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Arsenic Removal from Drinking Water by Iron Removal USEPA Demonstration Project at Climax, MN Six-Month Evaluation Report

by

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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 first six months of the arsenic removal treatment technology demonstration project at the Climax, MN site. 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 simplicity of required system operation and maintenance (O&M) and operator's skills, and (4) the cost-effectiveness of the technology. The project also is characterizing water in the distribution system and process residuals produced by the treatment system.

The Macrolite® FM-236-AS arsenic removal system at the Climax, MN site consisted of two 42-inch-diameter by 72-inch-tall contact tanks (345 gal) and two 36-inch-diameter by 72-inch-tall pressure vessels (264 gal), each containing 14 ft^3 of Macrolite® media. The design flowrate was 140 gal per minute (gpm), which yielded 5 min of contact time prior to pressure filtration. From August 11, 2004 through February 28, 2005, the system operated for a total of 1,075 hrs at approximately 5.3 hrs per day. Based on the totalizer to treatment readings, the system treated approximately 6,758,000 gal of water with an average daily water demand of 34,850 gal during this time period. The system operated in the service mode within the flow and pressure specifications provided by the vendor. During this time period, however, operational issues were noted with the automated backwash process that led to relatively frequent backwash failure conditions as discussed in this report.

Total arsenic concentrations in the source water ranged from 32.1 to 51.4 μg/L with As(III) being the predominating species at an average concentration of 35.5 μg/L. Prechlorination was used to oxidize As(III) to As(V) and promote the precipitation of iron solids prior to the Macrolite® pressure filtration. From August 11, 2004 to January 3, 2005, the total arsenic levels in the treated water ranged from 9.7 to 19 μg/L and averaged 14.1 μg/L, indicating that the natural iron content of the water was not high enough for sufficient arsenic removal to below 10 μg/L. The natural soluble iron concentrations in the raw water varied from 342 to 520 μg/L and averaged 455 μg/L. This corresponds to an iron:arsenic ratio of 12:1 given the average soluble iron and soluble arsenic levels in the source water. Supplemental iron addition using ferric chloride was subsequently initiated on January 3, 2005 in order to provide sufficient iron for effective arsenic removal. After iron addition at a target dose of 0.5 mg/L, total arsenic levels in the treated water averaged 6.0 μg/L. However, a slight increase in iron leakage from the Macrolite® filters was noted with total iron levels (existing solely as particulates) in the treated water ranging from <25 to 122 μg/L.

During this time period, the rate of backwash water production ranged from 2.2% to 2.4% of the treated water production. Prior to the iron addition, soluble arsenic concentrations in the backwash water ranged from 12.3 to 21.6 μg/L and soluble iron concentrations ranged from <25 to 39.9 μg/L. After iron addition, soluble arsenic concentrations decreased and ranged from 6.4 to 9.2 μg/L, while soluble iron concentrations increased and ranged from 27.3 to 148 μg/L.

Comparison of the distribution system sampling results before and after the system operation showed a decrease in the arsenic levels at all three sampling locations. Arsenic concentrations in the baseline samples ranged from 21.8 to 52.3 μg/L. Since the treatment system startup, arsenic levels in the distribution samples decreased from 11.3 to 17.0 μg/L before iron addition to 5.9 to 11.8 μg/L after iron addition. Neither lead nor copper concentrations at the sample sites appeared to have been affected by the operation of the system.

The capital investment cost was $249,081, which included $137,970 for equipment, $39,344 for engineering, and $71,767 for installation. Using the system's rated capacity of 140 gpm (201,600 gallons per day [gpd]), the capital cost was $1,779 per gpm ($1.24 per gpd) and equipment-only cost was $986 per gpm ($0.68 per gpd). These calculations did not include the cost of a building addition to house the treatment system.

O&M costs for the Macrolite® FM-236-AS system included only incremental costs associated with the chemical supply, electricity, and labor. O&M costs were estimated in this report at $0.27/1,000 gal and will be refined at the end of the one-year evaluation period.

