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Arsenic Removal from Drinking Water by Coagulation/Filtration U.S. EPA Demonstration Project at Village of Pentwater, MI Final Performance Evaluation Report

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Sally Gutierrez, Director
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ABSTRACT

This report documents the activities performed during and the results obtained from the arsenic removal treatment technology demonstration project at the Village of Pentwater, MI facility. The objectives of the project were to evaluate: (1) the effectiveness of Kinetico's FM-260-AS treatment system using Macrolite® media 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 review and approval of the engineering plan by the State, the FM-260-AS treatment system was installed and became operational on November 22, 2005. The system consisted of one 96-in × 96-in steel contact tank and two 60-in × 96-in steel pressure tanks configured in parallel. Each pressure tank was loaded with 40 ft^3 of Macrolite® media to which filtration rates up to 9.3 gpm/ft^2 were applied The system used an existing chlorination system to oxidize As(III) and Fe(II) and the contact tank to improve the formation of As(V)-laden iron particles prior to filtration. An iron addition system was installed midway through the study to improve arsenic removal. On average, the system operated at approximately 350 gal/min (gpm) for 5.1 hr/day, producing 39,185,000 gal of water through December 8, 2006. This average flowrate corresponded to a contact time of 6.8 min and a filtration rate of 8.9 gpm/ft^2. Several problems were encountered during the demonstration study, including programmable logic controller (PLC) settings, backwash and service flowrates, media loss, influent pressure spikes, and chlorine addition. The actions taken to address these problems are detailed in the report.

Source water had an average pH value of 7.9 and contained 14.6 to 21.8 μg/L of total arsenic. The predominant arsenic species was As(III) with an average concentration of 14.9 μg/L. Total iron concentrations ranged from 346 to 510 μg/L, which mostly existed in the soluble form. Chlorine was used to oxidize As(III) and Fe(II). Although breakpoint chlorination likely was achieved during most of the study period, chloramines might have been formed due to the occurrence of 0.3 mg/L (as N) of ammonia in source water, causing incomplete As(III) oxidation. As a result, as much as 1.6 μg/L of As(III) was measured in the treated water. Total arsenic concentrations in the treated water ranged from 7.8 to 15.6 μg/L and averaged 9.9 μg/L. After months of system operations, provisions were made to add $FeCl_3$ at an average dosage of 0.5 mg/L (as Fe) to improve As(V) removal. This pretreatment raised iron concentrations following the contact tank to 658 to 1,638 μg/L, thereby lowering the average arsenic concentration to 5.6 μg/L in the treated water.

The treatment system decreased arsenic levels in the distribution system from 16.5 to 7.5 μg/L. Iron and manganese levels also were reduced from 192 to <25 μg/L and from 23.8 to 13.7 μg/L, respectively. Alkalinity, pH, and lead levels did not appear to be affected.

Filters were backwashed automatically about 3 times/week triggered by 24-hr service time or 48-hr standby time. Approximately 749,800 gal of wastewater, or 1.9% of the amount of water treated, was generated during the study. Without iron addition, the backwash wastewater contained 252 to 646 mg/L of total dissolved solids (TDS) and 24 to 166 mg/L of total suspended solids (TSS). With iron addition, TDS ranged from 354 to 498 mg/L and TSS from 160 to 282 mg/L with the majority exisiting as particulates. The backwash solids contained approximately 2.10 lb of iron, 0.03 lb of manganese, and 0.03 lb of arsenic.

The capital investment for the treatment system was $334,573, consisting of $224,994 for equipment, $30,929 for site engineering, and $78,650 for installation, shakedown, and startup. Using the system's rated capacity of 400 gpm (or 576,000 gal/day [gpd]), the capital cost was $836/gpm (or $0.58/gpd). This calculation does not include the cost of the building to house the treatment system. O&M cost, estimated at $0.17/1,000 gal, included only the incremental cost for chemicals, electricity, and labor. Since chlorine addition already existed prior to the demonstration study, the incremental cost for chemical usage was for iron addition only.

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ABBREVIATIONS AND ACRONYMS

Δp	differential pressure
AA	activated alumina
AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
As	arsenic
ATS	Aquatic Treatment Systems
bgs	below ground surface
C/F	coagulation/filtration
Ca	calcium
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
$FeCl_3$	ferric chloride
FedEx	Federal Express
FTW	filter to waste
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
HAA	heloacetic acid
HDPE	high-density polyethylene
HIX	hybrid ion exchanger
hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IX	ion exchange
LCR	(EPA) Lead and Copper Rule
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 analyzed
NaOCl	sodium hypochlorite
ND	not detected
NS	not sampled
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
P&ID	piping and instrumentation diagram
Pb	lead
pCi/L	picocuries per liter
psi	pounds per square inch
psig	pounds per square inch gauge
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
RPD	relative percent difference
RO	reverse osmosis
Sb	antimony
SDWA	Safe Drinking Water Act
SiO_2	silica
SMCL	secondary maximum contaminant level
SO_4	sulfate
STS	Severn Trent Services
TDH	total dynamic head
TDS	total dissolved solids
THM	trihalomethanes
TOC	total organic carbon
TSS	total suspended solids

UPS	uninterruptible power supply
V	vanadium

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Section 1.0 INTRODUCTION

1.1 Background

The Safe Drinking Water Act (SDWA) mandates that the U.S. Environmental Protection Agency (EPA) identify and regulate drinking water contaminants that may have adverse human health effects and that are known or anticipated to occur in public water supply systems. In 1975 under the SDWA, EPA established a maximum contaminant level (MCL) for arsenic at 0.05 mg/L. Amended in 1996, the SDWA required that EPA develop an arsenic research strategy and publish a proposal to revise the arsenic MCL by January 2000. On January 18, 2001, EPA finalized the arsenic MCL at 0.01 mg/L (EPA, 2001). In order to clarify the implementation of the original rule, EPA revised the rule text on March 25, 2003, to express the MCL as 0.010 mg/L (10 μg/L) (EPA, 2003). The final rule 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 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 Village of Pentwater, 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. Kinetico's Macrolite® Arsenic Removal Technology was selected for demonstration at the Pentwater facility. As of December 2007, 37 of the 40 systems have been operational, and the performance evaluation of 26 systems has been completed.

1.2 Treatment Technologies for Arsenic Removal

The technologies selected for the Round 1 and Round 2 demonstration host sites include 25 adsorptive media (AM) systems (the Oregon Institute of Technology [OIT] site has three AM systems), 13 coagulation/filtration (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 cost 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 Kinetico system at the Village of Pentwater in Michigan from November 22, 2005 through December 8, 2006. The types of data collected include system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and preliminary O&M cost.

Table 1-1. Summary of 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

Based on the information collected from operation of Kinetico's FM-260-AS treatment system with Macrolite® media at Village of Pentwater, MI from November 22, 2005 to December 8, 2006, the following summary and conclusions are provided relating to the overall objectives of the treatment technology demonstration study.

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

- Chlorination was effective in oxidizing As(III) to As(V) and Fe(II) to Fe(III). However, the presence of chloramines might have contributed to incomplete oxidation of As(III), leaving as much as 1.6 µg/L of As(III) in treated water.
- Supplemental iron addition at 0.5 mg/L was needed to achieve consistent arsenic removal to <10 µg/L.
- With proper operation of the chlorine addition system and supplemental iron addition, the Macrolite® pressure filters were effective in removing arsenic and iron particles at filtration rates ranging from 8.4 to 9.3 gpm/ft^2. These filtration rates were two to three times higher than those normally applied to gravity filters.
- Even at high filtration rates up to 9.3 gpm/ft^2, the filter runs could last for 12 hr (on average), which was substantially better than the performance of some of the other Macrolite® systems evaluated by this demonstration project. Iron addition did not reduce the filter run length.
- Backwash was effective in restoring differential pressure (Δp) across a filter to its clean bed level of 4 to 6 lb/in^2 (psi).
- The system improved water quality in the distribution system by decreasing arsenic, iron, and manganese concentrations. Alkalinity, pH, and lead concentrations did not appear to be affected.

Required system O&M and operator skill levels:

- The daily demand on the operator was short, averaging 30 min for routine O&M. However, a significant amount of time and effort was required to troubleshoot backwash-related issues.
- Incorrectly calibrated flow meters caused much confusion and resulted in erroneous service and backwash flowrates and media loss. Flow meter readings should be verified, especially if and when a system is performing outside of its design specifications.

Characteristics of residuals produced by the technology:

- Wastewater production was equivalent to about 1.9% of the amount of water treated.
- Approximately 0.5 lb of residual solids was produced during each backwash cycle prior to iron addition. Thereafter, 2.6 lb of solids was produced including 2.10 lb of iron, 0.03 lb of manganese, and 0.03 lb of arsenic.

Capital and O&M cost of the technology:

- The capital investment for the system was $334,573, consisting of $224,994 for equipment, $30,929 for site engineering, and $78,650 for installation, shakedown, and startup.
- The unit capital cost was $836/gpm (or $0.58/gpd) based on a 400-gpm design capacity. This calculation does not reflect the building cost as it was funded by the Village.
- The O&M cost was $0.17/1,000 gal including incremental cost for chemicals, 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 Kinetico treatment system began on November 22, 2005, and ended on December 8, 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. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

The O&M and operator skill requirements were 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 and/or media handling and inventory, and general knowledge needed for relevant chemical processes and related health and safety practices. The staffing requirements for the system operation were recorded on an Operator Labor Hour Log Sheet.

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

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 media replacement and disposal, chemical supply, electricity usage, and labor.

Table 3-1. Predemonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	August 31, 2004
Draft Letter of Understanding Issued	October 19, 2004
Final Letter of Understanding Issued	November 4, 2004
Request for Quotation Issued to Vendor	November 10, 2004
Vendor Quotation Received	December 2, 2004
Purchase Order Established	February 1, 2005
Letter Report Issued	March 1, 2005
Engineering Package Submitted to MDEQ	March 29, 2005
Study Plan Issued	March 30, 2005
System Permit Granted by MDEQ	May 31, 2005
Building Construction Permit Granted by Oceana County	August 17, 2005
Building Construction Began	August 19, 2005
Building Completed and FM-260-AS System Shipped	October 21, 2005
System Installation Completed	November 4, 2005
System Shakedown Completed	November 11, 2005
Performance Evaluation Began	November 22, 2005

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 -Task analysis of preventative maintenance including number, frequency, and complexity of tasks -Chemical handling and inventory requirements -General knowledge needed for relevant chemical processes and health and safety practices
Residual Management	-Quantity and characteristics of aqueous and solid residuals generated by system operation
System Cost	-Capital cost for equipment, engineering, and installation -O&M cost for chemical usage, electricity consumption, and labor

3.2 System O&M and Cost Data Collection

The plant operator performed daily, 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) and ferric chloride ($FeCl_3$) levels, 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 and $FeCl_3$ 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, was tracked using an Operator Labor Hour Log Sheet. The routine system O&M included activities such as completing field logs, replenishing the chemical solutions, 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 wellhead, across the treatment plant, during Macrolite® filter backwash, and from the distribution system. The sampling schedule 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 schedule for each sampling location.

Table 3-3. Sampling Schedule and Analyses

Sample Type	Sample Locations(a)	No. of Samples	Frequency	Analytes	Collection Date(s) and Results
Source Water	IN	1	Once (during initial site visit)	On-site: pH, temperature, DO, and ORP Off-site: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, Cl, F, NH_3, NO_2, NO_3, SO_4, SiO_2, PO_4, TOC, TDS, turbidity, and alkalinity	Table 4-1
Treatment Plant Water	IN, AC, TA, TB	4	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
	IN, AC, TT	3	Monthly	Same as weekly analytes shown above plus the following: Off-site: As (soluble), As(III), As(V), Fe (soluble), Mn (soluble), Ca, Mg, F, NH_3, NO_3, SO_4, and TOC	Appendix B
Backwash Water	BW	2	Monthly	As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, TDS, and TSS	Table 4-10
Distribution Water	Three Non-LCR Residences	3	Monthly	Total As, Fe, Mn, Cu, and Pb, pH, and alkalinity	Table 4-12
Residual Solids	SS (backwash solids)	2	Twice	Total Al, As, Ca, Cd, Cu, Fe, Mg, Mn, Ni, P, Pb, Si, and Zn	Table 4-11

(a) Abbreviation corresponding to sample location in Figure 3-1, i.e., IN = at wellhead; AC = after contact tank; TA = after tank A; TB = after Tank B; TT = after filter tanks combined; BW = at backwash discharge line; SS = sludge sampling location

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

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.

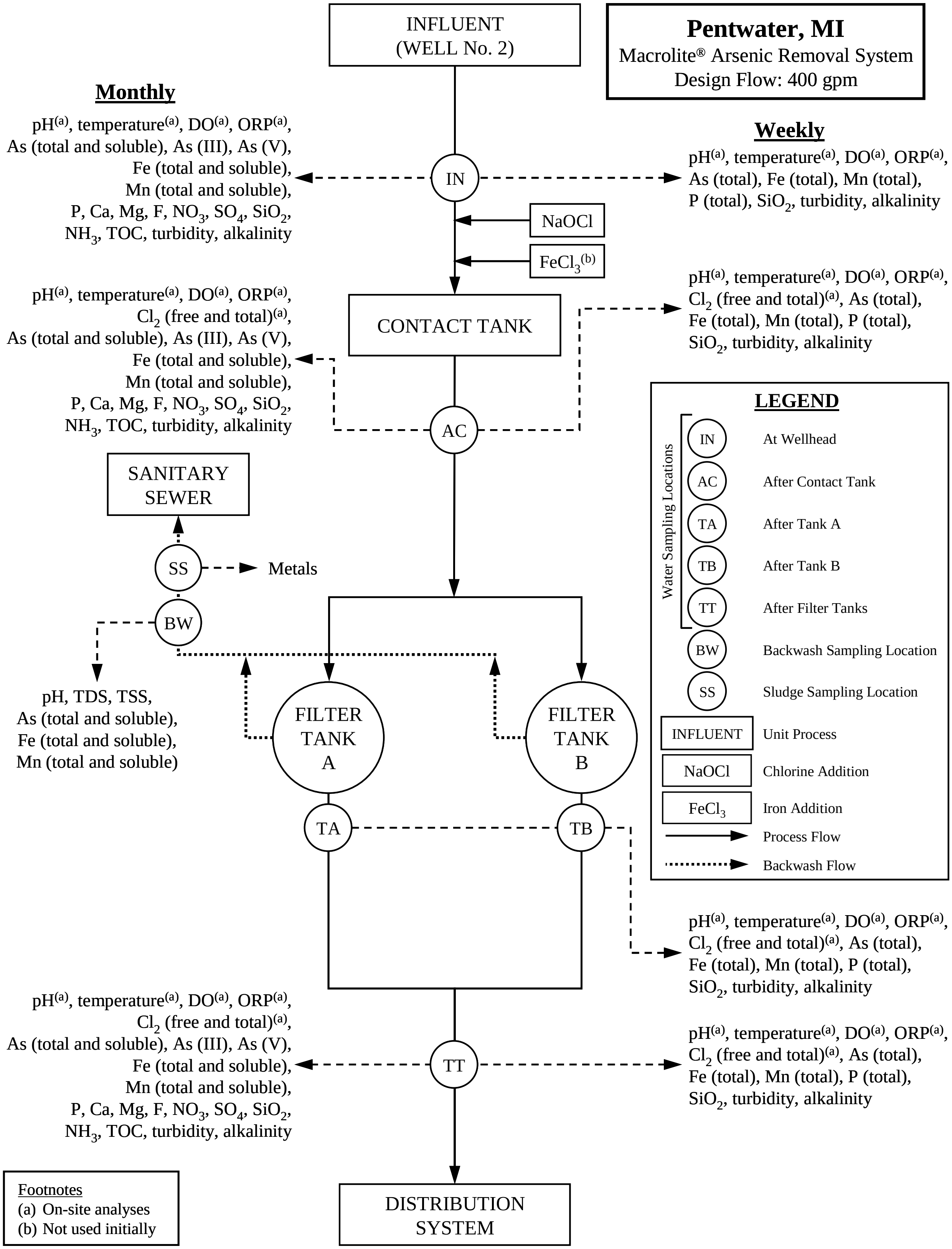


Figure 3-1. Process Flow Diagram and Sampling Schedule and Locations

3.3.2 Treatment Plant Water. The plant operator collected treatment plant water samples weekly, on a four-week cycle, for on- and off-site analyses. For the first week of each four-week cycle, samples were collected at the wellhead (IN), after the contact tank (AC), and after filter tanks combined (TT), and speciated on-site and analyzed for the analytes listed in Table 3-3. For the next three weeks, samples were collected at IN, AC, after Tank A (TA), and after Tank B (TB) and analyzed for the analytes listed in Table 3-3.

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 tank. After the content in the container was thoroughly mixed, composite samples were collected and/or filtered on-site with 0.45-µm disc filters. Analytes for the backwash samples are listed in Table 3-3.

3.3.4 Distribution System Water. Water samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically, the arsenic, lead, and copper levels. Prior to system startup from February to May 2005, four monthly baseline distribution water samples were collected from three residences within the distribution system. Following system startup, distribution system sampling continued on a monthly basis at the same three locations.

Homeowners collected samples following an instruction sheet developed according to the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The dates and times of last water usage before sampling and of actual 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 hours to ensure that stagnant water was sampled.

3.3.5 Residual Solids. Residual solids produced by the treatment process consisted of only backwash water 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 on two occasions for processing and analysis by Battelle. A portion of each of the solids/water mixtures was air-dried for metals 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). 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 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 location, placed in Ziplock® bags, and packed into the cooler.

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

3.4.3 Sample Shipping and Handling. After sample collection, samples for off-site analyses were packed carefully in the original coolers with wet ice and shipped back 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 Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) Laboratory. Samples for other water quality analyses were packed in separate coolers and picked up by couriers from American Analytical Laboratories (AAL) in Columbus, OH; TCCI Laboratories in New Lexington, OH; and/or Belmont Labs in Englewood, OH, which were under contract with Battelle for this demonstration study. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

3.5 Analytical Procedures

The analytical procedures described in Section 4.0 of the QAPP (Battelle, 2004) were followed by Battelle ICP-MS, AAL, and TCCI Laboratories, 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 RESULTS AND DISCUSSION

4.1 Site Description

4.1.1 Existing Facility. Three wells (Wells No. 1, 2, and 3) owned by the Village of Pentwater supplied water to a population of about 1,000, which increased during the summer months with the influx of tourists and summer residents. Well No. 2 was primarily used to meet the village's daily demand, and Wells No. 1 and 3 were used as backup wells to meet the peak demand of 300,000 gpd. Typical daily operational time was 16 to 18 hr during the summer and 4 to 5 hr during the winter.

Well No. 2, selected for this demonstration study, was a 10-in-diameter, 235-ft-deep well screened from 195 to 235 ft below ground surface (bgs) with a static water level at 40 ft bgs. The well was equipped with a 30-horsepower (hp) submersible pump rated for 250 gpm at 300 ft of total dynamic head (TDH). Operating at a reduced TDH of 184 ft, Well No. 2 had a capacity of approximately 350 gpm, which was notably less than the 420 gpm expected based on the pump curve.

Prior to the installation of the arsenic removal system, treatment consisted of chlorine and polyphosphate additions in the Well No. 2 pump house (Figure 4-1). A 15% NaOCl solution stored in a 55-gal drum was injected at 2 to 3 mg/L using a 1.0-gal/hr (gph) pump to attain a free chlorine residual of approximately 0.5 mg/L. A phosphate mixture (i.e., 85% polyphosphate and 15% orthophosphate) also was added at 2 mg/L using a 2.5-gph pump for iron sequestration and corrosion control. The treated water was stored in a 150,000-gal water tower with level sensors for well pump control.

Figure 4-1. Existing Facility and System Components
(Clockwise from Top: Well No. 2 Pump House, Water Tower, Polyphosphate Drum, Wellhead Totalizer, and Piping and Chlorine Addition Equipment)

4.1.2 Distribution System. The distribution system consisted of a looped distribution line, with 6- and 8-in-diameter ductile iron and sand cast iron piping, linked to the primary supply well (i.e., Well No. 2) and two backup wells (i.e., Wells No. 1 and 3). The individual service connections consisted of primarily ¾- to 1-in copper lines. Three residences served by the supply wells were selected for the distribution system sampling. These sampling locations were not part of the Village's historic sampling network for EPA's Lead and Copper Rule (LCR) due to limited availability of such homes year-round.

The Village samples water from the distribution system monthly for bacteria analysis, semi-annually for trihalomethanes (THMs) and haloacetic acids (HAAs) analysis under EPA's Disinfection Byproducts Rule (DBPR), and once every three years for lead and copper analysis at 10 residences under EPA's LCR. The wells also are sampled periodically for arsenic and other constituents.

4.1.3 Source Water Quality. Source water samples were collected by Battelle from Well No. 2 on August 31, 2004. The results of the source water analysis are presented in Table 4-1 and compared to those provided by the facility, vendor, and Michigan Department of Environmental Quality (MDEQ).

Total arsenic concentrations in source water ranged from 17 to 24 µg/L. The August 31, 2004, test results showed a total arsenic concentration of 13.4 µg/L, of which 13.2 µg/L existed as soluble arsenic and only 0.2 µg/L as particulate arsenic. The soluble fraction consisted of 11.1 µg/L (or 83%) of As(III) and 2.1 µg/L (or 16%) of As(V). 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 and manganese concentrations in source water ranged from 300 to 600 µg/L and 32.4 to 80 µg/L, respectively, which exceeded the secondary MCLs (SMCLs) of 0.3 mg/L for iron and 0.05 mg/L for manganese. Based on the August 31, 2004 results, both iron and manganese existed almost entirely in the soluble form. This, along with the high level of As(III) measured, suggested that the source water was under reducing conditions. These observations were consistent with the relatively low DO (at 1.3 mg/L) and ORP (at -97 mV) readings measured on site on August 31, 2004. To achieve compliance of the arsenic MCL, the general recommendations are that the soluble iron concentration should be at least 20 times the soluble arsenic concentration (Sorg, 2002), and that the pH value falls in the range between 5.5 and 8.5 (note that improved system performance may be observed at the lower end of this pH range). The results obtained on August 30, 2004 indicated a soluble iron to soluble arsenic ratio of 35:1 and a pH value of 6.9. Although the pH value measured by the vendor on November 6, 2003, was 1 unit higher at 7.9, no provisions were made for iron addition or pH adjustment.

The August 31, 2004 test results showed 0.3 mg/L (as N) of ammonia in raw water. The presence of ammonia will increase the chlorine demand. Chlorine added to raw water will oxidize As(III) and other reducing species, such as Fe(II) and Mn(II), and react with ammonia and organic nitrogen compounds, if any, to form combined chlorine (i.e., mono- and dichloramines 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. The theoretical chlorine dosage required was 3.2 mg/L (as Cl_2), which consisted of 1) the amount needed to oxidize As(III), Fe(II), Mn(II), and any other reducing species, estimated to be 0.4 mg/L (as Cl_2) (Ghurye and Clifford, 2001), 2) the amount needed to oxidize ammonia and combined chlorine formed during chlorination, estimated to be 2.3 mg/L (as Cl_2) (Clark et al., 1977), and 3) the amount needed to provide the target free chlorine residual of 0.5 mg/L (as Cl_2).

Because of the addition of 3.2 mg/L (as Cl_2) of chlorine and because of the presence of 2.5 mg/L of total organic carbon (TOC) in raw water, a potential for the formation of disinfection byproducts (DBPs) existed in the treated water. The formation of DBPs was monitored by the State through the collection of samples for THMs and HAAs analyses (Section 4.1.2). Chlorine residuals, ammonia, and TOC also were monitored during the performance evaluation study.

Table 4-1. Well No. 2 Source Water Quality Data

Parameter	Unit	Facility Data	Kinetico Data	Battelle Data	MDEQ Data
Date	-	NA	11/06/03	08/31/04	04/08/00–02/26/04
pH	S.U.	NA	7.9	6.9	NA
Temperature	°C	NA	NA	13.7	NA
DO	mg/L	NA	NA	1.3	NA
ORP	mV	NA	NA	-97	NA
Alkalinity (as $CaCO_3$)	mg/L	NA	144	141	NA
Hardness (as $CaCO_3$)	mg/L	188	204	252	180–211
Turbidity	NTU	NA	NA	2.3	NA
TDS	mg/L	NA	NA	450	NA
TOC	mg/L	NA	NA	2.5	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	148	144	130	140–165
Fluoride	mg/L	NA	0.7	0.4	0.5–0.7
Sulfate	mg/L	<5	<4	1	<5
Silica (as SiO_2)	mg/L	NA	17.1	11.1	NA
Orthophosphate (as P)	mg/L	NA	<0.5	<0.1	NA
As (total)	µg/L	18.0	17.0	13.4	17.0–24.0
As (soluble)	µg/L	NA	NA	13.2	NA
As (particulate)	µg/L	NA	NA	0.2	NA
As(III)	µg/L	NA	NA	11.1	NA
As(V)	µg/L	NA	NA	2.1	NA
Ba (total)	µg/L	NA	NA	NA	90–110
Cr (total)	µg/L	NA	NA	NA	10
Ca (total)	mg/L	NA	47.5	56	NA
Fe (total)	µg/L	550	530	466	300–600
Fe (soluble)	µg/L	NA	NA	465	NA
Mg (total)	mg/L	NA	21	27	NA
Mn (total)	µg/L	NA	80	32.4	NA
Mn (soluble)	µg/L	NA	NA	32.6	NA
Na (total)	mg/L	58	67	83	51–73
Se (total)	µg/L	NA	NA	NA	6–8
U (total)	µg/L	NA	NA	<0.1	NA
U (soluble)	µg/L	NA	NA	<0.1	NA
V (total)	µg/L	NA	NA	1.4	NA
V (soluble)	µg/L	NA	NA	1.0	NA
Ra-226	pCi/L	NA	NA	NA	0.3
Ra-228	pCi/L	NA	NA	NA	0.1

Note: MDEQ data also reported non-detect levels of Be, Cd, Hg, Ni, Pb, Sb, and Tl.
TDS = total dissolved solids; TOC = total organic carbon; NA = not analyzed

Other source water quality parameters also were analyzed (Table 4-1). Concentrations of chloride, fluoride, nitrate, nitrite, orthophosphate, sulfate, silica, vanadium, uranium, combined radium, and other constituents were found to be relatively low and/or less than the respective method reporting limits and not expected to impact the arsenic removal. The total dissolved solids (TDS) level was near the 500-mg/L SMCL, presumably due to high concentrations of iron. Before the treatment system was installed, the facility had added polyphosphate as a sequestering agent for iron (Section 4.1.1). Because the treatment process was expected to significantly reduce the iron level, polyphosphate addition was discontinued when the treatment system went online. Hardness levels measured ranged from 180 to

252 mg/L (as $CaCO_3$); some customers of the water system had installed point of entry softeners to lower the hardness.

4.2 Treatment Process Description

The treatment train consisted of prechlorination/oxidation, iron addition (commencing half-way through the study), and Kinetico's Macrolite® pressure filtration. Macrolite® is a spherical, low density, chemically inert, ceramic media designed for filtration rates up to 10 gpm/ft^2. Macrolite® is approved for use in drinking water applications under NSF International (NSF) Standard 61. The physical properties of the M2 Macrolite® media used are summarized in Table 4-2.

