	705.3	NA
	02/10/07	7:00	17	142	2755	125	156	3448	127	39222	1.5	1488	705.3	NA
	02/11/07	7:00	17	145	2876	121	150	3572	124	39346	1.5	1363	705.3	NA
	02/12/07	6:47	16	143	2999	123	146	3698	126	39472	1.6	1238	705.3	NA
	02/13/07	7:34	22	289	3208	209	119	3912	214	39686	1.6	1025	705.3	NA
	02/14/07	8:00	20	154	3391	183	158	4097	185	39871	2.0	839	705.3	NA
36	02/15/07	7:44	18	169	3539	148	180	4248	151	40022	1.5	1052	711.2	5.9
	02/16/07	6:18	18	156	3703	164	144	4415	167	40189	1.5	885	711.2	NA
	02/17/07	7:11	18	0	3886	183	0	4600	185	40374	NA	1038	717.2	6.0
	02/18/07	6:23	15	158	4004	118	139	4720	120	40494	1.5	918	717.2	NA

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	02/19/07	5:34	15	151	4130	126	160	4849	129	40623	1.5	788	717.2	NA
	02/20/07	7:26	16	0	4270	140	0	4994	145	40768	NA	644	717.2	NA
	02/21/07	5:16	20	182	4468	198	187	5192	198	40966	1.5	1002	723.0	5.8
37	02/22/07	5:20	20	152	4652	184	150	5380	188	41154	1.5	814	723.0	NA
	02/23/07	5:15	19	168	4850	198	166	5581	201	41355	1.6	612	723.0	NA
	02/24/07	5:13	26	178	5044	194	183	5778	197	41552	1.5	1037	729.0	6.0
	02/25/07	6:39	17	0	5204	160	0	5942	164	41716	NA	837	729.0	NA
	02/26/07	7:17	13	200	5341	137	190	6082	140	41856	1.5	733	729.0	NA
	02/27/07	7:22	23	170	5545	204	169	6289	207	42063	1.5	526	729.0	NA
	02/28/07	6:33	19	179	5719	174	189	6466	177	42240	1.5	1032	734.8	5.8
38	03/01/07	7:47	20	157	5907	188	112	6658	192	42432	1.5	840	734.8	NA
	03/02/07	7:56	20	149	6089	182	157	6842	184	42616	1.5	656	734.8	NA
	03/03/07	8:22	18	152	6259	170	162	7014	172	42788	1.5	1028	740.8	6.0
	03/04/07	7:59	17	0	6388	129	0	7147	133	42921	NA	896	740.8	NA
	03/05/07	6:29	15	149	6509	121	161	7270	123	43044	1.5	773	740.8	NA
	03/06/07	7:16	21	207	6723	214	102	7488	218	43262	1.5	555	740.8	NA
	03/07/07	7:30	20	161	6903	180	164	7671	183	43445	1.5	1026	746.6	5.8
39	03/08/07	6:51	18	150	7096	193	152	7867	196	43641	1.5	829	746.6	NA
	03/09/07	6:49	21	169	7307	211	179	8082	215	43856	1.5	614	746.6	NA
	03/10/07	6:27	21	178	7500	193	184	8277	195	44051	1.5	1022	752.6	6.0
	03/11/07	6:38	18	176	7655	155	181	8436	159	44210	1.5	863	752.6	NA
	03/12/07	6:57	19	186	7821	166	189	8606	170	44380	1.5	693	752.6	NA
	03/13/07	7:30	18	152	8007	186	157	8793	187	44567	1.5	506	752.6	NA
	03/14/07	7:15	23	153	8186	179	153	8975	182	44749	1.5	1022	758.6	6.0
40	03/15/07	7:15	26	150	8360	174	149	9152	177	44926	1.5	846	758.6	NA
	03/16/07	7:15	23	147	8535	175	146	9328	176	45102	1.5	669	758.6	NA
	03/17/07	6:40	21	151	8714	179	151	9510	182	45284	1.5	1028	764.5	5.9
	03/18/07	6:50	18	162	8843	129	93	9641	131	45415	1.5	897	764.5	NA
	03/19/07	7:28	19	159	8979	136	167	9778	137	45552	1.5	760	764.5	NA
	03/20/07	7:37	21	184	9164	185	185	9964	186	45738	1.5	574	764.5	NA
	03/21/07	7:13	23	184	9362	198	195	165	201	45939	1.5	1005	770.4	5.9
41	03/22/07	7:08	33	301	9672	310	301	479	314	46253	1.5	691	770.4	NA
	03/23/07	7:17	34	202	9	337	206	825	346	46599	1.5	346	770.4	NA
	03/24/07	7:00	23	0	192	183	0	1008	183	46782	NA	1024	776.4	6.0
	03/25/07	6:30	17	180	304	112	189	1121	113	46895	1.5	911	776.4	NA
	03/26/07	6:15	16	142	416	112	151	1233	112	47007	1.5	799	776.4	NA
	03/27/07	6:20	20	155	592	176	161	1410	177	47184	1.5	622	776.4	NA
	03/28/07	6:17	22	162	778	186	171	1597	187	47371	1.5	1020	782.3	5.9
42	03/29/07	6:19	23	151	964	186	160	1785	188	47559	1.5	832	782.3	NA
	03/30/07	6:24	21	155	1135	171	160	1956	171	47730	1.5	661	782.3	NA
	03/31/07	6:00	22	0	1309	174	0	2132	176	47906	NA	1032	788.2	5.9
	04/01/07	6:17	20	161	1426	117	107	2250	118	48024	1.5	914	788.2	NA
	04/02/07	6:21	17	166	1542	116	167	2365	115	48139	1.5	799	788.2	NA
	04/03/07	6:10	22	153	1719	177	158	2544	179	48318	1.5	620	788.2	NA
	04/04/07	6:07	23	155	1899	180	159	2726	182	48500	1.5	1032	794.1	5.9
43	04/05/07	6:13	23	156	2068	169	147	2897	171	48671	1.5	860	794.1	NA
	04/06/07	6:05	21	156	2228	160	161	3059	162	48833	1.5	699	794.1	NA
	04/07/07	6:25	20	160	2352	124	106	3185	126	48959	1.4	1090	800.1	6.0
	04/08/07	6:14	17	0	2479	127	66	3313	128	49087	1.5	962	800.1	NA
	04/09/07	7:00	18	164	2589	110	172	3424	111	49198	1.5	851	800.1	NA
	04/10/07	6:58	22	154	2759	170	162	3596	172	49370	1.5	679	800.1	NA
	04/11/07	7:06	27	168	2966	207	171	3805	209	49579	1.4	1007	806.0	5.9
44	04/12/07	7:10	18	173	3112	146	180	3953	148	49727	1.5	859	806.0	NA
	04/13/07	7:08	22	155	3305	193	159	4147	194	49921	1.5	665	806.0	NA
	04/14/07	7:18	27	165	3490	185	97	4335	188	50109	1.4	1024	811.9	5.9
	04/15/07	7:06	23	158	3620	130	154	4467	132	50241	1.5	892	811.9	NA
	04/16/07	7:45	23	170	3761	141	171	4607	140	50381	1.5	752	811.9	NA
	04/17/07	7:45	24	166	3948	187	170	4795	188	50569	1.5	563	811.9	NA
	04/18/07	7:45	26	155	4138	190	157	4987	192	50761	1.5	1014	817.8	5.9
45	04/19/07	7:45	22	154	4310	172	158	5160	173	50934	1.5	841	817.8	NA
	04/20/07	7:45	26	277	4495	185	283	5347	187	51121	1.5	654	817.8	NA
	04/21/07	7:45	27	148	4671	176	157	5525	178	51299	1.5	1034	823.8	6.0
	04/22/07	7:45	22	0	4789	118	0	5644	119	51418	NA	915	823.8	NA