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ABBREVIATIONS AND ACRONYMS

AAL	American Analytical Laboratories
Al	aluminum
As	arsenic
BTU-hr	British Thermal Units per hour
Ca	calcium
Cl	chlorine
CRF	capital recovery factor
Cu	copper
DO	dissolved oxygen
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
HDPE	high-density polyethylene
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
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
ORD	Office of Research and Development

ORP	oxidation-reduction potential
PE	professional engineer
P&ID	piping and instrumentation diagrams
PLC	programmable logic controller
psi	pounds per square inch
PVC	polyvinyl chloride
QA	quality assurance
QAPP	quality assurance project plan
QA/QC	quality assurance/quality control
RPD	relative percent difference
Sb	antimony
SDWA	Safe Drinking Water Act
TBD	to be determined
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
TOC	total organic carbon
V	vanadium

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The authors wish to extend their sincere appreciation to the staff of the Water Department in Climax, MN. The Climax, MN staff monitored the treatment system daily and collected samples from the treatment system and distribution system on a regular schedule throughout this reporting period. This performance evaluation would not have been possible without their efforts.

Section 1.0: INTRODUCTION

1.1 Background

The Safe Drinking Water Act (SDWA) mandates that United States Environmental Protection Agency (EPA) identify and regulate drinking water contaminants that may have adverse human health effects and that are known or anticipated to occur in public water supply systems. In 1975 under the SDWA, EPA established a maximum contaminant level (MCL) for arsenic at 0.05 mg/L. Amended in 1996, the SDWA required that EPA develop an arsenic research strategy and publish a proposal to revise the arsenic MCL by January 2000. On January 18, 2001, EPA finalized the arsenic MCL at 0.01 mg/L (EPA, 2001). In order to clarify the implementation of the original rule, EPA revised the rule text on March 25, 2003 to express the MCL as 0.010 mg/L (10 µg/L) (EPA, 2003). The final rule 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 the first round of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 sites from a list of 115 sites to be the host sites for the demonstration studies. The water system in Climax, MN was selected as one of the 17 Round 1 host sites for the demonstration program.

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the 17 host sites. EPA received 70 technical proposals for the 17 host sites, with each site receiving from one to six proposals. In April 2003, an independent technical review 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. Kinetico's Macrolite® pressure filtration process was selected for the Climax, MN facility.

1.2 Treatment Technologies for Arsenic Removal

The technologies selected for the 12 Round 1 EPA arsenic removal demonstration host sites include nine adsorptive media systems, one anion exchange system, one coagulation/filtration system, and one process modification with iron addition. Table 1-1 summarizes the locations, technologies, vendors, and key source water quality parameters (including arsenic, iron, and pH) of the 12 demonstration sites. The technology selection and system design for the 12 demonstration sites have been reported in an EPA report (Wang et al., 2004) posted on an EPA Web site (http://www.epa.gov/ORD/NRMRL/arsenic/resource.htm).

1.3 Project Objectives

The objective of the Round 1 arsenic demonstration program is to conduct 12 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 simplicity of required system operation and maintenance (O&M) and operator's skill levels.
- Determine the cost-effectiveness of the technologies.
- Characterize process residuals produced by the technologies.

This report summarizes the results gathered during the first six months of the Kinetico Macrolite® FM-236-AS system operation from August 11, 2004 through February 28, 2005. The types of data collected include system operational data, water quality data (both across the treatment train and in the distribution system), residuals characterization data, and capital and preliminary O&M cost data.

Table 1-1. Summary of Arsenic Removal Demonstration Technologies and Source Water Quality Parameters

Demonstration Site	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
				As (µg/L)	Fe (µg/L)	pH
Bow, NH	AM (G2)	ADI	70[(a)]	39	<25	7.7
Rollinsford, NH	AM (E33)	AdEdge	100	36[(b)]	46	8.2
Queen Anne's County, MD	AM (E33)	STS	300	19[(b)]	270[(c)]	7.3
Brown City, MI	AM (E33)	STS	640	14[(b)]	127[(c)]	7.3
Climax, MN	C/F	Kinetico	140	39[(b)]	546[(c)]	7.4
Lidgerwood, ND	SM	Kinetico	250	146[(b)]	1,325[(c)]	7.2
Desert Sands MDWCA, NM	AM (E33)	STS	320	23[(b)]	39	7.7
Nambe Pueblo, NM	AM (E33)	AdEdge	145	33	<25	8.5
Rimrock, AZ	AM (E33)	AdEdge	90[(a)]	50	170	7.2
Valley Vista, AZ	AM (AAFS50)	Kinetico	37	41	<25	7.8
Fruitland, ID	IX	Kinetico	250	44	<25	7.4
STMGID, NV	AM (GFH)	USFilter	350	39	<25	7.4