Table 4-2. Physical Properties of M2 Macrolite® Media

Property	Value
Color	Variable
Uniformity Coefficient	1.1
Sphere Size Range (mm) [mesh]	0.21–0.42 [40 × 70]
Nominal Size (mm)	0.30
Bulk Density (g/cm^3) [lb/ft^3]	0.86 [54]
Specific Gravity	2.05

The treatment system was composed of one contact tank, two pressure filtration tanks arranged in parallel, and associated instrumentation to monitor pressure, flowrate, and backwash water turbidity. The system also was equipped with a central control panel that housed a touch screen operator interface panel (OIP), a programmable logic controller (PLC), a modem, and an uninterruptible power supply (UPS). The Allen Bradley PLC automatically controlled the system by actuating polyvinyl chloride (PVC) pneumatic valves using a 7.5-hp compressor depending on various inputs and outputs of the system and corresponding PLC setpoints (Section 4.4.3.1). The system also featured schedule 80 PVC solvent bonded plumbing and all necessary isolation and check valves and sampling ports. Figure 4-2 is a simplified system piping and instrumentation diagram (P&ID). Figures 4-3 and 4-4 contain photographs of the key system components and control and instrumentation, respectively. The system's design specifications are summarized in Table 4-3. The major processes included the following:

- **Intake**. Raw water was pumped from Well No. 2 at approximately 350 gpm. The well pump was activated and deactivated based on the preset low and high levels in the water tower. The inlet piping from the well into the building and the secondary piping to bypass the treatment system, if needed, are shown in Figure 4-3.
- **Chlorination**. The existing chlorine addition system was used to oxidize As(III) to As(V) and Fe(II) to Fe(III). The addition system consisted of a 55-gal day tank containing a 15% NaOCl solution and a 1.0-gph LMI chemical feed pump with stroke and speed settings for dosage adjustment. The feed pump was energized only when the well pump was on.
- **Iron Addition**. Because of a soluble iron to soluble arsenic ratio of 35:1, it was anticipated that removal of the natural iron would help remove soluble arsenic through coprecipitation/adsorption of As(V) with/onto iron solids after chlorination. However, the test results during the first six months of system operation showed that the levels of natural iron were inadequate to consistently remove arsenic to <10 µg/L. An iron addition system was, therefore, purchased and installed in April 2006. The system included a 1.6-gph chemical feed pump with a 4-function valve (LMI model B111-94S), a 1/20-hp overhead

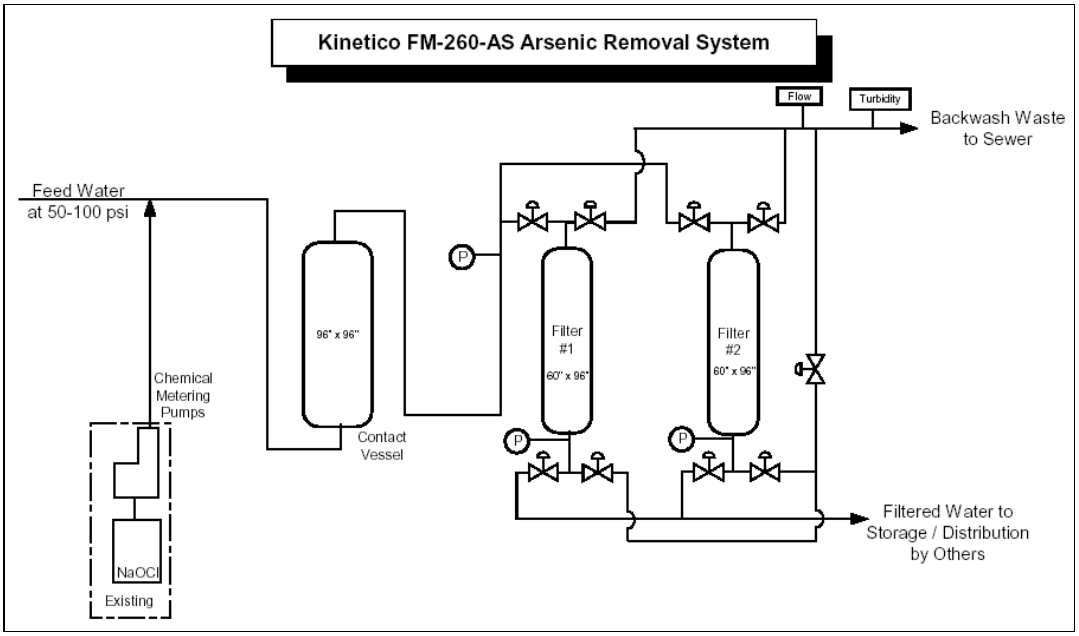


Figure 4-2. Schematic of Kinetico's FM-260-AS System

Figure 4-3. Treatment System Components
(Clockwise from Top: Well No. 2 Inlet and Bypass Piping with Iron Addition Point; Two Filter Tanks and a Contact Tank; Filter Tank Laterals and Viewglass; and Backwash Discharge Piping to Sump)

Figure 4-4. Control and Instrumentation

(Clockwise from Left: Control Panel Housing PLC; Turbidimeter Display; Compressor; and Sample Tap and Pressure Gauge)

Table 4-3. Design Specifications for Kinetico's FM-260-AS System

Parameter	Value	Remarks
Pretreatment		
Chlorine Dosage (mg/L [as Cl_2])	Field Determined	≥0.4 mg/L based on demand for As(III), Fe(II), and Mn(II) (Section 4.1.3)
Iron Dosage (mg/L [as Fe])	0.5	Not used until 06/15/06
Contact		
Tank Quantity	1	–
Tank Size (in)	96 D × 96 H	–
Tank Volume (gal)	2,400	–
Contact Time (min)	6	–
Filtration		
Tank Quantity	2	Parallel configuration
Tank Size (in)	60 D × 96 H	–
Tank Cross Section (ft^2)	19.6	–
Media Volume (ft^3/tank)	40	24-in bed depth
Peak Flowrate (gpm)	400	200 gpm/tank
Filtration Rate (gpm/ft^2)	10	200 gpm/tank
Δp across Tank (psi)	10–12	Across one clean filter
Maximum Production (gpd)	576,000	Based on peak flowrate, 24 hr/day
Hydraulic Utilization (%)	52	Estimated based on 300,000-gal peak daily demand in summer
Backwash		
Frequency	Variable	Based on PLC setpoints for Δp across tank, run time, and standby time
Hydraulic Loading Rate (gpm/ft^2)	8–10	157–196 gpm
Wastewater Production (gpd)	Variable	Based on PLC setpoints for minimum and maximum backwash time and turbidity

D = diameter; H = height

mixer (Pulsafeeder model FMTEH/Vinyl), a 55-gal high-density polyethylene (HDPE) tank (Pulsafeeder model J40366), and a 66-gal polyethylene spill containment pallet (U.S. Plastic model 2316). The chemical feed pump outlet was energized only when the well pump was on, and the pump had stroke and speed settings for dosage adjustment.

- **Coprecipitation/Adsorption.** One 96-in × 96-in epoxy-lined steel contact tank (Arrow Tank & Engineering), designed for 6 min of contact time, was used to improve the formation of iron flocs prior to pressure filtration. The 2,400-gal tank had 6-in top and bottom flanges connecting to the exit and inlet piping, respectively, for an upflow configuration (Figure 4-3).
- **Pressure Filtration**. Removal of iron particles from the contact tank effluent was achieved via downflow filtration through two 60-in × 96-in pressure tanks (Arrow Tank & Engineering) configured in parallel (Figure 4-3). Each tank contained 40 ft^3 (or 24 in) of M2 Macrolite® media loaded on top of fine garnet underbedding filled to 1 in above the 0.006-in slotted, stainless steel, wedge-wire underdrain (Leem/LSS Filtration model L-3230-60). The epoxy-lined steel pressure tanks featured windows for media and backwash observation, as shown in Figure 4-3, and were rated for a working pressure of 150 pounds per square inch (psi). The tanks were floor mounted and piped to a valve rack mounted on a welded, stainless steel frame. The flow through each tank was regulated to 200 gpm using a flow-limiting device (Flo-Et model FL-400-25-200) to prevent filter overrun. System operation with both tanks in service could produce a total flowrate of 400 gpm. Effluent flowrates and throughput were monitored using an insertion paddle wheel flow meter (Data Industrial model 220PVCS).

- **Filter Backwash**. The filters were automatically backwashed in succession in an upflow configuration based on service time, run time, or differential pressure (Δp) setpoints. Water was drained from the filter tank before an air compressor (Speedaire model 1WD61 [Figure 4-4]) delivered a 2-min air sparge at 100 pounds per square inch gauge (psig). After a 4-min settling period, the filter was backwashed with treated water from the distribution system until reaching a turbidity threshold setpoint (e.g., 20 nephlemetric turbidity units [NTU]) as measured using a turbidimeter (Hach™ model Surface Scatter 6 [Figure 4-4]). The resulting wastewater was sent to a 1,500-gal underground sump that emptied into the sanitary sewer (Figure 4-3). After the backwash step, the filter underwent a filter-to-waste (FTW) step for 2 min before returning to feed service.

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 system engineering package, prepared by Kinetico and its subcontractor, Wade Trim of Grand Rapids, MI, included a system design report, a general arrangement and P&ID, electrical and mechanical drawings and component specifications, and building construction drawings detailing connections from the system to the inlet piping and the village's water and sanitary sewer systems. The engineering package was certified by a Professional Engineer registered in the State of Michigan and submitted to MDEQ for review and approval on March 29, 2005. After MDEQ's review comments were addressed, the package was resubmitted along with a permit application on May 19, 2005. A water supply construction permit was issued by MDEQ on May 31, 2005, and fabrication of the system began thereafter.

4.3.2 Building Construction. A permit for building construction was applied for by the Village and issued by Oceana County on August 17, 2005. Construction began on the following day and was completed on October 21, 2005. The building was 37 ft × 33 ft with sidewall and roof peak heights of 16 and 22.7 ft, respectively. The foundation had a 42-in-depth overlain with a 6-in concrete slab. A 12-ft-wide overhead door enabled ease of equipment placement and installation. Wastewater discharge was facilitated with a 1,500-gal underground sump that emptied by gravity into the sanitary sewer. Figure 4-5 shows the new building constructed adjacent to the existing Well No. 2 pump house. In addition to electrical and plumbing connections, a phone line also was installed on January 19, 2006 with service available on February 22, 2006, to enable the equipment vendor to dial into the modem in the control panel for any troubleshooting.

Figure 4-5. New Building Constructed Next to Existing Well No. 2 Pump House

4.3.3 System Installation, Startup, and Shakedown. The FM-260-AS treatment system was delivered to the site on October 21, 2005. The vendor, through its subcontractor, performed the off-loading and installation of the system, including connections to the entry and distribution piping and electrical interlocking. System installation, hydraulic testing, and media loading were completed on November 4, 2005. System startup and shakedown activities that lasted until November 11, 2005, included PLC testing, instrument calibration, prolonged backwashing to remove Macrolite® media fines, chlorine disinfection and residual testing, and operator training on system O&M. The treatment system remained off through November 21, 2005, pending bacteriological results.

Battelle performed system inspections and operator training on sample and data collection on November 21 and 22, 2005. As a result of the system inspections, several punch-list items were identified, some of which appeared to fail relevant MDEQ requirements and system design specifications. Table 4-4 summarizes the items identified and corrective actions taken. While most of the items were resolved by December 2005, several problems related to filter backwash, as discussed in Section 4.4.3, were not corrected until June 2006.

Table 4-4. System Inspection Punch-List Items

Item No.	Punch-List Item Description	Corrective Action(s) Taken	Resolution Date
1	Elevate discharge piping to at least 2 times piping diameter off of floor	• Elevated discharge piping as required	12/15/05
2	Provide metal, saddled sample tap at combined effluent location	• Provided metal sample tap at combined effluent location with PVC saddle	12/15/05
3	Pipe air release valves to drain to keep water off of floor	• Piped air release valves to drain	12/15/05
4	Enable contact tank to be drained	• Installed ball valve between contact tank inlet (at bottom of contact tank) and treatment system inlet valve	12/15/05
5	Coordinate modem/phone line hookup with facility	• Completed modem/phone line connection (Section 4.3.2) • Dialed into PLC for modifications (Section 4.4.3.1)	01/19/06 02/22/06
6	Correct backwash flowrate readings	• Attempted to increase flowrate to specified range by adjusting diaphragm valve (Section 4.4.3) • Added tank stagger time to PLC to prevent/reduce sump overflow (Section 4.4.3) • Measured flowrate with portable meter, recalibrated flow meter, and adjusted diaphragm valve (Section 4.4.3.2) • Temporarily installed 150-gpm FTW flow restrictors and replaced lost media (Section 4.4.3)	12/06/05 03/10/06 05/15/06 06/14/06
7	Review/revise PLC field settings as appropriate	• Changed PLC settings (Section 4.4.3.1) • Recommended field setting changes due to recurring sump overflow (Section 4.4.3.1; Table 4-6)	12/15/05 03/10/06

4.3.4 Iron Addition Modification. Because the removal of the natural iron was not able to consistently reduce arsenic concentrations to below 10 µg/L, an iron addition system was requested from the vendor on December 6, 2005, and follow-on permitting and equipment supply services on January 23, 2006. Approval for iron addition was granted by MDEQ on April 20, 2006, and the equipment was delivered to the site and installed by the plant operator on May 8, 2006. On-going backwash problems prevented iron addition from being initiated until June 15, 2006 (Sections 4.4.2 and 4.4.3).

4.4 System Operation

4.4.1 Service Operation. The system operational parameters are tabulated and attached as Appendix A with the key parameters summarized in Table 4-5. The performance evaluation study began on November 22, 2005. Between November 22, 2005, and June 14, 2006, approximately 16,175,000 gal of water was processed whereupon iron was added at 0.5 mg/L (as Fe) to further reduce effluent arsenic concentrations as discussed in Section 4.4.2. An additional 23,010,000 gal of water was then treated through December 8, 2006, which marked the end of the study. The amount of water treated was based on the readings from the flow meter/totalizer installed at the effluent side of the pressure filters.

Through the entire study period, the system operated for a total of 1,947 hr, or 5.1 hr/day, based on the hour meter readings from the control panel. (Note that the hour meter was interlocked with the well pump.) With 39,185,000 gal of water treated, the average daily demand was 102,800 gal, equivalent to

Table 4-5. FM-260-AS Treatment System Operational Parameters

Parameter	11/22/05–06/14/06 (Without Iron Addition)	06/15/06–12/08/06[(a)] (With Iron Addition)	11/22/05–12/08/06[(a)] (Total Combined)
Pretreatment Operation			
NaOCl Dosage (mg/L [as Cl_2])	3.7 [0.0–8.8]	3.5 [0.0–6.3]	3.6 [0.0–8.8]
$FeCl_3$ Dosage (mg/L [as Fe])	0	0.5 [0.2–1.1]	Not used initially
Service Operation			
Total Operating Time (hr)	742	1,205	1,947
Average Daily Operating Time (hr)	3.6	6.8	5.1
Throughput (gal)	16,175,000	23,010,000	39,185,000
Average Daily Demand (gal)	79,300	131,000	102,800
Flowrate (gpm)	352 [345–365]	349 [328–364]	350 [328–365]
Contact Time (min)	6.8 [6.6–7.0]	6.9 [6.6–7.3]	6.8 [6.6–7.3]
Filtration Rate (gpm/ft^2)	9.0 [8.8–9.3]	8.9 [8.4–9.3]	8.9 [8.4–9.3]
Δp across Each Tank (psi)	6 [4–9][(b)]	11 [5–18]	9 [4–18]
Δp across System (psi)	20 [14–24]	24 [18–36]	22 [14–36]
Filter Run Time between Backwash Cycles[(c)] (hr)	8 [1–24]	16 [5–25]	12 [1–25]
Estimated Throughput between Cycles[(c,d)] (gal/tank)	88,900 [12,100–253,600]	172,600 [47,800–257,800]	129,100 [12,100–257,800]
Backwash Operation			
Frequency[(c)] (cycle/tank/week)	3	3	3
Number of Cycles (Tank A/Tank B)	118/115	71/71	189/186
Flowrate[(e)] (gpm)	214 [168–291]	172 [153–200]	190 [153–291]
Hydraulic Loading Rate[(e)] (gpm/ft^2)	10.9 [8.6–14.8]	8.8 [7.8–10.2]	9.7 [7.8–14.8]
Duration[(f)] (min/tank)	5	8 [6–10]	7 [5–10]
Backwash Volume[(f)] (gal/tank/cycle)	1,165 [840–2,100]	1,520 [1,150–1,850]	1,300 [840–2,100]
Filter to Waste Volume (gal/tank/cycle)	700	700	700
Wastewater Produced[(f)] (gal/tank/cycle)	1,865 [1,540–2,800]	2,240 [1,850–2,350]	2,000 [1,540–2,800]

Note: Average and [range] of select parameters presented.
(a) Week of July 17, 2006 data omitted from range due to use of another source well.
(b) One outlier (i.e., 15 psi on 12/12/05) omitted.
(c) Based on 24-hr service time and/or 48-hr standby time since 12/15/05.
(d) Based on 175-gpm/tank for service time between cycles.
(e) Based on monthly data from Backwash Log Sheet.
(f) Based on all cycles except for two appearing to occur for <5 min and two appearing to occur for >10 min possibly due to recording errors.

18% of the design capacity. The operational time was significantly higher during the second six months (i.e., 6.8 versus 3.6 hr/day) due to the increased demand during the summer months.

Due to severe weather during the week of July 17, 2006, resulting in failure of the well pump, the treatment system was temporarily supplied with water from another well (i.e., Well No. 3) and operated without iron addition. Unrepresentative operational parameters observed due to the lower flow of this well are not included in Table 4-5.

System flowrates were tracked by both instantaneous readings of the flow meter and calculated values based on hour meter and flow totalizer readings on the control panel. As shown in Figure 4-6, large discrepancies were observed between the instantaneous readings and calculated values since the system startup through February 22, 2006, when the hour meter display was modified to add one decimal place for tenths of an hour. The initial calculated values, denoted as "×" in Figure 4-6, scattered extensively from 304 to 950 gpm. After the decimal place was added, the calculated flowrates fell in a much tighter range, with values ranging from 339 to 392 gpm and averaging 374 gpm (excluding two outliers at 198 and 449 gpm on May 12 and 15, 2006, respectively) until May 15, 2006.

The initial instantaneous flowrate readings, denoted as boxes in Figure 4-6, ranged from 382 to 405 gpm and averaged 391 gpm from the system startup through May 15, 2006. During the vendor's site visit on May 15, 2006 to troubleshoot "low" backwash flowrates (Section 4.4.3), it was noticed that the paddle wheel flow meter was calibrated with an incorrect, factory-supplied K factor (i.e., 19.457), thus resulting in erroneously high flowrate and totalizer readings during the first six months. After being recalibrated with a revised K factor of 17.553, the flow meter read 355 gpm on May 17, 2006, compared to an average of 391 gpm beforehand. As a result, the original and corrected calibration values were used to adjust the previously obtained instantaneous flowrate and totalizer readings to reflect actual values. The revised and subsequently-collected instantaneous flowrate readings, denoted as boxes, ranged from 328 to 365 gpm, averaged 350 gpm, and were used as the system flowrates throughout this report.

Figure 4-6. Initial and Revised/Actual Service Flowrates

Due to the changes to totalizer readings, calculated flowrates were revised and plotted in Figure 4-6. As shown, the revised and subsequently-obtained calculated values, denoted as boxes in the figure, ranged from 272 to 463 gpm and averaged 345 gpm (except for four outliers) since the decimal place had been added on February 22, 2006. The revised calculated values were very close to the revised instantaneous readings.

The 350-gpm flowrate corresponded to a contact time of 6.8 min and a filtration rate of 8.9 gpm/ft^2, which were close to the design values of 6 min and 10 gpm/ft^2, respectively (Table 4-3). Δp readings ranged from 14 to 36 psi across the system and from 4 to 18 psi across each tank. In general, Δp increased as the filter run length increased. As shown in Figure 4-7, as particulates in the filter influent continued to be removed by the filters, Δp readings rose progressively from 4 to 6 psi after the beds were freshly backwashed up to 9 psi (one outlier of 15 psi not included). Iron addition further increased the Δp to as high as 18 psi, but not enough to affect the backwash frequency since backwashes were still initiated based on service or standby time triggers. Since the readings shown in Figure 4-7 and summarized in Table 4-5 could only be taken while the system was online, there are fewer readings at higher run times without iron addition due to lower daily demand of the system during that study period as discussed in Section 4.4.3. Δp was important to monitor because particulate breakthrough generally occurred with increasing Δp (Section 4.5.1.2).

Filter run times between backwash cycles ranged from 1 to 25 hr and averaged 12 hr. The corresponding throughputs ranged from 12,100 to 257,800 gal/tank and averaged 129,100 gal/tank based on a flowrate of 175 gpm/tank (i.e., one-half of the average 350-gpm service flow). The run times and throughputs increased once iron addition began, because higher daily demands caused the system operation to increase, thus enabling more water to be treated between backwash cycles as discussed in Section 4.4.3.

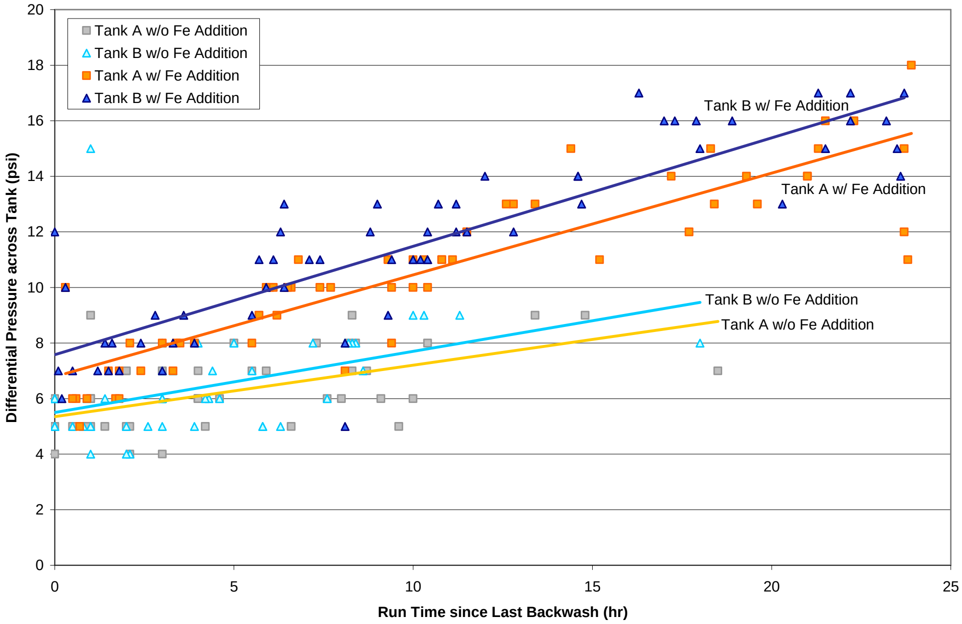


Figure 4-7. Differential Pressure vs. Filter Run Time

4.4.2 Chlorine and Iron Additions. Chemical pretreatments consisted of chlorine and iron additions. Chlorine dosages, as calculated based on daily NaOCl consumption (as measured through solution level changes in the chemical day tank) and daily flow (according to the system effluent totalizer), ranged from 0.0 to 8.8 mg/L (as Cl_2) and averaged 3.6 mg/L (as Cl_2) (Figure 4-8). This average dosage was somewhat higher than the theoretical dosage of 3.2 mg/L required to achieve 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 4.5.1.5.

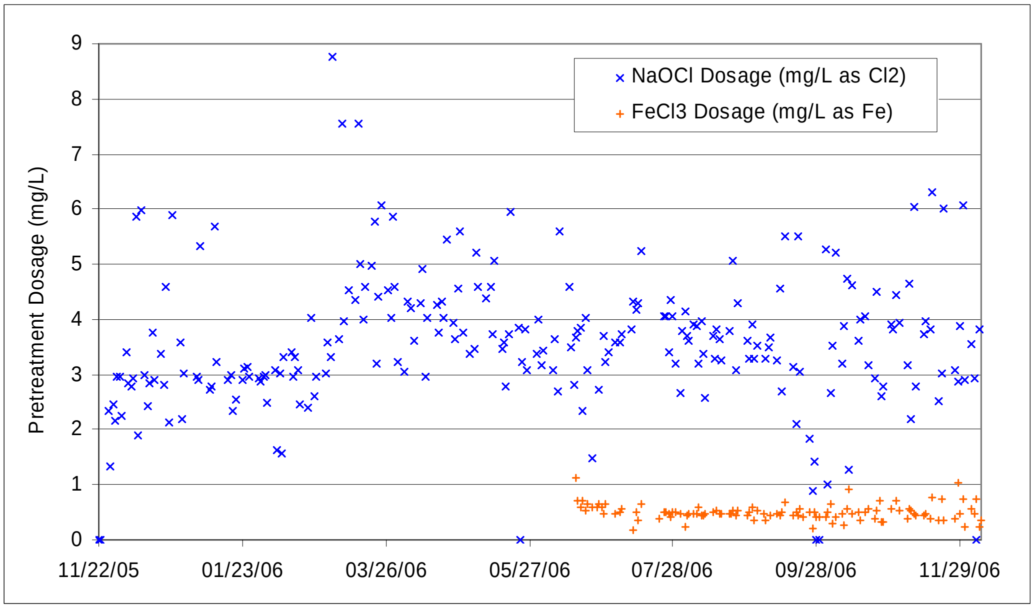


Figure 4-8. Chlorine and Ferric Chloride Dosages of Over Time

Initial sampling results across the treatment train indicated a need for iron addition to reduce arsenic concentrations below the 10-µg/L MCL. However, several on-going backwash problems, as discussed in Section 4.4.3, had to be resolved prior to initiation of iron addition due to the anticipated higher solids loading to the filters and possibly more frequent backwash. Therefore, iron addition was not initiated until June 15, 2006. Initially, the $FeCl_3$ stock solution was diluted by a factor of four with 50% speed and 50% stroke length settings on the 1.6-gph pump. To further adjust the dosage, the speed and stroke length settings were decreased to 30%, and the dilution factor was increased to five on June 15 and 30, 2006, respectively. The pump settings and dilution factor remained unchanged for the remainder of the study.

Iron dosages ranged from 0.2 to 1.1 mg/L (as Fe) and averaged 0.5 mg/L (as Fe) (Figure 4-8). Similar to the chlorine dosages, iron dosages were calculated based on daily $FeCl_3$ consumption (by changes of solution levels in the chemical day tank) and daily flow (according to the system effluent totalizer). The stock solution was consumed at a rate of 0.035 lb/1,000 gal of water treated.

As shown in Figure 4-8, extensive scattering of chemical dosages was observed during both NaOCl and $FeCl_3$ additions. The speed and stroke settings of the pumps were seldom adjusted, so more consistent dosages should have been achieved since the system flowrates remained fairly consistent. Because inconsistencies or inaccuracies in solution level measurements could significantly impact the calculated dosages, chemical consumption and dosage data could be better obtained by the use of a drum scale, which the Village plans to purchase.

4.4.3 Backwash Operation. The Macrolite® pressure filters, Tanks A and B, were backwashed 189 and 186 times, respectively. Backwash of each filter was triggered by either standby time or service run time setpoints based on the season. For example, during the winter and spring when water demand was low, operational times were as low as 0.8 hr/day, thus causing backwash to be triggered primarily by the standby time setpoint. In contrast, higher daily demands during the summer and fall resulted in longer operational times up to 17 hr/day, prompting backwash to be triggered mainly by the service run time setpoint. Although a Δp setpoint also was programmed into the PLC, pressure-triggered backwash occurred rarely, if ever. Occasionally, manual backwash cycles were initiated, but only for testing and sampling of backwash water and solids.

The backwash duration for each tank was affected by the minimum and maximum backwash time settings and the ability of the backwash water to meet the turbidity threshold setting as measured by an in-line Hach™ turbidimeter (Section 4.4.3.1). If the backwash water failed to meet the set threshold prior to reaching the maximum backwash time, the backwash failure alarm had to be acknowledged and a successful backwash cycle had to be conducted before the tank might return to the service mode. Backwash was followed by a 2-min FTW step to remove any particulates from the filter. The amount of wastewater produced ranged from 1,540 to 2,800 gal/tank, including 700 gal/tank produced during the 2-min FTW step. (Note that four backwash cycles, which appeared to occur outside of the permissible range of 5 to 10 min, possibly due to recording errors, are not included in the wastewater production range.) The amount of wastewater produced was equivalent to 1.9% of the total amount of water treated.

4.4.3.1 PLC Settings. Table 4-6 summarizes the initial backwash PLC settings at system startup and two subsequent modifications on December 15, 2005, and March 10, 2006. Initially, the PLC was set in the field to backwash with a standby time trigger of 12 hr, which resulted in frequent backwashes (i.e., often 2 cycle/tank/day) even though the filter service time during this 12-hr period ranged from only 1 to 5 hr/day and averaged only 2 hr/day. In addition, the field-set turbidity threshold of 65.5 NTU was significantly higher than the factory setpoint of 20 NTU, and the low flowrate alarm level of 5 gpm was well below the 157 to 196 gpm (8 to 10 gpm/ft^2) design values.