US EPA Arsenic Demonstration Project at Sandusky, MI - Daily System Operation

Week No.	Date	Time	12.5% Cl_2 Usage lb	Inlet Flow Flow rate gpm	Inlet Flow Meter kgal	Inlet Flow Daily Flow kgal	Effluent Flow Flow rate gpm	Effluent Flow Meter kgal	Effluent Flow Daily Flow kgal	Effluent Flow Cum. Flow kgal	Head Loss ft H2O	Backwash Elapsed Volume kgal	Backwash Cum. Volume kgal	Backwash Kgal/ event kgal
46	04/23/07	7:10	20	155	4901	112	157	5757	113	51531	1.5	802	823.8	NA
	04/24/07	7:10	27	159	5081	180	163	5940	183	51714	1.5	619	823.8	NA
	04/25/07	7:10	31	154	5268	187	158	6126	186	51900	1.5	1025	829.7	5.9
	04/26/07	7:15	31	149	5456	188	155	6317	191	52091	1.5	834	829.7	NA
	04/27/07	7:15	27	149	5621	165	160	6482	165	52256	1.5	669	829.7	NA
	04/28/07	7:10	29	151	5797	176	158	6660	178	52434	1.5	1032	835.7	6.0
	04/29/07	7:15	23	148	5920	123	156	6782	122	52556	1.5	910	835.7	NA
47	04/30/07	6:15	24	149	6043	123	149	6905	123	52679	1.5	787	835.7	NA
	05/01/07	6:14	29	151	6217	174	147	7079	174	52853	1.5	613	835.7	NA
	05/02/07	6:16	28	157	6387	170	152	7249	170	53023	1.5	1042	841.6	5.9
	05/03/07	6:10	32	151	6589	202	156	7454	205	53228	1.5	837	841.6	NA
	05/04/07	6:08	34	149	6792	203	157	7660	206	53434	1.5	631	841.6	NA
	05/05/07	6:12	33	150	6981	189	160	7851	191	53625	1.5	1017	847.6	6.0
	05/06/07	6:05	24	158	7098	117	163	7969	118	53743	1.5	899	847.6	NA
48	05/07/07	6:08	26	151	7227	129	156	8100	131	53874	1.5	768	847.6	NA
	05/08/07	6:10	29	153	7415	188	168	8291	191	54065	1.5	577	847.6	NA
	05/09/07	6:08	32	251	7616	201	182	8494	203	54268	1.5	1010	853.5	5.9
	05/10/07	6:12	27	151	7792	176	155	8672	178	54446	1.5	832	853.5	NA
	05/11/07	6:02	26	150	7977	185	156	8860	188	54634	1.5	644	853.5	NA
	05/12/07	6:30	29	154	8211	234	155	9095	235	54869	1.5	969	859.5	6.0
	05/13/07	7:00	25	0	8333	122	0	9219	124	54993	NA	845	859.5	NA
49	05/14/07	7:18	31	0	8472	139	0	9362	143	55136	NA	702	859.5	NA
	05/15/07	7:02	29	267	8651	179	264	9544	182	55318	1.5	520	859.5	NA
	05/16/07	7:18	32	266	8833	182	268	9726	182	55500	1.5	1026	865.4	5.9
	05/17/07	7:07	29	120	9008	175	132	9901	175	55675	1.5	851	865.4	NA
	05/18/07	7:21	30	0	9192	184	0	87	186	55861	NA	665	865.4	NA
	05/19/07	7:24	31	120	9307	115	92	198	111	55972	1.4	1095	871.4	6.0
	05/20/07	7:08	30	0	9418	111	0	307	109	56081	NA	986	871.4	NA
50	05/21/07	6:56	38	116	9550	132	114	438	131	56212	1.5	855	871.4	NA
	05/22/07	7:02	40	117	9702	152	123	592	154	56366	1.5	701	871.4	NA
	05/23/07	7:02	40	118	9836	134	121	723	131	56497	1.4	1076	877.3	5.9
	05/24/07	7:10	34	151	43	207	157	933	210	56707	1.5	866	877.3	NA
	05/25/07	6:33	39	147	241	198	150	1134	201	56908	1.5	665	877.3	NA
	05/26/07	6:59	38	164	416	175	163	1310	176	57084	1.5	1046	883.3	6.0
	05/27/07	7:01	33	115	550	134	126	1445	135	57219	1.5	911	883.3	NA
51	05/28/07	7:10	30	0	674	124	0	1569	124	57343	NA	787	883.3	NA
	05/29/07	7:15	34	152	819	145	154	1716	147	57490	1.5	640	883.3	NA
	05/30/07	7:15	42	150	1033	214	155	1929	213	57703	1.5	996	889.2	5.9
	05/31/07	7:15	39	147	1228	195	154	2126	197	57900	1.5	799	889.2	NA
	06/01/07	7:15	45	148	1426	198	149	2326	200	58100	1.5	599	889.2	NA
	06/02/07	7:15	51	0	1645	219	0	2546	220	58320	NA	989	895.1	5.9
	06/03/07	6:30	25	0	1761	116	0	2659	113	58433	NA	876	895.1	NA
52	06/04/07	7:12	0	0	1761	0	0	2659	NA	58433	NA	876	895.1	NA
	06/05/07	7:14	34	146	1919	158	146	2820	161	58594	1.5	714	895.1	NA
	06/06/07	7:25	41	147	2116	197	150	3018	198	58792	1.5	1021	900.1	5.0
	06/07/07	7:10	39	149	2299	183	151	3205	187	58979	1.5	834	900.9	0.8
	06/08/07	7:13	44	140	2514	215	0	3424	219	59198	1.5	1200	906.8	5.9
	06/09/07	6:57	34	193	2656	142	197	3561	137	59335	1.5	1069	909.0	2.2
	06/10/07	6:56	52	79	2813	157	80	3721	160	59495	1.5	910	909.0	NA
53	06/11/07	7:05	42	190	2953	140	190	3864	143	59638	1.5	767	909.0	NA
	06/12/07	7:04	44	143	3158	205	143	4072	208	59846	1.5	559	909.0	NA
	06/13/07	7:07	46	145	3375	217	149	4292	220	60066	1.5	994	914.9	5.9
	06/14/07	7:04	47	108	3597	222	106	4518	226	60292	1.5	768	914.9	NA
	06/15/07	7:00	47	82	3793	196	93	4718	200	60492	1.5	568	914.9	NA
	06/16/07	7:12	49	130	4009	216	143	4936	218	60710	1.5	990	920.8	5.9
	06/17/07	7:10	44	101	4177	168	124	5107	171	60881	1.5	818	920.8	NA
54	06/18/07	7:00	43	150	4356	179	159	5289	182	61063	1.5	636	920.8	NA
	06/19/07	7:00	40	147	4576	220	157	5512	223	61286	1.5	413	920.8	NA
	06/20/07	7:00	35	142	4744	168	147	5681	169	61455	1.5	1038	926.7	5.9
	06/21/07	7:00	45	135	4930	186	132	5870	189	61644	1.5	849	926.7	NA
	06/22/07	7:00	42	136	5117	187	136	6059	189	61833	1.5	660	926.7	NA