AM = adsorptive media process; C/F = coagulation/filtration process;
GFH = granular ferric hydroxide; IX = ion exchange process; SM = system modification;
MDWCA = Mutual Domestic Water Consumer's Association;
STMGID = South Truckee Meadows General Improvement District; STS = Severn Trent Services.
(a) Due to system reconfiguration from parallel to series operation, the design flowrate is reduced by 50%.
(b) Arsenic exists mostly as As(III).
(c) Iron exists mostly as soluble Fe(II).

Section 2.0 CONCLUSIONS

Based on the information collected during the first six months of 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:

- Before supplemental iron addition was initiated, total arsenic levels in the treated water averaged 14.1 μg/L, indicating that the natural iron content of the water was not high enough for sufficient arsenic removal to below 10 μg/L. After supplemental iron addition was implemented, total arsenic levels in the treated water averaged 6.0 μg/L.

- The natural soluble iron concentrations in the raw water averaged 455 μg/L. Supplemental iron was added at a dose of 0.4 to 0.8 mg/L with an average value of 0.65 mg/L (as Fe). Total iron concentrations in the treated water ranged from <25 μg/L to 66.4 μg/L before supplemental iron addition. Total iron concentrations in the treated water ranged from <25 μg/L to 122 μg/L after supplemental iron addition. The iron in the treated water existed primarily as particulate iron, indicating some leakage from the filter.

- Total manganese had an average concentration of 138.5 μg/L in the raw water. Before supplementation iron addition, manganese in the treated water averaged 70.6 μg/L. After supplemental iron addition, manganese in the treated water averaged 63.8 μg/L. This represents a removal rate between 49% and 54% for manganese.

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

- Operational issues were experienced during system shakedown related to higher than expected pressure drops across the treatment system. This was addressed through modification of the flow restrictors on each filter vessel. In addition, some backwash issues were experienced due to turbidimeter maintenance problems and inadequate field settings for the Macrolite® filter backwash.

- There was no unscheduled downtime during the first six months of operation.

- Under normal operating conditions, the skill requirements to operate the system were minimal, with a typical daily demand on the operator of 30 min. Other skills needed included performing O&M activities such as cleaning the turbidimeter photo cell, monitoring backwash operational issues, and working with the vendor to troubleshoot and perform minor on-site repairs.

Process residuals produced by the technology:

- Residuals produced by the operation of the treatment system included backwash water. Prior to the iron addition, the soluble arsenic concentrations in the backwash water ranged from 12.3 to 21.6 μg/L and the soluble iron concentrations ranged from <25 to 39.9 μg/L. After iron addition, the soluble arsenic concentrations decreased and ranged from 6.4 to 9.2 μg/L, while the soluble iron concentrations increased and ranged from 27.3 to 148 μg/L.

Cost-effectiveness of the technology:

- Using the system's rated capacity of 140 gallons per minute (gpm) (201,600 gallons per day [gpd]), the capital cost was $1,779 per gpm ($1.24 per gpd) and equipment-only cost was $986 per gpm ($0.68 per gpd). These calculations did not include the cost of the building construction.

- Based on a 30-min-per-day time commitment and a labor rate of $21/hr, the labor cost was $0.22/1,000 gal of water treated. The total O&M cost including labor was approximately $0.27/1,000 gal. The O&M costs included estimates of the projected chemical usage, electrical usage, and labor rates and will be verified during the next reporting period.