Table 4-6. Summary of PLC Settings for Backwash Operations

Parameter (for Each Tank)	Adjustment Date		
	11/22/05[(a)]	12/15/05	03/10/06
Drain Time (min)	4	2	4
Service Time Trigger (hr)	24	24	24
Standby Time Trigger (hr)	12	48	48[(b)]
Δp Trigger (psi)	18	22	22
Minimum Backwash Time (min)	5	5	5
Maximum Backwash Time (min)	16	20	10
Turbidity Threshold (NTU)	65.5	20	20
Low Flowrate Threshold (gpm)	5	120	75
Filter-to-Waste Time (min)	2	2	2
Backwash Stagger Time (min)	-	-	5

(a) Initial field settings.
(b) Temporarily increased to 99 hr from 10/17/06 through 10/20/06 and 199 hr from 11/02/06 through 11/14/06.

On December 15, 2005, several changes were made to the November 22, 2005, field settings, including increasing the setpoints for standby time (from 12 to 48 hr), Δp (from 18 to 22 psi), maximum backwash time (from 16 to 20 min), and low flowrate threshold (from 5 to 120 gpm), and decreasing the setpoints for drain time (from 4 to 2 min) and turbidity threshold (from 65.5 to 20 NTU). With these changes, the backwash frequency decreased to approximately 3 cycle/tank/week. On March 10, 2006, additional changes were made to increase the setpoint for drain time (from 2 to 4 min), decrease the setpoint for maximum backwash time (from 20 to 10 min), and add stagger time to allow the sump additional drain time between consecutive tank backwashes. These changes were made in an attempt to alleviate concerns over recurring sump overflow problems during backwash since system startup, which were based on the erroneous flowrate readings from the incorrectly calibrated flow meter as discussed in Section 4.4.3.2.

The low flowrate threshold also was decreased on March 10, 2006 due, in part, to a backwash alarm experienced on March 2, 2006, caused by insufficient flow from the water tower. Previously unacknowledged backwash alarms caused the system to remain in standby mode, which prevented the system from supplying water to the water tower. The plant operator bypassed the treatment system, refilled the water tower with untreated water, and restarted the system with vendor assistance on March 3, 2006. Possibly due to low water tower levels, another low backwash flow alarm occurred on July 3, 2006, without incident.

To facilitate a special study on filter leakage over 24 hr of run time between two backwash cycles, the standby time setpoint was temporarily increased to 99 hr from October 17 through 20, 2006, and to 199 hr from November 2 through 14, 2006. These changes were necessary due to the low demands during the winter and the tendency to reach the maximum allowable standby time setpoint of 99 hr before the 24-hr run time setpoint. The special study results are discussed in Section 4.5.1.2.

4.4.3.2 Backwash Flowrates and Associated Issues. Backwash flowrate readings on the touch screen OIP were initially 60 to 104 gpm, which were substantially lower than the design values of 157 to 196 gpm. Due to the use of an incorrect K factor (i.e., 7.354) for flow meter calibration, these flowrates were actually 168 to 291 gpm (or 8.6 to 14.8 gpm/ft^2) according to readings revised using the recalibrated flow meter's new K factor of 20.554 (Figure 4-9). This calibration problem, not identified until May 15, 2006, had created a great deal of confusion concerning the backwash flowrate, sump capacity, and media loss. Recurring overflow was observed from the building sump at these "low" 60- to 104-gpm flowrates

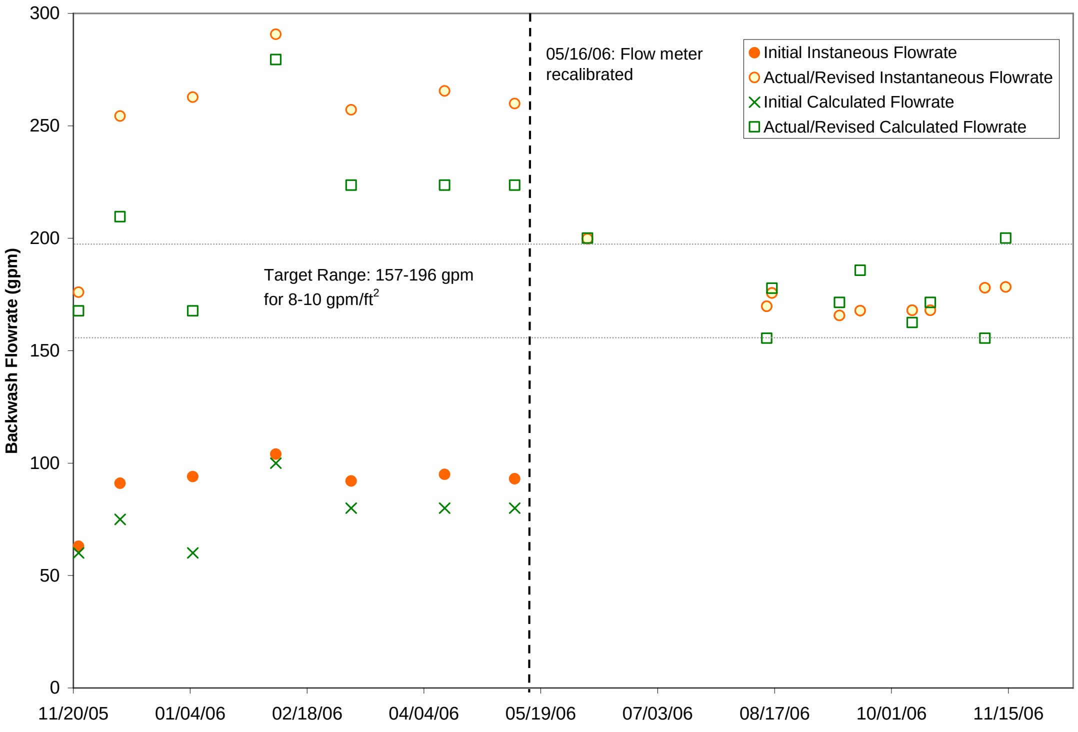


Figure 4-9. Initial and Revised/Actual Backwash Flowrates

(actually 168 to 291 gpm), which implied that the sump might have been underdesigned. The Village Engineer, however, affirmed that the sump was sized for a discharge capacity of at least 150 gpm. Further, some Macrolite® media was found in and around the sump after each backwash, which would not be expected at such "low" flowrates. Several attempts were made to verify the accuracy of flowrate readings (e.g., using a portable flow meter) and to establish strategies to overcome problems associated with the "underdesigned" sump (e.g., PLC setting modifications [Section 4.4.3.1]).

During a site visit on May 15, 2006, the vendor recognized the calibration error, recalibrated the backwash flow meter, and adjusted the flowrate to about 170 gpm using the diaphragm valve. It also was determined that the FTW flowrate of the filter was approximately 350 gpm instead of the 200-gpm design value because all of the influent flow was going through the filter during this step. The vendor measured and confirmed media loss at 3 and 4 in (or 5 and 7 ft^3) from Tanks A and B, respectively. Therefore, contrary to the initial thoughts, sump overflow was, in fact, caused by the incorrect backwash settings due to the erroneous flowrates and the surge experienced during the FTW rinse. Similarly, the media loss was a result of excessive backwash flowrates experienced by the pressure filters.

The vendor made a return trip to the site from June 13 to 14, 2006, to replace the 3 and 4 in of lost M2 Macrolite® media in Tanks A and B and install, but later remove, a 150-gpm flow restrictor on each FTW discharge line. The flow restrictors were intended to reduce the 350-gpm surge to the sump experienced during the 2-min FTW step, but caused concerns over influent pressure spikes as discussed in Section 4.4.3.3. Even though the flow restrictors were removed, no further problems with sump overflow or media loss occurred after correcting the target backwash flowrate following the flow meter recalibration. Backwash flowrates (i.e., 153 to 200 gpm) also were comparable to the design values for the remainder of the study.

4.4.3.3 Influent Pressure Spikes. The average system influent and effluent pressure readings during service were 80 and 58 psi, respectively, giving a 22-psi Δp across the system. During backwash, however, influent pressure could rise sharply depending on if the second filter was in standby or service mode as summarized in Table 4-7. Since backwash was mostly triggered by the standby time setpoint due to the low daily system run time during the winter and spring (Section 4.4.3), it was possible for one filter to be backwashed while the other filter remained offline. Under these circumstances, backwash obviously would not cause any influent pressure spikes because the well pump was off and because treated water was used for backwash. During the 2-min FTW step, minor and brief pressure spikes were observed because of the 350-gpm flowrate flowing through the FTW discharge line. In contrast, when backwash was triggered by the service run time setpoint as the system was in service, one filter was backwashed while the other remained in service. Backwash, therefore, caused substantial influent pressure spikes since the normal 350-gpm service flow would be forced through one filter, resulting in an elevated service flowrate of approximately 260 gpm. This flowrate was 85 gpm higher than the usual 175 gpm through each filter and 60 gpm higher than the permissible flowrate of the 200-gpm flow limiting device installed on the effluent side of the filter for overrun protection. This service mode backwash began occurring in mid-June 2006 and continued through the summer and fall due to the higher daily system run time (Section 4.4.3).

For both backwash modes, the FTW flowrate would be the same as or close to the 350-gpm service flowrate since the entire flow would be directed toward the sump due to substantially lower backpressure at the FTW discharge line than that at the entry point to the distribution system. This setup added to the concern over sump overflow (Section 4.4.3.2) and prompted the vendor to install a 150-gpm flow restrictor on each FTW discharge line on June 13, 2006. The restrictors, however, caused even higher influent pressure spikes (i.e., ≥ 35 psi) during backwash with influent pressures in excess of 115 psi. Due to concerns over the potential adverse effects on the well pump, the restrictors were removed on June 14, 2006.

Table 4-7. Comparison of Filter Operation during Backwash Modes

Parameter	Second Filter in Standby Mode	Second Filter in Operation Mode	
	Without FTW Restrictor[(a)]	Without FTW Restrictor[(b)]	With FTW Restrictor[(c)]
Influent Pressure Spike (psi)	None[(d)]	Not Measured[(e)]	≥35[(f)]
Backwash Step			
Service Flowrate (gpm)	0	260	280
Backwash Flowrate (gpm)	170	195	195
FTW Step			
Service Flowrate (gpm)	0	0	150–200
FTW Flowrate (gpm)	350	<350	150–200

(a) Based on data gathered by vendor on 05/15/06.
(b) Based on data gathered by operator on 06/14/06 after removal of restrictor.
(c) Based on data gathered by vendor with a restrictor temporarily installed during 06/13/06 through 06/14/06.
(d) During backwash step only; some spike observed during FTW step.
(e) Spikes observed during backwash and FTW steps.
(f) Highest spikes observed during backwash and FTW steps.

Because sump overflow did not occur after the vendor's June 2006 site visit, FTW continued to be conducted at close to 350 gpm without the use of flow restrictors. The pressure spikes experienced during service mode backwash, however, were still well above the recommended 100 psi system operating limit and continued to cause apprehension regarding any adverse effects on the well pump. Therefore, a request was made to the vendor to conduct only standby mode backwashes and delay any would-be service mode backwashes (as triggered based on run time) until the system was offline. The vendor was not willing to acknowledge this programming request without additional funding, but agreed to allow the system to operate at pressures up to 125 psi. Under this maximum operating pressure, the vendor agreed to uphold the system warranty should any problems occur as a result of the elevated pressures.

4.4.4 Residual Management. Residuals produced by the Macrolite® Arsenic Removal System included backwash wastewater and FTW water, which contained arsenic-laden solids as discussed in Section 4.5.2. Wastewater from backwash was discharged to the building sump, which emptied by gravity to the sanitary sewer. According to the backwash flow totalizer, 487,300 gal of wastewater were produced during the entire study period. Based on a 350-gpm flowrate and a duration of 2 min for 375 backwash cycles, 262,500 gal of FTW water also were produced. (Note that a flow meter was not able to be installed on the FTW discharge line due to anticipated complications caused by high solids content.) Therefore, over 749,800 gal of wastewater, or 1.9% of the treated water, were generated, similar to the 1.9 to 2.4% produced (not including the FTW volume) by a smaller Macrolite® system at Climax, MN (Condit and Chen, 2006).

4.4.5 Reliability and Simplicity of Operation. Inability to achieve acceptable arsenic removal due to insufficient iron levels in source water (Sections 4.5.1.1 and 4.5.1.2) and backwash-related issues including PLC settings (Section 4.4.3.1), media loss and sump overflow caused by erroneous backwash flowrates (Section 4.4.3.2), and influent pressure spikes (Section 4.4.3.3) were the primary sources of concern during the study. Following resolution of these major issues, system reliability and ease of operation greatly improved. Other O&M issues encountered included problems with the existing chlorine feed system. The total amount of system downtime for troubleshooting was no more than 1% of the operational time.

4.4.5.1 Pre- and Post-Treatment Requirements. Pretreatment consisted of chemical additions to improve arsenic removal. Chlorine in a 15% NaOCl solution was added using the existing equipment to oxidize As(III) and Fe(II) and provide chlorine residuals to the distribution system. In addition to tracking the depth of the NaOCl solution in the day tank, the operator measured chlorine concentrations to ensure that residuals existed throughout the treatment train. Little or no chlorine was added to oxidize As(III), Fe(II), and Mn(II) from February 21 to March 9, 2006, due to the inadvertent use of an off-spec solution provided by a chemical supplier and on May 23 and September 27 to 29, 2006, due to problems with the injector. Periods of non-treatment could have been shortened through more careful monitoring of free and total chlorine measurements and/or solution usage. Iron addition commenced on June 15, 2006, using a 37 to 42% $FeCl_3$ solution to improve arsenic removal. Iron was added upstream of the contact tank within the treatment plant where solution levels were tracked daily. No post-treatment was required.

4.4.5.2 System Automation. The FM-260-AS treatment system was automatically controlled by the PLC in the central control panel. The control panel contained a modem and a touch screen OIP that facilitated monitoring of system parameters, changing of system setpoints, and checking the alarm status. Service time, standby time, and Δp settings (Table 4-6) automatically determined when the tanks were backwashed. The touch screen OIP also enabled the operator to manually initiate the backwash sequence.

4.4.5.3 Operator Skill Requirements. Under normal operating conditions, the daily demand on the operator was about 30 min for visual inspection of the system and recording of operational parameters, such as pressure, volume, flowrate, and chemical usage on field log sheets. In Michigan, operator certifications are classified on a range of 1 to 4 based upon rated treatment capacity or population served. A level 1 certificate is for the largest treatment capacity and population served and a level 4 certificate for the smallest treatment capacity and population served. After receiving proper training during the 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 problems and perform minor on-site repairs.

4.4.5.4 Preventative Maintenance Activities. The vendor recommended several routine maintenance activities to prolong the integrity of the treatment system (Kinetico, 2005). Daily preventative maintenance tasks included recording pressures, flowrates, chemical drum levels, and visually checking for leaks, overheating components, proper manual valve positioning and pumps' lubricant levels, and any unusual conditions. The vendor recommended weekly checking for trends in the recorded data that might indicate a decline in system performance, and semi-annually servicing and inspecting ancillary equipment and replacing worn components. Cleaning and replacement of sensors and replacement of o-ring seals and gaskets of valves were performed as needed.

4.4.5.5 Chemical Handling and Inventory Requirements. Chlorine and iron addition were required for effective arsenic removal. The operator tracked the usage of the chemical solutions daily (by volume), coordinated the supplies, and refilled the day tanks as needed. A 15% NaOCl solution, supplied in 55-gal drums by Wilbur-Ellis, was transferred to the day tank and injected without dilution. A 37 to 42% $FeCl_3$ solution, supplied in 610 lb drums by Brenntag Great Lakes, was diluted in the 55-gal day tank prior to injection into the chlorinated water. The speed and stroke settings of the chemical pumps were adjusted, as needed, to acquire the target chlorine residuals, as measured regularly with a Hach pocket colorimeter, and iron concentrations after the contact tank. Although the chemical handling requirement was increased with iron addition, the reliability and consistency of the treatment system in meeting the 10-μg/L arsenic goal was paramount.

4.5 System Performance

The performance of the Macrolite® FM-260-AS Arsenic Removal System was evaluated based on analyses of water samples collected from the treatment plant, backwash line, and distribution system.

4.5.1 Treatment Plant Sampling. The treatment plant water was sampled on 51 occasions including three duplicate events and 13 speciation events during the study. Table 4-8 summarizes the analytical results for arsenic, iron, and manganese. Table 4-9 summarizes the results of the other water quality parameters. Five sets of samples (including four weekly and one monthly speciation sets) were collected when an off-spec chlorine stock solution was used or when problems were encountered with the chlorine injector and, therefore, the results for the associated AC, TA, TB, TT samples are omitted from the statistical calculations in Tables 4-8 and 4-9. However, the data plots are all-inclusive. Appendix B contains a complete set of analytical results. The results of the water samples collected across the treatment plant are discussed below.

4.5.1.1 Arsenic. Figure 4-10 presents the results of 13 speciation events, and Figure 4-11 shows total arsenic concentrations measured across the treatment train. Total arsenic concentrations in raw water ranged from 14.6 to 21.8 μg/L and averaged 17.7 μg/L with >96% existing in the soluble form. Of the soluble fraction, As(III) was the predominant species with concentrations averaging 14.9 μg/L; low levels of As(V) also were present, averaging 2.1 μg/L. The range of total arsenic concentrations measured was slightly higher than that of raw water collected on August 31, 2004 (i.e., 13.2 μg/L) (Table 4-1).

The use of an off-spec chlorine solution and problems with the chlorine injector as noted above resulted in rather incomplete As(III) oxidation during five sampling events as shown in Figures 4-10 and 4-11. For all other sampling events, the results obtained after prechlorination and the contact tank indicated that As(III) was more thoroughly oxidized to an average concentration of 0.4 μg/L. As much as 1.6 μg/L of As(III), however, was observed after chlorination. This incomplete oxidation might have been impacted by the presence of ammonia, which forms chloramines with the addition of NaOCl. Unless breakpoint chlorination was achieved, chloramines could play a role under the circumstances. Presumably, As(III) oxidation occurred initially due to free chlorine before it reacted with ammonia (Frank and Clifford, 1986), since only limited oxidation of As(III) would occur due to in-situ-formed monochloramine (Ghurye and Clifford, 2001).

Before iron addition was implemented, soluble As(III) and As(V) and particulate arsenic concentrations in water after the contact tank averaged 0.4, 10.5, and 6.4 μg/L, respectively. The high soluble As(V) and low particulate arsenic levels indicated insufficient Fe(II) in raw water. Otherwise, most of the soluble As(V), either present in raw water or converted from As(III) upon chlorination, would have coprecipitated with and/or adsorbed onto iron solids also formed during chlorination, leaving mostly particulate arsenic and trace levels of soluble As(III) and As(V) in water prior to filtration. It became clear soon after system startup that insufficient soluble iron was present in raw water to consistently remove arsenic to less than 10 μg/L (note that total arsenic concentrations after pressure filtration at TA, TB, and TT sampling locations ranged from 7.8 to 15.6 μg/L and averaged 9.9 μg/L). Although the average ratio of total iron to total arsenic was 24:1, the average ratio of soluble iron to soluble arsenic was about 15:1, which was lower than the rule of thumb ratio of 20:1 needed to reduce the arsenic level to below the 10 μg/L MCL (Sorg, 2002). Two weeks after the commencement of weekly sampling, planning began for iron addition.

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

Parameter	Location	Sample Count	Concentration (μg/L)			Standard Deviation
			Minimum	Maximum	Average	
As (total) (Figure 4-11)	IN	51	14.6	21.8	17.7	1.4
	AC	25 [21]	14.4 [13.6]	25.4 [27.9]	18.9 [19.3]	2.9 [4.0]
	TA	19 [15]	7.8 [3.8]	15.6 [6.7]	10.0 [5.5]	1.7 [0.8]
	TB	19 [15]	8.0 [4.2]	11.9 [7.2]	10.0 [6.0]	1.2 [0.8]
	TT	6 [6]	8.4 [4.0]	12.0 [5.8]	9.3 [5.0]	1.4 [0.8]
As (soluble)	IN	13	13.9	18.5	16.9	1.3
	AC	6 [6]	9.2 [3.9]	12.9 [6.9]	10.9 [5.6]	1.2 [1.2]
	TT	6 [6]	8.2 [3.0]	11.6 [5.6]	9.2 [4.2]	1.2 [0.9]
As (particulate) (Figure 4-10)	IN	13	<0.1	2.0	0.6	0.6
	AC	6 [6]	4.9 [9.6]	8.1 [14.2]	6.4 [12.0]	1.2 [1.8]
	TT	6 [6]	<0.1 [<0.1]	1.1 [2.0]	0.3 [0.8]	0.4 [0.6]
As(III) (Figure 4-10)	IN	13	8.7	17.8	14.9	2.4
	AC	6 [6]	<0.1 [<0.1]	1.4 [0.6]	0.4 [0.4]	0.5 [0.2]
	TT	6 [6]	0.2 [<0.1]	1.6 [0.6]	0.5 [0.4]	0.5 [0.2]
As(V) (Figure 4-10)	IN	13	<0.1	6.8	2.1	1.6
	AC	6 [6]	9.1 [3.6]	11.5 [6.4]	10.5 [5.3]	0.9 [1.1]
	TT	6 [6]	7.7 [2.4]	10.1 [5.0]	8.7 [3.8]	0.8 [1.0]
Fe (total) (Figure 4-12)	IN	51	346	510	426	34.1
	AC	25 [21]	344 [658]	902 [1,638]	519 [969]	137 [317]
	TA	18(b) [15]	<25 [<25]	<25 [147]	<25 [41.9]	- [44.3]
	TB	19 [15]	<25 [<25]	102 [225]	<25 [67.8]	20.9 [61.2]
	TT	6 [6]	<25 [<25]	66.2 [141]	34.3 [49.9]	20.2 [49.2]
Fe (soluble)	IN	13	45.2	433	250	126
	AC	6 [6]	<25 [<25]	<25 [<25]	<25 [<25]	- [-]
	TT	6 [6]	<25 [<25]	<25 [<25]	<25 [<25]	- [-]
Mn (total) (Figure 4-14)	IN	51	23.1	31.7	27.3	1.7
	AC	25 [21]	21.5 [25.6]	46.3 [41.6]	29.9 [30.8]	5.3 [4.0]
	TA	19 [15]	6.4 [10.4]	17.3 [19.8]	10.9 [15.1]	2.6 [3.0]
	TB	19 [15]	6.2 [11.7]	15.6 [20.1]	10.7 [15.7]	2.3 [2.8]
	TT	6 [6]	9.0 [12.9]	22.2 [24.9]	12.8 [19.1]	4.7 [4.0]
Mn (soluble)	IN	13	25.5	32.9	28.8	1.7
	AC	6 [6]	9.1 [9.4]	11.6 [19.6]	10.4 [15.9]	0.9 [3.7]
	TT	6 [6]	9.0 [12.3]	22.2 [25.2]	13.1 [18.6]	4.6 [4.2]

(a) Five sampling events omitted from AC, TA, TB, and TT calculations due to chlorination problems.
(b) One outlier (i.e., 483 μg/L on 11/29/05) omitted.
Data outside brackets before iron addition; data inside brackets after iron addition.
One-half of detection limit used for nondetect results and duplicate samples included for calculations.

Iron addition that started on June 15, 2006, increased the average total iron concentration from 519 to 969 μg/L measured after the contact tank (AC location) shown in Table 4-8. This increase in iron resulted in lowering arsenic concentrations in the treated water to a range of 3.8 to 7.2 μg/L. Speciation of the treated water (TT location) indicated the presence of mostly soluble As(V) (at 3.8 μg/L) and some soluble As(III) (at 0.4 μg/L) and particulate arsenic (at 0.8 μg/L).

Table 4-9. Summary of Other Water Quality Parameter Results[(a)]

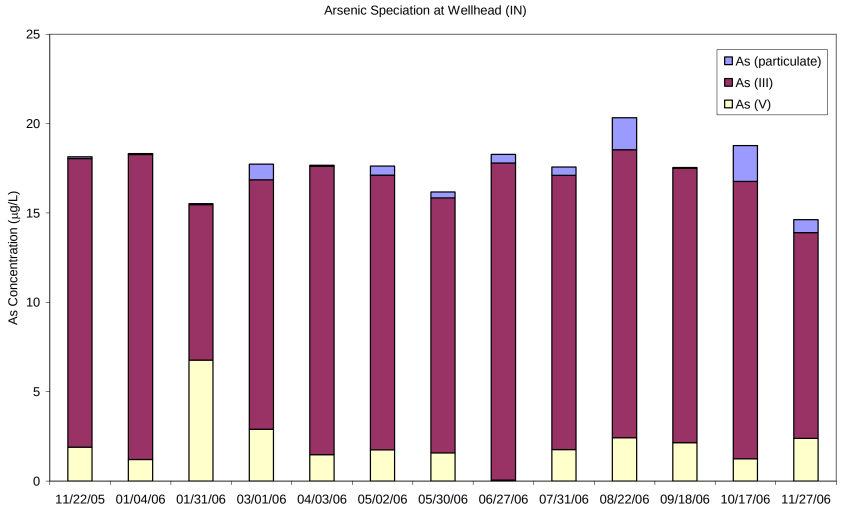
Parameter	Sampling Location	Unit	Sample Count	Minimum	Maximum	Average	Standard Deviation
Alkalinity (as $CaCO_3$)	IN	mg/L	51	135	171	150	7.0
	AC	mg/L	46	141	164	150	6.2
	TA	mg/L	34	138	162	150	6.2
	TB	mg/L	34	141	177	152	7.1
	TT	mg/L	12	141	160	150	6.4
Ammonia (as N)	IN	mg/L	6	0.3	0.4	0.3	0.0
	AC	mg/L	6	0.2	0.3	0.3	0.0
	TT	mg/L	6	0.2	0.3	0.3	0.0
Fluoride	IN	mg/L	13	0.4	1.1	0.6	0.2
	AC	mg/L	12	0.4	0.9	0.5	0.2
	TT	mg/L	12	0.4	1.3	0.6	0.3
Sulfate	IN	mg/L	13	<1	<1	<1	-
	AC	mg/L	12	<1	<1	<1	-
	TT	mg/L	12	<1	<1	<1	-
Nitrate (as N)	IN	mg/L	13	<0.05	<0.05	<0.05	-
	AC	mg/L	12	<0.05	0.1	<0.05	0.0
	TT	mg/L	12	<0.05	0.1	<0.05	0.0
Phosphorus (as P)	IN	μg/L	51	<10	74.5	57.4	10.9
	AC	μg/L	46	<10	169	75.1	32.0
	TA	μg/L	33	<10	39.3	17.3	10.7
	TB	μg/L	34	<10	38.4	18.7	10.8
	TT	μg/L	12	<10	51.9	17.1	14.2
Silica (as SiO_2)	IN	mg/L	51	10.1	13.2	11.2	0.5
	AC	mg/L	46	9.8	13.1	11.2	0.6
	TA	mg/L	34	10.2	12.5	11.1	0.5
	TB	mg/L	34	10.3	12.3	11.1	0.4
	TT	mg/L	12	10.1	12.9	11.1	0.8
Turbidity	IN	NTU	51	1.2	3.9	2.4	0.4
	AC	NTU	46	0.2	4.2	1.2	0.9
	TA	NTU	34	<0.1	4.7	0.9	1.1
	TB	NTU	34	<0.1	4.0	0.7	0.8
	TT	NTU	12	<0.1	4.0	1.3	1.2
TOC	IN	mg/L	8	1.9	2.1	2.0	0.1
	AC	mg/L	7	1.8	2.0	1.9	0.1
	TT	mg/L	7	1.8	2.1	1.9	0.1
pH	IN	S.U.	40	7.5	8.3	7.9	0.2
	AC	S.U.	37	7.5	8.4	8.0	0.2
	TA	S.U.	28	7.6	8.4	8.0	0.2
	TB	S.U.	28	7.7	8.4	8.0	0.2
	TT	S.U.	10	7.9	8.6	8.2	0.2
Temperature	IN	°C	40	11.5	15.6	12.9	1.1
	AC	°C	37	11.1	15.6	12.8	1.0
	TA	°C	28	11.1	15.6	13.0	1.1
	TB	°C	28	10.9	15.6	13.0	1.2
	TT	°C	10	12.0	14.5	13.2	1.0

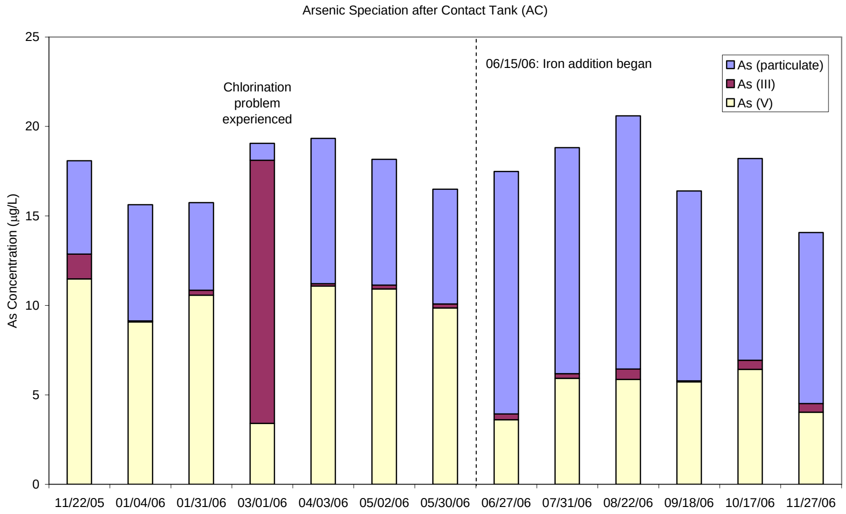
Table 4-9. Summary of Other Water Quality Parameter Results (Continued)

Parameter	Sampling Location	Unit	Sample Count	Minimum	Maximum	Average	Standard Deviation
DO	IN	mg/L	38	0.8	3.7	1.7	0.7
	AC	mg/L	36	0.5	2.0	1.1	0.4
	TA	mg/L	27	0.6	1.9	1.2	0.3
	TB	mg/L	27	0.5	4.1	1.4	0.7
	TT	mg/L	10	0.9	3.7	2.2	0.9
ORP	IN	mV	37[(b)]	187	473	342	65.2
	AC	mV	37	303	523	428	57.9
	TA	mV	28	305	516	420	58.3
	TB	mV	28	318	523	422	50.4
	TT	mV	10	403	511	442	28.9
Free Chlorine (as Cl_2) (Figure 4-15)	AC	mg/L	36	0.0	1.6	0.7	0.5
	TA	mg/L	28	0.2	1.4	0.8	0.4
	TB	mg/L	28	0.0	1.2	0.6	0.4
	TT	mg/L	9	0.0	1.4	0.8	0.4
Total Chlorine (as Cl_2) (Figure 4-15)	AC	mg/L	36	0.9	1.9	1.3	0.2
	TA	mg/L	28	0.5	1.9	1.3	0.3
	TB	mg/L	28	0.9	1.8	1.3	0.2
	TT	mg/L	9	1.0	1.6	1.3	0.2
Total Hardness (as $CaCO_3$)	IN	mg/L	13	167	223	205	16.3
	AC	mg/L	12	166	224	205	15.8
	TT	mg/L	12	167	223	205	17.8
Ca Hardness (as $CaCO_3$)	IN	mg/L	13	104	127	115	6.1
	AC	mg/L	12	106	124	115	5.5
	TT	mg/L	12	98.5	126	115	7.3
Mg Hardness (as $CaCO_3$)	IN	mg/L	13	62.3	103	90.1	11.8
	AC	mg/L	12	59.5	106	89.6	12.3
	TT	mg/L	12	60.2	105	90.3	12.7

(a) Five sampling events omitted from AC, TA, TB, and TT calculations due to chlorination problems.
(b) Two outliers (i.e., -3 mV on 11/22/05 and 91 mV on 11/29/05) omitted.
One-half of detection limit used for nondetect results and duplicate samples included for calculations.

