

**Arsenic Removal from Drinking Water by Iron Removal
U.S. EPA Demonstration Project at Sabin, MN
Final Performance Evaluation Report**

by

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Sally Gutierrez, Director
National Risk Management Research Laboratory

ABSTRACT

This report documents the activities performed and the results obtained from January 30, 2006 to April 29, 2007 at the U.S. Environmental Protection Agency (EPA) Arsenic Removal Technology Demonstration site in Sabin, MN. The main objective of the project was to evaluate the effectiveness of Kinetico's FM-248-AS arsenic removal system using Macrolite[®] media in removing arsenic from raw drinking water to meet the arsenic maximum contaminant level (MCL) of 10 µg/L. Additionally, this project evaluated: 1) the reliability of the treatment system for use at a small water facility; 2) the required system operation and maintenance (O&M) and operator skill levels; and 3) the cost-effectiveness 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 operational data, water quality data (both across the treatment train and in the distribution system), process residual data, and capital and O&M cost data.

After engineering plan review and approval by the state, the treatment system was installed and became operational on January 19, 2006. System inspection and operator training were performed on January 30 and 31, 2006, and the system performance evaluation began officially on January 30, 2006. The system consisted of two 63-in × 86-in fiberglass reinforced plastic (FRP) contact tanks and two 48-in × 72-in FRP pressure tanks, all configured in parallel. Each pressure tank contained 25 ft³ of Macrolite[®] media, a spherical, low density, chemically inert ceramic media designed for filtration rates up to 10 gal/min (gpm)/ft² at 125 gpm. The system used prechlorination to oxidize soluble As(III) and Fe(II) and the contact tank to promote the formation of As(V)-laden iron particles prior to entering the pressure filters. Later in the study, this prechlorination step also was used to increase oxidation, precipitation, and subsequent removal of manganese. The system operated at approximately 231 gpm, producing 14,884,800 gal of water through April 29, 2007. This represents an average finished water production of 32,858 gal/day (gpd). The average flowrate corresponds to a contact time of 7.4 min and a filtration rate of 9.2 gpm/ft². A number of issues related to the control of backwash frequency and duration were experienced and are discussed in the report.

Source water had an average pH of 7.3 and an average of total arsenic of 41.8 µg/L. The soluble fraction consisted of both As(V) and As(III) with concentrations varying from <0.1 to 41.7 and from 3.8 to 35.6 µg/L, respectively. Soluble As(III) concentrations exhibited a decreasing trend and soluble As(V) concentrations exhibited an increasing trend. Total iron concentrations ranged from 1,005 to 2,757 µg/L and averaged 1,350 µg/L, which existed primarily in the soluble form. Average soluble iron and soluble arsenic concentrations corresponded to a ratio of 29:1, which was sufficient for arsenic removal via iron removal. Manganese levels ranged at 153 to 449 µg/L and averaged 341 µg/L, which existed entirely in the soluble form. The source water also contained 0.2 mg/L of ammonia (as N), 30.4 µg/L of phosphorus (as P), 29.9 mg/L of silica (as SiO₂), and 1.7 mg/L of total organic carbon (as C).

With sufficient chlorine addition, soluble As(III) was effectively oxidized to soluble As(V), which was then adsorbed onto or co-precipitated with iron solids, formed during prechlorination, to become particulate arsenic. Total arsenic concentrations in the treated water were significantly reduced with concentrations averaging at 6.6 µg/L at Tanks A and B sampling locations and 8.3 µg/L at the combined effluent sampling location. Three exceedances (above the arsenic MCL) experienced were attributed to particulate arsenic and iron breakthrough. A special study was conducted in November 2006 to investigate the filter run length; a maximum of 12 hr was recommended to minimize particulate iron and arsenic breakthrough.

Prechlorination did not effectively oxidize Mn(II). Low rates of manganese removal across the treatment system and accumulation within the distribution system were issues. Manganese concentrations averaged 114 and 75 µg/L within the distribution system before and after system startup, respectively. In June 2006, the facility operator received complaints from a few customers concerning periodic slugs of dark solids from their taps, which might have been related to iron and/or manganese solids accumulating within the distribution system. It was hypothesized that the increased chlorine dose from post-chlorination and contact time within the distribution system resulted in manganese oxidation and subsequent attachment to pipe walls or iron deposits (tubercules), which are characteristic of older distribution systems.

Chlorine dosages for prechlorination were subsequently increased to enhance soluble manganese oxidation and particulate manganese removal by the pressure filters. Conversion from soluble Mn(II) to manganese solids increased from an average of 38.6% to 71.8% as chlorine residuals increased from an average value of 0.6 to 1.0 mg/L (as Cl₂). Manganese solids removal rates increased correspondingly to as high as 92%. Because of additional manganese solids loading, the maximum filter run length was reduced to 5 hr, which was just below the system median run length of 6 hr based on a 48-hr standby trigger.

Arsenic concentrations in the distribution system water samples were reduced from a pre-startup average of 27 µg/L to a post-startup average of 8.7 µg/L (excluding two outliers in the first quarter of operation). In general, total arsenic concentrations in the distribution system water were slightly higher than those in the treatment system effluent. Iron concentrations decreased significantly and averaged 1,211 µg/L and 157 µg/L before and after system startup, respectively. Lead and copper concentrations were reduced slightly since system startup. Alkalinity and pH did not appear to be significantly affected.

Filter tank backwash occurred automatically 1 to 4 times/tank/week, which was triggered primarily by the 48-hr standby time setpoint, due to low operational time of the treatment system. Approximately 521,250 gal of wastewater were generated during the performance evaluation study, which represents approximately 3.5% of the total amount of water treated. Under normal operating conditions, 1,924 gal of wastewater and 3.6 lb of solids were generated per backwash cycle (for two tanks). The solids generated included 0.6 lb of elemental iron, 0.03 lb of elemental manganese, and 0.01 lb of elemental arsenic.

The capital investment for the system was \$287,159, consisting of \$160,875 for equipment, \$49,164 for site engineering, and \$77,120 for system installation, shakedown, and startup. Using the system's rated capacity of 250 gpm (or 360,000 gpd), the capital cost was \$1,149/gpm or \$0.80/gpd. This calculation does not include the cost of the building to house the treatment system.

The estimated O&M costs included chemical supply, labor and electricity consumption. O&M costs were estimated at \$0.43/1,000 gal.

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ABBREVIATIONS AND ACRONYMS

Δp	differential pressure
AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
As	arsenic
ATS	Aquatic Treatment Systems
bgs	below ground surface
C/F	coagulation/filtration
Ca	calcium
Cl	chlorine
Cu	copper
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
FRP	fiberglass reinforced plastic
gpd	gallons per day
gpm	gallons per minute
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
MDH	Minnesota Department of Health
MDL	method detection limit
MEI	Magnesium Elektron, Inc.
Mg	magnesium
μm	micrometer
Mn	manganese
MPCA	Minnesota Pollution Control Agency
mV	millivolts
Na	sodium
NA	not analyzed
NaOCl	sodium hypochlorite

NTU	nephelometric 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&ID	pipng 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
POU	point-of-use
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
Ra	radium
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
TBD	to be determined
TCLP	toxicity characteristic leaching procedure
TDH	total dynamic head
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
UPS	uninterruptible power supply
V	vanadium

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1.0 INTRODUCTION

1.1 Background

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

In October 2001, EPA announced an initiative for additional research and development of cost-effective technologies to help small community water systems (<10,000 customers) meet the new arsenic standard and to provide technical assistance to operators of small systems to reduce compliance costs. As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, onsite 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 City of Sabin, MN 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 Round 2 sites to 28. Kinetico's Macrolite[®] arsenic removal system was selected for demonstration at the Sabin, MN facility.

As of April 2010, 39 of the 40 systems were operational and the performance evaluation of 36 systems was 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, iron [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 Web site 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 City of Sabin in Minnesota from January 30, 2006, through April 29, 2007. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and O&M cost.

Table 1-1. Summary of 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.)
<i>Northeast/Ohio</i>							
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
<i>Great Lakes/Interior Plains</i>							
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	7,827 ^(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
<i>Midwest/Southwest</i>							
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.)
<i>Far West</i>							
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)	Filtronic	750	18	69 ^(c)	8.0
Klamath Falls, OR	Oregon Institute of Technology	POE AM (Adsorbisia/ARM 200/ArsenX ^{np}) and POU AM (ARM 200) ^(g)	Kinetico	60/60/30	33	<25	7.9
Vale, OR	City of Vale	IX (Arsenex II)	Kinetico	525	17	<25	7.5
Reno, NV	South Truckee Meadows General Improvement District	AM (GFH)	Siemens	350	39	<25	7.4
Susanville, CA	Richmond School District	AM (A/I Complex)	ATS	12	37 ^(a)	125	7.5
Lake Isabella, CA	Upper Bodfish Well CH2-A	AM (HIX)	VEETech	50	35	125	7.5
Tehachapi, CA	Golden Hills Community Service District	AM (Isolux)	MEI	150	15	<25	6.9

AM = adsorptive media process; C/F = coagulation/filtration; HIX = hybrid ion exchanger; 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) Withdrew from program in 2007. Selected originally to replace 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.

2.0 SUMMARY AND CONCLUSIONS

Kinetico's FM-248-AS treatment system with Macrolite[®] media was installed and operated at Sabin, MN starting on January 19, 2006. System inspection and operator training were performed on January 30 and 31, 2006. The performance evaluation officially began on January 30, 2006. Based on the information collected during the performance evaluation study, the following conclusions were made relating to the overall project objectives.

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

- Chlorination was effective in oxidizing soluble As(III) to soluble As(V), reducing soluble As(III) concentrations from 11.6 µg/L (on average) in raw water to 0.8 µg/L (on average) after the contact tanks. Chlorine also was effective in oxidizing soluble iron, reducing its concentrations to less than the method detection limit of 25 µg/L after the contact tanks and pressure filters.
- Chlorination was not effective in oxidizing Mn(II). Increasing chlorine residuals from 0.6 to 1.4 mg/L (as Cl₂) (on average) significantly enhanced Mn(II) oxidation, resulting in over 70% Mn(II) conversion (from about 40%).
- At a ratio of 29:1 (on average), the amounts of soluble iron in source water were sufficient to turn soluble arsenic (existing primarily as As[V] after chlorination) into filterable particulate arsenic.
- Operating the pressure filters at a high filtration rate of 9.2 gpm/ft² (on average) effectively removed arsenic to below 10 µg/L.
- Filter run lengths up to 12 hr were achievable before particulate arsenic and iron began to break through. Increased manganese solids loading due to the use of higher chlorine dosages reduced the useful run length to about 5 hr.
- Servicing one filter while backwashing the other one led to very high pressure in the operating filter. The system inlet pressure could spike twice as high (e.g., to 63 lb/in² [psi]), which could cause the system to be operated outside of the design specifications.
- The treatment system improved water quality within the distribution system, with concentrations decreasing from 27 to 8.7 µg/L (on average) for arsenic, from 1,211 to 157 µg/L for iron, and from 114 to 75 µg/L for manganese before and after system startup. Further decreases in manganese concentration were occurring within the distribution system when comparing to the levels in the treatment system effluent. This is thought to be due to further oxidation of manganese due to elevated chlorine residuals (from post-chlorination) and prolonged contact times within the distribution system.

Required system O&M and operator skill levels:

- A significant amount of time and effort was required to troubleshoot issues related to control of backwash frequency and duration, although the daily demand on the operator was only 15 min.

Characteristics of residuals produced by the technology:

- Backwash was effective in restoring the filters' ability to remove arsenic-laden iron particles and manganese solids.
- The total amount of wastewater produced from backwash, which occurred at a frequency of 1 to 4 times/tank/week, was equivalent to about 3.5% of the amount of water treated.
- The amount of residual solids produced and discharged during each backwash cycle totaled 3.6 lb, which included 0.6 lb of elemental iron, 0.03 lb of elemental manganese, and 0.01 lb of elemental arsenic.

Cost-effectiveness of the technology:

- The capital investment for the system was \$287,159, consisting of \$160,875 for equipment, \$49,164 for site engineering, and \$77,120 for system installation, shakedown, and startup. The building cost was not included in the capital investment because it was funded by the city of Sabin. The unit capital cost was \$1,149/gpm (or \$0.80/gpd) based on a design capacity of 250 gpm.
- The O&M cost was estimated at \$0.43/1,000 gal based on chemical supply, labor, and electricity consumption costs.

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 January 30, 2006, and operational data collection ended on April 29, 2007. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall system performance was evaluated based on its ability to consistently remove arsenic to below the target MCL of 10 µg/L through the collection of water samples across the treatment train, as described in the Study Plan (Battelle, 2006). 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.

Table 3-1. Predemonstration and Demonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	08/31/04
Draft Letter of Understanding Issued	11/18/04
Final Letter of Understanding Issued	12/09/04
Request for Quotation Issued to Vendor	12/08/04
Vendor Quotation Received	02/10/05
Purchase Order Established	02/17/05
Engineering Package Submitted to MDH	03/04/05
Letter Report Issued	03/09/05
Discharge Permit Granted by MPCA	04/14/05
System Permit Granted by MDH	06/13/05
Building Construction Began	07/05/05
FM-248-AS System Delivered	12/02/05
Study Plan Issued	01/17/06
Treatment Building Completed	06/05/06
System Installation Completed	12/16/05
System Shakedown Completed	01/19/06
Performance Evaluation Began	01/30/06
Performance Evaluation Ended	04/29/07

MDH = Minnesota Department of Health;
MPCA = Minnesota Pollution Control Agency

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

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

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

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

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

3.2 System O&M and Cost Data Collection

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

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

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected at the wellhead, across the treatment plant, during Macrolite® filter backwash, and from the distribution system. Table 3-3 provides the sampling schedules and analytes measured during each sampling event.

In addition, a flow diagram of the treatment system along with the analytes and schedules at each sampling location is presented in Figure 3-1. Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2004). The procedure for arsenic speciation is described in Appendix A of the QAPP.

3.3.1 Source Water. During the initial site visit, one set of source water samples was collected and speciated using an arsenic speciation kit (Section 3.4.1). The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Analytes for the source water samples are listed in Table 3-3.

3.3.2 Treatment Plant Water. During the system performance evaluation study, the plant operator collected samples weekly, on a four-week cycle, for on and offsite analyses. For the first week of each four-week cycle, samples were taken at the wellhead (IN), after the contact tank (AC), and after Tanks A and B combined (TT), and speciated onsite and analyzed for the analytes listed in Table 3-3 for the monthly treatment plant water sampling. Until September 11, 2006, the “TT” sampling location was not functional as described in Section 4.3.3. Therefore, “TT” samples were collected at either the TA (on March 28, May 23, June 20, and August 21, 2006) or the TB tap (on January 31, February 28, April 25, and July 18, 2006). For the second, third, and fourth weeks of each four-week cycle, samples were taken at IN, AC, after Tank A (TA), and after Tank B (TB) and analyzed for the analytes listed in Table 3-3 for the weekly treatment plant water sampling.

3.3.3 Backwash Wastewater. Backwash wastewater samples were collected on 13 occasions by the plant operator. Tubing, connected to the tap on the discharge line, directed a portion of backwash wastewater 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 onsite with 0.45-µm disc filters. Analytes for the backwash samples are listed in Table 3-3.

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

The 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 use before sample collection were recorded for calculation of the stagnation time. All samples were collected from a cold-water faucet that had not been used for at least 6 hr to ensure that stagnant water was sampled.

3.3.5 Residual Solids. Residual solids produced by the treatment process consisted of only backwash wastewater solids. A residual solids sample was collected on one occasion on February 21, 2007. After solids in the backwash wastewater container had settled and the supernatant had been

Table 3-3. Sampling Schedules and Analyses

Sample Type	Sample Locations ^(a)	No. of Samples	Frequency	Analytes	Collection Date(s)
Source Water	IN	1	Once (during initial site visit)	Onsite: pH, temperature, DO, and ORP Offsite: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Mo (total and soluble), Sb (total and soluble), Na, Ca, Mg, Cl, F, NH ₃ , NO ₂ , NO ₃ , SO ₄ , SiO ₂ , P, TOC, TDS, turbidity, and alkalinity	08/31/04
Treatment Plant Water	IN, AC, TA, and TB	4	Weekly	Onsite: ^(b) pH, temperature, DO, ORP, and Cl ₂ (total and free) Offsite: As (total), Fe (total), Mn (total), SiO ₂ , P, turbidity, and alkalinity	See Appendix B
	IN, AC, and TT ^(c)	3	Monthly	Same as weekly analytes shown above plus the following: Offsite: As (soluble), As(III), As(V), Fe (soluble), Mn (soluble), Ca, Mg, F, NH ₃ , NO ₃ , SO ₄ , TOC, and TDS	See Appendix B
Backwash Wastewater	Backwash Wastewater Discharge Line	2	Monthly	As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, TDS, and TSS	See Table 4-9
Distribution Water	Three LCR Residences	3	Monthly	Total As, Fe, Mn, Pb, and Cu, pH, and alkalinity	See Table 4-10
Residual Solids	Backwash Solids from Each Tank	1	Once	Total Al, As, Ca, Cd, Cu, Fe, Mg, Mn, Ni, P, Pb, Si, and Zn	02/21/07

(a) Abbreviations corresponding to sampling locations shown in Figure 3-1; IN = at wellhead; AC = after contact tanks; TA = after Tank A; TB = after Tank B; TT = after filter effluent combined.

(b) Chlorine residuals analyzed only at AC, TA, and TB sampling locations.

(c) Four “TT” samples taken from TA tap and four from TB tap before September 11, 2006, due to problems with TT sample tap (see Section 4.3.3).

DO = dissolved oxygen; ORP = oxidation-reduction potential; TDS = total dissolved solids; TOC = total organic carbon; TSS = total suspended solids

carefully siphoned, a solids/water mixture was collected into a sample bottle and processed for metals analysis. The metals analyzed are listed in Table 3-3.

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 EPA-endorsed 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 specific water facility, sampling date, a two-letter code for a specific sampling location, and a one-letter code designating the arsenic speciation bottle (if necessary). The sampling locations at the treatment plant were color-coded for easy identification. The labeled bottles for each sampling location were placed in separate zip-lock[®] bags and packed in the cooler.

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

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

Samples for metal analyses were stored at the 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 and TCCI Laboratories in New Lexington, OH, both of which were under contract with Battelle for this demonstration study. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

3.5 Analytical Procedures

The analytical procedures described in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2004) were followed by Battelle ICP-MS, AAL, and TCCI Laboratories. 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 QA data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project.

Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a VWR Symphony SP90M5 handheld 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 SP90M5 probe in the beaker until a stable value was obtained. The plant operator also performed free and total chlorine measurements using Hach® DR/820 model chlorine test kits following the users' manual.

4.0 RESULTS AND DISCUSSION

4.1 Facility Description

Located on First Street in Sabin, MN, the municipal water system provided drinking water to approximately 500 community members through 175 service connections. Before the commencement of the arsenic demonstration study in January 2006, the facility typically operated 3 to 4 hr/day to meet the community's average daily demand of approximately 40,000 gpd. The peak daily demand was approximately 110,000 gpd. The water system was supplied by groundwater from one old well (Well No. 1) and one new well (Well No. 2), which were alternated on a weekly basis. Installed in 1960, Well No. 1 was 8-in in diameter and 94-ft deep with a 34-ft screen extending from 60 to 94 ft below ground surface (bgs). Well No. 2, installed in 1993, was 8-in in diameter and 92.5 ft deep with a 25-ft screen set between 67.5 and 92.5 ft bgs.

Well No. 2 was equipped with a 15-horsepower (hp) submersible pump with a design capacity of 250 gpm at a total dynamic head (TDH) of 200 ft of H₂O (87 psi). Well No. 1 had a submersible pump with a similar capacity, but the pump curve information was no longer available. The static water level in the vicinity of these two wells was approximately 22 ft bgs and the maximum drawdown was 52 ft bgs, yielding an approximate pressure of 59 psi at the ground level. Actual pressure in the inlet piping varied from additional aboveground piping headloss and/or degradation in pump performance since its installation in 1993. Both wells were connected to a pre-existing treatment system and the original design was to connect both wells to the Macrolite[®] treatment system. However, at the time of the new building construction, the City completed the connection piping only for Well No. 2. Thus, only Well No. 2 water was treated during the performance evaluation study.

The pre-existing treatment system consisted of a 210-gpm aeration and gravity filtration system with approximately 70 ft² of filter area operating at a hydraulic loading rate of approximately 3 gpm/ft². The treatment also included post-chlorination and fluoride addition to reach a free chlorine residual of 0.5 mg/L (as Cl₂) and a fluoride residual of 1.2 mg/L. Figure 4-1 shows the pre-existing pump house. Figure 4-2 shows the pre-existing filtration system and associated piping. A 15-hp booster pump rated for 210 gpm at a discharge pressure of 72 psi (or 165 ft of water) was used to transfer the filtered water to a 75,000-gal water tower located in the vicinity of the pump house (Figures 4-1 and 4-3). From March 11 to March 20, 2006, however, a burst in the water tower standpipe resulted in water being supplied to the distribution system by high service pumps alone.

4.1.1 Source Water Quality. Source water samples were collected by Battelle from Well No. 1 on August 31, 2004. Table 4-1 presents the results of the source water analyses, along with those obtained by EPA prior to the demonstration study on September 30, 2002, those provided by the facility to EPA in 2003 for the demonstration site selection, those submitted by the vendor for its proposal to EPA in 2004, and those collected by Battelle on July 30, 2003. Based on the discussions with the facility operator and the representatives of the respective organizations, it was established that the EPA, facility, and vendor samples also were collected from Well No. 1.

Arsenic. Prior to the performance evaluation study, total arsenic concentrations in Well No. 1 water varied significantly, ranging from 13.9 to 53.7 µg/L. (Although not collected, Well No. 2 water also contained varying amounts of arsenic, as observed during the performance evaluation study, with concentrations ranging from 27.7 to 54.5 µg/L). Based on the July 30, 2003, speciation results for Well No. 1 water, out of 53.7 µg/L of total arsenic, 9.8 µg/L (or 18.2%) existed as particulate arsenic and 43.9 µg/L (81.8%) as soluble arsenic, including 24.2 µg/L of soluble As(V) and 19.7 µg/L of soluble As(III).



Figure 4-1. Pre-Existing Pump House at Sabin, MN



Figure 4-2. Pre-Existing Filtration System at Sabin, MN

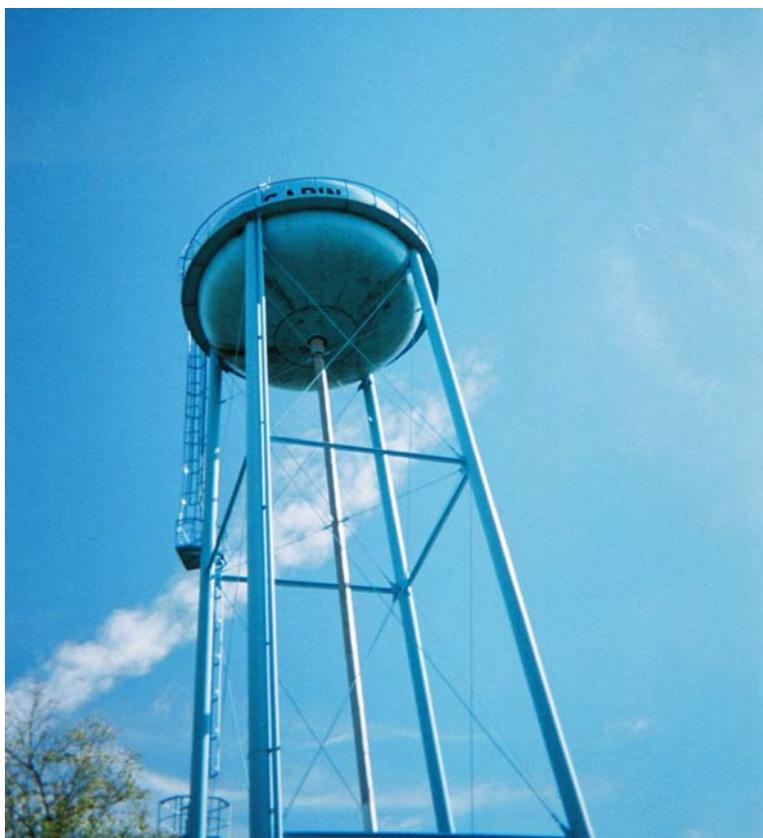


Figure 4-3. Water Tower at Sabin, MN

The presence of As(III) required the use of an oxidant to oxidize it to As(V). The Kinetico treatment process included prechlorination to oxidize As(III) to As(V) and subsequent adsorption/co-precipitation of As(V) onto/with iron solids.

Iron. The source water sampled prior to the performance evaluation study had iron levels ranging from 512 $\mu\text{g/L}$ to 1,550 $\mu\text{g/L}$, existing almost entirely as soluble iron. The iron levels were well above the secondary maximum contaminant level (SMCL) of 300 $\mu\text{g/L}$. Typically, the soluble iron concentration in raw water should be at least 20 times the soluble arsenic concentration to achieve effective arsenic removal via an iron removal process (Sorg, 2002). The ratio of soluble iron to soluble arsenic concentrations was approximately 26:1 and 67:1, as calculated for each of the two source water speciation events on July 30, 2003, and August 31, 2004, respectively. Based on these results, it was determined that no supplemental iron would be needed during the treatment.

Manganese. Total manganese concentrations in source water measured prior to the performance evaluation study ranged from 155 $\mu\text{g/L}$ to 327 $\mu\text{g/L}$, which existed entirely as soluble manganese based on the results of the two speciation events. The manganese levels were well above the SMCL of 50 $\mu\text{g/L}$ and are thought to have resulted in some taste and odor complaints during operation of the treatment system (as reported by the operator in June 2006).

pH. pH values of source water measured before the performance evaluation study ranged from 7.3 to 7.5, which were within the target range of 5.5 to 8.5 for arsenic removal via adsorption/co-precipitation with iron solids. As such, no pH adjustment was needed during the treatment.

Table 4-1. Water Quality Data at Sabin, MN

Parameter	Unit	EPA Raw Water Data	Facility Raw Water Data ^(a)	Kinetico Raw Water Data	Battelle Well No. 1 Raw Water Data	Battelle after Filtration Data	Battelle Well No. 1 Raw Water Data	MDH Treated Water Data ^(d)
	<i>Date</i>	09/30/02	2003	Before 04/04	07/30/03	07/30/03	08/31/04	01/16/01–10/26/04
pH	S.U.	NA	7.5	7.4	NA	NA	7.3	NA
Temperature	°C	NA	NA	NA	NA	NA	12.6	NA
DO	mg/L	NA	NA	NA	NA	NA	5.9	NA
ORP	mV	NA	NA	NA	NA	NA	-24	NA
Total Alkalinity (as CaCO ₃)	mg/L	297	295	284	NA	NA	302	NA
Hardness (as CaCO ₃)	mg/L	685	715	716	609	612	752	NA
Turbidity	NTU	NA	NA	NA	NA	NA	7.1	<1
TDS	mg/L	NA	NA	NA	NA	NA	2,050	NA
TOC	mg/L	NA	NA	NA	NA	NA	2.0, 1.5 ^(c)	NA
NO ₃ - NO ₂ (as N)	mg/L	NA	NA	NA	NA	NA	NA	<0.05–0.15
NO ₃ (as N)	mg/L	NA	NA	<1.0	NA	NA	<0.04	NA
NO ₂ (as N)	mg/L	NA	NA	NA	NA	NA	<0.01	NA
Ammonia (as N)	mg/L	NA	NA	NA	NA	NA	0.19	NA
Chloride	mg/L	45	28	53.5	NA	NA	34	NA
Fluoride	mg/L	NA	NA	0.96	NA	NA	0.12	0.93–1.6
Sulfate	mg/L	417	470	470	NA	NA	410	410–440
Silica (as SiO ₂)	mg/L	26.9	30, 27 ^(b)	25.7	NA	NA	29.7	NA
P (as P)	mg/L	NA	0.04, 0.09 ^(b)	<0.1	NA	NA	<0.1	NA
As (total)	µg/L	25	41	16	53.7	47	13.9	24.4–45.0
As (soluble)	µg/L	NA	NA	NA	43.9	NA	12.6	NA
As (particulate)	µg/L	NA	NA	NA	9.8	NA	1.3	NA
As(III)	µg/L	NA	NA	NA	19.7	NA	5.1	NA
As(V)	µg/L	NA	NA	NA	24.2	NA	7.5	NA
Fe (total)	µg/L	512	1,550	610	1,108	890	854	NA
Fe (soluble)	µg/L	NA	NA	NA	1,136	NA	844	NA
Mn (total)	µg/L	155	310	230	264	204	327	NA
Mn (soluble)	µg/L	NA	NA	NA	278	NA	331	NA
U (total)	µg/L	NA	NA	NA	NA	NA	5.5	NA
U (soluble)	µg/L	NA	NA	NA	NA	NA	5.3	NA
V (total)	µg/L	NA	NA	NA	<0.1	<0.1	0.30	NA
V (soluble)	µg/L	NA	NA	NA	<0.1	NA	0.12	NA
Mo (total)	µg/L	NA	NA	NA	2.7	3.1	NA	NA
Mo (soluble)	µg/L	NA	NA	NA	2.8	NA	NA	NA
Sb (total)	µg/L	<25	NA	NA	<0.1	<0.1	NA	NA
Sb (soluble)	µg/L	NA	NA	NA	<0.1	NA	NA	NA
Na (total)	mg/L	39	31	44	34	35	43	42–44
Ca (total)	mg/L	151	158	155	133	135	173	NA
Mg (total)	mg/L	75	78	73	67	67	78	NA
Radium-226	pCi/L	NA	NA	NA	NA	NA	NA	0.2 ^(e)
Radium-228	pCi/L	NA	NA	NA	NA	NA	NA	<0.8 ^(e)

(a) Provided by facility to EPA for demonstration site selection.

(b) Data provided by EPA.

(c) Sample taken on September 14, 2004.

(d) Samples taken in treatment plant and locations within the distribution system.

(e) Samples taken on June 23, 1994.

NA = not analyzed; TDS = total dissolved solids; TOC = total organic carbon

Competing Anions. The process of As(V) adsorption and co-precipitation with iron solids can be affected by the presence of competing anions, such as silica and phosphate. Data obtained by Battelle before the performance evaluation study (August 31, 2004) revealed 29.7 mg/L of silica (as SiO₂) and <0.1 mg/L of total phosphorus in source water. These data are comparable to the levels reported by other parties. Published data have shown that silica at high concentrations can significantly impact arsenic adsorption by iron solids (Smith and Edwards, 2005; Meng et al., 2000; Meng et al., 2002). Batch and column studies conducted by these investigators document that silica reduces arsenic adsorptive capacities on ferric oxides/hydroxides at levels even as low as 1.0 mg/L (as SiO₂). Arsenic adsorption may be inhibited in the presence of silica as a result of the following mechanisms:

- (1) Adsorption of silica may change the surface properties of adsorbents by lowering the iso-electric point (pH_{zpc}).
- (2) Silica may compete for arsenic adsorption sites.
- (3) Polymerization of silica may accelerate silica sorption and lower the available surface sites for arsenic adsorption.
- (4) Chemical reactions of silica with divalent cations, such as calcium, magnesium, and barium, may form precipitates.

As such, the effect of silica was carefully monitored during the performance evaluation study.

