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Arsenic Removal from Drinking Water by Iron Removal
U.S. EPA Demonstration Project at Sabin, MN
Six-Month 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 the first six months of the EPA arsenic removal technology demonstration project at the Sabin, MN facility. The main objective of the project is to evaluate the effectiveness of Kinetico's FM-248-AS arsenic removal system using Macrolite® media in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 μg/L. Additionally, this project evaluates (1) the reliability of the treatment system for use at small water facilities, (2) the required system operation and maintenance (O&M) and operator skill levels, and (3) the cost-effectiveness of the technology. The project also characterizes water in the distribution system and residuals generated by the treatment process. The types of data collected include system operation, water quality (both across the treatment train and in the distribution system), process residuals, and capital and O&M costs.

After engineering plan review and approval by the state, the FM-248-AS treatment system was installed and became operational on January 19, 2006. The system consisted of two 63-in-diameter, 86-in-tall fiberglass reinforced plastic (FRP) contact tanks and two 48-in-diameter, 72-in-tall FRP pressure tanks, all configured in parallel. Each pressure tank contained 25 ft^3 of Macrolite® media, which is a spherical, low density, chemically inert ceramic media designed for filtration rates up to 10 gal/min (gpm)/ft^2. The system used prechlorination to oxidize As(III) and Fe(II) and the contact tank to improve the formation of As(V)-laden particles prior to entering the pressure filters. The system operated at approximately 238 gpm for 3.0 hr/day (on average), producing 6,650,000 gal of water through July 30, 2006. The average flowrate corresponded to a contact time of 7.1 min and a filtration rate of 9.5 gpm/ft^2. A number of issues related to the control of the frequency and duration of backwash operation were experienced as discussed in the report.

The source water had an average pH of 7.4 and total arsenic concentrations ranged from 32.8 to 49.8 μg/L, with the soluble fraction consisting of As(V) at 23.9 μg/L and As(III) at 13.2 μg/L. Concentrations of both As(V) and As(III) varied considerably during the course of this six-month study period, with As(III) concentrations exhibiting a decreasing trend and As(V) concentrations exhibiting an increasing trend especially during the first month. Total iron concentrations ranged from 1,203 to 1,936 μg/L, which existed primarily in the soluble form with an average concentration of 1,135 μg/L. Raw water soluble iron and soluble arsenic concentrations corresponded to a ratio of 31:1. Total arsenic concentrations in treated water averaged 6.3 μg/L and ranged from 3.5 to 10.6 μg/L. Due to total arsenic breakthrough at 10.6 μg/L on July 26, 2006, a run length study will be conducted during the next six-month period.

Comparison of the distribution system sampling results before and after the second quarter of operations demonstrated a considerable decrease in arsenic (27.4 to 7.1 μg/L), iron (1,211 to 75 μg/L), and manganese (114 to 60 μg/L). Further decreases were observed in manganese concentrations within the distribution system, when compared to the concentrations in the filter effluent (i.e., 203 and 217 [on average] following Tanks A and B) to those in the distribution system (i.e., 60 μg/L [on average] in the second quarter of system operation). Copper (179 to 127 μg/L) and lead concentrations (4.2 to 1.3 μg/L) also decreased. Alkalinity and pH did not appear to be significantly affected.

Filter tank backwash occurred automatically about 3 times/tank/week, which was triggered primarily by the 48-hr standby time setpoint, due to low operational time of the treatment system (i.e., 3.0 hrs/day). Approximately 161,550 gal of wastewater, or 2.4% of the amount of water treated, was generated during the first six months. Under normal operating conditions, the backwash wastewater contained 116 to 550 mg/L of total suspended solids (TSS), 29.8 to 176.8 mg/L of iron, 2.0 to 8.6 mg/L of manganese, and

6.1 to 27.6 µg/L of arsenic, with the majority existing as particulates. The average amount of solids discharged per backwash cycle was approximately 5.2 lb, including 1.6 lb of elemental iron, 0.09 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 gal/day [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 and labor. O&M costs were estimated at $0.69/1,000 gal and will be refined at the end of the one-year evaluation period.

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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
CRF	capital recovery factor
Cu	copper
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
FedEx	Federal Express
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
ND	not detected
NS	not sampled
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	piping and instrumentation diagram
Pb	lead
pCi/L	picocuries per liter
psi	pounds per square inch
psig	pounds per square inch gauge
PLC	programmable logic controller
PO_4	orthophosphate
POU	point-of-use
PVC	polyvinyl chloride
QA	quality assurance
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
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 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 on March 25, 2003 to express the MCL as 0.010 mg/L (10 µg/L) (EPA, 2003). The final rule required all community and non-transient, non-community water systems to comply with the new standard by January 23, 2006.

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

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the 17 host sites. EPA received 70 technical proposals for the 17 host sites, with each site receiving one to six proposals. In April 2003, an independent technical panel reviewed the proposals and provided its recommendations to EPA on the technologies that it determined were acceptable for the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration project. Using the information provided by the review panel, EPA, in cooperation with the host sites and the drinking water programs of the respective states, selected one technical proposal for each site. As of October 2007, 37 of the 40 systems were operational and the performance evaluation of 25 systems was completed.

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.

1.2 Treatment Technologies for Arsenic Removal

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

1.3 Project Objectives

The objective of the arsenic demonstration program is to conduct 40 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 Sabin, MN during the first six months from January 30 through July 30, 2006. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and preliminary O&M cost.

Table 1-1. Summary of Arsenic Removal Demonstration Sites

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

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

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

AM = adsorptive media process; C/F = coagulation/filtration; HIX = hybrid ion exchanger; IX = ion exchange process; RO = reverse osmosis

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

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

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. Based on the information collected during the first six months of operation, the following preliminary 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 As(III) to As(V), reducing As(III) concentrations from 13.2 μg/L (on average) in raw water to 0.6 μg/L (on average) after the contact tanks. Fe(II) also was readily oxidized in the presence of chlorine with soluble iron concentrations being reduced to below the method reporting limit of 25 μg/L after the contact tanks and after the pressure filters. Chlorination was not as effective in oxidizing Mn(II). Depending on the chlorine dosage, 35% to 68% of manganese remained in the soluble form, which, therefore, was not removed by the pressure filters.

- Supplemental iron was not required because the level of natural iron in raw water was sufficient for arsenic removal to below 10 μg/L. The soluble iron to arsenic ratio was 31:1, above the recommended 20:1 ratio for effective arsenic removal. With prechlorination, As(V) was formed and co-precipitated with and/or adsorbed onto the iron solids also formed during chlorination. This converted arsenic primarily to the particulate form before entering into the Macrolite® pressure filters.

- Operating the pressure filters at a high filtration rate of 9.5 gpm/ft^2 (on average) can remove arsenic to below the 10 μg/L MCL. However, the median filter run length experienced during this six-month study period was only 6.2 hr. Some particulate arsenic and iron breakthrough did occur in the pressure filter effluent, including one sampling event with the concentration over 10 μg/L. Consequently, a filter run length study will be carried out during the next six-month study period.

- The treatment system experienced pressure spikes to as high as 63 pounds per square inch (psi) during backwash (or two times the average inlet pressure under normal service conditions). This occurred due to the flow being directed to only one tank that remained in service (while the second tank was in backwash) and the presence of a flow restrictor on the treated water line. For this site, the normal inlet pressure was relatively low at 33 psi during the service cycle, so the doubling of the inlet pressure during backwash could be accommodated and was within the 100 psi maximum inlet pressure specifications. However, this will not be the case for all sites, based on their site-specific pump curve characteristics and total dynamic head conditions.

- The treatment system significantly improved water quality in the distribution system after the second quarter of system operation. A considerable decrease was observed in arsenic (27.4 to 7.1 μg/L), iron (1,211 to 75 μg/L), and manganese (114 to 60 μg/L) concentrations by the second quarter of operations. Further decreases in manganese concentrations were observed within the distribution system with total manganese levels being 70% lower in the distribution system than in the plant effluent. Copper and lead also decreased slightly, while alkalinity and pH did not appear to be affected.

Required system O&M and operator skill levels:

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

Characteristics of residuals produced by the technology:

- Backwash appeared to be effective in restoring the filters' effectiveness in removing arsenic-laden iron particles and manganese solids. The total amount of wastewater produced from backwash, which occurred at a frequency of approximately 3 times/tank/week, was equivalent to about 2.4% of the amount of water treated.

- The amount of residual solids produced and discharged during each backwash cycle totaled 5.2 lb, which included 1.6 lb of elemental iron, 0.09 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, since 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 $0.69/1,000 gal based on chemical supply and labor 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. 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 tracked through the collection of water samples across the treatment train. The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement. The unscheduled downtime and repair information was recorded by the plant operator on a Repair and Maintenance Log Sheet.

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

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

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

Table 3-1. Predemonstration 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
Building Completed	06/05/06
System Installation Completed	12/16/05
System Shakedown Completed	01/19/06
Performance Evaluation Began	01/30/06

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

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

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

The capital cost for the arsenic removal system consisted of the cost for equipment, site engineering, and system installation. The O&M cost consisted of the cost for chemical usage, electricity consumption, and labor. Consumption of NaOCl was tracked on the Daily System Operation Log Sheet. Electricity 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.

Table 3-3. Sampling Schedule and Analyses

Sample Type	Sample Locations[a]	No. of Samples	Frequency	Analytes	Collection Date(s)
Source Water	At Wellhead (IN)	1	Once (during initial site visit)	On-site: pH, temperature, DO, and ORP Off-site: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, NH_3, NO_2, NO_3, Cl, F, SO_4, SiO_2, P, TOC, TDS, turbidity, and alkalinity	08/31/04
Treatment Plant Water	At Wellhead (IN), after Contact Tank (AC), after Tank A (TA), and after Tank B (TB)	4	Weekly	On-site:[b] pH, temperature, DO, ORP, and Cl_2 (total and free). Off-site: As (total), Fe (total), Mn (total), SiO_2, P, turbidity, and alkalinity	02/14/06, 02/21/06 03/06/06, 03/14/06 03/21/06, 04/04/06 04/11/06, 04/18/06, 05/02/06, 05/09/06, 05/17/06, 05/31/06, 06/06/06, 06/13/06, 06/28/06, 07/10/06, 07/11/06, 07/26/06
	At Wellhead (IN), after Contact Tank (AC), and after Tanks A and B Combined (TT)[c]	3	Monthly	Same as weekly analytes shown above plus the following: Off-site: As (soluble), As(III), As(V), Fe (soluble), Mn (soluble), Ca, Mg, NH_3, NO_3, F, SO_4, TOC, and TDS	01/31/06, 02/28/06, 03/28/06, 04/25/06, 05/23/06, 06/20/06, 07/18/06
Backwash Water	Backwash Discharge Line	2	Monthly[d]	As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, TDS, and TSS	02/28/06, 03/27/06 04/18/06, 06/21/06 07/18/06
Distribution Water	Three LCR Residences	3	Monthly	As (total), Fe (total), Mn (total), Pb, Cu, pH, and alkalinity	02/14/05[e], 03/16/05[e] 04/18/05[e], 05/18/05[e] 02/22/06, 03/29/06 04/18/06, 05/23/06 06/21/06, 07/11/06
Residual Solids	Backwash Solids from Each Tank	2	Twice	Total Al, As, Ca, Cd, Cu, Fe, Mg, Mn, Ni, P, Pb, Si, and Zn	TBD

(a) Abbreviation corresponding to sampling location in Figure 3-1.
(b) Chlorine residuals analyzed only at AC, TA, and TB sampling locations.
(c) Because TT sample tap did not yield water (see Section 4.3.3), three "TT" samples were taken from TA tap and four taken from TB tap during this study period.
(d) May 2006 sample not collected.
(e) Baseline sampling events performed before system startup.
TBD = to be determined

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected at the wellhead, across the treatment plant, during Macrolite® filter backwash, and from the distribution system. The sampling schedules and analytes measured during each sampling event are listed in Table 3-3. 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 off-site analyses. For the first week of each four-week cycle, samples taken at the wellhead (IN), after the contact tank (AC), and after Tanks A and B combined (TT), were speciated on-site and analyzed for the analytes listed in Table 3-3 for monthly treatment plant water. (For the six-month study period, the "TT" sampling location was not functional and an alternate sampling strategy was used as described in Section 4.3.3.) For the next three weeks, samples were collected at IN, AC, after Tank A (TA), and after Tank B (TB) and analyzed for the analytes listed in Table 3-3 for the weekly treatment plant water.

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

3.3.4 Distribution System Water. Samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically, the arsenic, lead, and copper levels. Prior to the system startup from February to May 2005, four sets of baseline distribution water samples were collected from three residences within the distribution system. 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 usage before sampling and sample collection were recorded for calculation of the stagnation time. All samples were collected from a cold-water faucet that had not been used for at least 6 hr to ensure that stagnant water was sampled.

3.3.5 Residual Solids. Residual solids produced by the treatment process included backwash solids, which were not collected during the initial six months of this demonstration.

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).