4.5.1.2 Iron. Figure 4-12 presents total iron concentrations measured across the treatment train. Total iron in raw water ranged from 346 to 510 μg/L and averaged 426 μg/L, of which approximately 60% was present in the soluble form (Table 4-8). The soluble iron concentration may have actually been significantly higher, but not reflected as such, due to the possibility of iron oxidation during sampling. As noted in Section 4.1.1, although the average soluble iron to soluble arsenic ratio was 15:1, ratios up to 25:1 (on April 3, 2006 [Appendix B]) and up to 35:1 (on August 30, 2004 [Section 4.1.3]) were observed. Nonetheless, iron addition was required to improve arsenic removal. In addition to the lower-than-expected soluble iron levels, factors such as pH and/or other water quality parameters also might have affected the arsenic removal capacity of the iron solids. After successfully addressing all backwash issues (Section 4.4.3), $FeCl_3$ addition was initiated on June 15, 2006. This pretreatment, dosed at an average rate of 0.5 mg/L (as Fe), raised iron levels following the contact tank to the range of 658 to 1,638 μg/L (969 μg/L on average). The variations in iron concentrations observed might have been caused by fluctuations in iron dosage, which ranged from 0.2 to 1.1 mg/L (as Fe). However, no direct correlation existed between the average daily dosages and the iron concentrations after the contact tank.





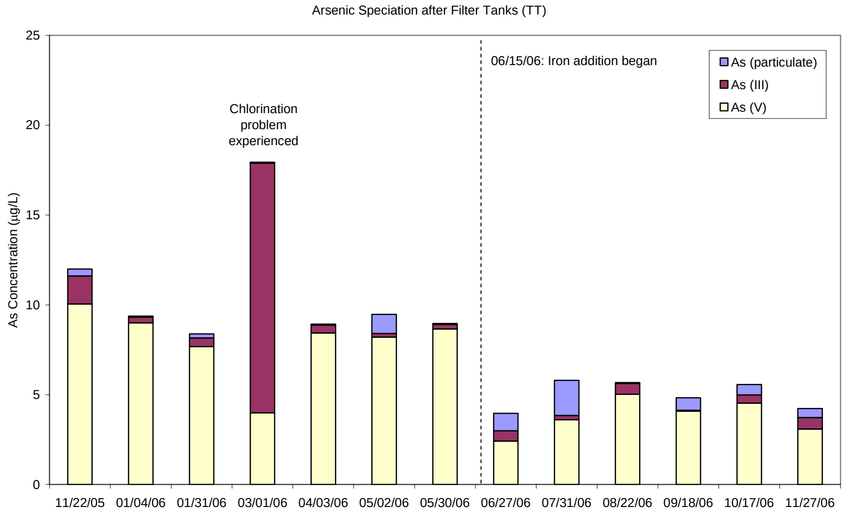


Figure 4-10. Arsenic Speciation Results

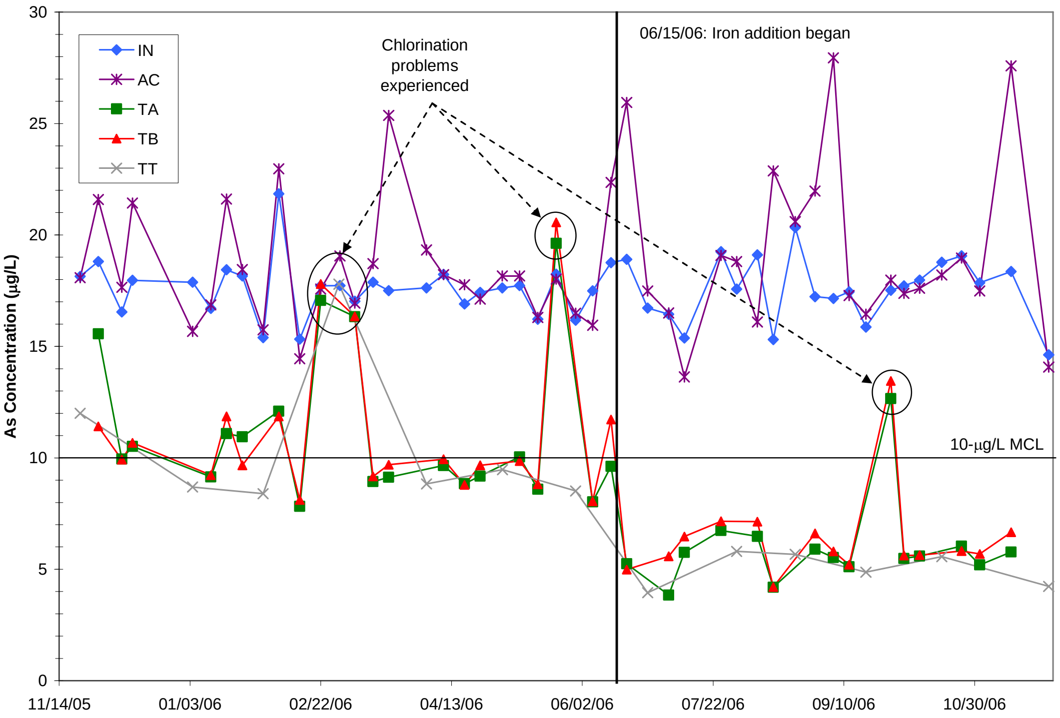


Figure 4-11. Total Arsenic Concentrations Across Treatment Train

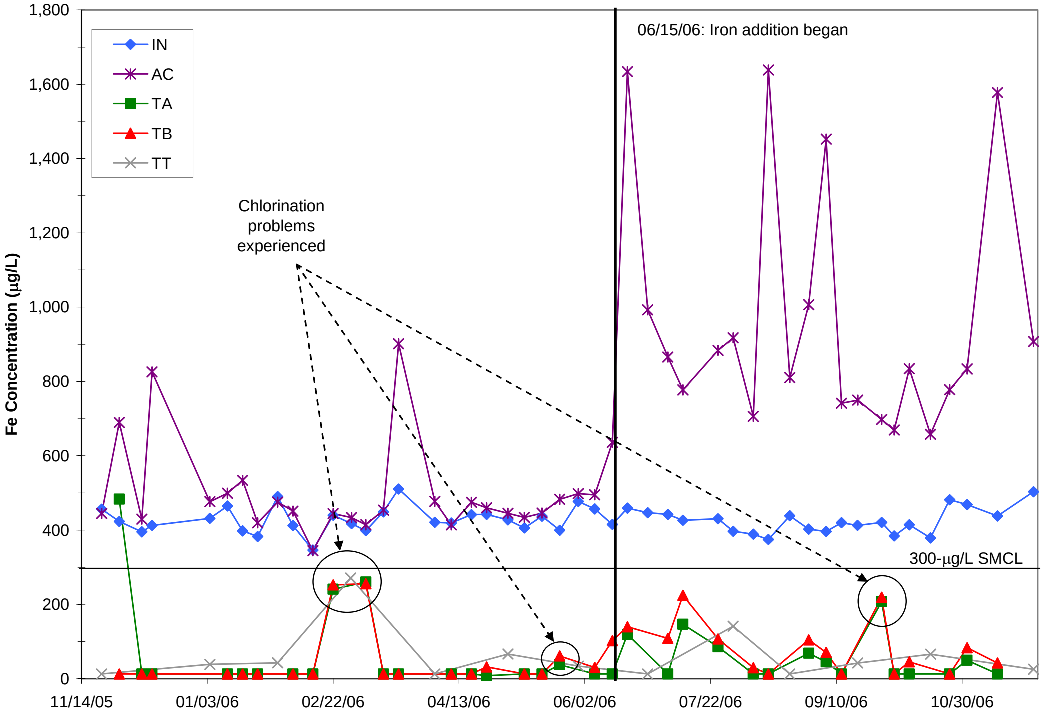


Figure 4-12. Total Iron Concentrations Across Treatment Train

Prior to iron addition, the treated water contained low iron concentrations, mostly near and/or less than the method reporting limit of 25 μg/L, except for one exceedance of 483 μg/L at the TA sampling location on November 29, 2005. With iron addition, effluent iron concentrations increased to an average of 50 μg/L with one spike as high as 225 μg/L (Table 4-8). The speciation tests for iron showed <25 μg/L of soluble iron at all sampling locations after chlorination, indicating that any chloramine formation had little or no effect on iron oxidation. Thus, the slight increase in the effluent iron concentration to near 50 μg/L was due to some small amounts of particulate iron exiting the filters.

To determine the extent of arsenic, iron, and manganese breakthrough during a 24-hr service run, a special study was conducted during November 8 through 14, 2006. Samples were collected at approximately 6, 12, 20, and 24 hr of service time over a duration of seven days while 165 hr of standby time was accrued. Concentrations of arsenic, iron, and manganese in the filter effluent remained below the respective MCLs or SMCLs during the entire filter run, as shown in Figure 4-13. Total arsenic and manganese concentrations, which were 70 to 100% soluble, were consistent with the regular treatment plant results and comparable for both filters. Conversely, total iron concentrations, which were nearly 100% particulate, differed between the filters. Tank A exhibited no breakthrough until almost 20 hr of service while Tank B showed breakthrough over 80 μg/L at 12 hr of service. Similar to the regular treatment plant sampling results, no correlation between particulate iron breakthrough and filter run time was observed, and no iron breakthrough was detected after the filters were freshly backwashed.

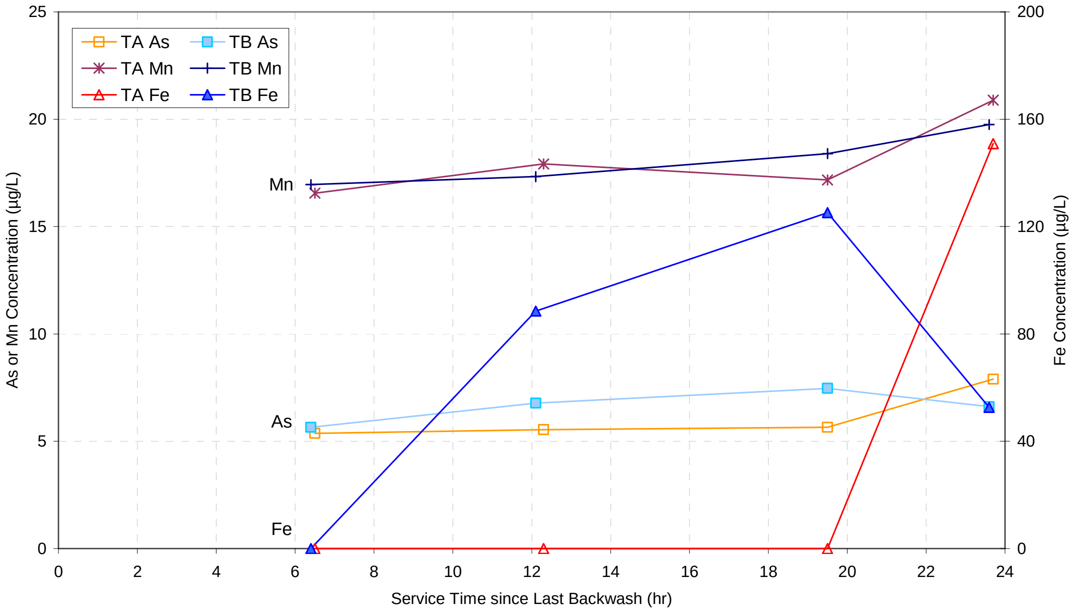


Figure 4-13. Arsenic, Iron, and Manganese Concentrations During a 24-hr Service Run

4.5.1.3 ***Manganese.*** Figure 4-14 presents total manganese concentrations measured during the study. In raw water, manganese ranged from 23.1 to 31.7 μg/L, existing primarily in the soluble form as Mn(II) at an average concentration of 28.8 μg/L. With chlorine addition and contact time, approximately 64 and 45% of the Mn(II) was converted to particulate manganese before and after iron addition, respectively. Because the Macrolite® filters removed only the particulates formed, soluble manganese levels after the contact tank were similar to the total and soluble levels after the pressure filters, with average effluent concentrations ranging from 11 to 13 μg/L before iron addition and 15 to 19 μg/L after iron addition. The cause for the decrease in manganese oxidation/removal with $FeCl_3$ addition is unknown. Studies have found 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; McCall et al., 2007).

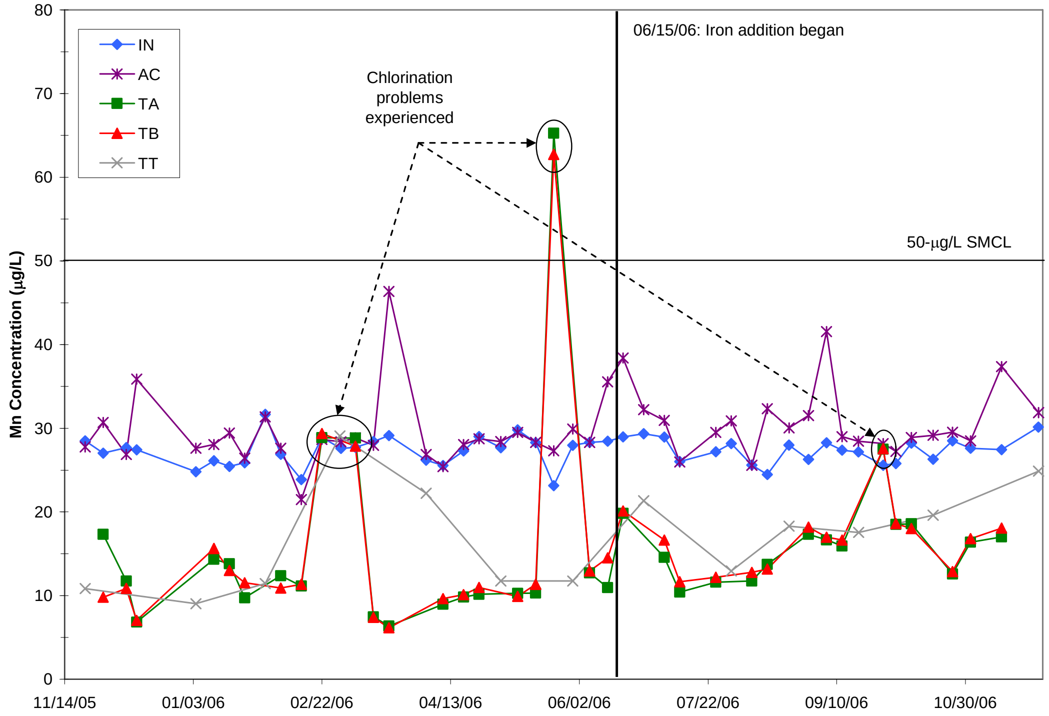


Figure 4-14. Total Manganese Concentrations Across Treatment Train

4.5.1.4 ***pH, DO, and ORP.*** pH values in raw water ranged from 7.5 to 8.3 and averaged 7.9. This range was significantly higher that what was measured by Battelle during source water sampling on August 31, 2004 (i.e., 6.9 [Table 4-1]). Average DO levels across the treatment train were low, ranging from 1.1 to 2.2 mg/L. As a result of chlorine addition, average ORP levels increased from 342 millivolts (mV) in raw water (except for two outliers of -3 and 91 mV on November 22 and 29, 2005, respectively) to over 400 mV after the contact tank.

4.5.1.5 ***Chlorine and Ammonia.*** Ammonia concentrations ranged from 0.2 to 0.4 mg/L (as N) and averaged 0.3 mg/L (as N) with no difference observed across the treatment train. Based on the NaOCl dosage and the amount of free chlorine residuals measured throughout the treatment train (see discussion below), ammonia should have been completely oxidized. Note that the MDL for ammonia was 0.1 mg/L (as N), which was close to some of the amounts measured.

Free and total chlorine residuals measured throughout the treatment train are presented in Figure 4-15. As shown in the figure, data for free and total chlorine residuals were scattered from 0.0 to 1.6 (0.6 to 0.8 on average) and 0.5 to 1.9 (1.3 on average) mg/L (as Cl_2), respectively. Considering that 3.6 mg/L of NaOCl (as Cl_2) was applied to raw water, 0.2 mg/L (as Cl_2) would have reacted with As(III), Fe(II), and Mn(II) based on the average amounts (i.e., 14.9, 250, and 28.8 µg/L, respectively) present in raw water (Table 4-8), and 2.3 mg/L (as Cl_2) would have reacted with 0.3 mg/L (as N) of ammonia to reach breakpoint chlorination. As such, 1.1 mg/L (as Cl_2) would be present as free chlorine in treated water These theoretical amounts seem to be consistent with actual chlorine residuals measured in the treated water.

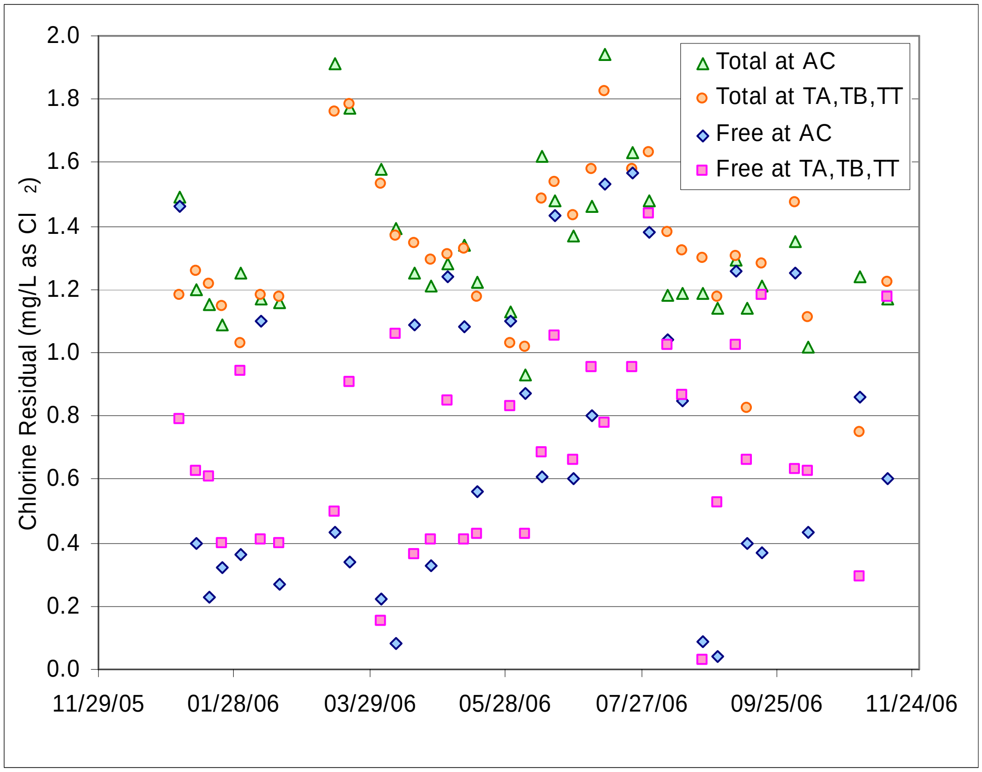


Figure 4-15. Chlorine Residuals Measured Throughout Treatment Train

4.5.1.6 ***Other Water Quality Parameters.*** Alkalinity, fluoride, sulfate, nitrate, silica, TOC, temperature, and hardness levels remained consistent across the treatment train and were not affected by the treatment process (Table 4-8). Phosphorus after the contact tank, which was slightly higher than the average raw water concentration of 57 µg/L (possibly due to trace quantities in the pretreatment chemicals), decreased from an average of 75 to <19 µg/L after the pressure filters. Turbidity also decreased slightly with treatment (i.e., from 2.4 to <1.5 NTU).

4.5.2 **Backwash Water and Solids Sampling.** Table 4-10 presents the analytical results of monthly backwash water sampling events. The results for the January and February 2006 sampling events are not included in the table because these samples were collected from an incorrect sampling tap. Among the events reported, relatively low values of total metals, TSS, and TDS were observed for Events 1 and 2, most likely due to the timing of the sampling (i.e., these manual backwash cycles were initiated soon after the pressure filters were automatically backwashed by the PLC [thus having fewer solids in backwash water for sampling]). Event 2 also was collected on March 7, 2006, when chlorine addition

Table 4-10. Backwash Water Sampling Test Results

Sampling Event[a]		Tank A										Tank B									
		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
1	12/08/05	8.0	252	26	30.0	8.2	21.8	1,564	<25	68.1	10.6	8.0	414	24	31.1	8.5	22.6	1,546	<25	66.1	11.4
2	03/07/06[b]	8.0	390	34	30.5	16.2	14.3	2,023	158	30.2	26.6	8.0	370	11	24.6	14.4	10.2	1,791	92.4	35.4	28.3
3	04/12/06	8.0	428	78	383	11.3	371	25,116	141	658	16.7	8.0	646	39	215	10.0	205	18,599	92.8	373	15.0
4	05/09/06	7.9	430	106	610	12.8	597	29,521	251	1,206	20.6	7.9	636	94	396	11.3	385	19,883	155	824	16.0
5	06/06/06	7.8	418	166	789	9.6	779	46,664	76.0	1,688	15.8	7.9	422	150	914	12.1	902	54,174	159	2,035	17.6
6	07/03/06[c]	7.9	498	282	1,307	6.5	1,301	105,594	80.8	1,875	17.6	7.9	468	200	1,081	8.1	1,073	85,431	208	1,533	18.5
7	08/16/06	7.8	406	269	1,223	5.7	1,217	87,210	101	1,664	14.9	7.8	428	258	1,389	8.3	1,381	95,470	254	1,867	19.5
8	09/19/06	7.8	404	220	903	11.4	891	61,376	263	1,084	20.5	7.8	372	205	1,027	10.9	1,016	64,439	202	1,144	19.5
9	10/09/06	7.6	436	190	978	11.3	967	56,427	200	1,066	20.8	7.7	432	204	1,115	11.3	1,104	62,140	155	1,203	19.8
10	11/14/06	7.6	354	235	1,088	7.7	1,081	82,624	52.0	1,102	17.1	7.6	398	160	1,188	6.9	1,181	77,879	48.5	1,195	16.8

(a) January and February 2006 results omitted since samples collected from an incorrect tap.

(b) Incomplete oxidation of treated water used for backwash due to chlorination problems from 02/21/06 through 03/09/06.

(c) $FeCl_3$ addition began 06/15/06.

Table 4-11. Backwash Solids Sampling Test Results

Date: Location	Mg	Al	Si	P	Ca	Mn	Fe	Ni	Cu	Zn	As	Cd	Pb
	mg/g	mg/g	µg/g	mg/g	mg/g	mg/g	mg/g	µg/g	µg/g	µg/g	mg/g	µg/g	µg/g
06/07/06: Tank A	6.2	9.8	<250	1.4	33.1	14.4	208	7.1	14.8	349	2.7	<0.5	6.3
06/07/06: Tank B	5.8	8.2	<250	2.8	51.6	17.1	258	6.2	16.7	74.6	3.9	<0.5	5.9
11/14/06: Tank A	8.2	6.4	318	21.0	47.8	5.1	371	8.1	44.7	71.4	4.5	0.15	9.4
11/14/06: Tank B	8.2	5.5	427	23.2	49.4	5.1	378	9.3	51.3	69.4	4.8	0.15	11.9

Note: Arsenic/iron (µg/mg) ratios of 13.0, 15.1, 12.1, and 12.7 from top to bottom problems were encountered as discussed in Section 4.4.5.1. The implication was that the backwash used treated water with minimal oxidation, if any, as evident by the somewhat elevated soluble arsenic and manganese concentrations for both tanks.

