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Arsenic Removal from Drinking Water by Iron Removal U.S. EPA Demonstration Project at Big Sauk Lake Mobile Home Park in Sauk Centre, MN Final Performance Evaluation Report

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FOREWORD

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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 one-year arsenic removal treatment technology demonstration project at the Big Sauk Lake Mobile Home Park (BSLMHP) in Sauk Centre, MN. The objectives of the project are to evaluate (1) the effectiveness of Kinetico's Macrolite® pressure filtration process in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 µg/L, (2) the reliability of the treatment system, (3) the required system operation and maintenance (O&M) and operator skill levels, and (4) the capital and O&M cost of the technology. The project also is characterizing water in the distribution system and process residuals produced by the treatment system.

BSLMHP provided water to 37 mobile homes with an average daily demand of 7,500 gal. Source water contained 27.5 µg/L (on average) of total arsenic, 2,385 µg/L of total iron, and 130 µg/L of total manganese. Because of the reducing condition with the source water, almost all iron and manganese existed in the soluble form and over 80% (on average) of arsenic existed as soluble As(III). The remainder of arsenic was present as soluble As(V) (13%) and particulate arsenic. The source water also contained, on average, 3.3 mg/L of total organic carbon (TOC), 1.2 mg/L of ammonia (as N), and 417 µg/L of phosphorous (as P).

The Macrolite® CP-213f arsenic removal system evaluated consisted of a $KMnO_4$ feed system, two 36-in × 57-in contact tanks (205 gal each), and four 13-in × 54-in pressure filters (two for each duplex unit) arranged in parallel. Potassium permanganate ($KMnO_4$) was used to oxidize As(III) and Fe(II) prior to Macrolite® pressure filtration. $KMnO_4$ was selected over chlorine due to the presence of elevated TOC and ammonia in source water. Each pressure filter contained 20 in (or 1.5 ft^3) of Macrolite®, a low-density, spherical media (40 × 60 U.S. Standard Mesh) designed for a filtration rate two times higher than a conventional gravity filter. The design flowrate was 20 gal/min (gpm), which yielded 20 min of contact time prior to filtration and 5.4 gpm/ft^2 of hydraulic loading to the Macrolite® filters. Because of the on-demand operation, the actual flowrates ranged from 1 to 15 gpm, corresponding to 27 to 412 min of contact time and 0.3 to 4.1 gpm/ft^2 of hydraulic loading.

From July 13, 2005, through October 1, 2006, the well operated for a total of 2,052 hr at approximately 4.6 hr/day. The system treated approximately 2,017,000 gal of water with an average daily demand of 4,523 gal. $KMnO_4$ effectively oxidized As(III) in source water even in the presence of TOC, as evidenced by reducing its concentrations from 21.9 µg/L (on average) to 1.0 µg/L after contact tanks and forming an average of 22.7 µg/L of particulate arsenic with arsenic presumably bound to iron particles.

During the performance evaluation study, total arsenic levels in the treated water were reduced to an average of 6.4 µg/L mainly in the soluble form. Out of 60 sampling events, arsenic concentrations in treated water exceeded the 10-µg/L MCL for a total of 13 times, mostly due to particulate breakthrough from the Macrolite® filters. To address particulate arsenic breakthrough, the backwash frequency was increased incrementally from every 2,743 gal to every 916 gal of throughput for each filter.

With an average soluble iron to soluble arsenic ratio of 88:1, there was sufficient natural iron present in the source water for effective arsenic removal. Soluble iron was oxidized by $KMnO_4$ to form iron particles, which adsorbed and/or co-precipitated with arsenic before being removed by the filters. Total iron concentrations in the treated water ranged from <25 to 2,363 µg/L and averaged 204 µg/L. An increase in particulate iron correlated with an increase in particulate arsenic, indicating particulate breakthrough from the Macrolite® filters.

The high levels of TOC in the source water appeared to have inhibited the formation of filterable manganese solids. Before November 15, 2005, with the addition of 1.4 to 3.8 mg/L of $KMnO_4$, manganese concentrations after the contact tanks were present primarily in the "soluble" and/or colloidal form that passed through 0.45-µm disc filters, with levels ranging from 416 to 1,126 µg/L. A series of jar tests were conducted in the laboratory to determine if higher $KMnO_4$ dosages might help overcome the TOC effect and form larger filterable MnO_2 solids. Based on the results of the jar tests, the $KMnO_4$ dosage was increased to 5.2 mg/L. After November 15, 2005, with the addition of 4.4 to 5.8 mg/L of $KMnO_4$, soluble manganese concentrations after the contact tank, as determined by the use of 0.45-µm disc filters, were reduced to as low as 35 µg/L (on average during February 3 through June 15, 2006) with total manganese concentrations remaining as high as 1,179 µg/L. Meanwhile, total and soluble manganese concentrations, as determined, again, by the use of 0.45-µm disc filters, were reduced, on average, to 163 and 78 µg/L, respectively, during the same test period.

During the 15-month performance period, the control valve on top of each duplex unit was changed out five times to increase the backwash frequency in order to control the particulate arsenic, iron, and manganese breakthrough. The backwash frequency was increased from the initial field setting of every 2,743 gal to every 916 gal per tank. Thereafter, except for three events with elevated arsenic and iron concentrations detected in treated water, the treatment system was working properly as indicated by nine consecutive sampling events where both arsenic and iron were below their respective MCL and secondary maximum contaminant level (SMCL).

The backwash water contained, on average, 130 µg/L of total arsenic, 19.5 mg/L of total iron, and 7.2 mg/L of total manganese. Total suspended solids (TSS) levels ranged from 22.0 to 150 mg/L, averaging 72 mg/L. Based on 72 mg/L of TSS in 130 gal of backwash wastewater produced by one tank, approximately 35.4 g (0.078 lb) of solids were discharged to the septic system and then to a sanitary sewer, containing 63.7 mg of arsenic, 9.6 g of iron, and 3.5 g of manganese. Arsenic, iron, and manganese levels in the backwash solids averaged 2.03 mg/g (or 0.2%), 190 mg/g (or 19%), and 136 mg/g (or 13.6%), respectively.

In general, with the exception of manganese, the water quality in the distribution system has improved after installation of the treatment system, as evidenced by the reduced arsenic and iron concentrations and little or no changes to the pH, alkalinity, lead, and copper. For example, after the treatment system began operation, arsenic and iron concentrations decreased from average baseline levels of 23.4 and 2,791 µg/L to 8.1 and 173 µg/L, respectively. Manganese concentrations increased from average baseline levels of 130 to 397 µg/L due to the additon of $KMnO_4$. Lead concentrations remained fairly constant and averaged 0.6 and 1.6 µg/L before and after system operation (except for a spike of 25.2 µg/L at DS3 on June 14, 2006). Copper concentrations increased from the baseline level of 1.8 to 18.5 µg/L, including a spike of 228 µg/L. Alkalinity and pH concentrations remained fairly constant.

The capital investment cost was $63,547, which included $22,422 for equipment, $20,227 for engineering, and $20,898 for installation. Using the system's rated capacity of 20 gpm (28,800 gal/day [gpd]), the capital cost was $3,177/gpm ($2.21/gpd). The O&M cost for the Macrolite® CP-213f system included only incremental cost associated with the chemical supply, electricity consumption, and labor. The O&M cost was estimated to be $0.36/1,000 gal during the entire performance evaluation period.

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ABBREVIATIONS AND ACRONYMS

Δp	differential pressure
AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
As	arsenic
bgs	below ground surface
BSLMHP	Big Sauk Lake Mobile Home Park
Ca	calcium
C/F	coagulation/filtration
Cu	copper
DO	dissolved oxygen
DOM	dissolved organic matter
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
FRP	fiberglass reinforced plastic
GFH	granular ferric hydroxide
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	Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MDH	Minnesota Department of Health
MEI	Magnesium Elektron, Inc.
Mg	magnesium
Mn	manganese
Mo	molybolenum
mV	millivolts
Na	sodium
NA	not applicable
NaOCl	sodium hypochlorite

NRMRL	National Risk Management Research Laboratory
NTU	nephelometric turbidity units
O&M	operation and maintenance
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
PE	professional engineer
P&ID	piping and instrumentation diagrams
POU	point-of-use
psi	pounds per square inch
PVC	polyvinyl chloride
QA	quality assurance
QAPP	quality assurance project plan
QA/QC	quality assurance/quality control
RO	reverse osmosis
RPD	relative percent difference
rpm	rotations per min
Sb	antimony
SDWA	Safe Drinking Water Act
SMCL	Secondary Maximum Contaminant Level
STS	Severn Trent Services
TBD	to be determined
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
TTHM	total trihalomethane
V	vanadium

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Ms. Tien Shiao, who is currently pursuing a Master's degree at Yale University, was the Battelle study lead for this demonstration project.

Section 1.0: INTRODUCTION

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

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

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

In 2003, EPA initiated Round 2 arsenic technology demonstration projects that were partially funded with Congressional add-on funding to the EPA budget. In June 2003, EPA selected 32 potential demonstration sites and the Big Sauk Lake Mobile Home Park (BSLMHP) in Sauk Centre, MN was one of them.

In September 2003, EPA, again solicited proposals from engineering firms and vendors for arsenic removal technologies. EPA received 148 technical proposals for the 32 host sites, with each site receiving from two to eight proposals. In April 2004, another technical panel was convened by EPA to review the proposals and provide recommendations to EPA with the number of proposals per site ranging from none (for two sites) to a maximum of four. The final selection of the treatment technology at the sites that received at least one proposal was made, again through a joint effort by EPA, the state regulators, and the host site. Since then, four sites have withdrawn from the demonstration program, reducing the number of sites to 28. Kinetico's Macrolite® Arsenic Removal Technology was selected for demonstration at the BSLMHP site.

As of December 2008, 39 of the 40 systems were operational, and the performance evaluation of 32 systems was completed.

1.1 Treatment Technologies for Arsenic Removal

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

1.2 Project Objectives

The objective of the Round 1 and Round 2 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 Macrolite® CP-213f arsenic removal system at BSLMHP in Sauk Centre, MN from July 13, 2005, through October 6, 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 Round 1 and Round 2 Arsenic Removal Demonstration Sites

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

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

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

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

(a) Arsenic existing mostly as As(III).
(b) Design flowrate reduced by 50% due to system reconfiguration from parallel to series operation.
(c) Iron existing mostly as Fe(II).
(d) Withdrew from program in 2008.
(e) Facilities upgraded systems in Springfield, OH from 150 to 250 gpm, Sandusky, MI from 210 to 340 gpm, and Arnaudville, LA from 385 to 770 gpm.
(f) Including nine residential units.
(g) Including eight under-the-sink units.

Section 2.0: SUMMARY AND CONCLUSIONS

Based on the information collected during the 15-month system operation, the following conclusions were made relating to the overall objectives of the treatment technology demonstration study.

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

- $KMnO_4$, selected over chlorine because of the presence of elevated total organic carbon (TOC) and ammonia in source water, was effective in oxidizing As(III), reducing its concentrations from 21.9 µg/L (on average) in source water to 1.0 µg/L after the contact tanks. $KMnO_4$ also was effective in oxidizing soluble iron. Soluble As(V) adsorbed onto and/or co-precipitated with iron solids, forming arsenic-laden solids ready to be filtered by the Macrolite® media.
- The Macrolite® filters removed arsenic-laden iron solids and met the arsenic MCL. However, particulate breakthrough from the Macrolite® filters was observed in 13 out of 60 sampling events. After incrementally shortening the backwash interval from 2,743 to 916 gal, total arsenic and iron were reduced to below their respective MCL and secondary maximum contaminant level (SMCL).
- Oxidation of Mn(II) with $KMnO_4$ was affected by dissolved organic matter (DOM) in raw water, forming fine colloidal particles that passed through 0.45-µm disc filters. At least 4.5 mg/L of $KMnO_4$ was needed to form filterable manganese solids for Macrolite® filtration. This dosage was determined based on a series of jar tests and subsequent field trials.
- The Macrolite® filtration process removed about 85% of total phosphorous.
- Except for manganese, the water quality in the distribution system was improved after installation of the treatment system, as evidenced by the reduced arsenic and iron concentrations meeting the respective MCL and SMCL and little or no changes to the pH, alkalinity, lead, and copper.

Simplicity of required system O&M and operator skill levels:

- The daily demand on the operator was about 5 min, which included performing O&M activities such as mixing the $KMnO_4$ solution, measuring the consumption of $KMnO_4$, adjusting the chemical feed pump, and working with the vendor to troubleshoot and perform minor on-site repairs.
- The system experienced some operational issues primarily related to the control of backwash. The control discs installed on top of the duplex units had to be changed repeatedly with difference sizes to reduce the backwash interval, thus increasing the backwash frequency.
- There was no significant downtime with the operation of the system during the performance evaluation period.

Process residuals produced by the technology:

- Each filter was backwashed with treated water after processing every 916 gal of water, producing 130 gal of wastewater. The amount of water supplying the distribution system was 86% of the total water production.

- The backwash water contained, on average, 72 mg/L of total suspended solids (TSS), 130 µg/L of total arsenic, 19.5 mg/L of total iron, and 7.2 mg/L of total manganese. Approximately 35.4 g (0.08 lb) of solids per filter were discharged to the septic system and then to a sanitary sewer.
- The backwash solids contained, on average, 2.03 mg/g (or 0.2%) of arsenic, 190 mg/g (or 19%) of iron, and 136 mg/g (or 13.6%) of manganese.

Cost of the technology:

- The capital investment cost including equipment, engineering, and installation was $63,547, or $3,177 per gpm of the system design capacity.
- The incremental O&M cost was $0.36/1000 gal, including chemical usage, electricity consumption, and labor.

Section 3.0: MATERIALS AND METHODS

3.1 General Project Approach

Following the predemonstration activities summarized in Table 3-1, the performance evaluation of the Macrolite® treatment system began on July 13, 2005. Table 3-2 summarizes the types of data collected and/or considered as part of the technology evaluation process. The overall system performance was evaluated based on its ability to consistently remove arsenic to below the target MCL of 10 µg/L through the collection of water samples across the treatment train. The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

Table 3-1. Predemonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	08/31/04
Request for Quotation Issued to Vendor	12/06/04
Vendor Quotation Received	02/17/05
Purchase Order Established	02/24/05
Letter of Understanding Issued	01/10/05
Letter Report Issued	03/09/05
Engineering Package Submitted to MDH	03/28/05
Permit Granted by MDH	06/14/05
Study Plan Issued	06/21/05
Macrolite® Unit Shipped	06/10/05
Macrolite® Unit Delivered	06/16/05
System Installation Completed	06/24/05
System Shakedown Completed	07/03/05
Performance Evaluation Begun	07/13/05

MDH = Minnesota Department of Health

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

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

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

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

The cost of the system 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. This task required tracking the capital cost for equipment, engineering, and installation, as well as the O&M cost for chemical supply, 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, volume, and hour meter readings on a Daily System Operation Log Sheet; checked the potassium permanganate ($KMnO_4$) tank 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 problems encountered, corrective actions taken, materials and supplies used, and associated cost and labor required, 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), and oxidation-reduction potential (ORP), and recorded the data on a Weekly Water Quality Parameters Log Sheet. The system was backwashed automatically, except during the monthly backwash sampling events when the system was backwashed manually to enable backwash wastewater sampling. 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 $KMnO_4$ was tracked on the Daily System Operation Log Sheet. Electricity usage was estimated based on the hours of operation and the chemical feed pump motor size. Labor for various activities, such as routine system O&M, troubleshooting and repairs, and demonstration-related work, were tracked using an Operator Labor Hour Log Sheet. The routine system O&M included activities such as completing field logs, replenishing the $KMnO_4$ solution, ordering supplies, performing system inspections, and others as recommended by the vendor. The labor for demonstration-related work, including activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead and the vendor, was recorded, but not used for the cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected at the wellhead, across the treatment train, 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. Figure 3-1 presents a flow diagram of the treatment system along with the analytes and sampling schedules at each sampling location.

Table 3-3. Sample Collection Schedule and Analyses

Sample Type	Sample Locations[(a)]	No. of Samples	Frequency	Analytes	Date(s) Samples Collected
Source Water	IN	1	Once (during initial site visit)	On-site: pH, temperature, DO, and ORP Off-site: As(III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, Cl, F, NO_3, NO_2, NH_3, SO_4, SiO_2, PO_4, turbidity, alkalinity, TDS, and TOC	Table 4-1
Treatment Plant Water	IN, AC, TA/TB, TC/TD	4	Weekly	On-site: pH, temperature, DO, and ORP Off-site: As(total), Fe(total), Mn(total), SiO_2, PO_4, turbidity, and alkalinity	Appendix B
	IN, AC, TT	3	Monthly	Same as weekly analytes shown above plus the following: Off-site: As (soluble), As(III), As(V), Fe (soluble), Mn (soluble), Ca, Mg, F, NO_3, SO_4, and TOC	Appendix B
Backwash Wastewater	BW	2	Monthly	As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, turbidity, TDS, and TSS	Table 4-11
Backwash Solids	BW	1	Once	Total Mg, Al, Si, P, Ca, V, Mn, Fe, Ni, Cu, Zn, As, Cd, Sb, Ba, and Pb	Table 4-12
Distribution Water	Three Non-LCR Residences	3	Monthly	As (total), Fe (total), Mn (total), Cu, Pb, pH, and alkalinity	Table 4-13

(a) Abbreviation corresponding to sample location in Figure 3-1, i.e., IN = at wellhead; AC = after contact tanks; TA/TB = after tanks TA/TB, TC/TD = after tanks TC/TD; TT = after tanks TA/TB and TC/TD combined; BW = at backwash discharge line

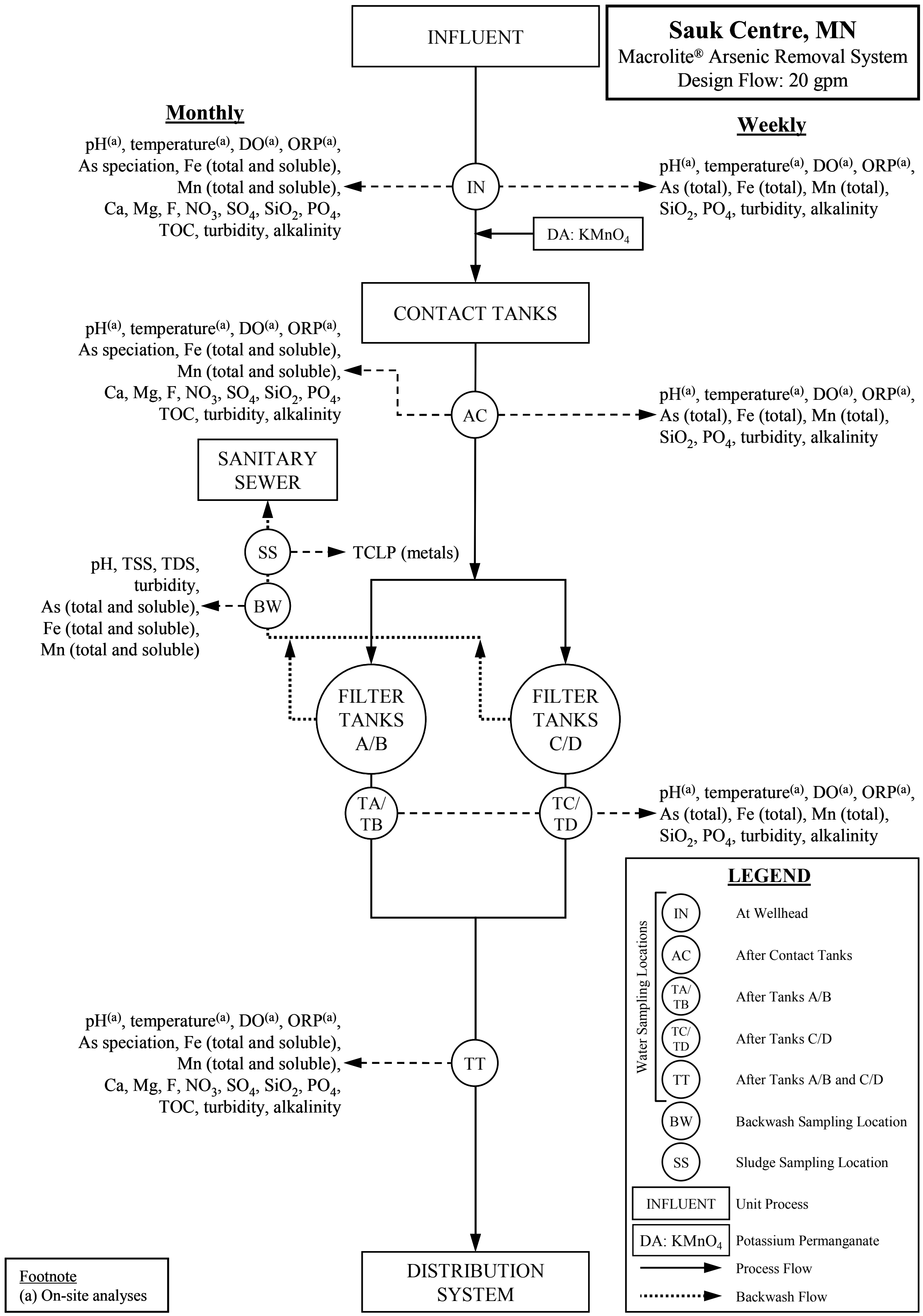


Figure 3-1. Process Flow Diagram and Sampling Locations

Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA- 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 visit to the site, one set of source water samples was collected and speciated using an arsenic speciation kit (see Section 3.4.1). The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Analytes for the source water samples are listed in Table 3-3.

3.3.2 Treatment Plant Water. 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 tanks (AC), and after Tanks A/B and Tanks C/D combined (TT), were speciated on-site and analyzed for the analytes listed in Table 3-3 for monthly treatment plant water. For the next three weeks, samples were collected at IN, AC, after Tanks A/B (TA/TB) and after Tanks C/D (TC/TD) and analyzed for the analytes listed in Table 3-3 for the weekly treatment plant water.

3.3.3 Special Study - $KMnO_4$ Jar Tests. Because significantly elevated soluble manganese concentrations were measured in the treated water after the Macrolite® filters, a series of jar tests were conducted at Battelle's laboratories on November 7, 2005, using the treated water taken at the TT location from the site to determine an appropriate $KMnO_4$ dosage for complete oxidation of Mn(II) and formation of filterable manganese solids.

The jar tests consisted of six 1-L jars of the treated water with increasing dosages of $KMnO_4$ ranging from 1.0 to 3.0 mg/L (Table 3-4). One jar was used as a control with no $KMnO_4$ addition. The jars were placed on a Phipps & Byrd overhead stirrer/jar tester with an illuminated base. The jars were mixed for a total of 31 min at various mixing speeds: 200 rotation/min (rpm) for 1 min immediately after the $KMnO_4$ addition, followed by 100 rpm for 19 min and 28 rpm for 11 min. After the specified contact time, the supernatant in each jar was filtered with 0.20-µm disc filters and analyzed for arsenic, iron, and manganese using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). The pH and ORP values of the contents in each jar also were measured using a VWR Symphony SP90M5 Handheld Multimeter at the beginning and end of each jar test. The results of the jar tests are discussed in Section 4.5.1.

Table 3-4. Summary of Jar Test Parameters

Parameter	Jar 1	Jar 2	Jar 3	Jar 4	Jar 5	Jar 6
Mix Time (min)[a]	31	31	31	31	31	31
$KMnO_4$ (mg/L)	0	1.0	1.5	2.0	2.5	3.0

(a) Mixing Speeds: 1 min at 200 rpm, 19 min at 100 rpm, and 11 min at 28 rpm.

3.3.4 Backwash Wastewater. Backwash wastewater samples were collected monthly by the plant operator. One backwash wastewater sample was collected as one of the tanks in each duplex unit was backwashed. For each of the first three sampling events, one grab sample was taken as the bulk of the solids/water mixture was being discharged from the sample tap located on the backwash water discharge line but before the backwash totalizer. Unfiltered samples were analyzed for pH, total dissolved solids (TDS), and turbidity measurements. Filtered samples using 0.45-µm disc filters were analyzed for soluble As, Fe, and Mn analyses. Starting from November 15, 2005, during the fourth sampling event, the sampling procedure was modified to include the collection of composite samples for total As, Fe, and

Mn as well as TSS analyses. This modified procedure involved diverting a portion of backwash wastewater at approximately 1 gpm into a clean, 32-gal plastic container over the duration of the backwash for each set of duplex tanks. 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.

3.3.5 Residual Solids. Residual solids produced from backwash were collected once from the backwash discharge line on September 21, 2006, and analyzed for the analytes listed in Table 3-3.

3.3.6 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 disribution system. Following the system startup, distribution system sampling continued on a monthly basis at the same three locations.

The three homes selected for the sampling had been included in the Park's Lead and Copper Rule (LCR) sampling. 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). First draw samples were collected from a cold-water faucet located upstream of the softener in each home. (Note that the samples thus collected were not from a frequently used kitchen or bathroom faucet nor from a faucet that was commonly used for human consumption.) To ensure collection of stagnant water, the faucet was not used for at least 6 hr. Dates and times of sample collection and last water usage were recorded for calculations of the stagnation time. Analytes for the distribution system water are listed in Table 3-3. Arsenic speciation was not performed for the distribution water samples.

3.4 Sampling Logistics

3.4.1 Preparation of Arsenic Speciation Kits. The arsenic field speciation method uses an anion exchange resin column to separate the soluble arsenic species, As(V) and As(III) (Edwards et al., 1998). Resin columns were prepared in batches at Battelle laboratories according to the procedures detailed in Appendix A of the EPA-endorsed QAPP (Battelle, 2004).

3.4.2 Preparation of Sample Coolers. For each sampling event, a sample cooler was prepared with the appropriate number and type of sample bottles, disc filters, and/or speciation kits. All sample bottles were new and contained appropriate preservatives. Each sample bottle was affixed with a pre-printed, colored-coded label consisting of the sample identification (ID), date and time of sample collection, collector's name, site location, sample destination. analysis required, and preservative. The sample ID consisted of a two-letter code for a specific water facility, sampling date, a two-letter code for a specific sampling location, and a one-letter code designating the arsenic speciation bottle (if necessary). The sampling locations at the treatment plant were color-coded for easy identification. The labeled bottles for each sampling location were placed in separate 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 analylses were stored at Battelle's 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 (TCCI) in 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 detail 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 (MDL), and completeness met the criteria estrablished 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 Multimeter, which was calibrated for pH and DO prior to use following the procedures provided in the user's manual. The ORP probe also was checked for accuracy by measuring the ORP of a standard solution and comparing it to the expected value. The plant operator collected a water sample in a clean, plastic beaker and placed the Symphony SP90M5 probe in the beaker until a stable value was obtained. The plant operator also performed free and total chlorine measurements using Hach chlorine test kits following the user's manual.

Section 4.0: RESULTS AND DISCUSSION

4.1 Facility Description and Preexisting Treatment System Infrastructure

Located at 43987 County Road 24 in Sauk Centre, MN, BSLMHP had a water system sized to supply water for up to 50 mobile home connections or approximately 100 residents. There were 37 mobile homes in the park during the study period. Prior to the demonstration study, the facility reported an average daily demand of 7,500 gpd and a peak daily demand of 16,000 gpd. The system typically operated approximately 6 hr/day. Figure 4-1 shows the preexisting well house at the facility.

The water system was supplied intermittently by two wells (i.e., Wells No. 1 and 2) installed at a depth of approximately 90 ft below ground surface (bgs). Well No. 2, the newest well, was used as the primary well and Well No. 1, the old well, a backup well. Well No. 2 was equipped with a 1½-horsepower (hp), 4-in submersible pump installed on a 60-ft drop pipe and rated for 25 gpm at 180 ft H_2O (or 78 lb/in^2 [psi]). The pump installed in the backup well reportedly had a similar capacity, but records were no longer available. Figure 4-2 shows the existing piping and two 62-gal Champion pressure tanks in the well house. There was no disinfection or other treatment at the wellheads, although most residents had water softeners in their homes.

4.1.1 Source Water Quality. Source water samples were collected on August 31, 2004, and subsequently analyzed for the analytes shown in Table 3-3. The results of source water analyses, along with those provided by the facility to EPA for the demonstration site selection and those independently collected and analyzed by the vendor, Battelle, and MDH are presented in Table 4-1.

As shown in Table 4-1, total arsenic concentrations in the source water of both wells ranged from 17.0 to 32.0 µg/L. Based on the August 31, 2004, speciation tests of Well No. 2 water, the total arsenic

Figure 4-1. Preexisting Well House at BSLMHP, MN Site

Figure 4-2. Existing Well Piping and Pressure Tanks at BSLMHP, MN Site

concentration was 25.3 µg/L, of which 20.7 µg/L was in the soluble form. Of the soluble arsenic, 13.6 µg/L existed as As(III) (65.7%) and 7.1 µg/L as As(V) (34.3%).

Iron concentrations in source water extracted from both wells ranged from 3,000 to 3,400 µg/L, existing entirely as soluble iron based on August 31, 2004 results. A rule of thumb is that the soluble iron concentration should be at least 20 times the soluble arsenic concentration for effective removal of arsenic onto iron solids (Sorg, 2002). Based on the August 31, 2004, speciation results, the soluble iron level was 152 times higher than soluble arsenic level. As such, there was no need to supplement the natural iron for arsenic removal. The proposed treatment process was designed to reduce iron levels in the treated water to below the secondary MCL of 300 µg/L.