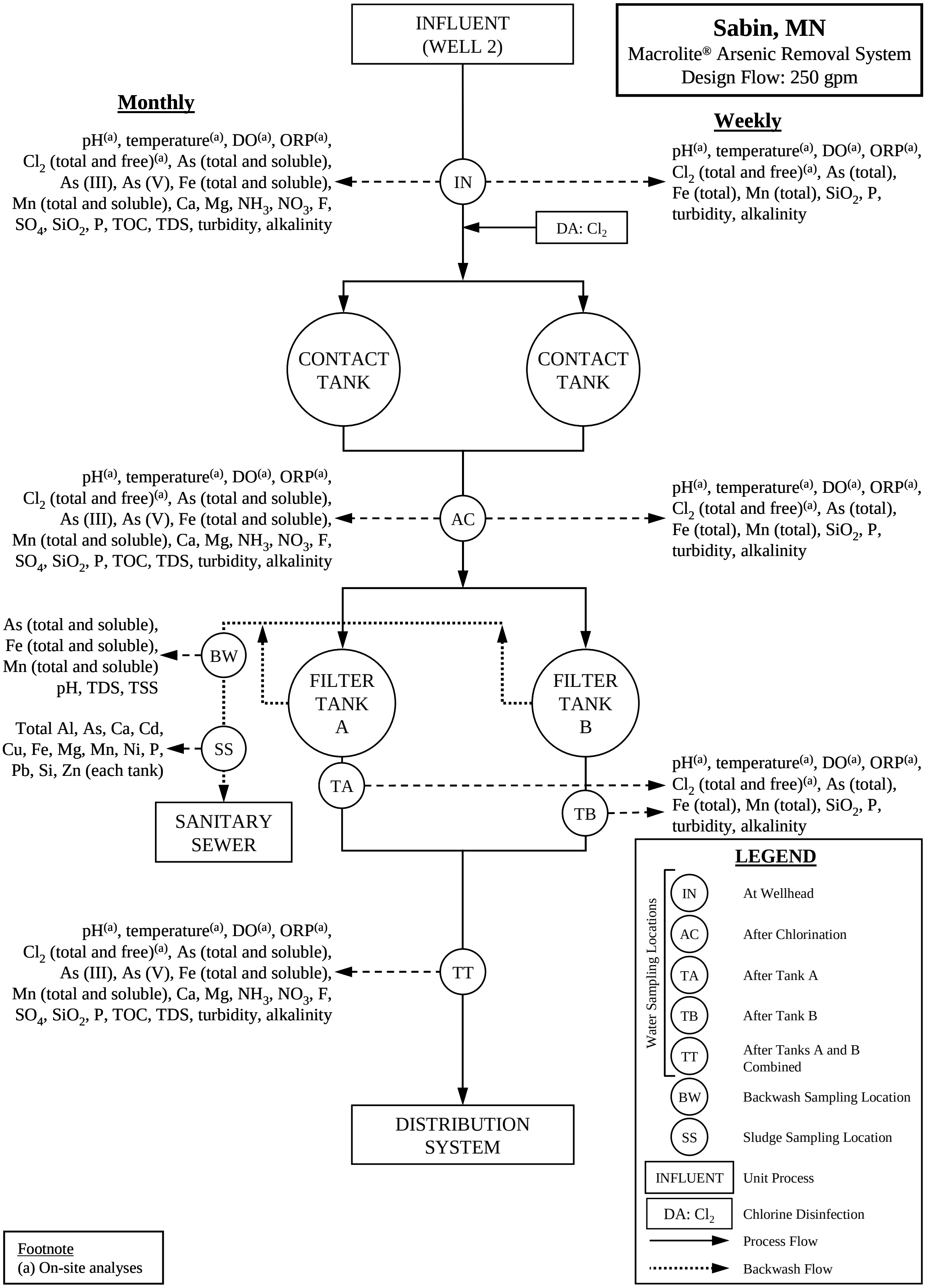


Figure 3-1. Process Flow Diagram and Sampling Schedule and Locations

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 Ziplock® bags and packed in the cooler.

In addition, all sampling- and shipping-related materials, such as disposable gloves, sampling instructions, chain-of-custody forms, prepaid/addressed 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 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 quality assurance (QA) data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project.

Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a 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™ chlorine test kits following the user's manual.

4.0 RESULTS AND DISCUSSION

4.1 Facility Description

Located on First Street in Sabin, MN, the municipal water system supplies 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 (a.k.a. Well No. 1) and one new well (a.k.a. Well No. 2), which were alternated on a weekly basis. Installed in 1960, the old well was 8-in in diameter and 94-ft deep with a 34-ft screen extending from 60 to 94 ft below ground surface (bgs). The new well, 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.

The new well was equipped with a 15-horsepower (hp) submersible pump with a design capacity of 250 gpm at a total dynamic head of 200 ft of H_2O (87 psi). The old well 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 might vary from additional above ground piping headloss and/or degradation in pump performance since its installation in 1993. Both the old and new wells were connected to a pre-existing gravity filtration 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 the new well. Thus, only the new well, or Well No. 2, water was treated during the demonstration study.

The pre-existing treatment system consisted of a 210-gpm aeration and gravity filtration system with approximately 70 ft^2 of filter area operating at a hydraulic loading rate of approximately 3 gpm/ft^2. The treatment system also included a NaOCl and a fluoride addition system to reach a free chlorine residual of 0.5 mg/L (as Cl_2) and 1.2 mg/L for fluoride, respectively. 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 H_2O) 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). The pre-existing treatment system and former building were demolished and removed from the site.

4.1.1 Source Water Quality. Source water samples were collected 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 in September 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. Total arsenic concentrations in Well No. 1 water varied significantly, ranging from 13.9 to 53.7 μg/L. Although no source water sample was collected from Well No. 2 prior to the demonstration study, similar, but less significant, variations in arsenic concentration were observed in Well No. 2 water during the first six-month demonstration study period, with concentrations varying from 32.8 to 49.8 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%) was particulate arsenic and 43.9 μg/L was soluble arsenic, which consisted

Figure 4-1. Preexisting Pump House at Sabin, MN

Figure 4-2. Preexisting Filtration System at Sabin, MN

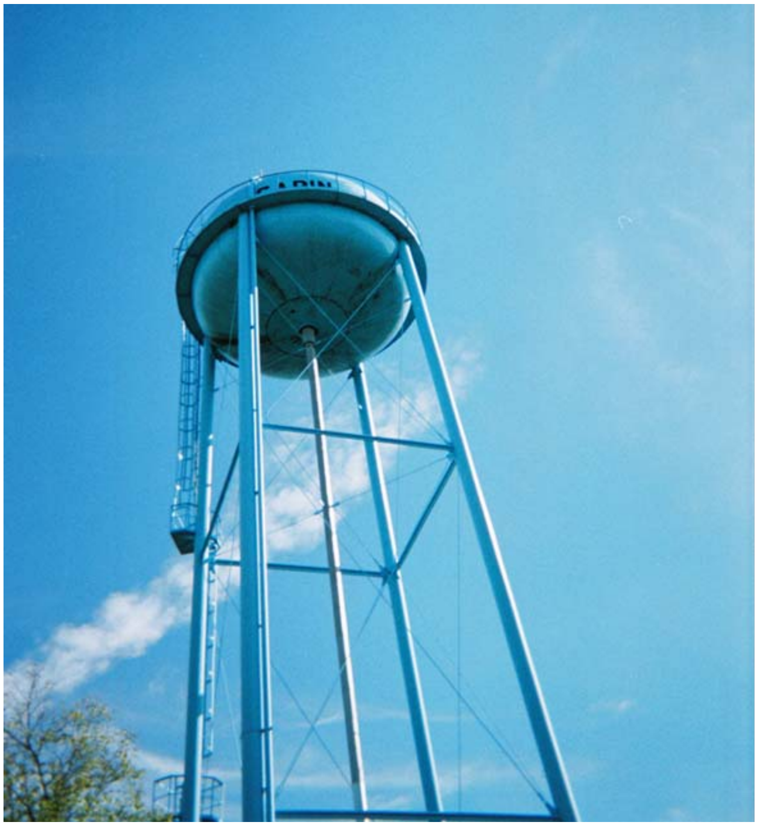


Figure 4-3. Water Tower at Sabin, MN

of 24.2 μg/L (or 45.1%) as As(V) and 19.7 μg/L (or 36.7%) as As(III). The presence of As(III) 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, however, was uncharacteristically high at 5.9 mg/L. DO levels will be further monitored during the study period. 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 and co-precipitation of As(V) onto the iron solids also formed during prechlorination.

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

Manganese. Total manganese concentrations in source water ranged from 155 to 327 μg/L. Based on the results of the two speciation events, manganese existed entirely as soluble manganese with concentrations ranging from 278 μg/L to 331 μg/L. The manganese levels were above the SMCL of 50 μg/L. The proposed treatment system was anticipated to provide for some manganese removal, but its effectiveness was to be evaluated as part of this demonstration project, due to the inherently slow oxidation kinetics of manganese during chlorination.

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)**
Date		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

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

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)]
	Date	09/30/02	2003	Before 04/04	07/30/03	07/30/03	08/31/04	01/16/01–10/26/04
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

pH. The pH values of source water 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 hydroxides. As such, no pH adjustment was needed during the treatment.

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 showed 29.7 mg/L of silica (as SiO_2) and <0.1 mg/L of total phosphorus, 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 authors document that silica reduces arsenic adsorptive capacities on ferric oxides/hydroxides. Arsenic adsorption may be inhibited in the presence of silica as follows: (1) adsorption of silica may change the surface properties of adsorbents by lowering the iso-electric point or 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; and (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 demonstration study. The 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. Total organic carbon (TOC) in source water ranged from 1.5 to 2 mg/L, which was not anticipated to adversely impact the treatment system performance.

Other Water Quality Parameters. The source water was very turbid at 7.1 nephelometric turbidity units (NTU), most likely resulting from iron precipitation during the sample collection and transit. The nitrate, nitrite, chloride, and fluoride levels all were below the corresponding SMCLs. The ammonia level at 0.19 mg/L would add 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 demonstration study, the distribution system at the City of Sabin 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. During the demonstration study beginning in January 2006, the distribution system was supplied only by Well No. 2.

The three locations selected for distribution water sampling for this demonstration study 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 various locations within the distribution system, such as residences, businesses (gas stations and cafes), fire hall, and city hall, from January 16, 2001, through October 26, 2004. As shown in the table, turbidity readings were <1.0 NTU, NO_3-NO_2 between <0.05 and 0.15 mg/L (as N), fluoride between 0.9 and 1.6 mg/L, sulfate between 410 and 440 mg/L, arsenic between 24.4 and 45.0 mg/L, sodium between 42 to 44 mg/L, radium-226 at 0.2 pCi/L, and radium-228 at <0.8 pCi/L. Compared to those in source water, fluoride concentrations were somewhat elevated due to fluoridation at the plant. As expected, the concentrations of the rest of the analytes measured at the entry point and within the distribution system were comparable to those found in source water (except for radium, for which no data were available for source water).

4.2 Treatment Process Description

Kinetico's FM-248-AS arsenic removal system was installed at the Sabin, MN site for the demonstration study. The treatment train included 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/ft^2 and approved for use in drinking water applications under NSF International 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 (ºC)	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 along with a 15-hp booster pump to provide a design flow rate of 250 gpm. (Deviating from the original design, Well No. 1 was not piped to the treatment system for the duration of the study). 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 0.5 mg/L (as Cl_2) after the treatment system. The feed system consisted of a 165-gal day tank containing a 15.6% (as Cl_2) NaOCl solution and a diaphragm metering pump with a maximum capacity of 42 gpd. The proper operation of the NaOCl system was tracked by the 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 has one 4-in top flange and one 4-in bottom flange, which are connected to the exit and inlet piping, respectively, for an upflow configuration.

- **Pressure Filtration**. Iron floc removal 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 ft^3 (or 24 in) 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. 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. System operation with both tanks in service could produce a 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, which were operated on an alternating basis.

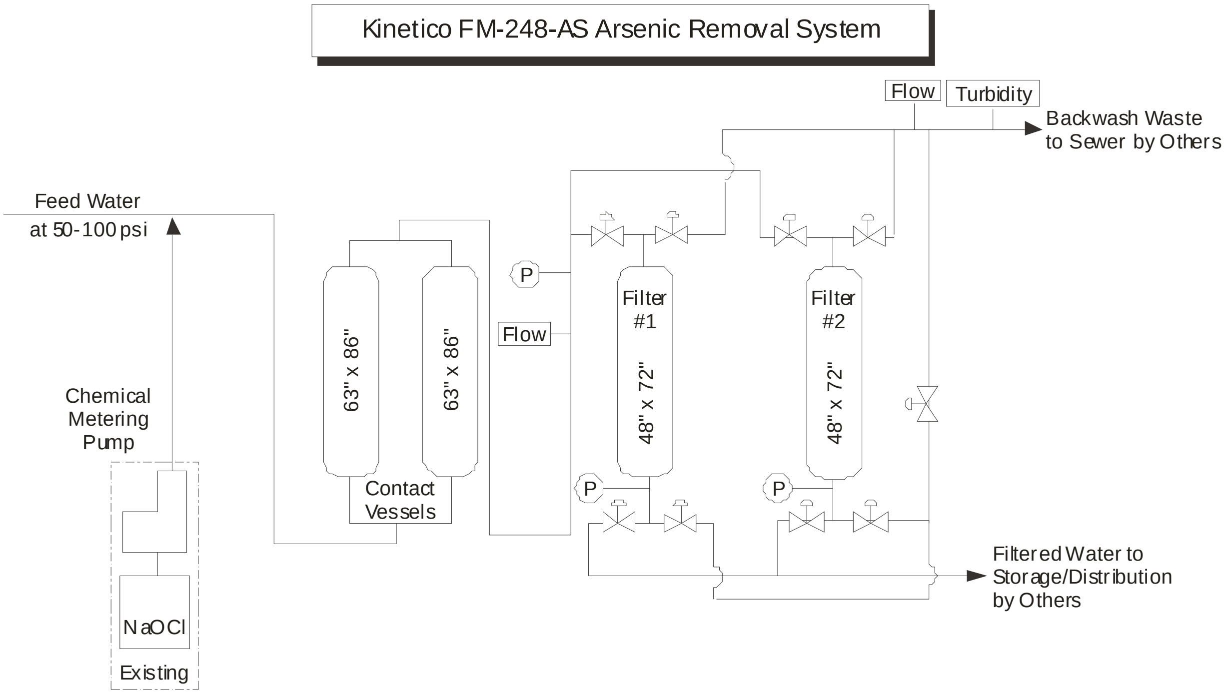


Figure 4-4. Schematic of Kinetico's FM-248-AS Arsenic Removal System

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/vessel)	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		
Peak 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

- **Filter Backwash**. Backwash removed solids accumulating in the filters, thereby reducing pressure buildup. The filters were automatically backwashed in succession in an upflow configuration 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 at 100 pounds per square inch gauge (psig) for 2 min. 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). Afterwards, the filter tank underwent a filter-to-waste rinse for 3 min using water from the contact tank before returning to service. The resulting 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, prepared by Kinetico and Ulteig Engineers, included a system design report and associated general arrangement 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. 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 of Sabin.