Concentrations of the backwash water for Events 1, 3, 4, and 5, characteristic of normal operating conditions without iron addition, ranged from 252 to 646 mg/L for TDS and 24 to 166 mg/L for TSS. Concentrations of total arsenic, iron, and manganese ranged from 30 to 914 µg/L, 1.5 to 54 mg/L, and 66 to 2,035 µg/L, respectively. Assuming that these average results existed during the production of 1,165 gal/tank of backwash water, approximately 0.01 lb of arsenic, 0.48 lb of iron, and 0.02 lb of manganese were disharged from both filtration tanks during each backwash. For the subsequent events with iron addition, parameter values ranged from 354 to 498 mg/L for TDS, 160 to 282 mg/L for TSS, and 0.9 to 1.4 mg/L, 56 to 106 mg/L, and 1.1 to 1.9 mg/L for total arsenic, iron, and manganese, respectively. Assuming that these average results existed during the production of 1,520 gal/tank of backwash water, approximately 0.03 lb of arsenic, 2.0 lb of iron, and 0.03 lb of manganese was disharged per backwash cycle (i.e., from both tanks combined). For all events, the backwash water had a pH of 7.8 to 8.0, with the majority of metals existing in particulate form.

The 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 June and November 2006 are presented in Table 4-11. Based on an average TSS concentration of 85 mg/L in backwash water prior to iron addition, approximately 0.5 lb of solids were produced from backwashing both tanks. The iron, manganese, and arsenic compositions of 0.38 lb, 0.03 lb, and 0.01 lb, respectively, were similar to those derived from the backwash water quality data. Increased solids loading due to iron addition produced 2.6 lb of solids from the backwash of both tanks based on an average TSS concentration of 222 mg/L in backwash water. The iron, manganese, and arsenic compositions of 2.10 lb, 0.03 lb, and 0.03 lb, respectively, again, agreed with the backwash water quality data derivations. The calcium composition also was noteworthy at 10 to 14% of the total solids mass for both events.

4.5.3 Distribution System Water Sampling. Table 4-12 summarizes the results of the distribution system sampling events. The water quality was similar among the three residences except for lead and copper at the DS3 residence, which exhibited lower concentrations than the other two residences. After the treatment system began operation, arsenic, manganese, and iron concentrations decreased from average baseline levels of 16.5, 23.8, and 192 µg/L to 7.5, 13.7, and <25 µg/L, respectively, as shown in Figure 4-16. Alkalinity, pH, and lead concentrations remained fairly consistent. Results of the DS2 sample on September 12, 2006 are not included in these findings due to the anomalously high arsenic, iron, and lead values observed. Otherwise, the water in the distribution system was comparable to that of the treatment system effluent, and the treatment system appeared to have beneficial effects on the arsenic, manganese, and iron concentrations (Figure 4-16).

4.6 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. Capital cost of the treatment system included cost for equipment, site engineering, and system installation, shakedown, and startup. O&M cost included cost for chemicals, electricity, and labor. Cost associated with the building including the sump, sanitary sewer connections, and water system telemetry was not included in the capital cost because it was not included in the scope of this demonstration project and was funded separately by the village.

4.6.1 Capital Cost. The capital investment for the FM-260-AS system was $334,573 (Table 4-13). The equipment cost was $224,994 (or 67% of the total capital investment), which included cost for an iron addition system, a contact tank, two pressure tanks, 80 ft^3 of Macrolite®, instrumentation and

Table 4-12. Distribution System Sampling Results

Sampling Event		DS1								DS2								DS3							
		Residence - 1st draw								Residence - 1st draw								Residence - 1st draw							
		Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu
No.	Date	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
BL1	02/22/05	8.0	7.2	158	15.6	144	29.4	3.2	56.5	10.5	7.2	158	12.4	<25	21.2	0.3	199	7.3	7.6	153	15.7	315	26.4	0.1	8.0
BL2	03/22/05$^{(a)}$	6.6	7.8	155	17.8	145	25.2	0.9	151	7.8	8.2	160	23.8	232	8.2	2.6	586	7.5	7.8	155	17.7	284	29.4	<0.1	10.3
BL3	04/19/05	8.0	7.9	155	14.7	144	24.8	0.4	113	7.5	7.9	155	14.2	123	23.8	0.8	202	7.5	7.9	155	17.6	382	29.8	<0.1	3.8
BL4	05/26/05	8.8	7.7	156	16.1	241	23.0	<0.1	32.6	7.5	7.8	156	18.0	188	18.7	0.9	209	7.0	7.9	156	15.0	93.7	26.3	<0.1	4.9
1	12/13/05	8.5	8.0	150	8.5	<25	8.2	<0.1	44.7	8.0	8.1	158	9.6	<25	0.9	1.3	58.6	7.0	8.0	150	10.2	<25	11.7	<0.1	2.3
2	01/17/06	9.5	7.9	154	9.0	<25	9.4	1.5	165	6.8	8.0	154	10.2	<25	12.1	<0.1	4.4	8.0	8.2	154	10.2	<25	13.0	0.1	3.8
3	02/14/06	8.8	8.0	138	7.6	<25	8.5	<0.1	47.1	7.5	8.0	146	4.9	<25	9.5	0.9	176	Homeowner Not Available							
4	03/14/06	6.5	8.0	149	8.6	<25	28.0	5.5	92.1	51.5	8.0	132	11.7	<25	25.1	0.1	26.3	7.5	8.0	145	8.8	<25	14.9	0.1	2.8
5	04/18/06	8.3	8.1	154	7.7	<25	11.5	0.1	125	8.7	8.4	154	11.0	36.5	1.3	0.9	134	8.0	8.1	154	8.6	27.0	10.0	<0.1	3.5
6	05/16/06	8.3	7.9	146	8.0	<25	8.9	<0.1	105	7.8	8.0	146	5.7	<25	11.9	0.6	202	7.5	7.9	142	9.1	<25	11.2	<0.1	3.6
7	06/13/06	8.3	7.8	145	8.4	<25	9.0	<0.1	155	6.5	7.9	145	7.8	89.2	14.9	1.4	391	7.5	7.9	145	9.2	<25	12.2	<0.1	12.8
8	07/11/06$^{(b)}$	7.5	7.8	147	4.3	30.3	11.1	5.0	44.2	7.3	7.8	147	5.0	86.5	19.5	1.4	264	7.5	7.8	147	5.2	64.2	13.7	<0.1	3.2
9	08/15/06	8.8	7.7	147	6.9	<25	16.6	3.7	177	7.5	7.8	126	5.8	48.0	16.6	1.0	308	8.0	7.8	147	6.4	46.5	15.8	0.2	4.1
10	09/12/06	8.2	7.8	151	5.8	<25	16.2	2.7	199	7.6	8.4	151	13.5	1,957	26.8	16.6	30.8	8.0	7.9	151	5.7	<25	16.1	0.5	5.6
11	10/10/06	8.3	7.7	157	6.2	<25	19.0	1.1	104	7.5	7.7	153	6.1	34.4	21.8	0.9	330	7.5	7.8	155	6.1	<25	19.2	0.1	4.5
12	11/28/06	8.3	7.7	162	6.2	<25	11.1	0.2	159	6.5	7.7	162	5.3	<25	18.1	0.5	326	9.0	7.7	162	5.9	<25	19.3	0.5	10.4

(a) DS2 sampled on 03/21/05.

(b) FeCl$_3$ addition began 06/15/06.

BL = baseline sampling; NA = data not available

Lead action level = 15 µg/L; copper action level = 1.3 mg/L

Alkalinity measured in mg/L as CaCO$_3$.

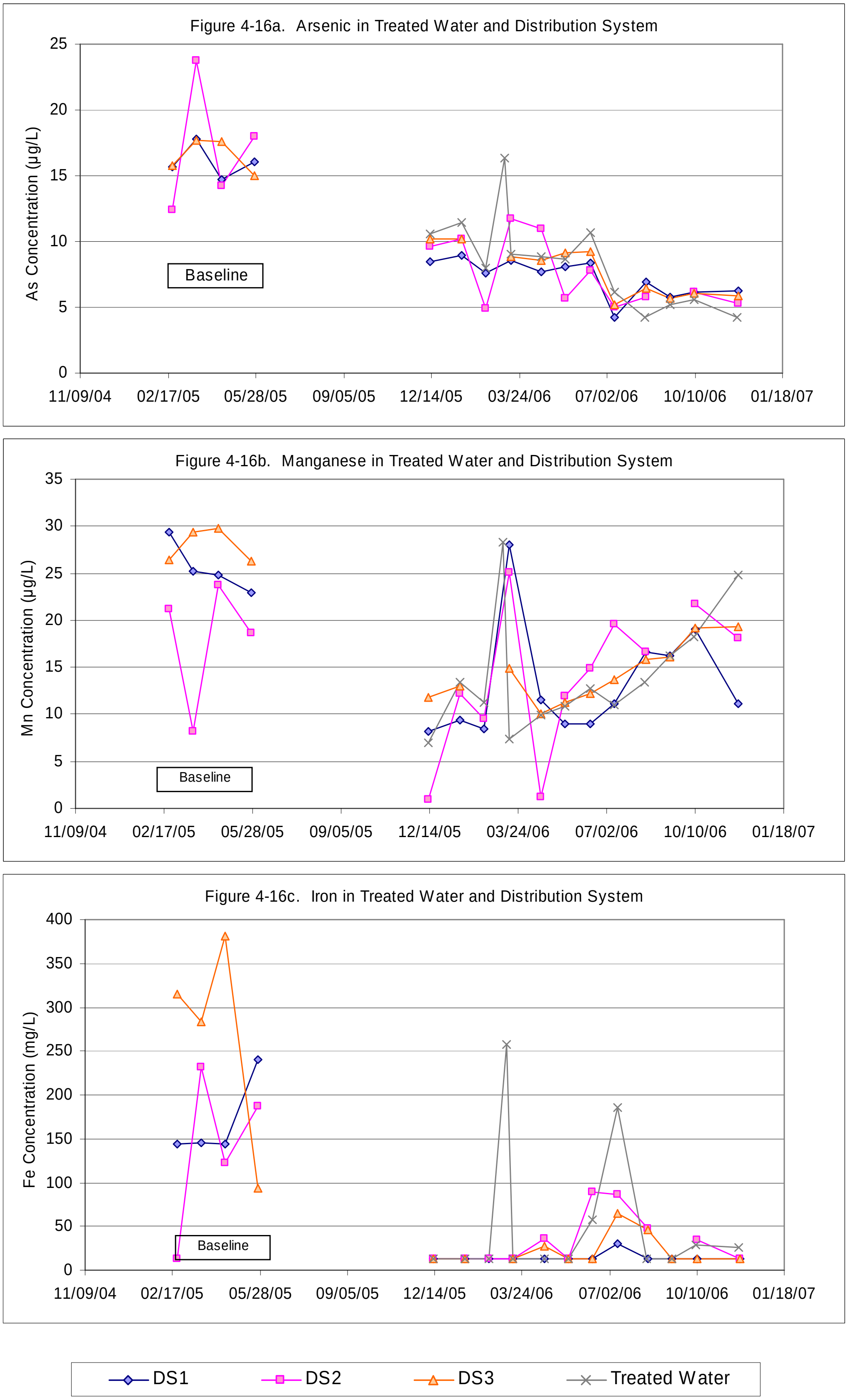


Figure 4-16. Effect of Treatment System on Arsenic, Manganese, and Iron in Distribution System

controls, miscellaneous materials and supplies, labor, and system warranty. The system warranty cost covered the cost for repair and replacement of defective system components and installation workmanship for twelve months after system startup.

The site engineering cost covered the cost for preparing the required permit application submittal, including a process design report, a general arrangement drawing, P&IDs, electrical diagrams, interconnecting piping layouts, tank fill details, and a schematic of the PLC panel, and obtaining the required permit approval from MDEQ. The engineering cost of $30,929 was 9% of the total capital investment.

The installation, shakedown, and startup cost covered the labor and materials required to unload, install, and test the system for proper operation. All installation activities were performed by the vendor's subcontractor, and startup and shakedown activities were performed by the vendor with the operator's assistance. The installation, startup, and shakedown cost of $78,650 was 24% of the total capital investment.

The total capital cost of $334,573 was normalized to $836/gpm ($0.58/gpd) of design capacity using the system's rated capacity of 400 gpm (or 576,000 gpd). The total capital cost also was converted to an annualized cost of $31,581 gal/yr using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-yr return period. Assuming that the system operated 24 hr/day, 7 day/week at the design flowrate of 400 gpm to produce 210,240,000 gal/yr, the unit capital cost would be $0.15/1,000 gal. During the first year, the system produced 38,291,000 gal of water, so the unit capital cost increased to $0.82/1,000 gal.

Table 4-13. Capital Investment for Kinetico's FM-260-AS System

Description	Cost	% of Capital Investment Cost
Equipment		
Tanks, Valves, and Piping	$122,315	–
Macrolite® Media (80 ft^3)	$20,607	–
Instrumentation and Controls	$25,123	–
Air Scour System	$6,305	–
Change Order for Iron Addition System	$3,395	–
Additional Sample Taps and Totalizers/Meters	$2,002	–
Labor	$42,747	–
Freight	$2,500	–
Equipment Total	**$224,994**	**67%**
Engineering		
Labor	$28,679	–
Subcontractor	$2,250	–
Engineering Total	**$30,929**	**9%**
Installation, Shakedown, and Startup		
Labor	$16,200	–
Subcontractor	$57,500	–
Travel	$4,950	–
Installation, Shakedown, and Startup	**$78,650**	**24%**
Total Capital Investment	**$334,573**	**100%**

A 37 ft × 33 ft building with a sidewall height of 16 ft was constructed by the Village to house the treatment system (Section 4.3.2). Not included in the capital cost, the total cost of the building and supporting utilities, which were sized for two treatment systems, was approximately $120,000.

4.6.2 O&M Cost. O&M costs included chemical usage, electricity consumption, and labor for a combined unit cost of $0.17/1,000 gal (Table 4-14). No cost was incurred for repairs because the system was under warranty. Since chlorination already existed prior to the demonstration study, incremental chemical cost for iron addition only at $0.013/1,000 gal was incurred once initiated. Electrical power consumption was calculated based on the difference between the average monthly cost from electric bills before and after building construction and system startup. The difference in cost was approximately $147.50/month or $0.05/1,000 gal of water treated. The routine, non-demonstration related labor activities consumed 30 min/day (Section 4.4.5.3). Based on this time commitment and a labor rate of $30/hr, the labor cost was $0.11/1,000 gal of water treated.

Table 4-14. O&M Costs for Kinetico's FM-260-AS System

Category	Value	Remarks
Volume Processed (1,000 gal)	39,185	From 11/22/05 through 12/08/06
Chemical Usage		
37–42% $FeCl_3$ Unit Cost ($/lb)	$0.37	Supplied in 610 lb drums including tax, surcharges, and drum deposit
$FeCl_3$ Consumption (1b/1,000 gal)	0.035	
Chemical Cost ($/1,000 gal)	$0.013	
Electricity Consumption		
Electricity Cost ($/month)	$147.50	Average incremental consumption after system startup; including building heating and lighting
Electricity Cost ($/1,000 gal)	$0.05	
Labor		
Labor (hr/week)	2.5	30 min/day, 5 day/week
Labor Cost ($/1,000 gal)	$0.11	Labor rate = $30/hr
Total O&M Cost ($/1,000 gal)	$0.17	Including $FeCl_3$ usage

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APPENDIX A

OPERATIONAL DATA

US EPA Arsenic Demonstration Project at Pentwater, MI – Daily System Operation

					Pressure Filtration								Totalizer to Distribution				Backwash					
																					Since Last BW	
Week No.	Date	Well #2 Meter	Run Time	15% Cl_2 Usage	Inlet	Outlet Tank A	Outlet Tank B	Effluent	Inlet-TA	Inlet-TB	Inlet-Effluent	Flow rate	Meter	Cum. Flow	Avg Flow rate	$FeCl_3$ Tank Level	Tank A	Tank B	Cum. Volume	Daily Volume	Run Time	Standby Time
		hr	hr	gal	psig	psig	psig	psig	psig	psig	psig	gpm	kgal	kgal	gpm	gal	No.	No.	kgal	kgal	A/B hr	A/B hr
1	11/22/05	4	NA	NA	80	74	75	56	6	5	24	350	202.7	NA	NA	NA	2	2	34.7	NA	1/1	8/8
	11/23/05	6	2.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	237.2	34	287	NA	4	4	38.0	3.4	1/1	3/3
	11/25/05	9	3.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	335.1	132	544	NA	8	8	42.5	4.5	1/1	2/2
	11/26/05	12	3.0	1.3	NA	NA	NA	NA	NA	NA	NA	NA	432.4	229	541	NA	9	9	46.4	3.9	1/1	4/4
	11/27/05	14	2.0	0.4	NA	NA	NA	NA	NA	NA	NA	NA	489.7	287	477	NA	10	10	48.1	1.7	1/1	11/11
2	11/28/05	17	3.0	1.3	NA	NA	NA	NA	NA	NA	NA	NA	582.9	380	518	NA	12	12	51.4	3.4	1/1	6/6
	11/29/05	19	2.0	0.9	80	74	75	NA	6	5	NA	353	653.7	451	590	NA	14	14	54.8	3.4	0/0	2/1
	11/30/05	22	3.0	1.3	NA	NA	NA	NA	NA	NA	NA	NA	730.5	527	427	NA	15	15	56.5	1.7	1/1	10/9
	12/01/05	24	2.0	1.3	NA	NA	NA	NA	NA	NA	NA	NA	807.1	604	639	NA	17	17	59.8	3.4	0/0	5/4
	12/02/05	27	3.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	875.1	672	377	NA	19	19	63.2	3.4	1/0	0/0
	12/04/05	31	4.0	2.2	NA	NA	NA	NA	NA	NA	NA	NA	986.7	784	465	NA	22	22	68.5	5.3	1/1	2/0
3	12/05/05	32	1.0	0.4	NA	NA	NA	NA	NA	NA	NA	NA	1013.3	810	444	NA	23	23	70.2	1.7	1/0	9/7
	12/06/05	35	3.0	1.3	NA	NA	NA	NA	NA	NA	NA	NA	1095.7	892	458	NA	25	25	73.5	3.4	1/1	6/4
	12/07/05	37	2.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	1147.4	944	432	NA	27	27	77.7	4.2	1/1	9/2
	12/08/05	38	1.0	0.9	NA	80	74	75	NA	NA	NA	351	1173.4	970	433	NA	28	28	80.5	2.8	0/0	3/9
	12/09/05	41	3.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	1254.1	1051	448	NA	30	30	85.0	4.5	1/1	9/6
	12/10/05	42	1.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	1279.5	1076	424	NA	31	31	88.0	3.1	0/1	2/11
4	12/12/05	47	5.0	2.2	90	81	75	76	9	15	14	350	1406.8	1204	424	NA	36	35	95.6	7.5	1/1	7/4
	12/13/05	48	1.0	0.4	NA	NA	NA	NA	NA	NA	NA	NA	1438.2	1235	523	NA	37	36	98.9	3.4	0/0	3/2
	12/14/05	50	2.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	1491.6	1288	445	NA	39	38	102.3	3.4	0/0	9/7
	12/15/05	53	3.0	1.8	NA	NA	NA	NA	NA	NA	NA	NA	1572.4	1369	449	NA	40	38	103.4	1.1	2/3	19/30
	12/16/05	55	2.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	1624.8	1422	436	NA	41	39	107.0	3.6	2/0	15/0
5	12/19/05	62	7.0	3.5	NA	NA	NA	NA	NA	NA	NA	NA	1805.5	1602	430	NA	42	40	109.8	2.8	4/1	29/10
	12/20/05	64	2.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	1859.8	1657	453	NA	43	41	112.1	2.2	0/2	0/18
	12/21/05	65	1.0	0.9	78	72	71	58	6	7	20	355	1892.9	1690	552	NA	43	41	112.1	0.0	1/3	15/34
	12/22/05	68	3.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	1964.3	1761	397	NA	43	42	113.5	1.4	4/1	39/10
	12/24/05	72	4.0	3.5	NA	NA	NA	NA	NA	NA	NA	NA	2067.6	1864	430	NA	44	42	114.9	1.4	3/5	27/46
6	12/27/05	78	6.0	3.5	78	71	72	58	7	6	20	359	2237.1	2034	471	NA	45	44	118.8	3.9	3/0	37/8
	12/28/05	81	3.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	2306.5	2103	385	NA	46	44	120.2	1.4	1/3	13/32
	12/29/05	83	2.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	2356.8	2154	419	NA	46	45	121.6	1.4	3/0	31/1
7	01/02/06	98	15.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	2722.9	2520	407	NA	48	46	126.1	4.5	1/3	9/27
	01/03/06	100	2.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	2774.5	2571	429	NA	48	46	126.1	0.0	3/5	24/42
	01/04/06	102	2.0	0.9	77	73	73	58	4	4	19	363	2827.0	2624	438	NA	49	47	128.6	2.5	0/1	0/18
	01/05/06	104	2.0	1.8	77	72	72	58	5	5	19	360	2884.0	2681	474	NA	49	48	129.7	1.1	2/0	19/0
	01/06/06	107	3.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	8.2	2689	NA	NA	49	48	129.7	0.0	5/3	39/20
8	01/09/06	113	6.0	2.7	NA	NA	NA	NA	NA	NA	NA	NA	176.5	2857	468	NA	51	49	133.9	4.2	1/4	2/31
	01/10/06	115	2.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	231.1	2912	455	NA	51	50	135.0	1.1	3/1	26/6
	01/11/06	116	1.0	0.9	78	72	72	58	6	6	20	359	257.9	2939	447	NA	51	50	135.0	0.0	4/0	44/0
	01/12/06	118	2.0	1.8	NA	NA	NA	NA	NA	NA	NA	NA	352.0	3033	784	NA	52	51	137.8	2.8	1/2	16/21
	01/13/06	119	1.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	376.8	3058	413	NA	52	51	137.8	0.0	2/3	29/34
	01/15/06	124	5.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	504.6	3185	426	NA	53	52	140.6	2.8	3/5	24/40
9	01/16/06	125	1.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	555.4	3236	848	NA	53	53	141.7	1.1	5/1	45/12
	01/17/06	127	2.0	0.9	78	73	72	58	5	6	20	358	607.7	3288	435	NA	54	53	143.1	1.4	1/3	17/32
	01/18/06	131	4.0	1.3	NA	NA	NA	NA	NA	NA	NA	NA	684.2	3365	319	NA	54	54	144.5	1.4	4/1	40/7
	01/19/06	133	2.0	0.9	80	74	74	58	6	6	22	365	749.0	3430	540	NA	55	54	145.9	1.4	1/3	9/25
	01/20/06	134	1.0	0.4	79	72	71	58	7	8	21	359	778.9	3460	499	NA	55	54	145.9	0.0	2/4	30/46
10	01/23/06	NA	NA	2.7	78	71	73	58	7	5	20	356	936.1	3617	NA	NA	56	56	149.5	3.6	4/0	41/8
	01/24/06	143	NA	1.3	NA	NA	NA	NA	NA	NA	NA	NA	1009.5	3690	NA	NA	57	56	150.9	1.4	2/3	17/32
	01/25/06	145	2.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	1057.9	3739	404	NA	57	57	152.0	1.1	4/1	39/5
	01/26/06	146	1.0	0.4	77	72	72	58	5	5	19	362	1083.7	3764	429	NA	58	57	153.4	1.4	0/2	5/19

US EPA Arsenic Demonstration Project at Pentwater, MI – Daily System Operation (Continued)

					Pressure Filtration								Totalizer to Distribution				Backwash					
																					Since Last BW	
Week No.	Date	Well #2 Meter hr	Run Time hr	15% Cl_2 Usage gal	Inlet psig	Outlet Tank A psig	Outlet Tank B psig	Effluent psig	Inlet-TA psig	Inlet-TB psig	Inlet-Effluent psig	Flow rate gpm	Meter kgal	Cum. Flow kgal	Avg Flow rate gpm	$FeCl_3$ Tank Level gal	Tank A No.	Tank B No.	Cum. Volume kgal	Daily Volume kgal	Run Time A/B hr	Standby Time A/B hr
11	01/30/06	155	9.0	4.0	NA	NA	NA	NA	NA	NA	NA	NA	1317.0	3998	432	NA	59	59	157.4	3.9	4/1	40/7
	01/31/06	157	2.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	1369.8	4051	440	NA	60	59	158.8	1.4	1/3	8/23
	02/01/06	158	1.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	1421.2	4102	857	NA	60	59	158.8	0.0	3/5	29/44
	02/02/06	161	3.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	1472.1	4153	283	NA	61	60	161.3	2.5	1/2	2/16
	02/03/06	161	NA	0.4	79	72	71	58	7	8	21	353	1502.7	4183	NA	NA	61	60	161.3	0.0	2/3	21/35
12	02/06/06	169	8.0	3.1	NA	NA	NA	NA	NA	NA	NA	NA	1675.3	4356	360	NA	62	61	164.1	2.8	3/5	31/45
	02/07/06	171	2.0	0.4	NA	NA	NA	NA	NA	NA	NA	NA	1722.2	4403	391	NA	63	62	166.6	2.5	2/2	20/20
	02/08/06	174	3.0	1.3	NA	NA	NA	NA	NA	NA	NA	NA	1798.0	4479	421	NA	63	62	166.6	0.0	5/5	44/44
	02/09/06	176	2.0	0.4	NA	NA	NA	NA	NA	NA	NA	NA	1846.7	4527	406	NA	64	63	169.4	2.8	1/1	11/11
	02/10/06	178	2.0	1.3	NA	NA	NA	NA	NA	NA	NA	NA	1915.2	4596	571	NA	64	63	169.4	0.0	3/3	32/32
13	02/13/06	185	7.0	3.5	NA	NA	NA	NA	NA	NA	NA	NA	2093.2	4774	424	NA	65	64	171.9	2.5	6/6	47/0
	02/14/06	186	1.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	2144.5	4825	856	NA	66	65	174.7	2.8	2/2	17/17
	02/15/06	189	3.0	1.8	80	72	72	59	8	8	21	352	2236.1	4917	509	NA	66	65	174.7	0.0	5/5	38/38
	02/16/06	192	3.0	0.9	78	73	72	58	5	6	20	355	2285.4	4966	274	NA	67	66	177.5	2.8	0/0	6/6
	02/17/06	194	2.0	0.9	78	71	72	58	7	6	20	355	2346.9	5028	513	NA	67	66	177.5	0.0	3/3	28/28
14	02/20/06	204	10.0	3.1	NA	NA	NA	NA	NA	NA	NA	NA	2567.5	5248	368	NA	68	67	178.9	1.4	6/6	36/36
	02/21/06	206	2.0	NA	78	73	73	60	5	5	18	351	2630.6	5311	526	NA	69	68	181.7	2.8	1/1	4/4
	02/22/06	208	2.0	1.3	78	74	73	58	4	5	20	355	2687.5	5368	474	NA	69	68	181.7	0.0	3/3	20/19
	02/23/06	3.8	NA	1.3	NA	NA	NA	NA	NA	NA	NA	NA	2774.6	5455	NA	NA	70	69	185.0	3.4	3.8/0	15.3/1.3
	02/24/06	10.0	6.2	2.2	78	72	73	58	6	5	20	352	2903.3	5584	346	NA	70	69	185.0	0.0	10.0/6.3	38.6/22.5
15	02/27/06	22.3	12.3	5.8	78	73	73	58	5	5	20	347	200.7	5785	NA	NA	71	70	187.5	2.5	9.6/5.8	42.6/28.0
	02/28/06	26.1	3.8	1.3	NA	NA	NA	NA	NA	NA	NA	NA	276.5	5861	332	NA	72	71	189.8	2.2	3.6/1.3	18.0/3.9
	03/01/06	29.1	3.0	1.3	79	74	73	58	5	6	21	347	339.9	5924	352	NA	72	71	189.8	0.0	6.6/4.3	32.6/15.5
	03/02/06	33.6	4.5	1.8	NA	NA	NA	NA	NA	NA	NA	NA	431.9	6016	341	NA	73	72	194.0	4.2	0.4/0.1	NR
	03/03/06	35.3	1.7	1.8	NA	NA	NA	NA	NA	NA	NA	NA	466.7	6051	341	NA	75	73	198.2	4.2	0.0/0.0	3.0/0.0
16	03/06/06	45.3	10.0	4.4	77	72	73	58	5	4	19	353	675.6	6260	348	NA	76	74	201.2	3.1	2.1/2.1	13.1/12.8
	03/07/06	47.2	1.9	1.8	78	72	73	58	6	5	20	346	715.9	6300	353	NA	76	74	201.2	0.0	4.0/3.9	28.4/28.1
	03/08/06	52.0	4.8	2.2	78	73	72	58	5	6	20	351	812.0	6396	334	NA	77	75	203.5	2.2	4.2/4.2	19.1/18.6
	03/09/06	55.5	3.5	NA	78	72	72	58	6	6	20	347	881.8	6466	332	NA	77	75	203.5	0.0	7.6/7.6	41.1/40.6
	03/10/06	58.8	3.3	1.8	77	72	71	58	5	6	19	345	948.9	6533	339	NA	78	76	206.3	2.8	1.4/1.4	11.5/11.0
17	03/13/06	70.8	12.0	6.2	NA	NA	NA	NA	NA	NA	NA	NA	1194.1	6778	341	NA	79	77	209.1	2.8	5.7/5.9	23.0/22.5
	03/14/06	73.3	2.5	2.2	NA	NA	NA	NA	NA	NA	NA	NA	1244.4	6828	336	NA	79	77	209.1	0.0	8.2/8.4	43.2/42.7
	03/15/06	76.9	3.6	2.2	NA	NA	NA	NA	NA	NA	NA	NA	1320.4	6904	352	NA	79	78	210.2	1.1	NA	NA
	03/16/06	80.6	3.7	1.8	NA	NA	NA	NA	NA	NA	NA	NA	1396.3	6980	342	NA	80	78	211.6	1.4	6.2/6.2	33.9/33.3
	03/17/06	85.6	5.0	2.7	78	73	72	59	5	6	19	347	1495.7	7080	331	NA	81	79	214.4	2.8	0.9/0.9	4.3/3.7
18	03/20/06	102.2	16.6	9.8	NA	NA	NA	NA	NA	NA	NA	NA	1832.8	7417	338	NA	82	80	217.2	2.8	5.2/3.7	13.8/13.9
	03/21/06	106.0	3.8	2.7	NA	NA	NA	NA	NA	NA	NA	NA	1911.6	7496	346	NA	82	80	217.2	0.0	9.0/7.6	32.0/31.6
	03/22/06	108.3	2.3	0.9	NA	NA	NA	NA	NA	NA	NA	NA	1959.3	7543	345	NA	83	81	219.7	2.5	0.0/0.0	1.9/1.5
	03/23/06	113.4	5.1	2.7	NA	NA	NA	NA	NA	NA	NA	NA	2063.0	7647	339	NA	83	81	219.7	0.0	5.1/5.1	23.3/23.0
	03/24/06	115.9	2.5	1.8	NA	NA	NA	NA	NA	NA	NA	NA	2113.1	7697	334	NA	83	81	219.7	0.0	7.6/7.6	40.9/40.6
19	03/27/06	126.7	10.8	5.8	77	72	72	58	5	5	19	347	2331.0	7915	336	NA	85	83	224.7	5.0	0.5/0.5	4.4/4.0
	03/28/06	131.4	4.7	2.2	NA	NA	NA	NA	NA	NA	NA	NA	2425.6	8010	336	NA	85	83	224.7	0.0	5.2/5.1	28.5/28.2
	03/29/06	135.3	3.9	2.7	NA	NA	NA	NA	NA	NA	NA	NA	2503.4	8088	333	NA	86	83	226.1	1.4	0.0/9.0	0/48.0
	03/30/06	137.8	2.5	1.3	NA	NA	NA	NA	NA	NA	NA	NA	2553.1	8137	331	NA	86	84	227.2	1.1	2.5/2.4	16.2/16.0
	03/31/06	141.2	3.4	1.3	79	72	72	59	7	7	20	347	2623.6	8208	346	NA	86	84	227.2	0.0	5.9/5.5	40.4/40
20	04/03/06	151.0	9.8	3.5	77	73	72	59	4	5	18	357	2823.8	8408	340	NA	88	86	232.0	4.8	0.0/0.0	2.7/2.4
	04/04/06	154.5	3.5	1.8	NA	NA	NA	NA	NA	NA	NA	NA	2894.0	8478	334	NA	88	86	232.0	0.0	3.5/3.5	20.8/20.5
	04/05/06	159.1	4.6	NA	80	72	72	58	8	8	22	345	31.8	8510	NA	NA	88	86	232.0	0.0	8.2/8.1	47.8/47.5
	04/06/06	161.0	1.9	0.9	NA	NA	NA	NA	NA	NA	NA	NA	68.1	8546	318	NA	89	87	234.5	2.5	1.2/1.2	14.1/13.9
	04/07/06	166.2	5.2	2.2	NA	NA	NA	NA	NA	NA	NA	NA	173.2	8651	337	NA	89	87	234.5	0.0	6.4/6.4	38.6/38.4