Notes: (1) Unit 1 backwashes Monday, Wednesday, and Friday w/ air wash at 60-70 scfm until 02/07/07. Afterwards, Tuesday and Friday w/ air wash at 60-70 scfm. (2) Unit 1 inlet valve throttled to allow 66-75% of flow to Unit 1 and 25-33% of flow to Unit 2 when both units operating until 09/19/06. Afterwards, Unit 1: 100% during day, 50% at night; Unit 2: 50% at night only. (3) Blower operates once/week to keep air diffuser grid from plugging. (4) Highlighted columns indicate calculated values.
NA = not available; NR = no reading taken

APPENDIX B

ANALYTICAL DATA TABLES

Analytical Results from Long-Term Sampling at Sandusky, MI

Sampling Date		06/22/06 - Well 1			06/28/06 - Well 1			07/05/06 - Well 1			07/12/06[e] - Well 3			07/18/06 - Well 3			07/25/06 - Well 3		
Sampling Location Parameter	Unit	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT
Alkalinity	mg/L[a]	297 -	297 -	297 -	293 -	297 -	293 -	297 -	302 -	302 -	302 -	302 -	302 -	311 -	307 -	307 -	312 -	317 -	308 -
Ammonia (as N)	mg/L	0.1	0.1	0.1	-	-	-	-	-	-	-	-	-	0.4	0.3	0.3	-	-	-
Fluoride	mg/L	0.7	0.7	0.7	-	-	-	-	-	-	-	-	-	1.5	1.4	1.6	-	-	-
Sulfate	mg/L	87	89	89	-	-	-	-	-	-	-	-	-	102	107	102	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-
P (total)	µg/L[b]	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -
Silica (as SiO_2)	mg/L	11.7 -	11.6 -	12.1 -	12.0 -	12.9 -	13.8 -	11.6 -	11.9 -	11.9 -	12.2 -	11.9 -	12.4 -	11.3 -	11.2 -	11.4 -	12.5 -	12.4 -	12.3 -
Turbidity	NTU	13.0 -	1.3 -	0.2 -	10.0 -	1.1 -	1.7 -	9.9 -	1.1 -	1.0 -	13.0 -	1.2 -	0.6 -	16.0 -	0.8 -	0.3 -	16.0 -	1.4 -	0.5 -
TOC	mg/L	NA[c]	NA[c]	NA[c]	-	-	-	-	-	-	-	-	-	<1.0	1.1	1.0	-	-	-
pH	S.U.	7.7	7.7	7.6	7.3	7.2	7.3	7.3	7.1	7.1	7.3	7.2	7.2	7.2	7.1	7.1	7.3	7.3	7.3
Temperature	^0C	11.8	11.5	13.0	13.3	12.0	13.5	12.3	12.0	13.0	12.3	12.0	12.6	11.9	12.6	12.5	12.4	11.4	12.1
DO	mg/L	1.8	2.4	2.3	2.8	3.7	5.6	1.8	2.0	2.0	1.7	2.6	3.1	1.4	2.6	2.8	3.7	4.2	3.9
ORP	mV	298	387	431	406	499	535	291	530	566	287	487	484	272	484	366	306	380	418
Free Chlorine	mg/L	-	0.2	0.1	-	0.2	0.2	-	0.3	0.2	-	1.4	0.4	-	0.4	0.3	-	1.7	3.1
Total Chlorine	mg/L	-	NA[d]	NA[d]	-	NA[d]	NA[d]	-	NA[d]	NA[d]	-	3.5	4.7	-	3.3	3.4	-	3.2	3.5
Total Hardness	mg/L[a]	375	384	407	-	-	-	-	-	-	-	-	-	378	407	402	-	-	-
Ca Hardness	mg/L[a]	247	252	267	-	-	-	-	-	-	-	-	-	262	286	283	-	-	-
Mg Hardness	mg/L[a]	128	132	140	-	-	-	-	-	-	-	-	-	115	121	119	-	-	-
As (total)	µg/L	7.6 -	7.6 -	1.2 -	7.3 -	7.4 -	1.4 -	8.1 -	10.4 -	5.5 -	8.9 -	10.0 -	5.6 -	10.6 -	10.6 -	1.6 -	15.3 -	21.2 -	1.6 -
As (soluble)	µg/L	7.3	1.3	0.9	-	-	-	-	-	-	-	-	-	10.4	1.6	1.4	-	-	-
As (particulate)	µg/L	0.2	6.3	0.3	-	-	-	-	-	-	-	-	-	0.2	9.0	0.2	-	-	-
As(III)	µg/L	6.0	0.3	0.3	-	-	-	-	-	-	-	-	-	9.8	0.6	0.6	-	-	-
As(V)	µg/L	1.3	1.0	0.6	-	-	-	-	-	-	-	-	-	0.6	1.0	0.7	-	-	-
Fe (total)	µg/L	689 -	694 -	<25 -	576 -	617 -	35 -	712 -	1,023 -	523 -	869 -	912 -	472 -	962 -	977 -	<25 -	1,156 -	1,785 -	<25 -
Fe (soluble)	µg/L	688	<25	<25	-	-	-	-	-	-	-	-	-	990	<25	<25	-	-	-
Mn (total)	µg/L	25.2 -	25.0 -	13.5 -	22.2 -	23.0 -	12.7 -	24.3 -	29.4 -	21.0 -	26.3 -	26.3 -	20.5 -	29.2 -	29.3 -	14.5 -	30.6 -	35.6 -	10.7 -
Mn (soluble)	µg/L	25.1	10.7	13.0	-	-	-	-	-	-	-	-	-	30.1	11.2	14.3	-	-	-

(a) As $CaCO_3$. (b) As P. (c) Sample failed laboratory QA/QC check. (d) Test reagent not available for measurement.
(e) Switched to Well No. 3 on 07/10/06. Water quality measurements taken on 07/10/06.