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, and the performance evaluation officially began on January 31, 2006. As a result of the system inspections, several punch-list items were identified and forwarded to the vendor after the site visit. The key items identified and corrective actions taken included:

- 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.

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)

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

- Modify the PLC to show a decimal place for all hour meter displays on the control panel. 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 related to the PLC programming change described above and the Hach^{TM} turbidimeter. As discussed in Section 4.4.2, the PLC programming change made on February 28, 2006, led to the failure of the system to 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 5-min minimum backwash duration. This issue was not resolved during the first six-month study period as discussed in Section 4.4.2. 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.

4.4 System Operation

4.4.1 Coagulation/Filtration Operation.

The operational parameters for the first six months of system operation are tabulated and attached as Appendix A with the key parameters summarized in Table 4-4. From January 30, 2006 through July 30, 2006, the treatment system operated for approximately 546 hr, based on the hour meter readings displayed on the PLC; the average daily operating time was 3.0 hr/day. (The service clock on the PLC was reset twice during this study period 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 approximately 6,650,000 gal based on flow totalizer readings on the PLC. The average daily demand was 37,049 gal/day, which is equivalent to a 10% hydraulic utilization rate.

The system flowrates ranged from 222 to 245 gpm and averaged 238 gpm, based on instantaneous readings from the flow meter/totalizer installed at the exit side of the pressure filters. The average flowrate corresponded to an average contact time of 7.1 min in the contact tanks and an average hydraulic loading rate of 9.5 gpm/ft^2 across the filters, compared to the design values of 6.8 min and 10 gpm/ft^2, 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 are compared with the instantaneous flowrate readings. As shown in Figure 4-8, the calculated average flowrate was highly variable due to the lack of a decimal place on the hour meter reading, which reduced the accuracy of the calculation. During the second quarter of operations, after implementation of the PLC programming changes described above, the readings converged with the instantaneous flow rate approximately 8% higher than the daily average system flow rate. This is consistent with the values measured at system startup, which indicated an instantaneous flow rate of 244 gpm and a calculated average flowrate of 225 gpm (based on a digital totalizer reading [i.e., 15,300 gal] and a stop watch reading [i.e., 68 min]).

Under normal service conditions, Δp readings across the system ranged from 31 to 39 psi. As shown in Figure 4-9, Δp readings across each filter over the course of a filter run increased from approximately 7 psi immediately after backwash up to 19 psi after 21 hr of filter run time. At the median filter run time of 6.2 hr, the corresponding Δp reading across the bed was approximately 12 psi, which was 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.

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

Parameter	Value
Operational Period	01/30/06–07/30/06
Coagulation/Filtration Operation	
Total Operating Time (hr)	546
Average Daily Operating Time (hr/day)	3.0
Total Throughput (gal)	6,650,000
Average Daily Demand (gpd)	37,049
Median Service Time between Backwash Cycles [Range] (hr)	6.2 [0.8–13.3] (a)
Median Throughput between Backwash Cycles [Range] (gal)	88,536 [11,424–189,924]
Average Flowrate [Range] (gpm)(b,c)	238 [222–245]
Average Contact Time [Range] (min)(b)	7.1 [6.9–7.7]
Average Filtration Rate [Range] (gpm/ft^2)(b)	9.5 [8.8–9.8]
Average Δp across Each Tank [Range] (psi)(c)	11.7 [7–19]
Average Δp across System [Range] (psi)(c)	33 [31–39]
Backwash Operation	
Average Frequency (times/tank/week)	3
Number of Cycles (Tank A/Tank B)	81/81
Average Flowrate [Range] (gpm)(d)	107 [105–110]
Average Hydraulic Loading Rate [Range] (gpm/ft^2)	8.5 [8.4–8.8]
Average Duration [Range] (min/tank)(d)	10 [5–19]
Average Backwash Volume [Range] (gal/tank)(d)	1,003 [400–1,900]
Estimated Filter to Waste Volume (gal/tank)(e)	375
Average Wastewater Produced [Range] (gal/tank)	1,378 [775–2,675]

(a) Data collected from February 28 through March 19, 2006 not included. Filter run times during this time period were uncharacteristically long (ranging from 18 to 25 hr), caused by the PLC control problems discussed in Section 4.4.2.

(b) Based on instantaneous flowrate readings from flow meter/totalizer for service.

(c) Pressure and flow data collected on February 7, 2006 not included (with one tank in service while the other tank was being backwashed).

(d) Based on readings recorded by operator on monthly backwash logsheet.

(e) Estimated based on 3-min filter-to-waste time and 125-gpm flow rate.

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 one pressure filter (Tank A) in service while the other (Tank B) was being backwashed. During this backwash event, the influent pressure spiked almost twice as high up 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). This spike in pressure occurs with each backwash event and is due to only one tank being in service and the increased pressure drop caused by the flow restrictor on the effluent line of that tank. During this backwash event, the Δp reading across Tank A was only 10 psi (because it had just been backwashed and returned to service) and the corresponding flowrate through Tank A was 155 gpm. While one tank is off-line for backwash (Tank B), the inlet pressure at 63 psi through the on-line tank (Tank A) was below the 100 psi manufacturer specifications. For this site, the normal inlet pressure was relatively low at 33 psi, so the doubling of the inlet pressure with only one tank on-line could be accommodated. However, this will not be the case for all sites, based on their site-specific pump curve characteristics and total dynamic head conditions. The flowrate at 155 gpm through Tank A was slightly above the 125 gpm limit per tank. This suggests that the system is able to operate with only one tank on-line, but the hydraulic loading at 12.3 gpm/ft^2 is slightly higher than the design specification of 10 gpm/ft^2 during this time period.

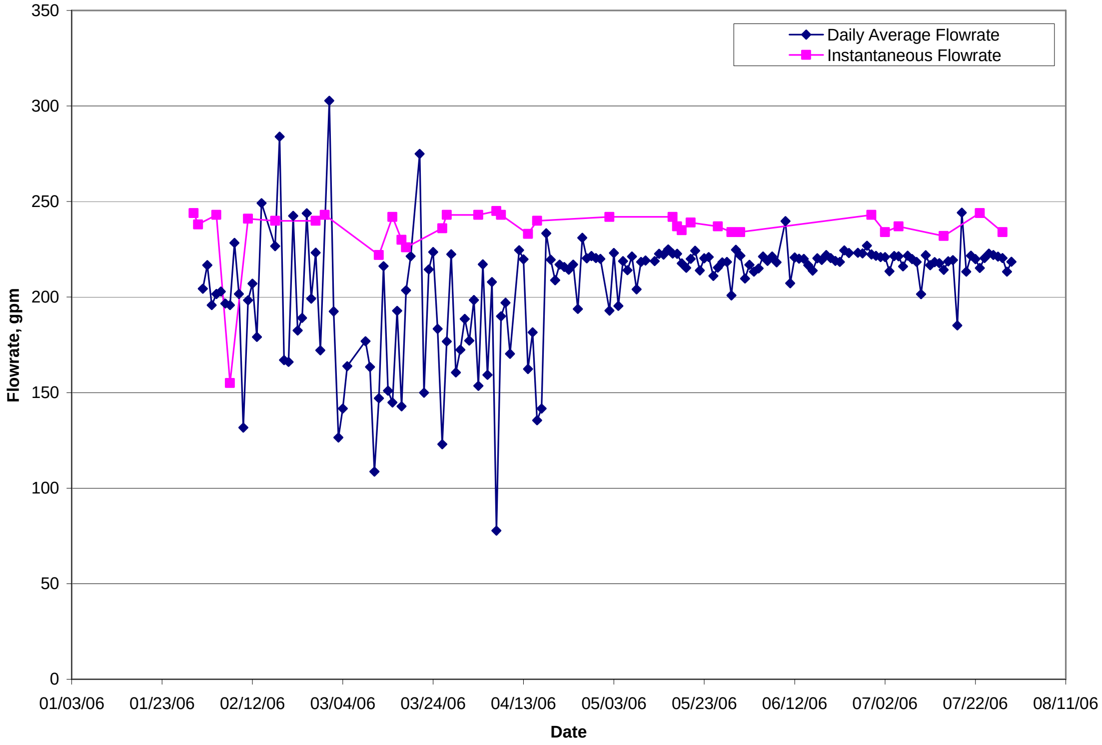


Figure 4-8. Calculated and Instantaneous Flowrate Readings

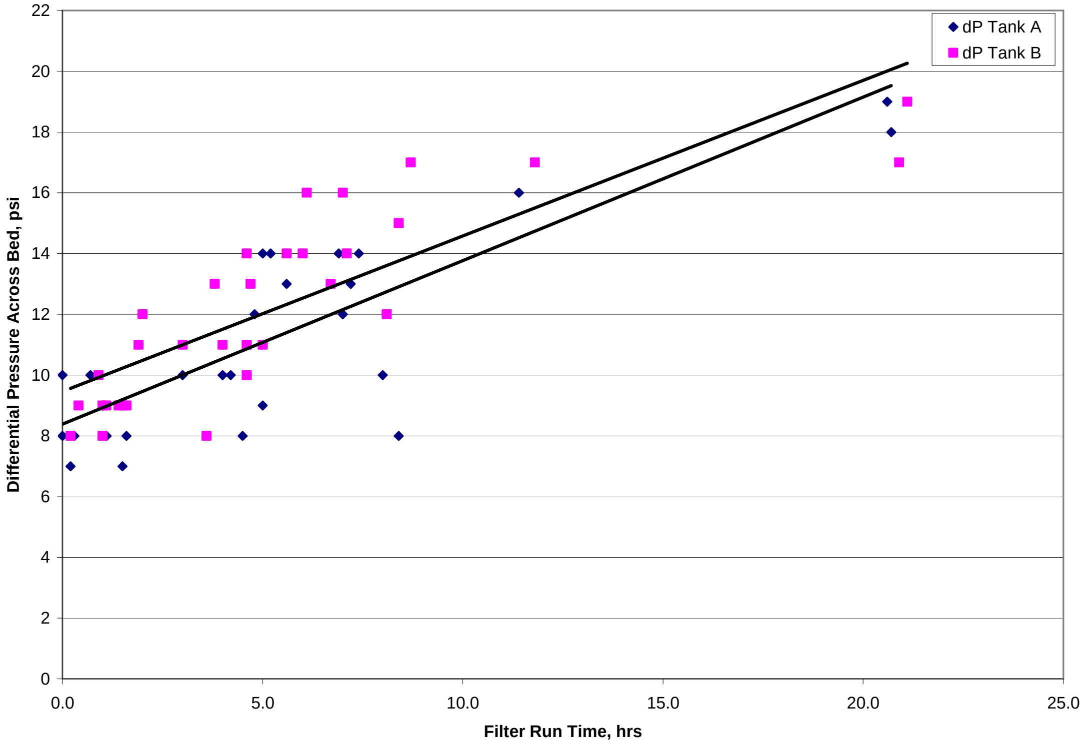


Figure 4-9. Differential Pressure Versus Filter Run Time

Since system startup, a total of 81 backwash cycles took place for each pressure filter. Backwash occurred at a frequency of approximately 3 times/tank/week and was triggered mainly by the 48-hr standby time due to the low daily run time of 3.0 hr/day. The median value of filter run times between two consecutive backwash cycles was 6.2 hr, which yielded a median throughput of 88,536 gal. Because total arsenic breakthrough at 10.6 μg/L was observed on July 26, 2006 (as discussed in Section 4.5.1.1), the filter run time will be further examined during the next six-month study period. In addition, several issues were encountered related to the frequency and duration of backwash, which will be discussed in Section 4.4.2. As noted in Table 4-4, these data were not included in the filter run time calculations.

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 filter, 48-hr standby time, or 24-hr filter run time. Due to short daily operational times, the majority of the backwash cycles were triggered by the standby time setpoint. Occasionally, manual backwash cycles also were initiated, but primarily for testing and sampling of backwash water 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 water to meet the turbidity threshold setting as measured by an in-line Hach™ turbidimeter. If backwash water failed to meet the set threshold prior to reaching the maximum backwash time, the backwash failure alarm had to be acknowledged and a successful backwash cycle had to be conducted before the tank could return to the service mode. Backwash was followed by a 3-min filter-to-waste rinse to remove any particulates from the filter.

Each pressure filter was backwashed 81 times during the first six-month study period. Backwash flowrates ranged from 105 to 110 gpm and averaged 107 gpm; the corresponding backwash hydraulic loading rates ranged from 8.4 to 8.8 gpm/ft^2 and averaged 8.5 gpm/ft^2. This range of backwash flowrates did not cause significant media loss during backwash. The backwash duration for each filter lasted for 5 to 19 min, or 10 min on average. The amount of backwash water produced averaged 1,003 gal with a range of 400 to 1,900 gal. Overall, the amount of backwash water generated was 100,800 gal, about 1.5% of the total amount of water treated. Including 375 gal of filter-to-waste rinse water per filter for each backwash cycle, approximately 161,550 gal of wastewater was generated, which is about 2.4% of the total amount of water treated.