Section 3.0: MATERIALS AND METHODS

3.1 General Project Approach

Following the pre-demonstration activities summarized in Table 3-1, the performance evaluation of the Macrolite® treatment system began on August 11, 2004. Table 3-2 summarizes the types of data collected and/or considered as part of the technology evaluation process. The overall performance of the system was determined based on its ability to consistently remove arsenic to the target MCL of 10 μg/L; this was monitored through the collection of weekly and monthly water samples across the treatment train. The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of equipment 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. Completion Dates of Pre-Demonstration Study Activities

Activity	Date
Introductory Meeting Held	07/30/03
Request for Quotation Issued to Vendor	07/30/03
Vendor Quotation Submitted to Battelle	10/02/03
Purchase Order Completed and Signed	10/16/03
Letter of Understanding Issued	09/09/03
Letter Report Issued	10/20/03
Engineering Package Submitted to Minnesota Department of Health (MDH)	02/09/04
Permit Issued by MDH	06/22/04
Building Construction Initiated	05/19/04
Final Study Plan Issued	07/12/04
Building Construction Completed	07/30/04
Macrolite® Unit Shipped by Kinetico	06/17/04
Macrolite® Unit Delivered to Climax, MN	06/21/04
System Installation Completed	07/30/04
System Shakedown Completed	08/11/04
Performance Evaluation Begun	08/11/04

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

Evaluation Objectives	Data Collection
Performance	-Ability to consistently meet 10 μg/L of arsenic in effluent
Reliability	-Unscheduled downtime for system -Frequency and extent of repairs to include man hrs, problem description, description of materials, and cost of materials
Simplicity of Operation and Operator Skill	-Pre- and post-treatment requirements -Level of system automation for data collection and system operation -Staffing requirements including number of operators and man hrs -Task analysis of preventive maintenance to include man hrs per month and number and complexity of tasks -Chemical handling and inventory requirements -General knowledge needed of safety requirements and chemical processes
Cost-Effectiveness	-Capital costs including equipment, engineering, and installation -O&M costs including chemical and/or media usage, electricity, and labor
Residual Management	-Quantity of the residuals generated by the process -Characteristics of the aqueous and solid residuals

Simplicity of the system operation and the level of operator skill required were evaluated based on a combination of quantitative data and qualitative considerations, including any pre-treatment and/or post-treatment requirements, level of system automation, operator skill requirements, task analysis of the preventive maintenance activities, frequency of chemical and/or media handling and inventory requirements, and general knowledge needed for safety requirements and chemical processes. The staffing requirements for the system operation were recorded on a Daily Field Log Sheet.

The cost-effectiveness 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 the tracking of capital costs such as equipment, engineering, and installation costs, as well as O&M costs for chemical supply, electrical power use, and labor hrs. The capital costs have been reported in an EPA report (Chen et al., 2004) posted on an EPA Web site (http://www.epa.gov/ORD/NRMRL/arsenic/resource.htm).

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

3.2 System O&M and Cost Data Collection

The plant operator performed daily, weekly, and monthly system O&M and data collection. On a daily basis, the plant operator recorded system operational data, such as pressure, flowrate, totalizer readings, and hour meter readings on a Daily Field Log Sheet and conducted visual inspections to ensure normal system operations. In the event of problems, the plant operator would contact the Battelle Study Lead, who then would determine if Kinetico should be contacted for troubleshooting. The plant operator recorded all relevant information on the Repair and Maintenance Log Sheet. On a weekly basis, the plant operator measured temperature, pH, dissolved oxygen (DO), and oxidation-reduction potential (ORP), and recorded the data on a Weekly Water Quality Parameters Log Sheet. During the six-month study period, the system was backwashed automatically, except during the monthly backwash sampling events when the system was backwashed manually to capture the required backwash samples.

Capital costs for the Kinetico Macrolite® system consisted of costs for equipment, site engineering, and system installation. The O&M costs consisted primarily of costs for chemicals, electricity, and labor. Ferric chloride consumption was tracked on the Daily Field Log Sheet. The electricity use was tracked through a comparison of utility bills before and after the system became operational. Labor hrs for various activities, such as the routine system O&M, system troubleshooting and repair, and demonstration-related work, were tracked using an Operator Labor Hour Record. The routine O&M included activities such as filling field logs and performing system inspections. The demonstration-related work included activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead. The demonstration-related activities were recorded, but not used for the cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate the performance of the system, samples were collected from the source, treatment plant, distribution system, and filtration vessel backwash. Table 3-3 provides the sampling schedules and analytes measured during each sampling event. Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2003).