Analytical Results from Long-Term Sampling at Sandusky, MI (Continued)

Sampling Date		08/01/06[c] - Well 1			08/08/06 - Well 1			08/15/06[d] - Well 1			08/22/06 - Well 1			08/29/06 - Well 1			09/06/06[e] - Well 1		
Sampling Location		IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT
Parameter	Unit																		
Alkalinity	mg/L[a]	299	295	295	302	307	307	307	312	337	331	324	333	320	315	324	326	335	335
		-	-	-	-	-	-	-	-	-	-	-	-	293	326	337	-	-	-
Ammonia (as N)	mg/L	-	-	-	-	-	-	0.3	0.2	0.2	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	3.4	1.8	1.9	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	93	94	94	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-
P (total)	µg/L[b]	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	22.1	19.3	<10
		-	-	-	-	-	-	-	-	-	-	-	-	<10	<10	<10	-	-	-
Silica (as SiO_2)	mg/L	13.3	13.9	11.4	12.7	12.1	11.8	12.3	12.0	12.0	11.5	11.3	11.6	11.8	11.3	11.7	11.3	11.7	11.6
		-	-	-	-	-	-	-	-	-	-	-	-	11.2	11.7	11.4	-	-	-
Turbidity	NTU	10.0	0.7	0.3	9.2	0.8	0.2	7.9	0.9	0.1	7.8	0.8	0.2	7.7	0.6	0.2	11.0	9.9[g]	0.5
		-	-	-	-	-	-	-	-	-	-	-	-	8.3	0.9	0.5	-	-	-
TOC	mg/L	-	-	-	-	-	-	1.1	1.1	1.1	-	-	-	-	-	-	-	-	-
pH	S.U.	7.3	7.2	7.2	7.2	7.1	7.2	7.3	7.2	7.3	7.2	7.2	7.2	7.3	7.3	7.3	7.1	7.2	7.2
Temperature	^0C	12.6	12.0	12.1	12.3	12.1	12.3	11.8	11.6	11.7	12.5	11.7	11.9	12.1	11.9	16.2	12.0	12.0	11.8
DO	mg/L	0.8	2.6	2.4	1.5	2.0	2.7	1.0	2.7	2.9	1.7	2.5	2.4	1.8	3.1	2.9	2.3	2.8	2.7
ORP	mV	248	305	303	3[f]	447	468	301	498	489	331	552	513	290	498	474	291	437	453
Free Chlorine	mg/L	-	0.5	0.5	-	0.5	0.5	-	2.3	2.0	-	0.3	0.3	-	1.4	0.4	-	0.4	3.1
Total Chlorine	mg/L	-	3.7	3.7	-	4.0	3.9	-	3.7	3.4	-	4.6	4.3	-	4.0	3.8	-	3.8	3.6
Total Hardness	mg/L[a]	-	-	-	-	-	-	392	424	411	-	-	-	-	-	-	-	-	-
Ca Hardness	mg/L[a]	-	-	-	-	-	-	257	277	282	-	-	-	-	-	-	-	-	-
Mg Hardness	mg/L[a]	-	-	-	-	-	-	135	148	129	-	-	-	-	-	-	-	-	-
As (total)	µg/L	10.3	10.6	1.7	11.8	11.5	1.7	10.0	9.4	2.0	10.4	10.8	1.6	8.5	8.7	1.2	23.5	21.6	4.6
		-	-	-	-	-	-	-	-	-	-	-	-	8.1	9.0	1.1	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	8.7	2.5	2.0	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	1.3	6.9	<0.1	-	-	-	-	-	-	-	-	-
As(III)	µg/L	-	-	-	-	-	-	7.5	0.8	0.8	-	-	-	-	-	-	-	-	-
As(V)	µg/L	-	-	-	-	-	-	1.2	1.6	1.2	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	757	755	<25	795	755	<25	841	789	<25	691	619	<25	708	724	<25	1,941	1,951	182
		-	-	-	-	-	-	-	-	-	-	-	-	707	724	<25	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	651	<25	<25	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	27.0	26.9	9.7	25.9	26.2	10.2	24.6	25.5	2.6	24.5	25.0	8.0	26.1	26.1	7.8	26.7	29.3	7.2
		-	-	-	-	-	-	-	-	-	-	-	-	25.4	25.7	8.0	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	26.3	10.2	2.6	-	-	-	-	-	-	-	-	-

(a) As $CaCO_3$. (b) As P. (c) Resumed Well No. 1 operation on 07/28/06. (d) Water quality measurements taken on 08/16/06. (e) Water quality measurements taken on 09/05/06. (f) Possible recording error. (g) Reanalysis indicated similar result.

Analytical Results from Long-Term Sampling at Sandusky, MI (Continued)

Sampling Date		09/14/06[c] - Well 1			09/19/06 - Well 1			09/27/06[d] - Well 1			10/03/06 - Well 1			10/11/06 - Well 1			10/17/06 - Well 6		
Sampling Location		IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT
Parameter	Unit																		
Alkalinity	mg/L[a]	316 -	314 -	323 -	324 -	317 -	320 -	319 -	331 -	321 -	315 -	315 -	310 -	327 -	323 -	325 -	339 -	324 -	337 -
Ammonia (as N)	mg/L	0.3	0.1	0.1	-	-	-	-	-	-	-	-	-	0.4	0.3	0.4	-	-	-
Fluoride	mg/L	0.6	0.6	0.6	-	-	-	-	-	-	-	-	-	0.6	0.5	0.5	-	-	-
Sulfate	mg/L	91	93	76	-	-	-	-	-	-	-	-	-	95	97	96	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-
P (total)	µg/L[b]	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	27.0 -	29.7 -	25.4 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -
Silica (as SiO_2)	mg/L	12.3 -	11.8 -	11.4 -	12.3 -	12.2 -	12.1 -	11.4 -	11.8 -	12.1 -	12.1 -	11.8 -	11.5 -	11.4 -	11.4 -	10.0 -	12.2 -	11.6 -	11.3 -
Turbidity	NTU	9.4 -	1.4 -	0.9 -	7.8 -	0.7 -	0.1 -	8.7 -	0.9 -	0.1 -	9.2 -	0.8 -	0.3 -	10.0 -	1.3 -	0.3 -	3.0 -	1.5 -	0.9 -
TOC	mg/L	1.1	1.1	<1.0	-	-	-	-	-	-	-	-	-	1.1	1.1	1.0	-	-	-
pH	S.U.	7.3	7.3	7.2	7.2	7.3	7.3	7.1	7.3	7.3	7.0	7.2	7.2	7.0	7.2	7.2	7.3	7.4	7.4
Temperature	^{0}C	12.6	11.6	11.6	12.0	11.3	11.5	11.8	11.5	11.7	11.9	11.2	11.3	11.6	11.0	11.2	11.3	11.2	11.2
DO	mg/L	1.9	2.4	2.6	1.5	2.8	3.6	1.8	2.9	3.0	1.9	3.2	3.2	2.0	3.2	2.7	1.8	3.3	3.2
ORP	mV	281	311	309	265	301	292	317	299	301	305	306	300	317	307	301	283	292	292
Free Chlorine	mg/L	-	1.4	0.3	-	0.4	0.9	-	0.7	0.1	-	0.2	0.2	-	0.9	1.9	-	0.4	0.3
Total Chlorine	mg/L	-	3.8	4.1	-	4.1	4.1	-	2.9	2.6	-	2.9	2.9	-	2.0	2.0	-	1.9	1.3
Total Hardness	mg/L[a]	387	377	379	-	-	-	-	-	-	-	-	-	396	400	408	-	-	-
Ca Hardness	mg/L[a]	254	250	252	-	-	-	-	-	-	-	-	-	278	276	281	-	-	-
Mg Hardness	mg/L[a]	133	126	127	-	-	-	-	-	-	-	-	-	118	124	127	-	-	-
As (total)	µg/L	9.6 -	7.7 -	1.0 -	7.5 -	7.5 -	1.2 -	11.8 -	12.7 -	6.3 -	10.5 -	11.0 -	1.7 -	11.6 -	9.1 -	1.9 -	10.2 -	10.1 -	1.9 -
As (soluble)	µg/L	8.3	1.3	1.1	-	-	-	-	-	-	-	-	-	8.1	2.2	1.9	-	-	-
As (particulate)	µg/L	1.4	6.3	<0.1	-	-	-	-	-	-	-	-	-	3.5	6.9	<0.1	-	-	-
As(III)	µg/L	7.4	<0.1	<0.1	-	-	-	-	-	-	-	-	-	7.5	1.0	1.0	-	-	-
As(V)	µg/L	0.8	1.2	1.0	-	-	-	-	-	-	-	-	-	0.6	1.2	0.9	-	-	-
Fe (total)	µg/L	789 -	691 -	<25 -	697 -	698 -	<25 -	732 -	854 -	<25 -	625 -	633 -	<25 -	1,202 -	735 -	<25 -	242 -	239 -	<25 -
Fe (soluble)	µg/L	610	<25	<25	-	-	-	-	-	-	-	-	-	680	<25	<25	-	-	-
Mn (total)	µg/L	23.4 -	22.8 -	3.4 -	26.1 -	25.0 -	7.0 -	25.8 -	27.0 -	2.0 -	23.5 -	24.1 -	1.1 -	26.5 -	26.2 -	20.8 -	23.2 -	24.1 -	0.4 -
Mn (soluble)	µg/L	23.5	6.3	3.5	-	-	-	-	-	-	-	-	-	26.5	18.8	20.8	-	-	-