Manganese levels of 130 to 150 µg/L were above the SMCL of 50 µg/L. The pH values ranged from 7.1 to 7.4, which were within the target range of 5.5 to 8.5 for the iron removal process. TOC levels at 3.9 to 4.9 mg/L were high and because of the high levels, $KMnO_4$ was used to oxidize iron and arsenic. The use of $KMnO_4$ should eliminate the formation of disinfection byproducts, which could occur if prechlorination was implemented. In April 2005, EPA conducted a disinfection byproduct formation test on source water and found that after 96 hr, the total trihalomethane (TTHM) level was 0.11 mg/L, existing almost completely as chloroform. The MCL for TTHM is 0.080 mg/L. This further confirmed the need to use an alternate oxidant to chlorine. The ammonia level at 1.2 mg/L also was elevated and could significantly increase the chlorine demand should chlorine be used as an oxidant. The turbidity of the water was 30 nephelometric turbidity units (NTU), presumably caused by iron precipitation during sample collection and transit. Hardness ranged from 300 to 360 mg/L, silica from 21 to 25 mg/L, and sulfate from <4 to 5.4 mg/L. Based on the historical data provided by MDH, there was no apparent difference in water quality between Wells No. 1 and 2. Total arsenic concentrations ranged from 26.0 to 32.0 µg/L for Well No. 1 and from 26.0 to 28.0 µg/L for Well No. 2; total iron concentrations were 3,400 for Well No. 1 and 3,000 µg/L for Well No. 2; and total manganese concentrations were 140 µg/L for Well No. 1 and 130 µg/L for Well No. 2.

Table 4-1. BSLMHP, MN Water Quality Data

Parameter	Unit	Facility Well 2 Data	Kinetico Well 2 Data	Battelle Well 2 Data	MDH Well 1 Data	MDH Well 2 Data	MDH Distribution Water Data[(a)]
Date		Not specified	10/14/03	08/31/04	01/25/01 – 08/10/04	01/25/01 –08/10/04	01/25/01– 08/10/04
pH	–	7.4	7.3	7.1	7.3	7.4	NS
Temperature	°C	NS	NS	NS	NS	NS	NS
DO	mg/L	NS	NS	1.48	NS	NS	NS
ORP	mV	NS	NS	-98	NS	NS	NS
Total Alkalinity (as $CaCO_3$)	mg/L	355	364	363	350	360	NS
Hardness (as $CaCO_3$)	mg/L	305	330	360	310	300	340
Turbidity	NTU	NS	NS	30	<1–22	<1–20	<1–22
TDS	mg/L	NS	NS	338	NS	NS	NS
TOC	mg/L	4.9	NS	3.9	NS	4.9	NS
Total N (Nitrite + Nitrate) (as N)	mg/L	NS	NS	NS	NS	NS	<0.05–0.01
Nitrate (as N)	mg/L	NS	NS	<0.04	NS	NS	NS
Nitrite (as N)	mg/L	NS	NS	<0.01	NS	NS	NS
Ammonia (as N)	mg/L	NS	NS	1.2	NS	NS	NS
Chloride	mg/L	1.5	<1.0	<1.0	1.5	1.5	NS
Fluoride	mg/L	NS	0.46	<0.1	NS	NS	0.29
Sulfate	mg/L	5.2	<4.0	<5.0	5.0	5.4	6.6
Silica (as SiO_2)	mg/L	24	21.4	25	23	24	23.0–24.0
Orthophosphate (as PO_4)	mg/L	0.02	<0.5	<0.1	NS	NS	NS
As (total)	µg/L	26	17	25.3	26.0–32.0	26.0–28.0	18.4–28.0
As (soluble)	µg/L	NS	NS	20.7	NS	NS	NS
As (particulate)	µg/L	NS	NS	4.6	NS	NS	NS
As(III)	µg/L	NS	NS	13.6	NS	NS	NS
As(V)	µg/L	NS	NS	7.1	NS	NS	NS
Fe (total)	µg/L	3,200	3,060	3,078	3,400	3,000	2,900
Fe (soluble)	µg/L	NS	NS	3,149	NS	NS	NS
Mn (total)	µg/L	140	150	150	140	130	140
Mn (soluble)	µg/L	NS	NS	154	NS	NS	NS
U (total)	µg/L	NS	NS	<0.1	NS	NS	NS
U (soluble)	µg/L	NS	NS	<0.1	NS	NS	NS
V (total)	µg/L	NS	NS	0.17	<2	<2	NS
V (soluble)	µg/L	NS	NS	<0.1	NS	NS	NS
Na (total)	mg/L	14	13	17	15	14	13.6
Ca (soluble)	mg/L	72	81	87	72	72	80
Mg (total)	mg/L	30	32	35	31	29	33
Gross-Alpha	pCi/L	NS	NS	NS	NS	NS	<1.00–<1.5
Gross-Beta	pCi/L	NS	NS	NS	NS	NS	<0.40–<0.91
Radon	pCi/L	NS	NS	NS	NS	NS	50–470
Radium-228	pCi/L	NS	NS	NS	NS	NS	<0.59

(a) Samples taken from various residences.
NS = not sampled

4.1.2 Distribution System and Treated Water Quality. Water extracted from both wells blends within the pressure tanks and the distribution system. The park owner indicated that the distribution system was solely constructed of polyvinyl chloride (PVC). Prior to this demonstration project, the treatment system had no disinfection or other treatment at the wellheads, although most residents had water softeners in their homes. The historic arsenic levels detected within the distribution system at several different sampling points, including residences and the wellhouse distribution entry piping, ranged from 18.4 to 28.0 μg/L based on MDH treated water sampling data shown in Table 4-1.

4.2 Treatment Process Description

The treatment processes at the BSLMHP site included $KMnO_4$ oxidation, co-precipitation/adsorption, and Macrolite® pressure filtration. Macrolite® is an engineered, low-density, spherical ceramic filtration media manufactured by Kinetico and approved for use in drinking water applications under NSF International (NSF) Standard 61. Macrolite® filtration systems can be operated at a hydraulic loading rate of 10 gpm/ft^2 (vendor claim), which is at least two times higher than that for most conventional filtration media. The physical properties of this media are summarized in Table 4-2. The vendor states that Macrolite® media is chemically inert and compatible with chemicals such as oxidants and ferric chloride.

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

Property	Value
Color	Taupe, Brown to Gray
Thermal Stability (°F)	2,000
Sphere Size Range (mm)	0.35–0.25
Sphere Size Range (in)	0.014–0.009
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

Source: Kinetico

Figure 4-3 is a schematic and Figure 4-4 a photograph of the Macrolite® CP-213f arsenic removal system. The treatment system was operated as an on-demand system and the volume of water treated was based on water usage. The well pump turned on when the pressure tank pressure reached 45 psi and shut off at 60 psi. The primary system components consisted of a $KMnO_4$ feed system (with the metering pump interlocked with a totalizer located after the pressure tanks and prior to the treatment system), two contact tanks, four pressure filtration tanks (two each within each duplex unit), and associated pressure and flow instrumentation. Various instruments were installed to track system performance, including the inlet and outlet pressure after each filter, flowrate to the distribution system, and backwash flowrate. All plumbing for the system was Schedule 80 PVC with the necessary valves, sampling ports, and other features. Table 4-3 summarizes the design features of the Macrolite® pressure filtration system. The major process steps and system components are presented as follows.

- **Potassium Permanganate Oxidation** – $KMnO_4$ was used to oxidize As(III), Fe(II), and Mn(II) in source water. $KMnO_4$ was selected in place of chlorine to prevent the formation of disinfection byproducts due to the presence of high TOC in the source water. The $KMnO_4$ addition system consisted of a 150-gal day tank, a Pulsatron metering pump, and an overhead mixer (Figure 4-5). The working solution was prepared by adding 0.75 gal (or 10 lb) of $KMnO_4$ crystals with 97% minimum purity into 40 gal of water to form a 3% $KMnO_4$ solution. During the one-year study period, the 21-in diameter and 31.5-in tall $KMnO_4$ tank was re-filled 11 times when the tank level reached an average of 16.7 in. The $KMnO_4$ feed pump was sized with a maximum capacity of 44 gpd or 6.9 L/hr. However, the pump was

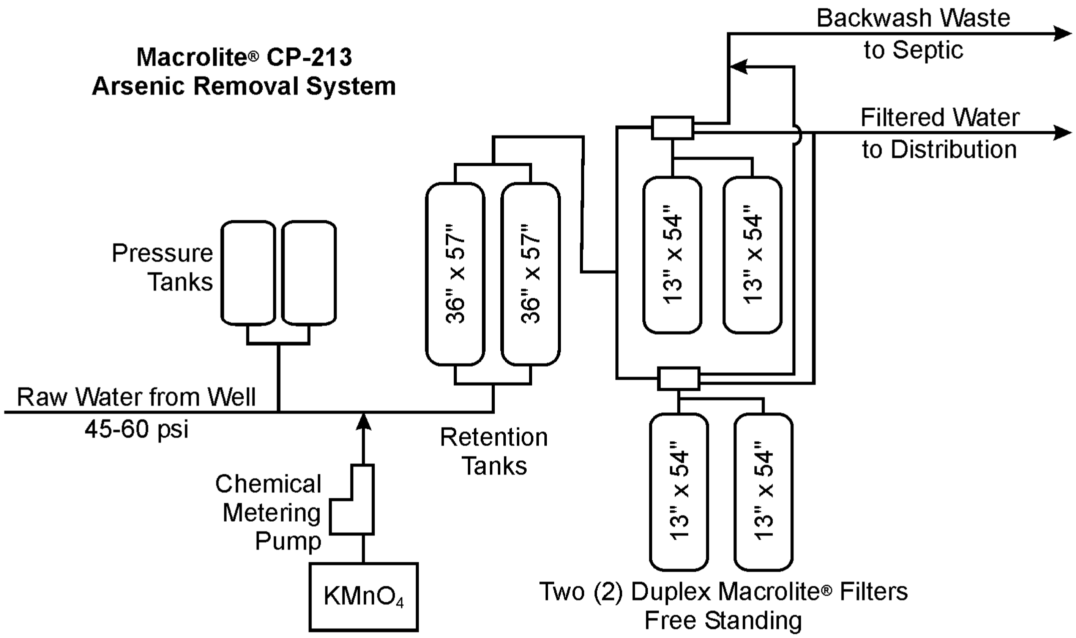


Figure 4-3. Process Schematic of Macrolite® Pressure Filtration System

Figure 4-4. Photograph of Macrolite® Pressure Filtration System
(1. Duplex Units, 2. Contact Tanks, 3. Pressure Filters, 4. Chemical Day Tank, and 5. Totalizer on Raw Water Line)

Table 4-3. Design Specifications for Macrolite® CP-213f Pressure Filtration System

Parameter	Value	Remarks
Pretreatment		
$KMnO_4$ Dosage (mg/L as [$KMnO_4$])	3.3	Calculated $KMnO_4$ demand based on arsenic, iron, and manganese in source water; actual demand higher due to presence of TOC in source water
Contact Tanks		
Tank Size (in)	36 D × 57 H	205 gal each tank
No. of Tanks	2	–
Configuration	Parallel	–
Contact Time (min/tank)	20	Based on peak flowrate of 20 gpm; actual contact time based on on-demand flowrate
Filtration Tanks		
Tank Size (in)	13 D × 54 H	–
Cross-Sectional Area (ft^2/tank)	0.92	–
No. of Tanks	4	–
Configuration	Parallel	Between two duplex units and between two filtration tanks within each duplex unit
Media Quantity (ft^3/tank)	1.5	20-in bed depth in each tank
Freeboard Measurements (in/tank)	28	Measured by vendor's contractor on 12/07/05 from top of filtration tank to top of media bed
Filtration Rate (gpm/ft^2)	5.4	Based on a 5 gpm system flowrate through each filtration tank; actual filtration rate based on demand
Pressure Drop (psi)	15	Across a clean bed
Throughput before Backwash (gal)	2,743	Based on initial field setting
Backwash Hydraulic Loading Rate (gpm/ft^2)	6.5	Based on a 6-gpm backwash flowrate through each filtration tank
Backwash Duration (min/tank)	20	–
Wastewater Production (gal)	130	For each tank
System Design Flowrate (gpm)	20	Peak flowrate; actual flowrate based on demand
Maximum Daily Production (gpd)	28,800	Based on peak flowrate, 24 hr/day
Hydraulic Utilization (%)	56	Estimated based on peak daily demand[(a)]

(a) Based on historic peak daily demand of 16,000 gpd.

flow-paced and the actual rate of $KMnO_4$ addition varied based on the influent flowrate to the treatment system. During the one-year system operation, $KMnO_4$ dosages varied from 1.3 to 6.5 mg/L. The operator indicated that the mixer was only turned on when the $KMnO_4$ crystals were mixed initially with water in the day tank.

- **Contactor** – Two 36-in by 57-in fiberglass reinforced plastic (FRP) contact tanks arranged in parallel provided at least 20 min of contact time when operating at the design (or peak) flowrate of 20 gpm. The longer retention time was designed to aid in the formation of manganese particles.

- **Pressure Filtration** – The filtration system consisted of downflow filtration through two sets of dual-pressure filtration tanks arranged in parallel. Each duplex unit was comprised of two 13-in by 54-in FRP tanks and a control valve. Each filtration tank was filled with approximately 20-in (1.5 ft^3) of 40/60 mesh Macrolite® media supported by 3-in (0.25 ft^3) of garnet underbedding. The standard operation had four tanks online, each treating a maximum of 5 gpm for a hydraulic loading rate of 5.4 gpm/ft^2. With four tanks online, the maximum system flowrate was 20 gpm. However, as shown in Figure 4-3, the system had an on-demand configuration with two pressure tanks located ahead of the treatment system. The

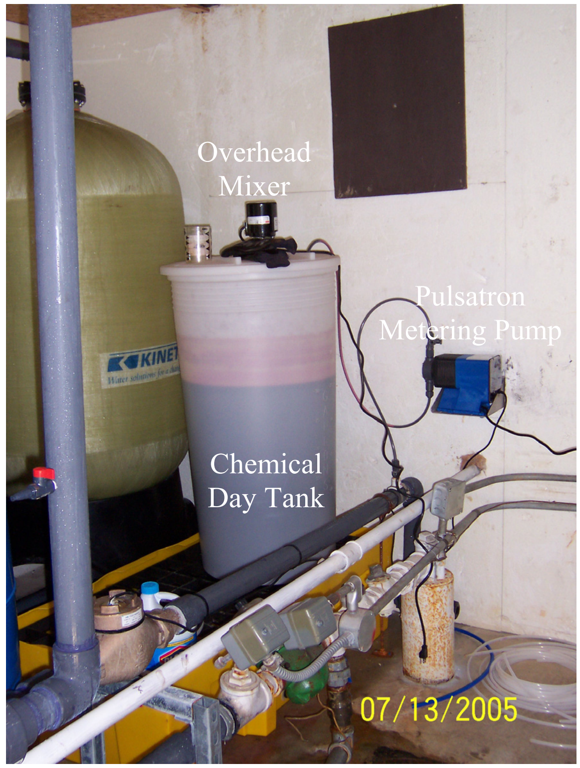


Figure 4-5. $KMnO_4$ Feed System

actual flowrate through the system varied based on water demand, but was limited to less than 20 gpm by flow restrictors located on the duplex units.

The control valve (Kinetico Mach 1250) located on top of each duplex unit (Figure 4-6) consisted of a gear stack, which determines the throughput between two consecutive backwash cycles. The control valve consisted of three chambers: inlet, outlet, and regeneration and only the influent water was measured and recorded by the gear stack.

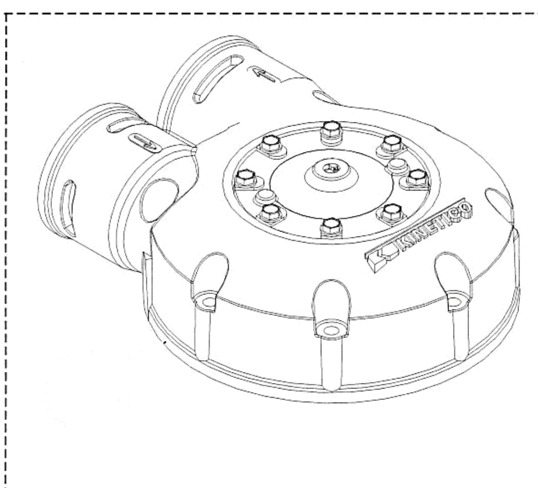


Figure 4-6. Kinetico's Mach 1250 Control Valve

- **Backwash Operations** – Backwash was a fully automated process triggered by a pre-set throughput measured by the gear stack associated with the control valve located on top of each duplex unit. The spent filtration tank was backwashed with the treated water from the other tank within the duplex unit and the resulting wastewater was discharged to a septic tank and then the sanitary sewer. The backwash time for each tank during each backwash cycle was 20 min from start to finish including 15 min of backwash at 6 gpm and a 5 min filter-to-waste rinse also at 6 gpm. The backwash process used about 130 gal of the treated water per tank (or per cycle). As discussed in section 4.4.2, it was necessary to incrementally increase the backwash frequency from the initial field setting of every 2,743 gal to every 916 gal. Figure 4-7 shows the backwash flow paths for the two tanks in each duplex unit (labeled as Tank A and Tank B); each of the two tanks was backwashed on an alternating basis after a pre-set throughput of 916 gal. The major steps involved in the backwash process are discussed as follows:

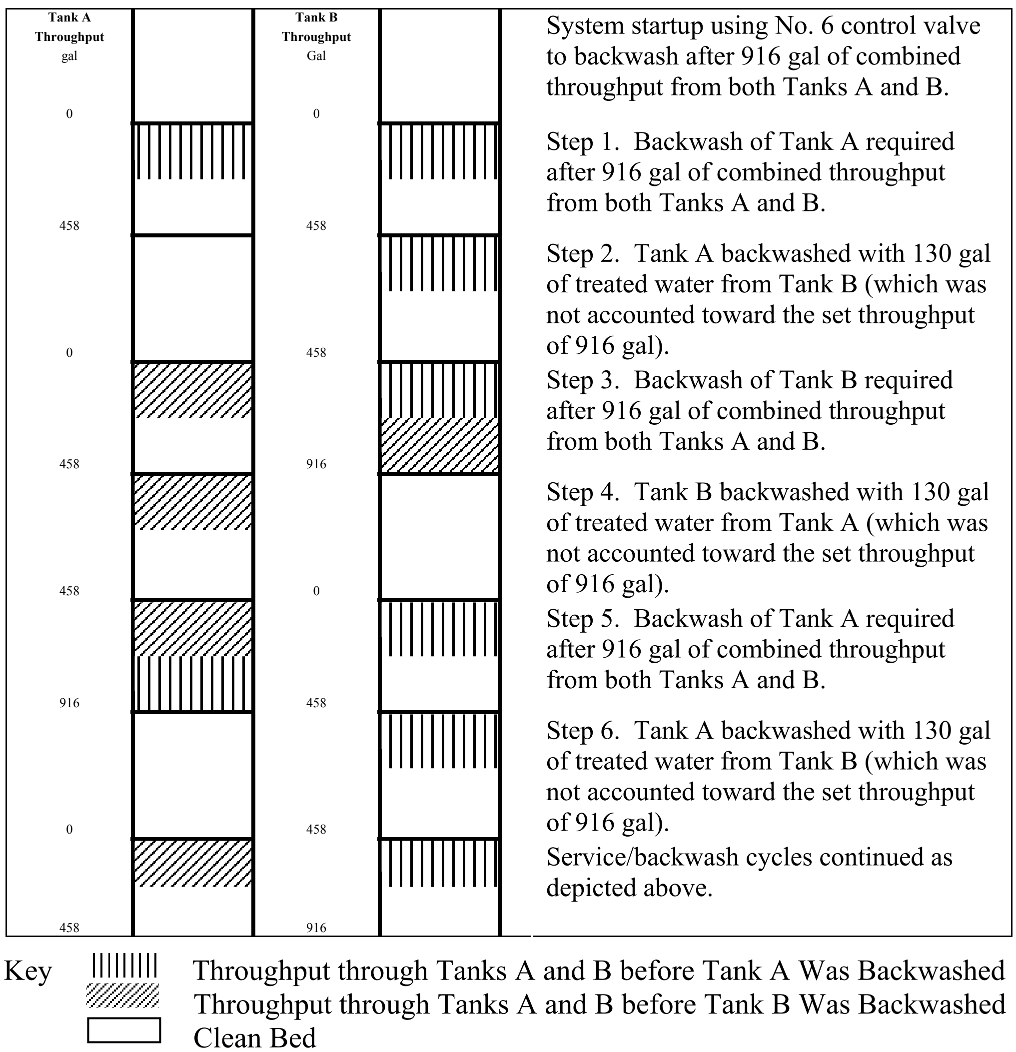


Figure 4-7. Backwash Flow Path for One Duplex Unit with a No. 6 Control Valve for a Throughput of 916 gal between Backwash Cycles

Again, both Tanks A and B provided the treated water in parallel. The backwash cycles were continuously repeated as shown in Steps 4 through 6 in Figure 4-7 during the treatment system operation. One set of duplex tanks functioned as one unit and always had a filtration capacity between 25% (immediately after backwash of one tank at Step 4) and 75% (right before backwash of the other tank at Step 5).

4.3 System Installation

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

4.3.1 Permitting. Engineering plans for the system permit application were prepared by the vendor. The plans included diagrams and specifications for the Macrolite® CP-213f arsenic removal system, as well as drawings detailing the connections of the new unit to the preexisting facility infrastructure. The plans were submitted to MDH on March 28, 2005, and MDH granted its approval of the application on June 14, 2005.

4.3.2 Building Construction. The existing well house had an adequate footprint to house the arsenic treatment system. The permit approval issued by MDH on June 14, 2005, indicated a need for an air gap, between the drain and the filter-to-waste line outlet, two times the diameter of the filter-to-waste line and a need for all chemicals to be injected on the lower half of the influent pipe. Figure 4-5 shows the chemical injection line located on the top half of the influent pipe. In addition, MDH required the filter-to-waste line and sewer connection to have at least a 50-ft distance from Well No. 1 and Well No. 2 wellheads and at a lower elevation.

4.3.3 System Installation, Shakedown, and Startup. The Macrolite® system was shipped on June 10, 2005, and delivered to the site on June 16, 2005. A subcontractor to the vendor off-loaded and installed the system, including piping connections to the existing entry and distribution system. System installation was completed by June 24, 2005, and the system shakedown was completed by July 3, 2005.

Shakedown activities included disinfection of the contact and filtration tanks and backwash of Macrolite® filtration media. The bacteriological test was passed on July 1, 2005. During the startup trip in July, the vendor conducted operator training for system O&M. Battelle arrived on-site on July 13, 2005, to perform system inspections and conduct operator training for system sampling and data collection. The first set of samples for the one year performance evaluation study was taken on July 13, 2005. No major mechanical or installation issues were noted at system startup; however, several pieces of equipment shown in the vendor's June 16, 2005 piping and instrumental diagrams (P&ID) were missing and several installed items did not meet the permit requirements. A list of punch-list items was summarized as follows:

- Install an hour meter.
- Install one raw water sample tap.
- Install one backwash sample tap.
- Install one sample tap after duplex units TA/TB and TC/TD.
- Install one pressure gauge after duplex units TA/TB and TC/TD.
- Replace the defective pressure gauge beneath the left most pressure tank.
- Install a level sensor on the $KMnO_4$ day tank.
- Install a ½-inch ball valve on the $KMnO_4$ injection tube.
- Move the $KMnO_4$ injection port from the top half of the influent pipe to the lower half per permit requirements.

- Verify that the air gap was two times the filter-to-waste pipe between the drain and the filter-to-waste pipe.

All punch-list items were resolved by the vendor by September 30, 2005.

4.4 System Operation

4.4.1 Operational Parameters. Table 4-4 summarizes the operational parameters for the one year system operation, including operational time, throughput, flowrate, and pressure. Detailed daily operational information is provided in Appendix A.

Between July 13, 2005, and October 1, 2006, the primary well pump operated for 2,052 hr, with an average daily operating time of 4.6 hr/day based on the readings of an hour meter installed on the primary well on September 28, 2005. This daily operating time was lower than the 6 hr/day estimated by the Park owner and higher than the 3.4 hr/day estimated during the first six months of system operations. Prior to September 28, 2005, the operational time was estimated based on wellhead totalizer readings and an average well pump flowrate of 21 gpm. The total system throughput was 2,017,215 gal based on readings of a totalizer installed on the treated water line. The average daily demand was 4,523 gal (versus 7,500 gal provided by the park owner) and the peak daily demand occurred on July 21, 2005, at 14,300 gal (compared to 16,000 gpd provided by the park owner).

The flowrates through the CP-213f system varied due to the on-demand system configuration. On-demand flowrates from the two pressure tanks located upstream of the system ranged from 1 to 15 gpm and averaged 4.0 gpm, corresponding to an average contact time of 103 min, which was five times longer than the design value of 20 min. At 4.0 gpm, the hydraulic loading rate to the filter was 1.1 gpm/ft^2, compared to the design value of 5.4 gpm/ft^2. Macrolite® filter media is rated for a maximum hydraulic loading rate of 10 gpm/ft^2.

At flowrates of 1 to 15 gpm, the inlet pressure to the treatment system ranged from 40 to 66 psi (compared to the pressure tank set points from 45 to 60 psi) and the outlet pressure ranged from 22 to 57 psi. Total pressure differential (Δp) readings across the system ranged from 0 to 25 psi depending on the flowrates. Δp readings ranged from 0 to 23 psi across Tanks A and B and from 0 to 22 psi across Tanks C and D, based on inlet and outlet pressure gauge readings.

During the performance evaluation study, 1,133 backwash cycles took place. Throughput values between two consecutive backwash cycles were reduced incrementally from 6,857 to 916 gal, increasing daily backwash cycles to as many as 11. There was one outlier on August 9, 2005, when over 1,720 gal of backwash wastewater was produced (equivalent to 13 backwash events in a single day). The vendor's contractor determined that sediment was lodged in the purge/control valve on one of the duplex units, preventing the valve from being closed; therefore, the duplex unit was stuck in the backwash mode before the operator bypassed the system.

4.4.2 Backwash. Backwash was initiated by a throughput setting determined by the control valve and associated gear stack located on top of each duplex unit. Table 4-5 summarizes the backwash frequency based on the use of five different control valves and two different gear stacks installed over the study period. The vendor switched out the control valves five times (including one that was done mistakenly) due to observations of particulate arsenic, iron, and manganese breakthrough from the Macrolite® filters. A No. 5 valve geared to backwash after a throughput of 2,743 gal was used initially from system startup on July 13, 2005, through September 20, 2005. The calculated throughput values between two consecutive backwash cycles averaged 2,449 gal based on the total volume of water treated

Table 4-4. System Operation from July 13, 2005, to October 1, 2006

Parameter	Values
Primary Well Pump (Well No. 2)	
Total Operating Time (hr)	2,052[(a)]
Average Daily Operating Time (hr)	4.6[(a)]
Range of Flowrates (gpm)	11–31[(b)]
Average Flowrate (gpm)	21[(b)]
System Throughput/Demand	
Throughput to Distribution (gal)	2,017,215
Average Daily Demand (gpd)	4,523
Peak Daily Demand (gpd)	14,300
CP-213f System – Service Mode	
Range of Flowrates (gpm)	1–15[(c)]
Average Flowrate (gpm)	4.0[(c)]
Range of Contact Times (min)	27–412
Average Contact Time (min)	103
Range of Hydraulic Loading Rates to Filters (gpm/ft^2)	0.3-4.1[(d)]
Average Hydraulic Loading Rate to Filters (gpm/ft^2)	1.1[(d)]
Range of System Inlet Pressure (psi)	40–66
Range of System Outlet Pressure (psi)	22–57
Range of Δp Readings across System (psi)	0–25
CP-213 System – Backwash Mode	
Number of Backwash Cycles (or Tanks Backwashed)	1,133[(e)]
Throughput between Backwash Cycles (gal)	916-6857[(f)]
Number of Backwash Cycles (or Tanks Backwashed) Per Day	0–11

(a) Hour meter installed on September 28, 2005. Run time before September 28, 2005 estimated based on wellhead totalizer readings and average well flowrate of 21 gpm.
(b) Based on raw water line totalizer and hour meter readings; excluding data from September 29, October 5, and October 6, 2005.
(c) Based on flow meter readings located on treated water line recorded starting September 28, 2005.
(d) Cross-sectional area for each tank was 0.92 ft^2 with four tanks in parallel.
(e) Based on totalizer readings on backwash water discharge line and 130 gal of wastewater produced during backwash of each tank.
(f) Backwash triggered by volume of water treated based on settings of control discs located on top of each set of duplex filtration tanks.

and the total number of tanks backwashed. The number of tanks backwashed per day ranged from 0 to 5 except for the outlier on August 9, 2005, discussed in Section 4.4.1. Because of breakthrough of particulate arsenic, iron, and manganese, the vendor dispatched its contractor to the site to install a new control valve in an attempt to curb the particulate breakthrough. While one with a higher number should have been used, a lower number control valve (i.e., No. 2 geared to backwash after a throughput of 6,857 gal) was inadvertently installed and used between September 21 through 29, 2005. On September 30, 2005, the No. 2 valve was replaced with a No. 7 valve, which was geared for a throughput of 1,957 gal. The average throughput for the No. 7 valve was 1,932 gal and the number of tanks backwashed per day ranged from 0 to 5. For this reason, a No. 8 valve was subsequently installed on December 7, 2005 to further reduce the throughput to 1,714 gal. The actual throughput was 1,684 gal and the number of tanks backwashed per day ranged from 1 to 5. After this changeout, particulate breakthrough continued. Therefore, a No. 6 control valve with a smaller gear at 5,500 gal was installed to backwash every 916 gal. The actual throughput was 916 gal and the number of tanks backwashed per day ranged from 1 to 11.

Table 4-5. Sizes of Control Valve and Respective Throughput between Backwash Cycles

Duration	Control Valve	Design Throughput between Consecutive Backwash Cycles (gal)	Average Throughput between Consecutive Backwash Cycles (gal)	Number of Backwash Cycles (or Tanks Backwashed) (No./day)	Backwash Water Generation Ratio (%)
07/13/05–09/20/05	No. 5[(a)]	2,743	2,449	0–5	5.5
09/21/05–09/29/05	No. 2[(a)]	6,857	3,469	0–3	2.8
09/30/05–12/06/05	No. 7[(a)]	1,957	1,932	0–5	6.6
12/07/05–01/17/06	No. 8[(a)]	1,714	1,684	1–5	7.2
01/18/06–10/01/06	No. 6[(b)]	916	916	1–11	7.9

(a) A 13,700-gal gear used.
(b) A 5,500-gal gear used.