Table 3-3. Sample Collection Schedule and Analyses

Sample Type	Sample Locations[(a)]	No. of Samples	Frequency	Analytes	Date(s) Samples Collected
Source Water	At Wellhead (IN)	1	Once during the initial site visit	As(total), particulate As, As(III), As(V), Fe (total and soluble), Mn (total and soluble), Al (total and soluble), Na, Ca, Mg, V, Mo, Sb, Cl, F, SO_4, SiO_2, PO_4, TOC, and alkalinity.	07/30/03
Treatment Plant Water	At Wellhead (IN), After Contact Tanks (AC), After Tank A (TA), After Tank B (TB)	4	Weekly	On-site: pH, temperature, DO/ORP, and Cl_2 (free and total) (except at wellhead). Off-site: As (total), Fe (total), Mn (total), SiO_2, PO_4, turbidity, and alkalinity.	08/18/04, 08/24/04, 08/31/04, 09/14/04, 09/21/04, 09/28/04, 10/12/04, 10/19/04, 10/26/04, 11/09/04, 11/16/04, 12/07/04, 12/14/04, 01/11/05, 01/18/05, 01/25/05, 02/01/05, 02/16/05, 02/22/05
	At Wellhead (IN), After Contact Tanks (AC), and After Tanks A and B Combined (TT)	3	Monthly	On-site: pH, temperature, DO/ORP, and Cl_2 (free and total) (except at wellhead). Off-site: As(total), particulate As, As(III), As(V), Fe (total and soluble), Mn (total and soluble), Ca, Mg, F, NO_3, SO_4, SiO_2, PO_4, turbidity, and alkalinity.	08/11/04, 09/07/04, 10/05/04, 11/02/04, 11/30/04, 01/04/05, 02/08/05
Distribution Water	Three LCR Residences	3	Monthly	pH, alkalinity, As (total), Fe (total), Mn (total), Pb (total), and Cu (total)	Baseline Sampling[(b)] 01/28/04, 02/23/04 03/22/04, 04/27/04 Monthly Sampling: 08/31/04, 09/28/04 10/26/04, 11/30/04 12/14/04, 01/11/05 02/8/05
Backwash Water	At Backwash discharge line from Tanks A and B	2	Monthly	TDS, turbidity, pH, As (soluble), Fe (soluble), and Mn (soluble)	09/24/2004, 10/20/2004, 11/16/2004, 12/13/2004, 01/12/2005, 02/16/2005
Residual Sludge	At backwash discharge point	2-3	TBD	TCLP Metals As(Total)	TBD

(a) The abbreviation in each parenthesis corresponds to the sample location in Figure 4-6.
(b) Four baseline sampling events were performed before the system became operational.
TBD = to be determined.

3.3.1 Source Water Sample Collection. During the initial visit to the site, one set of source water samples was collected for detailed water quality analyses. The source water also was speciated for particulate and soluble As, iron (Fe), manganese (Mn), aluminum (Al), and As(III) and As(V). The sample tap was flushed for several min before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Arsenic speciation kits and containers for water quality samples were prepared as described in Section 3.4.

3.3.2 Treatment Plant Water Sample Collection. During the system performance evaluation study, water samples were collected across the treatment train by the plant operator. Samples were collected weekly on a four-week cycle. For the first three weekly events, treatment plant samples were collected at four locations (i.e., at the wellhead [IN], after the contact tanks [AC], after Tank A [TA], and after Tank B [TB]) and analyzed for the analytes listed under the weekly treatment plant analyte list in Table 3-3. For the fourth weekly event, treatment plant samples were collected for arsenic speciation at three locations (i.e., IN, AC, and after Tanks A and B combined [TT]) and analyzed for the analytes listed under the monthly treatment plant analyte list in Table 3-3.