Sulfate. Sulfate levels in source water ranged from 410 to 470 mg/L, which were above the sulfate SMCL of 250 mg/L. Sulfate has not been shown to significantly hamper arsenate adsorption onto iron solids (Jain and Loeppert, 2000).

TOC. TOC in source water measured by Battelle prior to the performance evaluation study ranged from 1.5 to 2.0 mg/L, which was not anticipated to adversely impact the treatment system performance.

Other Water Quality Parameters. The presence of As(III) in raw water was consistent with the low ORP reading (i.e., -24 millivolts [mV]) measured on August 31, 2004. The DO concentration in the same source water was uncharacteristically high at 5.9 mg/L. DO levels were further monitored during the study period and averaged 3.4 mg/L. The source water sampled by Battelle on August 31, 2004, had a turbidity of 7.1 nephelometric turbidity units (NTU), most likely resulting from iron precipitation during sample collection and transit. The nitrate, nitrite, chloride, and fluoride levels all were below the corresponding SMCLs. The ammonia level was 0.19 mg/L, which adds to the chlorine demand, but was not anticipated to adversely impact As(III) or Fe(II) oxidation. Uranium, vanadium, molybdenum, and antimony levels were low and not anticipated to affect arsenic removal via the iron removal process.

4.1.2 Distribution System and Treated Water Quality. Prior to the commencement of the performance evaluation study, the distribution system was supplied by two wells, i.e., Wells No. 1 and 2. Water from both wells blended within the 75,000-gal water tower and the distribution system, which was constructed of mainly 4-in and 6-in cast iron and polyvinyl chloride (PVC) piping. Beginning on January 30, 2006 and throughout the performance evaluation study, the distribution system was supplied only by Well No. 2.

The three locations selected for distribution water sampling were part of the City's historic sampling network under the Lead and Copper Rule (LCR). In addition to lead and copper, coliform, fluoride, and arsenic were sampled on a quarterly basis and nitrate was sampled on an annual basis. Ra-226 and Ra-228 were sampled every other year. The historic data from Minnesota Department of Health (MDH) for treated water are provided in Table 4-1.

The historic treated water samples were collected at the entry point (after the treatment plant) and at various locations within the distribution system, such as residences, businesses (gas stations and cafes), the fire department, and city hall, from January 16, 2001, through October 26, 2004. As shown in Table 4-1, turbidity readings were <1.0 NTU, NO₃-NO₂ between <0.05 and 0.15 mg/L (as N), fluoride between 0.93 and 1.60 mg/L, sulfate between 410 and 440 mg/L, arsenic between 24.4 and 45.0 µg/L, radium-226 at 0.2 pCi/L, and radium-228 at <0.8 pCi/L. Fluoride in treated water was higher than in source water because of fluoride addition at the plant. As expected, the concentrations of the remaining analytes measured at the entry point and within the distribution system were comparable to those found in source water.

4.2 Treatment Process Description

The treatment process consisted of prechlorination/oxidation, coprecipitation/adsorption, and Macrolite[®] pressure filtration. Macrolite[®], a spherical, low density, chemically inert, ceramic media manufactured by Kinetico, is designed to allow for filtration rates up to 10 gpm/ft² and approved for use in drinking water applications under NSF International (NSF) Standard 61. The physical properties of Macrolite[®] are summarized in Table 4-2.

Table 4-2. Physical Properties of 40/60 Mesh Macrolite[®] Media

Property	Value
Color	Taupe, brown to grey
Thermal Stability (°C)	1,100
Sphere Mesh Size	40 × 60
Sphere Size Range (mm)	0.42–0.25
Sphere Size Range (in)	0.165–0.0098
Uniformity Coefficient	1.1
Bulk Density (g/cm ³)	0.86
Bulk Density (lb/ft ³)	54
Particle Density (g/cm ³)	2.05
Particle Density (lb/ft ³)	129

The FM-248-AS arsenic removal system was composed of two parallel contact tanks, two parallel pressure filtration tanks, and associated instrumentation to monitor pressure, flowrate, and turbidity (note that continuous turbidity monitoring was performed only during backwash). 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 PLC automatically controlled the system by actuating PVC pneumatic valves with air supplied by a 7.5-hp, 80-gal air compressor. The system also featured Schedule 80 PVC solvent bonded plumbing and all of the necessary isolation and check valves and sampling ports. Figure 4-4 is a simplified system piping and instrumentation diagram (P&ID). Figure 4-5 contains photographs of the key system components and control and instrumentation. The system's design specifications are summarized in Table 4-3. The major process steps are presented as follows:

- **Intake.** Raw water was pumped from Well No. 2 with a 15-hp booster pump (Gould 3656 M&L Group, Model 13 BF) to provide a design flowrate of 250 gpm at 116 ft TDH. (Deviating from the original design, Well No. 1 was not piped to the treatment system.)

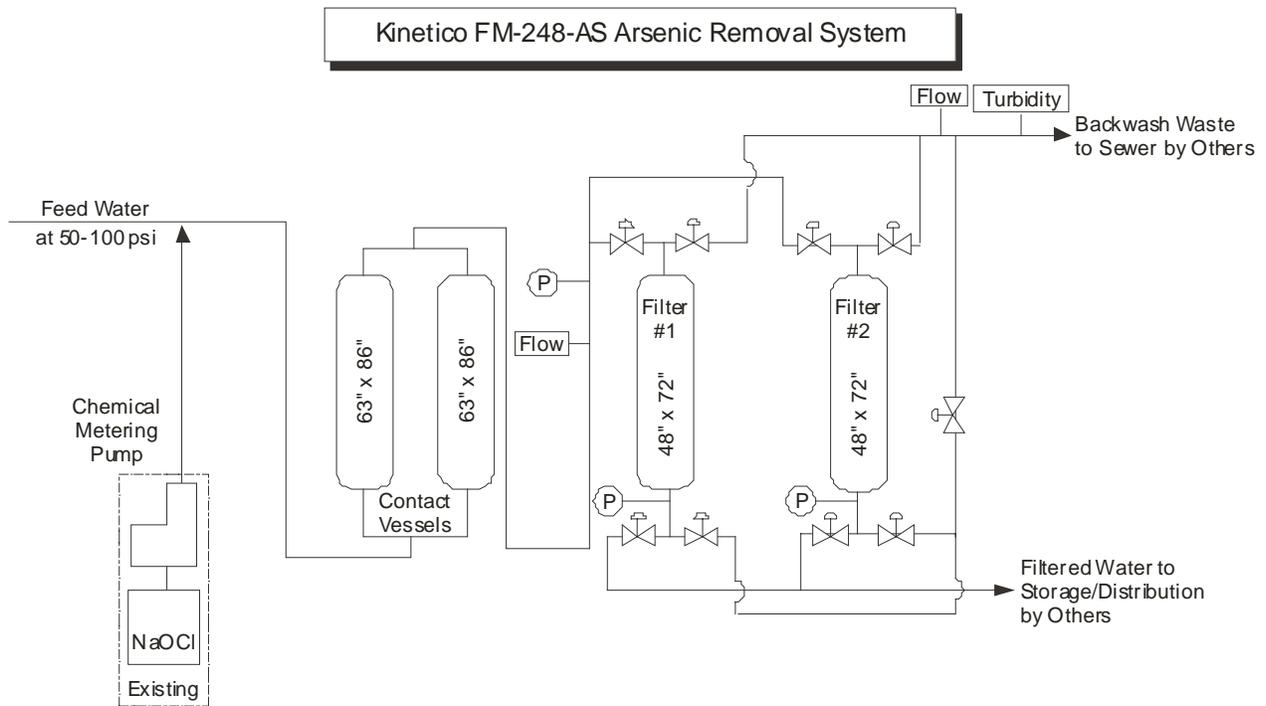


Figure 4-4. Schematic of Kinetico FM-248-AS Arsenic Removal System



Figure 4-5. Treatment System Components

Table 4-3. Design Features of Macrolite® Arsenic Removal System

Parameter	Value	Remarks
Pretreatment		
NaOCl Demand (mg/L [as Cl ₂])	1.7	Based on average oxidant demand from soluble arsenic, iron, and manganese in source water plus 0.5 mg/L of target residual; not including ammonia demand
Contact		
No. of Tanks	2	–
Configuration	Parallel	–
Tank Size (in)	63 D × 86 H	–
Tank Volume (gal)	850	–
Contact Time (min)	6.8	–
Filtration		
No. of Tanks	2	–
Configuration	Parallel	–
Tank Size (in)	48 D × 72 H	–
Tank Cross Sectional Area (ft ²)	12.6	
Media Volume (ft ³ /tank)	25	24-in bed depth of Macrolite®
Hydraulic Loading Rate (gpm/ft ²)	10	At 125 gpm
Pressure Drop across Clean Bed (psi)	10–12	–
Backwash		
Δp Setpoint (psi)	22	Backwash triggering pressure
Standby Time Setpoint (hr)	48	–
Service Time Setpoint (hr)	24	–
Hydraulic Loading Rate (gpm/ft ²)	10	125 gpm
Turbidity Setpoint (NTU)	20	To terminate backwash
Duration (min/tank)	5 to 15	Variable based on turbidity readings of backwash water
Wastewater Production (gpd)	Variable	Based on PLC set points shown above
Design Specifications		
Design Flowrate (gpm)	250	–
Maximum Daily Well Production (gpd)	360,000	Based on peak flow, 24 hr/day
Hydraulic Utilization (%)	13–17	Estimate based on historic utilization rate

The system was equipped with piping to bypass the treatment system and two 125-gpm flow-limiting devices, with one installed after each pressure filtration tank to prevent overrun.

- Chlorination.** Chlorine was used to oxidize As(III) to As(V) and Fe(II) to Fe(III) and to maintain a free chlorine residual of approximately 0.2 mg/L (as Cl₂) after the treatment system. The feed system consisted of a 165-gal day tank containing a 15.6% (as Cl₂) NaOCl solution and a diaphragm metering pump (Watson Marlow Model 520U/R2) with a maximum capacity of 42 gpd. The operation of the NaOCl system was tracked by measurements of NaOCl consumption in the day tank and free and total chlorine residuals across the treatment train.
- Adsorption/Co-precipitation.** Two 63-in-diameter by 86-in-tall fiberglass reinforced plastic (FRP) tanks arranged in parallel were used to provide 6.8 min of contact time to enhance the formation of iron flocs prior to pressure filtration. Each 850-gal tank had one 4-in top flange and one 4-in bottom flange, which were connected to the exit and inlet piping, respectively, for an upflow configuration.

- Pressure Filtration.** Removal of iron solids from the contact tank effluent was achieved via downflow filtration through two 48-in-diameter, 72-in-tall pressure tanks configured in parallel. Each tank contained 25 ft³ (or 24 in depth) of 40 × 60 mesh 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-1712-48). The FRP filtration tanks were rated for a working pressure of 150 psi and had two 10-in diameter side windows for media and backwash observations. 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 less than 125 gpm using a flow-limiting device to prevent filter overrun, which resulted in a 10 gpm/ft² hydraulic loading rate. System operation with both tanks in service could produce the total design flowrate of 250 gpm. Filtered water was sent to a 57,000-gal underground clearwell and then pumped to the water tower via two 20-hp high service pumps (with a variable speed drive for a design capacity of 400 gpm at 140 ft TDH), which were operated on an alternating basis. The high service pumps also were capable of providing water directly to the distribution system in the event that the water tower must be taken out of service (during cleaning, repair, etc.).
- Filter Backwash.** Backwashing removed accumulated solids in the filters, thereby reducing pressure buildup. The filters were automatically backwashed in succession based on service time, standby time, and/or differential pressure (Δp) setpoints. Backwash began with draining water from the first filter tank followed by air sparging the filter media with air supplied at 100 pounds per square inch gauge (psig) for 2 min by a 7.5-hp, 80-gal SPEEDAIRE air compressor. After a 3-min settling period, the filter tank was backwashed with treated water from the distribution system until the backwash water had reached the turbidity threshold setpoint (e.g., 20 NTU) as measured by an on-line Hach[®] turbidimeter. A filter-to-waste rinse for 3 min followed using water from the contact tank before returning to service. The wastewater was sent to a sump that emptied into the sanitary sewer.

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 was prepared by Kinetico and Ulteig Engineers. The package included a system design report and associated general arrangement diagram and a P&ID for the FM-248-AS system, electrical and mechanical drawings and component specifications, and building construction drawings detailing connections from the system to the entry piping. The engineering package was certified by a Professional Engineer registered in the State of Minnesota and submitted to MDH for review and approval on March 4, 2005. After MDH's review comments were addressed, the water supply construction permit was issued by MDH on June 13, 2005, and fabrication of the system began thereafter. The sanitary sewer extension permit for discharge of backwash water was received on April 14, 2005.

4.3.2 Building Construction. Building construction began on July 5, 2005, with the excavation for the building foundation including a 57,000-gal underground clearwell located directly underneath the building and a 2,350-gal underground sump. The footprint of the building was 48 ft × 56 ft with a roof height of 17.5 ft to ensure ample space for system housing and operator maneuverability. The building was fabricated from pre-cast concrete panels and included an 8-ft-wide double panel door at the entrance. Finished water from the arsenic removal system was stored in the clearwell and wastewater produced from filter backwash was discharged to the sump that emptied by gravity into the sanitary sewer. In addition to the filtration room that housed the treatment system, the building also had a chemical room, a

mechanical room, a laboratory, an office, and a restroom (see Figure 4-6). The new building was largely completed prior to the start of the demonstration study on January 30, 2006. However, finishing work such as improvements to the building ventilation continued until June 5, 2006, when the building was officially turned over to the city.



Figure 4-6. New Building and Associated Infrastructure

(Clockwise from Top, Left: New Building, Adjacent Office/Laboratory Area, and Electrical Control Panel, Clearwell Lid [Inset], and Backwash Sump)

4.3.3 System Installation, Startup, and Shakedown. The FM-248-AS treatment system was delivered to the site on December 2, 2005. The vendor, through its subcontractor, off-loaded and installed the system (Figure 4-7). Installation activities included connections to the entry and distribution piping and electrical interlocking. Upon completion of system installation and before media loading, the vendor performed hydraulic pressure testing to ensure that there were no leaks and that the system was mechanically sound. Macrolite[®] media loading and initial backwashing (to remove fines) was completed by December 16, 2005. Work resumed after the holiday break with activities spanning from PLC testing to instrument calibration, additional backwash testing (to set flow rates), system sanitation (using chlorine), chlorine residual testing, and operator training (on system O&M). The system startup and shakedown work was completed by January 19, 2006.

Battelle inspected the system and provided operator training on sample and data collection from January 30 to January 31, 2006. As a result of the system inspections, several punch-list items were identified and forwarded to the vendor on February 16, 2006, after the site visit. The key items identified and corrective actions taken included:



Figure 4-7. Delivery and Off-Loading of Macrolite[®] Treatment System Equipment

- Repair TT sampling tap. The TT sample tap did not provide water due to pulling a vacuum on the effluent line to the clearwell that was open to the atmosphere. The vendor proposed changing the location of the sample tap and provided a new tap to install on the bottom of the effluent line on April 25, 2006. However, the sample tap did not yield water until a vacuum breaker was installed at the highest point of the treated water line prior to the clearwell on September 11, 2006. Speciation samples were taken from the TA and TB locations (four samples each) while the TT location sample tap was being repaired.
- Install the missing compressed air flow meter.
- Modify the PLC. The vendor added a decimal place to all hour meter displays by updating the PLC program on February 28, 2006. However, this PLC programming change led to a backwash control issue related to the frequency of backwash as discussed under the next bullet point.
- Resolve backwash control issues. As discussed in Section 4.4.2, the PLC programming change made on February 28, 2006, led to a failure of the system backwash based on the backwash setpoints (e.g., 48-hr standby time). As such, the operator had to initiate each backwash event manually until this issue was resolved with another programming change on April 11, 2006. In addition, beginning in May 2006, backwash was consistently discontinued at the end of the 5-min minimum backwash duration. As a temporary measure, the operator changed the minimum backwash time to 10 min on July 21, 2006, to ensure adequate backwashing of the pressure filters. The issue was finally resolved through changes in the PLC logic and cleaning of the sample valve to the Hach[®] turbidimeter as discussed in Section 4.4.2.

4.4 System Operation

4.4.1 Coagulation/Filtration Operation. The operational parameters for the performance evaluation study period are tabulated and attached as Appendix A with the key parameters summarized in Table 4-4. From January 30, 2006 through April 29, 2007, the treatment system operated for 1,416 hr over 455 days, based on the hour meter readings displayed on the PLC. The average daily operating time was 3.1 hr/day. The service clock on the PLC was reset twice during the performance evaluation study when: 1) a programming change to add a decimal point to the hour meter readings was made on February 28, 2006; and 2) a backwash control issue was corrected on April 11, 2006, as discussed in Section 4.4.2. The total system throughput was 14,884,800 gal based on a digital impeller-type flow meter/totalizer (Data Industrial 200 Series) located on the treatment plant effluent line. This total system throughput was 9.1% lower than the throughput value (i.e., 16,375,670 gal) yielded by a pre-existing mechanical flow totalizer located at the entry point to the water tower and distribution system over the same time period. Calibration issues and multiple resets (i.e., six times) of the digital totalizer likely had contributed to the discrepancies observed. In order to maintain consistency between the totalizer and flowrate readings, the digital totalizer readings were used to track the system throughput.

Daily demands ranged from 0 to 113,600 gpd and averaged 32,858 gpd, which is equivalent to approximately 9.1% of the hydraulic use rate (i.e., 360,000 gpd based on the design flowrate of 250 gpm operating at 24 hr/day). The historic use rate as shown in Table 4-3 was 13% to 17%.

System flowrates ranged from 192 to 245 gpm and averaged 231 gpm, based on instantaneous readings from the digital flow meter/totalizer installed at the exit side of the pressure filters. The average flowrate corresponded to an average contact time of 7.4 min in the contact tanks and an average hydraulic loading rate of 9.2 gpm/ft² across the filters, compared to the design values of 6.8 min and 10 gpm/ft², respectively, as shown in Table 4-3. The daily average system flowrates also were calculated by dividing the amounts of water treated by the corresponding daily system run times and compared with the instantaneous flowrate readings. As shown in Figure 4-8, calculated daily average flowrate values were highly variable, but typically lower than the instantaneous flowrate readings. From system startup until the PLC update on April 11, 2006, the lack of a decimal place on hour meter readings reduced the accuracy of the daily average flowrate values. After implementation of the PLC programming changes described above, the calculated values converged with the instantaneous flowrate readings but still were approximately 10% lower than the instantaneous flowrate readings from April 11, 2006 through approximately October 2006.

After October 2006, instantaneous flowrate readings continued to trend higher than daily average flowrate values and 68 out of 160 daily average flowrate values were below (some significantly below) 200 gpm. The reason for the large discrepancies in the calculated values is unknown, but may be related to inaccurate totalizer readings due to instrument calibration and/or scaling of 4 to 20 mA signals to the PLC. Several PLC changes made in October and December 2006 might have inadvertently changed the scaling relationship in passing the signal between the digital flow meter/totalizer and PLC. At startup, the vendor reported an issue with the signal between the digital flow meter/totalizer and PLC with a discrepancy as high as 11% in instantaneous flowrate readings (with 250 gpm at the flow meter and 223 gpm at the PLC). The difference was attributed to low voltage from a bad card within the digital flow meter/totalizer based on testing on January 17, 2007. This flow meter/totalizer was then replaced on January 19, 2007, with a new one, which appeared to be calibrated (with 250 gpm at the flow meter and 248 gpm at the PLC). While onsite during system startup on January 30, 2006, Battelle became aware of an 8% difference between an instantaneous flowrate reading (i.e., 244 gpm) and a calculated flowrate value (i.e., 225 gpm) using the digital totalizer reading and a stop watch.

Table 4-4. FM-248-AS Treatment System Operational Parameters

Parameter	Value
Operational Period	01/30/06–04/29/07
<i>Coagulation/Filtration Operation</i>	
Total Operating Time (hr)	1,416
No. of Days System Operating (day)	455
Average Daily Operating Time (hr/day)	3.1
Total Throughput (gal) ^(a)	14,884,800
Average Daily Demand [Range] (gpd) ^(a,b)	0–113,600 [32,858]
Average Flowrate [Range] (gpm) ^(c,d,e)	231 [192–245]
Average Contact Time [Range] (min) ^(c)	7.4 [6.9–8.9]
Average Filtration Rate [Range] (gpm/ft ²) ^(c)	9.2 [7.6–9.8]
Average Δp across Each Tank [Range] (psi) ^(d)	10 [5–19]
Average Δp across System [Range] (psi) ^(d)	33 [29–39]
Median Service Time between Backwash Cycles [Range] (hr)	6.0 [0.0–18.9] ^(f)
Median Throughput between Backwash Cycles [Range] (gal)	83,160 [0–261,954] ^(c)
<i>Backwash Operation</i>	
Average Frequency [Range] (times/tank/week)	3 [1–4]
Number of Cycles (Tank A/Tank B)	205/205
Average Flowrate [Range] (gpm) ^(g)	96 [61–125]
Average Hydraulic Loading Rate [Range] (gpm/ft ²) ^(g)	7.9 [4.9–10]
Average Duration [Range] (min/tank) ^(g)	10.2 [5–19]
Average Backwash Volume [Range] (gal/tank) ^(g)	962 [400–1,900]
Estimated Filter to Waste Volume (gal/tank) ^(g,h)	375
Average Wastewater Produced [Range] (gal/tank) ^(g,h)	1,337 [775–2,275]

- (a) Based on digital totalizer readings recorded at plant effluent.
- (b) Excluding January 30 and April 11, 2006, when daily usage could not be recorded.
- (c) Based on instantaneous digital flowrate readings at pressure filter outlet.
- (d) Pressure and flow data collected on February 7, 2006 not included (with one tank in service while the other tank was being backwashed).
- (e) Days for which treatment plant had no demand not included in calculations.
- (f) Data collected from February 28 through March 19, 2006, not included. Filter run times during this time period were extended (ranging from 18 to 25 hr) due to PLC control problems as discussed in Section 4.4.2.
- (g) Based on data collected during 12 backwash events taking place on January 31, February 28, March 27, April 18, June 21, July 18, August 8, October 3, and November 9, 2006, and January 16, January 25, and January 31, 2007.
- (h) Estimated based on 3-min filter-to-waste time and 125-gpm flowrate.

System inlet and Tank A and Tank B outlet pressure readings are shown in Figure 4-9. System inlet pressure ranged from 29 to 63 psi and averaged 33 psi, which were well below the vendor-specified maximum value of 100 psi. Outlet pressure readings averaged 23 psi for Tank A and 22 psi for Tank B. The reason for the high system inlet pressure experienced on February 7, 2006 is described below.

The data shown in Figure 4-9 do not include those collected on February 7, 2006, when the pressure and flowrate readings were recorded with only Tank A in service while Tank B was being backwashed. During this backwash event, the system inlet pressure spiked almost twice as high to 63 psi, and the corresponding pressure drop across the system was 63 psi (since the plant effluent was discharged to the clearwell under the atmospheric pressure). Because there was only one pressure filter (i.e., Tank A) in service, the amount of the water that was normally filtered through both tanks would be pushed toward only one tank, thus resulting in a significantly elevated service flowrate (i.e., 155 gpm) and the pressure

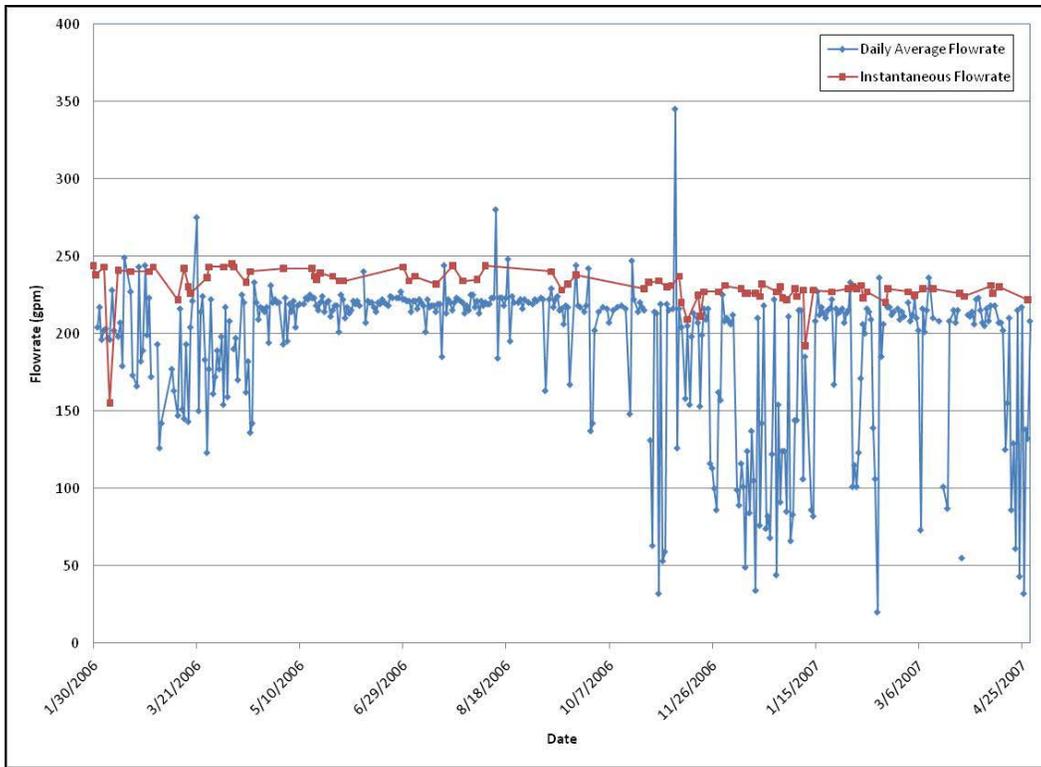


Figure 4-8. Calculated and Instantaneous Flowrate Readings

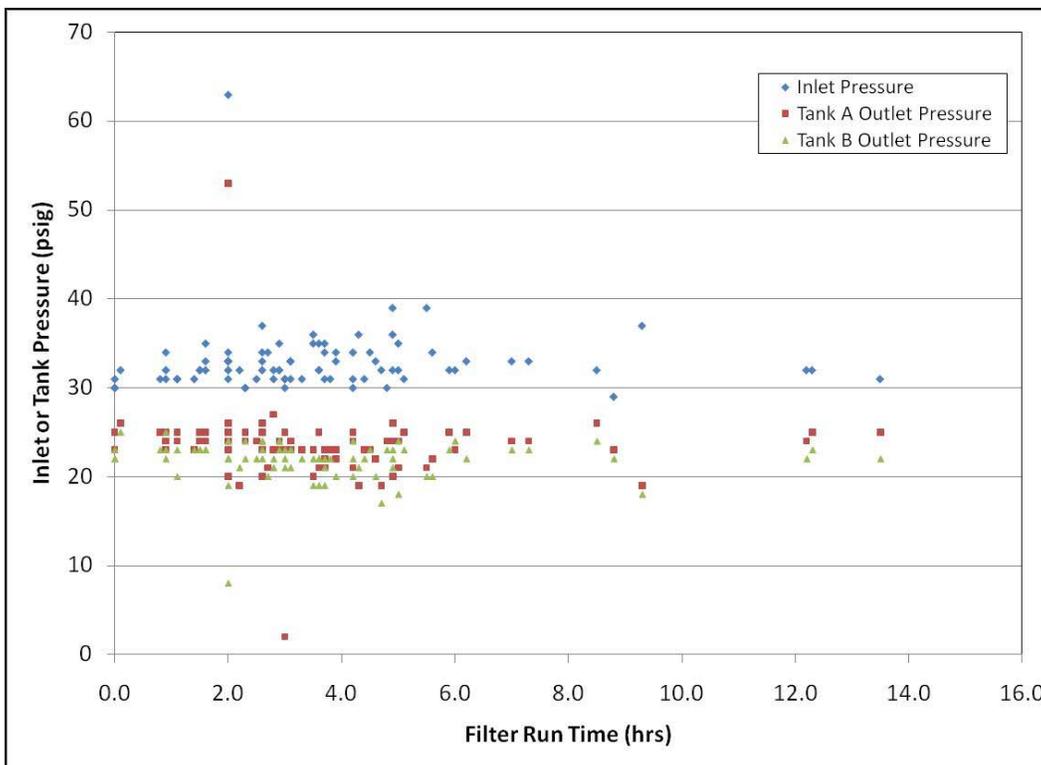


Figure 4-9. Filter Inlet and Outlet Pressure versus Filter Run Time

spike (i.e., 63 psi). (Note that a flow restrictor was installed on the effluent line of each tank to regulate the flow.) Nonetheless, the system pressure even with the pressure spike was still within the 100 psi maximum value specified by the vendor. This may not be the case for other sites, based on their site-specific pump curve characteristics and TDH conditions. Thus, it is important to realize that backwashing one tank, while keeping the other one in service, can lead to significantly elevated inlet pressure and Δp across the tank in service. The elevated pressure must be accounted for in order to prevent damage to the system. The flowrate at 155 gpm through Tank A was 22% above the 125-gpm design value. Operating the system at 22% higher hydraulic loading rate during this time period could result in reduced treatment performance and shortened filter run length.

Under normal service conditions, Δp readings across the system ranged from 29 to 39 psi omitting an outlier of 63 psi on February 7, 2006, as discussed above. As shown in Figure 4-10, Δp readings across Tanks A and B ranged from 5 to 6 and from 7 to 9 psi, respectively, immediately after backwash. The highest Δp readings observed were 19 psi in both Tanks A and B. In most cases, the Δp readings were significantly lower than the 22 psi Δp trigger set in the PLC. Under normal operating conditions, the Δp setpoint was never reached and backwash was triggered only by the standby time of 48 hr.