Except for disc No. 2, the ratios of backwash water generated ranged from 5.5% to 7.9% and averaged 7.2%.

4.4.3 Residual Management. Residuals produced by the Macrolite® system consisted of backwash water and associated solids, which were discharged to a nearby septic system and then to a sanitary sewer.

4.4.4 System/Operation Reliability and Simplicity. During system operation, total arsenic and iron breakthrough was observed in service mode and the backwash frequency had to be increased incrementally. Even after reducing the throughput value to 916 gal between backwash cycles, there was one incidence of total arsenic and iron breakthrough, therefore, the entire TC/TD module had to be replaced on May 12, 2006. Further, during the second half of the 15-month demonstration study, the pressure gauge for Duplex Unit TC/TD and the totalizer on the backwash line were both broken and had to be replaced (see Appendix A). The totalizer to distribution and the totalizer on the raw water line were re-set once and twice, respectively (see Appendix A). The flow meter on the treated water line was discolored and could not be read (see Appendix A).

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

Pre- and Post-Treatment Requirements. Pretreatment consisted of $KMnO_4$ addition for the oxidation of arsenic, iron, and manganese. Specific chemical handling requirements are further discussed below under chemical handling and inventory requirements. $KMnO_4$ was selected as an alternative oxidant to chlorine due to the high TOC levels in source water and the potential to form disinfection byproducts. However, as discussed in Section 4.5.1, the source water had a relatively high $KMnO_4$ demand, thus resulting in difficulties in controlling manganese levels (both particulate and soluble forms) in the treated water.

System Automation. All major functions of the treatment system were automated and required only minimal operator oversight and intervention if all functions were operating as intended. Automated processes included system startup in service mode when the well was energized; backwash initiation based on throughput; and system shutdown when the well pump was shut down. However, as noted in Section 4.4.1, an operational issue did arise with automated backwash on August 9, 2005. In addition, the pump on the primary well (Well No. 2) developed a leak and had to be shut down temporarily on January 4, 2006 for repairs. During the Well No. 2 repair period, Well No. 1 was used. The leak on the Well No. 2 pump was repaired the next day and the primary well resumed its normal operation thereafter. Also, the operator discovered an airlock in the chemical feed pump several times during the second half of the demonstration study.

Operator Skill Requirements. Under normal operating conditions, the skill set required to operate the Macrolite® system was limited to observation of the process equipment integrity and operating parameters such as pressure and flow. The daily demand on the operator was about 5 min to visually inspect the system and record operating parameters on the log sheets. Other skills needed including performing O&M activities such as replenishing the $KMnO_4$ solution in the chemical day tank, monitoring backwash operations, and working with the vendor to troubleshoot and perform minor on-site repairs.

For the state of Minnesota, there are five water operator certificate class levels, i.e., A, B, C, D, and E, with Class 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 operator for the BSLMHP system has a Class D certificate. Class D requires a high school diploma or equivalent with at least one year of experience in operating a Class D or E system or a postsecondary degree from an accredited institution.

Preventive Maintenance Activities. Preventive maintenance tasks recommended by the vendor included daily to monthly visual inspection of the piping, valves, tanks, flow meters, and other system components.

Chemical/Media Handling and Inventory Requirements. $KMnO_4$ addition was implemented since the system startup on July 13, 2005. Mixing of the $KMnO_4$ solution required only 10 min to complete, as reported by the operator. The chemical consumption was checked each day as part of the routine operational data collection. Several adjustments were made over time to optimize the $KMnO_4$ dosage for the oxidation of arsenic, iron, and manganese.

4.5 System Performance

The performance of the Macrolite® CP-213f arsenic removal 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. Water samples were collected at five locations across the treatment train: at the wellhead (IN), after the contact tanks (AC), after the first set of duplex unit tanks A and B (TA/TB), after the second set of duplex tanks C and D (TC/TD), and after the two sets of duplex tanks combined (TT). Sampling was conducted on 60 occasions (including four duplicate sampling events) during the 15-month system operation, with field speciation performed on samples collected from the IN, AC, and TT locations for 17 of the 60 occasions. Table 4-6 summarizes the arsenic, iron, and manganese analytical results. Table 4-7 summarizes the results of the other water quality parameters. Appendix B contains a complete set of analytical results through the 15-month system operation. The results of the water treatment plant sampling with a varying $KMnO_4$ dosage before and after the November 7, 2005, manganese jar tests are discussed below.

Arsenic and Iron Removal. Total arsenic concentrations in raw water ranged from 19.1 to 36.6 μg/L and averaged 27.5 μg/L with soluble As(III) as the predominant species averaging 21.9 μg/L (Table 4-6 and Figure 4-8). Some amounts of particulate arsenic and soluble As(V) also were present in raw water, with concentrations averaging 2.2and 3.5 μg/L, respectively. The total arsenic concentrations measured during the 15-month study period were consistent with those of the historical source water sampling (Table 4-1), although As(III) concentrations were significantly higher, representing over 80% (on average) of the total concentrations in source water (as compared to 54% during the August 31, 2004, source water sampling). The existence of As(III) as the predominating arsenic species was consistent with the low DO concentrations (averaged 1.2 mg/L, Table 4-7) and low ORP values (averaged -41 mV) in source water. One set of total arsenic data was not included in the summary table because the data were considered outliers. These were samples taken on August 8, 2006.

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

Parameters	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
As (total)	IN[a]	µg/L	59	19.1	36.6	27.5	4.3
	AC[b]	µg/L	59	18.6	36.1	26.8	3.9
	TA/TB	µg/L	40	2.4	29.8	6.6	5.5
	TC/TD	µg/L	40	2.5	17.5	6.4	3.6
	TT[c]	µg/L	21	2.0	17.7	5.9	4.4
As (soluble)	IN	µg/L	17	15.3	30.3	25.4	4.1
	AC	µg/L	17	1.8	8.7	4.4	2.2
	TT[c]	µg/L	18	1.9	6.2	3.5	1.5
As (particulate)	IN	µg/L	17	0.1	6.1	2.2	1.9
	AC	µg/L	17	10.6	32.8	22.7	5.7
	TT[c]	µg/L	18	0.1	10.9	1.7	3.3
As(III)	IN	µg/L	17	12.8	27.4	21.9	4.5
	AC	µg/L	17	0.1	5.4	1.0	1.3
	TT[c]	µg/L	18	0.1	4.4	1.2	1.3
As(V)	IN	µg/L	17	0.1	16.5	3.5	3.8
	AC	µg/L	17	1.7	8.4	3.4	1.9
	TT[c]	µg/L	18	1.3	4.9	2.3	1.1
Fe (total)	IN[a]	µg/L	59	478	3,758	2,385	772
	AC[b]	µg/L	59	633	3,173	2,295	669
	TA/TB	µg/L	40	<25	2,363	201	456
	TC/TD	µg/L	40	<25	1,140	211	332
	TT[c]	µg/L	21	<25	1,067	194	322
Fe (soluble)	IN	µg/L	17	127	3,274	2,223	966
	AC	µg/L	17	<25	306	31	71.1
	TT[c]	µg/L	18	<25	41	<25	6.6
Mn (total)	IN[d]	µg/L	59	102	176	130	12.2
	AC	µg/L	60	246	2,076	1,059	338
	TA/TB	µg/L	40	2.3	1,002	355	320
	TC/TD	µg/L	40	5.2	971	369	314
	TT[c]	µg/L	21	12.1	1,091	388	302
Mn (soluble)	IN	µg/L	17	110	159	132	11.5
	AC	µg/L	17	11.2	1,075	362	344
	TT[c]	µg/L	18	12.6	1,062	314	316

(a) 08/08/06 data considered outliers and not included in table.
(b) 11/02/05 data considered outliers and not included in table.
(c) Included data taken at TA/TB and TC/TD locations on 12/08/05.
(d) 09/07/05 data considered outliers and not included in table.
One-half of detection limit for non-detect samples used for calculations; duplicate samples included in calculations.

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

Parameters	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as $CaCO_3$)	IN	mg/L	59	338	396	366	12.7
	AC	mg/L	58	321	390	368	11.2
	TA/TB	mg/L	40	341	389	366	10.0
	TC/TD	mg/L	40	343	391	365	10.6
	TT	mg/L	19	356	392	371	11.4
Fluoride	IN	mg/L	17	0.1	0.3	0.2	0.05
	AC	mg/L	17	0.2	0.3	0.2	0.04
	TT[a]	mg/L	18	0.1	0.3	0.2	0.05
Sulfate	IN	mg/L	17	<1	<1	<1	–
	AC	mg/L	17	<1	<1	<1	–
	TT[a]	mg/L	18	<1	<1	<1	–
Nitrate (as N)	IN	mg/L	17	<0.05	0.06	<0.05	0.01
	AC	mg/L	17	<0.05	0.06	<0.05	0.01
	TT[a]	mg/L	18	<0.05	0.3	<0.05	0.05
Total P[b] (as PO_4)	IN[c]	mg/L	48	117	603	417	131
	AC[d]	mg/L	48	136	584	400	118
	TA/TB	mg/L	36	5.0	432	61.6	79.3
	TC/TD	mg/L	36	5.0	220	62.4	54.0
	TT	mg/L	13	32.1	196	73.3	56.0
Silica (as SiO_2)	IN	mg/L	59	22.4	29.4	24.2	1.2
	AC	mg/L	59	22.1	28.6	24.2	1.1
	TA/TB	mg/L	40	22.2	28.4	24.3	1.2
	TC/TD	mg/L	40	22.5	28.2	24.4	1.1
	TT	mg/L	19	21.7	24.7	23.4	0.8
Turbidity	IN	NTU	59	1.5	36.0	25.5	10.4
	AC	NTU	59	1.2	11.0	5.6	2.0
	TA/TB	NTU	40	0.1	14.0	1.4	2.6
	TC/TD	NTU	40	0.1	14.0	1.7	2.6
	TT	NTU	19	0.1	11.0	1.6	2.7
TOC	IN	mg/L	14	2.3	4.8	3.3	0.6
	AC	mg/L	14	2.3	4.6	3.2	0.5
	TT[e]	mg/L	15	2.7	4.8	3.1	0.6
pH	IN	S.U.	48	7.1	7.4	7.3	0.1
	AC	S.U.	48	7.1	7.5	7.3	0.1
	TA/TB	S.U.	32	7.2	7.4	7.3	0.05
	TC/TD	S.U.	32	7.2	7.5	7.3	0.1
	TT	S.U.	16	7.1	7.7	7.3	0.1
Temperature	IN	°C	48	9.3	14.9	10.5	0.9
	AC	°C	48	9.4	14.1	10.6	1.0
	TA/TB	°C	32	9.3	12.5	10.4	0.6
	TC/TD	°C	32	9.2	12.8	10.4	0.7
	TT	°C	16	9.5	13.8	11.1	1.3
DO	IN	mg/L	48	0.7	3.6	1.2	0.6
	AC	mg/L	48	0.5	2.3	1.1	0.4
	TA/TB	mg/L	32	0.5	2.0	1.0	0.3
	TC/TD	mg/L	32	0.5	2.1	1.0	0.3
	TT	mg/L	16	0.7	2.0	1.1	0.3

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

Parameters	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
ORP (Continued)	IN	mV	48	-76	2	-41.0	14.9
	AC	mV	48	1	403	88.0	76.4
	TA/TB	mV	32	-9	334	79.1	60.2
	TC/TD	mV	32	-12	299	81.5	56.2
	TT	mV	16	6	336	110	85.0
Total Hardness (as $CaCO_3$)	IN	mg/L	17	243	383	315	29.6
	AC	mg/L	17	256	346	311	21.5
	TT[(a)]	mg/L	18	280	346	314	17.9
Ca Hardness (as $CaCO_3$)	IN	mg/L	17	161	228	190	15.5
	AC	mg/L	17	145	201	186	13.4
	TT[(a)]	mg/L	18	167	212	187	11.8
Mg Hardness (as $CaCO_3$)	IN	mg/L	17	82.0	155	127	16.2
	AC	mg/L	17	95.3	145	125	11.4
	TT[(a)]	mg/L	18	96.9	144	126	10.3

(a) Included data taken at TA/TB and TC/TD locations on 12/08/05.
(b) Total P not analyzed until 10/05/05.
(c) 08/08/06 data considered as outlier and not included in table.
(d) 11/02/05 data considered outlier and not included in table.
(e) Included data taken at TA/TB and TC/TD locations on 01/17/06.
One-half of detection limit for non-detect samples are used for calculations. Duplicate samples included in calculations.

Total iron concentrations in raw water averaged 2,385 µg/L, existing almost entirely in the soluble form. The presence of predominating soluble iron was consistent with the presence of predominating As(III) as well as low DO concentrations and low ORP values. Given the average soluble iron and soluble arsenic levels in source water, this corresponded to an iron to arsenic ratio of 88:1, which was well above the target ratio of 20:1 for effective arsenic removal by iron removal (Sorg, 2002). As shown in Table 4-6 and Figure 4-9, total iron concentrations varied widely from 478 to 3,758 µg/L with possible seasonal variations. Two pieces of iron data were considered as outliers and not included in the data analyses as noted on Table 4-6. Varying iron concentrations could affect $KMnO_4$ dosage, which was critical to the formation of filterable manganese solids, as discussed later in this subsection.

After $KMnO_4$ addition and after the contact tanks, soluble arsenic concentrations averaged 4.4 µg/L, of which 1.0 µg/L was As(III), indicating effective oxidation of As(III) to As(V). As(V) concentrations after the contact tanks, however, were low, ranging from 1.7 to 8.4 µg/L and averaging 3.4 µg/L. Any As(V) formed apparently was adsorbed onto and/or co-precipitated with iron solids, as evidenced by the significantly elevated particulate iron and particulate arsenic levels (i.e., 2,264 and 22.7 µg/L [on average], respectively) after the contact tanks. The near complete precipitation of soluble iron observed suggested effective Fe(II) oxidation even in the presence of 3.3 mg/L of TOC (on average) (Table 4-7). Researchers have reported that Fe(II)-$KMnO_4$ reaction rates are more rapid than $KMnO_4$-DOC interactions (Knocke et al., 1994). It appears that the elevated TOC levels in raw water did not adversely impact As(III) and Fe(II) oxidation. Note that based on tank level measurements, $KMnO_4$ dosages used during the performance evaluation study ranged from 1.3 to 6.5 mg/L (as $KMnO_4$). The effects of $KMnO_4$ dosage on Mn(II) oxidation and removal are discussed later in this subsection.

From July 13, 2005, to October 4, 2006, total arsenic concentrations in the treated water ranged from 2.0 to 29.8 µg/L and averaged 6.4 µg/L (Table 4-6). Soluble arsenic concentrations in the treated water ranged from 1.9 to 6.2 µg/L and averaged 3.5 µg/L. As shown in Figure 4-10, out of the 60 sampling

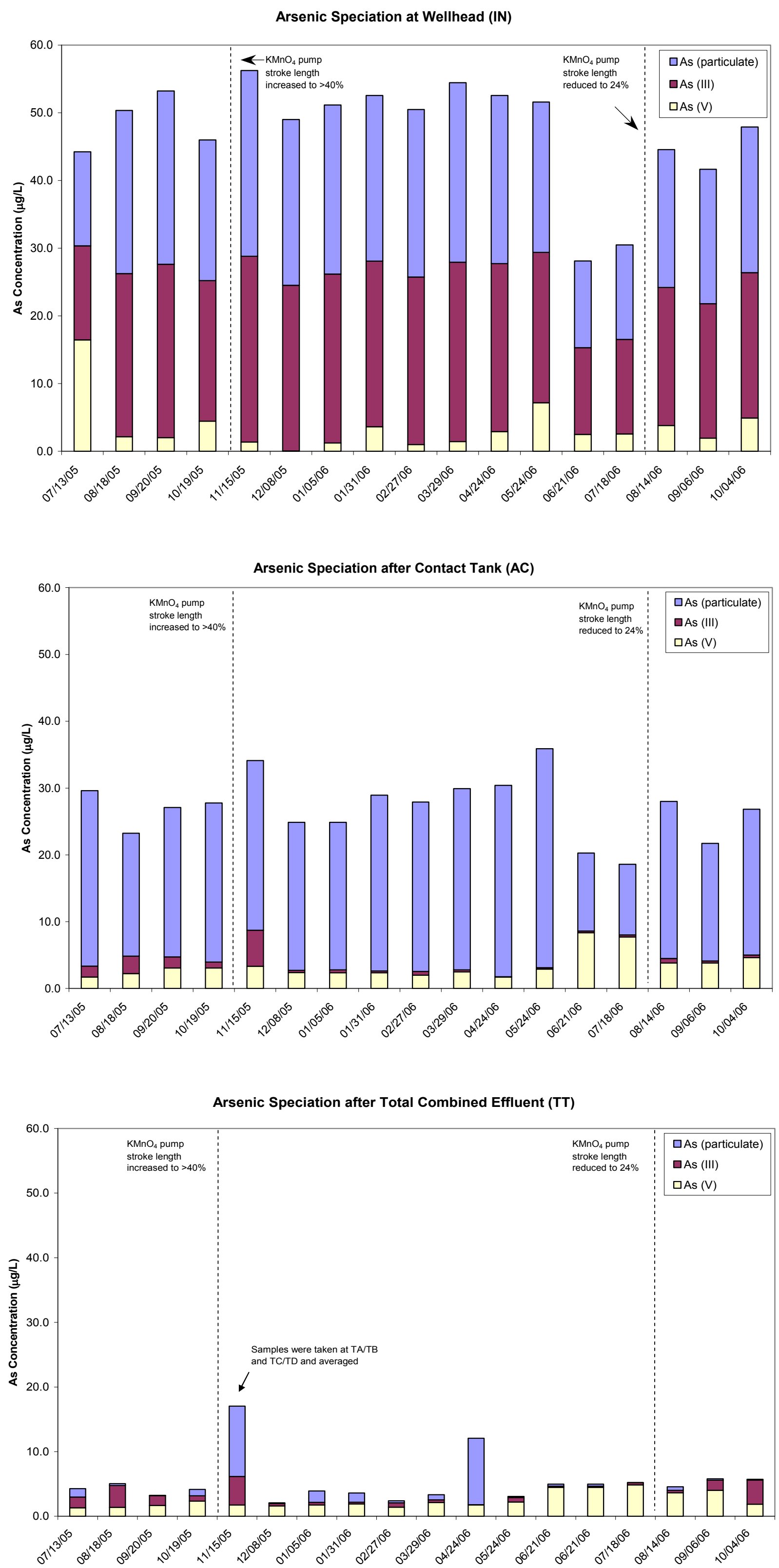


Figure 4-8. Concentrations of Arsenic Species at IN, AC, and TT Sampling Locations

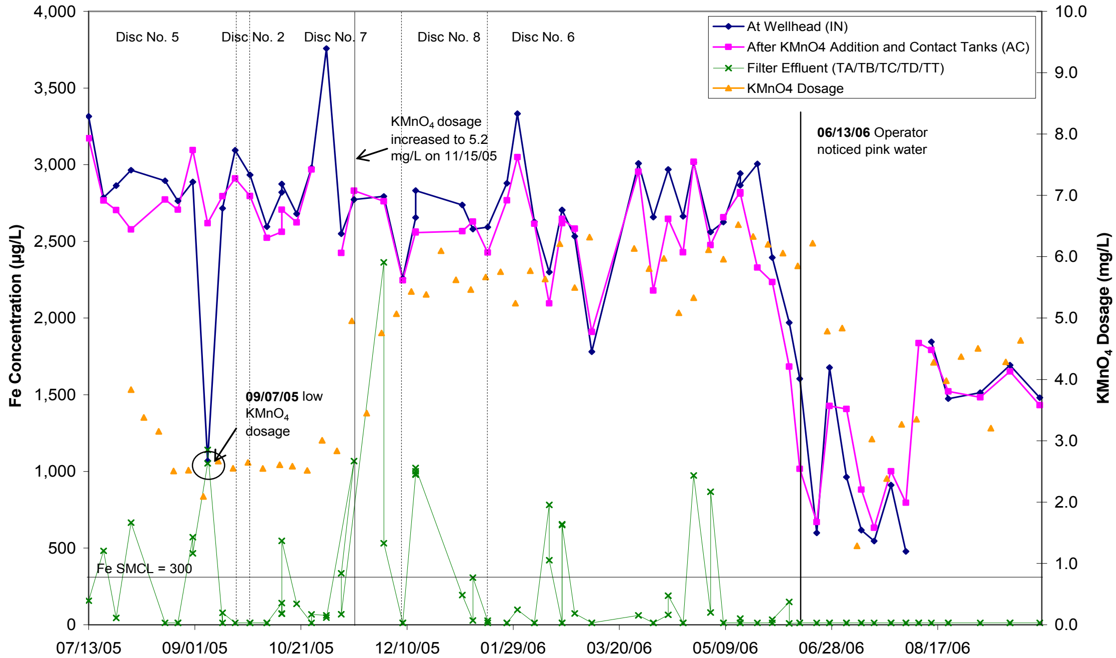


Figure 4-9. Total Iron Concentrations After Contact Tanks and after Macrolite® Filters

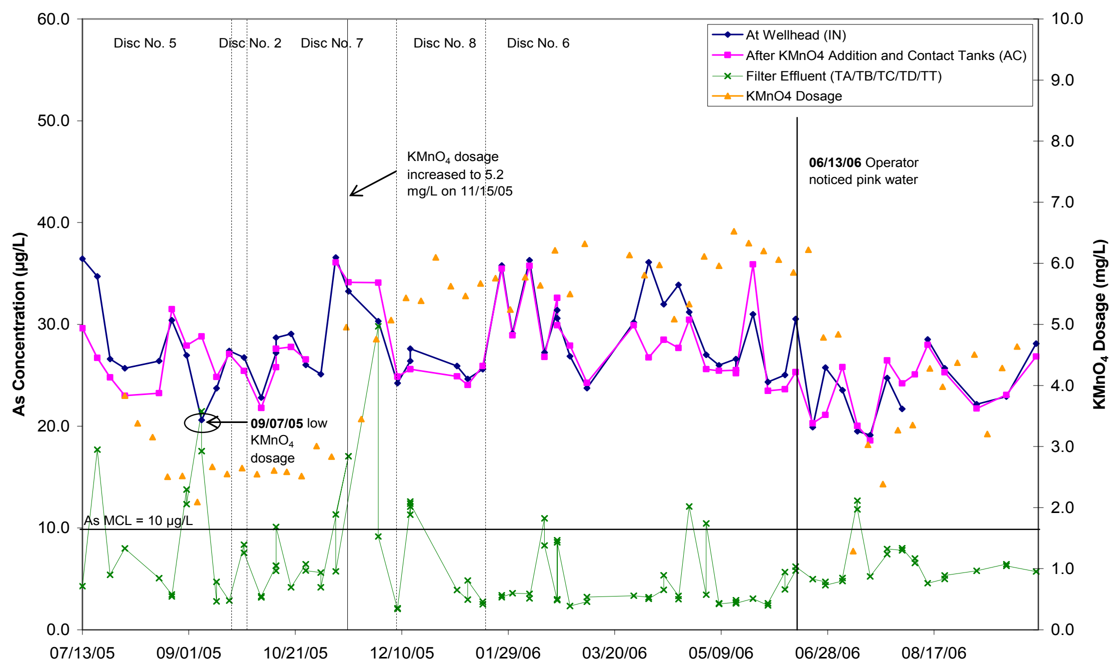


Figure 4-10. Total Arsenic Concentrations After Contact Tanks and after Macrolite® Filters

occasions, total arsenic concentrations in the treated water exceeded the 10-µg/L MCL for a total of 13 times, mostly due to particulate breakthrough from the Macrolite® filters. As shown in Figure 4-9, the elevated total arsenic concentrations were accompanied by elevated total iron concentrations. The iron concentrations in the treated water ranged from <25 to 2,363 µg/L and averaged 204 µg/L, with almost all existing as particulate iron. Soluble iron levels were <25 µg/L as measured in water samples filtered with 0.45-µm disc filters. On September 7, 2005, the total arsenic concentration in the treated water exceeded 10 µg/L due to low $KMnO_4$ dosage, as evidenced by the negative ORP readings across the treatment train, resulting in incomplete As(III) and Fe(II) oxidation.

A study has shown that Fe(II) complexed with DOM might be difficult to remove via oxidation and subsequent precipitation of $Fe(OH)_3(s)$. This was due to the formation of colloidal iron that had a size fraction small enough to pass through 0.2-µm disc filters. However, this phenomenon would be affected by the concentration and nature of the DOM in water (Knocke et al., 1994). The formation of colloidal iron did not appear to be an issue at the BSLMHP site with primarily particulate iron present after the contact tanks and after the Macrolite® filters (e.g. a size fraction large enough to be retained by a 0.45-µm disc filter). The increase in particulate iron also corresponded with an increase in particulate arsenic, indicating iron breakthrough from the Macrolite® filters.

In order to better control particulate breakthrough from the filtration tanks, the control valves located on top of the two duplex units were replaced three times from No. 5 to No. 7, from No. 7 to No. 8, and then from No. 8 to No. 6 during the study to allow for more frequent backwash. (Note that No. 2 was erroneously installed and used for a short duration before the mistake was caught and corrected). Table 4-8 lists the operating duration, valve number, gear volume, number of occurrence during which total arsenic concentrations exceeded 10 µg/L, and total iron concentrations with arsenic exceeding 10 µg/L.

Table 4-8. Control Valve Sizes and Corresponding Occurrences of High Total Arsenic and Iron Concentrations

Duration	Control Valve No.	Gear Volume (gal)	Number of Occurrence	Total Arsenic Concentration Exceeding 10 µg/L in Filter Effluent (µg/L)			Total Iron Concentration with Arsenic Exceeding 10 µg/L in Filter Effluent (µg/L)		
				Min	Max	Avg	Min	Max	Avg
07/13/05–09/20/05	No. 5	13,700	3	12.3	21.5	16.3	465	1,140	807
09/21/05–09/29/05	No. 2[(a)]	13,700	-	-	-	-	-	-	-
09/30/05–12/06/05	No. 7	13,700	4	10.1	29.8	17.1	336	2,363	1,078
12/07/05–01/17/06	No. 8	13,700	2[(b)]	11.3	12.6	12.1	978	1,023	996
01/18/06–10/04/06	No. 6	5,500	4	10.5	12.7	11.6	<25	973	658

(a) Incorrect disc inadvertently installed and corrected soon after installation.
(b) Including field duplicate.

The use of Valve No. 5 and No. 7 resulted in three and four occurrences, respectively, with arsenic concentrations measured as high as 29.8 µg/L and iron concentrations as high as 2,363 µg/L. Valve No. 8 was installed on December 7, 2005, and the treated water samples collected during December 7, 2005, through January 17, 2006, contained an average of 12.1 and 996 µg/L of total arsenic and iron, respectively. Valve No. 6 with a smaller-volume gear designed for even more frequent backwash than Valve No. 8 was installed on January 18, 2006. The treated water sample collected during January 18 to October 1, 2006, contained an average of 11.6 and 658 µg/L of total arsenic and iron, respectively, which were the lowest for the entire performance period. However, there were still three sampling events on

February 15, April 24, and May 2, 2006 that had elevated arsenic and iron due to particulate arsenic and iron breakthrough. By October 4, 2006, total arsenic and iron had remained below the arsenic MCL and iron detection limit for nine consecutive sampling events, therefore, the treatment system was considered working properly and a decision was made to conclude the performance evaluation.

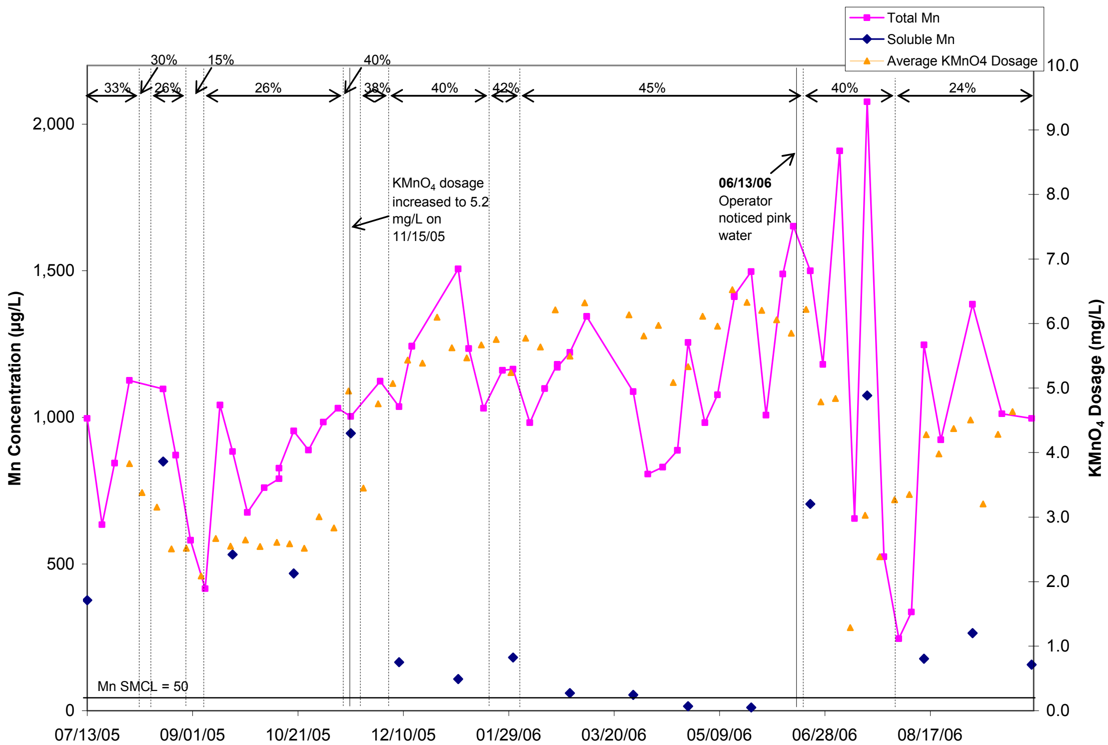
Manganese. As shown in Table 4-6, total manganese concentrations in raw water ranged from 102 to 176 μg/L and averaged 130 μg/L , which existed almost entirely in the soluble form. The manganese levels in raw water exceeded its secondary MCL of 50 μg/L.