3.3.3 Backwash Water Sample Collection. Two backwash water samples were collected during each of the six sampling events from the sample taps located at the backwash water effluent line from each vessel. Unfiltered samples were measured on-site for pH using a field pH meter and a 1-gal sample was sent to American Analytical Laboratories (AAL) for total dissolved solids (TDS) and turbidity measurements. Filtered samples using 0.45-µm disc filters were sent to Battelle's inductively coupled plasma-mass spectrometry (ICP-MS) laboratory for soluble As, Fe, and Mn analyses. Arsenic speciation was not performed for the backwash water samples.

3.3.4 Backwash Solid Sample Collection. Backwash solid samples were not collected in the initial six months of this demonstration. Two to three solid/sludge samples will be collected from the backwash discharge point at the site. A dipper (EPA III-1) or a scoop (EPA II-3) will be used for solid sample collection. The solid/sludge samples will be collected in glass jars and submitted to TCCI Laboratories for Toxicity Characteristic Leaching Procedure (TCLP) tests.

3.3.5 Distribution System Water Sample Collection. Samples were collected from the distribution system by the plant operator to determine the impact of the arsenic treatment system on the water chemistry in the distribution system; specifically, lead and copper levels. From January 2004 to April 2004, prior to the startup of the treatment system, four monthly baseline distribution system sampling events were conducted at three locations within the distribution system. Following the start-up of the arsenic adsorption system, 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 City's Lead and Copper Rule (LCR) sampling. Arsenic speciation was not performed for the distribution water samples. The samples collected at the LCR locations were taken following an instruction sheet developed according to the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The first draw sample was collected from a cold-water faucet that had not been used for at least six hrs to ensure that stagnant water was sampled. The sampler recorded the date and time of last water use before sampling and the date and time of sample collection for calculation of the stagnation time. Analytes for the baseline samples coincided with the monthly distribution system water samples as described in Table 3-3.

3.4 Sampling Logistics

All sampling logistics including arsenic speciation kits preparation, sample cooler preparation, and sample shipping and handling are discussed as follows:

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

Arsenic speciation kits were prepared in batches at Battelle laboratories according to the procedures detailed in Appendix A of the EPA-endorsed QAPP (Battelle, 2003).

3.4.2 Preparation of Sampling Coolers. All sample bottles were new and contained appropriate preservatives. Each sample bottle was taped with a pre-printed, colored-coded, and waterproof label. The sample label consisted of sample identification (ID), date and time of sample collection, sampler initials, location, sent to, analysis required, and preservative. The sample ID consisted of a two-letter code for a specific water facility, the sampling date, a two-letter code for a specific sampling location, and a one-letter code for the specific analysis to be performed. The sampling locations were color-coded for easy identification. For example, red, orange, yellow, green, and blue were used for IN, AC, TA, TB, and TT sampling locations. Pre-labeled bottles were placed in one of the plastic bags (each corresponding to a specific sampling location) in a sample cooler. When arsenic speciation samples were to be collected, an appropriate number of arsenic speciation kits also were included in the cooler.

When appropriate, the sample cooler was packed with bottles for the three distribution system sampling locations and/or the two backwash sampling locations (one for each vessel). In addition, a packet containing all sampling and shipping-related supplies, such as latex gloves, sampling instructions, chain-of-custody forms, prepaid Federal Express air bills, ice packs, and bubble wrap, also was placed in the cooler. Except for the operator's signature, the chain-of-custody forms and prepaid Federal Express air bills had already been completed with the required information. The sample coolers were shipped via Federal Express to the facility approximately one week prior to the scheduled sampling date.

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, sample custodians verified that all samples indicated on the chain-of-custody forms were included and intact. Sample label identifications were checked against the chain-of-custody forms and the samples were logged into the laboratory sample receipt log. Discrepancies were addressed with the field sample custodian, and the Battelle Study Lead was notified.