(a) As $CaCO_3$. (b) As P. (c) Water quality measurements taken on 09/12/06. (d) Water quality measurements taken on 09/28/06.

Analytical Results from Long-Term Sampling at Sandusky, MI (Continued)

Sampling Date		10/24/06 - Well 1			11/01/06[c] - Well 1			11/07/06 - Well 1			11/16/06 - Well 1			11/28/06 - Wells 3 & 6			12/06/06 - Well 1		
Sampling Location Parameter	Unit	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT
Alkalinity	mg/L[a]	333 -	320 -	322 -	320 -	320 -	322 -	324 -	315 -	320 -	327 -	334 -	332 -	350 346	350 350	344 346	321 -	323 -	321 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	0.3	0.3	0.3	-	-	-	-	-	-	0.3	0.2	0.2
Fluoride	mg/L	-	-	-	-	-	-	0.7	0.6	0.7	-	-	-	-	-	-	0.7	0.6	0.7
Sulfate	mg/L	-	-	-	-	-	-	105	106	101	-	-	-	-	-	-	95	91	93
Nitrate (as N)	mg/L	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	<0.05	<0.05	<0.05
P (total)	µg/L[b]	<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	12.3 -	12.2 -	11.6 -	11.3 -	11.5 -	11.5 -	11.5 -	11.8 -	10.9 -	11.2 -	11.7 -	11.1 -	11.7 11.6	11.5 11.2	11.5 11.1	12.0 -	11.5 -	11.8 -
Turbidity	NTU	9.7 -	0.9 -	0.3 -	11.0 -	1.1 -	0.7 -	11.0 -	1.1 -	0.5 -	6.0 -	1.1 -	0.4 -	2.1 2.2	1.5 1.6	0.3 0.4	12.0 -	1.9 -	0.9 -
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<1.0[e]	1.0[e]	<1.0[e]
pH	S.U.	7.0	7.3	7.2	7.0	7.2	7.1	7.1	7.2	7.2	7.0	7.0	7.1	7.2	7.2	7.1	7.1	7.2	7.1
Temperature	^0C	11.3	11.0	11.1	11.9	11.2	11.2	12.4	11.4	11.8	12.2	11.8	11.9	13.0	13.1	12.1	11.5	11.2	11.2
DO	mg/L	2.0	2.7	2.9	1.7	2.7	2.6	1.9	2.7	2.4	2.6	2.8	3.0	2.9	3.2	3.2	2.5	2.9	2.8
ORP	mV	291	294	293	285	321	311	329	316	314	265	351	315	258	286	301	268	318	291
Free Chlorine	mg/L	-	0.3	0.2	-	0.9	2.5	-	0.3	0.2	-	0.9	0.2	-	0.3	0.3	-	0.2	0.2
Total Chlorine	mg/L	-	2.9	2.9	-	2.6	2.6	-	2.9	2.7	-	2.8	2.7	-	2.8	3.3	-	3.3	3.3
Total Hardness	mg/L[a]	-	-	-	-	-	-	436	431	432	-	-	-	-	-	-	397	385	389
Ca Hardness	mg/L[a]	-	-	-	-	-	-	300	297	295	-	-	-	-	-	-	263	254	253
Mg Hardness	mg/L[a]	-	-	-	-	-	-	136	134	138	-	-	-	-	-	-	133	131	137
As (total)	µg/L	14.1 -	13.5 -	2.7 -	9.6 -	9.2 -	1.5 -	18.3 -	11.2 -	3.0 -	10.5 -	11.0 -	3.0 -	9.5 9.6	9.2 9.2	1.8 1.9	10.5 -	10.6 -	2.2 -
As (soluble)	µg/L	-	-	-	-	-	-	9.5	3.4	2.9	-	-	-	-	-	-	9.7	2.1	2.1
As (particulate)	µg/L	-	-	-	-	-	-	8.7	7.8	<0.1	-	-	-	-	-	-	0.8	8.5	0.1
As(III)	µg/L	-	-	-	-	-	-	7.8	2.1	2.1	-	-	-	-	-	-	8.5	0.6	0.6
As(V)	µg/L	-	-	-	-	-	-	1.8	1.3	0.8	-	-	-	-	-	-	1.2	1.5	1.5
Fe (total)	µg/L	754 -	759 -	<25 -	789 -	804 -	<25 -	3,214[d] -	1,277 -	<25 -	667 -	641 -	<25 -	236 245	240 245	<25 <25	851 -	862 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-	763	<25	<25	-	-	-	-	-	-	827	<25	<25
Mn (total)	µg/L	25.9 -	25.7 -	0.4 -	24.3 -	24.4 -	2.4 -	28.5 -	28.1 -	10.0 -	24.5 -	24.3 -	10.3 -	21.7 21.6	21.1 21.4	<0.1 <0.1	27.1 -	27.3 -	0.9 -
Mn (soluble)	µg/L	-	-	-	-	-	-	26.6	11.2	10.1	-	-	-	-	-	-	29.2	11.2	2.1

(a) As $CaCO_3$. (b) As P. (c) Water quality measurements taken on 10/31/06. (d) Reanalysis indicated similar result. (e) Sample analyzed outside of hold time.