Table 4-5 summarizes the backwash settings established on January 30, 2006 during system startup and on July 21, 2006 to modify the minimum backwash time due to a Hach™ turbidimeter malfunction. Backwash issues experienced during the first six months of system operation included backwash controls related to the frequency and duration of backwash, as well as backwash failure alarms.

4.4.2.1 Backwash Frequency Issues. On February 28, 2006, the vendor implemented a PLC programming change that added a decimal place to the 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 so that the filters were not properly backwashed based on the 48-hour standby setpoint. As a consequence, filter run times were significantly extended from an average of 6.2 hr during normal system operation to 18.1 hr from February 28 to March 7, 2006, 24.8 hr from March 7 to 14, 2006, and 23.7 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 manually initiated backwash cycles until the PLC program was updated by the vendor and the backwash control returned to normal operations on April 11, 2006.

4.4.2.2 Backwash Duration Issues. From May 7, 2006 to July 21, 2006, 38 out of 44 backwash events terminated at the minimum backwash time of 5 min, based on the volume of wastewater recorded on the Daily Operational Log Sheet and the average backwash flowrate. In addition, the operator observed during the June 18, 2006, backwash event that the turbidity readings of the backwash water

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

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

(a) Initial setpoint at startup.
(b) Minimum backwash time changed to 10-min due to issues with Hach™ turbidimeter readings.

peaked at 18 NTU, which was significantly lower than the NTU readings (i.e., up to 88 NTU) observed previously in January through April 2006. Lower than the established 20-NTU threshold, these abnormally low NTU readings caused backwash to stop as soon as reaching the minimum backwash time of 5 min. This issue was reported to the vendor on June 6, 2006, but not yet resolved during the first six-month study period. As a temporary measure, the operator adjusted the minimum backwash time from 5 to 10 min on July 21, 2006 to ensure adequate backwashing of the pressure filters.

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 more occasions (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 water and filter-to-waste rinse water. Backwash water was discharged to the building sump, which emptied by gravity to the sanitary sewer. According to the backwash flow totalizer, 100,800 gal of wastewater were produced during the pressure filter backwash. Based on a flowrate of 125 gpm and a duration of 3 min/tank for 81 backwash cycles, 60,750 gal of filter-to-waste rinse water also were produced. Therefore, over 161,550 gal of wastewater, or 2.4% of the treated water, was 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 has been required since installation 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 15.6% as Cl_2 solution was performed to oxidize As(III) and Fe(II) and to provide chlorine residuals to the distribution system. In addition to tracking the depth of the NaOCl solution in the day tank, the operator measured chlorine levels to ensure that adequate residuals existed throughout the treatment train. Insufficient chlorine was dosed due to a chlorine fitting leak reported by the operator as starting on February 12, 2006. Using spare parts, the operator made a series of repairs between the February 14 and 21, 2006 sampling events to restore prechlorination. No post-treatment was required for the arsenic removal 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 the frequency and duration of backwash events, which 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 malfunctions).

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 (A being the highest). 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 affected. 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 systems. 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 on-site 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 daily. 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 will be addressed during the second six-month study period.

4.4.4.5 Chemical Handling and Inventory Requirements. Prechlorination was required for effective treatment since system startup. 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 27 occasions including two duplicate events and seven speciation events during the first six months of system operation. Table 4-6 summarizes the analytical results for arsenic, iron, and manganese. Table 4-7 summarizes the results of the other water quality parameters. Appendix B contains a complete set of analytical results. The results of the water samples collected across the treatment plant are discussed as follows.

4.5.1.1 Arsenic. Figure 4-10 shows total arsenic concentrations measured across the treatment train and Figure 4-11 presents the results of seven speciation events. Total arsenic concentrations in raw water ranged from 32.8 to 49.8 μg/L and averaged 39.6 μg/L. Of the soluble fraction (93%), As(V) was the predominating species, except for the time period just after system startup as shown in Figure 4-11, with concentrations ranging from <0.1 to 33.6 μg/L and averaging 23.9 μg/L. Significant amounts of As(III) also existed with concentrations ranging from 4.6 to 35.6 μg/L and averaging 13.2 μg/L. Concentrations of both As(V) and As(III) varied considerably during the course of this six-month study period, with As(III) concentrations exhibiting a decreasing trend and As(V) concentrations an increasing trend especially during the first month.

Low levels of particulate As also were present with concentrations averaging 1.9 μg/L. The total arsenic concentrations measured during this study period were lower than that of the raw water sample collected on July 30, 2003, but higher than that collected on August 31, 2004 (Table 4-1). Note that the groundwater source for the demonstration study was from the new well (or Well No. 2) and that the pre-demonstration samples were collected only from the old well (or Well No. 1).

After prechlorination and the contact tanks, As(III) was effectively oxidized to As(V), which, in turn, was adsorbed onto or co-precipitated with iron solids, also formed during prechlorination, to become particulate As. This was as evidenced by the low levels of soluble arsenic (3.8 to 5.4 μg/L) and significantly elevated particulate As concentrations (i.e., 36.2 μg/L on average) in the samples taken after the contact tanks. The water samples collected on February 14, 2006, showed very little change in arsenic (Figure 4-10) and iron (Figure 4-12) concentrations across the treatment train, which corresponded well with the problem encountered with the chlorine injection system that developed a leak starting from February 12, 2006, caused by a faulty fitting. The leak was repaired by the operator before the February 21, 2006 sampling event.

With sufficient chlorine addition, total arsenic concentrations ranged from 3.9 to 10.6 μg/L and averaged 6.2 μg/L after Tank A and ranged from 3.5 to 9.9 μg/L and averaged 6.4 μg/L after Tank B. Based on the speciation results from three TA and four TB samples, arsenic in the filter effluent was present in both soluble and particulate forms, each comprising roughly 50% of the total amounts. The soluble fraction was composed of primarily As(V), with As(III) concentrations averaging at only 0.3 and 0.9 μg/L after Tanks A and B, respectively. Exceedance of the arsenic MCL occurred once after Tank A at 10.6 μg/L on July 26, 2006. The exceedance was attributed to potential particulate breakthrough of the filter due to the slightly elevated iron levels in the filter effluent (see Section 4.5.1.2). For this reason, a filter run length study will be conducted during the next six-month study period. Another factor that also might have contributed was the increase in the influent arsenic level up to 51.3 μg/L compared to the average influent arsenic level of 39.6 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	27	32.8	49.8	39.6	4.0
	AC	27	28.2	51.3[(a)]	40.5[(a)]	5.0[(a)]
	TA	23	3.9	10.6[(a)]	6.2[(a)]	1.9[(a)]
	TB	24	3.5	9.9[(a)]	6.4[(a)]	1.8[(a)]
As (soluble)	IN	7	34.1	40.3	36.9	2.1
	AC	7	3.8	5.4	4.3	0.5
	TA	3	3.0	3.2	3.2	0.1
	TB	4	2.3	3.7	3.1	0.6
As (particulate)	IN	7	<0.1	4.5	1.9	1.6
	AC	7	32.5	40.3	36.2	3.0
	TA	3	2.2	3.9	3.2	0.9
	TB	4	0.7	3.8	2.3	1.6
As (III)	IN	7	4.6	35.6	13.2	10.8
	AC	7	0.2	1.0	0.6	0.3
	TA	3	0.3	0.4	0.3	0.1
	TB	4	<0.1	2.0	0.9	0.9
As (V)	IN	7	<0.1	33.6	23.9	11.8
	AC	7	3.0	5.1	3.7	0.7
	TA	3	2.7	3.0	2.8	0.1
	TB	4	1.2	2.8	2.2	0.7
Fe (total)	IN	27	1,203	1,936	1,404	160
	AC	27	763	1,748[(a)]	1,364[(a)]	202[(a)]
	TA	23	<25	235[(a)]	81.9[(a)]	61.3[(a)]
	TB	24	<25	235[(a)]	92.5[(a)]	61.5[(a)]
Fe (soluble)	IN	7	914	1,283	1,135	129
	AC	7	<25	<25	<25	-
	TA	3	<25	<25	<25	-
	TB	4	<25	<25	<25	-
Mn (total)	IN	27	259	449	350	54.7
	AC	27	252	452	350[(a)]	57.4[(a)]
	TA	23	126	365	217[(a)]	63.1[(a)]
	TB	24	111	343	203[(a)]	57.6[(a)]
Mn (soluble)	IN	7	305	457	371	61.9
	AC	7	105	297	202	74.4
	TA	3	184	305	249	61.2
	TB	4	99	300	173	87.6

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

(b) 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 Minimum	Concentration Maximum	Concentration Average	Standard Deviation
Alkalinity (as $CaCO_3$)	IN	mg/L	27	284	329	300	11.0
	AC	mg/L	27	283	317	297	8.3
	TA	mg/L	23	283	312	296	7.8
	TB	mg/L	24	283	321	298	9.6
Ammonia (as N)	IN	mg/L	7	<0.05	0.25	0.16	0.08
	AC	mg/L	7	<0.05	0.09	0.06	0.02
	TA	mg/L	3	0.06	0.09	0.08	0.02
	TB	mg/L	4	<0.05	0.05	0.03	0.01
Fluoride	IN	mg/L	7	<0.1	0.2	0.1	0.1
	AC	mg/L	7	<0.1	0.2	0.1	0.1
	TA	mg/L	3	<0.1	0.1	0.1	0.0
	TB	mg/L	4	<0.1	0.1	0.1	0.0
Sulfate	IN	mg/L	7	376	835	474	160
	AC	mg/L	7	371	839	465	166
	TA	mg/L	3	420	845	562	245
	TB	mg/L	4	372	514	437	58.9
Nitrate (as N)	IN	mg/L	7	<0.05	<0.05	<0.05	-
	AC	mg/L	7	<0.05	<0.05	<0.05	-
	TA	mg/L	3	<0.05	<0.05	<0.05	-
	TB	mg/L	4	<0.05	<0.05	<0.05	-
Total P (as P)	IN	µg/L	26	<10	50.0	27.9	11.9
	AC	µg/L	26	<10	45.8	26.8	12.4
	TA	µg/L	22	<10	18.5	6.1	3.2
	TB	µg/L	23	<10	20.2	5.9	3.3
Silica (as SiO_2)	IN	mg/L	27	28.5	32.5	30.3	1.0
	AC	mg/L	27	27.4	32.5	30.2	1.2
	TA	mg/L	23	27.1	31.9	29.8	1.1
	TB	mg/L	24	26.9	31.9	29.9	1.1
Turbidity	IN	NTU	27	13.0	44.0	18.8	5.8
	AC	NTU	27	0.9	20.0	2.5	3.6
	TA	NTU	23	0.3	18.0	1.6	3.6
	TB	NTU	24	0.2	21.0	1.6	4.2
Total Organic Carbon (TOC)	IN	mg/L	5	1.5	1.8	1.6	0.1
	AC	mg/L	5	1.5	1.8	1.6	0.1
	TA	mg/L	1	1.6	1.6	1.6	-
	TB	mg/L	3	1.5	1.8	1.6	0.2
Total Dissolved Solids (TDS)	IN	mg/L	7	886	1,030	963	47.3
	AC	mg/L	7	914	1,020	963	34.4
	TA	mg/L	3	978	1,000	989	11.0
	TB	mg/L	4	920	1,030	977	51.6
pH	IN	S.U.	25	7.2	7.7	7.4	0.2
	AC	S.U.	25	7.0	7.7	7.4	0.2
	TA	S.U.	19	7.1	7.4	7.3	0.1
	TB	S.U.	22	7.1	7.4	7.3	0.1

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

Parameter	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Temperature	IN	°C	25	11.0	17.4	13.3	1.5
	AC	°C	25	10.9	17.8	13.3	1.5
	TA	°C	19	10.8	16.4	13.3	1.5
	TB	°C	22	11.2	17.1	13.3	1.6
DO	IN	mg/L	25	2.1	6.6	3.7(a)	1.4(a)
	AC	mg/L	25	1.2	4.7	3.2(a)	0.8(a)
	TA	mg/L	19	2.2	5.9	3.8(a)	1.3(a)
	TB	mg/L	22	0.8	4.0	3.0(a)	0.9(a)
ORP	IN	mV	25	-13	476	171	186
	AC	mV	25	385	678	479	72.1
	TA	mV	19	442	665	499	59.3
	TB	mV	22	83.9	677	530	127
Free Chlorine (as Cl_2)	AC	mg/L	25	0.0	1.0	0.2	0.3
	TA	mg/L	19	0.0	0.4	0.1	0.1
	TB	mg/L	22	0.0	0.9	0.1	0.2
Total Chlorine (as Cl_2)	AC	mg/L	25	0.0	2.1	0.7	0.4
	TA	mg/L	19	0.1	0.9	0.5	0.2
	TB	mg/L	22	0.0	1.1	0.5	0.3
Total Hardness (as $CaCO_3$)	IN	mg/L	7	584	741	658	55.3
	AC	mg/L	7	536	741	662	68.4
	TA	mg/L	3	603	743	671	69.9
	TB	mg/L	4	635	691	667	24.9
Ca Hardness (as $CaCO_3$)	IN	mg/L	7	354	414	390	19.5
	AC	mg/L	7	324	435	392	34.5
	TA	mg/L	3	345	413	377	34.3
	TB	mg/L	4	379	426	401	21.3
Mg Hardness (as $CaCO_3$)	IN	mg/L	7	210	327	267	40.2
	AC	mg/L	7	212	323	270	38.9
	TA	mg/L	3	258	329	293	35.6
	TB	mg/L	4	246	282	266	14.9

(a) Data with uncharacteristically high DO levels on 02/21/06, 2/28/06, 03/06/06, 03/14/06, 03/21/06, 03/28/06, 06/28/06, and 07/26/06 not included in the maximum, average, and standard deviation calculations.