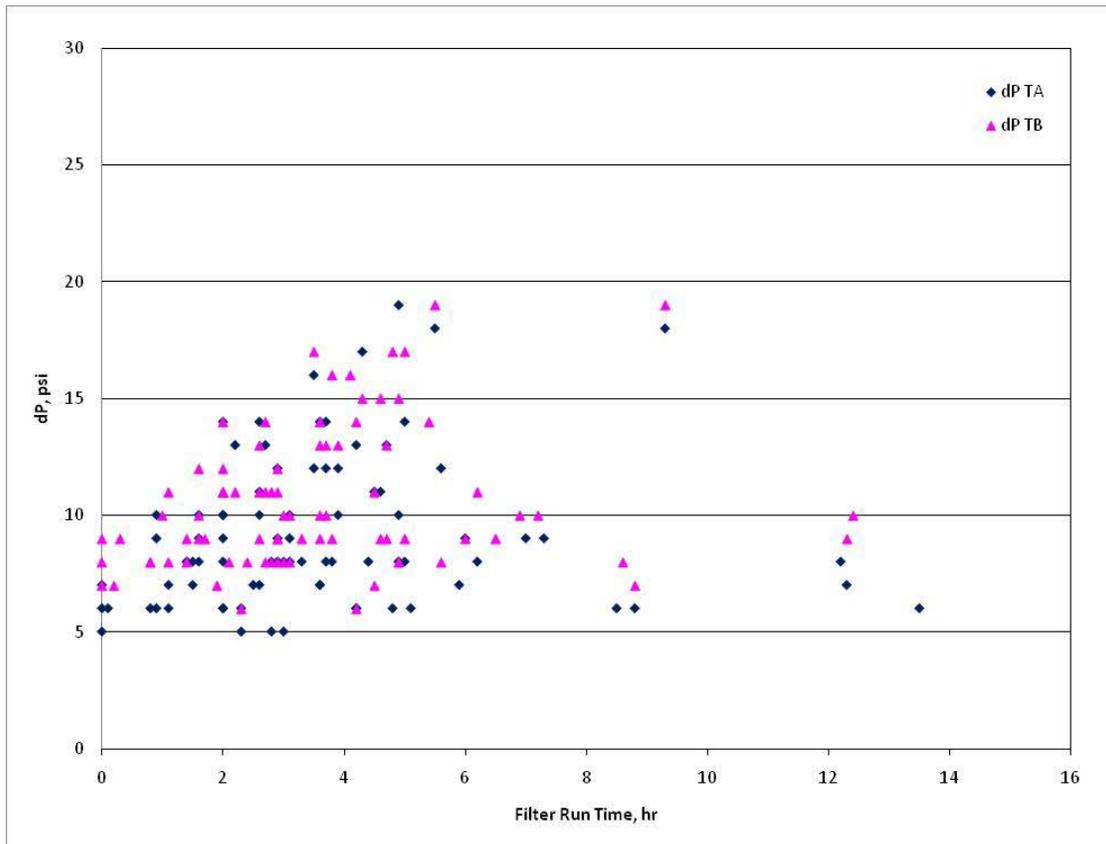


Figure 4-10. Differential Pressure versus Filter Run Time

Since system startup, a total of 205 backwash cycles took place for each pressure filter. Backwash occurred at a frequency of approximately 3 times/tank/week on average (with 205 backwashes occurring over 455 days or 65 weeks) and ranged from 1 to 4 times/tank/week. Backwash was triggered mainly by

the 48-hr standby time due to the low daily run time of 3.1 hr/day. The median value of filter run times between two consecutive backwash cycles was 6.0 hr, which yielded a median throughput of 83,160 gal. Over 10- $\mu\text{g/L}$ total arsenic breakthrough was observed twice in Tank A at 33.5 $\mu\text{g/L}$ on February 14, 2006, and at 10.6 $\mu\text{g/L}$ on July 26, 2006, and twice in Tank B at 30.8 and 11.1 $\mu\text{g/L}$ on February 14, 2006, and August 1, 2006, respectively. This will be discussed further in Section 4.5.1.1. In addition, several issues were encountered related to the frequency and duration of backwash, which will be discussed in Section 4.4.2.

4.4.2 Backwash Operation. Automatic backwash of the Macrolite[®] pressure filters could be initiated by one of the three triggers set in the PLC: 22 psi Δp across a single filter, 48-hr standby time, or 24-hr filter run time. Due to short daily operational times, the majority of backwash cycles were triggered by the standby time setpoint. Occasionally, manual backwash cycles also were initiated including events for testing and sampling of backwash wastewater and solids. The actual backwash duration for each filter was determined by the minimum and maximum backwash time settings and the ability of the backwash wastewater to meet the turbidity threshold setting as measured by the inline Hach[®] turbidimeter. If backwash wastewater 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 could return to the service mode. Backwash was followed by a 3-min filter-to-waste rinse at 125 gpm to remove any particulates from the filter.

Each pressure filter was backwashed 205 times during the performance evaluation study. Backwash flowrates ranged from 61 to 125 gpm and averaged 96 gpm, corresponding to a hydraulic loading rate of 7.9 gpm/ft² (compared to the design value of 10 gpm/ft²). This range of backwash flowrates did not cause significant media loss during backwash. The backwash duration for each filter lasted from 5 to 19 min, or 10.2 min on average. The amounts of backwash wastewater produced ranged from 400 to 1,900 gal/filter and averaged 962 gal/filter, based on readings collected during the 12 backwashes. The total amount of backwash water generated was 367,500 gal, which is about 2.5% of the amount of water treated. Including 375 gal of filter-to-waste rinse water per filter for each backwash cycle, approximately 521,250 gal of wastewater was generated, which is about 3.5% of the total amount of water treated.

Table 4-5 summarizes the backwash settings first established on January 30, 2006, during system startup and subsequent modifications on July 21, 2006, October 3, 2006, December 5, 2006 and December 15, 2006. Backwash issues experienced during the study period included backwash frequency and duration as well as backwash failure alarms, which resulted in further modifications to the PLC on October 3, 2006, December 5, 2006 and December 15, 2006.

4.4.2.1 Backwash Frequency Issues. On February 28, 2006, the vendor performed a PLC programming change by adding a decimal place to hour meter readings to improve accuracy of daily filter run time and average system flowrate records. In doing so, the backwash control process was inadvertently disrupted such that the filters would not backwash based on the 48-hr standby setpoint. As a consequence, filter run times were significantly extended from an average of 10.2 hr during normal system operation to 10.8 hr from February 28 to March 7, 2006, 21.2 hr from March 7 to 14, 2006, and 24.2 hr from March 14 to March 19, 2006. These extended filter run times are not included in the calculations of filter run times as shown in Table 4-4. After March 19, 2006, the operator began to manually initiate backwash cycles until the PLC program was updated by the vendor and the backwash control returned to normal operations on April 12, 2006.

4.4.2.2 Backwash Duration Issues. From May 7, 2006, to July 21, 2006, 38 out of 44 backwash events ended at the minimum backwash time of 5 min, based on the volume of wastewater produced on the Daily Operational Log Sheet and the average backwash flowrate. In addition, the operator observed during the June 21, 2006, backwash event that turbidity readings of the backwash wastewater peaked at

Table 4-5. Summary of PLC Settings for Backwash Operations

Parameter (for Each Pressure Filter)	01/30/06^(a)	07/21/06^(b)	10/03/06	12/05/06	12/15/06
Drain Time (min)	3	3	3	3	3
Run Time Trigger (hr)	24	24	24	12	12
Standby Time Trigger (hr)	48	48	48	48	48
Δp Trigger (psi)	22	22	22	22	22
Minimum Backwash Time (min)	5	10	5/10	10	5
Maximum Backwash Time (min)	15	15	15	15	15
Turbidity Threshold (NTU)	20	20	20	20	20
Low Flowrate Threshold (gpm)	70	70	70	70	70
Filter-to-Waste Time (min)	3	3	3	3	3

(a) Initial setpoint at startup.

(b) Minimum backwash time changed to 10 min due to issues with Hach[®] turbidimeter readings.

Bold values indicating changes from previous settings.

12.6 NTU, which was significantly lower than the previously recorded turbidity readings of up to 88 NTU observed in January 2006 through April 2006. Lower than the established 20-NTU threshold, these abnormally low turbidity readings caused backwash to stop as soon as reaching the minimum backwash time of 5 min.

After a discussion with the vendor on July 6, 2006, it was determined that the problem might have been caused by a failure of the inline Hach[®] turbidimeter. As a temporary measure on July 21, 2006, the operator adjusted the minimum backwash time from 5 to 10 min to ensure adequate backwashing of the pressure filters. A Hach[®] technician visited the site on August 22, 2006, to troubleshoot the turbidimeter. During the visit, the technician removed the calibration cup, cleaned and replaced the stained light source shield, and calibrated the instrument (which was done erroneously using a 4,000 NTU solution). On October 3, 2006, the operator temporarily reset the minimum backwash time to 5 min and manually backwashed the filters. During this backwash, the highest level of turbidity observed was 8.1 NTU, which was still well below the 20 NTU threshold set on the PLC. Because the issue regarding the Hach[®] turbidimeter had not been resolved, the operator returned the minimum backwash time setting to 10 min. After a troubleshooting call by the Hach[®] technician with the operator on December 15, 2006, it was confirmed that the problem actually stemmed from a clogged valve in the sample line, which prevented representative sample water from reaching the Hach[®] detector. After performing the required maintenance to the supply line and valve by the operator on December 15, 2006, turbidity readings returned to normal and the minimum backwash time was reset to 5 min on the PLC.

Possibly due to the changes made on the PLC on December 15, 2006, the operator reported that Tank B was not backwashed in either the automatic or the manual mode, resulting in >24 hr run time without backwash. The vendor dialed into the PLC that same day and successfully addressed the issue. Further observation of the backwash events taking place on January 16 and 25, 2007, indicated that the Hach[®] turbidimeter appeared to function properly and that the turbidity readings seemed to be normal in controlling the backwash time.

4.4.2.3 Backwash Alarms. The operator reported backwash alarms on February 13, 14, 19, and 21, 2006, when backwash water failed to reach the 20-NTU turbidity threshold at the end of the maximum backwash time of 15 min. The operator addressed these instances by using a bottle brush to clean and remove media fines from the Hach[®] turbidimeter body (e.g., the cone-shaped section through which the water sample flows). Based on the high volume of backwash water recorded on the Daily Operational

Log Sheet, failures occurred on six additional occasions on March 14, April 5, April 18, April 23, April 28, and July 4, 2006.

4.4.3 Residual Management. The only residuals produced by the Macrolite[®] arsenic removal system were backwash wastewater and filter-to-waste rinse water. Backwash wastewater was discharged to the building sump, which emptied by gravity to the sanitary sewer. According to the backwash flow totalizer, 367,500 gal of wastewater were produced during the pressure filter backwashes. Based on a flowrate of 125 gpm and a duration of 3 min/tank for 205 backwash cycles, 153,750 gal of filter-to-waste rinse water also were produced. Therefore, over 521,250 gal of wastewater, or 3.5% of the treated water, were generated as a result of this pressure filtration process.

4.4.4 Reliability and Simplicity of Operation. The simplicity of system operation and operator skill requirements are discussed including pre- and post-treatment requirements, levels of system automation, operator skill requirements, preventative maintenance activities, and frequency of chemical/media handling and inventory requirements. No significant scheduled or unscheduled downtime was required of the treatment system. However, some O&M issues did arise related to prechlorination and control of backwash operations as discussed below.

4.4.4.1 Pre- and Post-Treatment Requirements. Prechlorination with a 15.6% NaOCl (as Cl₂) solution was provided to oxidize As(III) and Fe(II) and provide a chlorine residual to the distribution system. In addition to tracking the depth of the NaOCl solution in the day tank, the operator measured chlorine levels to ensure that adequate residuals existed throughout the treatment train. A leak was developed due to a faulty fitting on February 12, 2006, causing improper chlorine injection. Using spare parts, the operator made a series of repairs between February 14 and 21, 2006. This temporary loss of chlorine addition resulted in above 10.0-µg/L levels of arsenic in the treated water following both pressure filters during the February 14, 2006 sampling event. Post-treatment with chlorine provided the necessary residuals to the distribution system.

4.4.4.2 System Automation. The FM-248-AS arsenic 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. Run time, standby time, and Δp settings automatically dictated when the pressure filters should be backwashed (see settings on Table 4-5). The touch screen OIP also enabled the operator to manually initiate the backwash sequence. Several issues were experienced related to control of backwash frequency and duration, and are detailed in Section 4.4.2. Problems with automation of the backwash process led to an increased need to monitor plant operations and manual intervention by the operator (e.g., manually initiating backwashes and/or changing setpoints in the PLC to accommodate Hach[®] turbidimeter malfunctioning).

4.4.4.3 Operator Skill Requirements. Under normal operating conditions, the daily demand on the operator was about 15 min for visual inspection of the system and recording of operational parameters, such as pressure, volume, flowrate, and chemical usage on field log sheets.

For the state of Minnesota, there are five water operator certificate class levels, i.e., A, B, C, D, and E (Level A representing the most skilled class level). The certificate levels are based on education, experience, and system characteristics, such as water source, treatment processes, water storage volume, number of wells, and population supplied. The certified water operator for the city of Sabin has a Class C certificate. Class C requires a high school diploma or equivalent with at least three years of experience in operation of Class A, B, or C systems or a bachelor's degree from an accredited institution with at least one year of experience in the operation of a Class A, B, C, or D system. 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 and perform minor onsite repairs.

4.4.4.4 Preventative Maintenance Activities. The vendor recommended several routine maintenance activities to prolong the integrity of the treatment system (Kinetico, 2005). Preventative maintenance tasks included recording pressure readings, flowrates, and chemical drum levels, as well as visually checking for leaks, overheating components, proper manual valve positioning and pumps' lubricant levels, and any unusual conditions on a daily basis. The vendor recommended checking for trends in the recorded data on a weekly basis, which 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 should be performed as needed. In addition, an intermittent compressed air leak developed in Tank B, potentially starting from June 28, 2006 to July 26, 2006, as noted by elevated DO readings in Tank B on these dates. This issue was addressed in October 2006, and the DO levels returned to normal.

4.4.4.5 Chemical Handling and Inventory Requirements. Since system startup, prechlorination was required for effective arsenic removal during treatment and maintenance of acceptable residual chlorine levels after treatment. The operator tracked the NaOCl usage daily and coordinated the solution delivery and refill with a local chemical supply company. All chemical handling and re-filling activities were performed by the chemical supply company, which reduced the level of effort required for O&M of the system by the operator.

4.5 System Performance

The performance of the Macrolite[®] FM-248-AS arsenic treatment system was evaluated based on analyses of water samples collected from the treatment plant, backwash lines, and distribution system.

4.5.1 Treatment Plant Sampling. The treatment plant water was sampled on 65 occasions including four duplicate and 15 speciation sampling events. The speciation sampling was performed at the IN, AC, and TT sampling locations (except for four events taken at TA and four at TB due to effluent sample tap issues described in Section 4.3.3). A complete set of analytical results are tabulated and presented in Appendix B. Table 4-6 summarizes the analytical results for arsenic, iron, and manganese. Table 4-7 summarizes the analytical results of the other water quality parameters. The results of the water samples collected across the treatment plant are discussed as follows.

4.5.1.1 Arsenic. Figure 4-11 shows total arsenic concentrations measured across the treatment train and Figure 4-12 presents the results of speciation sampling. Total arsenic concentrations in raw water ranged from 27.7 to 54.5 µg/L and averaged 41.8 µg/L. Total arsenic concentrations appeared to gradually increase over time to as high as 54.5 µg/L in the last two months of the performance evaluation study (Figure 4-11).

Of the soluble fraction (94% [on average]), soluble As(V) was the predominant species with concentrations ranging from <0.1 to 41.7 µg/L and averaging 27.8 µg/L. Concentrations of both soluble As(V) and soluble As(III) varied significantly during the course of the performance evaluation study (Figure 4-12). Soluble As(III) was initially elevated at 35.6 µg/L at system startup on January 31, 2006, under a more reducing condition (ORP at -13 mV). However, soluble As(III) concentrations decreased to as low as 3.8 µg/L on January 3, 2007, and averaged only 11.6 µg/L over the entire study period. Low levels of particulate arsenic also were present, ranging from <0.1 to 7.6 µg/L and averaging 3.0 µg/L.

Table 4-6. Summary of Arsenic, Iron, and Manganese Results

Parameter	Sample Location	Sample Count	Concentration (µg/L)			Standard Deviation
			Minimum	Maximum	Average	
As (total)	IN	65	27.7	54.5	41.8	6.2
	AC	65	28.2	54.5 ^(a)	43.3 ^(a)	5.3 ^(a)
	TA	54	3.9	10.6 ^(a)	6.6 ^(a)	4.0 ^(a)
	TB	54	3.5	11.1 ^(a)	6.6 ^(a)	3.6 ^(a)
	TT	7	6.3	10.9	8.3	1.9
As (soluble)	IN	15	25.0	49.2	39.3	6.2
	AC	15	3.8	8.3	4.9	1.2
	TA	4	3.0	3.7	3.3	0.3
	TB	4	2.3	3.7	3.1	0.6
	TT	7	3.6	8.0	5.0	1.5
As (particulate)	IN	15	<0.1	7.6	3.0	2.1
	AC	15	32.5	45.2	39.1	4.1
	TA	4	2.0	3.9	2.9	0.9
	TB	4	0.7	3.8	2.3	1.6
	TT	7	2.0	4.9	3.3	1.2
As (III)	IN	15	3.8	35.6	11.6	7.6
	AC	15	0.2	2.4	0.8	0.6
	TA	4	0.3	0.6	0.4	0.1
	TB	4	<0.1	2.0	0.9	0.9
	TT	7	0.2	3.7	1.1	1.2
As (V)	IN	15	<0.1	41.7	27.8	10.6
	AC	15	3.0	5.9	4.1	0.8
	TA	4	2.7	3.1	2.9	0.2
	TB	4	1.2	2.8	2.2	0.7
	TT	7	3.4	4.4	3.9	0.3
Fe (total)	IN	65	1,005	2,757	1,350	261
	AC	65	763	1,748 ^(a)	1,316 ^(a)	173 ^(a)
	TA	54	<25	243.3 ^(a)	76.2 ^(a)	167 ^(a)
	TB	54	<25	235.4 ^(a)	79.8 ^(a)	152 ^(a)
	TT	7	33.4	144	87.2	37.8
Fe (soluble)	IN	15	537	1,578	1,153	236
	AC	15	<25	<25	<25	-
	TA	4	<25	<25	<25	-
	TB	4	<25	<25	<25	-
	TT	7	<25	<25	<25	-
Mn (total)	IN	65	153	449	341	51.4
	AC	65	135	452 ^(a)	334 ^(a)	58.8 ^(a)
	TA	54	16.9	392 ^(a)	210 ^(a)	91.6 ^(a)
	TB	54	17.5	348 ^(a)	203 ^(a)	86.8 ^(a)
	TT	7	42.3	370	198	128
Mn (soluble)	IN	15	196	457	357	65.8
	AC	15	81.8	321	200	87.3
	TA	4	184	305	262	56.7
	TB	4	99.0	300	173	87.6
	TT	7	20.9	391	192	144

(a) Results for 02/14/06 sampling event not included because of insufficient chlorine addition due to a fitting leak.

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

Table 4-7. Summary of Other Water Quality Parameter Results

Parameter	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as CaCO ₃)	IN	mg/L	65	284	339	310	14.1
	AC	mg/L	64	257	341	308	15.0
	TA	mg/L	54	282	342	307	14.3
	TB	mg/L	54	278	335	308	14.0
	TT	mg/L	7	308	327	320	6.0
Ammonia (as N)	IN	mg/L	15	<0.05	0.3	0.2	0.1
	AC	mg/L	15	<0.05	0.2	0.1	0.1
	TA	mg/L	4	0.1	0.1	0.1	0.0
	TB	mg/L	4	<0.05	0.1	<0.05	0.0
	TT	mg/L	7	<0.05	0.2	0.1	0.1
Fluoride	IN	mg/L	15	<0.1	0.2	0.1	0.1
	AC	mg/L	15	<0.1	0.5	0.2	0.1
	TA	mg/L	4	<0.1	0.1	<0.1	0.0
	TB	mg/L	4	<0.1	0.1	<0.1	0.0
	TT	mg/L	7	0.2	0.2	0.2	0.0
Sulfate	IN	mg/L	15	376	835	456	110
	AC	mg/L	15	371	839	455	111
	TA	mg/L	4	416	845	525	213
	TB	mg/L	4	372	514	437	58.9
	TT	mg/L	7	422	508	453	35.7
Nitrate (as N)	IN	mg/L	15	<0.05	<0.05	<0.05	-
	AC	mg/L	15	<0.05	<0.05	<0.05	-
	TA	mg/L	4	<0.05	<0.05	<0.05	-
	TB	mg/L	4	<0.05	<0.05	<0.05	-
	TT	mg/L	7	<0.05	0.1	<0.05	0.0
P (as P)	IN	µg/L	65	<10	55.7	30.4	11.8
	AC	µg/L	65	<10	74.1	32.2	13.0
	TA	µg/L	54	<10	41.2	<10	5.6
	TB	µg/L	54	<10	48.2	<10	6.6
	TT	µg/L	7	<10	20.9	10.1	7.2
Silica (as SiO ₂)	IN	mg/L	65	27.9	34.4	29.9	1.2
	AC	mg/L	64	27.4	34.4	29.8	1.2
	TA	mg/L	54	27.1	34.9	29.4	1.3
	TB	mg/L	54	26.9	34.4	29.6	1.3
	TT	mg/L	7	28.0	30.5	29.0	0.9
Turbidity	IN	NTU	65	13.0	59.0	19.6	8.2
	AC	NTU	64	0.8	20.0	2.4	2.6
	TA	NTU	54	0.2	18.0	1.2	2.5
	TB	NTU	54	0.2	21.0	1.3	3.0
	TT	NTU	7	0.4	0.8	0.6	0.2
TOC	IN	mg/L	13	1.5	1.8	1.7	0.1
	AC	mg/L	14	1.5	2.0	1.7	0.1
	TA	mg/L	3	1.6	1.8	1.7	0.1
	TB	mg/L	4	1.5	2.0	1.7	0.2
	TT		7	1.5	1.8	1.7	0.1
TDS	IN	mg/L	15	870	1,030	948	43.0
	AC	mg/L	15	902	1,020	949	34.6
	TA	mg/L	4	978	1,000	992	10.6
	TB	mg/L	4	920	1,030	977	51.6
	TT	mg/L	7	456	992	870	184

Table 4-7. Summary of Other Water Quality Parameter Results (Continued)

Parameter	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
pH	IN	S.U.	59	6.7	7.8	7.3	0.3
	AC	S.U.	59	6.8	7.8	7.3	0.2
	TA	S.U.	46	6.9	7.5	7.2	0.2
	TB	S.U.	48	6.8	7.5	7.2	0.2
	TT	S.U.	7	6.8	7.7	7.3	0.4
Temperature	IN	°C	59	10.2	17.4	12.7	1.4
	AC	°C	59	10.1	17.8	12.4	1.5
	TA	°C	46	10.0	16.4	12.4	1.4
	TB	°C	48	10.2	17.1	12.4	1.6
	TT	°C	7	10.7	14.9	11.8	1.4
DO ^(a)	IN	mg/L	59	2.0	10.9	3.4	0.97
	AC	mg/L	59	1.2	10.3	3.4	0.83
	TA	mg/L	46	1.6	8.2	3.1	0.77
	TB	mg/L	48	0.8	10.6	3.1	0.85
	TT	mg/L	7	1.8	3.8	3.1	0.70
ORP	IN	mV	59	-13.0	476	253	187
	AC	mV	59	385	679	488	76.1
	TA	mV	46	400	667	501	80.7
	TB	mV	48	83.9	696	522	118
	TT	mV	7	422	651	481	79.9
Free Chlorine (as Cl ₂)	AC	mg/L	59	0.0	1.7	0.3	0.4
	TA	mg/L	46	0.0	1.0	0.1	0.2
	TB	mg/L	48	0.0	1.0	0.2	0.3
	TT	mg/L	7	0.0	1.5	0.3	0.5
Total Chlorine (as Cl ₂)	AC	mg/L	59	0.0	2.1	0.7	0.4
	TA	mg/L	46	0.1	1.3	0.5	0.3
	TB	mg/L	48	0.0	1.4	0.6	0.3
	TT	mg/L	7	0.1	2.0	0.6	0.7
Total Hardness (as CaCO ₃)	IN	mg/L	15	584	746	692	50.4
	AC	mg/L	15	536	764	686	57.1
	TA	mg/L	4	603	743	664	58.6
	TB	mg/L	4	635	691	667	24.9
	TT	mg/L	7	662	781	707	40.0
Ca Hardness (as CaCO ₃)	IN	mg/L	15	354	454	407	25.5
	AC	mg/L	15	324	456	400	34.8
	TA	mg/L	4	345	413	373	29.1
	TB	mg/L	4	379	426	401	21.3
	TT	mg/L	7	340	470	404	42.6
Mg Hardness (as CaCO ₃)	IN	mg/L	15	210	327	285	34.1
	AC	mg/L	15	212	323	286	34.5
	TA	mg/L	4	258	329	291	29.6
	TB	mg/L	4	246	282	266	14.9
	TT	mg/L	7	280	322	303	14.3

(a) Data with uncharacteristically high DO levels on 16 occasions and from June 28, 2006 to October 26, 2006 (due to air compressor leak) not included in average and standard deviation calculations.

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

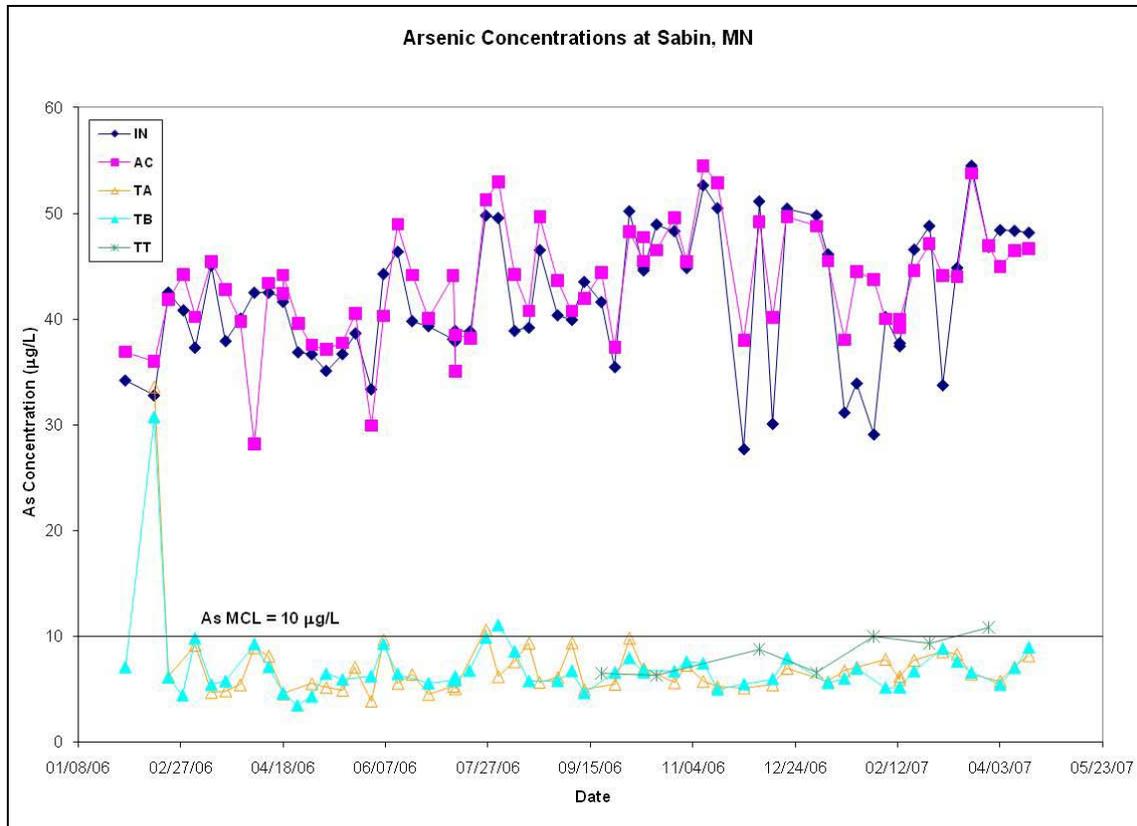


Figure 4-11. Total Arsenic Concentrations Across Treatment Train

After prechlorination and the contact tanks, soluble As(III) was effectively oxidized to soluble As(V), which was then adsorbed onto or co-precipitated with iron solids, formed during prechlorination, to become particulate arsenic. This was evidenced by the low level of soluble arsenic (4.9 µg/L [on average]) and significantly elevated particulate arsenic concentrations (39.1 µg/L [on average]) in the samples taken after the contact tanks (Figure 4-12). The water samples collected on February 14, 2006, showed very little change in arsenic (Figure 4-11) and iron (Figure 4-13) concentrations across the treatment train, apparently caused by the temporary malfunction of the chlorine injection system starting on February 12, 2006. The chemical feed system was subsequently repaired with a fitting replacement by the operator before the February 21, 2006 sampling event.

With sufficient chlorine addition, total arsenic in the treated water was significantly reduced, with concentrations averaging at 6.6 µg/L at the TA and TB and 8.3 µg/L at the TT sampling locations (TT samples were collected starting from September 20, 2006 after installation of a vacuum breaker on the effluent line). Three arsenic exceedances were experienced on July 26 and August 1, 2006, and March 28, 2007; all were associated with elevated total iron concentrations (Figure 4-14). (Iron in filter effluent existed entirely as particulate iron based on speciation results shown in Table 4-6). These include arsenic and iron concentrations at 10.6 and 175 µg/L, respectively, at TA on July 26, 2006; 11.1 and 177 µg/L, respectively, at TB on August 1, 2006; and 10.9 and 144 µg/L, respectively at TT on March 28, 2007. As a consequence of these exceedances, two filter run length studies were conducted to determine the impact of filter throughput on iron and arsenic breakthrough in treated water (see Section 4.5.1.7). The arsenic MCL exceedance on February 14, 2006 was due to the temporary loss of chlorine addition as discussed earlier.