Figure 4-11 and Table 4-9 show total and soluble manganese concentrations after $KMnO_4$ addition and after the contact tanks (AC) and after the Macrolite® filters (TA/TB, TC/TC, and TT) over time. Before and on November 15, 2005, total manganese levels after the contact tanks ranged from 416 to 1,126 μg/L and averaged 856 μg/L, with 38 to 94% comprised of "soluble" manganese based on the use of 0.45-μm disc filters. During this time period, the $KMnO_4$ dosage was incrementally decreased from the initial level of 3.8 to 1.4 mg/L, and then increased to 2.6 mg/L by adjusting the paced-pump stroke length from 33 to 15%, and then to 26%. The $KMnO_4$ dosage was decreased from the initial level of 3.8 mg/L because elevated total and "soluble" manganese levels at 900 (average) and 377 μg/L, respectively, were thought, at the time, to have been caused by overdosing of $KMnO_4$. Decreasing the $KMnO_4$ dosage from 3.8 to 3.4 and then to 3.0 mg/L did not appear to help reduce the manganese concentrations, with total and "soluble" levels measured, for example, at 1,097 and 850 μg/L, respectively, on August 18, 2005. A further decrease in $KMnO_4$ dosage to 1.4 mg/L helped reduce the total manganese levels, which, however, were still higher than those in raw water at 581 and 416 μg/L, respectively, on August 31 and September 7, 2005. This low level of $KMnO_4$ addition also caused significantly elevated arsenic and iron concentrations in the treated water due to incomplete oxidation of As(III) and Fe(II) as discussed in Section 4.5.1. Increasing the $KMnO_4$ dosage back to 2.6 mg/L returned the total manganese concentrations to 676 to 1,042 μg/L, with most (i.e., 468 to 946 μg/L) existing in the "soluble" form.

The addition of 1.4 mg/L to 3.8 mg/L of $KMnO_4$ during July 13 through November 15, 2005, resulted in significantly elevated manganese levels not only after the contact tanks, as discussed above, but also after the Macrolite® filters (ranging from 428 to 1,091 μg/L and averaging 722 μg/L, Figure 4-11 [bottom] and Table 4-9). Further, manganese in the treated water existed almost entirely (i.e., 535 to 1,062 μg/L) in the "soluble" form based on the use of 0.45-μm filter discs for obtaining the soluble fractions.

Mn(II) oxidation by $KMnO_4$ is dependent on the $KMnO_4$ dosage, pH, temperature, and DOM concentration in raw water. The reaction between $KMnO_4$ with Mn(II) is typically rapid and complete at pH values ranging from 5.5 to 9.0. However, elevated DOM levels can increase the $KMnO_4$ demand due to competition between these species and resulting kinetic effects (Knocke et al., 1987). Some researchers suggest that DOM can interfere with the formation of MnO_2 solids by exerting $KMnO_4$ demand and, possibly, forming complexes with fractions of Mn(II), thus rendering it less likely to be oxidized (Gregory and Carson, 2003). When modeling the Mn(II) oxidation with $KMnO_4$, Carlson et al. (1999) determined that incorporating a term to account for the DOM demand for MnO_4^- significantly improved the prediction of the MnO_4^- consumption. The incorporation of DOM into the oxidation term to account for complexation between DOM and Mn(II) also was postulated but no data were collected as part of that study. Further, high levels of DOM in source water also can form fine colloidal MnO_2 particles, which may not be filterable by conventional gravity or pressure filters. Knocke et al. (1991) defined colloidal particles as those passing through 0.20-μm filters and requiring ultrafiltration for removal.

The presence of significantly elevated "soluble" manganese levels after the contact tanks and after the Macrolite® filters, even with the use of less than the theoretical demand of $KMnO_4$ for reduced arsenic, iron, and manganese (i.e., 3.3 mg/L), prompted the speculation that the "soluble" manganese measured



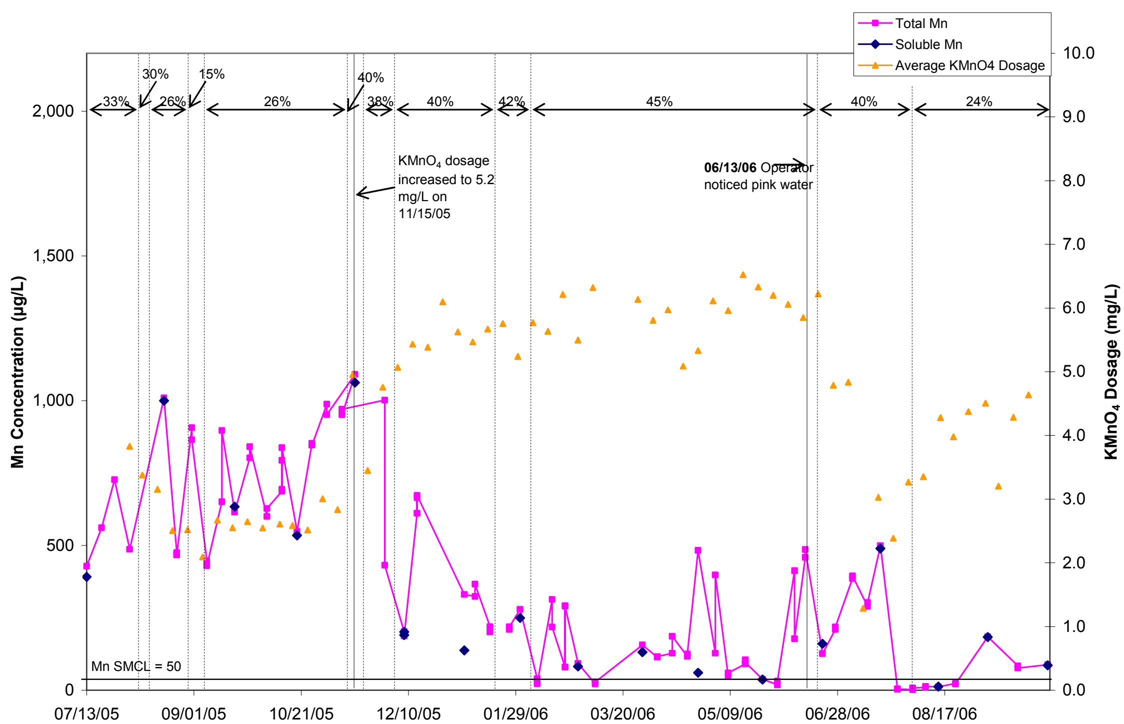


Figure 4-11. Total and Soluble Manganese Concentrations Following Contact Tanks (Top) and Macrolite® Filters (Bottom)

Table 4-9. Correlations between Pump Stroke Length, KMnO4 Dosage, and Total and Soluble Manganese Concentrations

Duration	Stroke Length (%)	Average $KMnO_4$ Dosage (µg/L)	Total Mn at AC Location (µg/L)	Soluble Mn at AC Location (µg/L)	Total Mn at TA/TB, TC/TD, and TT Locations (µg/L)	Soluble Mn at TA/TB, TC/TD, and TT Locations (µg/L)
07/13/05 to 08/07/05	33	3.8	634–1,126 (900)	377	428–727 (551)	391
08/08/05 to 08/13/05	30	3.4	N/A	N/A	N/A	N/A
08/14/05 to 08/30/05	26	3.0	871–1,097 (984)	850	467–1,010 (651)	1,000
08/31/05 to 09/07/05	15	1.4	416–581 (499)	N/A	430–906 (662)	N/A
09/08/05 to 11/15/05	26	2.6	676–1,042 (894)	468–946 (649)	548–1,091 (802)	535–1,062 (744)
11/16/05 to 11/20/05	40	5.2	N/A	N/A	N/A	N/A
11/21/05 to 12/04/05	38	4.4	1,123	N/A	432–1,002 (717)	N/A
12/05/05 to 01/20/06	40	5.6	1,031–1,506 (1,216)	108–166 (137)	201–673 (399)	138–202 (177)
01/21/06 to 02/02/06	42	5.8	1,160–1,164 (1,162)	182	210–280 (236)	250
02/03/06 to 06/15/06	45	4.4	807–1,652	11.2–60.1	19.0–486	36.7–132
06/16/06 to 08/01/06	40	3.5	525–2,076 (1,308)	705–1,075 (890)	2.5–499 (244)	161–490 (326)
08/02/06 to 10/04/06	24	3.8	246–1,385 (878)	157–264 (199)	2.3–185 (48)	12.6–184 (94)

N/A = Data not available
Data in parentheses representing average values.

might, in fact, be colloidal particles that had passed through the 0.45-µm disc filters. Therefore, jar tests were performed on November 7, 2005, to determine if higher $KMnO_4$ dosages might help overcome the DOM effect and form larger filterable MnO_2 solids in the treated water. Prior to the start of the jar tests, the additional $KMnO_4$ demand of a Macrolite®-treated water sample (to which 3.0 mg/L of $KMnO_4$ had already been added based on the $KMnO_4$ consumption in the chemical day tank during the week of sampling) was pre-determined by titrating 1 L of the water with a 1-g/L $KMnO_4$ titrant. After 2.5 mL of the titrant was added, the water being titrated developed a dark yellow color, and was filtered, after about 10 min, with 0.20-µm disc filters to remove any suspended solids including MnO_2. The filtrate was observed to have a pink color, indicating the presence of $KMnO_4$ residual.

Five $KMnO_4$ dosages ranging from 1.0 to 3.0 mg/L were then selected for the jar tests using the same Macrolite®-treated water sample mentioned above. (These dosages would be in addition to the $KMnO_4$ already added to the water to be treated). After 31 min of mixing time (including 1 min at 200 rpm, 19 at 100 rpm, and 11 min at 28 rpm), the water in the jars was filtered separately with 0.20-µm disc filters and analyzed for soluble arsenic, iron, and manganese. Table 4-10 summarizes the results of the jar tests.

During mixing, jars No. 2 to 4 formed large brown flocs in a pale to dark yellow solution (Figure 4-12). Jars No. 5 to 6 had smaller brown flocs in a dark copper solution. As shown in Table 4-10, soluble iron levels in all jars were below the MDL of 25 µg/L, suggesting that effective oxidation and removal of iron

Table 4-10. Jar Test Results for Macrolite®-Treated Water

Parameter	1	2	3	4	5	6
$KMnO_4$ Added (mg/L)[(a)]	0	1.0	1.5	2.0	2.5	3.0
Mixing Time (min)	31	31	31	31	31	31
Initial[(b)]/Final[(c)] pH@ 16.8°C	7.70/7.68	7.80/7.67	7.81/7.70	7.71/7.62	7.74/7.60	7.76/7.61
Initial[(b)]/Final[(c)] ORP @ 16.8°C	283/353	292/360	400/363	440/369	509/493	521/515
Residual $KMnO_4$ (mg/L)[(d)]	0.04	0.01	0.05	0.07	0.35	0.63
As (soluble)[(e)] (μg/L)	5.5	4.5	3.3	3.3	3.2	3.1
Fe (soluble)[(e)] (μg/L)	<25	<25	<25	<25	<25	<25
Mn (soluble)[(e)] (μg/L)	1,090	102	0.8	11.0	399	469

(a) Dosage was in addition to the 3.0 mg/L already added to the water prior to jar tests.
(b) Reading taken approximately 15 min into jar test.
(c) Reading taken at end of 31 min jar test.
(d) CAIROX® Method 103 (DPD spectrophotometry) for determination of $KMnO_4$ residual.
(e) Filtered with 0.20-μm filters.

had already been achieved prior to the jar tests. Soluble arsenic levels decreased slightly from 5.5 μg/L to 3.1 μg/L in jar No. 6 (the one with the highest $KMnO_4$ dosage 3.0 mg/L). Only soluble manganese concentrations varied significantly, decreasing from 1,090 μg/L in jar No. 1 to <1 μg/L in jar No. 3 and then increasing to 469 μg/L in jar No. 6. Knocke et al. (1990) reported that kinetics for Fe (II) oxidation are faster than for Mn (II) oxidation when $KMnO_4$ is used as the oxidant. The relevant stoichiometric equations are shown as follows:

$$3Fe^{2+} + KMnO_4 + 7H_2O \rightarrow 3Fe(OH)_{3(s)} + MnO_{2(s)} + K^+ + 5H^+$$

$$3Mn^{2+} + 2KMnO_4 + 2H_2O \rightarrow 5\,MnO_{2(s)} + 2K^+ + 4H^+$$

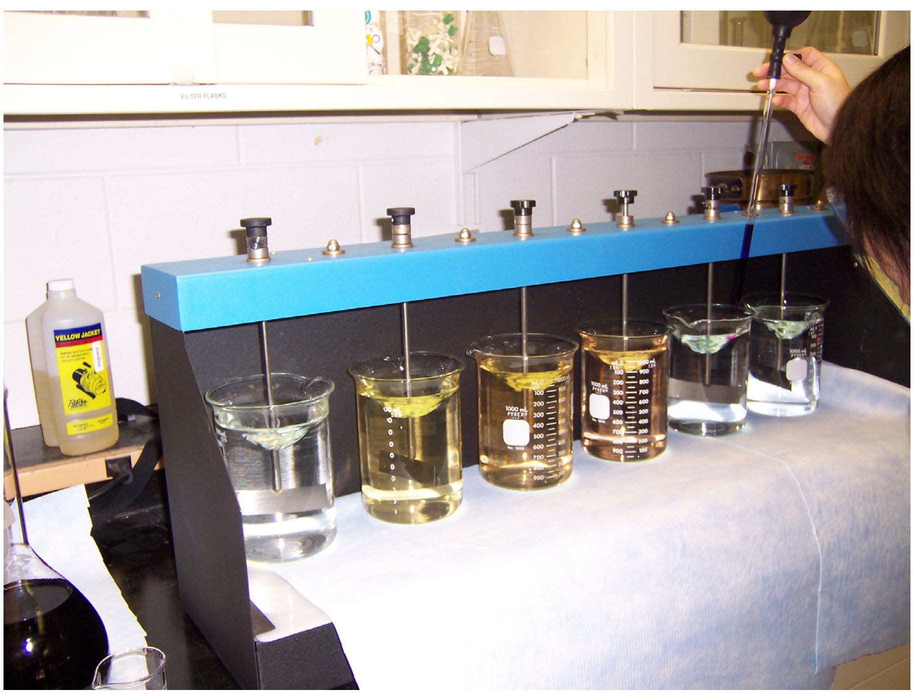


Figure 4-12. Jar Test Setup

In the control sample, the "soluble" manganese level was high presumably due to the slower Mn(II) oxidation kinetics and the presence of DOM as discussed above. The 1,090 µg/L of "soluble" manganese in the control sample confirmed that the manganese most likely was present as colloidal particles since the sample analyzed had already been filtered with 0.2 µm disc filters. Increasing the $KMnO_4$ dosage to 1.5 mg/L (on top of the 3.0 mg/L already added to the water prior to the jar tests) appeared to be sufficient to overcome the effects of DOM, allowing formation of filterable manganese particles. As a result, only 0.8 µg/L of manganese that passed through the 0.2-µm filters was reported as "soluble" manganese. Further increasing the $KMnO_4$ dosage up to 3 mg/L increased the soluble manganese level up to 469 µg/L, suggesting excess $KMnO_4$ in the treated water. The presence of $KMnO_4$ was supported by the elevated residual $KMnO_4$ levels and the elevated ORP readings (see results of jars No. 4 and 5).

Based on the jar test results, it was determined that an additional 1.5 mg/L of $KMnO_4$ was needed to attain filterable manganese solids. Therefore, the $KMnO_4$ dosage to the treatment system was increased on November 15, 2005 for a target dosage of 4.5 mg/L. The $KMnO_4$ pump stroke length was increased incrementally from 26 to 38–45% to achieve an average dosage of 4.4 to 5.8 mg/L between November 15, 2005, and June 15, 2006. In response, soluble manganese concentrations at the AC location, as determined by the use of 0.45-µm disc filters, were reduced to as low as 35 µg/L (on average during February 3 through June 15, 2006, as shown in Table 4-9) while total manganese concentrations remained as high as 1,179 µg/L (on average during February 3 through June 15, 2006). Meanwhile, total and soluble manganese concentrations, as determined, again, by the use of 0.45-µm disc filters in the filter effluent, were reduced, on average, to 163 and 78 µg/L, respectively, during the same test period (i.e., February 3 through June 15, 2006). The data clearly demonstrated that it was necessary to increase the $KMnO_4$ dosage in order to convert MnO_2 colloids to particles filterable by the Macrolite® pressure filters.

Controlling a proper $KMnO_4$ dosage always is a challenging task, especially if water quality varies. Starting from June 13, 2006, the operator observed pink color in the treated water, apparently due to overdosing of $KMnO_4$. A careful review of analytical data revealed that significant decreases in arsenic and iron concentration in raw water, as shown in Figures 4-9 and 4-10, occurred, although manganese and TOC concentrations remained relatively constant. Decreasing arsenic and iron concentrations caused total and soluble manganese concentrations at the AC location to increase to 1,308 and 890 µg/L, respectively, even at a somewhat reduced $KMnO_4$ dosage of 3.5 mg/L during June 16 through August 1, 2006. From August 2 through October 4, 2006, at a dosage of 3.8 mg/L, total and soluble manganese concentrations were reduced to 878 and 199 µg/L, respectively, on average, at the AC location, and to 48 and 94 µg/L, respectively, after the pressure filters. These concentrations were close to but still above the SMCL for manganese.

TOC. TOC levels in raw water were elevated, ranging from 2.3 to 4.8 mg/L and averaging 3.3 mg/L. Due to these high TOC levels, $KMnO_4$ was used as the oxidant to oxidize reduced arsenic, iron, and manganese. TOC levels were reduced by 3 to 6% across the treatment train, with 3.2 mg/L, on average, at the AC location and 3.1 mg/L after the pressure filters. These observation were consistent with the results of prior research, which had shown only minimal organic carbon removal (i.e., <10%), via $KMnO_4$ oxidation, in source water containing Mn (II) and DOC (Salbu and Steinnes, 1995; Knocke et al., 1990).

Other Water Quality Parameters. DO levels remained low across the treatment train (with average values ranging from 1.0 to 1.2 mg/L), but ORP values increased across the treatment train (ranging from -76 to 2 mV before versus 1 to 403 mV after $KMnO_4$ addition). Not included in the findings were two outliers on September 7 and October 26, 2005, where the ORP values after the contact tanks were negative due to low $KMnO_4$ dosage. The ORP value on September 7, 2005, was negative because the stroke length on the $KMnO_4$ pump was turned down to 15% on August 31, 2005. pH values of raw water had an average value of 7.3, which remained unchanged after treatment. Average alkalinity results ranged from 365 to 371 mg/L (as $CaCO_3$) across the treatment train. Average total hardness results ranged from 311 to 315 mg/L (as $CaCO_3$) across the treatment train (the total hardness is the sum of calcium hardness and magnesium hardness). The water had an almost even split of calcium and magnesium hardness. Fluoride concentrations were 0.2 mg/L in raw water and after contact tanks and were not affected by the Macrolite® filtration. The average nitrate concentration was <0.05 mg/L (as N) across the treatment train. There was no detection of sulfate and the silica concentrations remained at approximately 24 mg/L (as SiO_2) across the treatment train.

Total phosphorous analyzed starting from October 5, 2005 to October 4, 2006, showed an average of 423 μg/L (as P) in raw water and 63.8 μg/L (as P) in treated water (Figure 4-13). This 85% removal was most likely achieved through adsorption onto iron solids. The elevated total phosphorous levels were further confirmed by analyzing a raw water sample taken on December 14, 2005, for the various phosphorous species according to EPA Method 365.3 by Sierra Environmental Monitoring, Inc. It was determined that the total phosphorous level in raw water was 0.58 mg/L (as P), present primarily as total hydrolyzable phosphorous at 0.51 mg/L (as P). According to EPA Method 365.3, total hydrolyzable phosphorous includes both polyphosphorous and organic phosphorous. It also was later confirmed by EPA Method 507 that no organopesticides were present in source water. There were other potential sources for elevated phosphorous in groundwater. Based on research conducted by the Sauk River Watershed District, the Sauk River and Big Sauk Lake have sediment, phosphorous, and nitrates caused by non-point source discharges from septic systems, agriculture, and urban runoff (Post, 2005). The historical monitoring data for the surface water of Big Sauk Lake show a maximum total phosphorous level of 0.4 mg/L (as P) (Sauk River Watershed District, 2006) and the Big Sauk Lake is located approximately 1000 ft from the BSLMHP well house.

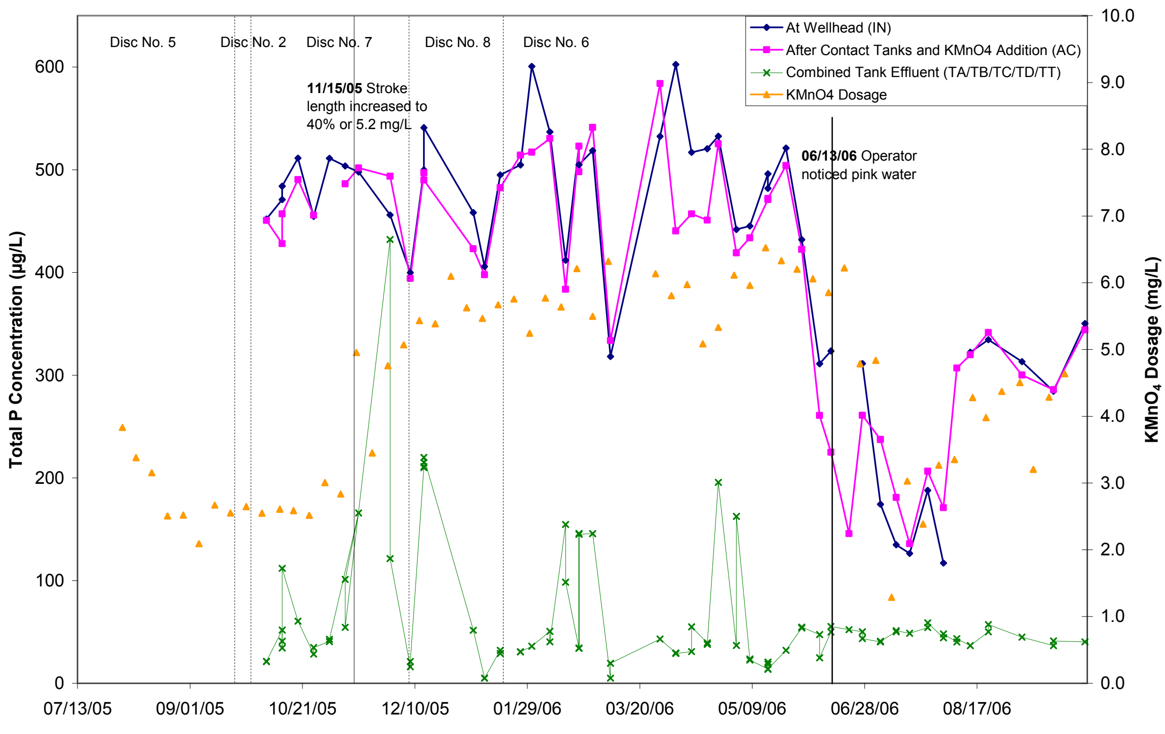


Figure 4-13. Total Phosphorous Concentrations After Contact Tanks and After Macrolite® Filters

4.5.2 Backwash Wastewater Sampling. Table 4-11 summarizes the analytical results from the 14 backwash wastewater sampling events. For Events 1, 2, and 3, only pH, turbidity, TDS, and soluble arsenic, iron, and manganese were analyzed for the samples collected at the outfall of the backwash wastewater discharge line. Soluble arsenic, iron, and manganese concentrations in the backwash water ranged from 3.5 to 8.5, <25 to 63, and 560 to 736 µg/L, respectively. The high "soluble" manganese concentrations in the backwash wastewater reflected the similar levels of manganese in treated water (i.e., 337 to 946 µg/L prior to November 15, 2005) used for backwashing.

Starting from November 15, 2005, backwash wastewater samples were collected using the modified sampling procedure discussed in Section 3.3.4. Turbidity was replaced by TSS, and total arsenic, iron, and manganese were added to the analyte list. Due to changes to the control disc on top of each duplex unit, the data collected from Events 7 to 14 when the control disc was kept constant at 6 are discussed herein. For both duplex units, total arsenic, iron, and manganese concentrations in the backwash wastewater ranged from 39 to 335 µg/L, 4.8 to 44.5 mg/L, and 1.6 to 14.0 mg/L, respectively, and the respective average concentrations were 130 µg/L, 19.5 mg/L, and 7.2 mg/L. TSS levels ranged from 22.0 to 150 mg/L, averaging 72 mg/L. The wide variations (as high as one order of magnitude) in these measurements were attributed, in part, to the difficulties in collecting representative samples containing suspended solids. Based on 72 mg/L of TSS in 130 gal of backwash wastewater produced by one tank, approximately 35.4 g (0.078 lb) of solids were discharged to the septic system and then to a sanitary sewer, with the solids containing 63.7 mg of arsenic, 9.6 g of iron, and 3.5 g of manganese. The soluble arsenic and iron concentrations were similar to those prior to November 15, 2005. However, the soluble manganese concentrations were significantly lower (ranging from 1.0 to 175 µg/L), which mirrored the treatment results due to the use of a higher $KMnO_4$ dosage.

Table 4-12 presents the total metal results of backwash solid samples collected from Tanks A and B. Arsenic, iron, and manganese levels averaged 2.03 mg/g (or 0.2%), 190 mg/g (or 19%), and 136 mg/g (or 13.6%), respectively. Based on 35.4 g of solids produced by each tank, the amount of arsenic, iron, and manganese existed would be 72 mg, 6.7 g, and 4.8 g, respectively, which are similar to those presented above via the analysis of backwash wastewater samples. Total phosphorous in the backwash solids also was noteworthy at an average of 32.8 mg/g (3.28%).

4.5.3 Distribution System Water Sampling. Table 4-13 summarizes the results of the distribution system sampling events. Figure 4-14 provides plots to contrast total As, Fe, and Mn concentrations before and after system startup. The water quality was similar among the three residences in the disctribution system. After the treatment system began operation, arsenic and iron concentrations decreased from average baseline levels of 23.4 and 2,791 µg/L to 8.1 and 173 µg/L, respectively. Manganese concentrations increased significantly from average baseline levels of 130 µg/L due to the additon of various amounts of $KMnO_4$. Lead concentrations remained fairly constant and averaged 0.6 and 1.6 µg/L before and after system startup, respectively (except for a spike of 25.2 µg/L at DS3 on June 14, 2006). Copper concentrations increased from the baseline level of 1.8 to 18.5 µg/L, including a spike of 228 µg/L. Several factors including low pH, high temperature, and soft water with lower dissolved minerals can increase the solubility of copper in drinking water in contact with plumbing fixtures. However, none of these factors would have been associated with the operation of the treatment system. Alkalinity and pH concentrations remained fairly constant.

As noted in Table 4-13, a few pieces of data were considered invalid because samples were taken from infrequenctly used sample taps and showed uncharacteristically high arsenic, iron, and/or manganse concentrations. Otherwise, most arsenic, iron, and manganese concentrations in the distribution system were comparable to those in the treated water except for three occasions when treated water had elevated concentrations due to particulate breakthrough (as marked on Figure 4-14). These spikes were not reflected in the distribution water samples. In general, except for manganese, the water quality in the

Table 4-11. Backwash Water Sampling Results

Sampling Event		KMnO$_4$ Dosage	Control Disc	BW1 (Tank A/B)										BW2 (Tank C/D)									
				pH	TDS	TSS	Total As	Soluble As	Particulate As	Total Fe	Soluble Fe	Total Mn	Soluble Mn	pH	TDS	TSS	Total As	Soluble As	Particulate As	Total Fe	Soluble Fe	Total Mn	Soluble Mn
No.	Date	mg/L	No.	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	09/08/05	2.6	5	7.2	576	NS	NS	3.9	NS	NS	<25	NS	624	7.3	544	NS	NS	3.5	NS	NS	<25	NS	560
2	09/20/05	2.6	5	7.3	550	NS	NS	3.6	NS	NS	<25	NS	624	7.3	368	NS	NS	8.5	NS	NS	<25	NS	736
3	10/12/05	2.6	7	7.3	356	NS	NS	4.4	NS	NS	<25	NS	685	7.3	350	NS	NS	4.3	NS	NS	63	NS	656
4	11/15/05[a]	2.6	7	7.5	54	102	329	6.9	322	63,108	163	1,595	836	Data not shown due to suspected sampling errors									
5	12/08/05	5.6	8	7.4	224	210	417	0.5	416	77,641	201	16,178	350	7.6	334	175	397	2.9	394	75,485	39	14,159	348
6	01/10/06	5.6	8	7.4	360	130	363	3.3	360	43,384	128	12,265	341	7.6	326	16[c]	114	5.3	109	14,069	304	4,016	376
7	02/08/06	4.4	6	7.4	328	116	313	3.3	310	37,949	75	12,571	35.1	7.4	340	150	335	3.7	331	44,534	80	14,055	38.6
8	03/07/06	4.4	6	7.4	336	66	178	3.7	174	24,100	24	11,502	33.0	7.4	342	60	177	5.6	171	24,391	<25	11,516	40.5
9	04/05/06	4.4	6	7.4	358	22	132	3.5	128	13,245	<25	4,869	92.1	7.3	410	8[c]	72.4	3.5	68.8	10,317	46	2,700	92.0
10	05/02/06	4.4	6	7.3	352	96	107	2.6	104	18,220	31	5,320	79.6	7.2	326	90	100	2.8	97.6	18,149	29	4,850	76.4
11	06/08/06	4.4	6	7.4	344	132	53.0	3.6	49.4	30,376	<25	9,432	175	7.3	334	90	53.9	3.8	50.1	21,748	34	7,202	163
12	07/26/06	3.5	6	7.3	358	45	46.3	6.5	39.8	6,005	<25	2,272	1.0	7.3	346	12[c]	38.9	6.6	32.3	4,803	<25	2,112	2.1
13	08/21/06	3.8	6	7.2	340	52	87.3	4.2	83.1	13,076	<25	4,068	17.8	7.2	346	30	65.5	4.4	61.1	8,774	<25	2,772	27.2
14	09/20/06	3.8	6	7.3	366	74	140	4.8	135	15,458	<25	8,699	18.9	7.3	365	106	172	6.4	166	21,504	<25	11,294	16.4
Average[b]		4.1	6	7.3	348	75	132	4.0	128	19,804	<25	7,342	56.6	7.3	351	68	127	4.6	122	19,278	30	7,063	57.0

(a) Modified backwash procedures implemented since November 15, 2005. For Events 1 to 3, turbidity was measured at 170, 160, and 120 NTU from Tank A/B and 120, 17, and 410 NTU from Tank C/D, respectively.
(b) Data represent averages of Events 7 to 14 when Disc No. 6 was used throughout the duration.
(c) Data appeared uncharacteristically low.