Analytical Results from Long-Term Sampling at Sandusky, MI (Continued)

Sampling Date		12/12/06 - Well 1			12/19/06 - Well 1			01/04/07 - Well 1			01/09/07 - Well 1			01/17/07 - Well 1			01/23/07 - Well 1		
Sampling Location Parameter	Unit	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT
Alkalinity	mg/L[(a)]	299 -	313 -	301 -	333 -	331 -	331 -	325 -	323 -	325 -	307 -	322 -	322 -	317 -	324 -	306 -	319 -	328 -	326 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	0.3	0.3	0.3	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	0.6	0.6	0.8	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	98	100	118	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-
Phosphorus	µg/L[(b)]	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -
Silica (as SiO_2)	mg/L	11.4 -	11.2 -	11.3 -	12.0 -	11.7 -	11.6 -	11.5 -	11.8 -	11.6 -	11.8 -	12.1 -	12.0 -	13.5 -	12.4 -	11.8 -	12.1 -	11.6 -	11.9 -
Turbidity	NTU	11.0 -	0.5 -	<0.1 -	12.0 -	1.1 -	0.7 -	11.0 -	1.2 -	0.3 -	12.0 -	1.2 -	0.4 -	17.0 -	2.1 -	0.7 -	13.0 -	0.9 -	0.2 -
TOC	mg/L	-	-	-	-	-	-	<1.0[(c)]	<1.0[(c)]	<1.0[(c)]	-	-	-	-	-	-	-	-	-
pH	S.U.	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.3	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2
Temperature	^0C	12.2	11.4	11.2	11.6	11.2	11.2	11.9	11.1	11.3	11.3	11.0	11.3	11.1	10.9	10.9	11.4	11.0	11.2
DO	mg/L	1.8	2.7	2.9	2.5	3.2	2.4	1.1	3.3	2.5	1.5	2.7	1.6	1.3	3.0	2.8	1.2	1.7	1.4
ORP	mV	255	284	490	272	286	447	267	430	438	297	344	290	297	454	433	356	356	378
Free Chlorine	mg/L	-	2.0	0.2	-	0.7	0.6	-	0.2	1.0	-	0.2	0.1	-	0.2	0.2	-	0.2	0.1
Total Chlorine	mg/L	-	2.9	2.9	-	2.5	2.6	-	2.2	2.3	-	2.5	2.4	-	2.0	2.0	-	2.0	1.9
Total Hardness	mg/L[(a)]	-	-	-	-	-	-	410	405	408	-	-	-	-	-	-	-	-	-
Ca Hardness	mg/L[(a)]	-	-	-	-	-	-	289	281	281	-	-	-	-	-	-	-	-	-
Mg Hardness	mg/L[(a)]	-	-	-	-	-	-	121	124	127	-	-	-	-	-	-	-	-	-
As (total)	µg/L	9.8 -	10.1 -	2.2 -	9.7 -	9.7 -	1.5 -	10.4 -	10.5 -	1.2 -	9.7 -	9.7 -	1.5 -	20.4 -	12.7 -	3.6 -	9.4 -	10.1 -	1.6 -
As (soluble)	µg/L	-	-	-	-	-	-	8.7	1.8	1.2	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	1.6	8.7	<0.1	-	-	-	-	-	-	-	-	-
As(III)	µg/L	-	-	-	-	-	-	7.3	0.3	0.2	-	-	-	-	-	-	-	-	-
As(V)	µg/L	-	-	-	-	-	-	1.4	1.5	1.0	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	777 -	788 -	<25 -	1,011 -	890 -	<25 -	862 -	873 -	<25 -	868 -	877 -	<25 -	1,523 -	1,429 -	182 -	790 -	804 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-	831	<25	<25	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	23.6 -	24.7 -	7.2 -	25.2 -	26.0 -	11.4 -	25.1 -	25.6 -	15.6 -	24.4 -	24.6 -	13.1 -	27.4 -	31.4 -	25.5 -	25.1 -	25.0 -	17.4 -
Mn (soluble)	µg/L	-	-	-	-	-	-	26.5	13.9	17.1	-	-	-	-	-	-	-	-	-

(a) As $CaCO_3$. (b) As P. (c) Sample analyzed outside of hold time.

Analytical Results from Long-Term Sampling at Sandusky, MI (Continued)

Sampling Date		01/30/07 - Well 1			02/06/07 - Well 1			02/13/07 - Well 1			02/20/07 - Well 1			02/28/07[d] - Well 1			03/06/07[e] - Well 1		
Sampling Location Parameter	Unit	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT
Alkalinity	mg/L[a]	335 -	340 -	337 -	327 -	329 -	322 -	318 -	320 -	322 -	330 337	330 327	330 332	322 -	318 -	320 -	322 -	327 -	332 -
Ammonia (as N)	mg/L	0.3	0.3	0.3	-	-	-	-	-	-	-	-	-	0.3	0.3	0.3	-	-	-
Fluoride	mg/L	1.2	1.2	0.7	-	-	-	-	-	-	-	-	-	0.7	0.6	0.6	-	-	-
Sulfate	mg/L	104	98	95	-	-	-	-	-	-	-	-	-	101	102	104	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	<0.05	0.1	<0.05	-	-	-
Phosphorus	µg/L[b]	<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	11.4 -	11.6 -	11.4 -	11.2 -	11.5 -	11.3 -	12.1 -	12.7 -	11.9 -	11.9 12.0	12.4 12.1	12.1 12.4	12.6 -	12.9 -	12.7 -	11.6 -	11.5 -	11.8 -
Turbidity	NTU	14.0 -	1.1 -	0.7 -	13.0 -	0.7 -	0.3 -	12.0 -	1.5 -	0.6 -	12.0 11.0	1.5 1.4	0.5 0.8	13.0 -	1.8 -	0.6 -	13.0 -	1.9 -	0.6 -
TOC	mg/L	<1.0	<1.0	<1.0	-	-	-	-	-	-	-	-	-	1.3	1.1	<1.0	-	-	-
pH	S.U.	7.1	7.2	7.1	6.4	7.1	7.3	7.2	7.2	7.2	7.2	7.2	7.2	7.1	7.3	7.2	7.2	7.3	7.2
Temperature	^0C	11.1	11.0	11.1	9.7	10.2	10.2	10.7	10.7	10.8	11.6	11.0	11.3	11.5	10.9	11.1	11.1	10.8	10.9
DO	mg/L	1.2	1.3	1.5	1.2	1.8	1.6	1.2	1.8	1.7	1.1	1.8	1.7	1.3	1.9	1.3	1.2	2.4	2.2
ORP	mV	368	375	340	353	373	286	318	353	279	307	295	275	386	344	275	336	369	298
Free Chlorine	mg/L	-	0.8	0.5	-	0.2	0.2	-	0.5	0.1	-	0.2	0.5	-	0.2	0.2	-	0.4	0.3
Total Chlorine	mg/L	-	1.1	1.2	-	1.9	1.6	-	1.6	1.5	-	1.7	1.5	-	1.6	1.4	-	1.5	1.3
Total Hardness	mg/L[a]	345	347	351	-	-	-	-	-	-	-	-	-	328	330	331	-	-	-
Ca Hardness	mg/L[a]	210	214	211	-	-	-	-	-	-	-	-	-	196	198	198	-	-	-
Mg Hardness	mg/L[a]	135	132	140	-	-	-	-	-	-	-	-	-	132	132	133	-	-	-
As (total)	µg/L	22.5 -	20.8 -	1.9 -	10.8 -	10.5 -	1.4 -	9.1 -	9.1 -	3.6 -	16.5 16.6	17.3 17.6	0.9 1.0	10.5 -	9.6 -	1.7 -	11.0 -	10.7 -	2.7 -
As (soluble)	µg/L	18.4	1.3	1.9	-	-	-	-	-	-	-	-	-	8.7	2.0	1.6	-	-	-
As (particulate)	µg/L	4.1	19.5	<0.1	-	-	-	-	-	-	-	-	-	1.8	7.7	<0.1	-	-	-
As(III)	µg/L	18.9	<0.1	1.0	-	-	-	-	-	-	-	-	-	7.0	0.8	0.7	-	-	-
As(V)	µg/L	<0.1	1.3	0.9	-	-	-	-	-	-	-	-	-	1.7	1.2	0.9	-	-	-
Fe (total)	µg/L	1,285 -	904 -	<25 -	880 -	797 -	<25 -	897 -	813 -	211[c] -	935 958	886 898	<25 <25	826 -	769 -	<25 -	804 -	783 -	<25 -
Fe (soluble)	µg/L	902	<25	<25	-	-	-	-	-	-	-	-	-	755	<25	<25	-	-	-
Mn (total)	µg/L	28.7 -	28.7 -	20.9 -	25.6 -	25.6 -	16.1 -	25.2 -	25.5 -	19.7 -	25.5 25.8	27.0 26.9	30.4 30.8	25.7 -	25.4 -	20.8 -	25.1 -	25.3 -	22.7 -
Mn (soluble)	µg/L	28.9	21.4	20.2	-	-	-	-	-	-	-	-	-	25.9	23.1	20.9	-	-	-