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

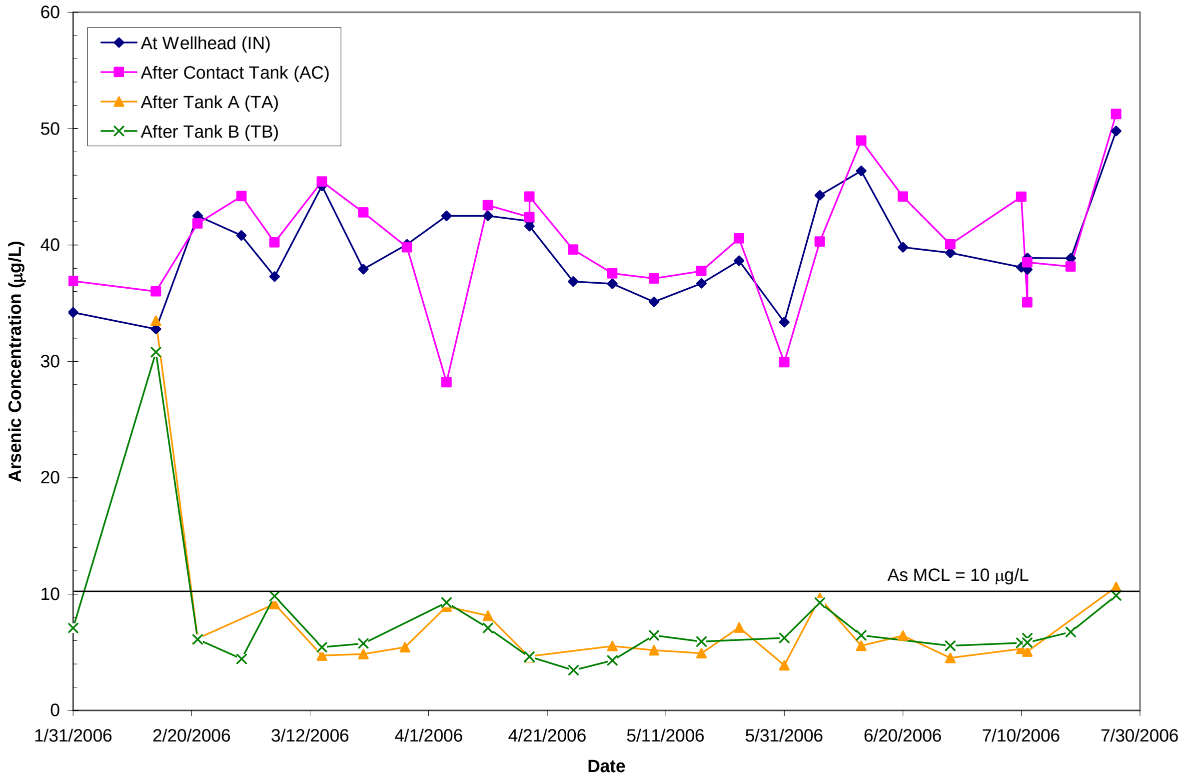


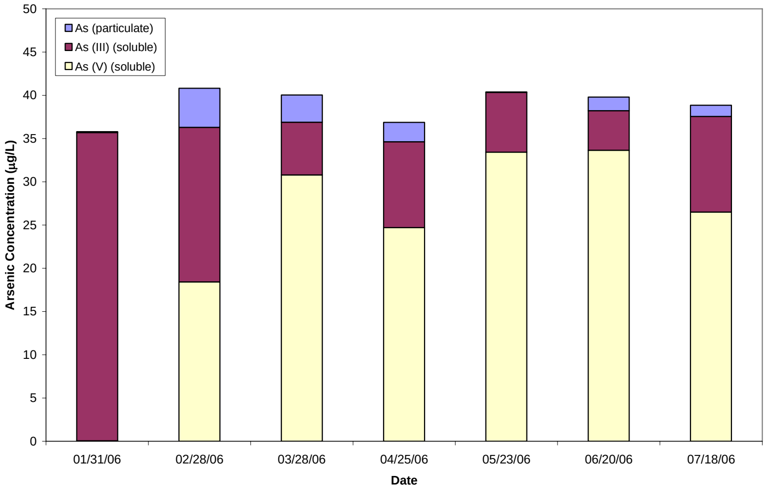
Figure 4-10. Total Arsenic Concentrations Across Treatment Train

4.5.1.2 ***Iron.*** Figure 4-12 presents total iron concentrations measured across the treatment train. Total iron concentrations in raw water ranged from 1,203 to 1,936 µg/L and averaged 1,404 µg/L, which existed primarily in the soluble form at 1,135 µg/L. The average soluble iron and average soluble arsenic concentrations in raw water corresponded to a ratio of 31:1 (Table 4-6), which was over the 20:1 target ratio for effective arsenic removal (Sorg, 2002). The amount of natural iron was sufficient for arsenic removal. The influent pH at 7.4 (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.

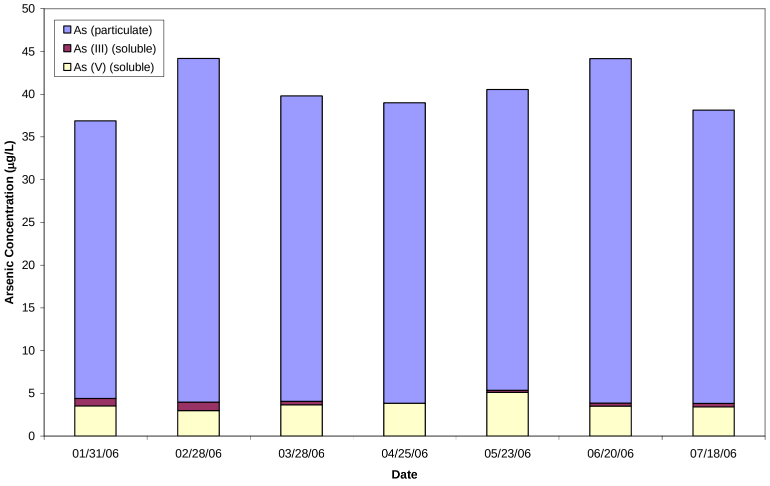
Upon chlorination, soluble iron levels were effectively reduced to below the method reporting limit of 25 µg/L after the contact tanks and after the Macrolite® filters. The only exception was the February 14, 2006, sampling event, where no change in iron concentrations was observed across the treatment train. As discussed previously in Section 4.4.4.1, insufficient chlorine was added to the treatment system due to a problem with the chlorine injection system during February 12 to 21, 2006. The February 14, 2006, data are shown in Figure 4-12, but not included in the average total iron calculations for the AC, TA, and TB samples.

Iron breakthrough from the pressure filters were observed with total iron levels ranging from <25 to 235 µg/L and particulate iron levels ranging from <25 to 103 µg/L (not including the February 14, 2006, data as discussed above). As shown in Figure 4-12, total iron levels averaged 81.9 µg/L for Tank A and 92.5 µg/L for Tank B and were maintained below the 300 µg/L secondary MCL for iron. Because of the concerns over particulate arsenic and iron breakthrough from the Macrolite® filters, as observed on July 26, 2006, a filter run length study will be conducted during the next six-month study period.

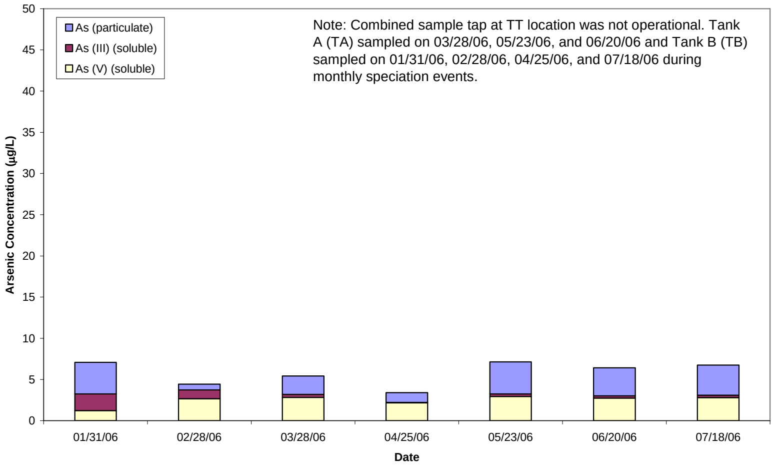
Arsenic Speciation at the Wellhead (IN)



Arsenic Speciation after Contact Tank (AC)



Arsenic Speciation after Tank A (TA) and Tank B (TB)



Note: Combined sample tap at TT location was not operational. Tank A (TA) sampled on 03/28/06, 05/23/06, and 06/20/06 and Tank B (TB) sampled on 01/31/06, 02/28/06, 04/25/06, and 07/18/06 during monthly speciation events.

Figure 4-11. Arsenic Speciation Results at Wellhead (IN), after Contact Tank (AC), after Tank A (TA), and after Tank B (TB)

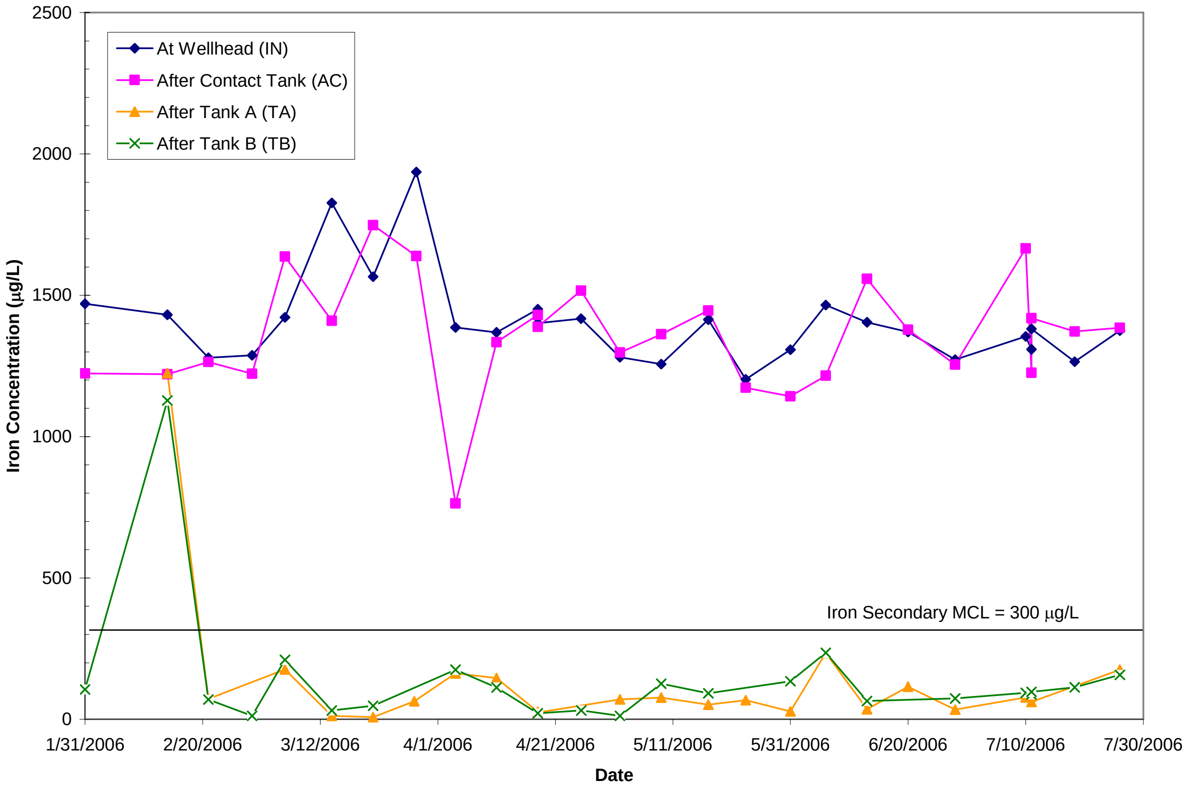


Figure 4-12. Total Iron Concentrations Across Treatment Train

4.5.1.3 ***Manganese.*** Manganese concentrations in raw water ranged from 259 to 449 µg/L and averaged 350 µg/L, which existed almost entirely in the soluble form at 371 µg/L (on average). Figure 4-13 presents total manganese concentrations across the treatment train. With prechlorination and 7.1-min contact time, only 32% to 65% 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). Further, the rate of conversion from soluble to particulate manganese appears to vary with the chlorine dosage. As shown in Figure 4-14, total manganese removal across the filters varied widely from 14% to 72% and averaged 40%. The rate of removal was influenced by the chlorine dosage with higher total chlorine residuals after the contact tank associated with increased manganese removal across the filter. For example, on June 13, 2006, the total chlorine residual was low at only 0.2 mg/L and the manganese effluent levels were elevated at 343 to 365 µg/L, which represented only 15% to 20% removal. However, a 63% manganese removal rate was achieved earlier on February 28, 2006, with 1.2 mg/L of total chlorine residual. Previous studies also have found that incomplete oxidation of Mn(II) occurs using free chlorine at pH values less than 8.5 (Knocke et al., 1987 and 1990; Condit and Chen, 2006). Because Macrolite® filters removed only particulate manganese, the soluble fraction after the contact tanks (i.e., 202 µg/L on average) remained essentially unchanged after the pressure filters (i.e., 249 and 173 µg/L after Tanks A and B, respectively). However, as discussed in Section 4.5.3, precipitation of manganese might have occurred after the treated water entered the distribution system, given additional chlorine dosage, upon post-chlorination, and substantially longer contact time within the distribution system. During the next six-month study period, an increased chlorine dosage will be implemented to study its potential effect on manganese oxidation across the treatment train.