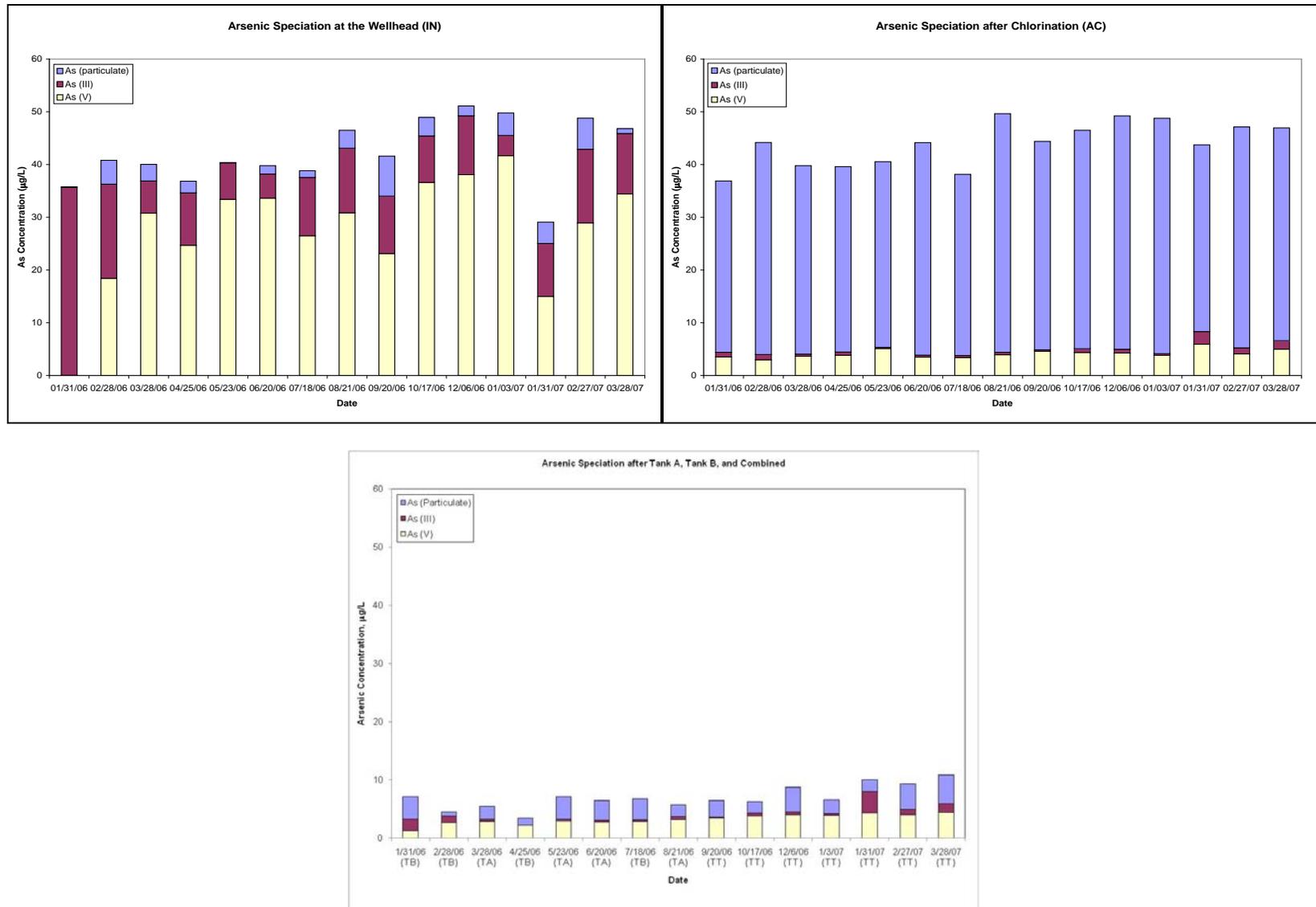


Figure 4-12. Arsenic Speciation Results at IN, AC, TA, TB, and TT Locations

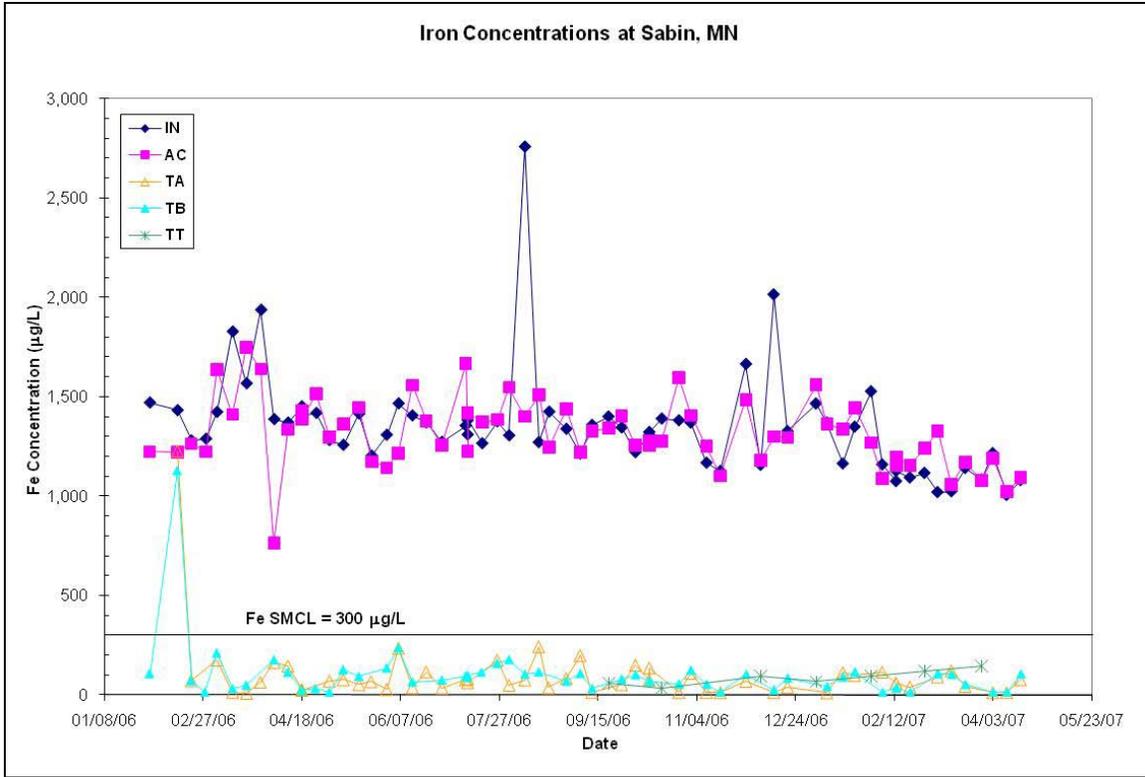


Figure 4-13. Total Iron Concentrations Across Treatment Train

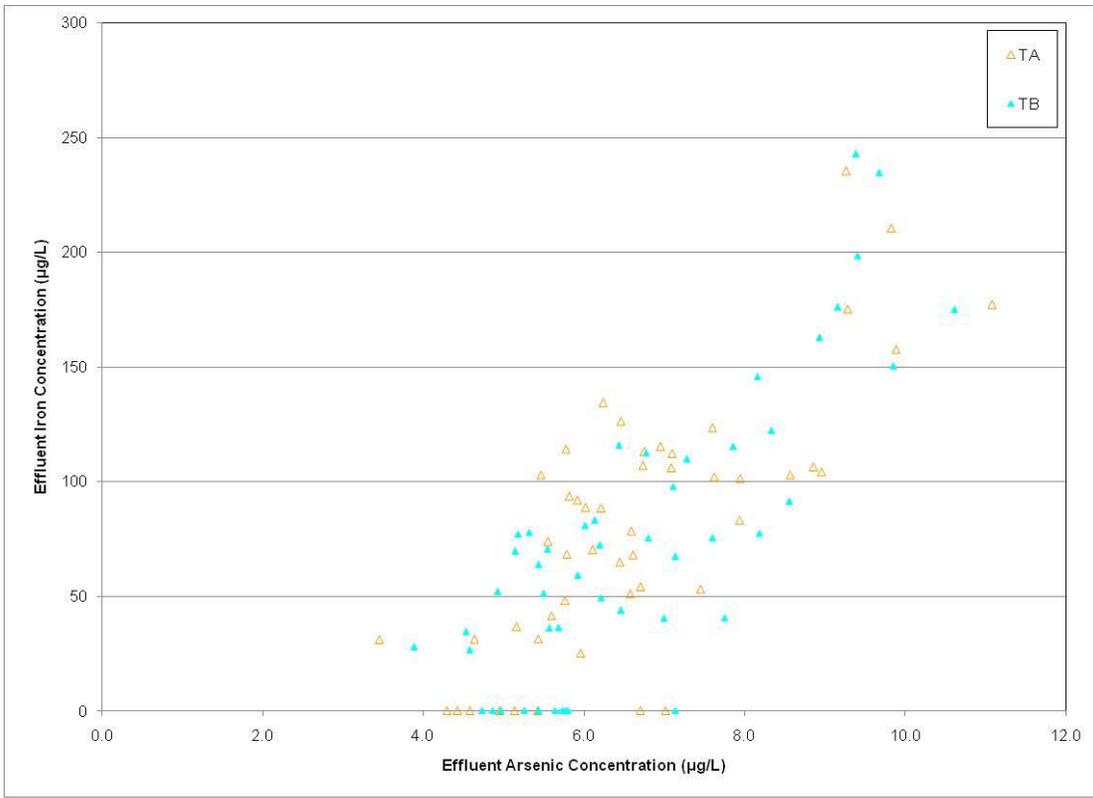


Figure 4-14. Total Iron versus Total Arsenic Concentrations in Filter Effluent

Based on the speciation results from January 31 to August 21, 2006 (at the TA and TB locations), arsenic in the treated water was present in both soluble and particulate forms, each comprising approximately 50% of the total amounts. The soluble fraction was composed of primarily As(V) with concentrations averaging 2.9 and 2.2 µg/L after Tanks A and B, respectively; As(III) concentrations averaged 0.4 and 0.9 µg/L after Tanks A and B, respectively. Speciation sampling results at the TT location starting from September 20, 2006, were slightly higher at 3.9 µg/L for soluble As(V) and 1.1 µg/L for soluble As(III). Particulate arsenic levels averaged 2.9 µg/L at TA, 2.3 µg/L at TB, and 3.3 µg/L at TT.

4.5.1.2 Iron. Figure 4-13 presents total iron concentrations measured across the treatment train. Total iron concentrations in raw water ranged from 1,005 to 2,757 µg/L and averaged 1,350 µg/L, which existed mostly in the soluble form at 1,153 µg/L (on average). The average soluble iron and average soluble arsenic concentrations in raw water corresponded to a ratio of 29:1 (Table 4-6), which was over the 20:1 target ratio for effective arsenic removal via the iron removal process (Sorg, 2002). Therefore, the amount of natural iron present was sufficient for arsenic removal. The raw water pH at 7.3 (on average) and other water quality parameters to be discussed in the following sections did not appear to have any adverse effect on arsenic removal by iron solids.

Upon chlorination, soluble iron levels were effectively reduced to below the MDL of 25 µg/L after the contact tanks and Macrolite[®] filters. The only exception was the February 14, 2006, sampling event, where no change in iron concentrations was observed across the treatment train due to a temporary malfunction of the chlorine addition system. The February 14, 2006, data can be seen in Figure 4-13, but is not included in the average total iron calculations for the AC, TA, and TB samples.

Particulate iron breakthrough from the pressure filters was observed with total iron levels ranging from 33.4 to 144 µg/L in the combined effluent from Tanks A and B. Assuming that the iron present in the treated water existed entirely in the particulate form, as much as 243.3 µg/L particulate iron would have been measured following Tanks A and B should speciation be performed. Although the amounts of iron in the filter effluent were significantly below the 300-µg/L secondary MCL for iron, the concerns over particulate arsenic and particulate iron breakthrough from the Macrolite[®] filters prompted the decision to conduct a special study to further investigate the filter run length from November 18 to 20, 2006 (see Section 4.5.1.7).

4.5.1.3 Manganese. Manganese concentrations in raw water ranged from 153 to 449 µg/L and averaged 341 µg/L, which existed almost entirely in the soluble form. With prechlorination and 7.4 min of contact time (on average), only 20.6 to 75.5% of soluble manganese was converted to particulate manganese after the contact tanks. These results suggest that, while being very effective for As(III) and Fe(II) oxidation, chlorine was not as effective in oxidizing Mn(II). This is most likely due to slow oxidation kinetics as observed previously by Knocke et al. (1987), who reported greater than 30 min Mn(II) oxidation lag times even in systems with a Cl₂/Mn ratio of 3.8. Hao et al. (1991) demonstrated that longer contact times could lead to sufficient manganese oxidation and, thus, enhanced particulate manganese removal. However, it would not be practical to consider a longer contact time at Sabin, MN unless more contact tanks were installed at the treatment facility.

Slow Mn(II) oxidation kinetics also were observed at a number of EPA arsenic removal demonstration sites (Table 4-8), where less than 10% conversion rates were observed at two sites (i.e., Delavan, WI and Bruni, TX) and 14.6 to 55.0% observed at seven sites. Alvin, TX, however, had high conversion rates, averaging 93.5%. The contact time did not seem to correlate directly with the conversion rate.

Table 4-8. Soluble Manganese Conversion Rates after Chlorination at Ten Arsenic Removal Demonstration Sites

Demonstration Location	Contact Time (min)	Average Mn Concentrations in Raw Water (Total/Soluble) (µg/L)	Average Mn Concentrations after Chlorination (Total/Soluble) (µg/L)	Average Conversion Rate (%)
Anthony, NM	<1 ^(a)	9.6/8.9	9.8/6.8	23.5
Alvin, TX	<1 ^(a)	54.0/53.4	50.9/2.8	93.5
Brown City, MI	<1 ^(a)	16.1/15.7	15.0/9.8	31.9
Bruni, TX	<1 ^(a)	5.0/4.7	3.9/3.5	5.8
Climax, MN	5 ^(b)	135/126	130/73.7	35.9
Delavan, WI	2 ^(b)	19.2/20.1	18.1/17.7	2.7
Pentwater, MI	6 ^(b)	27.3/28.8	30.1/14.3	52.5
Rollinsford, NH	<1 ^(a)	110/124	101/86.5	14.6
Sabin, MN	7 ^(b)	346/378	338/228	32.6
Sandusky, MI	41 ^(b)	25.3/26.7	26.0/11.7	55.0
Springfield, OH	8 ^(b)	35.6/36.3	29.5/8.3	71.9

(a) Contact time estimated from proximity of chlorine injection location to adsorption tank.

(b) Contact time estimated from flowrate and contact tank dimensions (CT = V/Q).

Previous studies also found that incomplete Mn(II) oxidation could occur using free chlorine at pH values less than 8.5 (Knocke et al., 1987 and 1990). The presence of ammonia and the formation of monochloramines also could lower the rate of Mn(II) oxidation as free chlorine would not be present prior to reaching the breakpoint chlorination. Moreover, the presence of TOC also could cause the formation of fine MnO₂ colloidal particles that would pass through 0.45-µm disc filters and be measured as “soluble” manganese.

The rates of conversion from soluble to particulate manganese correlated well with total chlorine residual levels. Figure 4-15 shows the rate of conversion (as %) as a function of total chlorine residual at the AC location. At the beginning of system operation when the chlorine dose was still being adjusted, total chlorine residuals at or above 1.2 mg/L (as Cl₂) (on January 31, February 14, and February 28, 2006) were measured; the corresponding manganese conversion rates also were high, ranging from 54.5% to 65.6% and averaging 60%. Since then, total chlorine residuals were better controlled, with 32 out of 47 total chlorine measurements falling within the range of 0.4 to 1.0 mg/L (as Cl₂) (or 0.6 mg/L [as Cl₂] on average). During this time period, the conversion rates ranged from 20.6% to 58% and averaged 40.6%. Beginning from February 27, 2007, total chlorine residual levels at the AC location were deliberately increased, on average, to 1.0 and then to 1.4 mg/L (as Cl₂) in an attempt to increase soluble manganese conversion. The conversion rates increased correspondingly to 71.4% and then to 75.5%.

Removal of total manganese across the pressure filters also correlate well with total chlorine residual levels (see Figure 4-16) and amounts of manganese solids formed following the contact tanks. For example, on June 13, 2006, the total chlorine residual was low at only 0.2 mg/L and manganese effluent levels were elevated at 343 µg/L to 365 µg/L, which represented only 15 to 20% removal. However, on April 17, 2007, with 1.0 mg/L of total chlorine residual, over 92% of manganese removal was achieved with only 30 µg/L of total manganese, on average, in the treated water.

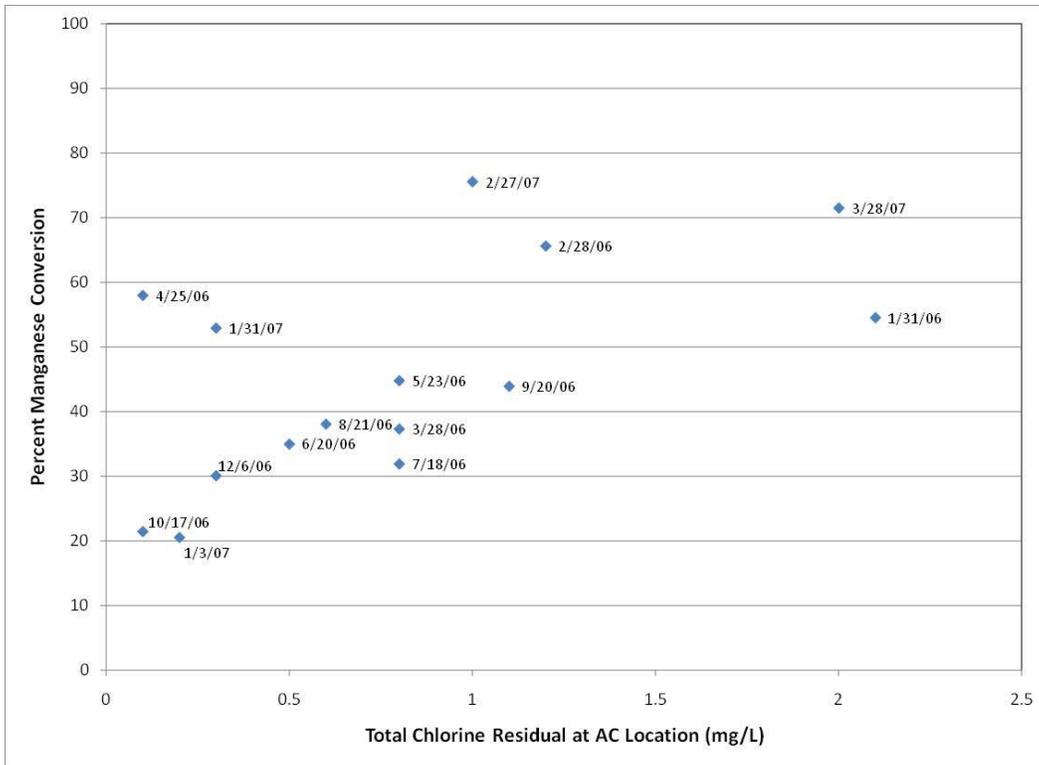


Figure 4-15. Soluble Manganese Conversion versus Total Chlorine Concentration at AC Location

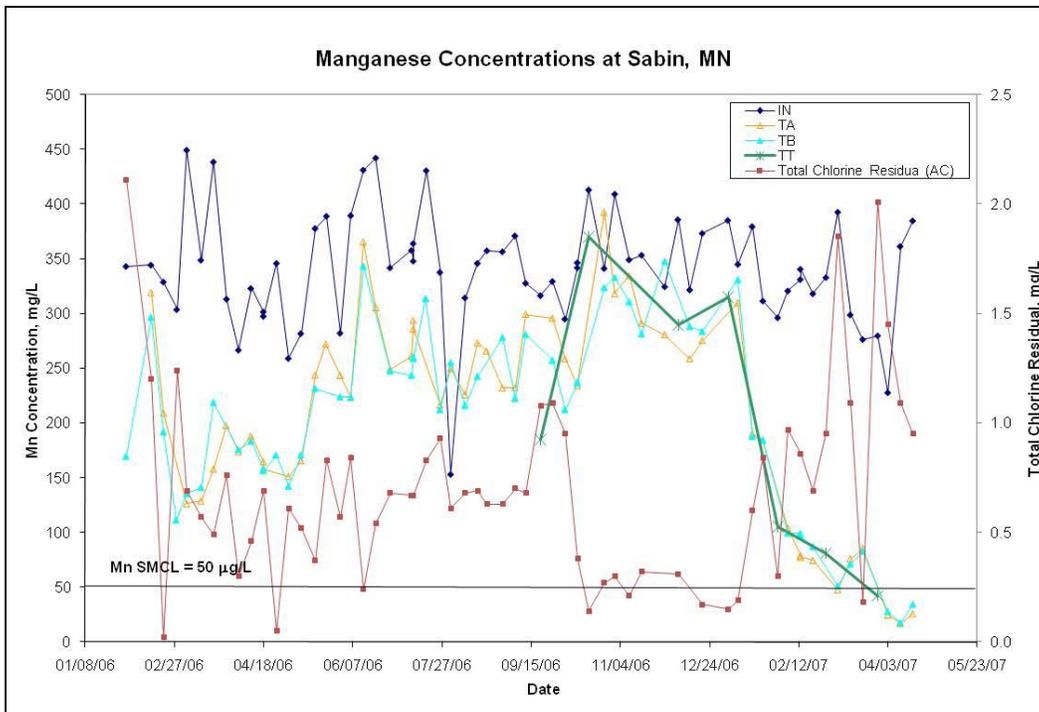


Figure 4-16. Total Manganese Concentrations in Filter Effluent versus Total Chlorine Residuals at AC Location

As discussed in Section 4.5.3, the operator had reported discolored water events in June 2006 that might have been related to elevated manganese levels within the distribution system. It was hypothesized that further manganese precipitation might have occurred in the clearwell and distribution system, given additional chlorine dosage upon post-chlorination and substantially longer contact times within the distribution system. As shown in Figures 4-15 and 4-16, increased chlorine residual levels were found to significantly decrease effluent manganese concentrations. Nonetheless, a special study was conducted in May 2007 to determine the resulting impact of increased manganese solids loading on filter run length under these modified process conditions (see Section 4.5.3).

4.5.1.4 pH, DO, and ORP. pH values in raw water ranged from 6.7 to 7.8 and averaged 7.3. There was no measurable change in pH across the treatment train. The pH was at a level favorable for As(V) adsorption onto iron solids. DO levels averaged 3.4 mg/L in source water and 3.1 mg/L in the treated water. Uncharacteristically high DO readings were recorded by the operator on several occasions that were not included in the calculation of average and standard deviation values (see footnote in Table 4-7). Also, elevated DO readings following Tank B starting from June 28, 2006, were not included in the data analysis because they were related to a compressed air leak that was repaired in October 2006. As a result of prechlorination, average ORP levels increased from 253 mV in raw water to over 488 mV after the contact tanks. This further contributed to the oxidizing nature of the process water.

4.5.1.5 Chlorine and Ammonia. Total chlorine residuals ranged from 0 to 2.1 mg/L (as Cl₂) and averaged 0.7 mg/L (as Cl₂) after the contact tanks. Total chlorine residuals were slightly lower following the pressure filters, with concentrations ranging from 0 to 2.0 mg/L (as Cl₂) and averaging 0.5 mg/L (as Cl₂ for TA, TB, and TT locations). Free chlorine residuals averaged 0.3 mg/L (as Cl₂) after the contact tanks and 0.2 mg/L (as Cl₂ for TA, TB, and TT locations) following the pressure filters; these concentrations were close to the MDL of 0.1 mg/L (as Cl₂). The difference between the total and free chlorine was combined chlorine (such as monochloramine), which was formed in the presence of ammonia (at 0.2 mg/L [as N], on average). (Note that 0.2 mg/L of ammonia [as N] would require 1.5 mg/L of chlorine [as Cl₂] to reach breakpoint chlorination). Because only 0.7 mg/L of total chlorine (or, more specifically, monochloramine) (as Cl₂) was formed, ammonia in raw water would not have been completely oxidized. The presence of ammonia and other reducing species, such as soluble As(III), Fe(II), and Mn(II) in raw water significantly increased the chlorine demand. Compared to the design value of 1.7 mg/L (as Cl₂) shown in Table 4-3, the actual chlorine dosage was estimated at an average of 2.6 mg/L (as Cl₂), based on solution level measurements and a solution strength of 15.6% (as Cl₂). This resulted in total chlorine residuals that averaged 0.7 mg/L.

As shown in Table 4-7, total chlorine levels after the contact tanks were highly variable during the performance evaluation study with an average of 0.7 mg/L and a standard deviation of 0.4 mg/L after the contact tanks. Although speciation results showed that the levels of prechlorination were adequate for soluble As(III) and soluble Fe(II) oxidation, the variation in chlorine level might have affected the rate of Mn(II) oxidation as discussed earlier. The variation in chlorine level could be caused by the control of the chemical feed pump and/or a declining NaOCl solution strength over time, which was refilled by the chemical supplier on a monthly to bi-monthly basis.

4.5.1.6 Other Water Quality Parameters. Alkalinity, fluoride, sulfate, nitrate, silica, TOC, TDS, temperature, and hardness levels remained consistent across the treatment train and were not affected by the treatment process (Table 4-7). Total phosphorus (as P) decreased from an average concentration of 30.4 µg/L in raw water to 10.1 µg/L after the pressure filters, likely due to removal by iron solids. Turbidity also decreased from 19.6 to 0.6 NTU with treatment.

4.5.1.7 Filter Run Length Special Study Addressing Arsenic and Iron Breakthrough. Two weekly and one monthly speciation sampling events resulted in above the MCL levels of total arsenic in the

pressure filter effluent, which also contained elevated levels of particulate arsenic and iron (Section 4.5.1.1). For this reason, a special study was conducted from November 18 to 20, 2006, to further investigate the filter run length to particulate breakthrough. Both filters were backwashed before the start of the special study. The filters were then allowed to run for a total of 12.4 hr with samples taken from the TT location at 0, 1.6, 2.4, and 12.4 hr for total and soluble arsenic, iron, and manganese analyses. The total throughput for the treated water also was recorded at these sampling times. The analytical results indicated that total arsenic, iron, and manganese concentrations in raw water sampled during November 16 through 29, 2006, averaged 39.1, 1,395, and 339 µg/L, respectively, which were comparable to the respective average values throughout the performance evaluation study.

Figures 4-17 and 4-18 present the particulate and soluble concentrations of arsenic and iron, respectively, during the filter run. Immediately after backwash (i.e., 0 hr of run time), the treated water from the pressure filters contained slightly elevated levels of total arsenic and iron at 8.7 and 116 µg/L, respectively. The elevated levels most likely were the result of an incomplete filter-to-waste rinse following the backwash. Subsequently, the treated water showed the expected gradual increase in arsenic concentration from 5.8 µg/L at 1.6 hr to 9.8 µg/L 12.4 hr. This result seemed to indicate a useful filter run length of approximately 12 hr, which was higher than the median filter run time of 6 hr based on the 48-hr standby trigger. Soluble arsenic concentrations ranged from 2.3 to 8.0 µg/L and averaged 4.1 µg/L over the duration of the study, indicating the presence of sufficient natural iron for arsenic removal.

After initial particulate iron breakthrough from the pressure filters, total iron levels remained low at <50 µg/L at 1.6 and 2.4 hr. Significant particulate iron breakthrough occurred sometime between 2.4 and 12.4 hr, as evidenced by the 202 µg/L of total iron, existing almost entirely as particulate iron, at 12.4 hr. Breakthrough of particulate iron at this elevated level confirms that the useful filter run length should be no longer than 12 hr. Any longer run length would result in more particulate arsenic and iron breakthrough, which certainly is not desirable from the human health and aesthetic perspectives.

In contrast to the behavior of arsenic and iron, manganese was not significantly removed across the pressure filters (Figure 4-19). An average of 272 µg/L was measured in the treated water, which was present primarily in the soluble form. The data also showed no trend in removal with filter run time. This can be explained by insufficient oxidation of manganese (in the presence of monochloramines and with a short contact time) and the potential presence of colloidal MnO₂ (which would pass through disc filters and be reported as part of the soluble fraction). As a result of this special study, it was recommended that filter run lengths be reduced to below 12 hr to minimize arsenic and iron breakthrough. A change to the run time in the PLC was made on December 5, 2006. A second special study, as discussed below, was later conducted to investigate the potential for increased particulate manganese removal.

4.5.1.8 Filter Run Length Special Study Addressing Manganese Solids Removal. Additional measures were taken to increase the oxidation and coagulation of soluble and colloidal manganese to improve its removal. These were prompted by the low manganese removal discussed earlier and complaints received from a few customers concerning periodic slugs of dark solids from their taps (which were thought to have been related to iron and/or manganese solids accumulating within the distribution system). It was hypothesized that an increase in chlorine residual after post-chlorination and an increase in contact time within the distribution system might have resulted in further manganese oxidation and subsequent attachment of MnO₂ particles to pipe walls and/or mineral deposits (tuberculation) – which are characteristic of older distribution systems. Further, the operator also reported “tea-colored” water in the clearwell. Upon conferring with the vendor on February 21, 2007, it was determined to increase the chlorine dose during prechlorination to more effectively oxidize manganese and increase its removal.

From February 27 to March 20, 2007, total chlorine residuals were increased to an average of 1.0 mg/L (as Cl₂), which resulted in 77.2% (on average) manganese removal during that time period. From March

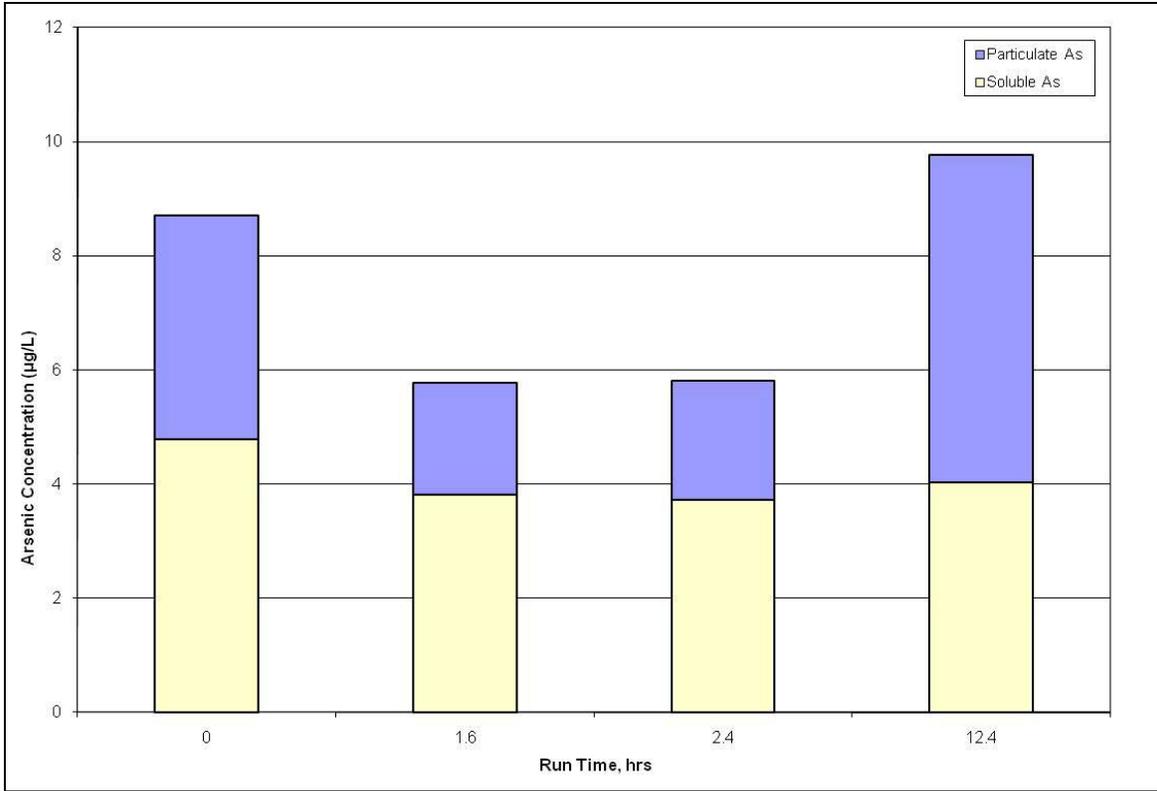


Figure 4-17. Particulate and Soluble Arsenic Concentrations versus Run Time

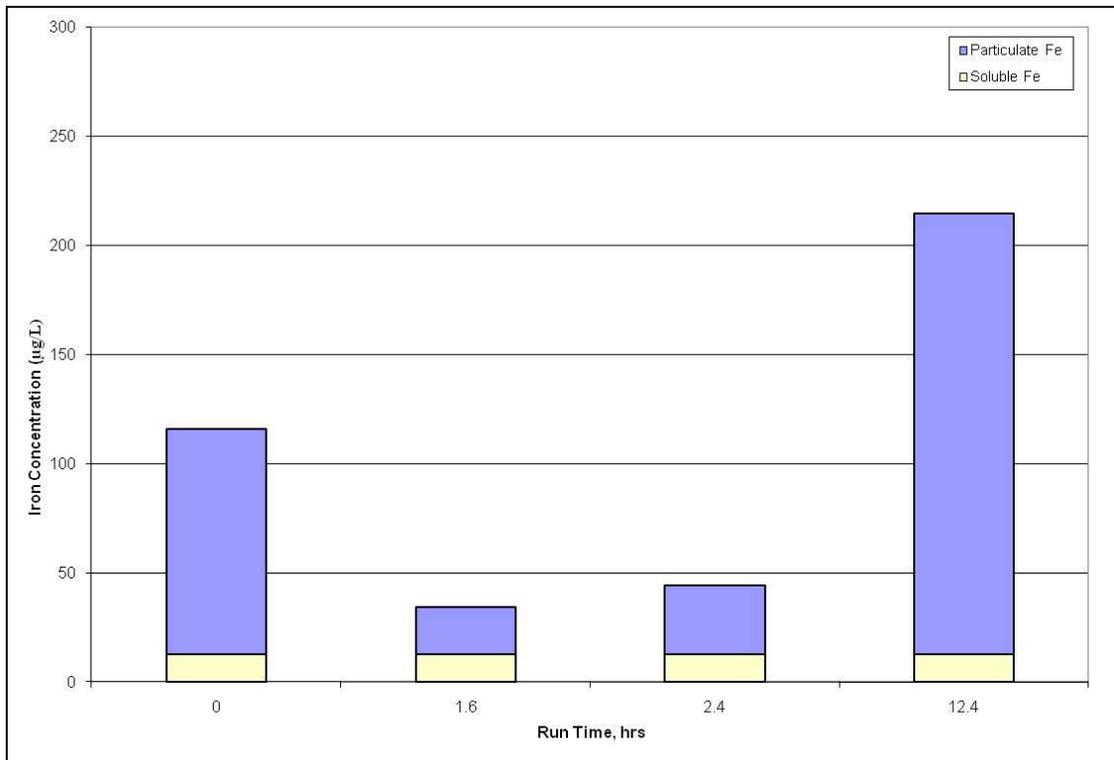


Figure 4-18. Particulate and Soluble Iron Concentrations versus Run Time

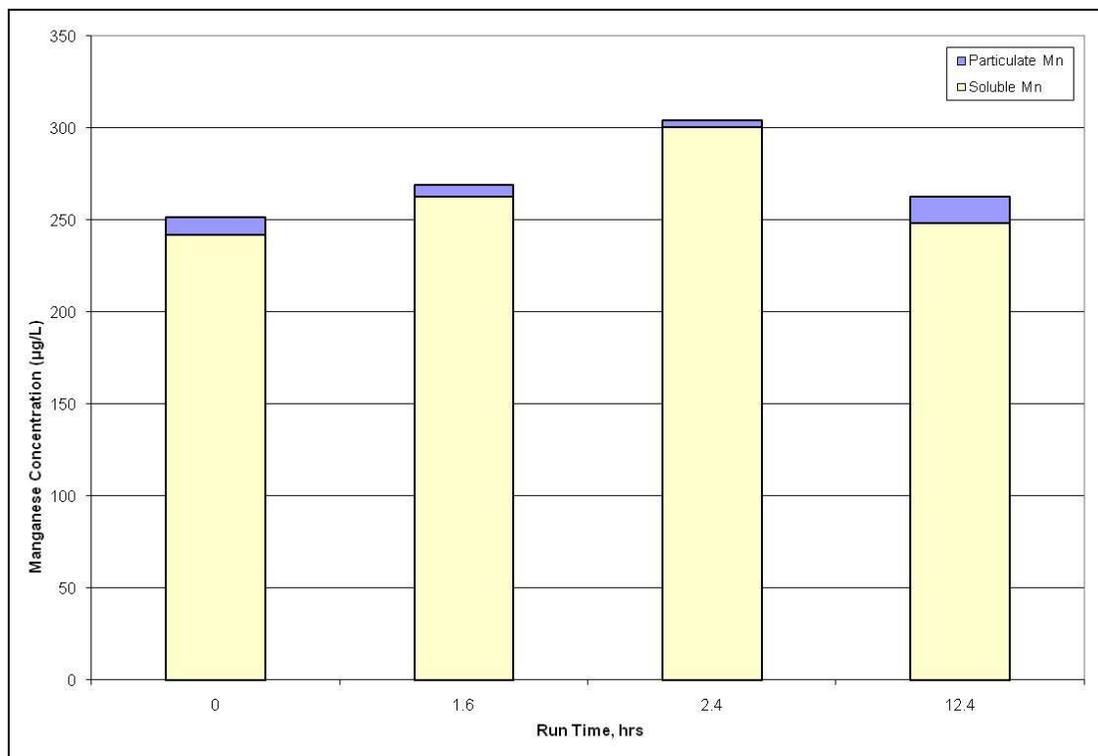


Figure 4-19. Particulate and Soluble Manganese Concentrations versus Run Time

20, 2007, to April 17, 2007, total chlorine residuals were further increased to an average of 1.4 mg/L (as Cl₂), which resulted in 91% manganese removal. With this change, a question was raised as to whether the increased loadings from manganese solids would result in earlier arsenic/iron breakthrough and shorter run lengths. (Note that 10.9 µg/L of total arsenic, consisting of 4.9 µg/L of particulate As, 4.4 µg/L of soluble As[V], and 1.6 µg/L of soluble As[III] were measured during a field speciation event on March 28, 2007). As a result, a second special study was conducted on May 23 and 24, 2007, to examine the effects of increased manganese loading on filter run length.