(a) As $CaCO_3$. (b) As P. (c) Elevated level possibly due to extended filter run length for special breakthrough study. (d) Water quality measurements taken on 02/27/07.
(e) Water quality measurements taken on 03/08/07.

Analytical Results from Long-Term Sampling at Sandusky, MI (Continued)

Sampling Date		03/13/07[c] - Well 1			03/20/07 - Well 1			03/27/07 - Well 1			04/03/07 - Well 1			04/11/07[f] - Well 1			04/18/07 - Well 1		
Sampling Location Parameter	Unit	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT
Alkalinity	mg/L[a]	333 -	331 -	328 -	327 -	332 -	327 -	312 -	315 -	317 -	323 -	325 -	320 -	332 -	320 -	308 -	319 -	321 -	326 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	0.2	0.3	0.2	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	0.5	0.6	0.6	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	80	90	92	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-
Phosphorus	µg/L[b]	<10 -	<10 -	<10 -	15.7 -	<10 -	<10 -	13.4 -	17.2 -	15.1 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -
Silica (as SiO_2)	mg/L	11.6 -	12.0 -	12.0 -	11.7 -	12.1 -	11.9 -	11.4 -	11.3 -	11.3 -	11.5 -	11.8 -	11.5 -	12.0 -	12.0 -	12.5 -	12.3 -	12.7 -	12.5 -
Turbidity	NTU	13.0 -	4.5 -	1.1 -	7.7[e] -	1.8 -	2.4 -	11.0 -	1.8 -	0.7 -	13.0 -	3.2 -	0.8 -	13.0 -	5.0 -	1.5 -	13.0 -	1.4 -	0.8 -
TOC	mg/L	-	-	-	-	-	-	1.0	1.0	<1.0	-	-	-	-	-	-	-	-	-
pH	S.U.	7.2	7.2	7.2	6.7	7.3	7.3	7.2	7.3	7.3	7.2	7.2	7.3	7.1	7.2	7.2	7.2	7.2	7.2
Temperature	^{0}C	11.8	11.1	11.3	11.6	11.0	10.8	11.7	11.6	11.5	12.0	11.2	11.4	11.8	11.0	11.2	11.7	11.1	11.1
DO	mg/L	1.1	1.5	1.4	1.3	2.6	3.3	1.2	3.6	2.6	1.7	2.9	3.0	2.0	3.1	2.8	1.8	2.7	2.3
ORP	mV	325	325	361	304	379	318	293	331	289	298	331	283	294	318	274	286	319	285
Free Chlorine	mg/L	-	0.2	0.1	-	0.1	0.1	-	0.6	0.3	-	0.1	0.1	-	0.2	0.7	-	0.2	0.2
Total Chlorine	mg/L	-	2.2	2.0	-	1.9	1.9	-	1.5	1.6	-	2.1	2.0	-	2.2	2.1	-	2.5	2.7
Total Hardness	mg/L[a]	-	-	-	-	-	-	435	421	411	-	-	-	-	-	-	-	-	-
Ca Hardness	mg/L[a]	-	-	-	-	-	-	293	279	270	-	-	-	-	-	-	-	-	-
Mg Hardness	mg/L[a]	-	-	-	-	-	-	142	142	141	-	-	-	-	-	-	-	-	-
As (total)	µg/L	11.3 -	14.9 -	7.5[d] -	15.3 -	13.1 -	9.8[d] -	13.5 -	14.2 -	4.4 -	12.4 -	15.5 -	3.8 -	14.6 -	18.8 -	1.5 -	11.5 -	11.1 -	1.8 -
As (soluble)	µg/L	-	-	-	-	-	-	11.7	4.5	4.5	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	1.9	9.7	<0.1	-	-	-	-	-	-	-	-	-
As(III)	µg/L	-	-	-	-	-	-	10.4	3.2	3.2	-	-	-	-	-	-	-	-	-
As(V)	µg/L	-	-	-	-	-	-	1.2	1.3	1.3	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	778 -	1,036 -	410[d] -	1,098 -	1,231 -	617[d] -	801 -	897 -	<25 -	894 -	1,204 -	99.2 -	817 -	820 -	<25 -	737 -	730 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-	782	<25	<25	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	23.4 -	24.4 -	19.9 -	24.0 -	25.9 -	22.7 -	25.8 -	25.9 -	19.5 -	25.7 -	28.7 -	23.0 -	24.2 -	23.7 -	7.9 -	25.8 -	25.4 -	14.2 -
Mn (soluble)	µg/L	-	-	-	-	-	-	35.6	22.3	19.8	-	-	-	-	-	-	-	-	-

(a) As $CaCO_3$. (b) As P. (c) Water quality measurements taken on 03/15/07. (d) Elevated level possibly due to sample collection shortly after backwash. Reanalysis indicated similar result. (e) Reanalyzed outside of hold time. (f) Water quality measurements taken on 04/12/07.