US EPA Arsenic Demonstration Project at Pentwater, MI – Daily System Operation (Continued)

					Pressure Filtration								Totalizer to Distribution				Backwash					
																					Since Last BW	
Week No.	Date	Well #2 Meter hr	Run Time hr	15% Cl_2 Usage gal	Inlet psig	Outlet Tank A psig	Outlet Tank B psig	Effluent psig	Inlet-TA psig	Inlet-TB psig	Inlet-Effluent psig	Flow rate gpm	Meter kgal	Cum. Flow kgal	Avg Flow rate gpm	$FeCl_3$ Tank Level gal	Tank A No.	Tank B No.	Cum. Volume kgal	Daily Volume kgal	Run Time A/B hr	Standby Time A/B hr
21	04/10/06	175.9	9.7	4.9	80	72	72	58	8	8	22	347	368.4	8846	335	NA	90	88	236.7	2.2	8.4/8.4	45.7/45.4
	04/11/06	180.4	4.5	2.7	NA	NA	NA	NA	NA	NA	NA	NA	461.0	8939	343	NA	91	89	239.2	2.5	3.8/3.8	21.6/21.3
	04/12/06	182.9	2.5	0.9	NA	NA	NA	NA	NA	NA	NA	NA	512.2	8990	342	NA	91	90	240.4	1.1	6.3/2.5	39.2/16.7
	04/13/06	187.5	4.6	2.2	78	72	72	59	6	6	19	347	606.7	9085	342	NA	92	91	242.6	2.2	4.6/4.6	22.6/22.5
22	04/17/06	201.0	13.5	7.1	NA	NA	NA	NA	NA	NA	NA	NA	892.9	9371	353	NA	94	93	247.6	5.0	0.0/0.0	0.7/0.4
	04/18/06	205.4	4.4	1.8	NA	NA	NA	NA	NA	NA	NA	NA	973.7	9452	306	NA	94	93	247.6	0.0	3.9/3.9	20.0/19.8
	04/19/06	209.8	4.4	2.2	80	71	72	58	9	8	22	349	1061.5	9540	332	NA	94	93	247.6	0.0	8.3/8.3	47.2/42.0
	04/20/06	214.4	4.6	2.2	NA	NA	NA	NA	NA	NA	NA	NA	1155.6	9634	341	NA	95	94	250.1	2.5	2.6/2.5	13.0/12.7
	04/21/06	219.1	4.7	3.1	80	72	72	58	8	8	22	346	1253.4	9731	347	NA	95	94	250.1	0.0	7.3/7.2	34.7/34.5
23	04/24/06	231.5	12.4	5.8	81	73	72	58	8	9	23	347	1504.4	9982	337	NA	96	95	252.7	2.5	10.4/10.0	42.6/42.6
	04/25/06	234.5	3.0	1.3	77	72	72	58	5	5	19	356	1567.0	10045	348	NA	97	96	255.2	2.5	0.0/2.6	0.0/13.7
	04/26/06	238.5	4.0	2.2	NA	NA	NA	NA	NA	NA	NA	NA	1650.6	10129	348	NA	98	96	256.3	1.1	4.0/6.7	16.5/30.4
	04/27/06	242.4	3.9	2.7	NA	NA	NA	NA	NA	NA	NA	NA	1732.3	10210	349	NA	98	97	257.4	1.1	7.9/1.2	36.3/1.9
	04/28/06	246.4	4.0	1.8	NA	NA	NA	NA	NA	NA	NA	NA	1813.5	10292	338	NA	99	97	258.8	1.4	1.2/5.2	7.7/21.0
24	05/01/06	261.9	15.5	6.2	NA	NA	NA	NA	NA	NA	NA	NA	2128.0	10606	338	NA	100	98	261.3	2.5	4.1/8.1	19.0/33.1
	05/02/06	266.0	4.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	2209.8	10688	333	NA	100	99	262.7	1.4	8.2/0.0	36.4/23.0
	05/03/06	271.4	5.4	2.2	NA	NA	NA	NA	NA	NA	NA	NA	2319.2	10797	338	NA	101	99	263.8	1.1	2.7/5.4	7.5/21.8
	05/04/06	274.2	2.8	1.8	79	72	71	58	7	8	21	355	2377.5	10856	347	NA	101	99	263.8	0.0	5.5/8.2	24.2/38.5
	05/05/06	280.0	5.8	3.1	NA	NA	NA	NA	NA	NA	NA	NA	2493.2	10971	332	NA	101	100	265.2	1.4	11.3/1.3	42.9/8.9
25	05/08/06	299.8	19.8	10.2	NA	NA	NA	NA	NA	NA	NA	NA	2892.1	11370	336	NA	103	101	269.2	3.9	1.6/6.3	3.2/17.5
	05/09/06	304.4	4.6	3.1	77	72	72	58	5	5	19	355	30.9	11401	NA	NA	104	102	271.4	2.2	0.0/0.0	2.0/0.4
	05/10/06	310.1	5.7	3.1	NA	NA	NA	NA	NA	NA	NA	NA	147.1	11517	340	NA	105	102	273.1	1.7	4.4/5.7	16.3/18.8
	05/11/06	314.1	4.0	1.8	NA	NA	NA	NA	NA	NA	NA	NA	228.5	11599	339	NA	105	102	273.1	0.0	8.8/9.7	34.3/36.8
	05/12/06	319.7	5.6	1.8	NA	NA	NA	NA	NA	NA	NA	NA	288.4	11659	178	NA	106	103	275.9	2.8	1.5/2.7	4.3/6.7
26	05/15/06	333.3	13.6	6.7	NA	NA	NA	NA	NA	NA	NA	NA	618.7	11989	405	NA	107	104	278.7	2.8	2.6/4.1	12.9/15.4
	05/16/06	337.4	4.1	1.8	NA	NA	NA	NA	NA	NA	NA	NA	703.7	12074	345	NA	107	104	278.7	0.0	0.0/8.3	0.0/28.4
	05/17/06	341.4	4.0	2.7	78	72	73	58	6	5	20	355	866.8	12237	NA	NA	108	105	101.3	NA	4.0/0.8	15.6/2.4
	05/18/06	346.4	5.0	2.2	NA	NA	NA	NA	NA	NA	NA	NA	968.6	12339	339	NA	108	105	101.3	0.0	9.0/5.7	37.1/24.4
	05/19/06	352.0	5.6	4.0	NA	NA	NA	NA	NA	NA	NA	NA	1083.4	12454	342	NA	109	105	102.6	1.3	2.7/11.2	6.6/42.4
27	05/22/06	368.2	16.2	7.5	NA	NA	NA	NA	NA	NA	NA	NA	1420.3	12790	347	NA	110	107	106.4	3.8	4.3/0.0	12.6/0.0
	05/23/06	372.6	4.4	NA	78	71	71	58	7	7	20	353	1513.4	12884	353	NA	110	107	106.4	0.0	8.7/4.4	31.3/18.7
	05/24/06	378.3	5.7	2.2	NA	NA	NA	NA	NA	NA	NA	NA	1630.9	13001	344	NA	110	107	106.4	0.0	14.4/10.1	47.3/34.8
	05/25/06	385.9	7.6	3.5	NA	NA	NA	NA	NA	NA	NA	NA	1790.2	13160	349	NA	111	108	109.1	2.7	7.6/3.1	21.3/8.8
	05/26/06	393.1	7.2	2.7	80	71	71	59	9	9	21	348	1938.8	13309	344	NA	111	108	109.1	0.0	14.8/10.3	35.4/22.8
28	05/30/06	432.6	39.5	15.9	NA	NA	NA	NA	NA	NA	NA	NA	2746.2	14116	341	NA	113	110	115.0	5.9	6.1/1.7	11.7/0.8
	05/31/06	438.2	5.6	2.7	NA	NA	NA	NA	NA	NA	NA	NA	2861.4	14232	343	NA	113	110	115.0	0.0	11.9/7.3	30.3/18.4
	06/01/06	443.8	5.6	2.1	NA	NA	NA	NA	NA	NA	NA	NA	2976.8	14347	343	NA	113	111	116.4	1.4	NR	NR
	06/02/06	449.4	5.6	2.3	NA	NA	NA	NA	NA	NA	NA	NA	3091.9	14462	343	NA	114	111	117.8	1.4	4.3/1.5	14.3/3.4
29	06/05/06	472.5	23.1	8.9	NA	NA	NA	NA	NA	NA	NA	NA	289.4	14751	NA	NA	115	112	120.5	2.7	8.4/3.2	15.1/4.2
	06/06/06	479.8	7.3	2.7	NA	NA	NA	NA	NA	NA	NA	NA	437.7	14900	339	NA	115	112	120.5	0.0	15.7/10.4	29.6/18.8
	06/07/06	487.8	8.0	3.5	78	72	73	58	6	5	20	351	604.4	15066	347	NA	116	113	123.1	2.6	8.0/5.8	16.1/15.6
	06/08/06	493.2	5.4	1.8	80	71	71	58	9	9	22	352	717.8	15180	350	NA	116	113	123.1	0.0	13.4/11.3	33.8/33.3
	06/09/06	501.2	8.0	5.3	76	72	72	59	4	4	17	358	880.7	15343	339	NA	117	114	125.8	2.7	2.1/2.0	4.8/4.4
30	06/12/06	525.0	23.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	1368.1	15830	341	NA	118	115	128.7	2.9	1.9/1.5	0.9/0.9
	06/13/06	532.2	7.2	4.0	78	72	71	58	6	7	20	354	1517.3	15979	345	NA	118	115	128.7	0.0	9.1/8.6	15.6/15.6
	06/14/06	541.6	9.4	4.0	79	72	71	58	7	8	21	347	1712.6	16175	346	NA	118	115	128.7	0.0	18.5/18	25.6/25.6
	06/15/06	550.7	9.1	3.1	78	71	71	58	7	7	20	356	1902.5	16365	348	45.0	119	116	131.4	2.7	8.3/3.3	14.8/10.2
	06/16/06	564.7	14.0	5.8	87	71	71	58	16	16	29	328	2171.6	16634	320	38.5	119	116	131.4	0.0	22.3/17.3	25.4/20.9
	06/17/06	577.5	12.8	5.8	82	71	69	58	11	13	24	352	2432.3	16894	339	34.5	120	117	134.6	3.2	11.1/10.7	7.6/7.5
	06/18/06	593.7	16.2	7.1	NA	NA	NA	NA	NA	NA	NA	NA	2748.6	17211	325	30.5	121	118	137.9	3.3	3.3/2.9	3.5/3.5

US EPA Arsenic Demonstration Project at Pentwater, MI – Daily System Operation (Continued)

					Pressure Filtration								Totalizer to Distribution				Backwash					
																					Since Last BW	
Week No.	Date	Well #2 Meter hr	Run Time hr	15% Cl_2 Usage gal	Inlet psig	Outlet Tank A psig	Outlet Tank B psig	Effluent psig	Inlet-TA psig	Inlet-TB psig	Inlet-Effluent psig	Flow rate gpm	Meter kgal	Cum. Flow kgal	Avg Flow rate gpm	$FeCl_3$ Tank Level gal	Tank A No.	Tank B No.	Cum. Volume kgal	Daily Volume kgal	Run Time A/B hr	Standby Time A/B hr
31	06/19/06	601.9	8.2	2.2	83	71	71	58	12	12	25	338	2911.7	17374	332	28.0	121	118	137.9	0.0	11.5/11.2	18.5/18.7
	06/20/06	608.7	6.8	3.1	86	71	70	58	15	16	28	335	3044.1	17506	325	26.5	121	118	137.9	0.0	18.3/17.9	33.4/33.6
	06/21/06	616.9	8.2	3.1	81	71	70	58	10	11	23	348	3217.2	17679	352	24.0	122	119	141.2	3.3	6/5.7	14/14
	06/22/06	624.4	7.5	4.4	NA	NA	NA	NA	NA	NA	NA	NA	91.3	17771	NA	22.0	122	119	141.2	0.0	13.5/13.2	28.1/28.1
	06/23/06	NR	NA	1.3	NA	NA	NA	NA	NA	NA	NA	NA	246.3	17926	NA	20.0	122	119	141.2	0.0	21.5/21.2	42.5/42.5
	06/25/06	654.0	NA	NA	86	72	70	50	14	16	36	334	685.4	18365	NA	14.5	123	120	144.6	3.4	19.3/18.9	25.6/25.6
32	06/26/06	624.7	NA	2.2	79	71	71	58	8	8	21	345	824.8	18504	NA	12.5	124	121	148.0	3.4	2.1/1.6	3.1/3.0
	06/27/06	666.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	942.4	18622	NA	11.0	124	121	148.0	0.0	8/7.4	18.1/18.1
	06/28/06	674.1	7.2	3.1	83	72	69	58	11	14	25	348	1086.2	18765	333	9.5	124	121	148.0	0.0	15.2/14.6	34.6/34.6
	06/29/06	681.3	7.2	2.7	NA	NA	NA	NA	NA	NA	NA	NA	1227.4	18907	327	7.5	125	122	151.1	3.1	0/0	1.5/1.0
	06/30/06	691.3	10.0	4.0	82	71	71	58	11	11	24	346	1428.8	19108	336	41.0	125	122	151.1	0.0	10/10	16/16
33	07/03/06	725.5	34.2	14.2	82	69	69	58	13	13	24	334	2107.5	19787	331	32.5	126	123	154.3	3.2	19.6/20.3	20.9/20.9
	07/05/06	750.4	24.9	10.2	NA	NA	NA	NA	NA	NA	NA	NA	2595.8	20275	327	26.0	127	124	157.6	3.3	22.2/21.8	19.1/19
	07/06/06	763.6	13.2	5.8	NA	NA	NA	NA	NA	NA	NA	NA	2861.1	20540	335	22.0	128	125	160.7	3.1	11.4/10.9	11.1/11.1
	07/07/06	774.0	10.4	4.0	NA	NA	NA	NA	NA	NA	NA	NA	2931.3	20611	113	19.0	128	125	160.7	0.0	22.8/21.3	22.9/22.5
	07/09/06	801.9	27.9	NA	77	71	70	58	6	7	19	345	343.4	20954	NA	12.0	130	127	166.9	6.2	1.7/1.2	1.5/1.5
34	07/10/06	814.0	12.1	5.3	NA	NA	NA	NA	NA	NA	NA	NA	581.8	21192	328	43.0	130	127	166.9	0.0	13.9/13.4	11.3/11.3
	07/11/06	823.0	9.0	4.9	86	71	70	58	15	16	28	328	774.9	21385	358	42.0	130	127	166.9	0.0	23.7/23.2	26.6/26.5
	07/12/06	830.7	7.7	3.5	82	72	70	58	10	12	24	340	920.2	21531	315	40.0	131	128	170.1	3.2	6.6/6.3	11.9/11.9
	07/13/06	838.8	8.1	4.0	NA	NA	NA	NA	NA	NA	NA	NA	1079.4	21690	328	38.5	131	128	170.1	0.0	14.7/14.4	27.3/27.3
	07/14/06	845.8	7.0	3.5	NA	NA	NA	NA	NA	NA	NA	NA	1195.3	21806	276	36.5	131	128	170.1	0.0	21.7/21.4	33.4/33.4
35	07/17/06	NA	NA	NA	84	73	69	58	11	15	26	NA	NA	NA	NA	36.0	131	128	170.1	0.0	23.8/23.5	33.4/33.4
	07/19/06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	36.0	131	128	170.1	0.0	8.5/8.6	9.1/8.8
	07/20/06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	36.0	131	128	170.1	0.0	20.3/20.5	20.2/19.8
	07/21/06	NA	NA	NA	74	68	67	58	6	7	16	NA	NA	NA	NA	36.0	132	129	175.9	5.8	4.5/5.0	8.5/8.5
	07/22/06	886.5	9.6	20.0	83	73	69	58	10	14	25	350	1867.5	22478	325	34.0	133	129	178.5	2.6	5.9/14.6	10.6/23.6
36	07/24/06	910.7	24.2	11.5	83	73	70	58	10	13	25	348	2356.3	22967	337	27.5	134	130	182.2	3.7	6.1/14.7	9.9/16
	07/25/06	918.0	7.3	3.5	85	72	69	58	13	16	27	346	2506.7	23117	343	25.5	134	130	182.2	0.0	13.4/22.2	23.1/29.2
	07/26/06	925.6	7.6	3.1	83	69	73	58	14	10	25	348	2663.6	23274	344	23.5	134	131	183.9	1.7	21/5.9	36.5/13
	07/27/06	933.8	8.2	4.4	NA	NA	NA	NA	NA	NA	NA	NA	2838.4	23449	355	21.5	135	131	185.6	1.7	5.2/14.5	12.8/28
	07/28/06	943.0	9.2	4.4	87	72	70	58	15	17	29	342	3026.4	23637	341	19.0	135	131	185.6	0.0	14.4/23.7	27.1/42.1
	07/29/06	953.2	10.2	4.0	80	74	69	58	6	11	22	345	3241.0	23852	351	16.0	136	132	188.9	3.3	0.6/10.2	0/12.9
	07/30/06	965.3	12.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	203.4	24055	NA	13.0	136	132	188.9	0.0	12.4/22	10.6/23.6
37	07/31/06	974.9	9.6	3.1	NA	NA	NA	NA	NA	NA	NA	NA	404.0	24256	348	10.5	136	133	190.6	1.7	22.3/7.4	24.5/13.2
	08/01/06	983.4	8.5	4.0	85	74	68	58	11	17	27	345	584.9	24436	355	43.0	137	133	192.2	1.6	6.8/16.3	12.1/27
	08/02/06	994.3	10.9	5.3	82	70	73	58	12	9	24	345	805.6	24657	337	41.5	137	134	194.0	1.8	17.7/2.8	25.6/7.0
	08/03/06	1004.0	9.7	4.4	82	74	70	58	8	12	24	348	1010.4	24862	352	39.0	138	134	195.7	1.7	3.4/12.8	8/23.2
	08/04/06	1013.5	9.5	4.0	87	74	70	58	13	17	29	335	1199.8	25051	332	36.5	138	134	195.7	0.0	12.8/22.2	20.5/35.6
	08/06/06	1036.0	22.5	10.6	NA	NA	NA	NA	NA	NA	NA	NA	1666.2	25518	345	30.5	139	135	199.0	3.3	11.5/21.0	11.4/22.5
38	08/07/06	1045.8	9.8	4.4	85	69	72	58	16	13	27	339	1862.2	25714	333	28.0	139	136	200.7	1.7	21.5/6.4	6.4/9.5
	08/08/06	1054.8	9.0	3.5	80	71	75	58	9	5	22	355	2051.6	25903	351	25.0	140	137	203.7	3.0	6.2/8.1	11.4/11.4
	08/09/06	1067.1	12.3	5.8	NA	NA	NA	NA	NA	NA	NA	NA	2300.4	26152	337	22.0	140	137	203.7	0.0	18.3/20.4	24.3/24.3
	08/10/06	1076.8	9.7	4.0	81	72	70	58	9	11	23	350	2503.0	26355	348	19.5	141	138	207.0	3.3	5.7/6.1	9.2/9.3
	08/11/06	1090.0	13.2	4.0	NA	NA	NA	NA	NA	NA	NA	NA	2768.4	26620	335	16.0	141	138	207.0	0.0	18.9/19.3	20.6/20.5
	08/13/06	1119.0	29.0	NA	84	66	72	58	18	12	26	348	67.9	26688	NA	8.5	142	140	212.1	5.1	23.9/0	15.5/0
39	08/14/06	1129.0	10.0	4.9	83	72	70	58	11	13	25	349	293.5	26913	376	5.5	143	140	213.8	1.7	10.8/11.2	8.5/8.5
	08/15/06	1141.1	12.1	4.4	82	72	71	58	10	11	24	357	525.5	27145	320	40.0	144	141	216.7	2.9	9.4/9.4	11.2/10.4
	08/16/06	1153.0	11.9	5.3	87	72	70	58	15	17	29	338	765.0	27385	335	36.5	144	141	216.7	0.0	21.3/21.3	20.7/20.5
	08/17/06	1166.4	13.4	5.8	83	72	71	58	11	12	25	351	1036.6	27657	338	33.0	145	142	220.0	3.3	9.3/8.8	9.5/9.5
	08/18/06	1178.6	12.2	4.4	85	71	70	58	14	15	27	342	1269.8	27890	319	30.0	145	142	220.0	0.0	21/21.5	20.5/21.5

US EPA Arsenic Demonstration Project at Pentwater, MI – Daily System Operation (Continued)