Both filters were backwashed just before the start of the special study. The filters were then allowed to run for a total of 6.9 hr with samples collected from the TT location at 4.4, 5.3, 5.6, and 6.9 hr for total and soluble arsenic, iron, and manganese analyses. Figures 4-20 and 4-21 present the analytical results for arsenic and iron, respectively. Total arsenic concentrations were measured above the arsenic MCL at 5.3 hr (11.5 µg/L) and 6.9 hr (11.9 µg/L), but below the arsenic MCL at 4.4 hr (6.9 µg/L) and 5.6 hr (8.4 µg/L). Total iron concentrations also showed a similar trend with particulate iron breakthrough up to 285 µg/L at 6.9 hr. Total manganese concentrations were effectively lowered to 34 µg/L, which is below the SMCL of 50 µg/L. Soluble manganese concentrations were lowered to 3.7 µg/L (Figure 4-22), which was 99% lower than the average soluble manganese concentration (264 µg/L) during the November 2007 special study. Because the median run length for the treatment system during the performance evaluation study was 6.0 hr (based on the 48-hr standby time trigger), the filter performance was considered to be acceptable with an increased chlorine dose and a higher manganese solids removal rate. As a result of the special study, it was suggested in a June 20, 2007, conference call with the operator to reduce the filter run length to 5.0 hr for future operations.

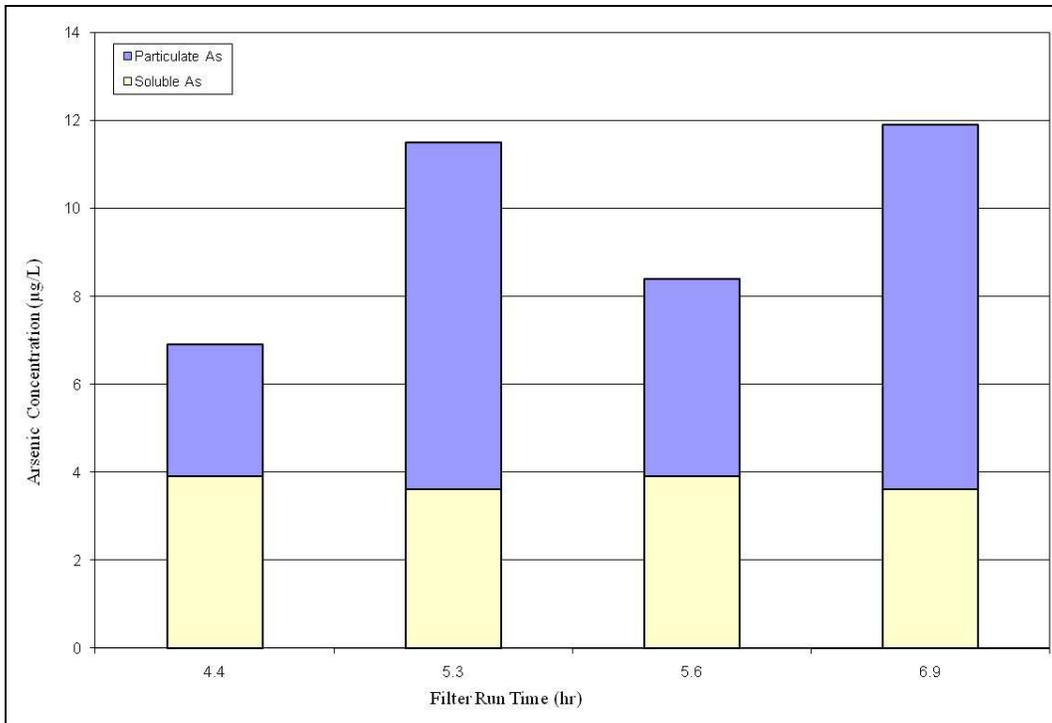


Figure 4-20. Particulate and Soluble Arsenic Concentrations versus Run Time (with 1.8 mg/L of Chlorine [as Cl₂])

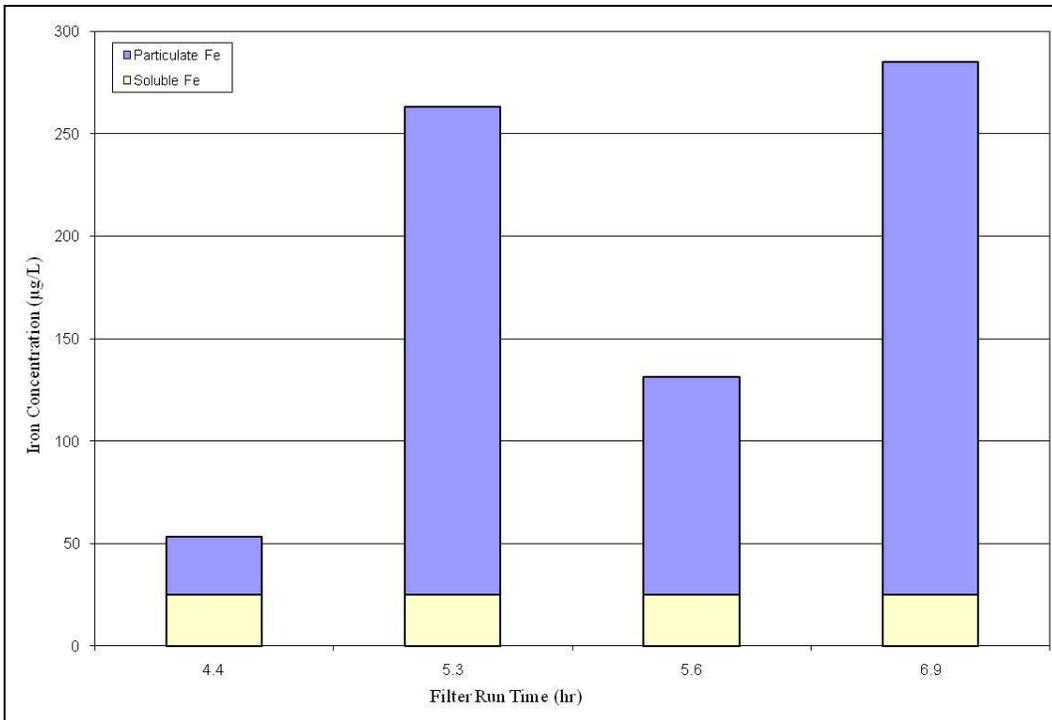


Figure 4-21. Particulate and Soluble Iron Concentrations versus Run Time (with 1.8 mg/L of Chlorine [as Cl₂])

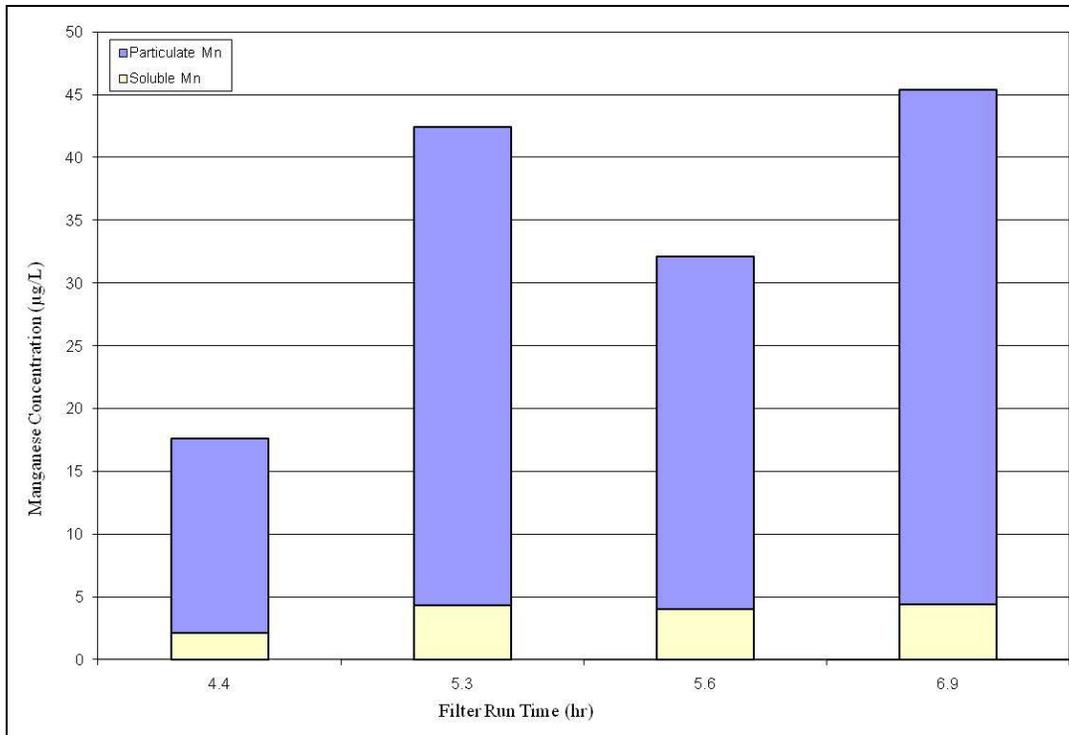


Figure 4-22. Particulate and Soluble Manganese Concentrations versus Run Time (with 1.8 mg/L of Chlorine [as Cl₂])

4.5.2 Backwash Wastewater Sampling. Table 4-9 presents the analytical results of 13 monthly backwash wastewater sampling events. The backwash water samples collected during Events 1, 2, 4, 5, 7, 9, 11, 12, and 13 were considered to be characteristic of normal operating conditions. Events 3, 6, 8, and 10 were excluded from the evaluation of results for the reasons discussed below:

- For Event 3, relatively low values of total metals and TSS were observed, which most likely was caused by the timing of the sampling, i.e., soon after the pressure filters had just been backwashed automatically by the PLC.
- For Event 6, sampling was not considered representative as the filters had been in service for less than 10 min before backwashing.
- Event 8 was eliminated due to elevated soluble metal results, which were rerun with similar results.
- Event 10 showed very different results for Tank A and B, which might have been attributable to the difference in service times for the two tanks (7.5 hr for Tank A and 45 min for Tank B).

Table 4-9. Backwash Wastewater Sampling Results

Sampling Event		BW1										BW2									
		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	02/28/06	7.5	938	116	444	6.1	438	45,061	67.3	3,086	86.4	7.4	964	174	455	11.1	444	29,838	203	2,009	91.8
2	03/27/06	7.6	978	220	466	26.4	439	36,502	755	2,220	137	7.6	940	200	391	27.6	364	40,349	808	2,451	151
3	04/18/06	7.6	958	52	287	6.6	280	10,324	117	1,037	102	7.6	966	42	273	6.7	267	9,599	115	1,033	100
4	06/21/06	7.3	1,030	368	688	26.6	661	143,856	827	7,815	354	7.4	994	324	770	24.9	745	118,608	772	7,035	360
5	07/18/06	7.3	1,010	550	791	8.7	783	175,722	149	8,136	225	7.4	776	528	852	10.5	842	176,777	239	8,649	246
6	08/08/06	7.5	1,020	270	1,011	9.7	1,001	29,293	175	1,714	220	7.5	952	135	1,087	12.1	1,075	30,637	267	1,736	223
7	10/03/06	7.2	932	378	799	11.0	788	65,871	168	4,280	197	7.3	958	250	745	10.5	734	51,682	115	3,213	117
8	11/09/06	7.3	948	120	1,302	56.4 ^(a)	1,245	51,016	1,832 ^(a)	3,290	365 ^(a)	7.4	910	145	1,896	8.9	1,887	73,976	142	4,907	270
9	11/18/06	7.4	970	110	1,494	11.3	1,483	50,900	181	2,888	271	7.3	946	135	1,697	15.3	1,682	56,951	314	3,103	270
10	01/16/07	7.4	960	95	658	5.0	653	37,156	32.4	3,133	160	7.5	912	30	140 ^(b)	4.3	136	6,209 ^(b)	<25	728 ^(b)	132
11	01/25/07	7.4	906	75	603	12.8	590	33,444	224	2,449	135	7.5	910	45	528	10.3	518	25,821	124	2,087	141
12	01/31/07	7.4	964	190	437	17.0	420	80,545	331	2,684	108	7.4	910	145	470	16.7	453	68,048	350	2,432	107
13	02/21/07	7.5	938	114	346	10.3	336	25,035	109	1,619	53.4	7.5	986	140	373	10.6	363	29,825	116	1,938	56.6

TDS = total dissolved solids; TSS = total suspended solids.

NA = not analyzed.

(a) 11/09/06 BW1 samples rerun with similar results for As, Fe, Mn.

(b) 01/16/07 BW2 samples rerun with similar results for As, Fe, Mn.

For Events 1, 2, 4, 5, 7, 9, 11, 12, and 13, concentrations of total arsenic, iron, and manganese ranged from 346 to 1,697 µg/L (averaged 686 µg/L), 25,035 to 176,777 µg/L (averaged 69,713 µg/L), and 1,619 to 8,649 µg/L (averaged 3,783 µg/L), respectively, with the majority existing as particulate. Assuming that 226 mg/L of TSS (i.e., the average TSS) was produced in 962 gal of backwash wastewater per filter (Table 4-5), approximately 3.6 lb of solids would have been discharged from both filters during each backwash event. Based on the average particulate metal data (i.e., 671 µg/L of particulate arsenic, 69,388 µg/L of particulate iron, and 3,610 µg/L of particulate manganese), the solids discharged would have been composed of 0.01 lb of arsenic (i.e. 0.3% by weight), 0.6 lb of iron (i.e. 17% by weight), and 0.03 lb of manganese (i.e. 8% by weight).

4.5.3 Backwash Solids Sampling. Backwash solids were collected on February 21, 2007, and analyzed for total silver, arsenic, barium, cadmium, chromium, mercury, lead and selenium. The samples were initially to be tested for toxicity characteristic leaching procedure (TCLP) metals, but due to inadequate sample volume were switched by the laboratory to total metals analysis. Arsenic, chromium, and lead were detected at 3,980 mg/kg, 2.42 mg/kg, and 11.4 mg/kg, respectively. Silver and barium concentrations were measured at 2.02 mg/kg and 151 mg/kg, respectively. Mercury and selenium were not detected above the detection limit (<0.1 mg/kg and 10.0 mg/kg, respectively).

The arsenic level in the solids averaged 3.98 mg/g (or 0.4%) on February 21, 2007. Based on the backwash wastewater samples collected on February 21, 2007, the average concentration of particulate arsenic was 349 µg/L. Assuming that 127 mg/L of TSS (i.e., the averaged TSS in the backwash wastewater samples collected on February 21, 2007) was produced in 962 gal of backwash wastewater from a filter (Table 4-5), the arsenic content in the solids was calculated to be 0.3%. The degree of inconsistency is considered reasonable, considering that the results are from two independent sampling systems (i.e., wastewater and backwash solids).

4.5.4 Distribution System Water Sampling. Distribution system water samples were collected to determine if water treated by the arsenic removal system would impact the lead, copper, and arsenic levels and other water chemistry in the distribution system. Prior to system startup, baseline distribution water samples were collected on February 14, March 16, April 18, and May 18, 2005. Since system startup, distribution water sampling continued monthly at the same three locations until March 6, 2007. The samples were analyzed for pH, alkalinity, arsenic, iron, manganese, lead, and copper and the results are presented in Table 4-10.

The main differences observed between the baseline samples and samples collected after system startup were decreases in arsenic concentration at each of the three sampling locations. Arsenic concentrations were reduced from a pre-startup average of 27 µg/L to a post-startup average of 8.7 µg/L (excluding two outliers in the first quarter of operation at DS2 on February 22, 2006 and March 29, 2006). The water quality was similar except at the DS2 residence, which was located in the older part of town and initially had higher arsenic and iron levels due to a history of periodic release of particulates (tubercles) from the distribution system. In general, total arsenic concentrations in the distribution system water were slightly higher than those in the treatment system effluent (averaging 7.2 µg/L at the TA, TB, and TT locations). Desorption and resuspension of arsenic previously accumulated on the distribution pipe surface most likely are the reason for higher arsenic concentration in the distribution system.

Iron concentrations decreased significantly from a pre-startup average of 1,211 µg/L and to a post-startup average of 157 µg/L. Manganese concentrations averaged 114 and 75 µg/L before and after system startup, respectively. In June 2006, the facility operator received complaints from a few customers concerning periodic slugs of dark solids from their taps, which might have been related to iron and/or manganese solids accumulating within the distribution system. It was hypothesized that the increased

Table 4-10. Distribution System Sampling Results

No. of Sampling Events	Sample Type	DS1 ^(b)									DS2 ^(c)							DS3 ^(b)							
		LCR									LCR							LCR							
		1st Draw									1st Draw							1st Draw							
		Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Pb	Cu
Sampling Date	Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Pb	Cu	
BL1	02/14/05 ^(a)	7.0	8.0	299	6.8	39.0	118	0.7	116	8.0	8.0	78.0	63.0	4,527	116	9.1	314	11.6	8.3	75.0	9.6	159	57.0	3.3	91.0
BL2	03/16/05	6.7	8.1	299	14.8	81.7	187	2.7	146	14.0	7.8	294	124	8,002	395	23.1	747	8.0	8.0	308	14.0	101	17.8	0.2	17.1
BL3	04/18/05	6.9	7.7	324	11.8	75.2	119	1.0	251	17.7	7.7	320	14.3	140	25.7	0.3	8.2	9.0	8.2	311	9.9	220	31.2	5.0	50.7
BL4	05/18/05	7.1	7.7	308	29.9	861	172	4.0	262	15.0	7.8	303	16.7	192	66.8	0.8	107	8.0	7.9	290	13.7	129	68.8	0.4	38.3
1	02/22/06	8.3	7.6	299	15.0	<25	271	1.0	163	49.0	7.6	295	76.0	2,889	569	26.5	646	8.0	7.6	299	13.9	36.6	16.4	0.3	22.4
2	03/29/06 ^(d)	7.0	7.8	290	9.5	64.7	294	7.3	344	67.3	7.5	298	39.3	1,173	264	14.7	575	8.0	7.5	290	4.8	<25	8.1	0.5	55.6
3	04/18/06	7.5	7.7	312	8.0	67.1	199	1.6	390	8.6	7.6	308	10.3	167	110	0.7	116	7.0	7.6	308	4.2	<25	6.9	0.9	96.5
4	05/23/06	7.5	7.8	301	6.0	72.4	56.3	1.6	58.5	12.0	7.5	292	7.4	76.9	57.8	2.0	125	8.5	7.7	292	3.4	<25	3.1	0.4	54.8
5	06/21/06	6.5	7.3	289	8.9	86.6	51.4	4.8	444	11.5	7.6	293	12.7	209	199	0.2	24.1	9.0	7.4	289	4.8	89.4	31.8	0.4	70.6
6	07/11/06	7.0	7.5	299	6.8	48.5	39.8	2.6	244	7.0	7.5	297	6.7	68.2	95.1	0.1	17.3	7.5	7.5	293	7.3	<25	4.0	1.0	103
7	08/15/06	7.0	7.4	295	6.3	<25	41.6	1.8	223	8.0	7.4	295	7.6	55.1	72.2	0.5	22.0	8.5	7.6	290	7.3	35.2	13.0	2.9	180
8	09/12/06	7.0	7.4	333	6.7	<25	28.2	3.2	236	14.0	7.4	330	7.4	<25	22.7	0.6	29.7	8.5	7.5	316	6.0	38.1	14.6	1.1	132
9	10/18/06	6.5	7.4	312	10.7	33.7	36.5	3.1	274	8.0	7.3	354	13.1	144	61.6	2.4	163	8.6	7.5	316	11.9	61.1	26.2	0.9	87.0
10	11/07/06	7.5	7.4	313	8.1	<25	40.7	0.6	148	29.0	7.5	315	13.1	<25	25.8	0.3	65.4	11.8	7.6	320	9.0	<25	34.8	0.3	58.0
11	12/13/06	6.5	7.4	313	6.7	<25	53.8	0.8	90.3	33.0	7.4	330	8.9	<25	0.1	0.6	153	8.5	7.6	324	7.2	<25	16.6	0.6	82.4
12	01/09/07	6.3	7.6	309	7.1	<25	45.9	1.5	283	17.5	7.6	313	9.6	91.4	21.3	1.8	164	8.5	7.7	315	5.5	33.6	14.2	1.2	130
13	02/06/07	7.0	7.6	327	11.6	179	79.8	5.8	226	17.0	7.6	322	9.1	60.6	52.8	3.2	151	8.5	7.6	318	7.9	180	53.2	2.2	119
14	03/06/07	7.3	7.6	317	15.4	211	51.6	6.0	287	13.0	7.6	312	13.4	97.2	35.0	3.5	175	8.5	7.7	310	8.5	126	31.4	1.9	82.9

(a) DS2 sampled on 02/13/05.

(b) Samples taken after softener system.

(c) DS2 located at old section of town.

(d) DS2 and DS3 collected on 03/28/06.

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

BL = baseline sampling

µg/L as unit for all analytical parameters except for alkalinity (mg/L as CaCO₃).

chlorine dose after post-chlorination and the prolonged contact time within the distribution system might have resulted in further manganese oxidation and subsequent attachment of MnO₂ solids to pipe walls and/or mineral deposits. From January 21, 2006, to January 9, 2007, manganese was not significantly removed across the pressure filters. For example, total manganese levels averaged 244 µg/L in the treated water during this time period, compared to the average concentration of 79 µg/L within the distribution system at the same time. However, chlorine dosages for prechlorination were subsequently raised starting in January 2007 to enhance manganese removal. In response, the manganese removal rate increased to 92.2%, reducing the total manganese concentration to 30 µg/L in the treated water by the end of the study in March 2007. In March 2007, manganese levels for the three distribution samples were 51.6, 35.0, and 31.4 µg/L, at DS1, DS2, and DS3 respectively, which were still slightly higher than the treated water effluent.

Alkalinity and pH values remained fairly consistent throughout the performance evaluation study period. The average lead level was 4.2 µg/L in the baseline samples and 2.7 µg/L in the samples taken after system startup; these concentrations were significantly lower than the action level of 15 µg/L. The average copper level was 179 µg/L in the baseline samples and 169 µg/L in the samples taken after system startup; these concentrations also were significantly lower than the action level of 1,300 µg/L.

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, engineering, and system installation, shakedown, and startup. O&M cost included cost for chemicals, electricity, and labor. Cost associated with the building, including the clearwell, sump, and sanitary sewer connections, 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 city of Sabin.

4.6.1 Capital Cost. The capital investment for the FM-248-AS system was \$287,159 (Table 4-11). The equipment cost was \$160,875 (or 56% of the total capital investment), which included the cost for two contact tanks, two pressure filtration tanks, 50 ft³ of Macrolite[®], instrumentation and 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 a period of 12 months after system startup.

The 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 MDH. The engineering cost was \$49,164, which was 17% 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 Kinetico's subcontractor, and startup and shakedown activities were performed by Kinetico with the operator's assistance. The installation, startup, and shakedown cost was \$77,120, or 27% of the total capital investment.

The total capital cost of \$287,159 was normalized to \$1,149/gpm (\$0.80/gpd) of design capacity using the system's rated capacity of 250 gpm (or 360,000 gpd). The total capital cost also was converted to an annualized cost of \$27,105/yr using a capital recovery factor 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 250 gpm to produce 131,400,000 gal/yr, the unit capital cost would be \$0.21/1,000 gal. The system

Table 4-11. Capital Investment for Kinetico FM-248-AS System

Description	Cost	% of Capital Investment Cost
<i>Equipment</i>		
Tanks, Valves, and Piping	\$79,349	-
Macrolite [®] Media (50 ft ³)	\$10,939	-
Instrumentation and Controls	\$21,970	-
Air Scour System	\$5,373	-
Additional Sample Taps and Totalizers/Meters	\$1,717	-
Labor	\$37,527	-
Freight	\$4,000	-
Equipment Total	\$160,875	56%
<i>Engineering</i>		
Labor	\$43,450	-
Subcontractor	\$5,714	-
Engineering Total	\$49,164	17%
<i>Installation, Shakedown, and Startup</i>		
Labor	\$14,000	-
Subcontractor	\$59,250	-
Travel	\$3,870	-
Installation, Shakedown, and Startup	\$77,120	27%
Total Capital Investment	\$287,159	100%

produced approximately 12,221,660 gal of water on an annual basis, so the unit capital cost increased to \$2.22/1,000 gal.

A 48 ft × 56 ft building with a sidewall height of 17.5 ft was constructed by the city of Sabin to house the treatment system (Section 4.3.2). The total cost of the building and supporting utilities was \$807,000 which, as noted above, was not included in the capital cost.

4.6.2 O&M Cost. The O&M cost included items such as chemicals, electricity, and labor (see Table 4-12). Prechlorination was performed for oxidation and post-chlorination was performed to maintain a residual within the distribution system. The chemical consumption was 0.04 lb/1,000 gal for both pre- and post-chlorination, which corresponded to \$0.05/1,000 gal in chemical usage cost. No cost was incurred for repairs because the system was under warranty. Electrical cost was estimated at \$0.01/1,000 gal based on the power requirements of the control panel and air compressor (7.5 hp). Electrical bills from before and after treatment system installation were not provided by the City of Sabin. Routine labor activities for O&M consumed 15 min/day for operational readings at a labor rate of \$10/hr and a \$300/month fixed fee. This is equivalent to 1.75 hr/wk on a seven day per week basis. The estimated labor cost is \$0.37/1,000 gal of water treated. The total O&M cost was estimated at \$0.43/1,000 gal of treated water.