Analytical Results from Long-Term Sampling at Sandusky, MI (Continued)

Sampling Date		04/25/07 - Well 1			05/02/07 - Well 1			05/09/07 - Well 1			05/15/07 - Well 1			05/23/07 - Well 1			05/29/07 - Well 1		
Sampling Location / Parameter	Unit	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT	IN	AD	TT
Alkalinity	mg/L[(a)]	337	337	334	320	320	316	319	310	307	305	298	298	310	310	310	322	320	322
		-	-	-	-	-	-	-	-	-	302	300	305	-	-	-	-	-	-
Ammonia (as N)	mg/L	0.3	0.2	0.2	-	-	-	-	-	-	-	-	-	0.5	0.4	0.4	-	-	-
Fluoride	mg/L	0.4	0.5	0.5	-	-	-	-	-	-	-	-	-	0.5	0.5	0.6	-	-	-
Sulfate	mg/L	100	98	96	-	-	-	-	-	-	-	-	-	101	103	103	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-
Phosphorus	µg/L[(b)]	<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	13.0	12.9	13.3	12.6	12.8	12.5	12.1	11.8	11.9	11.8	12.3	12.3	12.3	12.3	12.0	13.0	12.8	12.9
		-	-	-	-	-	-	-	-	-	11.9	12.5	11.9	-	-	-	-	-	-
Turbidity	NTU	14.0	1.0	0.5	12.0	1.5	0.3	11.0	1.3	0.3	15.0	2.5	1.8	12.0	1.2	0.5	13.0	1.0	0.8
		-	-	-	-	-	-	-	-	-	12.0	2.1	1.2	-	-	-	-	-	-
TOC	mg/L	1.0	1.3	<1.0	-	-	-	-	-	-	-	-	-	1.2	1.1	1.1	-	-	-
pH	S.U.	7.1	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.2	7.2	7.2	7.2	7.1	7.2	7.1	7.1	7.2	7.2
Temperature	^{0}C	11.9	11.1	11.1	11.9	11.3	11.4	12.5	11.5	11.9	12.5	11.6	11.7	12.3	11.5	11.7	12.6	11.7	11.7
DO	mg/L	1.8	2.3	2.4	2.1	2.7	2.4	1.9	2.3	2.0	0.9	2.6	2.7	2.3	2.8	2.2	1.5	1.8	1.9
ORP	mV	309	343	298	285	312	286	332	356	287	299	301	286	299	363	352	289	313	279
Free Chlorine	mg/L	-	0.2	0.5	-	0.3	0.3	-	0.3	0.1	-	0.5	0.2	-	0.2	0.3	-	0.2	0.8
Total Chlorine	mg/L	-	2.8	2.7	-	3.2	2.9	-	2.7	2.7	-	3.0	2.8	-	3.3	3.2	-	3.2	3.3
Total Hardness	mg/L[(a)]	379	387	395	-	-	-	-	-	-	-	-	-	372	395	411	-	-	-
Ca Hardness	mg/L[(a)]	253	258	254	-	-	-	-	-	-	-	-	-	261	274	288	-	-	-
Mg Hardness	mg/L[(a)]	125	129	141	-	-	-	-	-	-	-	-	-	112	121	122	-	-	-
As (total)	µg/L	10.9	9.6	1.4	11.1	10.6	2.6	9.3	8.8	1.7	9.5	8.4	1.5	10.4	9.8	1.0	11.9	11.3	3.1
		-	-	-	-	-	-	-	-	-	8.5	8.5	1.8	-	-	-	-	-	-
As (soluble)	µg/L	10.2	1.9	1.9	-	-	-	-	-	-	-	-	-	8.2	1.3	1.0	-	-	-
As (particulate)	µg/L	0.6	7.6	<0.1	-	-	-	-	-	-	-	-	-	2.2	8.5	<0.1	-	-	-
As(III)	µg/L	8.5	0.2	0.4	-	-	-	-	-	-	-	-	-	6.8	0.2	0.2	-	-	-
As(V)	µg/L	1.7	1.7	1.5	-	-	-	-	-	-	-	-	-	1.5	1.1	0.8	-	-	-
Fe (total)	µg/L	977	916	<25	1,061	907	<25	770	805	<25	1,023	838	<25	861	861	<25	1,026	969	<25
		-	-	-	-	-	-	-	-	-	851	819	<25	-	-	-	-	-	-
Fe (soluble)	µg/L	925	<25	<25	-	-	-	-	-	-	-	-	-	805	<25	<25	-	-	-
Mn (total)	µg/L	27.8	28.0	11.6	27.0	26.9	10.9	23.7	24.8	9.4	23.2	22.7	9.8	23.2	23.7	5.3	28.9	28.5	0.6
		-	-	-	-	-	-	-	-	-	23.0	22.2	9.6	-	-	-	-	-	-
Mn (soluble)	µg/L	28.9	23.5	11.7	-	-	-	-	-	-	-	-	-	25.0	19.4	5.5	-	-	-

(a) As $CaCO_3$. (b) As P.

Analytical Results from Long-Term Sampling at Sandusky, MI (Continued)

Sampling Date		06/05/07 - Well 1			06/12/07 - Well 1		
Sampling Location		IN	AD	TT	IN	AD	TT
Parameter	Unit						
Alkalinity	mg/L[(a)]	306 -	320 -	323 -	313 -	311 -	320 -
Ammonia (as N)	mg/L	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-
Phosphorus	µg/L[(b)]	<10 -	<10 -	<10 -	<10 -	<10 -	<10 -
Silica (as SiO_2)	mg/L	12.7 -	12.1 -	12.2 -	11.8 -	12.3 -	11.9 -
Turbidity	NTU	11.0 -	1.6 -	1.1 -	12.0 -	3.4 -	3.4 -
TOC	mg/L	-	-	-	-	-	-
pH	S.U.	7.0	7.1	7.1	7.2	7.2	7.2
Temperature	^{0}C	12.5	11.7	11.6	12.9	11.6	11.7
DO	mg/L	2.3	3.0	2.7	2.0	3.1	2.8
ORP	mV	314	361	297	334	358	313
Free Chlorine	mg/L	-	0.3	0.3	-	0.3	1.8
Total Chlorine	mg/L	-	3.5	3.5	-	3.3	3.3
Total Hardness	mg/L[(a)]	-	-	-	-	-	-
Ca Hardness	mg/L[(a)]	-	-	-	-	-	-
Mg Hardness	mg/L[(a)]	-	-	-	-	-	-
As (total)	µg/L	8.6 -	8.3 -	1.1 -	9.4 -	9.2 -	0.4 -
As (soluble)	µg/L	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-
As(III)	µg/L	-	-	-	-	-	-
As(V)	µg/L	-	-	-	-	-	-
Fe (total)	µg/L	1,015 -	948 -	<25 -	809 -	813 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-
Mn (total)	µg/L	24.9 -	25.7 -	8.1 -	26.7 -	26.9 -	0.9 -
Mn (soluble)	µg/L	-	-	-	-	-	-

(a) As $CaCO_3$. (b) As P.