					Pressure Filtration								Totalizer to Distribution				Backwash					
																					Since Last BW	
Week No.	Date	Well #2 Meter hr	Run Time hr	15% Cl_2 Usage gal	Inlet psig	Outlet Tank A psig	Outlet Tank B psig	Effluent psig	Inlet-TA psig	Inlet-TB psig	Inlet-Effluent psig	Flow rate gpm	Meter kgal	Cum. Flow kgal	Avg Flow rate gpm	$FeCl_3$ Tank Level gal	Tank A No.	Tank B No.	Cum. Volume kgal	Daily Volume kgal	Run Time A/B hr	Standby Time A/B hr
40	08/21/06	1213.1	34.5	15.1	77	67	66	56	10	11	21	362	1950.1	28570	329	21.0	147	144	226.8	6.8	7.7/7.1	1.5/1.6
	08/22/06	1230.0	16.9	NA	77	72	71	58	5	6	19	345	2270.4	28890	316	17.0	148	145	230.2	3.4	0.7/0.2	0/0
	08/23/06	1241.8	11.8	7.1	84	71	70	58	13	14	26	345	2510.6	29131	339	13.5	148	145	230.2	0.0	12.6/12.0	8.8/8.8
	08/24/06	1254.1	12.3	4.4	NA	NA	NA	NA	NA	NA	NA	NA	2758.3	29378	336	10.5	149	146	233.7	3.5	1.0/0.6	0.7/0.7
	08/25/06	1259.1	5.0	2.7	NA	NA	NA	NA	NA	NA	NA	NA	2864.6	29485	354	9.0	149	146	233.7	0.0	6.1/5.7	13.8/13.8
41	08/28/06	1295.0	35.9	14.2	NA	NA	NA	NA	NA	NA	NA	NA	308.8	29793	NA	35.0	150	147	237.0	3.3	17.8/17.6	24.0/24.1
	08/29/06	1303.1	8.1	3.5	79	72	71	59	7	8	20	349	476.6	29961	345	33.0	151	148	240.4	3.4	1.8/1.4	4.0/4.0
	08/30/06	1311.8	8.7	3.5	83	72	71	59	11	12	24	350	661.6	30146	354	30.5	151	148	240.4	0.0	10.8/10.4	21.3/21.3
	08/31/06	1319.6	7.8	3.5	85	72	70	58	13	15	27	349	816.7	30301	331	28.0	151	148	240.4	0.0	18.4/18.0	35.8/35.8
	09/01/06	1329.7	10.1	4.0	NA	NA	NA	NA	NA	NA	NA	NA	1024.6	30509	343	26.0	152	149	243.7	3.3	4.5/4.0	8.2/8.2
	09/02/06	1350.1	20.4	8.4	78	72	71	60	6	7	18	357	1435.4	30920	336	20.0	153	150	247.0	3.3	0.9/0.5	0/0
42	09/05/06	1382.3	32.2	NA	84	73	71	58	11	13	26	342	2089.4	31574	339	11.5	154	151	250.4	3.4	9.3/9.0	12.2/12.3
	09/06/06	1390.2	7.9	3.1	86	72	70	58	14	16	28	353	2250.9	31735	341	10.0	154	151	250.4	0.0	17.2/17.0	27.1/27.1
	09/07/06	1397.5	7.3	3.1	79	73	72	58	6	7	21	360	2402.9	31887	347	38.0	155	152	253.7	3.3	0.5/0.1	0/0
	09/08/06	1405.5	8.0	3.5	NA	NA	NA	NA	NA	NA	NA	NA	2569.0	32054	346	36.0	155	152	253.7	0.0	8.5/8.1	16.3/16.3
43	09/11/06	1425.9	20.4	8.0	NA	NA	NA	NA	NA	NA	NA	NA	2989.2	32474	343	30.5	157	154	259.4	5.7	0/16.9	0/16.9
	09/12/06	1429.8	3.9	2.2	80	72	72	58	8	8	22	363	3072.7	32557	357	29.5	157	154	259.4	0.0	3.9/3.9	17.0/17.2
	09/13/06	1435.3	5.5	1.8	80	72	71	58	8	9	22	354	3185.3	32670	341	28.0	157	154	259.4	0.0	9.4/9.3	33.8/34.0
	09/14/06	1439.2	3.9	2.7	80	70	70	58	10	10	22	361	3268.2	32753	354	26.5	158	155	262.2	2.8	0.3/0.3	0/0
	09/15/06	1444.8	5.6	2.2	NA	NA	NA	NA	NA	NA	NA	NA	107.4	32860	NA	25.0	158	155	262.2	0.0	5.2/5.7	18.1/18.5
44	09/18/06	1463.0	18.2	7.1	NA	NA	NA	NA	NA	NA	NA	NA	493.8	33247	354	20.5	159	156	265.2	3.0	6.3/6.2	19.1/19.6
	09/19/06	1468.9	5.9	1.3	84	72	72	58	12	12	26	354	602.9	33356	308	19.0	159	156	265.2	0.0	11.5/11.5	37.3/38.8
	09/20/06	1473.0	4.1	2.7	80	73	72	58	7	8	22	360	685.8	33439	337	18.0	160	157	267.9	2.7	3.3/3.3	17.7/17.4
	09/21/06	1478.0	5.0	1.8	80	73	72	58	7	8	22	350	785.9	33539	334	16.5	160	157	267.9	0.0	8.1/8.1	36.7/36.4
	09/22/06	1482.4	4.4	4.0	NA	NA	NA	NA	NA	NA	NA	NA	877.2	33630	346	15.5	161	158	270.6	2.7	1.5/1.4	6.9/6.6
45	09/25/06	1498.2	15.8	3.5	NA	NA	NA	NA	NA	NA	NA	NA	1208.0	33961	349	11.0	162	159	273.4	2.8	4.1/4.1	15.7/15.3
	09/26/06	1502.4	4.2	0.4	NA	NA	NA	NA	NA	NA	NA	NA	1293.8	34047	340	10.5	162	159	273.4	0.0	8.2/8.3	34.8/34.4
	09/27/06	1507.5	5.1	0.9	80	73	72	60	7	8	20	352	1401.5	34154	352	0.2	163	160	276.0	2.6	2.4/2.4	7.7/7.2
	09/28/06	1511.5	4.0	0.0	NA	NA	NA	NA	NA	NA	NA	NA	1493.0	34246	381	43.0	163	160	276.0	0.0	6.8/6.8	28.2/27.7
	09/29/06	1516.3	4.8	0.0	NA	NA	NA	NA	NA	NA	NA	NA	1584.3	34337	317	42.0	164	160	277.3	1.3	0/0	0.3/0
46	10/02/06	1530.5	14.2	9.3	NA	NA	NA	NA	NA	NA	NA	NA	1887.0	34640	355	38.5	165	162	281.1	3.8	2.8/2.8	7.1/6.7
	10/03/06	1533.2	2.7	0.4	81	73	72	58	8	9	23	350	1962.0	34715	463	37.5	165	162	281.1	0.0	5.5/5.5	23.2/22.8
	10/04/06	1538.0	4.8	1.3	83	72	72	58	11	11	25	352	2047.2	34800	296	36.0	165	162	281.1	0.0	10.3/10.4	45.6/45.1
	10/05/06	1541.0	3.0	1.3	NA	NA	NA	NA	NA	NA	NA	NA	2111.9	34865	359	35.5	166	163	283.7	2.6	2.7/2.7	14.5/13.8
	10/06/06	1545.0	4.0	2.7	NA	NA	NA	NA	NA	NA	NA	NA	2199.2	34952	364	34.5	166	163	283.7	0.0	6.9/31.2	6.9/30.7
47	10/09/06	1560.0	15.0	5.8	82	72	71	58	10	11	24	360	2508.8	35262	344	30.5	167	164	286.4	2.7	10.4/10.4	39.8/39.8
	10/10/06	1566.0	6.0	3.1	NA	NA	NA	NA	NA	NA	NA	NA	2645.9	35399	381	29.5	168	165	289.1	2.7	5.3/5.3	19.2/18.9
	10/11/06	1569.0	3.0	1.8	NA	NA	NA	NA	NA	NA	NA	NA	2710.2	35463	357	28.5	168	165	289.1	0.0	8.4/38.7	8.3/38.4
	10/12/06	1572.6	3.6	0.4	79	72	72	58	7	7	21	362	2769.7	35522	275	27.0	169	166	291.8	2.7	1.5/1.5	7.2/6.8
	10/13/06	1578.0	5.4	3.1	NA	NA	NA	NA	NA	NA	NA	NA	2884.9	35638	356	25.5	169	166	291.8	0.0	7/7.1	26.5/26.3
48	10/16/06	1592.1	14.1	6.2	NA	NA	NA	NA	NA	NA	NA	NA	3179.8	35933	349	21.5	170	167	294.8	3.0	8.5/8.6	3.4/33.5
	10/17/06	1595.4	3.3	1.8	NA	NA	NA	NA	NA	NA	NA	NA	3255.8	36009	384	20.8	171	168	297.2	2.4	3.5/3.5	15.3/18.6
	10/18/06	1598.6	3.2	1.3	NA	NA	NA	NA	NA	NA	NA	NA	38.7	36047	NA	20.0	171	168	297.2	0.0	6.5/6.5	40.3/39.9
	10/19/06	1602.1	3.5	1.8	83	73	72	58	10	11	25	357	113.8	36122	358	19.0	171	168	297.2	0.0	10.0/10.0	58.6/58.2
	10/20/06	1606.8	4.7	1.8	NA	NA	NA	NA	NA	NA	NA	NA	209.9	36218	341	17.5	171	168	297.2	0.0	14.7/14.6	82.3/81.8
49	10/23/06	1617.8	11.0	4.0	80	74	73	58	6	7	22	353	442.6	36451	353	15.0	173	170	302.5	5.3	1.8/1.8	7.3/6.9
	10/24/06	1620.9	3.1	1.8	NA	NA	NA	NA	NA	NA	NA	NA	510.1	36519	363	14.0	173	170	302.5	0.0	4.9/5.0	27.0/26.6
	10/25/06	1623.4	2.5	1.8	NA	NA	NA	NA	NA	NA	NA	NA	562.6	36571	350	13.0	174	171	305.2	2.7	0/0	0/0
	10/26/06	1626.0	2.6	0.9	NA	NA	NA	NA	NA	NA	NA	NA	620.8	36629	373	12.5	174	171	305.2	0.0	2.6/2.8	18.3/19.9
	10/27/06	1629.0	3.0	1.8	NA	NA	NA	NA	NA	NA	NA	NA	730.0	36739	607	11.5	174	171	305.2	0.0	6.5/6.7	40.1/39.7

US EPA Arsenic Demonstration Project at Pentwater, MI – Daily System Operation (Continued)

					Pressure Filtration								Totalizer to Distribution				Backwash					
																					Since Last BW	
Week No.	Date	Well #2 Meter	Run Time	15% Cl_2 Usage	Inlet	Outlet Tank A	Outlet Tank B	Effluent	Inlet-TA	Inlet-TB	Inlet-Effluent	Flow rate	Meter	Cum. Flow	Avg Flow rate	$FeCl_3$ Tank Level	Tank A	Tank B	Cum. Volume	Daily Volume	Run Time	Standby Time
		hr	hr	gal	psig	psig	psig	psig	psig	psig	psig	gpm	kgal	kgal	gpm	gal	No.	No.	kgal	kgal	A/B hr	A/B hr
50	10/30/06	1640.5	11.5	4.4	NA	NA	NA	NA	NA	NA	NA	NA	925.2	36934	283	8.5	176	173	310.7	5.5	1.2/1.2	5.0/5.4
	10/31/06	1644.0	3.5	1.8	NA	NA	NA	NA	NA	NA	NA	NA	1005.0	37014	380	43.5	176	173	310.7	0.0	5.0/5.0	28.4/28.8
	11/01/06	1646.0	2.0	1.3	83	73	72	58	10	11	25	354	1056.5	37065	429	42.5	176	173	310.7	0.0	7.4/7.4	44.8/45.2
	11/03/06	1653.0	7.0	3.1	NA	NA	NA	NA	NA	NA	NA	NA	1192.1	37201	323	40.5	177	174	313.3	2.6	6.3/6.5	41.4/41.7
51	11/06/06	1662.2	9.2	3.5	NA	NA	NA	NA	NA	NA	NA	NA	1384.6	37393	349	38.5	177	174	313.3	0.0	15.5/15.8	97.2/97.7
	11/07/06	1665.2	3.0	1.8	80	72	73	58	8	7	22	363	1450.1	37459	364	37.5	178	175	316.3	3.0	3.0/3.0	19.8/19.4
	11/08/06	1668.7	3.5	0.9	82	72	72	58	10	10	24	361	1519.9	37528	332	36.5	178	175	316.3	0.0	6.5/6.4	43.0/42.6
	11/09/06	1670.5	1.8	1.3	NA	NA	NA	NA	NA	NA	NA	NA	1557.7	37566	350	36.0	178	175	316.3	0.0	8.3/8.2	60.1/59.7
	11/10/06	1674.5	4.0	1.3	NA	NA	NA	NA	NA	NA	NA	NA	1640.0	37649	343	35.0	178	175	316.3	0.0	12.3/12.1	81.9/81.7
52	11/13/06	1684.0	9.5	4.4	NA	NA	NA	NA	NA	NA	NA	NA	1843.2	37852	356	32.5	178	175	316.3	0.0	21.9/21.8	141.6/141.5
	11/14/06	1685.0	1.0	0.9	85	73	71	58	12	14	27	360	1881.5	37890	638	32.0	178	175	316.3	0.0	23.7/23.6	165.0/164.9
	11/16/06	1691.1	6.1	2.2	80	72	71	58	8	9	22	364	1981.0	37990	272	31.0	179	176	319.6	3.3	3.5/3.6	44.7/44.3
	11/17/06	1693.3	2.2	1.8	NA	NA	NA	NA	NA	NA	NA	NA	2029.3	38038	366	30.0	180	177	321.9	2.3	1.2/1.1	13.8/13.5
53	11/20/06	1700.3	7.0	2.2	NA	NA	NA	NA	NA	NA	NA	NA	2181.1	38190	361	28.5	181	178	324.2	2.3	3.5/3.5	29.2/58.9
	11/21/06	1702.3	2.0	0.9	NA	NA	NA	NA	NA	NA	NA	NA	2231.6	38240	421	27.5	182	179	326.9	2.7	0.0/0.0	4.4/4.0
	11/22/06	1704.6	2.3	1.8	NA	NA	NA	NA	NA	NA	NA	NA	2282.1	38291	366	27.0	182	179	326.9	0.0	2.3/2.3	24.2/23.7
54	11/27/06	1718.5	13.9	5.3	NA	NA	NA	NA	NA	NA	NA	NA	2578.8	38587	356	24.0	184	181	332.0	5.1	2.5/2.6	30.8/30.5
	11/28/06	1721.0	2.5	0.9	NA	NA	NA	NA	NA	NA	NA	NA	2631.5	38640	351	22.5	185	182	334.4	2.4	0.0/0.0	4.0/3.6
	11/29/06	1724.7	3.7	1.8	NA	NA	NA	NA	NA	NA	NA	NA	2710.2	38719	355	21.5	185	182	334.4	0.0	3.7/3.7	31.3/30.9
	11/30/06	1725.5	0.8	0.9	NA	NA	NA	NA	NA	NA	NA	NA	2735.3	38744	523	21.0	185	182	334.4	0.0	4.9/4.9	46.7/46.2
	12/01/06	1729.6	4.1	1.3	NA	NA	NA	NA	NA	NA	NA	NA	2814.0	38823	320	20.5	186	183	336.9	2.5	2.4/2.4	21.7/21.1
55	12/04/06	1735.9	6.3	2.7	NA	NA	NA	NA	NA	NA	NA	NA	2942.5	38951	340	18.5	187	184	339.4	2.5	3.6/3.6	35.8/35.1
	12/05/06	1739.4	3.5	1.3	NA	NA	NA	NA	NA	NA	NA	NA	3020.2	39029	370	17.5	188	185	342.0	2.6	1.2/1.2	13.2/12.5
	12/06/06	1740.6	1.2	0.0	NA	NA	NA	NA	NA	NA	NA	NA	3045.1	39054	346	17.0	188	185	342.0	0.0	2.4/2.4	29.4/28.7
	12/07/06	1744.2	3.6	1.8	NA	NA	NA	NA	NA	NA	NA	NA	3124.5	39133	368	16.5	189	186	344.6	2.6	1.2/1.3	6.6/5.9
	12/08/06	1746.6	2.4	3.1	NA	NA	NA	NA	NA	NA	NA	NA	3176.5	39185	361	16.0	189	186	344.6	0.0	3.6/3.7	29.7/29.0

Note: Average calculated flowrates before 02/22/06 not accurate due to hour meter limitations.

Flowrate and Totalizer to Distribution Meter readings before 05/16/06 proportionally calculated due to incorrect initial calibration.

Highlighted columns indicate calculated values.

NA = data not available

APPENDIX B

ANALYTICAL DATA TABLES

Analytical Results from Long-Term Sampling at Pentwater, MI

Sampling Date		11/22/05			11/29/05				12/08/05				12/12/05				01/04/06		
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT
Alkalinity	mg/L$^{(a)}$	141 -	154 -	154 -	150 -	154 -	154 -	158 -	154 -	150 -	154 -	154 -	154 -	154 -	150 -	145 -	150 -	150 -	154 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.5	0.4	0.4	-	-	-	-	-	-	-	-	-	-	-	-	0.4	0.4	0.4
Sulfate	mg/L	<1	<1	<1	-	-	-	-	-	-	-	-	-	-	-	-	<1	<1	<1
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05
P (total)	µg/L$^{(b)}$	55.0 -	71.2 -	51.9 -	66.2 -	126$^{(d)}$ -	218$^{(d)}$ -	32.2 -	56.6 -	58.0 -	23.6 -	17.8 -	60.6 -	87.6 -	25.2 -	25.7 -	55.7 -	59.9 -	27.0 -
Silica (as SiO$_2$)	mg/L	11.4 -	11.7 -	11.3 -	11.4 -	11.5 -	11.5 -	11.5 -	11.2 -	10.5 -	11.1 -	10.7 -	11.2 -	11.1 -	11.1 -	10.9 -	11.6 -	11.1 -	11.1 -
Turbidity	NTU	2.6 -	0.6 -	<0.1 -	1.8 -	0.4 -	0.5 -	0.7 -	2.3 -	0.4 -	0.1 -	0.2 -	1.7 -	0.2 -	<0.1 -	<0.1 -	1.9 -	0.7 -	0.5 -
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	8.3	8.3	8.6	8.1	8.1	8.1	8.0	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	8.3	8.4	8.1
Temperature	°C	12.2	12.3	12.0	11.5	12.3	12.5	12.1	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	15.0	14.0	14.3
DO	mg/L	0.9	1.2	0.9	3.3	0.9	1.6	4.1	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	2.4	1.9	3.7
ORP	mV	-3	496	424	91	469	516	511	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	187	523	511
Free Chlorine	mg/L	-	2.0+$^{(c)}$	2.0+$^{(c)}$	-	2.0+$^{(c)}$	2.0+$^{(c)}$	2.0+$^{(c)}$	-	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	-	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	-	1.5	0.8
Total Chlorine	mg/L	-	2.0+$^{(c)}$	2.0+$^{(c)}$	-	2.0+$^{(c)}$	2.0+$^{(c)}$	2.0+$^{(c)}$	-	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	-	NA$^{(e)}$	NA$^{(e)}$	NA$^{(e)}$	-	1.5	1.2
Total Hardness	mg/L$^{(a)}$	210	215	217	-	-	-	-	-	-	-	-	-	-	-	-	202	207	210
Ca Hardness	mg/L$^{(a)}$	118	122	121	-	-	-	-	-	-	-	-	-	-	-	-	113	114	117
Mg Hardness	mg/L$^{(a)}$	92.1	92.6	96.0	-	-	-	-	-	-	-	-	-	-	-	-	89.0	92.4	93.9
As (total)	µg/L	18.1 -	18.1 -	12.0 -	18.8 -	21.6$^{(d)}$ -	15.6$^{(d)}$ -	11.4 -	16.5 -	17.7 -	9.9 -	9.9 -	18.0 -	21.4 -	10.5 -	10.7 -	17.9 -	15.7 -	8.7 -
As (soluble)	µg/L	18.0	12.9	11.6	-	-	-	-	-	-	-	-	-	-	-	-	18.3	9.2	9.3
As (particulate)	µg/L	0.1	5.2	0.4	-	-	-	-	-	-	-	-	-	-	-	-	<0.1	6.5	<0.1
As (III)	µg/L	16.2	1.4	1.6	-	-	-	-	-	-	-	-	-	-	-	-	17.1	<0.1	0.3
As (V)	µg/L	1.9	11.5	10.1	-	-	-	-	-	-	-	-	-	-	-	-	1.2	9.1	9.0
Fe (total)	µg/L	456 -	445 -	<25 -	423 -	690$^{(d)}$ -	483$^{(d)}$ -	<25 -	395 -	429 -	<25 -	<25 -	413 -	826 -	<25 -	<25 -	431 -	476 -	38.5 -
Fe (soluble)	µg/L	433	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-	422	<25	<25
Mn (total)	µg/L	28.5 -	27.8 -	10.8 -	27.0 -	30.7$^{(d)}$ -	17.3$^{(d)}$ -	9.8 -	27.7 -	26.9 -	11.7 -	10.8 -	27.4 -	35.9 -	6.8 -	7.0 -	24.8 -	27.6 -	9.0 -
Mn (soluble)	µg/L	28.9	10.5	11.0	-	-	-	-	-	-	-	-	-	-	-	-	25.5	9.1	9.0

(a) As CaCO$_3$. (b) As P. (c) Residual was estimated by operator based on color of solution with reagent. (d) Rerun analysis indicated similar results. (e) Water quality parameter not measured.

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

Sampling Date		01/11/06				1/17/2006[d]				01/23/06[e]				01/31/06			02/06/06[f]			
Sampling Location		IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB
Parameter	Unit																			
Alkalinity	mg/L[a]	154	145[c]	154	158	154	154	158	150	167	150	154	154	148	152	144	150	150	150	150
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	146	150	150	150
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.4	0.4	0.4	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-
P (total)	µg/L[b]	<10	<10	<10	<10	48.5	59.9	15.2	18.3	69.7	72.8	29.2	26.5	44.0	46.2	<10	58.4	64.8	19.8	21.2
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	62.9	62.5	21.4	21.3
Silica (as SiO_2)	mg/L	11.1	11.2	11.4	11.3	11.5	11.2	11.6	11.6	11.0	10.8	11.2	11.3	11.3	10.6	11.5	10.9	11.5	11.2	11.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11.4	11.5	11.1	11.7
Turbidity	NTU	2.5	0.6	0.6	0.4	2.7	0.6	2.2	1.1	2.9	2.0	4.7	1.0	2.6	0.9	1.6	2.5	0.7	0.3	0.5
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.5	0.7	0.3	0.4
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	2.0	1.6[g]	2.5[g]	-	-	-	-
pH	S.U.	8.1	8.0	7.9	8.0	8.0	8.0	8.0	7.9	8.1	8.3	8.3	8.3	8.0	8.0	8.5	8.0	8.0	8.0	8.0
Temperature	°C	12.6	12.6	12.9	12.6	12.0	12.4	12.9	13.6	12.1	12.1	12.4	12.6	13.8	13.5	14.5	12.2	12.3	12.8	13.1
DO	mg/L	1.3	1.1	1.1	1.2	0.8	0.5	1.4	1.1	1.2	0.8	1.7	0.7	3.7	1.7	1.5	1.9	0.9	1.5	1.1
ORP	mV	331	403	400	478	264	437	444	413	322	487	471	466	397	395	443	302	311	318	364
Free Chlorine	mg/L	-	0.4	0.3	1.0	-	0.2	0.4	0.9	-	0.3	0.2	0.6	-	0.4	0.9	-	1.1	0.6	0.2
Total Chlorine	mg/L	-	1.2	1.3	1.3	-	1.2	1.2	1.2	-	1.1	1.1	1.2	-	1.3	1.0	-	1.2	1.2	1.2
Total Hardness	mg/L[a]	-	-	-	-	-	-	-	-	-	-	-	-	191	197	197	-	-	-	-
Ca Hardness	mg/L[a]	-	-	-	-	-	-	-	-	-	-	-	-	114	117	117	-	-	-	-
Mg Hardness	mg/L[a]	-	-	-	-	-	-	-	-	-	-	-	-	77.2	79.7	79.9	-	-	-	-
As (total)	µg/L	16.7	16.9	9.1	9.2	18.4	21.6	11.1	11.9	18.2	18.5	10.9	9.7	15.4	15.7	8.4	21.8	23.0	12.1	11.9
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.8	20.1	11.0	11.1
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	15.5	10.9	8.2	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.1	4.9	0.2	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	8.7	0.3	0.5	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	6.8	10.6	7.7	-	-	-	-
Fe (total)	µg/L	465	499	<25	<25	398	534	<25	<25	383	419	<25	<25	490	475	42.4	412	451	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	433	471	<25	<25
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	297	<25	<25	-	-	-	-
Mn (total)	µg/L	26.1	28.1	14.3	15.6	25.4	29.4	13.8	13.0	25.9	26.4	9.7	11.5	31.7	31.4	11.4	26.9	27.6	12.4	10.9
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27.2	27.3	12.0	10.3
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	32.9	10.9	11.9	-	-	-	-

(a) As $CaCO_3$. (b) As P. (c) Reanalyzed outside of hold time. (d) Water quality measurements taken on 01/19/06. (e) Water quality measurements taken on 01/26/06.

(f) Water quality measurements taken on 02/09/06. (g) Result is an estimated concentration.

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

Sampling Date		02/14/06[c]				02/22/06[d]				03/01/06[d]			03/07/06[d,f]				03/14/06			
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB
Alkalinity	mg/L[a]	150 -	146 -	146 -	158 -	146 -	146 -	146 -	150 -	145 -	145 -	149 -	145 -	149 -	149 -	145 -	145 -	145 -	145 -	145 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	0.5	0.5	0.5	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	<1	<1	<1	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-
P (total)	µg/L[b]	59.8 -	64.4 -	31.7 -	26.9 -	55.9 -	56.0 -	40.3 -	43.7 -	56.7 -	63.2 -	47.8 -	50.1 -	51.2 -	35.8 -	34.0 -	54.4 -	56.5 -	19.5 -	20.8 -
Silica (as SiO_2)	mg/L	11.0 -	11.4 -	10.7 -	11.2 -	11.6 -	11.4 -	12.4 -	11.7 -	11.1 -	12.0 -	11.7 -	10.8 -	10.9 -	11.2 -	10.4 -	10.2 -	11.1 -	10.2 -	10.8 -
Turbidity	NTU	3.0 -	1.5 -	1.0 -	1.5 -	2.5 -	4.0 -	2.1 -	1.9 -	3.9 -	5.6 -	5.8 -	2.9 -	5.1 -	2.6 -	2.5 -	2.5 -	0.9 -	0.7 -	1.0 -
TOC	mg/L	-	-	-	-	-	-	-	-	1.9	1.9	1.9	-	-	-	-	-	-	-	-
pH	S.U.	7.9	7.9	7.8	7.8	8.1	8.1	8.1	8.1	NA[e]	NA[e]	NA[e]	7.5	8.1	8.1	8.1	8.0	8.0	8.0	8.0
Temperature	°C	12.6	11.7	12.1	12.2	12.1	12.2	12.5	12.4	NA[e]	NA[e]	NA[e]	12.7	12.1	13.4	11.9	13.1	12.4	13.2	13.6
DO	mg/L	1.6	1.3	1.5	1.3	2.4	2.6	2.0	2.5	NA[e]	NA[e]	NA[e]	2.0	1.1	2.9	1.8	2.2	2.0	1.3	1.8
ORP	mV	288	303	310	318	265	268	273	287	NA[e]	NA[e]	NA[e]	257	261	264	259	473	494	501	523
Free Chlorine	mg/L	-	0.3	0.4	0.4	-	0.0	0.0	0.0	-	NA[e]	NA[e]	-	0.3	0.3	0.3	-	0.4	0.4	0.6
Total Chlorine	mg/L	-	1.2	1.2	1.2	-	0.0	0.1	0.1	-	NA[e]	NA[e]	-	1.0	1.0	1.0	-	1.9	1.8	1.7
Total Hardness	mg/L[a]	-	-	-	-	-	-	-	-	212	215	211	-	-	-	-	-	-	-	-
Ca Hardness	mg/L[a]	-	-	-	-	-	-	-	-	112	114	112	-	-	-	-	-	-	-	-
Mg Hardness	mg/L[a]	-	-	-	-	-	-	-	-	99.9	101	99.3	-	-	-	-	-	-	-	-
As (total)	µg/L	15.3 -	14.4 -	7.8 -	8.1 -	17.7 -	17.6 -	17.1 -	17.8 -	17.7 -	19.1 -	17.8 -	17.0 -	16.9 -	16.3 -	16.3 -	17.9 -	18.7 -	8.9 -	9.2 -
As (soluble)	µg/L	-	-	-	-	-	-	-	-	16.9	18.1	17.9	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	0.9	0.9	<0.1	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	14.0	14.7	13.9	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	2.9	3.4	4.0	-	-	-	-	-	-	-	-
Fe (total)	µg/L	346 -	344 -	<25 -	<25 -	440 -	444 -	241 -	253 -	418 -	434 -	271 -	398 -	414 -	260 -	255 -	449 -	454 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	45.2[g]	355	167	-	-	-	-	-	-	-	-
Mn (total)	µg/L	23.9 -	21.5 -	11.1 -	11.3 -	28.9 -	28.7 -	28.9 -	29.4 -	27.6 -	28.4 -	29.1 -	27.7 -	28.8 -	28.8 -	27.9 -	28.4 -	28.0 -	7.5 -	7.4 -
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	27.1	28.2	28.5	-	-	-	-	-	-	-	-

(a) As $CaCO_3$. (b) As P. (c) Water quality measurements taken on 02/17/06. (d) Insufficient chlorine dosed for treatment due to off-spec solution per communication with operator. Chlorine solution replaced on 03/09/06. (e) Water quality measurement not recorded. (f) Water quality measurements taken on 03/09/06. (g) Reanalysis indicated similar result.