Table 4-12. Backwash Solids Sample ICP/MS Results

Date: Location	Mg	Al	Si	P	Ca	V	Mn	Fe	Ni	Cu	Zn	As	Cd	Sb	Ba	Pb	Fe/As
	mg/g	mg/g	µg/g	mg/g	mg/g	µg/g	mg/g	mg/g	µg/g	µg/g	µg/g	mg/g	µg/g	µg/g	mg/g	µg/g	Ratio
09/21/06: Tank A	15.1	0.5	633	31.7	80.5	14.1	121	183	3.55	9.88	245	1.92	<0.5	<0.5	5.15	3.57	95
09/21/06: Tank B	10.4	0.4	387	33.9	85.5	15.4	151	198	3.69	5.59	232	2.14	<0.5	<0.5	5.47	2.71	93
Average	12.7	0.4	510	32.8	83.0	14.8	136	191	3.62	7.74	238	2.03	<0.5	<0.5	5.31	3.14	94

Note: Data represent averages of triplicate analysis.

Table 4-13. Distribution Sampling Results

Sampling Event		DS1 Residence - 1st Draw								DS2 Residence - 1st Draw								DS3 Residence - 1st Draw							
		Stagnation Time	pH	Alkalinity	Total As	Total Fe	Total Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	Total As	Total Fe	Total Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	Total As	Total Fe	Total Mn	Pb	Cu
No.	Date	hr	S.U.	mg/L	μg/L	μg/L	μg/L	μg/L	μg/L	Hr	S.U.	mg/L	μg/L	μg/L	μg/L	μg/L	μg/L	hr	S.U.	mg/L	μg/L	μg/L	μg/L	μg/L	μg/L
BL1	02/16/05	7.0	7.2	382	24.3	2,649	128	0.6	4.1	8.3	7.4	374	19.8	2,792	129	0.6	0.2	NS	NS	NS	NS	NS	NS	NS	NS
BL2	03/23/05	6.0	7.3	362	21.9	2,175	130	0.4	2.2	8.3	7.4	367	26.2	4,986	147	0.3	2.5	7.3	7.5	376	26.3	2,590	128	<0.1	1.9
BL3	04/19/05	6.2	7.0	377	25.3	2,878	141	2.4	3.9	10.0	7.2	395	15.3	2,137	127	1.6	3.4	8.4	7.4	386	24.6	2,751	133	0.2	0.4
BL4	05/23/05	5.8	7.3	384	25.7	2,578	124	0.5	0.7	7.3	7.3	370	24.2	2,639	123	<0.1	0.4	8.8	7.3	379	22.6	2,649	119	0.1	0.9
Average		**NA**	**7.2**	**376**	**24.3**	**2,570**	**131**	**1.0**	**2.7**	**NA**	**7.3**	**377**	**21.4**	**3,139**	**132**	**0.8**	**1.6**	**NA**	**7.4**	**380**	**24.5**	**2,663**	**127**	**0.1**	**1.1**
1	07/26/05	7.3	7.2	365	5.1	73	722	0.5	0.4	9.3	7.3	374	5.4	84	617	0.4	0.2	9.3	7.3	370	6.3	162	612	0.4	0.6
2	09/07/05	8.5	7.4	356	14.2	52	438	0.3	0.2	9.0	7.5	352	12.7	<25	516	<0.1	1.7	8.0	7.6	365	13.9	84	525	<0.1	1.4
3	09/27/05	8.3	7.3	370	4.3	72	687	2.1	11.0	7.3	7.4	361	5.1	127	717	0.2	<0.1	9.5	7.4	374	4.2	98	659	1.1	1.0
4	11/02/05	12.5	7.6	361	6.8	<25	976	0.2	8.8	7.0	7.6	352	7.9	142	950	<0.1	0.2	9.3	7.6	365	8.5	37	935	0.2	0.3
5	11/29/05	8.0	7.4	365	4.1	266	367	0.9	6.2	6.0	7.5	365	3.6	57	369	0.1	0.2	9.3	7.5	361	3.7	222	478	1.1	2.4
6	12/15/05	11.3	7.5	374	4.1	57	400	1.2	3.9	8.0	7.6	374	5.7	184	443	0.8	0.2	9.0	7.5	374	6.3	279	468	1.0	0.7
7	01/17/06	9.0	7.5	383	24.1[(a)]	1,999[(a)]	923[(a)]	1.0	21.8	8.5	7.5	383	4.9	187	267	0.2	0.7	7.5	7.6	383	4.9	342	226	4.7	3.2
8	02/21/06	7.0	7.4	361	3.8	<25	119	0.2	5.5	8.2	7.5	365	7.8	132	34.1	1.2	4.5	9.5	7.5	365	4.0	<25	216	<0.1	4.2
9	03/29/06	7.5	7.6	361	3.7	41	191	0.8	6.4	7.4	7.6	369	5.2	239	8.5	1.5	1.5	10.0	7.6	352	4.9	286	323	1.6	0.9
10	04/24/06	8.5	7.2	375	4.6	63	102	0.5	3.2	8.0	7.4	375	7.4	109	104	0.5	1.2	9.0	7.4	384	28.3	84	183	0.1	2.4
11	05/25/06	10.0	7.3	357	7.6	303	228	0.4	4.6	8.0	7.5	353	5.8	113	2.8	0.3	3.0	9.3	7.4	353	5.1	280	202	0.9	1.8
12	06/14/06	8.0	7.2	382	6.0	<25	236	2.2	228	8.5	7.2	361	12.4	429	250	0.2	4.4	9.0	7.3	374	8.6	<25	356	25.2	193
13	07/13/06	10.5	7.2	364	15.5	<25	294	0.9	112	9.8	7.4	364	17.4	27	55.6	9.2	71.5	8.5	7.4	360	13.8	<25	304	1.0	5.9
Average		**NA**	**7.4**	**367**	**8.0**	**229**	**437**	**0.8**	**31.7**	**NA**	**7.5**	**365**	**7.8**	**142**	**333**	**1.1**	**6.9**	**NA**	**7.5**	**368**	**8.6**	**147**	**422**	**2.9**	**16.8**

(a) Sample tap not used on a regular basis.
Arsenic MCL = 10 μg/L, iron MCL = 300 μg/L, manganese SMCL = 50 μg/L, lead MCL = 50 μg/L, and copper MCL = 1.3 mg/L.
BL = baseline sampling, NS = not sampled, NA = not analyzed

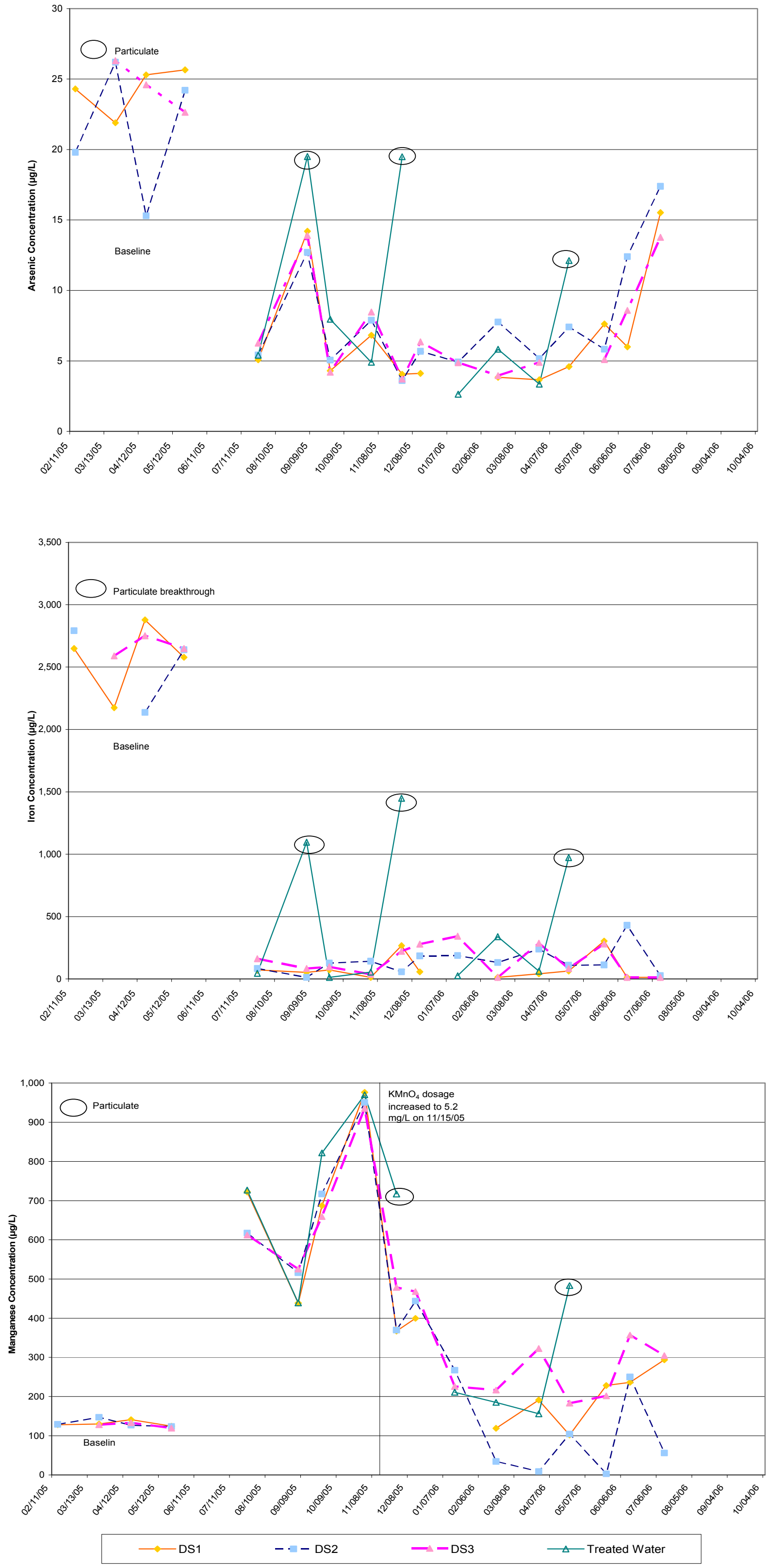


Figure 4-14. Effects of Treatment System on Arsenic (top), Iron (middle), and Manganese (bottom) in Distribution System

distribution system has improved after installation of the treatment system, as evidenced by the reduced arsenic and iron concentrations meeting the respective MCL and SMCL and little or no changes to the pH, alkalinity, lead, and copper.

4.6 System Cost

The cost of the system 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. This required tracking of the capital cost for equipment, engineering, and installation cost and the O&M cost for chemical supply, electrical power use, and labor. The cost associated with improvements to the building and any other discharge-related infrastructure, which were outside of the scope of the demonstration project, was paid by the host site and not included in the treatment system cost.

4.6.1 Capital Cost. The capital investment was $63,547 for the CP-213f system (Table 4-14). The equipment cost was $22,422 (or 35% of the total capital investment), which included cost for the four pressure filtration tanks, Macrolite® media, contact tanks, process valves and piping, instrumentation and controls, a chemical feed system (including a storage tank with a secondary containment), additional sample taps and totalizer/meters, shipping, equipment assembly labor, and system warranty.

Table 4-14. Summary of Capital Investment for BSLMHP Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Cost			
Media and Tanks	1	$8,549	–
Process Valves and Piping	1	$1,935	–
Chemical Feed	1	$1,150	–
Chemical Storage and Secondary Containment	1	$680	–
Instrumentation and Controls	1	$1,079	–
Additional Flowmeter/Totalizers	1	$359	–
Shipping	–	$750	–
Labor	–	$7,920	–
Equipment Total	–	**$22,422**	**35%**
Engineering Cost			
Labor	–	$15,620	–
Travel	–	$1,750	
Subcontractor	–	$2,857	–
Engineering Total	–	**$20,227**	**32%**
Installation Cost			
Labor	–	$5,000	–
Travel	–	$2,913	–
Subcontractor	–	$12,985	–
Installation Total	–	**$20,898**	**33%**
Total Capital Investment	–	**$63,547**	**100%**

The site engineering cost covered the cost for preparing a process design report and required engineering plans, including a general arrangement drawing, P&IDs, interconnecting piping layouts, tank fill details, an electrical on-line diagram, and other associated drawings. After reviewed and certificated by a Minnesota-registered professional engineer (PE), the plans were submitted to the MDH for permit review and approval (Section 4.3.1). The engineering cost was $20,227, which was 32% of the total capital investment.

The installation, shakedown, and startup cost covered the labor and materials required to unload, anchor, plumb, and mechanical and electrical connections for proper operation (Section 4.3.3). All installation activities were performed by the vendor's subcontractor, and startup and shakedown activities were performed by the vendor with the operator's assistance. The installation, startup, and shakedown cost was $20,898, about 33% of the total capital investment.

Using the system's rated capacity of 20 gpm (or 28,800 gpd), the capital cost of $63,547 was normalized to be $3,177/gpm (or $2.21/gpd). The capital cost of $63,547 was converted to an annualized cost of $5,998/year using a capital recovery factor of 0.09439 based on a 7% interest rate and a 20-year return. Assuming that the system was operated 24 hours a day, 7 days a week at the design flowrate of 20 gpm to produce 10.5 million gallons (Mgal) of water per year, the unit capital cost would be $0.57/1,000 gal. However, since the system only produced 2.0 Mgal of water over the 15-month study period (see Table 4-4), corresponding to an annual production of 1.6 Mgal, the unit capital cost was increased to $3.75/1,000 gal at this reduced rate of production.

4.6.2 Operation and Maintenance Cost. The O&M cost primarily included cost associated with chemical supply, electricity consumption, and labor (Table 4-15). The actual usage rate for the $KMnO_4$ stock solution was approximately 72 lb (or 5.3 gal) for the entire performance period. Incremental electrical power consumption was calculated for the chemical feed pump. The power demand was calculated based on the total operational hours throughout the duration of the performance study, the chemical feed pump horsepower, and the unit cost from the utility bills.

Table 4-15. O&M Cost for BSLMHP, MN Treatment System

Cost Category	Value	Assumption
Volume of Water Processed (gal)	2,017,215	From 07/13/05 through 10/01/06 (see Table 4-4)
Chemical Usage		
Chemical Unit Price ($/lb)	$2.07	97% $KMnO_4$ in a 55-lb pail (approximately 4 gal) based on June 2005 and January 2006 invoices for the two pails used during the study
Total Chemical Consumption (lb)	72.4	Or 5.3 gal
Chemical Usage (lb/1,000 gal)	0.036	–
Total Chemical Cost ($)	$149.87	–
Unit Chemical Cost ($/1,000 gal)	$0.07	–
Electricity		
Electricity Unit Cost ($/kwh)	0.067	–
Estimated Electricity Usage (kwh)	257	Calculated based on 2,052 hr of operation of a 0.17-hp chemical feed pump
Estimated Electricity Cost ($)	$17.19	–
Estimated Power Use ($/1,000 gal)	$0.01	–
Labor		
Average Weekly Labor (hr)	0.42	5 min/day; 5 days a week
Total Labor Hours (hr)	27	Based on 64 weeks of study period
Total Labor Cost ($)	564	Labor rate = $21/hr
Labor Cost ($/1,000 gal)	$0.28	–
Total O&M Cost/1,000 gal	**$0.36**	–

The routine, non-demonstration related labor activities consumed about 25 min per week (or 5 min per day, 5 days a week), as noted in Section 4.4.4. Based on this time commitment and a labor rate of $21/hr, the labor cost was $0.28/1,000 gal of water treated. In sum, the total O&M cost was approximately $0.36/1,000 gal for the entire period of the demonstration study.

Section 5.0: REFERENCES

Battelle. 2004. *Quality Assurance Project Plan for Evaluation of Arsenic Removal Technology*. Prepared under Contract No. 68-C-00-185, Task Order No. 0029, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.

Carlson, Kenneth H., and William R. Knocke. 1999. "Modeling Manganese Oxidation with $KMnO_4$ for Drinking Water Treatment." *JAWWA 125(10):* 892-896.

Chen, A.S.C., L. Wang, J. Oxenham, and W. Condit. 2004. *Capital Costs of Arsenic Removal Technologies: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1.* EPA/600/R-04/201. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.

Edwards, M., S. Patel, L. McNeill, H. Chen, M. Frey, A.D. Eaton, R.C. Antweiler, and H.E. Taylor. 1998. "Considerations in As Analysis and Speciation." *JAWWA 90(3)*: 103-113.

EPA. 2001. National Primary Drinking Water Regulations: Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring. *Federal Register*, 40 CFR Part 9, 141, and 142.

EPA. 2002. *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems*. EPA/816/R-02/009. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

EPA. 2003. Minor Clarification of the National Primary Drinking Water Regulation for Arsenic. *Federal Register*, 40 CFR Part 141.

Gregory, D., and K. Carlson. 2003. "Effect of Soluble Mn Concentration on Oxidation Kinetics ." *JAWWA 95(1):* 98-108.

Knocke, William R., Hoehn, Robert C.; Sinsabaugh, Robert L. 1987. "Using Alternative Oxidants to Remove Dissolved Manganese from Waters Laden with Organics." *JAWWA*, *79(3)*: 75-79.

Knocke, William R., John E. Van Benschoten, Maureen J. Kearney, Andrew W. Soborski, and David A. Reckhow. 1990. *Alternative Oxidants for the Remove of Soluble Iron and Manganese*. Final report prepared for the AWWA Research Foundation, Denver, CO.

Knocke, William R., John E. Van Venschoten, Maureen J. Kearney, Andrew W, Soborski, and David A. Reckhow. 1991. "Kinetics of Manganese and Iron Oxidation by Potassium Permanganate and Chlorine Dioxide." *JAWWA 83(6)*: 80-87.

Knocke, William R., Holly L. Shorney, and Julia D. Bellamy. 1994. "Examining the Reactions Between Soluble Iron, DOC, and Alternative Oxidants During Conventional Treatment." *JAWWA 86(1)*: 117-127.

Post, Tim. 2005. "Pollution Cleanup Cost is Hard to Comprehend." *Minnesota Public Radio.* Available at: http://news.minnesota.publicradio.org/features/2005/10/10_postt_impairedcleanup/.

Salbu, B. and E. Steinnes. 1995. *Trace Elements in Natural Waters*. CRC Press, Boca Raton, Florida.

Sauk River Watershed District. 2006. "Monitoring Our Resources." Available at: http://www.srwdmn.org/monitoring/html.

Sorg, T.J. 2002. "Iron Treatment for Arsenic Removal Neglected." *Opflow*, AWWA, *28(11)*: 15.

Wang, L., W. Condit, and A.S.C. Chen. 2004. *Technology Selection and System Design: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1.* EPA/600/R-05/001. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.

APPENDIX A

OPERATIONAL DATA SHEETS

US EPA Arsenic Demonstration Project at BSLMHP, MN – Daily System Operation Log Sheet

			New Well		Volume to Treatment			Pressure Tanks		Pressure Filtration					Volume to Distribution		Backwash			$KMnO_4$ Application	
Week No.	Date	Time	Hour Meter (Hr)	Daily Operation (hr)	Totalizer (gal)	Daily Volume (gal)	Average Flowrate (gpm)	Pressure Tank 1 (psig)	Pressure Tank 2 (psig)	IN (psig)	TA/TB (psig)	TC/TD (psig)	OUT (psig)	ΔP Across System (psig)	Flowrate (gpm)	Daily Volume (gal)	Totalizer (kgal)	No. of Tanks Backwashed	Wastewater Produced (gal)	$KMnO_4$ Tank Level (in)	Average $KMnO_4$ Dose (mg/L)
	07/13/05	21:13	NM	NA	117,750	NA	NA	NM	NM	42	NM	NM	30	12	NM	NA	4,870	NM	NA	NM	NA
	07/14/05	20:10	NM	NA	124,730	6,980	NA	NM	NM	54	NM	NM	37	17	NM	7,000	4,980	1	110	NM	NA
1	07/15/05	20:00	NM	NA	131,610	6,880	NA	NM	NM	40	NM	NM	30	10	NM	6,700	5,220	2	240	NM	NA
	07/16/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NA	NM	NA	NM	NA
	07/17/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NA	NM	NA	NM	NA
	07/18/05	18:45	NM	NA	153,050	NA	NA	NM	NM	58	NM	NM	45	13	NM	NA	5,940	NM	NA	NM	NA
	07/19/05	19:10	NM	NA	162,175	9,125	NA	NM	NM	40	NM	NM	36	4	NM	8,900	6,290	3	350	NM	NA
	07/20/05	19:00	NM	NA	173,250	11,075	NA	NM	NM	45	NM	NM	22	23	NM	10,800	6,730	3	440	NM	NA
2	07/21/05	18:30	NM	NA	187,720	14,470	NA	NM	NM	45	NM	NM	35	10	NM	14,300	7,220	4	490	NM	NA
	07/22/05	20:00	NM	NA	195,400	7,680	NA	NM	NM	48	NM	NM	42	6	NM	7,400	7,580	3	360	NM	NA
	07/23/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NA	NM	NA	NM	NA
	07/24/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NA	NM	NA	NM	NA
	07/25/05	19:30	NM	NA	209,650	14,250	NA	NM	NM	47	NM	NM	45	2	NM	13,900	8,050	4	470	NM	NA
	07/26/05	20:10	NM	NA	213,670	4,020	NA	NM	NM	41	NM	NM	40	1	NM	3,900	8,180	1	130	NM	NA
	07/27/05	23:15	NM	NA	217,700	4,030	NA	NM	NM	58	NM	NM	55	3	NM	3,900	8,290	1	110	NM	NA
3	07/28/05	20:15	NM	NA	221,880	4,180	NA	NM	NM	41	NM	NM	40	1	NM	3,900	8,530	2	240	NM	NA
	07/29/05	18:15	NM	NA	225,220	3,340	NA	NM	NM	56	NM	NM	53	3	NM	3,200	8,650	1	120	NM	NA
	07/30/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA
	07/31/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA
	08/01/05	19:05	NM	NA	243,890	18,670	NA	52	72	58	NM	NM	48	10	NM	18,100	9360	5	710	30.0	NA
	08/02/05	20:30	NM	NA	249,947	6,057	NA	46	72	42	NM	NM	40	2	NM	5,900	9600	2	240	29.6	
	08/03/05	23:55	NM	NA	254,680	4,733	NA	45	72	41	NM	NM	38	3	NM	4,500	9720	1	120	29.3	
4	08/04/05	23:55	NM	NA	258,315	3,635	NA	53	72	49	NM	NM	46	3	NM	3,600	9840	1	120	28.9	
	08/05/05	22:00	NM	NA	262,300	3,985	NA	45	72	42	NM	NM	40	2	NM	3,700	10080	2	240	28.7	3.8
	08/06/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA
	08/07/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA
	08/08/05	21:30	NM	NA	274,320	12,020	NA	60	72	58	NM	NM	50	8	NM	11,600	10,570	4	490	NM	
	08/09/05[a, b]	21:30	NM	NA	281,515	7,195	NA	55	72	55	44	38	42	13	NM	5,100	12,290	13	1,720	27.4	
	08/10/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	
5	08/11/05[c]	18:00	NM	NA	286,400	4,885	NA	50	46	42	40	34	40	2	NM	4,200	13,030	6	740	27.1	
	08/12/05	20:30	NM	NA	291,600	5,200	NA	56	50	48	38	30	37	11	NM	5,000	13,180	1	150	26.8	3.7
	08/13/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	08/14/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	08/15/05	21:00	NM	NA	306,690	15,090	NA	54	49	46	42	34	40	6	NM	14,600	13,670	4	490	25.8	
	08/16/05	21:30	NM	NA	312,100	5,410	NA	45	40	43	38	30	39	4	NM	5,100	13,790	1	120	25.4	
	08/17/05	20:00	NM	NA	315,460	3,360	NA	55	54	55	30	22	30	25	NM	3,400	14,110	2	320	25.3	
6	08/18/05	19:15	NM	NA	321,320	5,860	NA	49	45	42	36	30	36	6	NM	5,530	14,240	1	130	24.9	
	08/19/05	20:30	NM	NA	325,940	4,620	NA	54	50	47	42	38	43	4	NM	4,205	14,620	3	380	24.6	3.2
	08/20/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	08/21/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	08/22/05	20:20	NM	NA	337,400	11,460	NA	54	51	48	45	40	42	6	NM	10,315	15,410	6	790	23.9	
	08/23/05	22:10	NM	NA	342,540	5,140	NA	60	59	50	46	40	47	3	NM	5,110	15,530	1	120	23.8	
	08/24/05	21:00	NM	NA	346,940	4,400	NA	46	44	42	40	34	40	2	NM	3,930	15,900	3	370	23.5	
7	08/25/05	21:15	NM	NA	350,620	3,680	NA	48	44	40	34	30	33	7	NM	3,640	15,900	0	0	23.4	
	08/26/05	NM	NM	NA	353,590	2,970	NA	53	50	48	43	40	46	2	NM	2,535	16,280	3	380	23.1	2.5
	08/27/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	08/28/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA

US EPA Arsenic Demonstration Project at BSLMHP, MN – Daily System Operation Log Sheet (Continued)

			New Well		Volume to Treatment			Pressure Tanks		Pressure Filtration					Volume to Distribution		Backwash			$KMnO_4$ Application	
Week No.	Date	Time	Hour Meter (Hr)	Daily Operation (hr)	Totalizer (gal)	Daily Volume (gal)	Average Flowrate (gpm)	Pressure Tank 1 (psig)	Pressure Tank 2 (psig)	IN (psig)	TA/TB (psig)	TC/TD (psig)	OUT (psig)	ΔP Across System (psig)	Flowrate (gpm)	Daily Volume (gal)	Totalizer (kgal)	No. of Tanks Backwashed	Wastewater Produced (gal)	$KMnO_4$ Tank Level (in)	Average $KMnO_4$ Dose (mg/L)
	08/29/05	21:00	NM	NA	367,570	13,980	NA	50	48	44	40	32	40	4	NM	13,775	16,940	5	660	22.4	
	08/30/05	21:00	NM	NA	374,860	7,290	NA	48	43	42	40	30	39	3	NM	5,900	17,460	4	520	22.0	
	08/31/05	22:30	NM	NA	379,390	4,530	NA	55	50	49	48	40	46	3	NM	4,095	17,710	2	250	21.9	
8	09/01/05	21:30	NM	NA	382,630	3,240	NA	48	46	43	40	32	40	3	NM	3,125	17,850	1	140	21.8	
	09/02/05	21:15	NM	NA	385,820	3,190	NA	45	42	40	38	36	38	2	NM	3,120	18,050	2	200	21.6	2.5
	09/03/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	09/04/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	09/05/05	20:00	NM	NA	401,775	15,955	NA	51	50	46	42	35	44	2	NM	14,625	18,900	7	850	21.4	
	09/06/05	21:30	NM	NA	406,930	5,155	NA	50	49	45	43	34	42	3	NM	4,725	19,290	3	390	21.2	
	09/07/05	20:15	NM	NA	411,250	4,320	NA	50	46	40	40	32	40	0	NM	4,205	19,430	1	140	21.1	
9	09/08/05	21:15	NM	NA	416,000	4,750	NA	60	55	59	55	48	54	5	NM	4,275	19,820	3	390	20.9	
	09/09/05	20:30	NM	NA	421,010	5,010	NA	54	50	55	52	46	50	5	NM	5,040	19,940	1	120	20.6	2.1
	09/10/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	09/11/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	09/12/05	21:00	NM	NA	431,850	10,840	NA	46	44	41	36	30	38	3	NM	9,645	20,600	5	660	20.1	
	09/13/05	22:15	NM	NA	436,525	4,675	NA	45	43	45	40	35	44	1	NM	4,255	20,870	2	270	19.9	
	09/14/05	23:50	NM	NA	441,515	4,990	NA	48	48	43	41	34	41	2	NM	4,435	21,260	3	390	19.6	
10	09/15/05	22:00	NM	NA	444,535	3,020	NA	60	60	55	52	46	52	3	NM	2,925	21,260	0	0	19.5	
	09/16/05	21:00	NM	NA	447,250	2,715	NA	55	53	52	50	45	50	2	NM	2,700	21,390	1	130	19.4	2.7
	09/17/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	09/18/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	09/19/05	20:00	NM	NA	460,655	13,405	NA	51	50	46	42	34	42	4	NM	12,265	22,160	6	770	18.7	
	09/20/05	17:30	NM	NA	465,515	4,860	NA	45	48	45	52	46	44	1	NM	4,095	22,820	5	660	18.5	
	09/21/05[(d)]	20:00	NM	NA	470,455	4,940	NA	62	60	55	46	43	52	3	NM	4,495	23,100	2	280	18.2	
11	09/22/05	20:15	NM	NA	475,120	4,665	NA	60	58	53	55	50	52	1	NM	4,445	23,100	0	0	18.0	
	09/23/05	20:00	NM	NA	478,010	2,890	NA	45	43	43	40	32	38	5	NM	3,000	23,100	0	0	17.9	2.6
	09/24/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	09/25/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	09/26/05	21:15	NM	NA	490,360	12,350	NA	54	51	47	42	34	43	4	NM	11,670	23,580	4	480	31.8	
	09/27/05	20:30	NM	NA	494,550	4,190	NA	50	47	45	43	40	43	2	NM	4,185	23,580	0	0	31.6	
	09/28/05[(e)]	19:15	0.3	NA	497,655	3,105	NA	60	60	55	50	44	51	4	6.0	2,755	23,580	0	0	31.5	
12	09/29/05	19:30	3.2	2.9	500,910	3,255	19	52	50	43	40	32	40	3	5.5	3,840	23940	3	360	31.3	
	09/30/05[(f)]	21:30	6.1	2.9	506,255	5,345	31	50	50	45	42	40	43	2	1.0	3,850	24190	2	250	31.0	2.6
	10/01/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	10/02/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	10/03/05	21:30	15.8	9.7	520,265	14,010	24	60	57	54	50	50	52	2	0.0	12,880	25,080	7	890	30.3	
	10/04/05	21:30	18.9	3.1	524,758	4,493	24	55	52	50	46	44	49	1	3.0	4,060	25,470	3	390	30.1	
	10/05/05	23:30	21.0	2.1	529,135	4,377	35	65	60	57	56	52	55	2	1.0	4,175	25,640	1	170	29.9	
13	10/06/05	18:30	23.7	2.7	531,448	2,313	14	60	56	55	40	42	50	5	3.0	2,295	25,640	0	0	29.8	
	10/07/05	18:30	26.2	2.5	535,065	3,617	24	45	43	43	38	38	37	6	10.0	3,350	25,720	1	80	29.6	2.5
	10/08/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	10/09/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	10/10/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	10/11/05	18:45	38.1	11.9	552,115	17,050	24	50	48	42	38	36	38	4	9.0	15,975	26,590	7	870	28.8	
	10/12/05	17:15	40.9	2.8	556,015	3,900	23	64	60	57	54	53	54	3	2.5	3,503	26,970	3	380	28.6	
14	10/13/05	20:00	43.9	3.0	560,295	4,280	24	50	47	44	38	36	38	6	9.0	3,862	27,360	3	390	28.4	
	10/14/05	20:00	47.2	3.3	565,165	4,870	25	50	49	45	40	40	40	5	2.5	4,500	27,610	2	250	28.2	2.6
	10/15/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	10/16/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA