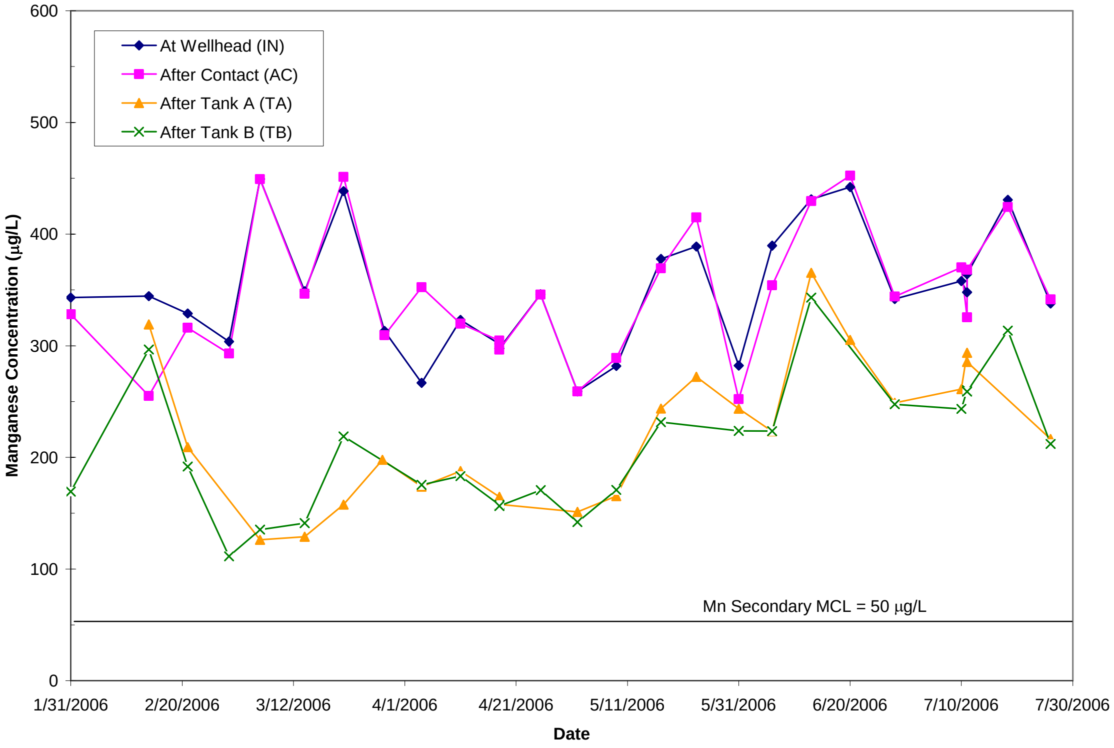


Figure 4-13. Total Manganese Concentrations Across Treatment Train

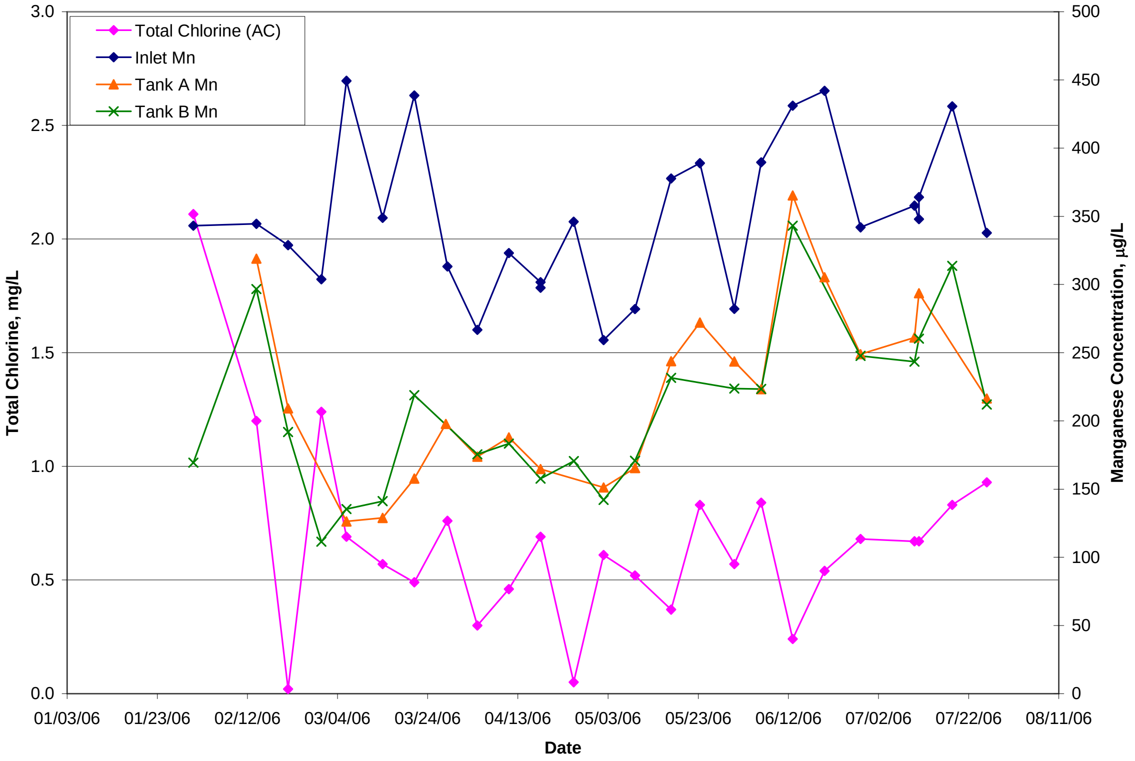


Figure 4-14. Total Manganese Concentrations Versus Total Chlorine Residuals

4.5.1.4 pH, DO, and ORP. pH values in raw water ranged from 7.2 to 7.7 and averaged 7.4. 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. Average DO levels across the treatment train ranged from 3.0 to 3.7 mg/L. Uncharacteristically high DO readings were recorded by the operator on eight occasions during the weekly sampling events (see Table 4-7). These elevated DO readings were not included in the calculation of average and standard deviation values for DO levels. In addition, elevated DO readings experienced in Tank B on June 28, 2006 and July 26, 2006 were related to a compressed air leak addressed during the next six-month study period. As a result of prechlorination, average ORP levels increased from 171 mV, on average, in raw water to over 479 mV, on average, after the contact tanks.

4.5.1.5 Chlorine and Ammonia. Total chlorine residuals ranged from 0 to 2.1 mg/L (as Cl_2) and averaged 0.7 mg/L (as Cl_2) at the AC location and were slightly lower at the TA and TB locations, ranging from 0 to 1.1 mg/L (as Cl_2) and averaging 0.5 mg/L (as Cl_2). Free chlorine residuals averaged 0.2 mg/L (as Cl_2) at the AC location and 0.1 mg/L (as Cl_2) at the TA and TB locations and were close to the method detection limit of 0.1 mg/L (as Cl_2), indicating negligible amounts in treated water. The difference between the total and free chlorine was monochloramine, which was formed in the presence of ammonia (at 0.16 mg/L [as N], on average). (Note that 0.16 mg/L of ammonia (as N) would form 0.8 mg/L of monochloramine [as Cl_2] upon chlorination). Because only 0.5 to 0.7 mg/L of total chlorine (or, more specifically, monochloramine) (as Cl_2) was formed, ammonia in raw water would not have been completely oxidized. This observation was supported by some amounts of ammonia measured, i.e., 0.06, 0.08, and 0.03 mg/L (as N), on average, after the contact tanks and after Tanks A and B, respectively. The presence of ammonia and other reducing species, such as 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 Cl_2) shown in Table 4-3, the actual chlorine dosage was estimated at an average of 4.8 mg/L (as Cl_2), based on solution level measurements and a solution strength of 15.6% (as Cl_2).

As shown in Table 4-7, total chlorine levels after the contact tanks were highly variable during the six-month study period with an average value of 0.7 mg/L and a standard deviation of +/- 0.4 mg/L. Although speciation results showed that the levels of prechlorination were adequate for As(III) and Fe(II) oxidation, the variation in chlorine levels may have affected the rate of Mn(II) oxidation. The variation in chlorine levels 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). TOC levels were 1.6 mg/L in raw water and remained unchanged across treatment train. Total phosphorus (as P) decreased from an average concentration of 27.9 μg/L in raw water to 6.0 μg/L after the pressure filters, likely due to removal onto iron solids. Turbidity also decreased from 18.8 to <1.6 NTU with treatment.

4.5.2 Backwash Water Sampling. Table 4-8 presents the analytical results of five monthly backwash water sampling events. The backwash water collected during Events 1, 2, 4, and 5 was considered characteristic of normal operating conditions. During these events, pH values ranged from 7.3 to 7.6; TDS from 938 to 1,030 mg/L (excluding Event 5); and TSS from 116 to 550 mg/L. For these events, concentrations of total arsenic, iron, and manganese ranged from 391 to 852 μg/L, 29,838 to 176,777 μg/L, and 2,009 to 8,649 μg/L, respectively, with the majority existing as particulate. Event 5 on July 18, 2006, corresponded to a filter run length of 6.0 hrs, but yielded the highest TSS at 550 mg/L and iron solids levels at 177 mg/L. Relatively low values of total metals and TSS were observed for Event 3, most likely due to the timing of the sampling, that is the manual backwash cycles might have been initiated soon after the pressure filters had just been backwashed automatically by the PLC, thus having fewer solids in backwash water for sampling. Using the average TSS of 310 mg/L for Events 1, 2, 4, and 5 and an average of 1,003 gal of backwash water per tank, approximately 5.2 lb of solids would have been generated and discharged per backwash cycle (for two tanks). This includes 1.6 lb of elemental iron, 0.09 lb of elemental manganese, and 0.01 lb of elemental arsenic.

4.5.3 Distribution System Water Sampling. Table 4-9 summarizes the results of the distribution system sampling. The water quality was similar except at the DS2 residence, which was located in the older part of town and had higher iron levels due to a history of periodic release of particulates from the distribution system. The treatment system appeared to have beneficial effects on the water quality in the distribution system. For the first three months after system startup, arsenic, iron, and manganese levels declined from the respective baseline levels, but were still relatively elevated especially at the DS2 residence. By the second quarter, the arsenic, iron, and manganese levels had decreased even further from average baseline levels of 27.4, 1,211, and 114 μg/L to 7.1, 75, and 60 μg/L (on average), respectively, which, except for manganese, were similar to those of the treatment plant effluent. Further reduction in manganese concentration was observed within the distribution system. For example, total manganese levels averaged 217 μg/L in Tank A effluent and 203 μg/L in Tank B effluent, compared to the average concentration of 60 μg/L in the distribution system in the second quarter of system operation. In June 2006, the facility operator received complaints from a few customers concerning periodic slugs of dark solids from their taps, which, among others, might have been iron and/or manganese solids accumulating within the distribution system. In the second quarter, copper decreased slightly from 179 to 127 μg/L (on average) and lead decreased from 4.2 to 1.3 μg/L (on average). Alkalinity and pH values remained fairly consistent throughout the six-month study period.

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 4-10). The equipment cost was $160,875 (or 56% of the total capital investment), which included cost for two contact tanks, two pressure filter tanks, 50 ft^3 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.

Table 4-8. Backwash Water Sampling Results

Sampling Event		BW1										BW2									
		Backwash Vessel No. 1										Backwash Vessel No. 2									
		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

Table 4-9. Distribution System Sampling Results

No. of Sampling Events	Sampling Date	DS1[b]								DS2[c]								DS3[b]							
		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	390	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	12.4	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	752	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	647	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	724	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	548
5	06/21/06	6.5	7.3	289	8.9	866	51.4	4.8	444	11.5	7.6	293	12.7	209	199	0.2	241	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

(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 $CaCO_3$).

Table 4-10. Capital Investment for Kinetico's FM-248-AS System

Description	Cost	% of Capital Investment Cost
Equipment		
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%**
Labor	$43,450	-
Subcontractor	$5,714	-
Engineering Total	**$49,164**	**17%**
Labor	$14,000	-
Subcontractor	$59,250	-
Travel	$3,870	-
Installation, Shakedown, and Startup	**$77,120**	**27%**
Total Capital Investment	**$287,159**	**-**

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 a unit cost of $0.21/1,000 gal using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-yr return period. This calculation assumed that the system operated 24 hr/day at its rated capacity. Because the system operated at approximately 238 gpm (Table 4-4), producing 6,650,000 gal of water from January 30 to July 30, 2006, the total unit cost increased to $2.00/1,000 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 4-11). Prechlorination was performed for oxidation and post-chlorination was performed to maintain a residual within the distribution system. The chemical consumption was 0.31 lb/1,000 gal for both pre- and post-chlorination, which corresponded to $0.35/1,000 gal in chemical usage cost. No cost was incurred for repairs because the system was under warranty. A comparison of the electrical bills before and after system installation will be conducted for the one-year study period. 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 $0.34/1,000 gal of water treated. The total O&M cost was estimated at $0.69/1,000 gal of treated water.