Table 4-12. O&M Cost for Kinetico FM-248-AS System

Category	Value	Remarks
Volume Processed (1,000 gal)	14,884,800	From 01/30/06 to 04/29/07
<i>Chemical Consumption</i>		
Sodium Hypochlorite Unit Price (\$/lb)	\$1.10	15.6% as Cl ₂
Consumption Rate (lb/1,000 gal)	0.04	Pre- and post-chlorination at 2.6 mg/L as Cl ₂ each
Chemical Costs (\$/1,000 gal)	\$0.05	Pre- and post-chlorination at 2.6 mg/L as Cl ₂ each
<i>Electricity Consumption</i>		
Electricity Cost (\$/1,000 gal)	\$0.01	Based on control panel and 7.5 hp air compressor power requirements and \$0.08/kWh
<i>Labor</i>		
Labor (hr/week)	1.75	15 min/day, 7 days/week
Labor Cost (\$/1,000 gal)	\$0.37	Labor rate = \$10/hr + \$300/month fee
Total O&M Cost (\$/1,000 gal)	\$0.43	

5.0: REFERENCES

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APPENDIX A
OPERATIONAL DATA

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

Week No.	Date	Tank A Run Time hrs	Tank B Run Time hrs						Backwash		
				Δp Across Tank A psig	Δp Across Tank B psig	Δp Across System psig	Digital Flow Rate gpm	Daily Usage gal	Tank A No.	Tank B No.	Cum. Waste-water Volume kgal
1	01/30/06	NA	NA	9	9	32	244	NA	6	6	13.2
	01/31/06	2.0	2.0	10	11	33	238	40,700	6	6	13.2
	02/01/06	3.0	3.0	NA	NA	NA	NA	36,800	7	7	15.4
	02/02/06	2.0	2.0	NA	NA	NA	NA	26,000	7	7	15.4
	02/03/06	2.0	2.0	NA	NA	NA	NA	23,500	8	8	17.2
	02/04/06	2.0	2.0	10	11	33	243	24,200	8	8	17.2
2	02/05/06	4.0	4.0	NA	NA	NA	NA	48,700	9	9	19.0
	02/06/06	2.0	2.0	NA	NA	NA	NA	23,600	9	9	19.0
	02/07/06	2.0	2.0	10	55	63	155	23,500	10	10	21.2
	02/08/06	3.0	3.0	NA	NA	NA	NA	41,100	10	10	21.2
	02/09/06	2.0	2.0	NA	NA	NA	NA	24,200	10	10	21.2
	02/10/06	3.0	3.0	NA	NA	NA	NA	23,700	11	11	23.7
	02/11/06	2.0	2.0	9	11	33	241	23,800	11	11	23.7
3	02/12/06	4.0	4.0	NA	NA	NA	NA	49,700	12	12	26.6
	02/13/06	2.0	2.0	NA	NA	NA	NA	21,500	12	12	26.6
	02/14/06	2.0	2.0	NA	NA	NA	NA	29,900	12	12	27.2
	02/15/06	2.0	2.0	NA	NA	NA	NA	0	13	13	29.4
	02/16/06	2.0	2.0	NA	NA	NA	NA	49,200	13	13	29.4
	02/17/06	3.0	3.0	NA	8	31	240	40,800	14	14	31.5
4	02/18/06	3.0	3.0	NA	NA	NA	NA	31,200	14	14	31.5
	02/19/06	2.0	2.0	NA	NA	NA	NA	40,000	14	14	32.2
	02/20/06	3.0	3.0	NA	NA	NA	NA	29,900	15	15	34.4
	02/21/06	2.0	2.0	NA	NA	NA	NA	29,100	15	15	34.4
	02/22/06	2.0	2.0	NA	NA	NA	NA	21,900	16	16	37.3
	02/23/06	2.0	2.0	NA	NA	NA	NA	22,700	16	16	37.3
	02/24/06	3.0	3.0	NA	NA	NA	NA	43,900	17	17	39.1
5	02/25/06	2.0	2.0	NA	NA	NA	NA	23,900	17	17	39.1
	02/26/06	2.0	2.0	8	14	33	240	26,800	18	18	40.0
	02/27/06	4.0	4.0	NA	NA	NA	NA	41,300	18	18	41.8
	02/28/06	NA	NA	7	8	31	243	32,700	19	19	44.1
	03/01/06	NA	1.8	NA	NA	NA	NA	32,700	19	19	44.1
	03/02/06	2.0	2.0	NA	NA	NA	NA	23,100	19	19	44.1
6	03/03/06	3.2	3.1	NA	NA	NA	NA	23,900	19	19	44.1
	03/04/06	2.6	2.6	NA	NA	NA	NA	22,100	19	19	44.1
	03/05/06	4.8	4.8	NA	NA	NA	NA	47,200	19	19	44.1
	03/06/06	NA	NA	NA	NA	NA	NA	NA	19	19	44.1
	03/07/06	NA	NA	NA	NA	NA	NA	26,500	20	20	46.5
	03/08/06	2.4	2.4	NA	NA	NA	NA	NA	20	20	0.0
7	03/09/06	2.1	2.2	NA	NA	NA	NA	22,800	20	20	0.0
	03/10/06	4.7	4.7	NA	NA	NA	NA	46,100	20	20	0.0
	03/11/06	5.6	5.6	NA	NA	NA	NA	36,500	20	20	0.0
	03/12/06	4.9	4.8	19	17	39	222	42,800	20	20	0.0
	03/13/06	1.6	2.1	NA	NA	NA	NA	24,000	20	20	0.0
	03/14/06	3.7	3.1	NA	NA	NA	NA	30,800	21	21	3.4
7	03/15/06	2.6	2.6	10	11	33	242	22,600	21	21	3.4
	03/16/06	3.7	3.7	NA	NA	NA	NA	42,800	21	21	3.4
	03/17/06	3.5	3.5	16	17	36	230	30,000	21	21	3.4
	03/18/06	9.3	9.3	18	19	37	226	113,600	21	21	3.4
	03/19/06	3.1	3.3	NA	NA	NA	NA	42,500	22	22	5.8

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

Week No.	Date	Tank A Run Time hrs	Tank B Run Time hrs						Backwash		
				Δp Across Tank A psig	Δp Across Tank B psig	Δp Across System psig	Digital Flow Rate gpm	Daily Usage gal	Tank A No.	Tank B No.	Cum. Waste-water Volume kgal
8	03/20/06	0.0	0.0	NA	NA	NA	NA	0	22	22	5.8
	03/21/06	0.2	0.2	NA	NA	NA	NA	3,300	22	22	5.8
	03/22/06	2.8	2.8	NA	NA	NA	NA	25,200	22	22	5.8
	03/23/06	3.0	3.0	NA	NA	NA	NA	38,600	22	22	5.8
	03/24/06	3.5	3.7	NA	NA	NA	NA	48,300	23	23	8.8
	03/25/06	2.3	2.3	NA	NA	NA	NA	25,300	23	23	8.8
03/26/06	3.7	3.7	12	13	34	236	27,300	23	23	8.8	
9	03/27/06	3.3	3.3	8	9	31	243	35,000	24	24	10.9
	03/28/06	2.3	2.3	NA	NA	NA	NA	30,700	24	24	10.9
	03/29/06	2.4	2.5	NA	NA	NA	NA	23,600	24	24	10.9
	03/30/06	2.3	2.3	NA	NA	NA	NA	23,800	25	25	12.9
	03/31/06	2.2	2.2	NA	NA	NA	NA	24,900	25	25	12.9
	04/01/06	4.8	4.7	NA	NA	NA	NA	50,500	25	25	13.7
04/02/06	2.2	2.2	NA	NA	NA	NA	26,200	26	26	14.5	
10	04/03/06	1.4	1.4	8	8	31	243	12,900	26	26	14.5
	04/04/06	3.5	3.5	NA	NA	NA	NA	45,600	27	26	14.5
	04/05/06	2.7	2.7	NA	NA	NA	NA	25,800	27	27	16.4
	04/06/06	1.9	1.9	NA	NA	NA	NA	23,700	27	27	16.4
	04/07/06	2.5	2.6	7	9	31	245	11,900	28	28	17.8
	04/08/06	3.0	3.0	8	10	31	243	34,200	28	28	17.8
04/09/06	2.9	2.9	NA	NA	NA	NA	34,300	28	28	17.8	
11	04/10/06	2.3	2.3	NA	NA	NA	NA	23,500	29	29	19.6
	04/11/06	NA	NA	NA	NA	NA	NA	NA	27	27	16.4
	04/12/06	2.8	2.5	NA	NA	NA	NA	35,700	27	28	17.5
	04/13/06	1.6	1.6	NA	NA	NA	NA	21,100	27	28	17.5
	04/14/06	4.3	4.3	17	15	36	233	41,900	27	28	17.5
	04/15/06	5.2	5.5	NA	NA	NA	NA	58,300	28	29	19.8
04/16/06	3.1	2.9	10	12	33	240	24,400	28	29	19.8	
12	04/17/06	4.8	4.8	NA	NA	NA	NA	40,800	29	30	21.8
	04/18/06	0.8	0.8	NA	NA	NA	NA	11,200	30	31	25.2
	04/19/06	3.7	3.8	NA	NA	NA	NA	49,400	30	31	25.2
	04/20/06	2.3	2.2	NA	NA	NA	NA	28,200	30	31	25.2
	04/21/06	2.7	2.6	NA	NA	NA	NA	34,500	31	32	27.2
	04/22/06	2.7	2.8	NA	NA	NA	NA	35,600	31	32	27.2
04/23/06	2.6	2.5	NA	NA	NA	NA	32,800	32	32	30.7	
13	04/24/06	2.5	2.6	NA	NA	NA	NA	33,200	32	33	30.7
	04/25/06	1.5	1.7	NA	NA	NA	NA	18,600	33	34	33.6
	04/26/06	2.2	2.1	NA	NA	NA	NA	29,800	33	34	33.6
	04/27/06	2.3	2.3	NA	NA	NA	NA	30,400	34	35	36.5
	04/28/06	2.4	2.4	NA	NA	NA	NA	31,900	35	35	38.5
	04/29/06	2.2	2.2	NA	NA	NA	NA	29,100	35	35	38.5
04/30/06	4.4	4.6	NA	NA	NA	NA	59,400	36	36	40.1	
14	05/01/06	4.4	4.2	NA	NA	NA	NA	0	36	36	41.1
	05/02/06	4.4	4.6	8	9	31	242	52,100	37	37	44.0
	05/03/06	0.7	0.6	NA	NA	NA	NA	8,700	37	37	44.0
	05/04/06	8.0	8.0	NA	NA	NA	NA	93,800	37	38	44.6
	05/05/06	2.3	2.3	NA	NA	NA	NA	30,200	38	38	45.0
	05/06/06	2.6	2.6	NA	NA	NA	NA	33,400	38	38	45.0
05/07/06	2.3	2.4	NA	NA	NA	NA	31,200	39	39	45.9	

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

Week No.	Date	Tank A Run Time hrs	Tank B Run Time hrs						Backwash		
				Δp Across Tank A psig	Δp Across Tank B psig	Δp Across System psig	Digital Flow Rate gpm	Daily Usage gal	Tank A No.	Tank B No.	Cum. Waste-water Volume kgal
15	05/08/06	3.3	3.3	NA	NA	NA	NA	40,400	39	39	45.9
	05/09/06	2.8	2.8	NA	NA	NA	NA	36,700	39	39	46.3
	05/10/06	2.7	2.7	NA	NA	NA	NA	35,500	40	40	46.8
	05/11/06	0.0	0.0	NA	NA	NA	NA	0	40	41	47.2
	05/12/06	3.1	3.1	NA	NA	NA	NA	40,700	41	41	47.7
	05/13/06	2.5	2.5	NA	NA	NA	NA	33,400	41	42	48.1
05/14/06	2.7	2.7	NA	NA	NA	NA	36,000	42	42	48.6	
16	05/15/06	2.4	2.4	NA	NA	NA	NA	32,400	42	42	48.6
	05/16/06	0.9	1.0	9	10	32	242	12,700	43	43	49.5
	05/17/06	3.9	3.6	12	14	34	237	50,100	43	43	49.5
	05/18/06	2.6	2.7	14	11	34	235	34,600	43	44	50.0
	05/19/06	4.8	4.8	NA	NA	NA	NA	62,000	44	44	50.4
	05/20/06	2.0	2.0	14	12	34	239	26,400	44	45	50.9
	05/21/06	4.2	4.2	NA	NA	NA	NA	56,500	45	45	51.3
17	05/22/06	3.3	3.4	NA	NA	NA	NA	43,000	45	45	51.3
	05/23/06	3.2	3.2	NA	NA	NA	NA	42,300	46	46	52.2
	05/24/06	3.0	2.9	NA	NA	NA	NA	39,100	46	46	52.2
	05/25/06	3.3	3.3	NA	NA	NA	NA	41,800	46	47	52.7
	05/26/06	3.9	3.9	10	13	33	237	50,400	47	47	53.1
	05/27/06	6.2	6.1	NA	NA	NA	NA	80,500	47	48	53.6
	05/28/06	3.3	3.4	NA	NA	NA	NA	43,900	48	48	54.0
18	05/29/06	3.6	4.1	14	16	35	234	46,400	48	48	54.0
	05/30/06	6.4	6.0	NA	NA	NA	NA	83,600	48	49	54.5
	05/31/06	5.0	5.0	14	17	35	234	66,500	49	49	54.9
	06/01/06	4.3	4.3	NA	NA	NA	NA	54,100	49	49	54.9
	06/02/06	5.9	5.9	NA	NA	NA	NA	76,800	50	50	55.8
	06/03/06	3.2	3.3	NA	NA	NA	NA	41,600	50	50	55.8
06/04/06	3.0	3.0	NA	NA	NA	NA	38,700	50	51	56.8	
19	06/05/06	2.9	2.9	NA	NA	NA	NA	38,500	51	51	57.3
	06/06/06	2.9	2.9	NA	NA	NA	NA	38,100	52	52	58.2
	06/07/06	3.4	3.5	NA	NA	NA	NA	45,800	52	52	58.2
	06/08/06	2.8	2.7	NA	NA	NA	NA	36,000	53	53	59.1
	06/09/06	2.9	2.9	NA	NA	NA	NA	NA	54	53	59.1
	06/10/06	2.6	2.2	NA	NA	NA	NA	34,500	54	54	60.0
	06/11/06	2.8	3.2	NA	NA	NA	NA	37,300	54	54	60.0
20	06/12/06	3.4	3.5	NA	NA	NA	NA	45,700	55	55	61.0
	06/13/06	3.4	3.4	NA	NA	NA	NA	44,900	55	55	61.0
	06/14/06	2.8	2.7	NA	NA	NA	NA	36,300	56	56	61.8
	06/15/06	2.7	2.7	NA	NA	NA	NA	35,100	56	56	61.8
	06/16/06	3.3	3.2	NA	NA	NA	NA	41,700	57	57	62.7
	06/17/06	3.0	2.9	NA	NA	NA	NA	39,000	57	57	62.7
	06/18/06	3.0	3.0	NA	NA	NA	NA	39,500	57	57	62.7
21	06/19/06	3.0	2.9	NA	NA	NA	NA	39,300	58	58	63.7
	06/20/06	3.3	3.4	NA	NA	NA	NA	44,300	59	59	64.6
	06/21/06	3.0	3.0	NA	NA	NA	NA	39,400	60	60	65.5
	06/22/06	2.9	2.9	NA	NA	NA	NA	38,000	60	60	65.5
	06/23/06	5.8	5.8	NA	NA	NA	NA	78,100	61	61	66.4
	06/24/06	2.8	2.7	NA	NA	NA	NA	36,800	61	61	66.4
	06/25/06	0.0	0.0	NA	NA	NA	NA	0	62	62	67.3

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

Week No.	Date	Tank A Run Time hrs	Tank B Run Time hrs						Backwash		
				Δp Across Tank A psig	Δp Across Tank B psig	Δp Across System psig	Digital Flow Rate gpm	Daily Usage gal	Tank A No.	Tank B No.	Cum. Waste-water Volume kgal
22	06/26/06	2.8	2.8	NA	NA	NA	NA	37,500	63	63	68.3
	06/27/06	2.7	2.7	NA	NA	NA	NA	36,100	63	63	68.3
	06/28/06	2.9	2.8	NA	NA	NA	NA	38,800	63	63	68.3
	06/29/06	3.7	3.6	8	9	31	243	48,700	65	65	74.6
	06/30/06	1.9	1.8	NA	NA	NA	NA	24,600	65	65	74.6
	07/01/06	6.2	6.2	NA	NA	NA	NA	82,200	66	66	76.9
	07/02/06	2.7	2.7	13	14	34	234	35,800	66	66	76.9
23	07/03/06	4.0	3.9	NA	NA	NA	NA	50,600	66	66	76.9
	07/04/06	3.0	2.9	NA	NA	NA	NA	39,200	67	67	80.8
	07/05/06	4.2	4.2	13	14	34	237	55,800	67	67	80.8
	07/06/06	5.5	5.5	NA	NA	NA	NA	71,300	68	68	83.1
	07/07/06	2.2	2.1	NA	NA	NA	NA	28,600	69	69	84.1
	07/08/06	2.1	2.1	NA	NA	NA	NA	27,700	69	69	84.1
	07/09/06	4.7	4.9	NA	NA	NA	NA	62,900	70	70	85.0
24	07/10/06	2.3	2.2	NA	NA	NA	NA	27,200	70	70	85.0
	07/11/06	5.1	5.1	NA	NA	NA	NA	67,900	71	71	85.9
	07/12/06	2.3	2.3	NA	NA	NA	NA	29,900	71	71	85.9
	07/13/06	2.1	2.1	NA	NA	NA	NA	27,500	71	71	85.9
	07/14/06	4.7	4.7	NA	NA	NA	NA	61,400	72	72	86.8
	07/15/06	3.7	3.8	14	16	35	232	48,200	72	72	86.8
	07/16/06	3.3	3.3	NA	NA	NA	NA	43,300	73	73	87.7
25	07/17/06	2.1	2.2	NA	NA	NA	NA	28,300	73	73	87.7
	07/18/06	4.0	5.0	NA	NA	NA	NA	50,000	74	74	87.7
	07/19/06	5.9	5.1	NA	NA	NA	NA	80,600	74	74	87.7
	07/20/06	2.7	2.8	NA	NA	NA	NA	35,200	74	74	88.7
	07/21/06	2.3	2.3	NA	NA	NA	NA	30,600	75	75	89.6
	07/22/06	2.1	2.1	NA	NA	NA	NA	27,700	75	75	89.6
	07/23/06	2.8	2.9	8	9	31	244	36,800	76	76	91.5
26	07/24/06	4.3	4.2	NA	NA	NA	NA	56,200	76	76	91.5
	07/25/06	2.2	2.2	NA	NA	NA	NA	29,400	77	77	93.5
	07/26/06	2.2	2.2	NA	NA	NA	NA	29,300	77	77	93.5
	07/27/06	2.2	2.2	NA	NA	NA	NA	29,200	78	78	95.4
	07/28/06	4.6	4.7	11	13	33	234	61,500	78	78	95.4
	07/29/06	2.2	2.3	NA	NA	NA	NA	28,800	78	78	95.4
	07/30/06	4.6	4.6	NA	NA	NA	NA	60,300	79	79	97.4
27	07/31/06	2.2	2.2	NA	NA	NA	NA	28,400	79	79	97.4
	08/01/06	2.1	2.2	NA	NA	NA	NA	29,000	80	80	99.3
	08/02/06	2.3	2.3	NA	NA	NA	NA	31,000	80	80	99.3
	08/03/06	4.3	4.3	NA	NA	NA	NA	56,100	81	80	100.3
	08/04/06	5.6	5.4	12	14	34	235	72,900	81	81	101.2
	08/05/06	2.9	3.1	NA	NA	NA	NA	38,300	81	81	101.2
	08/06/06	2.1	2.1	NA	NA	NA	NA	27,900	82	82	103.2
28	08/07/06	2.3	2.4	NA	NA	NA	NA	30,800	82	82	103.2
	08/08/06	2.3	2.4	6	8	30	244	31,000	83	83	105.2
	08/09/06	3.0	2.9	NA	NA	NA	NA	38,700	83	83	105.2
	08/10/06	3.6	3.6	NA	NA	NA	NA	47,200	84	84	107.1
	08/11/06	2.5	2.5	NA	NA	NA	NA	33,400	84	84	107.1
	08/12/06	2.8	2.8	NA	NA	NA	NA	37,400	84	84	107.1
	08/13/06	1.5	2.5	NA	NA	NA	NA	33,600	85	85	109.0

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

Week No.	Date	Tank A Run Time hrs	Tank B Run Time hrs						Backwash		
				Δp Across Tank A psig	Δp Across Tank B psig	Δp Across System psig	Digital Flow Rate gpm	Daily Usage gal	Tank A No.	Tank B No.	Cum. Waste-water Volume kgal
29	08/14/06	3.6	2.5	NA	NA	NA	NA	33,600	85	85	109.0
	08/15/06	2.8	2.8	NA	NA	NA	NA	37,400	86	86	111.0
	08/16/06	2.8	2.9	NA	NA	NA	NA	38,200	86	86	111.0
	08/17/06	2.3	2.4	NA	NA	NA	NA	30,700	87	87	112.9
	08/18/06	2.6	2.6	NA	NA	NA	NA	34,800	87	87	112.9
	08/19/06	2.8	2.1	NA	NA	NA	NA	36,500	88	88	114.9
08/20/06	2.7	3.4	NA	NA	NA	NA	35,600	88	88	114.9	
30	08/21/06	2.8	2.8	NA	NA	NA	NA	37,700	88	88	114.9
	08/22/06	5.4	5.3	NA	NA	NA	NA	70,600	90	89	117.8
	08/23/06	0.0	0.0	NA	NA	NA	NA	0	90	89	117.8
	08/24/06	2.6	2.7	NA	NA	NA	NA	35,000	91	90	119.7
	08/25/06	2.8	2.8	NA	NA	NA	NA	37,300	91	90	119.7
	08/26/06	3.0	3.0	NA	NA	NA	NA	38,800	92	91	120.6
	08/27/06	2.8	2.9	NA	NA	NA	NA	38,000	92	91	120.6
31	08/28/06	0.0	0.0	NA	NA	NA	NA	0	92	92	121.0
	08/29/06	2.9	2.9	NA	NA	NA	NA	38,300	93	92	121.9
	08/30/06	2.9	2.9	NA	NA	NA	NA	NA	93	93	121.9
	08/31/06	2.5	2.5	NA	NA	NA	NA	32,800	94	93	123.8
	09/01/06	2.9	2.9	NA	NA	NA	NA	38,700	94	94	124.7
	09/02/06	2.9	3.0	NA	NA	NA	NA	39,200	95	94	125.6
	09/03/06	0.0	0.0	NA	NA	NA	NA	0	95	95	126.6
32	09/04/06	2.9	2.8	NA	NA	NA	NA	38,100	95	95	126.6
	09/05/06	2.7	2.8	NA	NA	NA	NA	36,600	96	95	127.5
	09/06/06	5.6	5.6	NA	NA	NA	NA	54,800	97	96	128.5
	09/07/06	0.0	0.0	NA	NA	NA	NA	18,900	97	96	129.3
	09/08/06	2.7	2.7	NA	NA	NA	NA	35,900	97	97	130.2
	09/09/06	1.1	1.1	7	11	31	240	15,100	98	97	131.2
09/10/06	1.7	1.8	NA	NA	NA	NA	22,800	98	98	132.1	
33	09/11/06	3.2	3.2	NA	NA	NA	NA	42,600	99	98	133.0
	09/12/06	2.7	2.8	NA	NA	NA	NA	37,000	99	99	133.9
	09/13/06	2.8	2.7	NA	NA	NA	NA	35,400	99	99	133.9
	09/14/06	4.9	4.9	10	15	36	228	63,500	100	99	134.9
	09/15/06	3.2	3.2	NA	NA	NA	NA	39,600	100	100	135.8
	09/16/06	4.4	4.4	NA	NA	NA	NA	57,600	101	100	136.7
	09/17/06	2.9	2.9	12	11	35	232	37,700	101	101	137.6
34	09/18/06	0.2	0.2	NA	NA	NA	NA	2,000	102	101	138.6
	09/19/06	2.6	1.9	NA	NA	NA	NA	55,000	102	101	138.6
	09/20/06	2.8	3.5	NA	NA	NA	NA	14,800	102	102	139.5
	09/21/06	0.1	0.2	6	7	32	238	2,200	103	103	141.3
	09/22/06	2.8	2.7	NA	NA	NA	NA	35,900	103	103	141.3
	09/23/06	2.9	2.9	NA	NA	NA	NA	37,800	104	103	142.2
09/24/06	0.0	0.0	NA	NA	NA	NA	0	104	104	143.2	
35	09/25/06	4.0	4.1	NA	NA	NA	NA	51,900	105	104	144.1
	09/26/06	3.9	3.9	NA	NA	NA	NA	50,900	105	105	145.0
	09/27/06	0.2	0.2	NA	NA	NA	NA	2,900	106	105	145.9
	09/28/06	2.8	2.8	NA	NA	NA	NA	23,000	106	106	146.3
	09/29/06	2.6	2.6	NA	NA	NA	NA	22,200	106	106	146.3
	09/30/06	7.2	7.2	NA	NA	NA	NA	87,300	107	107	147.2
10/01/06	0.0	0.0	NA	NA	NA	NA	0	107	107	147.2	

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

Week No.	Date	Tank A Run Time hrs	Tank B Run Time hrs						Backwash		
				Δp Across Tank A psig	Δp Across Tank B psig	Δp Across System psig	Digital Flow Rate gpm	Daily Usage gal	Tank A No.	Tank B No.	Cum. Waste-water Volume kgal
36	10/02/06	4.5	4.5	NA	NA	NA	NA	57,900	108	107	147.6
	10/03/06	0.0	0.0	NA	NA	NA	NA	0	109	109	149.0
	10/04/06	4.4	4.4	NA	NA	NA	NA	57,400	109	109	149.0
	10/05/06	0.0	0.0	NA	NA	NA	NA	0	110	110	150.8
	10/06/06	4.3	4.4	NA	NA	NA	NA	56,500	110	110	150.8
	10/07/06	14.5	14.5	NA	NA	NA	NA	179,800	110	110	150.8
	10/08/06	0.0	0.0	NA	NA	NA	NA	0	111	111	152.6
37	10/09/06	4.4	4.5	NA	NA	NA	NA	57,300	111	111	152.6
	10/10/06	0.0	0.0	NA	NA	NA	NA	0	112	112	154.4
	10/11/06	4.4	4.3	NA	NA	NA	NA	56,700	112	112	154.4
	10/12/06	0.0	0.0	NA	NA	NA	NA	0	112	112	154.4
	10/13/06	4.1	4.2	NA	NA	NA	NA	54,400	113	113	156.2
	10/14/06	0.0	0.0	NA	NA	NA	NA	0	113	113	156.2
	10/15/06	4.7	4.6	NA	NA	NA	NA	60,300	114	114	158.0
38	10/16/06	0.0	0.0	NA	NA	NA	NA	0	114	114	158.0
	10/17/06	0.4	1.0	NA	NA	NA	NA	6,200	115	115	159.7
	10/18/06	2.4	1.9	NA	NA	NA	NA	31,900	115	115	159.7
	10/19/06	2.4	2.4	NA	NA	NA	NA	32,000	116	116	161.5
	10/20/06	0.0	0.0	NA	NA	NA	NA	0	116	116	161.5
	10/21/06	2.2	2.3	NA	NA	NA	NA	28,900	117	117	163.3
	10/22/06	2.3	2.3	NA	NA	NA	NA	30,400	117	117	163.3
39	10/23/06	2.2	2.2	NA	NA	NA	NA	28,700	117	117	163.3
	10/24/06	2.8	2.8	5	11	32	229	36,100	119	118	166.1
	10/25/06	0.0	0.0	NA	NA	NA	NA	400	119	118	166.1
	10/26/06	0.9	0.3	10	9	34	233	30,000	120	119	167.8
	10/27/06	4.1	4.3	NA	NA	NA	NA	32,900	120	119	167.8
	10/28/06	9.8	9.9	NA	NA	NA	NA	37,100	120	120	168.7
	10/29/06	1.5	1.5	NA	NA	NA	NA	19,300	121	120	169.6
40	10/30/06	2.0	2.0	NA	NA	NA	NA	25,500	121	121	170.5
	10/31/06	8.5	8.6	6	8	32	234	16,500	122	121	171.4
	11/01/06	3.1	3.2	NA	NA	NA	NA	41,400	122	121	171.4
	11/02/06	8.6	7.4	NA	NA	NA	NA	25,300	122	121	171.4
	11/03/06	7.9	9.0	NA	NA	NA	NA	30,100	123	122	173.2
	11/04/06	1.6	1.6	10	12	35	230	21,000	123	122	173.2
	11/05/06	4.7	5.0	NA	NA	NA	NA	62,600	124	123	175.1
41	11/06/06	0.0	0.0	6	9	31	231	0	124	123	175.1
	11/07/06	3.8	3.8	NA	NA	NA	NA	49,200	124	124	176.0
	11/08/06	1.9	1.0	NA	NA	NA	NA	30,000	125	125	178.8
	11/09/06	1.4	2.4	NA	NA	NA	NA	14,400	126	125	178.8
	11/10/06	2.0	2.1	6	8	32	237	26,600	126	125	178.8
	11/11/06	2.6	2.6	11	13	37	220	31,900	126	125	178.8
	11/12/06	0.0	0.0	NA	NA	NA	NA	0	126	125	178.8
42	11/13/06	2.6	3.0	NA	NA	NA	NA	26,500	126	125	178.8
	11/14/06	2.2	2.2	13	11	32	209	27,100	126	125	178.8
	11/15/06	3.5	3.6	NA	NA	NA	NA	32,700	127	126	180.6
	11/16/06	2.7	2.7	NA	NA	NA	NA	32,100	128	127	182.6
	11/17/06	2.3	2.2	NA	NA	NA	NA	28,800	128	127	182.6
	11/18/06	2.4	2.4	NA	NA	NA	NA	NA	129	128	184.4
	11/19/06	7.0	6.9	9	10	33	225	86,500	129	128	184.4

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

Week No.	Date	Tank A Run Time hrs	Tank B Run Time hrs						Backwash		
				Δp Across Tank A psig	Δp Across Tank B psig	Δp Across System psig	Digital Flow Rate gpm	Daily Usage gal	Tank A No.	Tank B No.	Cum. Waste-water Volume kgal
43	11/20/06	5.5	5.5	18	19	39	211	50,400	129	128	184.4
	11/21/06	3.2	3.2	NA	NA	NA	NA	38,200	130	129	186.2
	11/22/06	1.5	1.4	7	9	32	227	18,800	130	129	186.2
	11/23/06	1.5	1.6	NA	NA	NA	NA	19,400	131	130	188.1
	11/24/06	1.6	1.7	NA	NA	NA	NA	21,400	131	130	188.1
	11/25/06	2.9	2.9	NA	NA	NA	NA	20,100	132	131	189.9
11/26/06	4.5	4.5	NA	NA	NA	NA	30,600	132	131	189.9	
44	11/27/06	3.2	3.4	NA	NA	NA	NA	19,800	132	131	189.9
	11/28/06	5.8	5.6	NA	NA	NA	NA	29,300	133	132	191.7
	11/29/06	4.9	5.0	8	9	32	227	48,000	133	132	191.7
	11/30/06	1.0	1.1	NA	NA	NA	NA	9,900	134	132	193.6
	12/01/06	3.2	3.0	NA	NA	NA	NA	41,900	134	132	193.6
	12/02/06	2.0	1.9	6	7	31	231	24,300	135	134	195.4
12/03/06	2.4	2.4	NA	NA	NA	NA	30,300	135	134	195.4	
45	12/04/06	1.3	1.3	NA	NA	NA	NA	16,200	135	134	195.4
	12/05/06	2.9	3.0	NA	NA	NA	NA	36,400	136	135	197.2
	12/06/06	2.5	2.5	NA	NA	NA	NA	31,800	136	135	197.2
	12/07/06	0.0	0.0	NA	NA	NA	NA	0	137	136	199.1
	12/08/06	3.3	3.3	NA	NA	NA	NA	19,600	137	136	199.1
	12/09/06	5.9	5.9	NA	NA	NA	NA	31,400	138	137	200.9
12/10/06	2.9	2.9	8	9	32	229	20,100	138	137	200.9	
46	12/11/06	5.1	5.0	NA	NA	NA	NA	30,700	138	137	200.9
	12/12/06	4.8	4.5	6	7	30	226	13,700	139	138	202.8
	12/13/06	3.8	3.8	8	9	31	224	28,200	139	138	202.8
	12/14/06	6.9	6.9	NA	NA	NA	NA	34,600	140	138	203.8
	12/15/06	2.5	2.7	NA	NA	NA	NA	21,300	140	140	205.7
	12/16/06	6.4	6.3	NA	NA	NA	NA	39,900	140	140	205.7
12/17/06	12.3	12.3	7	9	32	232	25,400	142	141	208.9	
47	12/18/06	1.8	1.8	NA	NA	NA	NA	22,700	142	141	208.9
	12/19/06	6.0	5.6	9	8	32	227	26,300	142	142	210.0
	12/20/06	3.6	3.7	7	10	32	230	31,200	143	142	211.3
	12/21/06	1.9	1.9	NA	NA	NA	NA	24,800	143	143	212.6
	12/22/06	5.9	5.9	NA	NA	NA	NA	26,300	144	143	214.0
	12/23/06	7.0	6.7	NA	NA	NA	NA	33,800	144	144	215.2
12/24/06	3.9	3.9	NA	NA	NA	NA	15,800	144	144	215.2	
48	12/25/06	4.2	4.6	NA	NA	NA	NA	32,200	145	144	216.6
	12/26/06	2.0	2.1	NA	NA	NA	NA	27,300	145	145	218.0
	12/27/06	13.5	6.5	6	9	31	223	26,600	146	145	219.4
	12/28/06	0.5	7.2	NA	NA	NA	NA	35,500	146	146	220.8
	12/29/06	4.2	4.7	6	9	31	222	24,200	147	146	222.3
	12/30/06	5.0	4.9	8	8	32	229	36,700	147	147	222.7
12/31/06	3.4	3.5	NA	NA	NA	NA	25,700	147	147	222.7	
49	01/01/07	6.2	6.2	8	11	33	224	31,700	148	147	223.1
	01/02/07	1.9	2.0	NA	NA	NA	NA	24,700	148	148	223.5
	01/03/07	5.2	5.5	NA	NA	NA	NA	21,300	149	148	225.2
	01/04/07	5.1	5.0	NA	NA	NA	NA	25,300	149	148	225.2
	01/05/07	2.9	2.8	9	8	32	228	24,600	149	149	226.5
	01/06/07	4.7	4.6	13	15	32	192	40,100	150	149	227.7
01/07/07	2.6	2.6	NA	NA	NA	NA	33,600	150	150	228.9	