US EPA Arsenic Demonstration Project at BSLMHP, MN – Daily System Operation Log Sheet (Continued)

			New Well		Volume to Treatment			Pressure Tanks		Pressure Filtration					Volume to Distribution		Backwash			$KMnO_4$ Application	
Week No.	Date	Time	Hour Meter (Hr)	Daily Operation (hr)	Totalizer (gal)	Daily Volume (gal)	Average Flowrate (gpm)	Pressure Tank 1 (psig)	Pressure Tank 2 (psig)	IN (psig)	TA/TB (psig)	TC/TD (psig)	OUT (psig)	ΔP Across System (psig)	Flowrate (gpm)	Daily Volume (gal)	Totalizer (kgal)	No. of Tanks Backwashed	Wastewater Produced (gal)	$KMnO_4$ Tank Level (in)	Average $KMnO_4$ Dose (mg/L)
15	10/17/05	20:30	59.3	12.1	NM	NA	NA	55	52	48	45	44	45	3	3.0	16,780	28,870	10	1,260	27.3	
	10/18/05	20:15	62.5	3.2	588,375	NA	NA	58	54	51	43	42	45	6	7.5	4,390	29,130	2	260	27.0	
	10/19/05	20:15	66.1	3.6	594,000	5,625	26	65	60	56	52	50	52	4	2.5	5,195	29,380	2	250	26.8	
	10/20/05	21:30	70.5	4.4	600,975	6,975	26	50	48	52	48	45	46	6	NM	6,335	29,740	3	360	26.4	
	10/21/05	20:30	74.0	3.5	606,505	5,530	26	54	50	55	40	40	40	15	NM	5,055	29,990	2	250	26.2	2.6
	10/22/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	10/23/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
16	10/24/05	20:00	82.4	8.4	619,765	13,260	26	65	60	56	52	50	50	6	5.0	12,265	30,510	4	520	25.5	
	10/25/05	22:15	85.1	2.7	623,865	4,100	25	55	52	50	46	44	47	3	1.0	3,750	30,860	3	350	25.3	
	10/26/05	18:30	87.4	2.3	627,435	3,570	26	52	49	44	30	30	31	13	15.0	3,360	30,980	1	120	25.1	
	10/27/05	18:30	89.9	2.5	630,865	3,430	23	60	55	53	45	44	48	5	0.0	3,105	31,230	2	250	24.9	
	10/28/05	21:30	92.6	2.7	634,755	3,890	24	60	55	54	50	50	50	4	0.0	3,635	31,350	1	120	24.8	2.5
	10/29/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	10/30/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
17	10/31/05	18:30	100.5	7.9	646,195	11,440	24	55	50	48	45	44	46	2	0.0	10,480	31,960	5	610	24.3	
	11/01/05	18:30	103.1	2.6	650,988	4,793	31	64	60	58	54	52	53	5	1.0	3,643	32,080	1	120	24.0	
	11/02/05	18:00	105.9	2.8	654,345	3,357	20	55	50	46	42	40	41	5	2.5	3,927	32,440	3	360	23.8	
	11/03/05	16:30	108.0	2.1	657,425	3,080	24	65	60	57	52	52	53	4	2.5	2,930	32,560	1	120	23.7	
	11/04/05	19:00	111.0	3.0	662,185	4,760	26	56	54	51	44	44	45	6	2.5	4,315	32,800	2	240	23.4	3.0
	11/05/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	11/06/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
18	11/07/05	18:30	117.5	6.5	672,242	10,057	26	60	55	48	44	44	45	3	2.5	8,826	33,490	5	690	NM	
	11/08/05	17:00	120.8	3.3	677,078	4,836	24	54	50	46	38	38	40	6	6.0	4,749	33,630	1	140	22.6	
	11/09/05	19:30	124.4	3.6	682,527	5,449	25	65	60	57	48	48	50	7	8.0	5,050	33,990	3	360	22.3	
	11/10/05	21:15	127.8	3.4	687,695	5,168	25	55	45	41	40	39	40	1	2.5	4,640	34,230	2	240	22.1	
	11/11/05	23:15	130.4	2.6	691,776	4,081	26	56	54	51	45	44	46	5	1.0	3,705	34,470	2	240	21.9	2.8
	11/12/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	11/13/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
19	11/14/05	17:00	138.0	7.6	702,762	10,986	24	55	53	48	33	32	35	13	2.5	10,081	35,290	6	820	21.3	
	11/15/05	18:00	141.0	3.0	707,505	4,743	26	55	50	47	42	42	40	7	6.0	4,209	35,530	2	240	20.9	
	11/16/05	18:30	144.3	3.3	713,153	5,648	29	55	49	53	50	50	49	4	5.0	5,095	35,910	3	380	20.4	
	11/17/05	18:00	146.8	2.5	716,935	3,782	25	63	60	58	54	54	55	3	1.0	3,470	36,040	1	130	20.0	
	11/18/05	17:30	149.5	2.7	721,161	4,226	26	63	60	56	54	52	55	1	0.0	3,860	36,290	2	250	19.6	5.0
	11/19/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	11/20/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
20	11/21/05	10:15	159.5	10.0	736,144	14,983	25	62	60	60	55	54	55	5	7.5	13,405	37,450	9	1,160	18.3	
	11/22/05	18:00	162.9	3.4	741,535	5,391	26	65	62	58	54	53	55	3	5.0	4,805	37,840	3	390	18.0	
	11/23/05	21:00	167.3	4.4	748,605	7,070	27	65	60	58	52	52	55	3	7.5	6,240	38,480	5	640	17.5	
	11/24/05	17:30	169.8	2.5	752,270	3,665	24	58	60	52	50	48	50	2	1.0	3,250	38,740	2	260	17.3	
	11/25/05	18:30	173.4	3.6	758,198	5,928	27	55	50	42	40	40	38	4	1.5	5,330	38,990	2	250	NM	3.5
	11/26/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	11/27/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
21	11/28/05	17:00	183.2	9.8	773,853	15,655	27	55	52	46	41	40	40	6	1.0	14,115	40,010	8	1,020	29.6	
	11/29/05	18:30	187.2	4.0	779,725	5,872	24	55	50	46	42	40	42	4	3.0	5,230	40,380	3	370	29.1	
	11/30/05	14:30	189.9	2.7	783,735	4,010	25	54	50	44	40	39	40	4	1.0	3,350	40,870	4	490	28.8	
	12/01/05	18:00	193.8	3.9	790,125	6,390	27	55	50	41	39	38	39	2	7.5	5,855	41,120	2	250	28.3	
	12/02/05	21:00	197.9	4.1	796,286	6,161	25	54	50	44	40	40	41	3	1.5	5,250	41,630	4	510	27.8	4.8
	12/03/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	12/04/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA

US EPA Arsenic Demonstration Project at BSLMHP, MN – Daily System Operation Log Sheet (Continued)

Week No.	Date	Time	New Well		Volume to Treatment			Pressure Tanks		Pressure Filtration					Volume to Distribution		Backwash			$KMnO_4$ Application	
			Hour Meter (Hr)	Daily Operation (hr)	Totalizer (gal)	Daily Volume (gal)	Average Flowrate (gpm)	Pressure Tank 1 (psig)	Pressure Tank 2 (psig)	IN (psig)	TA/TB (psig)	TC/TD (psig)	OUT (psig)	ΔP Across System (psig)	Flowrate (gpm)	Daily Volume (gal)	Totalizer (kgal)	No. of Tanks Backwashed	Wastewater Produced (gal)	$KMnO_4$ Tank Level (in)	Average $KMnO_4$ Dose (mg/L)
	12/05/05	21:30	210.0	12.1	815,166	18,880	26	55	50	41	38	36	37	4	3.0	16,870	43,020	11	1,390	26.0	
	12/06/05	20:00	213.1	3.1	819,866	4,700	25	54	50	49	42	42	45	4	5.0	4,345	43,150	1	130	25.6	
	12/07/05	19:00	216.7	3.6	825,832	5,966	28	54	50	44	39	36	37	7	3.0	5,445	43,400	2	250	25.1	
22	12/08/05	13:00	219.0	2.3	829,900	4,068	29	65	60	57	52	50	52	5	3.0	3,220	43,880	4	480	24.7	
	12/09/05	18:00	224.1	5.1	838,490	8,590	28	64	60	56	51	50	52	4	6.0	7,310	44,580	5	700	23.9	5.1
	12/10/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	12/11/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	12/12/05	18:00	235.4	11.3	854,915	16,425	24	64	60	59	56	54	55	4	3.0	15,230	45,550	7	970	22.3	
	12/13/05	19:30	239.4	4.0	860,890	5,975	25	55	50	48	46	44	45	3	5.0	5,500	45,800	2	250	21.7	
	12/14/05	19:30	242.8	3.4	865,680	4,790	23	65	60	56	52	50	52	4	2.5	4,360	45,920	1	120	21.3	
23	12/15/05	18:00	246.3	3.5	870,304	4,624	22	65	60	55	49	47	49	6	4.0	4,170	46,290	3	370	20.6	
	12/16/05	07:12	249.4	3.1	874,955	4,651	25	55	50	40	30	30	30	10	10.0	4,200	46,500	2	210	20.4	5.4
	12/17/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	12/18/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	12/19/05	21:00	266.2	16.8	901,055	26,100	26	55	48	45	39	38	40	5	6.0	23,690	47,820	10	1,320	17.8	
	12/20/05	18:00	270.9	4.7	908,815	7,760	28	59	55	53	48	47	48	5	7.5	6,970	48,290	4	470	17.0	
	12/21/05	19:00	277.3	6.4	918,785	9,970	26	62	56	53	48	47	48	5	4.0	8,900	48,880	5	590	30.6	
24	12/22/05	19:30	281.7	4.4	925,035	6,250	24	60	60	59	52	52	54	5	4.0	5,690	49,230	3	350	30.0	5.4
	12/23/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	12/24/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	12/25/05	NM	NM	NA	NM	NA	NA	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	12/26/05	18:30	300.8	19.1	954,207	29,172	25	54	50	42	37	36	37	5	5.0	25,740	51,000	14	1,770	27.4	
	12/27/05	18:00	304.9	4.1	960,977	6,770	28	65	60	55	43	42	45	10	5.0	4,900	51,470	4	470	26.8	
	12/28/05	19:15	309.7	4.8	966,885	5,908	21	54	50	45	40	38	40	5	3.0	5,925	51,820	3	350	26.1	
25	12/29/05	19:30	313.5	3.8	972,455	5,570	24	54	47	44	40	39	40	4	2.0	4,845	52,170	3	350	25.6	
	12/30/05	19:00	316.9	3.4	977,105	4,650	23	55	45	42	40	40	40	2	3.0	2,320	52,310	1	140	25.2	6.1
	12/31/05	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	01/01/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	01/02/06	10:30	331.5	14.6	1,000,155	23,050	26	65	60	57	56	55	55	2	2.0	21,300	53,930	12	1,620	23.0	
	01/03/06[(g)]	12:30	336.2	4.7	7,500	NA	NA	60	55	58	53	52	52	6	2.0	6,080	54,400	4	470	22.4	
	01/04/06	17:00	336.4	0.2	12,050	4,550	NA	65	59	55	52	50	50	5	3.0	3,940	54,750	3	350	21.9	
26	01/05/06	10:00	341.2	4.8	19,415	7,365	26	56	53	50	44	44	45	5	2.5	6,130	55,210	4	460	21.1	
	01/06/06	19:30	345.8	4.6	26,705	7,290	26	55	52	48	40	40	40	8	7.5	6,000	55,680	4	470	20.5	5.6
	01/07/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	01/08/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	01/09/06	18:00	362.3	16.5	52,188	25,483	26	55	50	45	40	38	40	5	4.0	21,500	57,200	12	1,520	17.9	
	01/10/06	17:00	366.4	4.1	58,248	6,060	25	65	60	55	51	52	53	2	1.0	4,835	57,890	5	690	17.3	
	01/11/06	17:00	370.5	4.1	64,648	6,400	26	65	60	59	52	50	52	7	12.0	5,495	58,140	2	250	31.0	
27	01/12/06	19:15	376.1	5.6	73,283	8,635	26	54	50	43	39	38	38	5	5.0	7,125	58,790	5	650	30.2	
	01/13/06	19:00	380.5	4.4	79,668	6,385	24	55	50	45	38	36	38	7	3.0	5,465	59,170	3	380	29.6	5.5
	01/14/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	01/15/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	01/16/06[(h)]	17:00	394.7	14.2	101,633	21,965	26	65	60	59	52	50	52	7	8.0	NA	60,810	13	1,640	27.6	
	01/17/06	21:00	399.8	5.1	109,390	7,757	25	65	60	57	50	50	52	5	12.5	6,280	61,430	5	620	26.9	
	01/18/06	21:00	403.9	4.1	115,461	6,071	25	65	60	58	55	52	50	8	5.0	5,165	61,820	3	390	26.3	
28	01/19/06	18:30	408.4	4.5	122,700	7,239	27	65	60	58	52	50	50	8	4.0	5,675	62,720	7	900	25.6	
	01/20/06	19:30	413.3	4.9	130,332	7,632	26	55	50	40	38	38	38	2	3.0	6,045	63,730	8	1,010	24.9	5.7
	01/21/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	01/22/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA

US EPA Arsenic Demonstration Project at BSLMHP, MN – Daily System Operation Log Sheet (Continued)

			New Well		Volume to Treatment			Pressure Tanks		Pressure Filtration					Volume to Distribution		Backwash			$KMnO_4$ Application	
Week No.	Date	Time	Hour Meter (Hr)	Daily Operation (hr)	Totalizer (gal)	Daily Volume (gal)	Average Flowrate (gpm)	Pressure Tank 1 (psig)	Pressure Tank 2 (psig)	IN (psig)	TA/TB (psig)	TC/TD (psig)	OUT (psig)	ΔP Across System (psig)	Flowrate (gpm)	Daily Volume (gal)	Totalizer (kgal)	No. of Tanks Backwashed	Wastewater Produced (gal)	$KMnO_4$ Tank Level (in)	Average $KMnO_4$ Dose (mg/L)
	01/23/06	18:00	427.0	13.7	150,146	19,814	24	60	57	50	47	46	46	4	2.5	15,585	66,250	19	2,520	23.0	
	01/24/06	19:00	432.0	5.0	157,404	7,258	24	55	50	47	42	42	43	4	7.5	5,650	67,170	7	920	22.3	
	01/25/06	17:30	436.3	4.3	163,684	6,280	24	65	60	58	35	36	38	20	4.0	5,150	67,910	6	740	21.6	
29	01/26/06	17:30	440.2	3.9	169,625	5,941	25	55	50	40	36	35	35	5	12.5	4,810	68,550	5	640	21.0	
	01/27/06	21:30	445.5	5.3	176,807	7,182	23	65	60	66	56	55	56	10	2.5	5,740	69,430	7	880	20.4	5.8
	01/28/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	01/29/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	01/30/06	19:30	458.7	13.2	195,955	19,148	24	65	60	50	44	44	45	5	7.5	15,300	71,850	19	2,420	18.4	
	01/31/06	17:30	462.9	4.2	201,643	5,688	23	65	60	59	50	52	52	7	7.5	4,645	72,545	5	695	17.9	
	02/01/06	18:00	468.3	5.4	209,147	7,504	23	65	60	58	52	52	52	6	7.5	6,030	73,565	8	1,020	17.1	
30	02/02/06	18:00	473.1	4.8	215,755	6,608	23	55	50	40	38	38	38	2	NM	5,225	74,420	7	855	31.0	5.2
	02/03/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	02/04/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	02/05/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	02/06/06[i]	18:00	494.5	21.4	247,085	31,330	24	55	50	49	42	42	42	7	2.0	25,475	76,270	14	1,850	30.5	
	02/07/06	20:30	499.1	4.6	253,375	6,290	23	65	60	52	50	50	50	2	2.5	5,125	76,770	4	500	29.8	
	02/08/06	18:15	503.1	4.0	259,058	5,683	24	65	60	53	52	52	50	3	4.0	4,430	NM	NM	NA	29.2	
31	02/09/06	18:45	507.7	4.6	265,713	6,655	24	54	49	43	39	38	40	3	12.5	5,370	NM	NM	NA	28.5	
	02/10/06	18:00	511.3	3.6	271,540	5,827	27	58	53	50	48	46	48	2	4.0	4,815	NM	NM	NA	27.9	5.8
	02/11/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	02/12/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	02/13/06	19:00	525.7	14.4	290,560	19,020	22	55	50	41	38	38	40	1	5.0	15,315	NM	NM	NA	25.9	
	02/14/06	22:00	529.2	3.5	294,955	4,395	21	65	60	56	52	52	52	4	4.0	3,685	NM	NM	NA	25.4	
	02/15/06	22:30	534.0	4.8	301,410	6,455	22	60	53	50	50	48	48	2	2.5	5,669	NM	NM	NA	NM	
32	02/16/06	15:00	538.2	4.2	307,385	5,975	24	65	60	54	52	50	50	4	4.0	4,461	NM	NM	NA	24.2	
	02/17/06	16:15	543.6	5.4	314,770	7,385	23	65	60	55	52	52	53	2	2.0	5,865	NM	NM	NA	23.4	5.6
	02/18/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	02/19/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	02/20/06	18:00	559.5	15.9	337,085	22,315	23	60	55	50	48	48	48	2	4.0	18,340	NM	NM	NA	21.0	
	02/21/06	17:15	563.9	4.4	342,428	5,343	20	55	50	45	43	42	42	3	1.0	4,395	NM	NM	NA	20.4	
	02/22/06	19:00	569.5	5.6	349,857	7,429	22	65	60	59	52	52	54	5	4.0	6,195	131	1	131	19.5	
33	02/23/06	17:45	573.6	4.1	355,833	5,976	24	54	49	41	36	36	36	5	2.0	4,840	870	6	739	18.9	
	02/24/06	18:00	577.3	3.7	361,970	6,137	28	55	50	44	42	42	40	4	7.5	3,650	1,480	5	610	18.1	6.2
	02/25/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	02/26/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	02/27/06[j]	15:00	592.4	15.1	381,985	20,015	22	65	60	56	54	54	54	2	5.0	17,060	3,860	18	2,380	16.0	
	02/28/06	20:30	598.8	6.4	389,466	7,481	19	65	60	55	52	52	52	3	2.0	7,020	4,850	8	990	30.8	
	03/01/06	19:00	603.8	5.0	396,361	6,895	23	60	55	52	52	50	48	4	2.0	5,540	5,740	7	890	30.0	
34	03/02/06	19:30	608.5	4.7	402,705	6,344	22	65	60	60	52	52	50	10	12.0	5,350	6,480	6	740	29.4	
	03/03/06	18:30	613.1	4.6	408,940	6,235	23	65	60	58	54	52	52	6	8.0	5,150	7,220	6	740	28.8	5.5
	03/04/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	03/05/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	03/06/06	18:15	631.0	17.9	434,635	25,695	24	65	60	58	54	54	55	3	7.5	21,140	11,048	29	3,828	26.1	
	03/07/06	18:00	NM	NA	442,510	7,875	NA	60	55	52	50	48	50	2	6.0	6,030	11,690	5	642	25.5	
	03/08/06	18:30	642.8	11.8	451,135	8,625	12	65	60	58	54	52	54	4	3.0	7,420	12,480	6	790	24.3	
35	03/09/06	18:00	646.9	4.1	456,510	5,375	22	60	55	50	50	48	48	2	4.0	4,670	13,205	6	725	23.8	
	03/10/06	16:00	651.9	5.0	462,545	6,035	20	65	60	58	56	54	54	4	1.0	4,540	13,910	5	705	23.1	6.3
	03/11/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	03/12/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA

US EPA Arsenic Demonstration Project at BSLMHP, MN – Daily System Operation Log Sheet (Continued)

			New Well		Volume to Treatment			Pressure Tanks		Pressure Filtration					Volume to Distribution		Backwash			$KMnO_4$ Application	
Week No.	Date	Time	Hour Meter (Hr)	Daily Operation (hr)	Totalizer (gal)	Daily Volume (gal)	Average Flowrate (gpm)	Pressure Tank 1 (psig)	Pressure Tank 2 (psig)	IN (psig)	TA/TB (psig)	TC/TD (psig)	OUT (psig)	ΔP Across System (psig)	Flowrate (gpm)	Daily Volume (gal)	Totalizer (kgal)	No. of Tanks Backwashed	Wastewater Produced (gal)	$KMnO_4$ Tank Level (in)	Average $KMnO_4$ Dose (mg/L)
36	03/13/06																				
	03/14/06																				
	03/15/06																				
	03/16/06																				
	03/17/06																				
	03/18/06																				
	03/19/06	No operational data taken.																			
37	03/20/06																				
	03/21/06																				
	03/22/06																				
	03/23/06																				
	03/24/06																				
	03/25/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	03/26/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
38	03/27/06	17:00	728.5	76.6	560,870	98,325	21	65	60	54	52	50	52	2	2.5	79,650	25,620	90	11,710	28.0	
	03/28/06	17:00	732.2	3.7	564,783	3,913	18	65	60	53	52	50	50	3	2.5	3,370	26,129	4	509	27.5	
	03/29/06	17:15	736.1	3.9	569,450	4,667	20	60	55	50	44	44	45	5	1.0	3,910	26,770	5	641	27.0	
	03/30/06	17:30	739.5	3.4	572,834	3,384	17	54	50	41	39	38	40	1	1.0	2,980	27,150	3	380	26.6	
	03/31/06	18:30	743.6	4.1	577,678	4,844	20	55	50	44	38	39	40	4	2.0	3,905	27,890	6	740	26.1	6.1
	04/01/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	04/02/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
39	04/03/06	19:00	755.3	11.7	590,687	13,009	19	56	51	50	46	44	48	2	6.0	11,043	29,546	13	1,656	24.8	
	04/04/06	18:30	758.6	3.3	594,073	3,386	17	65	60	55	54	52	52	3	2.5	2,882	29,935	3	389	24.5	
	04/05/06	17:30	762.2	3.6	598,075	4,002	19	53	50	45	42	41	43	2	2.5	3,120	30,700	6	765	24.0	
	04/06/06	19:00	766.2	4.0	602,460	4,385	18	55	50	44	42	41	42	2	2.5	3,725	31,214	4	514	23.6	
	04/07/06	15:30	769.6	3.4	606,212	3,752	18	65	60	55	53	52	53	2	5.0	3,015	31,850	5	636	23.1	5.8
	04/08/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	04/09/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
40	04/10/06	18:30	781.3	11.7	619,907	13,695	20	65	60	55	52	50	52	3	3.0	11,770	33,470	12	1,620	21.8	
	04/11/06	21:15	785.3	4.0	624,975	5,068	21	60	55	48	46	44	45	3	2.5	3,440	33,950	4	480	21.3	
	04/12/06	17:30	789.3	4.0	628,282	3,307	14	65	60	54	52	52	50	4	4.0	3,564	34,590	5	640	20.8	
	04/13/06	19:00	793.7	4.4	632,960	4,678	18	65	60	56	51	54	55	1	2.5	4,031	35,110	4	520	20.4	
	04/14/06	16:30	796.8	3.1	636,144	3,184	17	60	55	50	46	46	45	5	3.0	2,605	35,590	4	480	20.0	6.0
	04/15/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	04/16/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
41	04/17/06	20:30	809.9	13.1	649,393	13,249	17	60	55	48	46	46	45	3	2.5	10,960	37,430	14	1,840	18.5	
	04/18/06	21:00	813.8	3.9	653,515	4,122	18	65	60	56	54	53	54	2	5.0	3,625	37,920	4	490	18.0	
	04/19/06	19:30	817.6	3.8	657,412	3,897	17	62	56	50	48	48	46	4	2.5	3,405	38,320	3	400	17.6	
	04/20/06	19:15	821.1	3.5	660,518	3,106	15	65	60	55	54	54	52	3	2.5	2,520	38,820	4	500	17.4	
	04/21/06	18:00	825.2	4.1	664,120	3,602	15	65	60	54	52	50	50	4	4.4	3,205	39,210	3	390	17.1	5.1
	04/22/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	04/23/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
42	04/24/06	20:30	838.9	13.7	678,925	14,805	18	65	60	56	54	54	54	2	4.0	12,705	40,900	13	1,690	29.6	
	04/25/06	19:45	843.3	4.4	683,660	4,735	18	58	54	48	43	42	44	4	4.0	3,910	41,540	5	640	29.1	
	04/26/06	18:30	847.5	4.2	687,732	4,072	16	62	60	55	52	50	50	5	2.5	3,588	42,020	4	480	28.8	
	04/27/06	19:00	851.5	4.0	691,724	3,992	17	65	60	55	52	52	50	5	4.0	3,202	42,670	5	650	28.3	
	04/28/06	18:00	855.1	3.6	696,130	4,406	20	65	60	56	50	52	52	4	2.5	4,310	42,910	2	240	27.9	5.3
	04/29/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	04/30/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA

US EPA Arsenic Demonstration Project at BSLMHP, MN – Daily System Operation Log Sheet (Continued)