Samples for water quality analyses by Battelle's subcontract laboratories were packed in coolers at Battelle and picked up by a courier from either AAL (Columbus, OH) or TCCI Laboratories (New Lexington, OH). The samples for arsenic speciation analyses were stored at Battelle's ICP-MS Laboratory. 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 are described in detail in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2003). Field measurements of pH, temperature, and DO/ORP were conducted by the plant operator using a WTW Multi 340i handheld meter, which was calibrated prior to use following the procedures provided in the user's manual. The plant operator collected a water sample in a 400-mL, plastic beaker and placed the Multi 340i probe in the beaker until a stable measured value was reached. The plant operator also performed free and total chlorine measurements using Hach™ chlorine test kits.

Laboratory quality assurance/quality control (QA/QC) of all methods followed the guidelines provided in the QAPP (Battelle, 2003). Data quality in terms of precision, accuracy, method detection limit (MDL), and completeness met the criteria established in the QAPP, i.e., relative percent difference (RPD) of 20%, percent recovery of 80% to 120%, and completeness of 80%. The QA data associated with each analyte will be presented and evaluated in a QA/QC summary report to be prepared under separate cover and to be shared with the other 11 demonstration sites included in the Round 1 arsenic study.

Section 4.0: RESULTS AND DISCUSSION

4.1 Facility Description and Pre-Existing Treatment System Infrastructure

The water treatment system located on West Broadway in Climax, MN supplies drinking water to 264 community members. Figure 4-1 shows the pre-existing pump house at the facility. The water source is groundwater from two wells in a Quaternary Buried Artesian aquifer. Each well is 141 feet deep with 15 feet of slotted screen. Well No. 1 is 6 inches in diameter and has a 7.5 horsepower (hp) submersible pump with a capacity of 140 gpm. Well No. 2 is 8 inches in diameter and has a 10 hp submersible pump with a capacity of 160 gpm. These two wells are alternated every month to meet the peak daily demand of 105,000 gpd based on historic records. Both pumps are used during fire emergencies with a full capacity of 300 gpm. The treatment system originally consisted of a gas chlorine feed to reach a target chlorine residual level of 0.6 mg/L. The water also is fluoridated to a target level of 1.0 mg/L. Figure 4-2 shows the pre-existing wellhead and associated piping. The treated water is stored in a nearby water tower as shown in Figure 4-3.

4.1.1 Source Water Quality. Source water samples were collected on July 30, 2003 and subsequently analyzed for the analytes shown in Table 3-3. The results of the source water analyses, along with those provided by the facility to EPA for the demonstration site selection and those independently collected and analyzed by EPA, MDH, and the vendor are presented in Table 4-1.

As shown in Table 4-1, total arsenic concentrations in the source water ranged from 31 to 41 µg/L. Based on the July 30, 2003 sampling results, as much as 90% of the total arsenic, or 34.8 µg/L, was found to exist as As(III) and 10% existed as particulate As.