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

Sampling Date		03/20/06				04/03/06			04/10/06				04/18/06				04/24/06$^{(c)}$			
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Alkalinity	mg/L$^{(a)}$	145 -	145 -	145 -	145 -	146 -	146 -	146 -	145 -	145 -	141 -	141 -	153 -	153 -	153 -	158 -	154 -	154 -	154 -	159 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	0.5	0.5	0.5	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	<1	<1	<1	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-
P (total)	µg/L$^{(b)}$	65.3 -	110 -	21.5 -	20.6 -	58.2 -	63.0 -	25.9 -	51.3 -	49.4 -	13.4 -	16.1 -	66.5 -	69.3 -	29.2 -	30.7 -	46.3 -	50.4 -	15.0 -	17.7 -
Silica (as SiO_2)	mg/L	11.4 -	11.8 -	10.9 -	11.4 -	11.1 -	11.6 -	11.2 -	11.2 -	11.3 -	10.9 -	10.7 -	10.5 -	11.2 -	10.9 -	10.8 -	11.4 -	11.0 -	10.7 -	11.2 -
Turbidity	NTU	2.3 -	1.0 -	0.3 -	0.3 -	2.4 -	1.6 -	0.9 -	2.9 -	2.6 -	1.4 -	1.5 -	2.6 -	0.7 -	0.3 -	0.5 -	2.1 -	0.6 -	0.4 -	0.4 -
TOC	mg/L	-	-	-	-	1.9	1.9	1.9	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	7.9	8.0	7.9	7.9	7.7	8.1	7.9	8.0	7.9	8.0	7.9	7.9	8.0	8.0	8.0	7.9	8.0	7.9	7.7
Temperature	°C	11.7	12.1	12.5	12.6	14.3	14.0	14.1	12.7	12.6	12.4	12.3	12.7	12.7	12.8	12.7	11.9	12.6	12.8	12.7
DO	mg/L	2.0	0.8	1.2	1.2	1.0	1.0	1.0	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	1.3	1.1	1.1	2.7	1.1	1.1	1.1	1.5
ORP	mV	325	476	461	456	353	401	403	363	402	385	379	330	432	409	415	349	373	444	427
Free Chlorine	mg/L	-	0.3	1.3	0.5	-	0.2	0.2	-	0.1	1.2	0.9	-	1.1	0.7	0.0	-	0.3	0.2	0.6
Total Chlorine	mg/L	-	1.8	1.8	1.8	-	1.6	1.5	-	1.4	1.3	1.5	-	1.3	1.4	1.3	-	1.2	1.3	1.3
Total Hardness	mg/L$^{(a)}$	-	-	-	-	190	195	177	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness	mg/L$^{(a)}$	-	-	-	-	104	106	98.5	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness	mg/L$^{(a)}$	-	-	-	-	86.6	89.2	78.8	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L	17.5 -	25.4 -	9.1 -	9.7 -	17.6 -	19.3 -	8.8 -	18.2 -	18.2 -	9.7 -	9.9 -	16.9 -	17.8 -	8.8 -	8.8 -	17.4 -	17.1 -	9.2 -	9.7 -
As (soluble)	µg/L	-	-	-	-	17.6	11.2	8.9	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	<0.1	8.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	16.1	0.1	0.4	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	1.5	11.1	8.4	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	510 -	902 -	<25 -	<25 -	421 -	477 -	<25 -	419 -	414 -	<25 -	<25 -	441 -	475 -	<25 -	<25 -	442 -	460 -	<25 -	31.9 -
Fe (soluble)	µg/L	-	-	-	-	432	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	29.1 -	46.3 -	6.4 -	6.2 -	26.2 -	26.9 -	22.2 -	25.6 -	25.4 -	9.0 -	9.6 -	27.3 -	28.1 -	9.8 -	10.1 -	29.0 -	28.7 -	10.2 -	11.0 -
Mn (soluble)	µg/L	-	-	-	-	28.2	10.5	22.2	-	-	-	-	-	-	-	-	-	-	-	-

(a) As $CaCO_3$. (b) As P. (c) Water quality measurements taken on 04/25/06. (d) DO probe not operational.

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

Sampling Date		05/02/06			05/09/06$^{(c)}$				05/16/06				05/23/06$^{(d)}$				05/30/06		
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT
Alkalinity	mg/L$^{(a)}$	146	150	150	147	142	142	147	142	146	146	146	146	146	142	146	141	141	141
		-	-	-	142	147	147	147	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	0.4	0.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.6	0.5	0.5	-	-	-	-	-	-	-	-	-	-	-	-	0.4	0.4	0.4
Sulfate	mg/L	<1	<1	<1	-	-	-	-	-	-	-	-	-	-	-	-	<1	<1	<1
Nitrate (as N)	mg/L	<0.05	0.1	0.1	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05
P (total)	µg/L$^{(b)}$	57.6	63.6	23.1	67.8	73.4	39.3	36.7	43.1	45.7	<10	<10	42.4	46.2	<10	<10	52.1	52.2	23.4
		-	-	-	72.3	103	36.5	37.6	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	11.4	10.9	10.9	11.5	12.3	12.1	11.9	11.4	11.2	11.1	10.9	11.7	11.5	11.9	11.5	10.9	11.2	10.6
		-	-	-	11.7	11.6	12.5	11.7	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	2.3	0.5	0.6	2.4	0.6	0.2	0.4	2.3	0.6	0.2	0.4	2.7	3.2	1.0	0.6	3.0	1.2	3.3
		-	-	-	2.2	0.5	0.3	0.3	-	-	-	-	-	-	-	-	-	-	-
TOC	mg/L	1.9	1.9	1.9	-	-	-	-	-	-	-	-	-	-	-	-	1.9	1.9	1.9
pH	S.U.	8.1	7.9	8.2	7.7	8.0	7.9	7.9	7.8	8.0	8.0	7.9	NA	NA	NA	NA	7.9	7.5	8.0
Temperature	°C	12.2	12.1	12.0	12.2	12.4	12.3	12.5	12.3	12.4	12.3	12.2	12.7	NA	11.9	12.7	13.8	13.8	13.9
DO	mg/L	1.1	1.5	3.2	1.3	0.8	0.6	0.9	1.6	1.0	1.0	1.2	NA	NA	0.9	1.0	2.2	1.1	2.5
ORP	mV	438	455	436	333	375	376	415	370	356	421	396	NA	NA	326	340	451	461	447
Free Chlorine	mg/L	-	1.2	0.9	-	1.1	0.3	0.5	-	0.6	0.5	0.3	-	0.0	0.0	0.0	-	1.1	0.8
Total Chlorine	mg/L	-	1.3	1.3	-	1.3	1.3	1.3	-	1.2	1.2	1.2	-	0.0	0.0	0.0	-	1.1	1.0
Total Hardness	mg/L$^{(a)}$	208	210	209	-	-	-	-	-	-	-	-	-	-	-	-	167	166	167
Ca Hardness	mg/L$^{(a)}$	114	114	113	-	-	-	-	-	-	-	-	-	-	-	-	105	106	107
Mg Hardness	mg/L$^{(a)}$	94.4	95.9	96.0	-	-	-	-	-	-	-	-	-	-	-	-	62.3	59.5	60.2
As (total)	µg/L	17.6	18.2	9.5	17.7	18.2	10.0	9.9	16.2	16.3	8.6	8.8	18.2	18.0	19.6	20.6	16.2	16.5	8.5
		-	-	-	18.1	24.8	10.3	10.4	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	17.1	11.1	8.4	-	-	-	-	-	-	-	-	-	-	-	-	15.8	10.1	8.9
As (particulate)	µg/L	0.5	7.0	1.1	-	-	-	-	-	-	-	-	-	-	-	-	0.3	6.4	<0.1
As (III)	µg/L	15.4	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-	14.3	0.2	0.2
As (V)	µg/L	1.7	10.9	8.2	-	-	-	-	-	-	-	-	-	-	-	-	1.6	9.9	8.7
Fe (total)	µg/L	427	445	66.2	406	434	<25	<25	437	446	<25	<25	399	483	37.4	60.9	477	498	34.0
		-	-	-	410	770	<25	<25	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	249	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-	220	<25	<25
Mn (total)	µg/L	27.7	28.4	11.7	29.8	29.5	10.3	9.9	28.3	28.3	10.3	11.4	23.1	27.3	65.2	62.7	28.0	29.9	11.8
		-	-	-	29.1	42.6	10.3	10.2	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	29.3	10.1	11.8	-	-	-	-	-	-	-	-	-	-	-	-	29.7	11.6	12.5

(a) As $CaCO_3$. (b) As P. (c) Water quality measurements taken on 05/10/06. (d) After sample collection, operator noticed lack of chlorine residual while performing water quality measurements and corrected problem. Remaining water quality measurements not collected due to time constraints.

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

Sampling Date		06/06/06				06/13/06(c)				06/19/06(d)				06/27/06			07/05/06(f)			
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB
Alkalinity	mg/L(a)	142 -	150 -	146 -	150 -	149 -	141 -	149 -	153 -	146 -	142 -	138 -	146 -	142 -	142 -	142 -	146 -	146 -	146 -	142 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.5	0.5	0.5	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-
P (total)	µg/L(b)	63.1 -	68.7 -	30.2 -	29.2 -	68.7 -	95.9 -	27.9 -	38.4 -	57.9 -	105 -	13.1 -	<10 -	57.2 -	54.1 -	<10 -	54.8 -	56.2 -	<10 -	11.8 -
Silica (as SiO_2)	mg/L	11.4 -	11.5 -	11.4 -	11.3 -	11.3 -	11.9 -	11.1 -	11.6 -	12.4 -	12.4 -	12.1 -	11.2 -	12.7 -	12.0 -	12.1 -	11.8 -	11.9 -	11.4 -	11.2 -
Turbidity	NTU	2.4 -	1.0 -	0.4 -	0.8 -	2.4 -	1.0 -	0.4 -	0.4 -	2.3 -	1.0 -	0.7 -	0.7 -	2.3 -	1.2 -	0.7 -	2.3 -	0.9 -	0.4 -	0.2 -
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	NA(e)	NA(e)	NA(e)	-	-	-	-
pH	S.U.	7.7	8.4	8.3	8.1	8.0	8.4	8.4	8.4	7.6	7.8	8.0	8.0	8.0	8.0	8.2	7.8	7.8	7.8	7.9
Temperature	°C	13.1	12.9	12.9	12.9	14.5	14.4	14.6	14.7	12.9	12.3	12.7	12.8	13.2	13.1	13.0	13.2	13.3	13.3	13.3
DO	mg/L	1.6	1.2	0.9	1.0	1.1	0.9	0.8	1.6	1.2	0.7	0.9	0.6	2.1	1.1	2.2	1.9	1.2	0.9	0.7
ORP	mV	305	325	305	319	282	382	405	404	285	499	464	448	284	472	448	283	478	461	443
Free Chlorine	mg/L	-	0.9	0.4	0.5	-	0.6	1.2	0.2	-	1.4	0.9	1.2	-	0.6	0.7	-	0.8	0.9	1.0
Total Chlorine	mg/L	-	0.9	1.0	1.0	-	1.6	1.5	1.5	-	1.5	1.6	1.5	-	1.4	1.4	-	1.5	1.5	1.6
Total Hardness	mg/L(a)	-	-	-	-	-	-	-	-	-	-	-	-	221	215	214	-	-	-	-
Ca Hardness	mg/L(a)	-	-	-	-	-	-	-	-	-	-	-	-	118	115	114	-	-	-	-
Mg Hardness	mg/L(a)	-	-	-	-	-	-	-	-	-	-	-	-	102	100	100	-	-	-	-
As (total)	µg/L	17.5 -	15.9 -	8.0 -	8.0 -	18.8 -	22.4 -	9.6 -	11.7 -	18.9 -	25.9 -	5.2 -	5.0 -	16.7 -	17.5 -	4.0 -	16.4 -	16.5 -	3.8 -	5.6 -
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	16.2	3.9	3.0	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.5	13.5	1.0	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	17.8	0.3	0.6	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.1	3.6	2.4	-	-	-	-
Fe (total)	µg/L	457 -	495 -	<25 -	30.0 -	415 -	636 -	<25 -	102 -	459 -	1634 -	119 -	140 -	447 -	993 -	<25 -	442 -	866 -	<25 -	109 -
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	147	<25	<25	-	-	-	-
Mn (total)	µg/L	28.3 -	28.3 -	12.7 -	12.9 -	28.5 -	35.5 -	11.0 -	14.5 -	29.0 -	38.4 -	19.8 -	20.1 -	29.3 -	32.2 -	21.3 -	29.0 -	30.9 -	14.6 -	16.6 -
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	29.5	19.1	20.0	-	-	-	-

(a) As $CaCO_3$. (b) As P. (c) Extra media loaded into tanks by Kinetico after sampling. (d) $FeCl_3$ addition began 06/15/06 with speed/stroke 50/50 and 4x dilution. Speed/stroke reduced to 30/30 on 06/19/06. (e) Sample failed laboratory QA/QC check. (f) $FeCl_3$ dilution increased to 5x on 06/30/06. Water quality measurements taken on 07/07/06.

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

Sampling Date		07/11/06				07/25/06(c)				07/31/06			08/08/06				08/14/06(d)			
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB
Alkalinity	mg/L(a)	152	143	147	147	147	147	147	146	171	146	146	147	143	143	143	135	152	147	156
		-	-	-	-	-	-	-	-	-	-	-	147	143	143	147	-	-	-	-
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	0.3	0.2	0.2	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	0.4	0.5	0.4	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	<1	<1	<1	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-
P (total)	µg/L(b)	60.3	58.0	25.9	31.5	64.1	86.7	15.1	18.0	59.6	91.4	16.4	57.3	52.4	<10	10.8	74.5	130	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	63.2	125	<10	<10	-	-	-	-
Silica (as SiO_2)	mg/L	11.3	10.9	10.6	11.3	11.0	9.8	10.7	10.9	13.2	13.1	12.9	10.7	11.2	10.8	10.9	10.9	11.2	10.9	11.1
		-	-	-	-	-	-	-	-	-	-	-	10.8	10.8	10.4	10.4	-	-	-	-
Turbidity	NTU	2.3	0.5	1.1	1.0	2.1	3.2	2.8	0.5	2.5	1.0	1.6	2.5	0.8	0.3	0.5	1.9	0.9	0.3	0.3
		-	-	-	-	-	-	-	-	-	-	-	2.0	3.0	0.1	0.2	-	-	-	-
TOC	mg/L	-	-	-	-	-	-	-	-	1.9	1.9	2.0	-	-	-	-	-	-	-	-
pH	S.U.	7.7	7.8	7.8	7.7	7.9	8.1	8.1	8.2	7.8	7.7	7.9	7.9	8.1	8.2	8.2	7.9	8.3	8.3	8.2
Temperature	°C	11.6	11.7	12.0	12.0	15.2	15.2	15.1	15.2	13.9	13.7	13.9	12.7	12.2	11.1	10.9	12.4	12.5	12.7	12.8
DO	mg/L	1.5	1.2	0.9	1.2	1.4	1.3	1.5	1.3	1.4	1.0	2.3	2.5	1.5	1.9	1.5	1.9	0.6	0.9	1.0
ORP	mV	276	312	317	344	439	449	453	430	377	445	416	367	355	349	361	305	418	387	400
Free Chlorine	mg/L	-	1.5	0.4	1.2	-	1.6	1.4	0.5	-	1.4	1.4	-	1.0	0.8	1.2	-	0.9	1.3	0.4
Total Chlorine	mg/L	-	1.9	1.9	1.8	-	1.6	1.6	1.6	-	1.5	1.6	-	1.2	1.5	1.3	-	1.2	1.4	1.3
Total Hardness	mg/L(a)	-	-	-	-	-	-	-	-	192	195	195	-	-	-	-	-	-	-	-
Ca Hardness	mg/L(a)	-	-	-	-	-	-	-	-	113	112	111	-	-	-	-	-	-	-	-
Mg Hardness	mg/L(a)	-	-	-	-	-	-	-	-	79.0	83.2	84.4	-	-	-	-	-	-	-	-
As (total)	µg/L	15.4	13.6	5.8	6.5	19.3	19.1	6.7	7.2	17.6	18.8	5.8	19.1	16.1	6.5	7.1	15.3	22.9	4.2	4.2
		-	-	-	-	-	-	-	-	-	-	-	20.3	18.4	6.1	6.7	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	-	-	17.1	6.2	3.8	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	0.5	12.6	2.0	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	15.3	0.3	0.2	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	1.8	5.9	3.6	-	-	-	-	-	-	-	-
Fe (total)	µg/L	426	777	147	225	430	884	86.1	107	397	918	141	389	706	<25	29.6	374	1,638	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	369	919	<25	<25	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	236	<25	<25	-	-	-	-	-	-	-	-
Mn (total)	µg/L	26.0	26.0	10.4	11.7	27.2	29.5	11.6	12.2	28.2	30.9	12.9	25.6	25.6	11.7	12.8	24.5	32.3	13.7	13.2
		-	-	-	-	-	-	-	-	-	-	-	24.4	27.1	11.9	12.7	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	29.6	9.4	12.3	-	-	-	-	-	-	-	-

(a) As $CaCO_3$. (b) As P. (c) Water quality measurements taken on 07/23/06. (d) Water quality measurements taken on 08/15/06.

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

Sampling Date		08/22/06[c]			08/30/06				09/06/06[d]				09/12/06				09/18/06		
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT
Alkalinity	mg/L[a]	160 -	156 -	156 -	154 -	156 -	159 -	159 -	156 -	159 -	159 -	177 -	158 -	160 -	158 -	158 -	154 -	154 -	154 -
Ammonia (as N)	mg/L	0.3	0.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.3	0.3
Fluoride	mg/L	0.8	0.9	0.9	-	-	-	-	-	-	-	-	-	-	-	-	1.1	0.6[f]	1.3
Sulfate	mg/L	<1	<1	<1	-	-	-	-	-	-	-	-	-	-	-	-	<1	<1	<1
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05
P (total)	μg/L[b]	58.9 -	60.7 -	<10 -	69.7 -	93.1 -	25.9 -	29.2 -	59.2 -	152 -	<10 -	12.1 -	48.6 -	52.0 -	<10 -	<10 -	46.6 -	44.2 -	<10 -
Silica (as SiO_2)	mg/L	10.8 -	10.6 -	10.6 -	10.7 -	10.9 -	11.1 -	10.3 -	10.1 -	9.8 -	10.4 -	10.6 -	11.2 -	11.1 -	11.0 -	10.5 -	11.5 -	11.3 -	10.5 -
Turbidity	NTU	2.1 -	0.8 -	0.7 -	2.9 -	0.7 -	0.4 -	0.2 -	1.2 -	0.7 -	0.3 -	0.4 -	2.2 -	0.4 -	<0.1 -	0.3 -	2.1 -	0.6 -	0.5 -
TOC	mg/L	2.0	1.8	1.9	-	-	-	-	-	-	-	-	-	-	-	-	2.0	2.0	1.9
pH	S.U.	7.7	8.4	8.3	7.9	NA[e]	NA[e]	NA[e]	7.9	8.0	8.4	8.1	7.7	7.7	7.6	7.7	7.8	8.1	8.2
Temperature	°C	11.7	12.2	12.3	NA[e]	NA[e]	NA[e]	NA[e]	12.0	11.9	12.1	11.9	15.3	15.2	15.3	15.4	12.0	12.3	12.2
DO	mg/L	1.1	0.9	2.5	NA[e]	NA[e]	NA[e]	NA[e]	1.6	0.8	1.2	1.1	1.6	1.6	1.9	1.5	1.4	0.9	2.6
ORP	mV	439	482	454	NA[e]	NA[e]	NA[e]	NA[e]	430	471	463	454	412	426	417	414	338	447	441
Free Chlorine	mg/L	-	0.1	0.0	-	0.0	1.0	0.1	-	1.3	0.9	1.2	-	0.4	0.5	0.9	-	0.4	1.2
Total Chlorine	mg/L	-	1.2	1.3	-	1.1	1.2	1.2	-	1.3	1.3	1.3	-	1.1	0.7	0.9	-	1.2	1.3
Total Hardness	mg/L[a]	222	210	215	-	-	-	-	-	-	-	-	-	-	-	-	206	200	218
Ca Hardness	mg/L[a]	127	124	126	-	-	-	-	-	-	-	-	-	-	-	-	117	113	122
Mg Hardness	mg/L[a]	95.2	86.9	89.6	-	-	-	-	-	-	-	-	-	-	-	-	88.3	86.7	96.1
As (total)	μg/L	20.3 -	20.6 -	5.7 -	17.2 -	22.0 -	5.9 -	6.6 -	17.2 -	27.9 -	5.5 -	5.8 -	17.4 -	17.3 -	5.1 -	5.2 -	15.9 -	16.4 -	4.9 -
As (soluble)	μg/L	18.5	6.4	5.6	-	-	-	-	-	-	-	-	-	-	-	-	17.5	5.8	4.2
As (particulate)	μg/L	1.8	14.2	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	<0.1	10.6	0.7
As (III)	μg/L	16.1	0.6	0.6	-	-	-	-	-	-	-	-	-	-	-	-	15.4	<0.1	<0.1
As (V)	μg/L	2.4	5.9	5.0	-	-	-	-	-	-	-	-	-	-	-	-	2.1	5.7	4.1
Fe (total)	μg/L	438 -	811 -	<25 -	402 -	1,007 -	68.6 -	104 -	396 -	1,452 -	45.2 -	70.6 -	420 -	741 -	<25 -	<25 -	412 -	750 -	41.9 -
Fe (soluble)	μg/L	145	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-	271	<25	<25
Mn (total)	μg/L	28.0 -	30.0 -	18.3 -	26.3 -	31.5 -	17.3 -	18.2 -	28.3 -	41.6 -	16.7 -	17.0 -	27.4 -	29.0 -	15.9 -	16.6 -	27.2 -	28.5 -	17.5 -
Mn (soluble)	μg/L	28.5	15.6	18.0	-	-	-	-	-	-	-	-	-	-	-	-	28.1	14.8	16.8

(a) As $CaCO_3$. (b) As P. (c) Water quality measurements taken on 08/23/06. (d) Water quality measurements taken on 09/07/06. (e) Water quality parameter not measured.

(f) Reanalysis conducted outside of holding time.

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

Sampling Date		09/28/06$^{(c)}$				10/03/06				10/09/06				10/17/06			10/25/06			
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB
Alkalinity	mg/L$^{(a)}$	160 -	155 -	155 -	155 -	153 -	164 -	162 -	155 -	152 -	154 -	154 -	154 -	159 -	157 -	157 -	154 -	154 -	160 -	156 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.4	0.3	0.3	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.6	0.6	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-
P (total)	µg/L$^{(b)}$	68.7 -	72.6 -	23.0 -	23.5 -	68.2 -	67.8 -	22.5 -	23.7 -	60.6 -	139 -	<10 -	<10 -	68.9 -	75.0 -	12.9 -	50.3 -	57.3 -	<10 -	<10 -
Silica (as SiO_2)	mg/L	10.8 -	11.1 -	10.8 -	10.8 -	10.9 -	11.2 -	11.0 -	11.2 -	11.3 -	10.8 -	10.7 -	12.3 -	10.8 -	11.1 -	10.1 -	11.0 -	10.8 -	10.6 -	10.7 -
Turbidity	NTU	2.6 -	1.1 -	1.3 -	1.1 -	1.8 -	0.8 -	0.7 -	1.2 -	2.6 -	0.9 -	0.8 -	0.4 -	2.5 -	1.3 -	0.8 -	2.8 -	4.2 -	4.0 -	4.0 -
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	2.0	2.0	2.1	-	-	-	-
pH	S.U.	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	7.8	7.9	7.9	8.0	7.8	7.9	7.9	8.1	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$
Temperature	°C	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	12.8	12.9	12.7	12.8	15.6	15.6	15.6	15.6	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$
DO	mg/L	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	1.4	0.8	1.3	1.6	2.0	1.6	1.7	1.4	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$
ORP	mV	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	330	458	446	469	385	458	441	430	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$
Free Chlorine	mg/L	-	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	-	1.3	1.0	0.3	-	0.4	1.0	0.3	-	NA$^{(d)}$	NA$^{(d)}$	-	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$
Total Chlorine	mg/L	-	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$	-	1.4	1.4	1.6	-	1.0	1.2	1.0	-	NA$^{(d)}$	NA$^{(d)}$	-	NA$^{(d)}$	NA$^{(d)}$	NA$^{(d)}$
Total Hardness	mg/L$^{(a)}$	-	-	-	-	-	-	-	-	-	-	-	-	219	224	221	-	-	-	-
Ca Hardness	mg/L$^{(a)}$	-	-	-	-	-	-	-	-	-	-	-	-	117	118	115	-	-	-	-
Mg Hardness	mg/L$^{(a)}$	-	-	-	-	-	-	-	-	-	-	-	-	102	106	105	-	-	-	-
As (total)	µg/L	17.5 -	18.0 -	12.7 -	13.4 -	17.7 -	17.4 -	5.5 -	5.6 -	18.0 -	17.6 -	5.6 -	5.6 -	18.8 -	18.2 -	5.6 -	19.1 -	19.0 -	6.0 -	5.8 -
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	16.8	6.9	5.0	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	2.0	11.3	0.6	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	15.5	0.5	0.5	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	1.2	6.4	4.5	-	-	-	-
Fe (total)	µg/L	421 -	698 -	207 -	219 -	384 -	669 -	<25 -	<25 -	414 -	834 -	<25 -	45.5 -	379 -	658 -	65.9 -	481 -	778 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	259	<25	<25	-	-	-	-
Mn (total)	µg/L	25.6 -	28.2 -	27.5 -	27.6 -	25.8 -	27.2 -	18.5 -	18.6 -	28.2 -	28.9 -	18.6 -	18.0 -	26.3 -	29.2 -	19.6 -	28.5 -	29.5 -	12.6 -	12.9 -
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	27.8	16.6	19.0	-	-	-	-

(a) As $CaCO_3$. (b) As P. (c) Chlorine injection system down 09/27/06 to 09/29/06. Samples not received until 10/02/06; turbidity outside of holding time.

(d) Water quality parameter not measured.

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

Sampling Date		11/01/06				11/13/06				11/27/06		
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT
Alkalinity	mg/L(a)	157 -	157 -	159 -	155 -	157 -	161 -	145 -	157 -	164 -	164 -	160 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	0.3	0.3	0.3
Fluoride	mg/L	-	-	-	-	-	-	-	-	0.6	0.7	0.7
Sulfate	mg/L	-	-	-	-	-	-	-	-	<1	<1	<1
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05
P (total)	µg/L(b)	62.8 -	63.9 -	13.6 -	17.4 -	54.2 -	169 -	<10 -	<10 -	46.3 -	44.3 -	<10 -
Silica (as SiO_2)	mg/L	10.6 -	10.8 -	10.8 -	11.0 -	11.0 -	10.5 -	10.6 -	11.1 -	11.1 -	10.8 -	10.9 -
Turbidity	NTU	2.4 -	2.3 -	1.4 -	0.7 -	3.4 -	3.7 -	3.0 -	2.6 -	2.3 -	2.0 -	4.0 -
TOC	mg/L	-	-	-	-	-	-	-	-	2.1	1.9	1.8
pH	S.U.	7.7	7.9	7.9	7.8	7.8	8.0	8.0	8.3	NA(c)	NA(c)	NA(c)
Temperature	°C	11.6	11.1	11.3	11.4	12.9	12.3	12.7	12.7	NA(c)	NA(c)	NA(c)
DO	mg/L	3.0	1.4	1.1	1.8	1.1	0.7	1.1	0.5	NA(c)	NA(c)	NA(c)
ORP	mV	412	454	486	453	327	444	452	448	NA(c)	NA(c)	NA(c)
Free Chlorine	mg/L	-	0.9	0.5	0.1	-	0.6	1.2	1.2	-	NA(c)	NA(c)
Total Chlorine	mg/L	-	1.2	0.5	1.0	-	1.2	1.2	1.2	-	NA(c)	NA(c)
Total Hardness	mg/L(a)	-	-	-	-	-	-	-	-	223	223	223
Ca Hardness	mg/L(a)	-	-	-	-	-	-	-	-	120	120	119
Mg Hardness	mg/L(a)	-	-	-	-	-	-	-	-	103	103	103
As (total)	µg/L	17.9 -	17.5 -	5.2 -	5.7 -	18.4 -	27.6 -	5.8 -	6.7 -	14.6 -	14.1 -	4.2 -
As (soluble)	µg/L	-	-	-	-	-	-	-	-	13.9	4.5	3.7
As (particulate)	µg/L	-	-	-	-	-	-	-	-	0.7	9.6	0.5
As (III)	µg/L	-	-	-	-	-	-	-	-	11.5	0.5	0.6
As (V)	µg/L	-	-	-	-	-	-	-	-	2.4	4.0	3.1
Fe (total)	µg/L	468 -	833 -	49.8 -	83.1 -	438 -	1,577 -	<25 -	42.1 -	503 -	908 -	25.5 -
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	89.5	<25	<25
Mn (total)	µg/L	27.6 -	28.5 -	16.4 -	16.8 -	27.4 -	37.4 -	17.0 -	18.1 -	30.1 -	31.9 -	24.9 -
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	29.6	19.6	25.2

(a) As $CaCO_3$. (b) As P. (c) Water quality parameter not measured.