Table 4-11. O&M Costs for Kinetico's FM-248-AS System

Category	Value	Remarks
Volume Processed (1,000 gal)	6,650,000	From 01/30/06 to 07/30/06
Chemical Consumption		
Sodium Hypochlorite Unit Price ($/lb)	$1.10	15.6% as Cl_2
Consumption Rate (lb/1,000 gal)	0.31	Pre- and post-chlorination
Chemical Costs ($/1,000 gal)	$0.35	Pre- and post-chlorination
Electricity Consumption		
Electricity Cost ($/1,000 gal)	TBD	To be evaluated on annual basis
Labor		
Labor (hr/week)	1.75	15 min/day, 7 days/week
Labor Cost ($/1,000 gal)	$0.34	Labor rate = $10/hr + $300/month fee
Total O&M Cost ($/1,000 gal)	$0.69	

TBD = to be determined

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APPENDIX A

OPERATIONAL DATA

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

Week No.	Date	Tank A Cumulative Run Time	Run Time	Tank B Cumulative Run Time	Run Time	Pressure Filtration					Backwash		
						Inlet-TA	Inlet-TB	Inlet-Effluent	Flow rate	Gallon Usage	Tank A	Tank B	Cum. Volume
		hrs	hrs/day	hrs	hrs/day	psig	psig	psig	gpm	gpd	No.	No.	kgal
1	01/30/06	33.0	NA	32.0	NA	9	9	32	244	NA	6	6	13.2
	01/31/06	35.0	2.4	34.0	2.4	10	11	33	238	48,557	6	6	13.2
	02/01/06	38.0	2.4	37.0	2.4	NA	NA	NA	NA	29,588	7	7	15.4
	02/02/06	40.0	2.0	39.0	2.0	NA	NA	NA	NA	25,874	7	7	15.4
	02/03/06	42.0	2.0	41.0	2.0	NA	NA	NA	NA	23,338	8	8	17.2
	02/04/06	44.0	2.2	43.0	2.2	10	11	33	243	27,014	8	8	17.2
	02/05/06	48.0	3.5	47.0	3.5	NA	NA	NA	NA	42,997	9	9	19.0
2	02/06/06	50.0	2.1	49.0	2.1	NA	NA	NA	NA	24,467	9	9	19.0
	02/07/06	52.0	2.0	51.0	2.0	10	55	63	155	23,500	10	10	21.2
	02/08/06	55.0	3.0	54.0	3.0	NA	NA	NA	NA	41,100	10	10	21.2
	02/09/06	57.0	2.0	56.0	2.0	NA	NA	NA	NA	24,200	10	10	21.2
	02/10/06	60.0	3.0	59.0	3.0	NA	NA	NA	NA	23,700	11	11	23.7
	02/11/06	62.0	2.0	61.0	2.0	9	11	33	241	23,314	11	11	23.7
	02/12/06	66.0	4.1	65.0	4.1	NA	NA	NA	NA	50,721	12	12	26.6
3	02/13/06	68.0	2.0	67.0	2.0	NA	NA	NA	NA	21,061	12	12	26.6
	02/14/06	70.0	2.0	69.0	2.0	NA	NA	NA	NA	29,838	12	12	27.2
	02/15/06	72.0	2.0	71.0	2.0	NA	NA	NA	NA	NA	13	13	29.4
	02/16/06	74.0	2.0	73.0	2.0	NA	NA	NA	NA	49,371	13	13	29.4
	02/17/06	77.0	3.0	76.0	3.0	NA	8	31	240	40,800	14	14	31.5
	02/18/06	80.0	3.0	79.0	3.0	NA	NA	NA	NA	31,662	14	14	31.5
	02/19/06	82.0	2.0	81.0	2.0	NA	NA	NA	NA	39,425	14	14	32.2
4	02/20/06	85.0	2.8	84.0	2.8	NA	NA	NA	NA	27,635	15	15	34.4
	02/21/06	87.0	2.2	86.0	2.2	NA	NA	NA	NA	31,770	15	15	34.4
	02/22/06	89.0	2.0	88.0	2.0	NA	NA	NA	NA	22,366	16	16	37.3
	02/23/06	91.0	2.0	90.0	2.0	NA	NA	NA	NA	22,313	16	16	37.3
	02/24/06	94.0	2.9	93.0	2.9	NA	NA	NA	NA	42,916	17	17	39.1
	02/25/06	96.0	1.9	95.0	1.9	NA	NA	NA	NA	23,067	17	17	39.1
	02/26/06	98.0	2.1	97.0	2.1	8	14	33	240	28,314	18	18	40.0

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

Week No.	Date	Tank A Cumulative Run Time	Run Time	Tank B Cumulative Run Time	Run Time	Pressure Filtration					Backwash		
		hrs	hrs/day	hrs	hrs/day	Inlet-TA psig	Inlet-TB psig	Inlet-Effluent psig	Flow rate gpm	Gallon Usage gpd	Tank A No.	Tank B No.	Cum. Volume kgal
5	02/27/06	102.0	3.9	101.0	3.9	NA	NA	NA	NA	40,375	18	18	41.8
	02/28/06	NA	NA	1.5	NA	7	8	31	243	33,044	19	19	44.1
	03/01/06	3.3	NA	3.3	1.8	NA	NA	NA	NA	33,067	19	19	44.1
	03/02/06	5.3	2.0	5.3	2.0	NA	NA	NA	NA	23,084	19	19	44.1
	03/03/06	8.5	3.1	8.4	3.0	NA	NA	NA	NA	23,380	19	19	44.1
	03/04/06	11.1	2.4	11.0	2.4	NA	NA	NA	NA	20,426	19	19	44.1
	03/05/06	15.9	5.1	15.8	5.1	NA	NA	NA	NA	50,272	19	19	44.1
6	03/06/06	NA	NA	NA	NA	NA	NA	NA	NA	22,897	19	19	44.1
	03/07/06	20.0	NA	19.7	NA	NA	NA	NA	NA	26,155	20	20	46.5
	03/08/06	22.4	2.4	22.1	2.4	NA	NA	NA	NA	NA	20	20	0.0
	03/09/06	24.5	2.2	24.3	2.3	NA	NA	NA	NA	23,843	20	20	0.0
	03/10/06	29.2	4.4	29.0	4.4	NA	NA	NA	NA	43,645	20	20	0.0
	03/11/06	34.8	5.2	34.6	5.2	NA	NA	NA	NA	33,932	20	20	0.0
	03/12/06	39.7	4.9	39.4	4.8	19	17	39	222	43,009	20	20	0.0
7	03/13/06	41.3	1.7	41.5	2.3	NA	NA	NA	NA	25,753	20	20	0.0
	03/14/06	45.0	3.6	44.6	3.0	NA	NA	NA	NA	30,028	21	21	3.4
	03/15/06	47.6	2.7	47.2	2.7	10	11	33	242	23,081	21	21	3.4
	03/16/06	51.3	3.8	50.9	3.8	NA	NA	NA	NA	43,495	21	21	3.4
	03/17/06	54.8	3.5	54.4	3.5	16	17	36	230	30,000	21	21	3.4
	03/18/06	64.1	9.3	63.7	9.3	18	19	37	226	113,521	21	21	3.4
	03/19/06	67.2	2.9	67.0	3.1	NA	NA	NA	NA	39,484	22	22	5.8
8	03/20/06	67.2	0.0	67.0	0.0	NA	NA	NA	NA	0	22	22	5.8
	03/21/06	67.4	0.2	67.2	0.2	NA	NA	NA	NA	3,261	22	22	5.8
	03/22/06	70.2	2.8	70.0	2.8	NA	NA	NA	NA	24,923	22	22	5.8
	03/23/06	73.2	2.8	73.0	2.8	NA	NA	NA	NA	35,517	22	22	5.8
	03/24/06	76.7	3.8	76.7	4.0	NA	NA	NA	NA	52,811	23	23	8.8
	03/25/06	79.0	2.0	79.0	2.0	NA	NA	NA	NA	22,545	23	23	8.8
	03/26/06	82.7	3.7	82.7	3.7	12	13	34	236	27,491	23	23	8.8

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

Week No.	Date	Tank A Cumulative Run Time	Run Time	Tank B Cumulative Run Time	Run Time	Pressure Filtration					Backwash		
						Inlet-TA	Inlet-TB	Inlet-Effluent	Flow rate	Gallon Usage	Tank A	Tank B	Cum. Volume
		hrs	hrs/day	hrs	hrs/day	psig	psig	psig	gpm	gpd	No.	No.	kgal
9	03/27/06	86.0	3.8	86.0	3.8	8	9	31	243	40,417	24	24	10.9
	03/28/06	88.3	2.2	88.3	2.2	NA	NA	NA	NA	29,810	24	24	10.9
	03/29/06	90.7	2.2	90.8	2.3	NA	NA	NA	NA	21,968	24	24	10.9
	03/30/06	93.0	2.6	93.1	2.6	NA	NA	NA	NA	26,796	25	25	12.9
	03/31/06	95.2	2.1	95.3	2.1	NA	NA	NA	NA	23,268	25	25	12.9
	04/01/06	100.0	5.0	100.0	4.9	NA	NA	NA	NA	52,696	25	25	13.7
	04/02/06	102.2	2.1	102.2	2.1	NA	NA	NA	NA	24,854	26	26	14.5
10	04/03/06	103.6	1.5	103.6	1.5	8	8	31	243	13,873	26	26	14.5
	04/04/06	107.1	3.6	107.1	3.6	NA	NA	NA	NA	46,471	27	26	14.5
	04/05/06	109.8	2.7	109.8	2.7	NA	NA	NA	NA	25,412	27	27	16.4
	04/06/06	111.7	2.0	111.7	2.0	NA	NA	NA	NA	24,395	27	27	16.4
	04/07/06	114.2	2.4	114.3	2.5	7	9	31	245	11,626	28	28	17.8
	04/08/06	117.2	2.8	117.3	2.8	8	10	31	243	31,549	28	28	17.8
	04/09/06	120.1	2.9	120.2	2.9	NA	NA	NA	NA	34,205	28	28	17.8
11	04/10/06	122.4	2.4	122.5	2.4	NA	NA	NA	NA	24,737	29	29	19.6
	04/11/06	112.7	NA	112.7	NA	NA	NA	NA	NA	NA	27	27	16.4
	04/12/06	115.5	2.8	115.2	2.5	NA	NA	NA	NA	35,259	27	28	17.5
	04/13/06	117.1	1.6	116.8	1.6	NA	NA	NA	NA	21,144	27	28	17.5
	04/14/06	121.4	4.0	121.1	4.0	17	15	36	233	39,410	27	28	17.5
	04/15/06	126.6	5.1	126.6	5.4	NA	NA	NA	NA	57,344	28	29	19.8
	04/16/06	129.7	3.3	129.5	3.1	10	12	33	240	26,065	28	29	19.8
12	04/17/06	134.5	5.3	134.3	5.3	NA	NA	NA	NA	45,439	29	30	21.8
	04/18/06	135.3	0.7	135.1	0.7	NA	NA	NA	NA	10,378	30	31	25.2
	04/19/06	139.0	3.7	138.9	3.8	NA	NA	NA	NA	48,924	30	31	25.2
	04/20/06	141.3	2.3	141.1	2.2	NA	NA	NA	NA	28,239	30	31	25.2
	04/21/06	144.0	2.7	143.7	2.6	NA	NA	NA	NA	34,669	31	32	27.2
	04/22/06	146.7	2.6	146.5	2.7	NA	NA	NA	NA	33,905	31	32	27.2
	04/23/06	149.3	2.4	149.0	2.3	NA	NA	NA	NA	29,894	32	32	30.7

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

Week No.	Date	Tank A Cumulative Run Time	Run Time	Tank B Cumulative Run Time	Run Time	Pressure Filtration					Backwash		
						Inlet-TA	Inlet-TB	Inlet-Effluent	Flow rate	Gallon Usage	Tank A	Tank B	Cum. Volume
		hrs	hrs/day	hrs	hrs/day	psig	psig	psig	gpm	gpd	No.	No.	kgal
13	04/24/06	151.8	2.9	151.6	3.0	NA	NA	NA	NA	38,805	32	33	30.7
	04/25/06	153.3	1.5	153.3	1.6	NA	NA	NA	NA	18,000	33	34	33.6
	04/26/06	155.5	2.3	155.4	2.2	NA	NA	NA	NA	31,073	33	34	33.6
	04/27/06	157.8	2.3	157.7	2.3	NA	NA	NA	NA	30,253	34	35	36.5
	04/28/06	160.2	2.4	160.1	2.4	NA	NA	NA	NA	32,191	35	35	38.5
	04/29/06	162.4	2.1	162.3	2.1	NA	NA	NA	NA	27,880	35	35	38.5
	04/30/06	166.8	4.0	166.9	4.2	NA	NA	NA	NA	54,656	36	36	40.1
14	05/01/06	171.2	5.0	171.1	4.8	NA	NA	NA	NA	NA	36	36	41.1
	05/02/06	175.6	4.2	175.7	4.4	8	9	31	242	49,685	37	37	44.0
	05/03/06	176.3	0.7	176.3	0.6	NA	NA	NA	NA	9,032	37	37	44.0
	05/04/06	184.3	8.4	184.3	8.4	NA	NA	NA	NA	98,881	37	38	44.6
	05/05/06	186.6	2.2	186.6	2.2	NA	NA	NA	NA	29,187	38	38	45.0
	05/06/06	189.2	2.6	189.2	2.6	NA	NA	NA	NA	33,704	38	38	45.0
	05/07/06	191.5	2.2	191.6	2.3	NA	NA	NA	NA	29,500	39	39	45.9
15	05/08/06	194.8	3.4	194.9	3.4	NA	NA	NA	NA	41,554	39	39	45.9
	05/09/06	197.6	2.8	197.7	2.8	NA	NA	NA	NA	36,074	39	39	46.3
	05/10/06	200.3	2.8	200.4	2.8	NA	NA	NA	NA	36,671	40	40	46.8
	05/11/06	200.3	0.0	200.4	0.0	NA	NA	NA	NA	NA	40	41	47.2
	05/12/06	203.4	3.1	203.5	3.1	NA	NA	NA	NA	40,308	41	41	47.7
	05/13/06	205.9	2.5	206.0	2.5	NA	NA	NA	NA	33,078	41	42	48.1
	05/14/06	208.6	2.6	208.7	2.6	NA	NA	NA	NA	34,956	42	42	48.6
16	05/15/06	211.0	2.4	211.1	2.4	NA	NA	NA	NA	32,949	42	42	48.6
	05/16/06	211.9	0.9	212.1	1.0	9	10	32	242	13,072	43	43	49.5
	05/17/06	215.8	3.9	215.7	3.6	12	14	34	237	50,031	43	43	49.5
	05/18/06	218.4	2.5	218.4	2.6	14	11	34	235	33,733	43	44	50.0
	05/19/06	223.2	4.6	223.2	4.6	NA	NA	NA	NA	59,839	44	44	50.4
	05/20/06	225.2	2.2	225.2	2.2	14	12	34	239	28,519	44	45	50.9
	05/21/06	229.4	3.9	229.4	3.9	NA	NA	NA	NA	52,221	45	45	51.3