			New Well		Volume to Treatment			Pressure Tanks		Pressure Filtration					Volume to Distribution		Backwash			$KMnO_4$ Application	
Week No.	Date	Time	Hour Meter (Hr)	Daily Operation (hr)	Totalizer (gal)	Daily Volume (gal)	Average Flowrate (gpm)	Pressure Tank 1 (psig)	Pressure Tank 2 (psig)	IN (psig)	TA/TB (psig)	TC/TD (psig)	OUT (psig)	ΔP Across System (psig)	Flowrate (gpm)	Daily Volume (gal)	Totalizer (kgal)	No. of Tanks Backwashed	Wastewater Produced (gal)	$KMnO_4$ Tank Level (in)	Average $KMnO_4$ Dose (mg/L)
	05/01/06	18:30	868.5	13.4	709,110	12,980	16	65	55	50	48	46	48	2	6.0	10,520	44,660	13	1,750	26.6	
	05/02/06	18:00	872.8	4.3	713,825	4,715	18	60	55	48	46	45	46	2	3.0	4,130	45,250	5	590	26.1	
	05/03/06	19:30	878.2	5.4	719,724	5,899	18	65	55	50	50	46	48	2	2.5	4,890	46,130	7	880	25.5	
43	05/04/06	18:30	881.9	3.7	724,085	4,361	20	65	55	50	50	46	48	2	4.0	3,750	46,520	3	390	25.0	
	05/05/06	20:30	886.3	4.4	728,804	4,719	18	60	55	48	48	46	46	2	3.0	4,080	47,170	5	650	24.4	6.1
	05/06/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	05/07/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	05/08/06	20:00	899.2	12.9	743,227	14,423	19	65	60	56	54	54	56	0	5.0	11,990	49,230	16	2,060	23.0	
	05/09/06	19:30	903.2	4.0	747,378	4,151	17	65	60	55	53	54	55	0	2.5	3,515	49,730	4	500	22.5	
	05/10/06	19:00	907.1	3.9	750,920	3,542	15	60	55	48	44	44	46	2	4.0	2,525	50,180	3	450	22.1	
44	05/11/06	19:30	911.8	4.7	756,468	5,548	20	65	60	56	54	52	54	2	3.0	5,140	50,850	5	670	21.5	
	05/12/06	19:00	915.8	4.0	760,761	4,293	18	65	60	55	54	52	54	1	2.5	3,300	51,670	6	820	21.1	6.0
	05/13/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	05/14/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	05/15/06	18:30	929.6	13.8	775,537	14,776	18	65	60	55	52	52	53	2	2.5	12,680	53,350	13	1,680	19.6	
	05/16/06	17:00	933.3	3.7	779,063	3,526	16	63	58	52	49	48	50	2	2.5	2,790	53,990	5	640	19.1	
	05/17/06	18:00	937.8	4.5	783,828	4,765	18	65	60	58	54	54	55	3	2.5	4,115	54,480	4	490	18.8	
45	05/18/06	19:00	942.2	4.4	788,350	4,522	17	60	55	52	50	50	52	0	2.5	3,975	55,020	4	540	18.1	
	05/19/06	18:30	947.0	4.8	793,380	5,030	17	65	60	56	52	52	54	2	5.0	3,910	55,870	7	850	17.5	6.5
	05/20/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	05/21/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	05/22/06	18:00	959.8	12.8	807,144	13,764	18	65	60	56	48	48	49	7	2.5	11,180	57,840	15	1,970	16.1	
	05/23/06	19:30	964.9	5.1	812,170	5,026	16	60	54	50	45	46	46	4	3.0	4,520	58,380	4	540	15.5	
	05/24/06	18:00	969.2	4.3	816,478	4,308	17	65	60	54	50	50	50	4	2.5	3,500	58,990	5	610	15.0	
46	05/25/06	20:00	973.6	4.4	820,676	4,198	16	65	60	55	52	52	52	3	3.0	3,540	59,490	4	500	14.5	
	05/26/06	20:30	978.1	4.5	825,136	4,460	17	60	55	48	46	45	45	3	2.0	3,690	60,110	5	620	14.0	6.3
	05/27/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	05/28/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	05/29/06	18:30	993.6	15.5	843,715	18,579	20	60	54	50	48	48	50	0	1.0	15,555	62,640	19	2,530	11.8	
	05/30/06	18:00	1,000.3	6.7	849,920	6,205	15	60	55	48	46	45	45	3	3.0	4,825	63,205	4	565	11.1	
	05/31/06	19:30	1,005.0	4.7	857,110	7,190	25	65	60	54	50	52	52	2	2.5	6,325	64,410	9	1,205	10.3	
47	06/01/06	19:00	1,009.7	4.7	862,820	5,710	20	65	60	55	52	52	52	3	3.0	4,605	65,310	7	900	9.6	
	06/02/06	19:00	1,013.1	3.4	868,480	5,660	28	65	60	55	50	50	52	3	2.5	4,780	66,205	7	895	31.5	6.2
	06/03/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	06/04/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	06/05/06	18:00	1,033.1	20.0	890,661	22,181	18	60	54	48	45	44	45	3	3.0	18,310	68,750	20	2,545	28.6	
	06/06/06	19:30	1,040.8	7.7	900,945	10,284	22	65	60	54	52	50	52	2	2.5	8,800	69,940	9	1,190	27.5	
	06/07/06	21:00	1,048.3	7.5	910,484	9,539	21	60	55	48	45	42	44	4	5.0	7,895	71,140	9	1,200	26.5	
48	06/08/06	20:00	1,055.2	6.9	919,732	9,248	22	65	60	54	50	50	52	2	15.0	7,585	72,120	8	980	25.5	
	06/09/06	19:30	1,060.0	4.8	924,661	4,929	17	60	54	50	46	45	46	4	3.0	3,906	72,740	5	620	25.0	6.1
	06/10/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	06/11/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	06/12/06	19:45	1,075.2	15.2	940,067	15,406	17	65	60	54	50	52	52	2	3.0	12,309	74,570	14	1,830	23.5	
	06/13/06	19:30	1,080.6	5.4	945,160	5,093	16	60	55	52	48	47	48	4	4.0	4,225	75,320	6	750	23.0	
	06/14/06	10:00	1,086.1	5.5	950,879	5,719	17	65	60	55	52	48	50	5	2.5	4,850	75,940	5	620	22.6	
49	06/15/06	11:00	1,092.0	5.9	956,284	5,405	15	65	60	55	50	46	48	7	3.0	4,405	76,670	6	730	21.8	
	06/16/06	18:45	1,096.7	4.7	960,503	4,219	15	62	56	52	46	46	48	4	2.5	3,455	77,170	4	500	21.4	5.9
	06/17/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	06/18/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA

US EPA Arsenic Demonstration Project at BSLMHP, MN – Daily System Operation Log Sheet (Continued)

			New Well		Volume to Treatment			Pressure Tanks		Pressure Filtration					Volume to Distribution		Backwash			$KMnO_4$ Application	
Week No.	Date	Time	Hour Meter (Hr)	Daily Operation (hr)	Totalizer (gal)	Daily Volume (gal)	Average Flowrate (gpm)	Pressure Tank 1 (psig)	Pressure Tank 2 (psig)	IN (psig)	TA/TB (psig)	TC/TD (psig)	OUT (psig)	ΔP Across System (psig)	Flowrate (gpm)	Daily Volume (gal)	Totalizer (kgal)	No. of Tanks Backwashed	Wastewater Produced (gal)	$KMnO_4$ Tank Level (in)	Average $KMnO_4$ Dose (mg/L)
50	06/19/06	21:30	1,115.8	19.1	979,050	18,547	16	65	60	55	50	52	52	3	4.0	14,925	79,260	16	2,090	21.0	
	06/20/06	21:30	1,121.8	6.0	984,847	5,797	16	65	60	55	50	50	50	5	7.5	4,435	80,130	7	870	20.5	
	06/21/06	20:00	1,127.2	5.4	989,895	5,048	16	65	60	56	52	52	52	4	2.0	3,980	80,650	4	520	19.9	
	06/22/06	20:00	1,132.6	5.4	994,324	4,429	14	65	60	55	50	52	52	3	10.0	3,235	81,270	5	620	19.3	
	06/23/06	21:15	1,138.4	5.8	999,548	5,224	15	65	60	55	52	52	52	3	5.0	3,985	81,780	4	510	18.9	6.2
	06/24/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	06/25/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
51	06/26/06[k]	17:00	1,159.3	20.9	17,428	17,880	14	65	60	55	48	48	50	5	0.0	13,035	84,100	18	2,320	31.5	
	06/27/06	16:00	1,166.0	6.7	23,850	6,422	16	65	60	54	50	50	50	4	2.5	4,720	84,870	6	770	31.0	
	06/28/06	19:00	1,172.9	6.9	31,974	8,124	20	60	55	50	48	50	50	0	3.0	5,015	85,850	8	980	30.4	
	06/29/06	18:00	1,179.4	6.5	36,820	4,846	12	65	60	55	52	50	52	3	2.5	4,320	86,720	7	870	29.6	
	06/30/06	20:00	1,187.1	7.7	44,780	7,960	17	65	60	54	50	50	52	2	4.0	5,565	87,420	5	700	29.0	4.8
	07/01/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	07/02/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
52	07/03/06	18:00	1,207.2	20.1	66,010	21,230	18	65	60	52	52	52	52	0	4.0	13,735	89,720	18	2,300	27.1	
	07/04/06	18:30	1,215.6	8.4	74,317	8,307	16	65	60	54	52	50	52	2	2.5	7,580	90,640	7	920	26.3	
	07/05/06	19:30	1,223.3	7.7	81,771	7,454	16	65	60	55	50	40	50	5	3.0	5,340	91,370	6	730	25.5	
	07/06/06	22:00	1,234.5	11.2	93,120	11,349	17	65	60	55	50	50	52	3	4.0	8,350	92,540	9	1,170	24.5	
	07/07/06	18:30	1,240.6	6.1	98,525	5,405	15	65	60	55	52	50	52	3	10.0	3,820	93,010	4	470	24.0	4.8
	07/08/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	07/09/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
53	07/10/06[l]	19:45	1,265.4	24.8	124,576	26,051	18	65	60	55	50	52	52	3	NM	18,190	95,580	20	2,570	21.5	
	07/11/06	18:00	1,274.5	9.1	134,585	10,009	18							NA	NM	6,935	96,530	7	950	20.9	
	07/12/06	19:30	1,283.5	9.0	144,274	9,689	18							NA	NM	6,875	97,490	7	960	20.8	
	07/13/06	16:00	1,289.0	5.5	149,137	4,863	15							NA	NM	3,350	97,970	4	480	20.8	
	07/14/06	20:00	1,297.3	8.3	156,903	7,766	16							NA	NM	5,150	98,860	7	890	20.8	1.3
	07/15/06	NM	NM	NA	NM	NM	NM							NA	NM	NA	NM	NM	NA	NM	NA
	07/16/06	NM	NM	NA	NM	NM	NM							NA	NM	NA	NM	NM	NA	NM	NA
54	07/17/06	10:30	1,321.3	24.0	179,460	22,557	16							NA	NM	15,500	101,070	17	2,210	18.8	
	07/18/06	18:00	1,327.9	6.6	185,288	5,828	15							NA	NM	3,880	101,700	5	630	18.1	
	07/19/06	18:30	1,334.3	6.4	190,557	5,269	14							NA	NM	3,660	102,200	4	500	17.6	
	07/20/06	18:00	1,340.1	5.8	195,010	4,453	13							NA	NM	4,070	102,820	5	620	31.5	
	07/21/06	16:30	1,346.9	6.8	202,065	7,055	17							NA	NM	3,580	103,320	4	500	31.5	3.0
	07/22/06	17:00	NM	NA	NM	NM	NM	Pressure readings not recorded.						NA	NM	NA	NM	NM	NA	NM	NA
	07/23/06	NM	NM	NA	NM	NM	NM							NA	NM	NA	NM	NM	NA	NM	NA
55	07/24/06	18:30	1,367.3	20.4	219,801	17,736	14							NA	NM	11,270	105,360	16	2,040	30.5	
	07/25/06	NM	NM	NA	NM	NM	NM							NA	NM	NA	NM	NM	NA	NM	
	07/26/06	NM	NM	NA	NM	NM	NM							NA	NM	NA	NM	NM	NA	NM	
	07/27/06	NM	NM	NA	NM	NM	NM							NA	NM	NA	NM	NM	NA	NM	
	07/28/06	18:30	1,399.4	32.1	250,475	30,674	16							NA	NM	19,730	109,250	30	3,890	29.5	2.4
	07/29/06	NM	NM	NA	NM	NM	NM							NA	NM	NA	NM	NM	NA	NM	NA
	07/30/06	NM	NM	NA	NM	NM	NM							NA	NM	NA	NM	NM	NA	NM	NA
56	07/31/06	18:00	1,426.3	26.9	277,425	26,950	17							NA	NM	18,440	111,440	17	2,190	28.0	
	08/01/06	19:00	1,437.1	10.8	289,145	11,720	18							NA	NM	8,170	112,830	11	1,390	27.5	
	08/02/06	19:30	1,445.2	8.1	295,965	6,820	14							NA	NM	4,965	113,740	7	910	27.0	
	08/03/06	19:30	1,453.1	7.9	301,057	5,092	11	65	60	58	58	56	55	3	NM	5,335	114,520	6	780	26.8	3.3
	08/04/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	08/05/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	08/06/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA

US EPA Arsenic Demonstration Project at BSLMHP, MN – Daily System Operation Log Sheet (Continued)

			New Well		Volume to Treatment			Pressure Tanks		Pressure Filtration					Volume to Distribution		Backwash			$KMnO_4$ Application	
Week No.	Date	Time	Hour Meter (Hr)	Daily Operation (hr)	Totalizer (gal)	Daily Volume (gal)	Average Flowrate (gpm)	Pressure Tank 1 (psig)	Pressure Tank 2 (psig)	IN (psig)	TA/TB (psig)	TC/TD (psig)	OUT (psig)	ΔP Across System (psig)	Flowrate (gpm)	Daily Volume (gal)	Totalizer (kgal)	No. of Tanks Backwashed	Wastewater Produced (gal)	$KMnO_4$ Tank Level (in)	Average $KMnO_4$ Dose (mg/L)
57	08/07/06	09:00	1,484.2	31.1	324,624	23,567	13	50	47	43	33	32	33	10	NM	19,520	117,750	25	3,230	25.3	
	08/08/06	08:30	1,491.5	7.3	329,842	5,218	12	65	60	56	53	52	53	3	NM	4,050	118,610	7	860	24.9	
	08/09/06	11:45	1,497.6	6.1	334,861	5,019	14	65	60	58	57	55	57	1	NM	4,230	119,130	4	520	24.5	
	08/10/06	06:30	1,501.7	4.1	338,497	3,636	15	65	60	57	56	54	57	0	NM	2,610	119,770	5	640	24.5	
	08/11/06	15:00	1,506.0	4.3	342,647	4,150	16	65	60	55	54	55	55	0	NM	3,390	120,280	4	510	24.3	3.4
	08/12/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	08/13/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
58	08/14/06	17:00	1,523.6	17.6	359,670	17,023	16	65	60	56	55	54	54	2	NM	NA	122,150	18	2,380	23.3	
	08/15/06	20:00	1,529.8	6.2	366,217	6,547	18	65	60	54	50	52	52	2	NM	5,025	123,050	7	900	22.6	
	08/16/06	20:00	1,541.0	11.2	377,433	11,216	17	65	60	56	54	54	54	2	NM	8,670	NM	NA	NA	22.3	
	08/17/06	21:00	1,545.6	4.6	382,385	4,952	18	65	60	55	53	52	52	3	NM	4,020	125,180	NA	NA	21.5	4.3
	08/18/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	
	08/19/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	08/20/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
59	08/21/06	17:00	1,565.0	19.4	402,298	19,913	17	65	60	58	54	54	55	3	NM	14,710	127,540	18	2,360	20.8	
	08/22/06	18:00	1,570.5	5.5	407,608	5,310	16	65	60	58	55	55	55	3	NM	4,045	128,180	5	640	20.6	
	08/23/06	19:00	1,574.9	4.4	412,355	4,747	18	65	60	56	54	54	56	0	NM	3,450	128,830	5	650	20.5	
	08/24/06	18:30	1,579.6	4.7	417,285	4,930	17	60	55	52	52	50	52	0	NM	3,765	129,340	4	510	20.0	
	08/25/06	20:00	1,584.3	4.7	422,680	5,395	19	60	56	50	48	46	48	2	NM	3,900	130,080	6	740	19.5	4.0
	08/26/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	08/27/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
60	08/28/06	18:00	1,598.2	13.9	438,345	15,665	19	56	52	48	44	45	46	2	NM	11,830	131,720	13	1,640	18.5	
	08/29/06	19:00	1,602.8	4.6	443,832	5,487	20	65	60	56	55	53	54	2	NM	3,815	132,610	7	890	18.1	
	08/30/06	16:00	1,606.8	4.0	448,695	4,863	20	65	60	55	53	52	53	2	NM	3,625	133,130	4	520	17.9	
	08/31/06	20:30	1,612.8	6.0	455,369	6,674	19	65	60	56	54	54	54	2	NM	4,880	133,900	6	770	17.4	
	09/01/06	18:00	1,617.5	4.7	460,430	5,061	18	65	60	55	53	52	53	2	NM	NA	134,540	5	640	31.5	4.4
	09/02/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	09/03/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
61	09/04/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	09/05/06	20:00	1,639.9	22.4	483,908	23,478	17	65	60	57	55	54	55	2	NM	20,340	137,560	NA	3,020	31.0	
	09/06/06	19:00	1,644.1	4.2	488,662	4,754	19	65	60	56	55	54	55	1	NM	3,495	138,060	4	500	30.6	
	09/07/06	18:30	1,649.8	5.7	495,037	6,375	19	65	60	58	56	55	56	2	NM	4,450	138,850	6	790	30.3	
	09/08/06	17:00	1,653.5	3.7	499,065	4,028	18	60	55	52	50	48	48	4	NM	2,750	139,370	4	520	30.0	4.5
	09/09/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	09/10/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
62	09/11/06	17:30	1,667.7	14.2	514,335	15,270	18	65	60	56	55	55	56	0	NM	10,960	141,170	14	1,800	29.0	
	09/12/06	18:00	1,672.5	4.8	519,667	5,332	19	60	55	50	48	46	48	2	NM	3,695	141,830	5	660	28.8	
	09/13/06	19:00	1,678.0	5.5	525,352	5,685	17	65	60	56	54	52	54	2	NM	3,930	142,590	6	760	28.3	
	09/14/06	17:00	1,682.4	4.4	530,053	4,701	18	60	55	54	52	50	52	2	NM	3,340	143,200	5	610	28.3	
	09/15/06	20:00	1,687.7	5.3	535,806	5,753	18	65	60	56	54	52	54	2	NM	4,050	143,740	4	540	28.0	3.2
	09/16/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	09/17/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
63	09/18/06	18:00	1,702.2	14.5	551,497	15,691	18	65	60	56	54	52	52	4	NM	10,790	145,640	15	1,900	27.4	
	09/19/06	18:15	1,706.0	3.8	556,440	4,943	22	65	60	55	52	50	52	3	NM	3,480	146,210	4	570	27.0	
	09/20/06	18:30	1,711.0	5.0	561,625	5,185	17	65	60	58	55	56	56	2	NM	3,490	146,830	5	620	26.8	
	09/21/06	20:00	1,716.0	5.0	567,193	5,568	19	65	60	56	54	52	54	2	NM	3,840	147,350	4	520	26.3	
	09/22/06	18:30	1,721.0	5.0	572,038	4,845	16	60	55	52	50	50	50	2	NM	3,270	148,000	5	650	26.1	4.3
	09/23/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	09/24/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA

US EPA Arsenic Demonstration Project at BSLMHP, MN – Daily System Operation Log Sheet (Continued)

			New Well		Volume to Treatment			Pressure Tanks		Pressure Filtration					Volume to Distribution		Backwash			$KMnO_4$ Application	
Week No.	Date	Time	Hour Meter (Hr)	Daily Operation (hr)	Totalizer (gal)	Daily Volume (gal)	Average Flowrate (gpm)	Pressure Tank 1 (psig)	Pressure Tank 2 (psig)	IN (psig)	TA/TB (psig)	TC/TD (psig)	OUT (psig)	ΔP Across System (psig)	Flowrate (gpm)	Daily Volume (gal)	Totalizer (kgal)	No. of Tanks Backwashed	Wastewater Produced (gal)	$KMnO_4$ Tank Level (in)	Average $KMnO_4$ Dose (mg/L)
64	09/25/06	18:00	1,736.0	15.0	589,057	17,019	19	65	60	58	56	54	56	2	NM	11,600	150,030	16	2,030	25.5	
	09/26/06	17:00	1,740.0	4.0	594,185	5,128	21	65	60	56	54	52	52	4	NM	3,470	150,680	5	650	25.0	
	09/27/06	18:30	1,744.0	4.0	598,958	4,773	20	60	55	50	48	46	48	2	NM	3,310	151,190	4	510	24.8	
	09/28/06	17:00	1,748.0	4.0	602,510	3,552	15	60	55	52	50	50	50	2	NM	2,965	151,810	5	620	24.5	
	09/29/06	16:00	1,753.0	5.0	608,175	5,665	19	65	60	58	56	54	56	2	NM	3,265	152,220	3	410	24.3	4.6
	09/30/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA
	10/01/06	NM	NM	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NA	NM	NM	NA	NM	NA

(a) On 08/09/05, both sets of duplex filters stuck in backwash mode due to sediment dislodged in purge/control valve, preventing it from closing. System bypassed.
(b) On 08/09/06, a pressure gauge after each set of duplex filters installed.
(c) On 08/11/05, pressure gauge on pressure tank 2 replaced.
(d) On 09/12/05, two flow meters, one on treated water line and one on backwash discharge line, installed although readings not recorded until 09/28/05.
(e) On 09/28/05, hour meter installed.
(f) On 09/30/06, pressure gauge changed out for duplex units TC/TD.
(g) On 01/03/06, totalizer on raw water line re-set.
(h) On 01/16/06, totalizer to distribution re-set.
(i) On 02/06/06, totalizer on the backwash line stopped working, therefore, dosage calculated based on totalizer on distribution line.
(j) On 02/27/06, totalizer on the backwash line fixed.
(k) On 06/26/06, totalizer on raw water line re-set.
(l) Starting on 07/10/06, flow meter on the treated water line was discolored and could not be read.

APPENDIX B

ANALYTICAL DATA

Analytical Results from Long Term Sampling at BSLMHP, MN

Sampling Date		07/13/05			07/20/05[b]			07/26/05[b]			08/02/05[b]			08/18/05[c, d]			08/24/05			
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TA/TB	TC/TD
Stroke Length	%	33			33			33			33			26			26			
Disc No./BW Frequency	No./gal	5/2,743			5/2,743			5/2,743			5/2,743			5/2,743			5/2,743			
Alkalinity (as $CaCO_3$)	mg/L	352	374	374	365	365	361	365	370	365	352	365	374	352	365	361	352	365	361	374
Fluoride	mg/L	0.2	0.2	0.2	-	-	-	-	-	-	-	-	-	0.2	0.2	0.2	-	-	-	-
Sulfate	mg/L	<1	<1	<1	-	-	-	-	-	-	-	-	-	<1	<1	<1	-	-	-	-
Nitrate (as N)	mg/L	0.1	0.1	0.3	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-
P (total) (as P)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	23.3	23.3	22.7	24.7	24.4	24.2	23.5	23.6	23.9	23.8	24.0	23.6	24.1	24.2	23.9	29.4	28.6	28.4	28.2
Turbidity	NTU	25.0	3.1	0.6	23.0	2.8	0.5	25.0	2.9	0.1	26.0	4.7	11.0	33.0	3.7	0.4	24.0	2.9	0.7	0.2
TOC	mg/L	NA[a]	NA[a]	NA[a]	-	-	-	-	-	-	-	-	-	4.1	3.9	4.0	-	-	-	-
pH	S.U.	7.4	7.5	7.7	7.3	7.2	7.2	7.4	7.3	7.2	7.4	7.3	7.3	7.2	7.3	7.3	7.3	7.4	7.3	7.4
Temperature	^0C	14.9	12.7	12.3	11.4	12.3	11.9	10.4	11.0	11.0	11.2	12.1	12.1	10.8	14.1	13.8	12.3	12.8	12.5	12.8
DO	mg/L	2.0	0.7	1.1	2.5	0.5	0.7	3.6	1.7	0.9	3.5	1.0	1.2	0.9	0.9	0.7	1.0	0.8	0.7	1.1
ORP	mV	-23	196	219	-29	85	144	-40	144	173	-35	154	196	-76	2	43	-48	138	159	181
Total Hardness (as $CaCO_3$)	mg/L	383	330	329	-	-	-	-	-	-	-	-	-	320	317	323	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	228	197	197	-	-	-	-	-	-	-	-	-	188	190	187	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	155	133	132	-	-	-	-	-	-	-	-	-	131	128	137	-	-	-	-
As (total)	µg/L	36.4	29.6	4.3	34.7	26.7	17.7	26.6	24.8	5.5	25.7	23.0	8.0	26.4	23.2	5.1	30.4	31.5	3.5	3.3
As (soluble)	µg/L	30.3	3.3	3.0	-	-	-	-	-	-	-	-	-	26.2	4.8	4.8	-	-	-	-
As (particulate)	µg/L	6.1	26.3	1.3	-	-	-	-	-	-	-	-	-	0.2	18.4	0.3	-	-	-	-
As (III)	µg/L	13.9	1.6	1.7	-	-	-	-	-	-	-	-	-	24.1	2.6	3.4	-	-	-	-
As (V)	µg/L	16.5	1.7	1.3	-	-	-	-	-	-	-	-	-	2.1	2.2	1.4	-	-	-	-
Fe (total)	µg/L	3,315	3,173	157	2,786	2,766	482	2,864	2,704	45	2,964	2,578	666	2,895	2,773	<25	2,764	2,706	<25	<25
Fe (soluble)	µg/L	2,792	<25	<25	-	-	-	-	-	-	-	-	-	2,954	<25	<25	-	-	-	-
Mn (total)	µg/L	154	996	428	139	634	561	137	844	727	135	1,126	487	139	1,097	1,010	130	871	475	467
Mn (soluble)	µg/L	133	377	391	-	-	-	-	-	-	-	-	-	142	850	1,000	-	-	-	-

(a) Samples not taken. (b) Easy week samples were taken at TT and not at TA/TB and TC/TD because sample taps were not installed. (c) Onsite water quality parameters taken on 08/17/05. (d) System bypassed on 08/09/05 therefore samples not collected that week.

Analytical Results from Long Term Sampling at BSLMHP, MN (Continued)

Sampling Date		08/31/05				09/07/05[b]				09/14/05				09/20/05			09/27/05[d]			
Sampling Location / Parameter	Unit	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TT	IN	AC	TA/TB	TC/TD
Stroke Length	%	15				15				26				26			26			
Disc No./BW Frequency	No./gal	5/2,743				5/2,743				5/2,743				5/2,743			6/6,857			
Alkalinity (as $CaCO_3$)	mg/L	383	370	374	374	361	365	361	365	356	370	370	352	374	374	370	378	374	374	374
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	0.2	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-
P (total) (as P)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	25.8	25.6	25.8	25.8	24.1	24.3	24.0	24.2	22.6	22.9	22.5	22.7	22.6	22.5	22.2	25.7	25.7	25.6	25.3
Turbidity	NTU	32.0	5.3	4.2	4.2	13.0	6.0	14.0	14.0	32.0	3.4	0.2	0.3	31.0	3.4	0.5	32.0	4.1	<0.1	<0.1
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	4.8	4.6	4.8	-	-	-	-
pH	S.U.	NA[a]	NA[a]	NA[a]	NA[a]	7.3	7.4	7.3	7.5	7.3	7.2	7.2	7.2	7.2	7.3	7.2	7.4	7.4	7.4	7.4
Temperature	^{0}C	NA[a]	NA[a]	NA[a]	NA[a]	10.8	11.3	10.7	11.5	11.5	10.9	11.2	10.7	10.7	13.4	13.6	9.5	9.8	9.9	10.0
DO	mg/L	NA[a]	NA[a]	NA[a]	NA[a]	0.9	0.5	0.9	0.7	1.5	0.7	0.5	0.5	0.7	1.0	0.9	0.8	1.6	0.7	0.7
ORP	mV	NA[a]	NA[a]	NA[a]	NA[a]	-63	-22[c]	-9	-12	-49	101	96	101	-66	18	6	-54	1	6	8
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	307	307	306	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	177	178	176	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	131	129	130	-	-	-	-
As (total)	µg/L	27.0	27.9	13.8	12.3	20.6	28.8	21.5	17.5	23.7	24.8	2.8	4.7	27.4	27.1	2.9	26.7	25.4	8.4	7.6
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	27.6	4.7	3.2	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.1	22.4	<0.1	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	25.6	1.7	1.5	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	2.0	3.1	1.7	-	-	-	-
Fe (total)	µg/L	2,888	3,096	571	465	1,069	2,619	1,052	1,140	2,716	2,795	<25	78	3,094	2,911	<25	2,934	2,796	<25	<25
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	2,883	<25	<25	-	-	-	-
Mn (total)	µg/L	133	581	906	865	NA	416	447	430	131	1,042	651	897	149	883	616	141	676	802	841
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	145	533	634	-	-	-	-

(a) Onsite water quality parameters not taken. (b) Onsite water quality parameters taken on 09/06/05. (c) Result was negative due to low $KMnO_4$ dosage, therefore, it was considered an outlier and not included in calculations.
(d) Onsite water quality parameters taken on 09/28/05.

Analytical Results from Long Term Sampling at BSLMHP, MN (Continued)

Sampling Date		10/05/05[a]				10/12/05[b]				10/19/05[c]			10/26/05[d]				11/02/05[e]			
Sampling Location / Parameter	Unit	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TT	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD
Stroke Length	%	26				26				26			26				26			
Disc No./BW Frequency	No./gal	7/1,959				7/1,959				7/1,959			7/1,959				7/1,959			
Alkalinity (as $CaCO_3$)	mg/L	356	321	352	374	365 365	374 370	374 374	365 365	383	378	383	352	365	361	361	361	352	356	352
Fluoride	mg/L	-	-	-	-	-	-	-	-	0.2	0.2	0.2	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	<1	<1	<1	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-
P (total) (as P)	µg/L	452	451	21.1	21.4	471 484	428 457	51.9 41.1	34.4 112	511	490	60.5	454	456	28.3	34.8	511	NA[f]	40.6	42.9
Silica (as SiO_2)	mg/L	23.1	22.6	23.6	25.6	23.2 23.3	23.6 23.6	23.2 23.3	23.2 23.0	23.0	23.2	21.7	24.5	25.1	24.1	24.5	24.7	24.5	24.0	23.9
Turbidity	NTU	28.0	4.6	1.2	<0.1	34.0 34.0	3.0 3.3	0.4 0.5	0.5 0.5	34.0	4.0	1.3	33.0	3.3	0.2	1.3	33.0	3.1	0.1	0.3
TOC	mg/L	-	-	-	-	-	-	-	-	3.7	3.3	3.8	-	-	-	-	-	-	-	-
pH	S.U.	7.4	7.5	7.4	7.5	7.4	7.4	7.4	7.4	7.4	7.4	7.3	7.3	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Temperature	^0C	10.0	10.0	10.0	10.0	10.5	10.2	10.3	10.3	10.8	10.8	10.8	10.6	10.5	10.5	10.6	10.0	10.1	10.1	10.2
DO	mg/L	0.9	1.5	1.2	1.3	0.7	1.1	0.8	0.8	0.8	1.0	0.7	1.1	1.3	1.1	1.0	0.7	0.7	1.0	0.8
ORP	mV	-64	175	177	183	-58	28	35	45	-56	23	29	-50	-1	28	33	-30	55	71	78
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	315	315	313	-	-	-	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	188	189	184	-	-	-	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	128	126	129	-	-	-	-	-	-	-	-
As (total)	µg/L	22.8	21.8	3.2	3.3	27.2 28.7	25.8 27.6	6.3 5.8	6.3 10.1	29.1	27.8	4.2	26.0	26.6	6.4	5.8	25.1	NA[f]	5.6	4.2
As (soluble)	µg/L	-	-	-	-	-	-	-	-	25.2	4.0	2.9	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	3.8	23.8	1.3	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	20.8	0.9	0.8	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	4.5	3.1	2.4	-	-	-	-	-	-	-	-
Fe (total)	µg/L	2,596	2,523	<25	<25	2,820 2,874	2,562 2,707	142 74	72 547	2,680	2,624	136	2,979	2,968	<25	67	3,758	NA[f]	62	48
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	2,594	25	<25	-	-	-	-	-	-	-	-
Mn (total)	µg/L	119	760	600	628	128 130	791 827	687 694	794 838	128	953	548	134	888	852	846	176	984	988	952
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	132	468	535	-	-	-	-	-	-	-	-

(a) Onsite water quality parameters taken on 10/06/05. (b) Duplicate sampling week. (c) Onsite water quality parameters taken on 10/18/05. (d) Onsite water quality parameters taken on 10/27/05.
(e) Onsite water quality parameters taken on 11/01/05. (f) Result was questionable and not reported.