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

Week No.	Date	Tank A Run Time hrs	Tank B Run Time hrs						Backwash		
				Δp Across Tank A psig	Δp Across Tank B psig	Δp Across System psig	Digital Flow Rate gpm	Daily Usage gal	Tank A No.	Tank B No.	Cum. Waste-water Volume kgal
50	01/08/07	1.6	1.6	NA	NA	NA	NA	20,600	151	150	230.1
	01/09/07	4.2	4.2	6	6	30	228	26,800	151	151	231.1
	01/10/07	3.0	2.9	5	8	30	227	32,700	152	151	232.1
	01/11/07	4.9	5.0	NA	NA	NA	NA	0	152	151	232.1
	01/12/07	2.0	2.1	NA	NA	NA	NA	55,200	152	152	233.2
	01/13/07	7.4	7.4	NA	NA	NA	NA	38,300	153	152	234.2
	01/14/07	5.9	6.0	7	9	32	229	29,200	154	153	236.1
51	01/15/07	2.5	2.4	NA	NA	NA	NA	30,600	154	153	236.1
	01/16/07	1.7	1.3	NA	NA	NA	NA	20,400	155	155	239.2
	01/17/07	3.6	3.7	NA	NA	NA	NA	46,500	155	155	239.2
	01/18/07	1.7	1.7	NA	NA	NA	NA	22,100	156	156	241.2
	01/19/07	1.7	1.7	NA	NA	NA	NA	21,700	156	156	241.2
	01/20/07	3.7	3.7	NA	NA	NA	NA	46,600	156	156	241.2
	01/21/07	1.9	2.0	NA	NA	NA	NA	25,200	157	157	243.2
52	01/22/07	1.9	1.9	NA	NA	NA	NA	24,600	157	157	243.2
	01/23/07	2.6	2.7	7	8	32	230	35,300	158	158	245.1
	01/24/07	0.1	0.1	NA	NA	NA	NA	1,000	158	158	245.1
	01/25/07	2.5	2.4	NA	NA	NA	NA	31,700	159	159	247.7
	01/26/07	1.4	1.4	NA	NA	NA	NA	17,900	159	159	247.7
	01/27/07	2.7	2.7	NA	NA	NA	NA	34,700	160	160	249.7
	01/28/07	1.5	1.5	NA	NA	NA	NA	19,400	160	160	249.7
53	01/29/07	2.6	2.6	NA	NA	NA	NA	32,300	161	160	250.7
	01/30/07	1.5	1.4	NA	NA	NA	NA	18,500	161	161	251.7
	01/31/07	2.3	2.3	5	6	30	229	29,700	162	162	252.7
	02/01/07	0.5	0.6	NA	NA	NA	NA	7,700	162	162	252.7
	02/02/07	5.1	4.9	6	8	31	231	30,300	163	163	254.1
	02/03/07	4.8	4.8	NA	NA	NA	NA	33,100	163	163	254.1
	02/04/07	4.5	4.5	11	11	34	223	27,200	163	163	254.1
54	02/05/07	5.1	4.9	NA	NA	NA	NA	36,800	164	164	255.6
	02/06/07	7.3	7.2	9	10	33	227	74,500	165	165	258.0
	02/07/07	3.5	3.6	12	13	35	220	43,900	165	165	258.0
	02/08/07	0.3	0.4	NA	NA	NA	NA	4,200	165	165	258.0
	02/09/07	1.6	1.7	8	9	32	229	21,400	166	166	260.2
	02/10/07	0.9	0.8	NA	NA	NA	NA	10,900	166	166	260.2
	02/11/07	2.9	2.8	NA	NA	NA	NA	35,700	167	167	262.0
55	02/12/07	3.8	3.9	NA	NA	NA	NA	32,100	167	167	262.0
	02/13/07	2.2	5.0	NA	NA	NA	NA	23,000	168	168	263.5
	02/14/07	10.8	8.0	NA	NA	NA	NA	11,300	168	168	263.5
	02/15/07	3.0	3.0	NA	NA	NA	NA	42,400	169	169	265.2
	02/16/07	2.7	2.7	NA	NA	NA	NA	30,000	169	169	265.2
	02/17/07	3.2	3.2	NA	NA	NA	NA	39,600	170	170	267.1
	02/18/07	0.0	0.0	7	8	30	227	0	170	170	267.1
56	02/19/07	3.1	3.1	8	8	31	225	40,300	170	170	267.1
	02/20/07	2.5	2.4	NA	NA	NA	NA	31,900	171	171	268.8
	02/21/07	2.4	2.4	NA	NA	NA	NA	30,500	172	172	270.5
	02/22/07	2.9	2.9	NA	NA	NA	NA	37,200	172	172	270.5
	02/23/07	0.0	0.0	NA	NA	NA	NA	0	173	173	272.0
	02/24/07	2.6	2.6	NA	NA	NA	NA	33,700	173	173	272.0
	02/25/07	2.8	2.8	NA	NA	NA	NA	35,100	174	174	273.7

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

Week No.	Date	Tank A Run Time hrs	Tank B Run Time hrs						Backwash		
				Δp Across Tank A psig	Δp Across Tank B psig	Δp Across System psig	Digital Flow Rate gpm	Daily Usage gal	Tank A No.	Tank B No.	Cum. Waste-water Volume kgal
57	02/26/07	3.2	3.3	NA	NA	NA	NA	41,700	174	174	273.7
	02/27/07	2.9	2.9	NA	NA	NA	NA	36,700	174	174	273.7
	02/28/07	0.0	0.0	NA	NA	NA	NA	0	175	175	275.5
	03/01/07	0.9	0.8	6	8	31	229	11,200	175	175	275.5
	03/02/07	2.6	2.7	NA	NA	NA	NA	33,100	176	176	277.1
	03/03/07	3.6	3.6	NA	NA	NA	NA	45,800	176	176	277.1
03/04/07	0.8	0.8	6	8	31	229	10,700	177	177	278.5	
58	03/05/07	2.6	2.7	NA	NA	NA	NA	33,400	177	177	278.5
	03/06/07	2.8	2.8	NA	NA	NA	NA	34,000	178	178	280.2
	03/07/07	4.5	4.6	NA	NA	NA	NA	19,900	178	178	280.2
	03/08/07	1.6	1.6	9	10	33	226	20,700	178	178	280.2
	03/09/07	1.6	1.6	NA	NA	NA	NA	19,300	179	179	281.8
	03/10/07	3.3	3.3	NA	NA	NA	NA	42,600	179	179	281.8
	03/11/07	2.5	3.0	NA	NA	NA	NA	39,000	180	180	283.3
59	03/12/07	0.6	0.0	NA	NA	NA	NA	0	180	180	283.3
	03/13/07	3.1	3.1	9	10	33	224	39,100	181	181	285.0
	03/14/07	9.9	9.9	NA	NA	NA	NA	200	181	181	285.0
	03/15/07	5.4	5.3	NA	NA	NA	NA	NA	182	182	286.4
	03/16/07	3.2	3.3	NA	NA	NA	NA	40,600	182	182	286.4
	03/17/07	0.0	0.0	NA	NA	NA	NA	0	183	183	288.2
	03/18/07	9.1	9.0	NA	NA	NA	NA	54,800	183	183	288.2
60	03/19/07	7.2	7.2	NA	NA	NA	NA	100	184	184	288.8
	03/20/07	7.9	7.9	NA	NA	NA	NA	41,100	185	185	291.2
	03/21/07	2.7	2.6	NA	NA	NA	NA	33,100	185	185	291.2
	03/22/07	0.0	0.0	NA	NA	NA	NA	0	186	186	292.9
	03/23/07	2.9	3.0	NA	NA	NA	NA	38,100	186	186	292.9
	03/24/07	3.3	3.3	NA	NA	NA	NA	41,000	187	187	294.5
03/25/07	2.9	2.8	NA	NA	NA	NA	36,700	187	187	294.5	
61	03/26/07	0.0	0.0	5	7	30	231	0	188	188	296.0
	03/27/07	14.4	14.2	NA	NA	NA	NA	46,800	189	189	297.5
	03/28/07	1.5	1.6	8	9	32	226	0	189	189	297.5
	03/29/07	1.9	1.8	NA	NA	NA	NA	42,200	190	190	299.2
	03/30/07	1.8	1.7	NA	NA	NA	NA	22,300	190	190	299.2
	03/31/07	1.8	1.8	NA	NA	NA	NA	22,800	190	190	299.2
	04/01/07	2.4	2.5	NA	NA	NA	NA	31,500	191	191	300.8
62	04/02/07	2.7	2.7	NA	NA	NA	NA	33,400	191	191	300.8
	04/03/07	0.6	0.6	NA	NA	NA	NA	8,000	192	192	302.5
	04/04/07	2.4	2.4	NA	NA	NA	NA	32,100	192	192	302.5
	04/05/07	2.6	2.7	NA	NA	NA	NA	34,200	193	193	304.1
	04/06/07	2.5	2.5	NA	NA	NA	NA	31,100	193	193	304.1
	04/07/07	4.4	4.4	NA	NA	NA	NA	54,100	194	194	306.2
04/08/07	2.1	2.2	NA	NA	NA	NA	27,900	194	194	306.2	
63	04/09/07	2.5	2.5	NA	NA	NA	NA	31,200	194	194	306.1
	04/10/07	1.1	1.1	6	8	31	230	14,400	195	195	308.4
	04/11/07	8.8	8.8	6	7	29	222	100	195	195	308.4
	04/12/07	3.8	4.2	NA	NA	NA	NA	52,300	196	196	310.8
	04/13/07	0.0	0.0	NA	NA	NA	NA	0	196	196	310.8
	04/14/07	12.2	12.4	8	10	32	227	152,900	197	197	313.1
	04/15/07	5.1	5.0	NA	NA	NA	NA	62,600	197	197	313.1

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

Week No.	Date	Tank A Run Time hrs	Tank B Run Time hrs						Backwash		
				Δp Across Tank A psig	Δp Across Tank B psig	Δp Across System psig	Digital Flow Rate gpm	Daily Usage gal	Tank A No.	Tank B No.	Cum. Waste-water Volume kgal
64	04/16/07	2.1	2.0	NA	NA	NA	NA	24,900	197	197	313.1
	04/17/07	4.7	4.8	NA	NA	NA	NA	35,500	198	198	315.6
	04/18/07	2.7	2.7	NA	NA	NA	NA	25,100	198	198	315.6
	04/19/07	2.5	2.6	NA	NA	NA	NA	32,200	199	199	318.1
	04/20/07	1.2	1.1	NA	NA	NA	NA	5,900	199	199	318.1
	04/21/07	6.7	6.6	NA	NA	NA	NA	51,400	200	200	320.4
	04/22/07	9.3	9.1	NA	NA	NA	NA	33,600	201	201	322.8
65	04/23/07	2.0	1.9	NA	NA	NA	NA	25,100	202	202	324.8
	04/24/07	5.7	5.8	NA	NA	NA	NA	14,700	202	202	324.8
	04/25/07	3.2	3.0	NA	NA	NA	NA	40,400	203	203	327.1
	04/26/07	9.6	10.0	NA	NA	NA	NA	18,700	204	204	328.1
	04/27/07	3.0	2.8	NA	NA	NA	NA	24,000	204	204	329.1
	04/28/07	3.6	3.6	7	10	32	227	28,500	205	204	330.1
	04/29/07	4.0	3.9	NA	NA	NA	NA	49,300	205	205	331.0

NA = data not available.

APPENDIX B
ANALYTICAL DATA

Table B-1: Analytical Data

Sampling Date		01/31/06 ^(a)			02/14/06 ^(d)				02/21/06				02/28/06			03/06/06			
Sampling Location	Parameter	IN	AC	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TB	IN	AC	TA	TB
Unit																			
Alkalinity (as CaCO ₃)	mg/L	291	291	291	329	283	283	283	290	298	294	290	300	296	296	286	290	290	286
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	0.2	<0.05	<0.05	-	-	-	-	-	-	-	-	0.1	<0.05	<0.05	-	-	-	-
Fluoride	mg/L	0.1	0.1	0.1	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	-	-	-	-
Sulfate	mg/L	376	376	372	-	-	-	-	-	-	-	-	425	424	421	-	-	-	-
Sulfide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-
Total P (as P)	µg/L	10.5	13.7	<10	<10	<10	<10	<10	33.0	30.3	<10	<10	31.4	34.1	<10	14.0	20.3	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	30.0	30.3	29.7	30.6	31.1	31.1	30.1	30.9	31.1	30.9	31.5	29.7	31.1	30.2	28.5	29.6	29.1	28.5
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	19.0	1.2	0.4	13.0	20.0	18.0	21.0	16.0	1.5	0.6	0.7	28.0	1.6	1.1	16.0	3.6	2.2	1.2
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOC	mg/L	1.8	1.6	2.0 ^(c)	-	-	-	-	-	-	-	-	1.6	1.5	1.5	-	-	-	-
TDS	mg/L	886	914	920	-	-	-	-	-	-	-	-	932	954	1010	-	-	-	-
pH	S.U.	7.7	7.3	7.3	7.6	7.0	-	7.3	7.6	7.7	-	7.4	7.5	7.4	7.2	7.6	7.3	7.3	7.3
Temperature	°C	12.0	10.9	17.1	13.0	13.0	-	13.0	12.6	12.8	-	12.6	12.5	13.0	11.4	13.3	11.9	12.2	13.2
DO	mg/L	2.1	1.2	0.8	2.2	2.8	-	0.8	9.8	8.9	-	3.1	10.0	3.9	3.7	10.9	3.6	7.5	3.6
ORP	mV	-13	623	648	-13	461	-	650	331	466	-	587	410	678	677	433	623	665	670
Free Chlorine	mg/L	-	0.6	0.0 ^(b)	-	1.0	-	0.0	-	0.0	-	0.0	-	0.9	0.9	-	0.4	0.4	0.5
Total Chlorine	mg/L	-	2.1	0.0 ^(b)	-	1.2	-	0.0	-	0.0	-	0.1	-	1.2	1.1	-	0.7	0.5	0.6
Total Hardness (as CaCO ₃)	mg/L	596	619	635	-	-	-	-	-	-	-	-	680	680	661	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	386	383	389	-	-	-	-	-	-	-	-	393	393	379	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	210	236	246	-	-	-	-	-	-	-	-	287	286	282	-	-	-	-
As (total)	µg/L	34.2	36.9	7.1	32.8	36.0	33.5	30.8	42.5	41.8	6.2	6.1	40.8	44.2	4.4	37.3	40.2	9.2	9.8
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	34.1	4.4	3.2	-	-	-	-	-	-	-	-	36.3	4.0	3.7	-	-	-	-
As (particulate)	µg/L	0.1	32.5	3.8	-	-	-	-	-	-	-	-	4.5	40.2	0.7	-	-	-	-
As (III)	µg/L	35.6	0.9	2.0	-	-	-	-	-	-	-	-	17.9	1.0	1.1	-	-	-	-
As (V)	µg/L	<0.1	3.5	1.2	-	-	-	-	-	-	-	-	18.4	3.0	2.7	-	-	-	-
Fe (total)	µg/L	1,470	1,224	106	1,431	1,221	1,225	1,128	1,279	1,264	72	70	1,288	1,222	<25	1,422	1,637	176	210
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	1,222	<25	<25	-	-	-	-	-	-	-	-	1,115	<25	<25	-	-	-	-
Mn (total)	µg/L	343	328	169	344	255	319	297	329	316	209	192	304	293	111	449	449	126	135
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	332	151	142	-	-	-	-	-	-	-	-	305	105	99.0	-	-	-	-

(a) Sample taken from TB location because TT sample tap was under vacuum and did not yield water. (b) Slight tint present, but no reading on meter.

(c) Result is an estimated concentration. (d) No treatment due to chlorine fitting leak on 02/12/06.

Table B-1. Analytical Data (Continued)

Sampling Date		03/14/06 ^(a)				03/21/06				03/28/06			04/04/06				04/11/06				
Sampling Location	Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	IN	AC	TA	TB	IN	AC	TA	TB
Alkalinity (as CaCO ₃)		mg/L	294	294	289	294	290	290	294	290	289	289	289	288	292	296	292	316	316	308	321
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)		mg/L	-	-	-	-	-	-	-	-	0.3	0.1	0.1	-	-	-	-	-	-	-	-
Fluoride		mg/L	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-
Sulfate		mg/L	-	-	-	-	-	-	-	-	419	415	420	-	-	-	-	-	-	-	-
Sulfide		mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)		mg/L	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-
Total P (as P)		µg/L	22.9	21.6	<10	<10	16.7	19.0	<10	<10	32.2	33.6	<10	26.6	<10	<10	<10	20.5	18.1	<10	<10
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)		mg/L	29.4	27.4	27.1	26.9	30.5	29.5	29.2	30.0	30.3	29.4	30.4	29.7	30.2	29.4	29.8	29.4	28.5	28.7	29.1
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity		NTU	19.0	1.7	0.7	0.5	16.0	2.0	0.4	0.8	22.0	1.8	1.0	44.0	2.0	1.1	1.3	16.0	1.9	1.4	0.9
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOC		mg/L	-	-	-	-	-	-	-	-	1.5	1.5	1.6	-	-	-	-	-	-	-	-
TDS		mg/L	-	-	-	-	-	-	-	-	966	942	988	-	-	-	-	-	-	-	-
pH		S.U.	7.4	7.3	7.2	7.1	7.6	7.3	7.4	7.2	7.5	7.5	7.2	7.3	7.3	7.3	7.4	7.3	7.3	7.4	7.3
Temperature		°C	13.2	12.6	12.9	12.0	14.2	13.1	13.7	14.6	12.8	13.8	12.6	14.1	14.3	13.5	13.4	13.6	15.4	14.7	13.0
DO		mg/L	8.8	3.2	4.4	2.6	9.9	2.7	5.2	3.4	10.6	10.3	5.6	6.6	4.7	3.8	3.1	5.6	3.8	5.8	3.4
ORP		mV	38.1	430	566	578	462	442	535	619	287	529	496	476	480	543	596	433	465	567	529
Free Chlorine		mg/L	-	0.1	0.0	0.0	-	0.0	0.0	0.0	-	0.2	0.0	-	0.0	0.0	0.0	-	0.0	0.0	0.0
Total Chlorine		mg/L	-	0.6	0.2	0.2	-	0.5	0.4	0.3	-	0.8	0.9	-	0.3	0.5	0.4	-	0.5	0.3	0.3
Total Hardness (as CaCO ₃)		mg/L	-	-	-	-	-	-	-	-	686	741	666	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)		mg/L	-	-	-	-	-	-	-	-	391	435	373	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)		mg/L	-	-	-	-	-	-	-	-	295	306	293	-	-	-	-	-	-	-	-
As (total)		µg/L	45.1	45.5	4.7	5.4	37.9	42.8	4.9	5.8	40.0	39.8	5.4	42.5	7.5	8.9	9.3	42.5	43.4	8.2	7.1
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)		µg/L	-	-	-	-	-	-	-	-	36.9	4.1	3.2	-	-	-	-	-	-	-	-
As (particulate)		µg/L	-	-	-	-	-	-	-	-	3.1	35.7	2.2	-	-	-	-	-	-	-	-
As (III)		µg/L	-	-	-	-	-	-	-	-	6.1	0.4	0.4	-	-	-	-	-	-	-	-
As (V)		µg/L	-	-	-	-	-	-	-	-	30.8	3.7	2.8	-	-	-	-	-	-	-	-
Fe (total)		µg/L	1,827	1,410	<25	31	1,566	1,748	<25	48	1,936	1,638	64	1,386	119	163	175	1,369	1,334	146	112
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)		µg/L	-	-	-	-	-	-	-	-	1,172	<25	<25	-	-	-	-	-	-	-	-
Mn (total)		µg/L	349	347	129	141	438	451	158	219	313	309	198	267	186	174	175	323	320	188	183
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)		µg/L	-	-	-	-	-	-	-	-	308	193	184	-	-	-	-	-	-	-	-

(a) Backwash control malfunction allowed system to operate without backwashing every 48 hours of standby time from 03/14/06 to 04/11/06. Manual backwash performed until programming changed.

Table B-1. Analytical Data (Continued)

Sampling Date		04/18/06				04/25/06			05/02/06				05/09/06				05/17/06			
Sampling Location	Parameter	IN	AC	TA	TB	IN	AC	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
	Unit																			
Alkalinity (as CaCO ₃)	mg/L	316 321	312 312	312 312	312 312	313 -	317 -	317 -	300 -	292 -	292 -	296 -	302 -	297 -	297 -	302 -	298 -	298 -	294 -	302 -
Ammonia (as N)	mg/L	-	-	-	-	<0.05	0.1	<0.05	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	411	410	514	-	-	-	-	-	-	-	-	-	-	-	-
Sulfide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	36.2 34.8	36.1 37.7	<10 <10	<10 <10	30.9 -	31.1 -	<10 -	-	-	-	-	14.8 -	16.0 -	<10 -	<10 -	14.0 -	14.5 -	<10 -	<10 -
Silica (as SiO ₂)	mg/L	30.5 28.7	29.4 28.7	28.4 28.8	28.9 29.3	29.1 -	30.0 -	29.1 -	31.3 -	30.5 -	30.6 -	31.5 -	31.4 -	30.9 -	30.4 -	31.1 -	31.6 -	31.1 -	30.8 -	31.0 -
Turbidity	NTU	18.0 19.0	1.5 1.6	0.5 0.4	0.4 0.9	15.0 -	1.3 -	0.4 -	17.0 -	1.7 -	0.5 -	0.4 -	16.0 -	2.3 -	1.1 -	0.6 -	14.0 -	1.7 -	0.4 -	0.6 -
TOC	mg/L	-	-	-	-	1.5	1.5	1.5	-	-	-	-	-	-	-	-	-	-	-	-
TDS	mg/L	-	-	-	-	944	954	948	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	7.3	7.4	7.3	7.4	7.2	7.1	7.3	7.2	7.4	7.3	7.3	7.2	7.0	7.1	7.1	7.2	7.3	7.3	7.2
Temperature	°C	14.9	15.5	14.1	15.2	16.0	14.9	15.5	13.8	13.7	14.0	13.9	17.4	13.4	16.4	14.0	14.4	12.4	11.7	11.3
DO	mg/L	2.3	2.2	2.4	2.1	4.8	2.9	3.1	3.4	2.6	3.6	3.1	6.4	3.6	5.5	3.8	2.7	3.3	2.5	4.0
ORP	mV	304	385	566	623	437	534	596	276	472	465	510	60.4	508	497	587	11.9	436	469	474
Free Chlorine	mg/L	-	0.0	0.0	0.2	-	0.0	0.1	-	0.1	0.0	0.0	-	0.0	0.0	0.0	-	0.0	0.0	0.0
Total Chlorine	mg/L	-	0.7	0.1	0.3	-	0.1	0.2	-	0.6	0.5	0.2	-	0.5	0.3	0.3	-	0.4	0.4	0.5
Total Hardness (as CaCO ₃)	mg/L	-	-	-	-	680	684	682	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	-	-	-	-	409	414	412	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	-	-	-	-	271	270	270	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L	42.0 41.6	42.4 44.2	4.6 4.6	4.6 4.6	36.9 -	39.6 -	3.5 -	36.7 -	37.6 -	5.5 -	4.3 -	35.1 -	37.1 -	5.2 -	6.5 -	36.7 -	37.8 -	4.9 -	5.9 -
As (soluble)	µg/L	-	-	-	-	34.6	4.4	2.3	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	2.3	35.2	1.2	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	9.9	0.6	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	24.7	3.8	2.2	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	1,451 1,401	1,430 1,389	27 <25	<25 <25	1,417 -	1,516 -	31 -	1,281 -	1,297 -	70 -	<25 -	1,257 -	1,362 -	77 -	126 -	1,413 -	1,447 -	52 -	92 -
Fe (soluble)	µg/L	-	-	-	-	914	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	302 298	305 296	165 158	158 156	346 -	346 -	171 -	259 -	259 -	151 -	142 -	282 -	289 -	165 -	171 -	378 -	369 -	244 -	231 -
Mn (soluble)	µg/L	-	-	-	-	352	148	150	-	-	-	-	-	-	-	-	-	-	-	-

Table B-1. Analytical Data (Continued)

Sampling Date		05/23/06			05/31/06 ^(a)				06/06/06				06/13/06				06/20/06			
Sampling Location	Parameter	Unit	IN	AC	TA	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA
Alkalinity (as CaCO ₃)		mg/L	301	298	290	299	295	291	295	301	297	288	297	302	289	298	298	293	297	301
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)		mg/L	0.2	0.1	0.1	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.1	0.1
Fluoride		mg/L	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	0.1
Sulfate		mg/L	835	839	845	-	-	-	-	-	-	-	-	-	-	-	-	421	419	420
Sulfide		mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)		mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05
Total P (as P)		µg/L	<10	<10	<10	50	45.8	18.5	20.2	42.5	37.1	10.0	10.8	36.1	39.6	<10	<10	34.2	35.2	<10
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)		mg/L	30.1	30.8	30.0	29.2	28.9	29.3	29.1	30.8	31.3	30.7	30.3	31.9	32.3	31.3	31.9	32.2	32.5	31.9
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity		NTU	18.0	1.6	1.0	19.0	1.7	0.6	0.7	19.0	1.2	0.7	0.5	19.0	2.1	0.4	0.4	21.0	1.4	0.7
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOC		mg/L	1.6	1.6	1.6	-	-	-	-	-	-	-	-	-	-	-	-	NA ^(b)	NA ^(b)	NA ^(b)
TDS		mg/L	990	1020	978	-	-	-	-	-	-	-	-	-	-	-	-	1030	968	1000
pH		S.U.	7.2	7.4	7.2	7.4	7.4	7.2	7.2	7.3	7.5	7.3	7.3	7.4	7.4	7.2	7.2	7.4	7.5	7.3
Temperature		°C	12.0	14.5	15.3	14.2	13.7	14.5	14.4	14.5	17.8	13.3	14.8	11.5	13.5	13.7	12.9	11.0	11.3	10.8
DO		mg/L	4.0	4.4	3.2	5.3	2.8	3.8	3.4	2.8	2.4	2.8	2.9	2.8	2.4	2.2	2.6	3.2	2.9	2.8
ORP		mV	56.0	450	479	0.7	437	455	468	4.5	405	452	460	4.5	406	451	463	21.0	448	464
Free Chlorine		mg/L	-	0.0	0.0	-	0.3	0.0	0.0	-	0.0	0.4	0.0	-	0.0	0.0	0.0	-	0.5	0.0
Total Chlorine		mg/L	-	0.8	0.5	-	0.6	0.2	0.7	-	0.8	0.8	0.9	-	0.2	0.3	0.5	-	0.5	0.5
Total Hardness (as CaCO ₃)		mg/L	584	536	603	-	-	-	-	-	-	-	-	-	-	-	-	741	719	743
Ca Hardness (as CaCO ₃)		mg/L	354	324	345	-	-	-	-	-	-	-	-	-	-	-	-	414	396	413
Mg Hardness (as CaCO ₃)		mg/L	230	212	258	-	-	-	-	-	-	-	-	-	-	-	-	327	323	329
As (total)		µg/L	38.6	40.6	7.1	33.4	29.9	3.9	6.2	44.3	40.3	9.7	9.3	46.4	49.0	5.6	6.4	39.8	44.2	6.4
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)		µg/L	40.3	5.4	3.2	-	-	-	-	-	-	-	-	-	-	-	-	38.2	3.9	3.0
As (particulate)		µg/L	<0.1	35.2	3.9	-	-	-	-	-	-	-	-	-	-	-	-	1.6	40.3	3.4
As (III)		µg/L	6.9	0.2	0.3	-	-	-	-	-	-	-	-	-	-	-	-	4.6	0.4	0.3
As (V)		µg/L	33.4	5.1	3.0	-	-	-	-	-	-	-	-	-	-	-	-	33.6	3.5	2.7
Fe (total)		µg/L	1,203	1,173	67	1,307	1,142	28	134	1,465	1,216	235	235	1,405	1,558	36	65	1,370	1,378	116
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)		µg/L	1,218	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-	1,283	<25	<25
Mn (total)		µg/L	389	415	272	282	252	243	224	390	354	223	223	431	430	365	343	442	452	305
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)		µg/L	413	228	258	-	-	-	-	-	-	-	-	-	-	-	-	457	297	305

(a) Water quality parameters measured on 05/30/06. (b) Sample failed laboratory QA/QC check.