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

Week No.	Date	Tank A Cumulative Run Time	Run Time	Tank B Cumulative Run Time	Run Time	Pressure Filtration					Backwash		
						Inlet-TA	Inlet-TB	Inlet-Effluent	Flow rate	Gallon Usage	Tank A	Tank B	Cum. Volume
		hrs	hrs/day	hrs	hrs/day	psig	psig	psig	gpm	gpd	No.	No.	kgal
17	05/22/06	232.7	3.5	232.8	3.6	NA	NA	NA	NA	45,935	45	45	51.3
	05/23/06	235.9	3.2	236.0	3.2	NA	NA	NA	NA	42,300	46	46	52.2
	05/24/06	238.9	3.0	238.9	2.9	NA	NA	NA	NA	39,318	46	46	52.2
	05/25/06	242.2	3.3	242.2	3.3	NA	NA	NA	NA	41,598	46	47	52.7
	05/26/06	246.1	4.1	246.1	4.1	10	13	33	237	52,591	47	47	53.1
	05/27/06	252.3	8.3	252.2	8.1	NA	NA	NA	NA	107,333	47	48	53.6
	05/28/06	255.6	2.7	255.6	2.8	NA	NA	NA	NA	36,289	48	48	54.0
18	05/29/06	259.2	3.4	259.7	3.8	14	16	35	234	43,557	48	48	54.0
	05/30/06	265.6	6.2	265.7	5.8	NA	NA	NA	NA	81,506	48	49	54.5
	05/31/06	270.6	5.1	270.7	5.1	14	17	35	234	67,342	49	49	54.9
	06/01/06	274.9	4.2	275.0	4.2	NA	NA	NA	NA	52,780	49	49	54.9
	06/02/06	280.8	6.1	280.9	6.1	NA	NA	NA	NA	78,769	50	50	55.8
	06/03/06	284.0	3.1	284.2	3.2	NA	NA	NA	NA	39,750	50	50	55.8
	06/04/06	287.0	3.1	287.2	3.1	NA	NA	NA	NA	39,636	50	51	56.8
19	06/05/06	289.9	3.0	290.1	3.0	NA	NA	NA	NA	39,685	51	51	57.3
	06/06/06	292.8	2.9	293.0	2.9	NA	NA	NA	NA	38,100	52	52	58.2
	06/07/06	296.2	3.3	296.5	3.4	NA	NA	NA	NA	45,080	52	52	58.2
	06/08/06	299.0	2.8	299.2	2.7	NA	NA	NA	NA	35,776	53	53	59.1
	06/09/06	301.9	2.9	302.1	2.9	NA	NA	NA	NA	NA	54	53	59.1
	06/10/06	304.5	3.6	304.3	3.1	NA	NA	NA	NA	48,421	54	54	60.0
	06/11/06	307.3	2.1	307.5	2.3	NA	NA	NA	NA	27,390	54	54	60.0
20	06/12/06	310.7	3.5	311.0	3.6	NA	NA	NA	NA	46,838	55	55	61.0
	06/13/06	314.1	3.6	314.4	3.6	NA	NA	NA	NA	46,886	55	55	61.0
	06/14/06	316.9	2.9	317.1	2.8	NA	NA	NA	NA	37,151	56	56	61.8
	06/15/06	319.6	2.6	319.8	2.6	NA	NA	NA	NA	33,584	56	56	61.8
	06/16/06	322.9	3.5	323.0	3.4	NA	NA	NA	NA	43,799	57	57	62.7
	06/17/06	325.9	2.7	325.9	2.6	NA	NA	NA	NA	34,539	57	57	62.7
	06/18/06	328.9	3.1	328.9	3.1	NA	NA	NA	NA	40,513	57	57	62.7

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

Week No.	Date	Tank A Cumulative Run Time	Run Time	Tank B Cumulative Run Time	Run Time	Pressure Filtration					Backwash		
						Inlet-TA	Inlet-TB	Inlet-Effluent	Flow rate	Gallon Usage	Tank A	Tank B	Cum. Volume
		hrs	hrs/day	hrs	hrs/day	psig	psig	psig	gpm	gpd	No.	No.	kgal
21	06/19/06	331.9	3.3	331.8	3.2	NA	NA	NA	NA	43,299	58	58	63.7
	06/20/06	335.2	3.2	335.2	3.3	NA	NA	NA	NA	42,699	59	59	64.6
	06/21/06	338.2	3.1	338.2	3.1	NA	NA	NA	NA	40,555	60	60	65.5
	06/22/06	341.1	2.8	341.1	2.8	NA	NA	NA	NA	36,480	60	60	65.5
	06/23/06	346.9	5.8	346.9	5.8	NA	NA	NA	NA	77,615	61	61	66.4
	06/24/06	349.7	2.4	349.6	2.4	NA	NA	NA	NA	32,058	61	61	66.4
	06/25/06	349.7	0.0	349.6	0.0	NA	NA	NA	NA	0	62	62	67.3
22	06/26/06	352.5	2.9	352.4	2.9	NA	NA	NA	NA	38,710	63	63	68.3
	06/27/06	355.2	2.8	355.1	2.8	NA	NA	NA	NA	37,862	63	63	68.3
	06/28/06	358.1	2.8	357.9	2.7	NA	NA	NA	NA	37,523	63	63	68.3
	06/29/06	361.8	3.3	361.5	3.2	8	9	31	243	43,830	65	65	74.6
	06/30/06	363.7	2.1	363.3	2.0	NA	NA	NA	NA	27,062	65	65	74.6
	07/01/06	369.9	5.5	369.5	5.5	NA	NA	NA	NA	72,752	66	66	76.9
	07/02/06	372.6	3.1	372.2	3.1	13	14	34	234	41,407	66	66	76.9
23	07/03/06	376.6	3.6	376.1	3.5	NA	NA	NA	NA	45,798	66	66	76.9
	07/04/06	379.6	3.3	379.0	3.2	NA	NA	NA	NA	43,123	67	67	80.8
	07/05/06	383.8	3.9	383.2	3.9	13	14	34	237	51,212	67	67	80.8
	07/06/06	389.3	5.6	388.7	5.6	NA	NA	NA	NA	72,457	68	68	83.1
	07/07/06	391.5	2.3	390.8	2.2	NA	NA	NA	NA	30,417	69	69	84.1
	07/08/06	393.6	2.2	392.9	2.2	NA	NA	NA	NA	29,222	69	69	84.1
	07/09/06	398.3	4.0	397.8	4.2	NA	NA	NA	NA	53,437	70	70	85.0
24	07/10/06	400.6	2.7	400.0	2.6	NA	NA	NA	NA	32,211	70	70	85.0
	07/11/06	405.7	4.2	405.1	4.2	NA	NA	NA	NA	55,904	71	71	85.9
	07/12/06	408.0	3.0	407.4	3.0	NA	NA	NA	NA	39,285	71	71	85.9
	07/13/06	410.1	2.1	409.5	2.1	NA	NA	NA	NA	26,884	71	71	85.9
	07/14/06	414.8	4.7	414.2	4.7	NA	NA	NA	NA	61,103	72	72	86.8
	07/15/06	418.5	3.5	418.0	3.6	14	16	35	232	45,158	72	72	86.8
	07/16/06	421.8	3.5	421.3	3.5	NA	NA	NA	NA	46,531	73	73	87.7

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

Week No.	Date	Tank A Cumulative Run Time	Run Time	Tank B Cumulative Run Time	Run Time	Pressure Filtration Inlet-TA	Pressure Filtration Inlet-TB	Pressure Filtration Inlet-Effluent	Pressure Filtration Flow rate	Pressure Filtration Gallon Usage	Backwash Tank A	Backwash Tank B	Backwash Cum. Volume
		hrs	hrs/day	hrs	hrs/day	psig	psig	psig	gpm	gpd	No.	No.	kgal
25	07/17/06	423.9	2.1	423.5	2.2	NA	NA	NA	NA	28,438	73	73	87.7
	07/18/06	427.9	4.0	428.5	5.0	NA	NA	NA	NA	50,035	74	74	87.7
	07/19/06	433.8	5.2	433.6	4.5	NA	NA	NA	NA	70,384	74	74	87.7
	07/20/06	436.5	3.1	436.4	3.2	NA	NA	NA	NA	40,197	74	74	88.7
	07/21/06	438.8	2.4	438.7	2.4	NA	NA	NA	NA	32,023	75	75	89.6
	07/22/06	440.9	1.9	440.8	1.9	NA	NA	NA	NA	25,118	75	75	89.6
	07/23/06	443.7	3.0	443.7	3.1	8	9	31	244	38,936	76	76	91.5
26	07/24/06	448.0	4.4	447.9	4.3	NA	NA	NA	NA	57,971	76	76	91.5
	07/25/06	450.2	2.2	450.1	2.2	NA	NA	NA	NA	29,420	77	77	93.5
	07/26/06	452.4	2.0	452.3	2.0	NA	NA	NA	NA	27,029	77	77	93.5
	07/27/06	454.6	2.4	454.5	2.4	NA	NA	NA	NA	32,171	78	78	95.4
	07/28/06	459.2	4.5	459.2	4.6	11	13	33	234	59,878	78	78	95.4
	07/29/06	461.4	2.1	461.5	2.2	NA	NA	NA	NA	27,984	78	78	95.4
	07/30/06	466.0	4.4	466.1	4.4	NA	NA	NA	NA	57,581	79	79	97.4

APPENDIX B

ANALYTICAL DATA TABLES

Sampling Date		01/31/06(a)			02/14/06(d)				02/21/06				02/28/06(d)			03/6/06(d)			
Sampling Location Parameter	Unit	IN	AC	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TB	IN	AC	TA	TB
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(b)	-	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	-	0.02	-	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) Estimated concentration. (d) No treatment due to chlorine fitting leak on 02/12/06. A series of repairs were made between 02/14/06 and 02/21/06 to restore prechlorination.
(d) Backwash control malfunction allowed system to operate without backwashing every 48 hours of standby time until PLC change on 04/11/06.

Sampling Date		03/14/06[a]				03/21/06[b]				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 until PLC change on 04/11/06.
(b) Backwash manually initiated by operator until PLC change on 04/11/06.
Manual backwash performed until programming changed.

Sampling Date		04/18/06				04/25/06			05/02/06				05/09/06				05/17/06			
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Alkalinity (as $CaCO_3$)	mg/L	316	312	312	312	313	317	317	300	292	292	296	302	297	297	302	298	298	294	302
		321	312	312	312	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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	36.1	<10	<10	30.9	31.1	<10	-	-	-	-	14.8	16.0	<10	<10	14.0	14.5	<10	<10
		34.8	37.7	<10	<10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	30.5	29.4	28.4	28.9	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
		28.7	28.7	28.8	29.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	18.0	1.5	0.5	0.4	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
		19.0	1.6	0.4	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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	42.4	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
		41.6	44.2	4.6	4.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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	1,430	27	<25	1,417	1,516	31	1,281	1,297	70	<25	1,257	1,362	77	126	1,413	1,447	52	92
		1,401	1,389	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	914	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	302	305	165	158	346	346	171	259	259	151	142	282	289	165	171	378	369	244	231
		298	296	158	156	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	352	148	150	-	-	-	-	-	-	-	-	-	-	-	-

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.

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	297 297	302 297	297 302	284 -	301 -	288 -	296 -	292 -	292 -	300 -
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 40.7	37.5 42.4	10.3 <10	<10 <10	27.4 -	30.5 -	<10 -	35.3 -	35.6 -	<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	29.8 30.3	29.5 29.5	29.6 29.4	29.3 -	29.3 -	29.2 -	30.1 -	30.5 -	29.1 -	29.9 -
Turbidity	NTU	18.0 -	1.3 -	0.5 -	0.7 -	16.0 -	3.5 -	0.8 -	1.6 -	19.0 19.0	2.3 1.6	2.5 0.5	0.2 0.4	16.0 -	2.2 -	0.7 -	16.0 -	0.9 -	0.3 -	0.9 -
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(b)	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 38.9	35.1 38.5	6.0 5.1	6.2 5.8	38.8 -	38.1 -	6.8 -	49.8 -	51.3 -	10.6(c) -	9.9 -
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 1,381	1,226 1,419	81 62	88 97	1,265 -	1,372 -	113 -	1,375 -	1,385 -	175 -	158 -
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	1,020	<25	<25	-	-	-	-
Mn (total)	µg/L	342 -	344 -	249 -	248 -	358 -	370 -	261 -	243 -	348 364	325 368	294 285	260 259	431 -	424 -	314 -	338 -	342 -	216 -	212 -
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	432	294	300	-	-	-	-

(a)Water quality parameters measured on 07/10/06. (b) DO levels high on TB potentially due to compressed air line leak. (c) Exceedance of arsenic MCL occurred.