Analytical Results from Long Term Sampling at BSLMHP, MN (Continued)

Sampling Date		11/09/05				11/15/05[a]			11/29/05[c]				12/08/05				12/14/05[d]			
Sampling Location Parameter	Unit	IN	AC	TA/TB	TC/TD	IN	AC	TT	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD
Stroke Length	%	26				40			38				40				40			
Disc No./BW Frequency	No./gal	7/1,959				7/1,959			7/1,959				8/1,714				8/1,714			
Alkalinity (as $CaCO_3$)	mg/L	370	370	365	370	352	365	370	352	370	361	356	374	374	370	370	374 378	365 374	378 378	378 378
Fluoride	mg/L	-	-	-	-	0.2	0.2	0.2	-	-	-	-	0.2	0.2	0.2	0.2	-	-	-	-
Sulfate	mg/L	-	-	-	-	<1	<1	<1	-	-	-	-	<1	<1	<1	<1	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	<0.05	<0.05	<0.05	<0.05	-	-	-	-
P (total) (as P)	µg/L	504	486	101	54.5	498	502	166	456	494	432	121	400	394	16.2	21.1	500 541	497 490	211 215	210 220
Silica (as SiO_2)	mg/L	23.9	23.6	24.0	24.0	23.5	23.7	23.7	24.3	24.6	24.7	25.0	23.5	23.9	23.9	23.8	25.4 26.1	25.6 26.4	25.1 25.5	25.8 24.9
Turbidity	NTU	33.0	3.2	0.1	0.7	34.0	3.2	0.9	32.0	4.2	1.3	0.5	26.0	3.9	0.1	0.5	34.0 35.0	5.1 5.2	0.7 0.8	1.9 1.2
TOC	mg/L	-	-	-	-	NA[b]	NA[b]	NA[b]	-	-	-	-	NA[b]	NA[b]	NA[b]	NA[b]	-	-	-	-
pH	S.U.	7.4	7.4	7.4	7.4	7.3	7.3	7.2	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
Temperature	^{0}C	10.0	10.2	10.2	10.4	9.4	9.5	9.5	9.8	9.6	9.6	9.7	9.6	9.4	9.3	9.4	9.3	9.5	9.3	9.2
DO	mg/L	0.9	0.8	0.9	0.8	1.3	1.0	1.0	1.2	1.6	0.9	1.0	1.1	1.1	0.9	1.1	1.2	1.1	1.6	0.9
ORP	mV	-38	39	65	68	-39	62	76	-39	55	65	71	-42	54	65	68	-26	52	59	64
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	311	321	338	-	-	-	-	296	295	304	307	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	186	192	212	-	-	-	-	184	182	185	185	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	125	129	126	-	-	-	-	112	114	119	122	-	-	-	-
As (total)	µg/L	36.6	36.1	11.3	5.7	33.2	34.1	17.1	30.3	34.1	29.8	9.2	24.2	24.9	2.0	2.1	26.4 27.6	25.6 25.6	12.1 11.3	12.6 12.4
As (soluble)	µg/L	-	-	-	-	28.8	8.7	6.2	-	-	-	-	24.4	2.7	2.0	2.0	-	-	-	-
As (particulate)	µg/L	-	-	-	-	4.4	25.4	10.9	-	-	-	-	<0.1	22.2	<0.1	0.1	-	-	-	-
As (III)	µg/L	-	-	-	-	27.4	5.4	4.4	-	-	-	-	24.5	0.3	0.3	0.4	-	-	-	-
As (V)	µg/L	-	-	-	-	1.4	3.3	1.7	-	-	-	-	<0.1	2.4	1.6	1.6	-	-	-	-
Fe (total)	µg/L	2,549	2,425	336	68	2,774	2,830	1,067	2,793	2,761	2,363	532	2,258	2,247	<25	<25	2,655 2,832	2,564 2,558	983 978	1,001 1,023
Fe (soluble)	µg/L	-	-	-	-	2,873	306	41	-	-	-	-	2,263	<25	<25	<25	-	-	-	-
Mn (total)	µg/L	117	1,031	951	971	130	1,004	1,091	124	1,123	1,002	432	110	1,037	203	187	123 125	1,242 1,243	611 611	665 673
Mn (soluble)	µg/L	-	-	-	-	138	946	1,062	-	-	-	-	110	166	202	190	-	-	-	-

(a) Onsite water quality parameters taken on 11/16/06. (b) TOC samples not taken. (c) Onsite water quality parameters taken on 11/30/05. (d) Onsite water quality parameters taken on 12/15/05.

Analytical Results from Long Term Sampling at BSLMHP, MN (Continued)

Sampling Date		01/05/06[(a)]			01/10/06[(b)]				01/17/06[(c)]				01/26/06				01/31/06		
Sampling Location / Parameter	Unit	IN	AC	TT	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TT
Stroke Length	%	40			40				40				42				42		
Disc No./BW Frequency	No./gal	8/1,714			8/1,714				8/1,714				6/916				6/916		
Alkalinity (as $CaCO_3$)	mg/L	378	383	378	374	378	378	383	383	378	378	378	383	387	378	374	359	368	368
Fluoride	mg/L	0.2	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	0.2
Sulfate	mg/L	<1	<1	<1	-	-	-	-	-	-	-	-	-	-	-	-	<1	<1	<1
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05
P (total) (as P)	µg/L	458	423	51.6	406	398	<10	<10	495	483	32.1	29.0	505	514	30.6	30.6	601	517	36.0
Silica (as SiO_2)	mg/L	24.9	25.3	24.7	24.4	24.2	23.8	24.2	25.3	25.4	24.1	24.7	24.5	24.2	23.7	24.2	24.0	24.2	23.4
Turbidity	NTU	31.0	5.8	1.4	31.0	4.3	0.2	4.6	32.0	6.5	0.3	3.3	31.0	4.7	1.4	0.3	33.0	5.2	0.7
TOC	mg/L	3.2	3.1	3.0	-	-	-	-	3.1	2.9	2.8	2.8	-	-	-	-	3.2	3.1	2.9
pH	S.U.	7.3	7.4	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
Temperature	^0C	9.7	10.0	9.8	9.8	9.6	10.0	9.8	9.6	9.8	9.8	10.1	10.1	9.8	9.9	9.8	10.2	9.9	9.8
DO	mg/L	0.9	1.0	1.0	0.9	1.2	0.9	1.0	1.0	1.1	1.0	0.9	1.1	1.0	1.1	1.1	1.2	0.9	1.1
ORP	mV	-42	58	68	-38	62	57	61	-45	59	55	57	-29	60	44	47	-20	65	69
Total Hardness (as $CaCO_3$)	mg/L	305	316	318	-	-	-	-	-	-	-	-	-	-	-	-	243	280	280
Ca Hardness (as $CaCO_3$)	mg/L	190	195	193	-	-	-	-	-	-	-	-	-	-	-	-	161	184	183
Mg Hardness (as $CaCO_3$)	mg/L	114	121	125	-	-	-	-	-	-	-	-	-	-	-	-	82.0	95.3	96.9
As (total)	µg/L	25.9	24.9	3.9	24.6	24.0	3.0	4.8	25.6	25.9	2.8	2.5	35.8	35.5	3.4	3.2	29.1	28.9	3.6
As (soluble)	µg/L	26.2	2.8	2.2	-	-	-	-	-	-	-	-	-	-	-	-	28.1	2.6	2.2
As (particulate)	µg/L	<0.1	22.1	1.7	-	-	-	-	-	-	-	-	-	-	-	-	1.0	26.3	1.4
As (III)	µg/L	25.0	0.4	0.4	-	-	-	-	-	-	-	-	-	-	-	-	24.5	0.3	0.3
As (V)	µg/L	1.2	2.4	1.7	-	-	-	-	-	-	-	-	-	-	-	-	3.6	2.4	1.9
Fe (total)	µg/L	2,737	2,566	194	2,581	2,629	28	307	2,593	2,427	27	<25	2,878	2,768	<25	<25	3,333	3,050	98
Fe (soluble)	µg/L	2,474	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-	3,274	<25	<25
Mn (total)	µg/L	125	1,506	331	135	1,235	324	366	130	1,031	220	201	127	1,160	210	219	155	1,164	280
Mn (soluble)	µg/L	121	108	138	-	-	-	-	-	-	-	-	-	-	-	-	159	182	250

(a) Onsite water quality parameters taken on 01/04/06. (b) Onsite water quality parameters taken on 01/11/06. (c) Onsite water quality parameters taken on 01/18/06.

Analytical Results from Long Term Sampling at BSLMHP, MN (Continued)

Sampling Date		02/08/06				02/15/06				02/21/06				02/27/06			03/07/06			
Sampling Location / Parameter	Unit	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TT	IN	AC	TA/TB	TC/TD
Stroke Length	%	45				45				45				45			45			
Disc No./BW Frequency	No./gal	6/916				6/916				6/916				6/916			6/916			
Alkalinity (as $CaCO_3$)	mg/L	354	362	362	367	349	366	341	391	365 361	365 361	365 365	356 365	372	368	364	365	365	361	361
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	0.2	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-
P (total) (as P)	µg/L	537	530	50.5	40.3	412	384	155	98.5	523 505	523 498	34.0 34.4	146 145	519	541	146	318	334	<10	19.5
Silica (as SiO_2)	mg/L	23.7	24.4	24.3	24.2	25.6	25.5	25.9	25.0	24.8 25.0	25.1 25.2	24.9 25.1	24.9 24.7	24.1	23.1	23.6	23.4	23.0	23.4	22.8
Turbidity	NTU	32.0	7.3	0.9	1.2	36.0	7.1	1.6	1.8	33.0 34.0	6.4 6.6	1.7 1.6	1.4 1.5	31.0	5.6	0.2	23.0	7.2	0.2	1.2
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	3.0	3.0	2.7	-	-	-	-
pH	S.U.	7.3	7.4	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
Temperature	^0C	10.2	10.0	10.2	9.9	9.8	9.7	9.7	9.9	9.8	9.8	9.6	9.8	9.8	9.9	9.8	9.8	10.0	9.8	9.8
DO	mg/L	1.0	0.9	1.0	0.9	1.1	0.9	0.9	1.0	1.0	0.9	0.9	1.0	0.9	0.9	1.0	0.9	1.0	1.0	1.1
ORP	mV	-24	65	61	70	-36	59	59	65	-39	68	69	70	-40	70	69	-38	69	70	72
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	342	346	342	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	195	201	198	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	147	145	144	-	-	-	-
As (total)	µg/L	36.3	35.8	3.5	3.1	27.2	26.8	10.9	8.3	31.4 30.6	32.6 29.9	2.9 3.0	8.8 8.6	26.9	27.9	2.3	23.7	24.3	2.7	3.2
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	25.7	2.5	2.1	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	1.1	25.4	0.3	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	24.7	0.6	0.7	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	1.0	2.0	1.4	-	-	-	-
Fe (total)	µg/L	2,628	2,615	<25	<25	2,300	2,096	782	421	2,703 2,705	2,619 2,647	<25 <25	655 650	2,533	2,583	75	1,780	1,910	<25	<25
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	2,443	<25	<25	-	-	-	-
Mn (total)	µg/L	127	982	39.7	22.2	102	1,098	314	219	128 125	1,181 1,171	80.2 79.0	292 290	128	1,222	93.1	120	1,344	21.7	28.6
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	127	60.1	81.9	-	-	-	-

Analytical Results from Long Term Sampling at BSLMHP, MN (Continued)

Sampling Date		03/29/06[a]			04/05/06[b]				04/12/06[c]				04/19/06				04/24/06[e]		
Sampling Location / Parameter	Unit	IN	AC	TT	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TT
Stroke Length	%	45			45				45				45				45		
Disc No./BW Frequency	No./gal	6/916			6/916				6/916				6/916				6/916		
Alkalinity (as $CaCO_3$)	mg/L	352	369	356	356	360	360	360	NA[d]	NA[d]	NA[d]	NA[d]	392	384	388	375	375	379	375
Fluoride	mg/L	0.2	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	0.2
Sulfate	mg/L	<1	<1	<1	-	-	-	-	-	-	-	-	-	-	-	-	<1	<1	<1
Nitrate (as N)	mg/L	0.1	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05
P (total) (as P)	µg/L	533	584	43.0	603	440	29.6	29.1	517	457	30.9	54.9	520	451	39.4	38.0	533	525	196
Silica (as SiO_2)	mg/L	24.2	24.5	23.7	23.5	23.9	23.5	23.6	NA[d]	NA[d]	NA[d]	NA[d]	23.0	23.6	23.0	24.3	22.7	23.8	23.3
Turbidity	NTU	36.0	7.5	1.0	35.0	6.4	1.1	1.4	NA[d]	NA[d]	NA[d]	NA[d]	32.0	7.7	0.2	0.3	33.0	7.3	1.0
TOC	mg/L	2.9	2.9	2.7	-	-	-	-	-	-	-	-	-	-	-	-	3.0	3.0	2.8
pH	S.U.	7.3	7.3	7.3	7.3	7.3	7.4	7.3	7.3	7.2	7.3	7.3	7.2	7.3	7.3	7.3	7.3	7.3	7.3
Temperature	^0C	10.1	9.8	10.2	10.4	10.5	10.4	10.4	10.5	10.8	10.8	10.8	10.6	10.6	10.8	10.7	10.8	10.8	10.9
DO	mg/L	1.1	1.0	1.0	1.0	0.9	1.1	1.0	0.9	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	0.9	1.0
ORP	mV	-43	62	68	-39	69	71	74	-42	71	73	74.1	-46	64	70	72	-51	74	79
Total Hardness (as $CaCO_3$)	mg/L	323	309	304	-	-	-	-	-	-	-	-	-	-	-	-	314	313	317
Ca Hardness (as $CaCO_3$)	mg/L	191	180	176	-	-	-	-	-	-	-	-	-	-	-	-	196	196	198
Mg Hardness (as $CaCO_3$)	mg/L	133	129	128	-	-	-	-	-	-	-	-	-	-	-	-	118	118	119
As (total)	µg/L	30.2	29.9	3.4	36.1	26.8	3.2	3.1	32.0	28.5	3.9	5.4	33.9	27.7	3.3	3.0	31.2	30.5	12.1
As (soluble)	µg/L	27.9	2.8	2.5	-	-	-	-	-	-	-	-	-	-	-	-	27.7	1.8	1.9
As (particulate)	µg/L	2.3	27.1	0.8	-	-	-	-	-	-	-	-	-	-	-	-	3.5	28.7	10.3
As (III)	µg/L	26.5	0.3	0.4	-	-	-	-	-	-	-	-	-	-	-	-	24.8	<0.1	<0.1
As (V)	µg/L	1.4	2.5	2.1	-	-	-	-	-	-	-	-	-	-	-	-	2.9	1.7	1.8
Fe (total)	µg/L	3,008	2,954	62	2,659	2,180	<25	<25	2,969	2,647	65	190	2,664	2,429	<25	<25	3,015	3,019	973
Fe (soluble)	µg/L	3,000	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-	2,959	<25	<25
Mn (total)	µg/L	133	1,088	156	119	807	114	116	131	830	128	186	123	888	117	125	141	1,255	483
Mn (soluble)	µg/L	131	54.3	132	-	-	-	-	-	-	-	-	-	-	-	-	141	15.3	60.8

(a) Operator on vacation between 03/13/06 to 03/24/06. (b) Onsite water quality parameters taken on 04/06/06. (c) Onsite water quality parameters taken on 04/13/06. (d) Samples lost. (e) Onsite water quality parameters taken on 04/26/06.

Analytical Results from Long Term Sampling at BSLMHP, MN (Continued)

Sampling Date		05/02/06[(a)]				05/08/06				05/16/06[(b)]				05/24/06			05/31/06			
Sampling Location Parameter	Unit	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TT	IN	AC	TA/TB	TC/TD
Stroke Length	%	45				45				45				45			45			
Disc No./BW Frequency	No./gal	6/916				6/916				6/916				6/916			6/916			
Alkalinity (as $CaCO_3$)	mg/L	362	379	362	350	358	362	358	358	355 338	351 351	355 376	351 343	356	365	361	388	362	362	358
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	0.2	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-
P (total) (as P)	µg/L	442	419	36.9	163	445	434	23.6	22.6	496 482	471 472	14.0 20.7	18.6 13.7	521	504	32.1	432	422	53.8	54.7
Silica (as SiO_2)	mg/L	24.2	24.6	23.6	23.7	24.5	24.2	24.3	25.0	25.1 25.1	24.9 25.1	24.8 24.7	24.6 25.1	24.4	23.9	24.2	22.7	23.6	23.1	23.7
Turbidity	NTU	33.0	7.2	0.8	4.3	34.0	6.7	0.1	0.3	30.0 30.0	6.7 5.5	0.3 0.2	0.1 0.2	34.0	7.9	0.6	29.0	6.6	0.4	0.3
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	3.1	3.0	3.0	-	-	-	-
pH	S.U.	7.3	7.3	7.3	7.3	7.3	7.4	7.4	7.3	7.4	7.3	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Temperature	^0C	10.6	10.8	10.8	10.8	10.3	10.5	10.4	10.4	10.2	10.4	10.5	10.4	10.4	10.5	10.5	10.6	10.8	10.8	10.8
DO	mg/L	0.9	0.9	1.0	1.0	1.0	1.0	1.0	0.9	1.0	0.9	0.9	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0
ORP	mV	-47	69	72	74	-52	73	67	69	-47	66	68	70	-48	66	71	-53	78	79	79
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	338	256	307	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	200	145	179	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	138	111	128	-	-	-	-
As (total)	µg/L	27.0	25.6	3.4	10.5	26.0	25.4	2.6	2.6	26.6 25.5	25.5 25.2	2.7 2.9	2.6 2.6	31.0	35.9	3.1	24.3	23.5	2.4	2.6
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	29.4	3.1	2.9	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	1.6	32.8	0.2	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	22.2	0.2	0.7	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	7.2	2.9	2.2	-	-	-	-
Fe (total)	µg/L	2,561	2,476	80	867	2,626	2,656	<25	<25	2,942 2,866	2,822 2,811	<25 41	<25 <25	3,005	2,329	<25	2,395	2,235	<25	33
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	2,632	<25	<25	-	-	-	-
Mn (total)	µg/L	118	982	128	398	128	1,076	49.8	60.0	133 132	1,411 1,417	91.1 105	92.9 96.2	126	1,497	38.2	120	1,007	19.0	31.6
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	120	11.2	36.7	-	-	-	-

(a) Onsite water quality parameters taken on 05/03/06. (b) Onsite water quality parameters taken on 05/17/06.

Analytical Results from Long Term Sampling at BSLMHP, MN (Continued)

Sampling Date		06/08/06[a]				06/13/06[b]				06/21/06			06/27/06[f]				07/05/06			
Sampling Location / Parameter	Unit	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TT	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD
Stroke Length	%	45				45				40			40				40			
Disc No./BW Frequency	No./gal	6/916				6/916				6/916			6/916				6/916			
Alkalinity (as $CaCO_3$)	mg/L	376	355	363	368	378	369	369	359	367	363	359	358	362	358	358	359	368	363	359
Fluoride	mg/L	-	-	-	-	-	-	-	-	0.3	0.3	0.3	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	<1	<1	<1	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-
P (total) (as P)	µg/L	311	261	47.4	24.8	324	225	50.0	55.4	131	146	52.3	311	261	50.2	43.5	174	237	40.2	41.0
Silica (as SiO_2)	mg/L	24.2	24.6	24.3	24.8	27.1	25.8	26.4	25.8	22.6	23.2	22.4	25.8	26.2	25.9	25.9	24.5	24.8	23.7	23.6
Turbidity	NTU	11.0	6.9	2.8	2.4	11.0	9.3	7.0	6.2	3.9	9.7	1.8	18.0	6.4	2.7	2.7	4.2	7.3	6.0	6.0
TOC	mg/L	-	-	-	-	-	-	-	-	NA[c]	NA[c]	NA[c]	-	-	-	-	-	-	-	-
pH	S.U.	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	NA[d]	NA[d]	NA[d]	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Temperature	^0C	10.5	10.6	10.7	10.7	10.4	10.6	10.8	10.7	NA[d]	NA[d]	NA[d]	10.8	10.8	10.8	10.6	10.9	10.9	10.9	10.8
DO	mg/L	1.0	1.1	1.1	1.1	0.9	1.0	1.0	1.0	NA[d]	NA[d]	NA[d]	1.0	1.0	1.0	1.0	0.9	1.1	1.0	1.0
ORP	mV	-44	67	69	71	-50	66	68	66	NA[d]	NA[d]	NA[d]	-41	75	78	81	-49	79	80	81
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	342	331	346	-	-	-	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	202	195	204	-	-	-	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	139	136	142	-	-	-	-	-	-	-	-
As (total)	µg/L	25.0	23.6	5.7	4.0	30.5	25.3	5.8	6.2	19.9	20.3	5.0	25.8	21.1	4.7	4.4	23.5	25.8	4.8	5.1
As (soluble)	µg/L	-	-	-	-	-	-	-	-	15.3	8.6	4.7	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	4.6	11.7	0.3	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	12.8	0.2	0.2	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	2.5	8.4	4.5	-	-	-	-	-	-	-	-
Fe (total)	µg/L	1,971	1,684	149	8.5	1,605	1,016	<25	<25	600	670	<25	1,677	1,427	<25	<25	963	1,407	<25	<25
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	127	<25	<25	-	-	-	-	-	-	-	-
Mn (total)	µg/L	123	1,489	413	178	165	1,652	459	486	130	1,500	127	141	1,181	210	218	134	1,908	386	395
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	124	705	161	-	-	-	-	-	-	-	-

(a) Onsite water quality parameters taken on 06/07/06. (b) Onsite water quality parameters taken on 06/14/06. (c) TOC samples failed QC and were not reported. (d) Onsite water quality parameters not taken by operator. (e) Results were outliers and not reported. (f) Onsite water quality parameters taken on 06/28/06.

Analytical Results from Long Term Sampling at BSLMHP, MN (Continued)

Sampling Date		07/12/06[a]				07/18/06			07/26/06				08/02/06				08/08/06			
Sampling Location / Parameter	Unit	IN	AC	TA/TB	TC/TD	IN	AC	TT	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD	IN	AC	TA/TB	TC/TD
Stroke Length	%	40				40			40				24				24			
Disc No./BW Frequency	No./gal	6/916				6/916			6/916				6/916				6/916			
Alkalinity (as $CaCO_3$)	mg/L	369	NA[a]	369	356	357	357	361	367	362	362	362	362	362	354	358	349	365	357	357
Fluoride	mg/L	-	-	-	-	0.2	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	<1	<1	<1	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-
P (total) (as P)	µg/L	135	181	50.1	51.2	126	136	48.8	188	206	54.3	58.9	117	171	44.4	48.1	NA[c]	307	40.2	43.5
Silica (as SiO_2)	mg/L	23.6	23.2	23.6	23.3	22.9	23.0	23.4	24.0	23.4	23.8	24.4	23.6	23.5	22.2	23.2	24.3	23.0	22.9	22.5
Turbidity	NTU	2.7	6.8	0.3	0.2	2.5	9.0	6.4	4.3	4.5	0.2	0.2	1.5	8.0	0.6	0.3	13.0	11.0	0.2	0.2
TOC	mg/L	-	-	-	-	3.1	2.9	2.9	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]
Temperature	°C	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]
DO	mg/L	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]
ORP	mV	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	279	292	284	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	162	172	167	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	116	120	117	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L	19.5	20.0	12.7	11.8	19.1	18.6	5.2	24.7	26.5	7.4	7.9	21.7	24.2	7.8	8.0	NA[c]	25.1	6.6	7.0
As (soluble)	µg/L	-	-	-	-	16.5	8.0	5.2	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	2.6	10.6	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	14.0	0.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	2.5	7.7	4.9	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	617	882	<25	<25	546	633	<25	911	1,001	<25	<25	478	796	<25	<25	NA[c]	1,837	<25	<25
Fe (soluble)	µg/L	-	-	-	-	148	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	118	655	289	303	122	2,076	499	131	525	2.5	5.2	119	246	2.3	7.8	139	337	10.6	13.5
Mn (soluble)	µg/L	-	-	-	-	122	1,075	490	-	-	-	-	-	-	-	-	-	-	-	-

(a) Samples lost. (b) Operator did not take water quality parameters. (c) Samples were outliers and were not reported.

Analytical Results from Long Term Sampling at BSLMHP, MN (Continued)

Sampling Date		08/14/06[a]			08/22/06[b]				09/06/06			09/20/06				10/04/06		
Sampling Location / Parameter	Unit	IN	AC	TT	IN	AC	TA/TB	TC/TD	IN	AC	TT	IN	AC	TA/TB	TC/TD	IN	AC	TT
Stroke Length	%	24			24				24			24				24		
Disc No./BW Frequency	No./gal	6/916			6/916				6/916			6/916				6/916		
Alkalinity (as $CaCO_3$)	mg/L	362	345	392	396	384	389	378	394	390	392	375	379	379	382	380	385	390
Fluoride	mg/L	0.1	0.2	0.2	-	-	-	-	0.1	0.2	0.1	-	-	-	-	0.3	0.3	0.3
Sulfate	mg/L	<1	<1	<1	-	-	-	-	<1	<1	<1	-	-	-	-	<1	<1	<1
Nitrate (as N)	mg/L	0.1	<0.05	<0.05	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	<0.05	<0.05	<0.05
P (total) (as P)	µg/L	322	320	36.7	335	342	50.1	57.3	313	300	45.0	284	286	36.6	41.3	350	344	40.3
Silica (as SiO_2)	mg/L	23.6	23.0	23.9	23.7	23.2	23.2	23.7	22.4	22.1	22.7	24.4	24.2	24.4	23.9	23.8	23.2	22.9
Turbidity	NTU	18.0	5.8	0.3	12.0	5.6	0.2	0.3	14.0	1.2	0.4	16.0	6.0	0.3	0.4	14.0	6.9	0.5
TOC	mg/L	2.3	2.3	2.8	-	-	-	-	3.2	3.0	2.9	-	-	-	-	3.3	3.2	3.0
pH	S.U.	7.1	7.1	7.1	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	NA[c]	NA[c]	NA[c]
Temperature	^0C	10.5	10.4	10.6	11.1	11.0	11.0	11.0	10.6	10.6	10.6	10.0	10.2	10.0	10.0	NA[c]	NA[c]	NA[c]
DO	mg/L	2.2	1.9	1.7	2.0	2.3	1.9	2.1	2.2	2.1	2.0	1.2	2.1	2.0	2.0	NA[c]	NA[c]	NA[c]
ORP	mV	-7	103	109	2	174	171	169	-23	403	336	-12	370	334	299	NA[c]	NA[c]	NA[c]
Total Hardness (as $CaCO_3$)	mg/L	329	329	320	-	-	-	-	308	305	309	-	-	-	-	327	325	299
Ca Hardness (as $CaCO_3$)	mg/L	202	200	193	-	-	-	-	180	179	181	-	-	-	-	192	189	170
Mg Hardness (as $CaCO_3$)	mg/L	126	129	126	-	-	-	-	128	126	128	-	-	-	-	135	136	129
As (total)	µg/L	28.5	28.0	4.6	25.7	25.3	5.0	5.3	22.2	21.7	5.8	22.9	23.1	6.4	6.3	28.1	26.8	5.7
As (soluble)	µg/L	24.2	4.5	4.0	-	-	-	-	21.8	4.1	5.6	-	-	-	-	26.4	5.0	5.6
As (particulate)	µg/L	4.4	23.5	0.5	-	-	-	-	0.3	17.6	0.2	-	-	-	-	1.7	21.8	0.1
As (III)	µg/L	20.4	0.7	0.4	-	-	-	-	19.8	0.3	1.6	-	-	-	-	21.5	0.4	3.7
As (V)	µg/L	3.8	3.8	3.6	-	-	-	-	2.0	3.8	4.0	-	-	-	-	4.9	4.6	1.9
Fe (total)	µg/L	1,845	1,792	<25	1,474	1,522	<25	<25	1,514	1,484	<25	1,692	1,651	<25	<25	1,481	1,433	<25
Fe (soluble)	µg/L	1,683	<25	<25	-	-	-	-	1,264	<25	<25	-	-	-	-	1,419	<25	<25
Mn (total)	µg/L	141	1,247	12.1	119	924	23.6	21.9	134	1,385	185	122	1,013	84.0	76.5	124	997	88.4
Mn (soluble)	µg/L	138	177	12.6	-	-	-	-	134	264	184	-	-	-	-	128	157	86.2

(a) Onsite water quality parameters taken on 08/16/06. (b) Onsite water quality parameters taken on 08/24/06. (c) Onsite water quality parameters not taken.