Table B-1. Analytical Data (Continued)

Sampling Date		06/28/06				07/10/06				07/11/06 ^(a)				07/18/06			07/26/06				
Sampling Location	Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TB	IN	AC	TA	TB
Alkalinity (as CaCO ₃)		mg/L	293	297	293	293	303	299	307	303	302	297	302	297	284	301	288	296	292	292	300
			-	-	-	-	-	-	-	-	297	297	297	302	-	-	-	-	-	-	-
Ammonia (as N)		mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.1	0.1	-	-	-	-
Fluoride		mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	-	-	-	-
Sulfate		mg/L	-	-	-	-	-	-	-	-	-	-	-	-	434	371	440	-	-	-	-
Sulfide		mg/L	-	-	-	-	<5	<5	<5	<5	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)		mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-
Total P (as P)		µg/L	35.2	33.6	<10	<10	40.5	44.0	<10	<10	37.8	37.5	10.3	<10	27.4	30.5	<10	35.3	35.6	<10	<10
			-	-	-	-	-	-	-	-	40.7	42.4	<10	<10	-	-	-	-	-	-	-
Silica (as SiO ₂)		mg/L	32.5	31.7	31.1	30.8	30.3	30.2	29.2	29.5	29.5	29.8	29.5	29.6	29.3	29.3	29.2	30.1	30.5	29.1	29.9
			-	-	-	-	-	-	-	-	29.8	30.3	29.5	29.4	-	-	-	-	-	-	-
Turbidity		NTU	18.0	1.3	0.5	0.7	16.0	3.5	0.8	1.6	19.0	2.3	2.5	0.2	16.0	2.2	0.7	16.0	0.9	0.3	0.9
			-	-	-	-	-	-	-	-	19.0	1.6	0.5	0.4	-	-	-	-	-	-	-
TOC		mg/L	-	-	-	-	-	-	-	-	-	-	-	-	1.8	1.8	1.8	-	-	-	-
TDS		mg/L	-	-	-	-	-	-	-	-	-	-	-	-	994	992	1030	-	-	-	-
pH		S.U.	7.5	7.5	7.3	7.4	7.5	7.4	7.3	7.2	7.5	7.4	7.3	7.2	7.4	7.6	7.3	7.7	7.5	7.3	7.3
Temperature		°C	12.1	13.2	14.8	15.0	12.1	12.0	11.9	11.5	12.1	12.0	11.9	11.5	11.3	11.5	11.5	12.4	11.5	11.5	11.2
DO		mg/L	3.1	3.1	2.5	10.2	3.6	4.3	5.9	3.7	3.6	4.3	5.9	3.7	3.5	3.1	4.0	2.3	2.7	2.8	9.8 ^(b)
ORP		mV	23.0	530	442	451	71.6	440	455	466	71.6	440	455	466	25	445	83.9	67.2	445	455	464
Free Chlorine		mg/L	-	0.2	0.0	0.0	-	0.0	0.0	0.3	-	0.0	0.0	0.3	-	0.4	0.4	-	0.4	0.3	0.3
Total Chlorine		mg/L	-	0.7	0.3	0.7	-	0.7	0.5	0.9	-	0.7	0.5	0.9	-	0.8	0.9	-	0.9	0.9	0.9
Total Hardness (as CaCO ₃)		mg/L	-	-	-	-	-	-	-	-	-	-	-	-	636	656	691	-	-	-	-
Ca Hardness (as CaCO ₃)		mg/L	-	-	-	-	-	-	-	-	-	-	-	-	385	400	426	-	-	-	-
Mg Hardness (as CaCO ₃)		mg/L	-	-	-	-	-	-	-	-	-	-	-	-	252	256	266	-	-	-	-
As (total)		µg/L	39.3	40.1	4.5	5.6	38.1	44.1	5.3	5.8	37.9	35.1	6.0	6.2	38.8	38.1	6.8	49.8	51.3	10.6	9.9
			-	-	-	-	-	-	-	-	38.9	38.5	5.1	5.8	-	-	-	-	-	-	-
As (soluble)		µg/L	-	-	-	-	-	-	-	-	-	-	-	-	37.6	3.8	3.1	-	-	-	-
As (particulate)		µg/L	-	-	-	-	-	-	-	-	-	-	-	-	1.3	34.3	3.7	-	-	-	-
As (III)		µg/L	-	-	-	-	-	-	-	-	-	-	-	-	11.1	0.4	0.3	-	-	-	-
As (V)		µg/L	-	-	-	-	-	-	-	-	-	-	-	-	26.5	3.4	2.8	-	-	-	-
Fe (total)		µg/L	1,272	1,255	35	74	1,354	1,666	78	94	1,309	1,226	81	88	1,265	1,372	113	1,375	1,385	175	158
			-	-	-	-	-	-	-	-	1,381	1,419	62	97	-	-	-	-	-	-	-
Fe (soluble)		µg/L	-	-	-	-	-	-	-	-	-	-	-	-	1,020	<25	<25	-	-	-	-
Mn (total)		µg/L	342	344	249	248	358	370	261	243	348	325	294	260	431	424	314	338	342	216	212
			-	-	-	-	-	-	-	-	364	368	285	259	-	-	-	-	-	-	-
Mn (soluble)		µg/L	-	-	-	-	-	-	-	-	-	-	-	-	432	294	300	-	-	-	-

(a) Water quality parameters measured on 07/10/06. (b) DO levels high on TB due to compressed air line leak.

Table B-1. Analytical Data (Continued)

Sampling Date		08/01/06				08/09/06				08/16/06				08/21/06			08/30/06			
Sampling Location	Parameter	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	IN	AC	TA	TB
Alkalinity (as CaCO ₃)	mg/L	298	294	294	298	298	-	290	298	290	257	282	278	296	304	315	315	320	328	315
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.1	0.1	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	421	427	416	-	-	-	-
Sulfide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-
Total P (as P)	µg/L	12.9	20.2	<10	<10	23.6	17.7	<10	<10	27.6	29.8	<10	<10	30.5	34.6	<10	40.5	43.7	<10	13.7
Silica (as SiO ₂)	mg/L	34.4	34.4	34.9	34.4	28.4	-	27.9	27.8	30.2	29.6	29.6	29.7	29.1	29.0	28.8	27.9	28.6	27.7	27.0
Turbidity	NTU	15.0	2.2	0.3	0.4	59.0	-	0.4	0.4	14.0	1.6	0.6	1.1	19.0	1.9	0.6	13.0	0.8	0.3	0.4
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	1.7	1.7	1.8	-	-	-	-
TDS	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	974	968	1000	-	-	-	-
pH	S.U.	7.5	7.5	7.4	7.4	7.6	7.4	7.3	7.4	7.7	7.5	7.3	7.3	7.4	7.5	7.5	7.7	7.5	7.3	7.1
Temperature	°C	12.8	11.3	11.3	11.0	14.5	12.6	11.9	11.5	11.1	10.2	10.5	10.2	11.7	11.7	11.0	11.6	10.7	11.0	10.9
DO	mg/L	4.0	4.0	5.2	10.1 ^(a)	3.0	3.4	3.1	9.7 ^(a)	3.7	3.9	6.8	10.6 ^(a)	2.7	2.5	2.8	5.0	3.4	6.6	4.5
ORP	mV	146	449	458	461	64.4	443	445	455	68.1	445	451	456	23.0	440	444	30.0	452	445	456
Free Chlorine	mg/L	-	0.0	0.3	0.0	-	0.4	0.0	0.3	-	0.5	0.0	0.4	-	0.5	0.2	-	0.4	0.0	0.2
Total Chlorine	mg/L	-	0.6	0.6	0.7	-	0.7	0.7	0.8	-	0.7	0.7	0.9	-	0.6	0.5	-	0.6	0.6	0.7
Total Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	693	656	645	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	405	374	362	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	289	282	283	-	-	-	-
As (total)	µg/L	49.6	53.0	6.2	11.1	38.9	44.2	7.6	8.6	39.2	40.8	9.4	5.8	46.5	49.6	5.7	40.4	43.6	6.1	5.8
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	43.1	4.4	3.7	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	3.4	45.2	2.0	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	12.3	0.5	0.6	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	30.8	4.0	3.1	-	-	-	-
Fe (total)	µg/L	1,305	1,547	49	177	2,757	1,400	75	103	1,270	1,510	243	114	1,424	1,246	36	1,337	1,439	83	68
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	1,370	<25	<25	-	-	-	-
Mn (total)	µg/L	153	151	250	255	314	135	226	216	346	353	273	243	357	343	266	357	368	232	278
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	357	221	302	-	-	-	-

(a) DO levels high on TB due to compressed air line leak.

Table B-1. Analytical Data (Continued)

Sampling Date		09/06/06				09/12/06				09/20/06			09/27/06				10/04/06			
Sampling Location	Parameter	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB
	Unit																			
Alkalinity (as CaCO ₃)	mg/L	294 ^(a)	320	320	324	328	323	307	335	315	315	320	324	312	324	319	320	323	314	325
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	0.2	<0.05	0.1	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	<0.1	<0.1	0.2	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	383	417	422	-	-	-	-	-	-	-	-
Sulfide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	<0.05	<0.05	0.1	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	26.8	27.7	<10	<10	23.5	22.1	<10	<10	<10	28.6	<10	49.4	74.1	41.2	48.2	38.2	38.3	<10	<10
Silica (as SiO ₂)	mg/L	29.0	28.9	28.3	27.7	29.1	29.7	27.7	29.2	30.8	31.4	30.5	28.6	29.2	28.7	28.8	28.9	29.5	28.9	29.4
Turbidity	NTU	16.0	1.0	0.3	0.3	16.0	0.9	0.2	0.2	18.0	1.8	0.8	14.0	1.8	0.4	0.6	15.0	1.5	0.5	0.3
TOC	mg/L	-	-	-	-	-	-	-	-	1.8	2.0	1.7	-	-	-	-	-	-	-	-
TDS	mg/L	-	-	-	-	-	-	-	-	980	958	456	-	-	-	-	-	-	-	-
pH	S.U.	7.6	7.5	7.4	7.3	7.4	7.5	7.3	7.3	7.8	7.5	7.6	7.7	7.5	7.4	7.4	7.7	7.4	7.3	7.3
Temperature	°C	11.5	10.3	10.5	10.7	11.4	11.3	11.4	11.3	12.3	11.6	12.2	11.7	11.2	11.2	11.5	13.4	12.2	12.7	12.0
DO	mg/L	2.5	4.0	3.3	9.1 ^(b)	2.6	4.0	4.4	8.5 ^(b)	3.6	3.8	3.4	2.5	3.4	2.6	9.1 ^(b)	3.6	3.6	2.7	7.1 ^(b)
ORP	mV	33.8	406	421	428	39.7	433	450	438	39.7	452	441	33.8	433	450	438	457	457	448	451
Free Chlorine	mg/L	-	0.5	0.3	0.4	-	0.5	0.3	0.3	-	0.3	0.3	-	0.3	0.3	0.4	-	0.4	0.0	0.2
Total Chlorine	mg/L	-	0.7	0.8	0.8	-	0.7	0.8	0.7	-	1.1	1.0	-	1.1	0.8	0.8	-	1.0	0.4	0.9
Total Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	716	708	701	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	403	395	388	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	313	312	313	-	-	-	-	-	-	-	-
As (total)	µg/L	39.9	40.8	9.4	6.7	43.5	41.9	5.0	4.6	41.6	44.4	6.5	35.4	37.3	5.5	6.6	50.2	48.2	9.8	7.9
As (soluble)	µg/L	-	-	-	-	-	-	-	-	34.0	4.9	3.6	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	<0.1	39.5	2.9	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	10.9	0.3	0.2	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	30.0	4.6	3.4	-	-	-	-	-	-	-	-
Fe (total)	µg/L	1,213	1,221	198	107	1,357	1,328	<25	31	1,399	1,342	59	1,344	1,403	51	78	1,220	1,256	150	101
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	1,343	<25	<25	-	-	-	-	-	-	-	-
Mn (total)	µg/L	371	380	232	222	328	330	299	281	331	330	185	329	323	296	257	295	295	258	212
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	330	185	182	-	-	-	-	-	-	-	-

(a) Reanalysis conducted outside of hold time. (b) DO levels high on TB due to compressed air line leak.

Table B-1. Analytical Data (Continued)

Sampling Date		10/11/06				10/17/06			10/26/06				11/01/06				11/09/06			
Sampling Location	Parameter	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
	Unit																			
Alkalinity (as CaCO ₃)	mg/L	325	325	338	314	320	327	324	326	314	316	322	318	318	318	318	312	322	300	310
		331	325	342	323	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	-	-	-	-	0.2	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	0.2	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	470	475	469	-	-	-	-	-	-	-	-	-	-	-	-
Sulfide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	25.3	26.3	<10	<10	33.4	33.2	<10	25.6	25.8	<10	<10	35.4	34.3	<10	<10	25.8	28.8	<10	<10
		24.5	32.1	<10	<10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	30.8	29.1	29.4	30.7	28.8	29.2	29.7	30.0	28.8	28.8	29.1	30.2	29.9	28.7	29.0	29.0	29.6	28.6	29.8
		29.9	29.2	29.6	29.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	18.0	1.3	0.4	0.5	18.0	1.6	0.8	21.0	3.9	1.8	1.4	17.0	1.5	0.5	0.9	20.0	8.5	3.6	9.2 ^(b)
		18.0	1.2	0.4	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOC	mg/L	-	-	-	-	1.7	1.8	1.8	-	-	-	-	-	-	-	-	-	-	-	-
TDS	mg/L	-	-	-	-	930	914	924	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	7.1	7.1	7.1	7.2	7.5	7.4	7.3	7.6	7.8	7.4	7.4	7.7	7.5	7.3	7.3	7.7	7.6	7.5	7.5
Temperature	°C	12.2	12.4	12.4	12.2	15.8	14.9	14.9	11.0	10.9	11.9	11.0	12.0	12.0	10.0	10.9	12.3	11.9	11.6	11.6
DO	mg/L	2.9	3.9	2.8	8.2 ^(a)	2.7	3.5	2.4	2.8	2.9	4.8	7.0	2.6	2.9	1.6	2.2	2.9	3.5	2.7	3.7
ORP	mV	450	451	444	441	464	464	454	464	465	450	441	363	389	400	409	436	423	413	406
Free Chlorine	mg/L	-	0.2	0.2	0.2	-	0.0	0.0	-	0.2	0.2	0.2	-	0.0	0.2	0.0	-	0.1	0.0	0.0
Total Chlorine	mg/L	-	0.4	0.4	0.4	-	0.1	0.1	-	0.3	0.4	0.4	-	0.3	0.2	0.2	-	0.2	0.1	0.1
Total Hardness (as CaCO ₃)	mg/L	-	-	-	-	734	662	662	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	-	-	-	-	441	358	340	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	-	-	-	-	293	304	322	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L	44.8	45.5	6.8	6.6	48.9	46.5	6.3	48.3	49.6	5.6	6.7	44.8	45.4	7.3	7.6	52.6	54.5	5.8	7.5
		44.6	47.7	7.0	6.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	45.4	5.1	4.3	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	3.5	41.4	2.0	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	8.8	0.7	0.5	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	36.6	4.4	3.7	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	1,307	1,276	75	68	1,389	1,276	33	1,380	1,597	<25	54	1,369	1,406	110	123	1,167	1,252	<25	53
		1,322	1,255	136	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	1,275	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	342	343	234	236	413	384	370	341	342	392	324	409	412	318	333	349	342	334	311
		346	312	237	238	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	409	321	391	-	-	-	-	-	-	-	-	-	-	-	-

(a) DO levels high on TB due to compressed air line leak.

Table B-1. Analytical Data (Continued)

Sampling Date		11/16/06				11/29/06				12/06/06			12/13/06				12/20/06			
Sampling Location	Parameter	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB
	Unit																			
Alkalinity (as CaCO ₃)	mg/L	338	334	327	329	316	312	306	314	323	331	321	320	326	322	313	320	316	318	318
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	0.2	0.2	0.2	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	0.2	0.2	0.2	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	502	486	508	-	-	-	-	-	-	-	-
Sulfide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	38.9	40.8	<10	<10	28.4	30.0	<10	<10	22.0	22.1	<10	18.3	21.1	<10	<10	28.4	30.0	<10	<10
Silica (as SiO ₂)	mg/L	28.7	29.3	27.9	28.3	29.9	28.0	28.4	28.9	28.6	27.9	28.0	28.9	29.2	28.5	28.3	29.3	29.2	29.1	28.9
Turbidity	NTU	17.0	1.4	0.6	0.6	32.0	1.9	0.6	0.4	17.0	1.4	0.5	46.0	1.3	0.8	0.4	16.0	1.8	0.9	0.8
TOC	mg/L	-	-	-	-	-	-	-	-	1.7	1.6	1.6	-	-	-	-	-	-	-	-
TDS	mg/L	-	-	-	-	-	-	-	-	906	902	926	-	-	-	-	-	-	-	-
pH	S.U.	7.8	7.6	7.4	7.4	NA ^(a)	NA ^(a)	NA ^(a)	NA ^(a)	7.4	7.6	7.7	NA ^(a)	NA ^(a)	NA ^(a)	NA ^(a)	7.4	7.5	7.4	7.4
Temperature	°C	11.9	11.9	11.6	11.6	NA ^(a)	NA ^(a)	NA ^(a)	NA ^(a)	10.2	10.1	10.7	NA ^(a)	NA ^(a)	NA ^(a)	NA ^(a)	10.5	10.5	10.5	10.5
DO	mg/L	2.0	2.7	2.0	3.0	NA ^(a)	NA ^(a)	NA ^(a)	NA ^(a)	2.8	3.7	3.8	NA ^(a)	NA ^(a)	NA ^(a)	NA ^(a)	2.7	3.7	2.6	3.3
ORP	mV	333	422	412	407	NA ^(a)	NA ^(a)	NA ^(a)	NA ^(a)	436	423	435	NA ^(a)	NA ^(a)	NA ^(a)	NA ^(a)	437	425	415	406
Free Chlorine	mg/L	-	0.1	0.0	0.0	-	NA ^(a)	NA ^(a)	NA ^(a)	-	0.1	0.1	-	NA ^(a)	NA ^(a)	NA ^(a)	-	0.0	0.0	0.0
Total Chlorine	mg/L	-	0.3	0.1	0.1	-	NA ^(a)	NA ^(a)	NA ^(a)	-	0.3	0.6	-	NA ^(a)	NA ^(a)	NA ^(a)	-	0.2	0.1	0.1
Total Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	733	731	718	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	409	408	412	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	323	323	306	-	-	-	-	-	-	-	-
As (total)	µg/L	50.5	52.9	5.3	5.0	27.7	38.0	5.1	5.5	51.1	49.2	8.8	30.1	40.2	5.4	6.0	50.4	49.7	7.0	7.9
As (soluble)	µg/L	-	-	-	-	-	-	-	-	49.2	5.0	4.5	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	1.9	44.3	4.3	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	11.2	0.7	0.5	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	38.1	4.3	4.0	-	-	-	-	-	-	-	-
Fe (total)	µg/L	1,126	1,101	<25	<25	1,664	1,485	70	103	1,156	1,179	93	2,014	1,299	<25	25	1,326	1,294	40	83
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	1,133	<25	<25	-	-	-	-	-	-	-	-
Mn (total)	µg/L	353	322	291	281	325	332	281	348	386	373	289	322	302	259	288	373	368	275	284
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	395	276	293	-	-	-	-	-	-	-	-

(a) Water quality parameters were not measured.

Table B-1. Analytical Data (Continued)

Sampling Date		01/03/07			01/09/07				01/17/07				01/23/07				01/31/07		
Sampling Location	Parameter	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT
	Unit																		
Alkalinity (as CaCO ₃)	mg/L	339	341	327	320	315	324	324	299	308	311	301	310	310	310	328	328	304	320
Ammonia (as N)	mg/L	0.2	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-	0.2	<0.05	<0.05
Fluoride	mg/L	0.2	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	0.2
Sulfate	mg/L	417	435	439	-	-	-	-	-	-	-	-	-	-	-	-	431	433	422
Sulfide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05
Total P (as P)	µg/L	23.0	20.6	<10	17.5	19.1	<10	<10	40.5	53.0	<10	<10	36.6	42.3	<10	<10	55.7	64.5	20.9
Silica (as SiO ₂)	mg/L	29.6	29.9	28.6	29.7	28.9	28.9	29.1	29.4	29.8	29.1	29.8	28.7	29.1	28.4	28.7	28.5	28.7	28.2
Turbidity	NTU	19.0	1.5	0.4	17.0	1.7	0.4	0.4	21.0	2.3	0.4	0.8	18.0	1.5	0.7	0.7	45.0	2.2	0.6
TOC	mg/L	1.6	1.6	1.6	-	-	-	-	-	-	-	-	-	-	-	-	1.6	1.6	1.5
TDS	mg/L	870	904	918	-	-	-	-	-	-	-	-	-	-	-	-	946	922	936
pH	S.U.	7.7	7.8	7.6	7.1	7.2	7.2	7.1	7.1	7.0	7.0	7.0	6.9	6.9	6.9	6.9	6.8	6.8	6.8
Temperature	°C	11.5	11.5	11.3	12.5	11.2	11.3	11.2	11.0	10.7	10.9	10.8	12.2	11.8	11.6	11.5	12.2	11.2	11.4
DO	mg/L	3.9	3.9	3.4	4.1	4.8	3.6	3.3	4.8	4.5	7.3	4.3	3.5	3.6	3.2	3.1	5.6	3.9	3.7
ORP	mV	232	504	422	390	436	407	407	441	466	470	466	440	458	476	463	432	484	508
Free Chlorine	mg/L	-	0.0	0.1	-	0.0	0.0	0.0	-	0.0	0.0	0.0	-	0.1	0.0	0.1	-	0.1	0.0
Total Chlorine	mg/L	-	0.2	0.1	-	0.2	0.1	0.1	-	0.6	0.5	0.4	-	0.8	0.8	0.8	-	0.3	0.2
Total Hardness (as CaCO ₃)	mg/L	717	702	710	-	-	-	-	-	-	-	-	-	-	-	-	727	746	711
Ca Hardness (as CaCO ₃)	mg/L	454	453	430	-	-	-	-	-	-	-	-	-	-	-	-	431	425	419
Mg Hardness (as CaCO ₃)	mg/L	263	250	280	-	-	-	-	-	-	-	-	-	-	-	-	296	320	293
As (total)	µg/L	49.8	48.8	6.6	46.1	45.5	5.7	5.6	31.2	38.0	6.8	6.0	33.9	44.5	7.1	7.0	29.1	43.7	10.0
As (soluble)	µg/L	45.5	4.2	4.1	-	-	-	-	-	-	-	-	-	-	-	-	25.0	8.3	8.0
As (particulate)	µg/L	4.3	44.6	2.4	-	-	-	-	-	-	-	-	-	-	-	-	4.0	35.4	2.0
As (III)	µg/L	3.8	0.3	0.2	-	-	-	-	-	-	-	-	-	-	-	-	10.0	2.4	3.7
As (V)	µg/L	41.7	3.8	3.9	-	-	-	-	-	-	-	-	-	-	-	-	15.0	5.9	4.3
Fe (total)	µg/L	1,465	1,561	66	1,368	1,362	<25	41	1,163	1,338	112	89	1,348	1,442	98	115	1,526	1,269	95
Fe (soluble)	µg/L	1,578	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-	537	<25	<25
Mn (total)	µg/L	385	387	315	345	336	310	331	380	330	190	188	312	323	184	184	296	313	105
Mn (soluble)	µg/L	398	316	314	-	-	-	-	-	-	-	-	-	-	-	-	196	92.3	88.7

Table B-1. Analytical Data (Continued)

Sampling Date		02/06/07				02/13/07				02/20/07				02/27/07			03/06/07			
Sampling Location	Parameter	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB
Alkalinity (as CaCO ₃)	mg/L	324	320	317	327	313	318	315	313	330	325	315	320	316	314	318	322	320	317	312
		-	-	-	-	313	318	315	318	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.2	<0.05	<0.05	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.5	0.2	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	478	479	490	-	-	-	-
Sulfide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-
Total P (as P)	µg/L	26.5	27.3	<10	<10	42.1	44.2	<10	<10	43.8	43.4	11.1	<10	43.0	44.7	10.2	18.4	30.4	<10	<10
		-	-	-	-	41.5	44.4	10.3	<10	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	28.7	28.8	27.9	28.7	31.6	31.0	31.5	31.7	29.9	30.3	30.1	30.5	29.5	29.9	29.2	29.1	28.6	28.2	28.2
		-	-	-	-	30.9	30.8	30.9	30.7	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	19.0	1.8	0.6	0.5	17.0	2.1	0.6	0.5	18.0	2.9	0.4	1.2	14.0	1.8	0.6	18.0	7.0	0.4	1.7
		-	-	-	-	16.0	2.9	0.5	0.6	-	-	-	-	-	-	-	-	-	-	-
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	1.8	1.8	1.7	-	-	-	-
TDS	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	918	932	940	-	-	-	-
pH	S.U.	6.8	6.9	6.9	6.9	6.7	6.8	6.9	6.9	6.8	6.8	6.9	6.9	6.9	6.9	6.9	7.0	7.0	7.0	7.0
Temperature	°C	14.1	12.0	12.2	12.0	12.7	12.0	12.0	12.0	13.5	12.3	12.6	12.3	13.0	11.3	11.3	13.0	14.3	14.5	14.5
DO	mg/L	4.0	2.9	3.6	2.8	4.8	4.0	8.2	4.4	4.1	5.8	4.0	3.9	2.7	2.2	1.8	4.4	5.9	6.7	4.0
ORP	mV	423	657	616	657	369	585	608	628	385	589	581	666	385	585	651	331	561	667	696
Free Chlorine	mg/L	-	0.8	0.2	0.5	-	0.3	0.1	0.2	-	0.1	0.0	0.2	-	0.6	0.3	-	1.4	0.9	1.0
Total Chlorine	mg/L	-	1.0	0.4	0.8	-	0.9	0.4	0.6	-	0.7	0.5	0.6	-	1.0	0.6	-	1.9	1.3	1.4
Total Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	746	764	781	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	433	456	470	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	312	308	311	-	-	-	-
As (total)	µg/L	40.2	40.0	7.9	5.1	37.4	39.2	5.9	5.2	46.6	44.6	7.7	6.7	48.8	47.1	9.3	33.7	44.1	8.5	8.9
		-	-	-	-	37.7	40.0	6.2	5.2	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	42.9	5.2	4.9	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	5.9	41.9	4.4	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	14.0	1.1	1.0	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	28.9	4.1	4.0	-	-	-	-
Fe (total)	µg/L	1,158	1,087	115	<25	1,074	1,155	59	37	1,092	1,153	40	<25	1,116	1,241	121	1,019	1,328	91	106
		-	-	-	-	1,126	1,195	59	35	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	1,108	<25	<25	-	-	-	-
Mn (total)	µg/L	321	316	104	99.3	331	332	78.8	99.0	318	314	74.5	87.0	333	335	81.1	393	367	47.6	51.1
		-	-	-	-	341	340	77.4	96.7	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	334	81.8	53.7	-	-	-	-

Table B-1. Analytical Data (Continued)

Sampling Date		03/13/07				03/20/07				03/28/07			04/03/07				04/10/07			
Sampling Location	Parameter	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB
Alkalinity (as CaCO ₃)	mg/L	323	328	326	328	325	325	322	327	306	303	308	316	309	311	316	315	315	315	317
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	0.2	<0.05	<0.05	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	0.2	0.3	0.2	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	421	422	423	-	-	-	-	-	-	-	-
Sulfide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	33.0	34.2	<10	<10	46.2	46.7	<10	11.3	52.9	51.9	19.7	34.4	30.1	<10	<10	46.6	48.7	17.2	17.8
Silica (as SiO ₂)	mg/L	28.9	29.2	29.1	29.2	30.5	30.6	30.1	30.7	29.6	29.3	29.1	28.3	28.4	27.9	28.1	30.0	29.4	29.2	29.3
Turbidity	NTU	18.0	2.9	5.0	1.6	19.0	5.1	1.9	1.4 ^(a)	16.0	1.9	0.8	16.0	1.9	0.9	0.6	19.0	3.4	1.6	1.9
TOC	mg/L	-	-	-	-	-	-	-	-	1.8	1.6	1.7	-	-	-	-	-	-	-	-
TDS	mg/L	-	-	-	-	-	-	-	-	958	984	992	-	-	-	-	-	-	-	-
pH	S.U.	7.2	7.2	7.1	7.1	6.9	6.9	6.9	6.9	7.2	7.2	7.1	6.8	6.9	6.9	6.8	7.1	7.3	7.2	7.2
Temperature	°C	11.9	11.3	11.4	10.6	14.4	13.2	13.5	13.6	12.2	11.0	11.0	12.7	11.3	11.3	11.4	12.5	11.7	12.4	12.1
DO	mg/L	9.2	3.5	2.5	3.3	5.1	4.2	3.4	3.2	3.5	6.1	3.2	4.2	4.4	4.8	3.6	3.2	3.8	3.9	3.5
ORP	mV	446	679	624	686	404	575	658	658	431	600	455	406	579	630	686	408	600	631	640
Free Chlorine	mg/L	-	0.8	0.4	0.7	-	0.2	0.0	0.1	-	1.7	1.5	-	1.3	1.0	1.0	-	0.9	0.2	0.5
Total Chlorine	mg/L	-	1.1	0.9	0.8	-	0.2	0.1	0.3	-	2.0	2.0	-	1.5	1.2	1.3	-	1.1	0.3	0.9
Total Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	708	687	664	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	395	381	369	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	312	306	294	-	-	-	-	-	-	-	-
As (total)	µg/L	44.8	44.0	8.3	7.6	54.5	53.8	6.5	6.6	46.8	46.9	10.9	48.4	45.0	5.8	5.4	48.3	46.5	7.1	7.0
As (soluble)	µg/L	-	-	-	-	-	-	-	-	45.9	6.6	5.9	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	0.9	40.3	4.9	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	11.4	1.6	1.6	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	34.4	5.0	4.4	-	-	-	-	-	-	-	-
Fe (total)	µg/L	1,023	1,056	122	102	1,140	1,170	44	51	1,082	1,078	144	1,215	1,190	<25	<25	1,005	1,024	<25	<25
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	1,014	<25	<25	-	-	-	-	-	-	-	-
Mn (total)	µg/L	299	292	76.0	71.0	276	250	85.3	82.8	280	274	42.3	228	218	24.6	27.7	361	365	16.9	17.5
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	297	84.8	20.9	-	-	-	-	-	-	-	-

(a) Reanalysis outside of hold time.

Table B-1. Analytical Data (Continued)

Sampling Date		04/17/07			
Sampling Location		IN	AC	TA	TB
Parameter	Unit				
Alkalinity (as CaCO ₃)	mg/L	314 -	312 -	314 -	312 -
Ammonia (as N)	mg/L	-	-	-	-
Fluoride	mg/L	-	-	-	-
Sulfate	mg/L	-	-	-	-
Sulfide	mg/L	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-
Total P (as P)	µg/L	42.1 -	43.9 -	11.5 -	12.9 -
Silica (as SiO ₂)	mg/L	31.0 -	31.2 -	30.5 -	30.9 -
Turbidity	NTU	18.0 -	2.0 -	1.4 -	0.7 -
TOC	mg/L	-	-	-	-
TDS	mg/L	-	-	-	-
pH	S.U.	7.0	7.3	7.1	7.2
Temperature	°C	12.5	11.5	12.5	12.5
DO	mg/L	3.3	3.7	3.5	3.5
ORP	mV	409	593	641	657
Free Chlorine	mg/L	-	0.6	0.3	0.6
Total Chlorine	mg/L	-	1.0	0.6	0.8
Total Hardness (as CaCO ₃)	mg/L	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	-	-	-	-
As (total)	µg/L	48.2 -	46.7 -	8.2 -	9.0 -
As (soluble)	µg/L	-	-	-	-
As (particulate)	µg/L	-	-	-	-
As (III)	µg/L	-	-	-	-
As (V)	µg/L	-	-	-	-
Fe (total)	µg/L	1,079 -	1,093 -	77 -	104 -
Fe (soluble)	µg/L	-	-	-	-
Mn (total)	µg/L	385 -	382 -	25.8 -	34.2 -
Mn (soluble)	µg/L	-	-	-	-