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

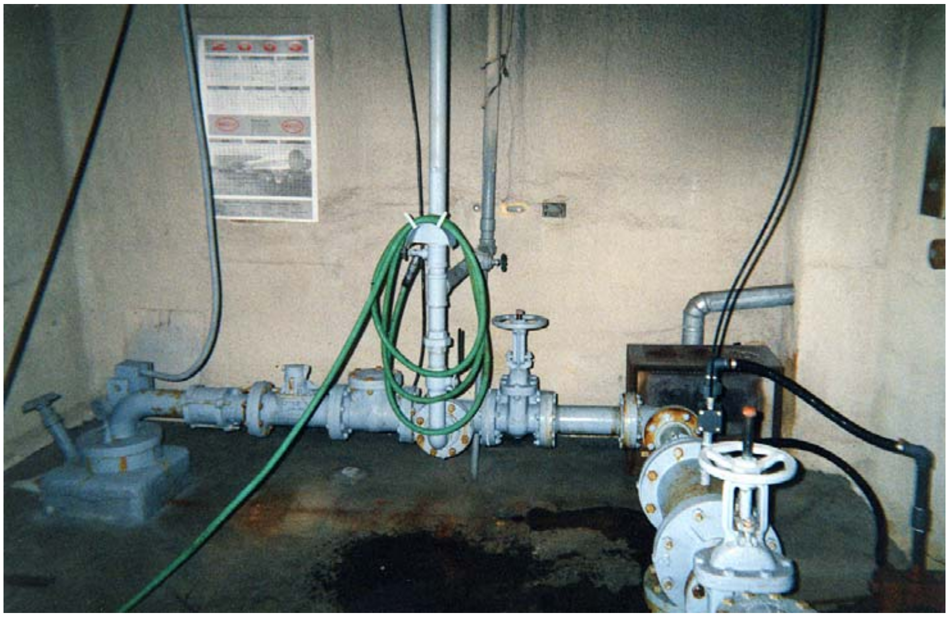

Figure 4-2. Pre-Existing Wellhead and Associated Piping

Figure 4-3. Climax, MN, Water Tower

Table 4-1. Climax, MN, Water Quality Data

Parameter	Unit	Utility Data	Vendor Data	EPA Data	Battelle Data	MDH Raw Water Data	MDH Treated Water Data
Date		Not Specified	Not Specified	10/16/02	07/30/03	2000-2003	2000-2003
pH	–	7.6	7.9	NS	7.4	NS	NS
Total Alkalinity	mg/L	325.0	332	328.2	304.0	NS	NS
Hardness (as $CaCO_3$)	mg/L	256.0	288	NS	227.6	NS	NS
Chloride	mg/L	180.0	180.1	183.0	190.0	NS	NS
Fluoride	mg/L	NS	0.45	NS	1.7	NS	0.46 to 1.6
Sulfate	mg/L	114.0	100	106.5	120.0	NS	110 to 120
Silica (as SiO_2)	mg/L	27.8[(a)]	29.9	28.0	27.3	NS	NS
Orthophosphate	mg/L	<0.065[(a)]	<0.1	NS	<0.10	NS	NS
TOC	mg/L	NS	NS	NS	<1.0	NS	NS
As (total)	μg/L	38	31	33	38.7	33 to 41	<1.0 to 36
As (total soluble)	μg/L	NS	NS	NS	34.6	NS	NS
As (particulate)	μg/L	NS	NS	NS	4.2	NS	NS
As(III)	μg/L	NS	NS	NS	34.8	NS	NS
As(V)	μg/L	NS	NS	NS	<0.1	NS	NS
Total Fe	μg/L	850[(a)]	820	850	546.3	NS	NS
Soluble Fe	μg/L	NS	NS	NS	540.4	NS	NS
Total Al	μg/L	NS	NS	NS	<10	NS	NS
Soluble Al	μg/L	NS	NS	NS	<10	NS	NS
Total Mn	μg/L	145[(a)]	170	149.3	128.3	NS	NS
Soluble Mn	μg/L	NS	NS	NS	130.0	NS	NS
Total V	μg/L	NS	NS	NS	0.4	NS	NS
Soluble V	μg/L	NS	NS	NS	0.4	NS	NS
Total Mo	μg/L	NS	NS	NS	8.9	NS	NS
Soluble Mo	μg/L	NS	NS	NS	8.7	NS	NS
Total Sb	μg/L	NS	NS	NS	<0.1	NS	<0.6
Soluble Sb	μg/L	NS	NS	NS	<0.1	NS	NS
Total Na	mg/L	170.0	175	180.9	177.2	NS	180 to 190
Total Ca	mg/L	74[(a)]	76	74.3	60.6	NS	NS
Total Mg	mg/L	25[(a)]	24	24.5	18.5	NS	NS

(a) Data provided by EPA.
NS = not sampled.

Iron concentrations in the source water ranged from 546 to 850 μg/L with almost all existing as soluble iron based on July 30, 2003 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). The results from the July 30, 2003 sampling event indicated that the soluble iron level was approximately 16 times the soluble arsenic level. Because the natural iron content in the source water was close to the target Fe/As ratio of 20:1 value, the initial plan was to operate the system without supplemental iron addition. The manganese levels were relatively elevated, ranging from 128.3 to 170 μg/L. The pH values ranged from 7.4 to 7.9, which were within the target range of 5.5 to 8.5 for the iron removal process. Hardness ranged from 228 to 288 mg/L, silica from 27 to 29 mg/L, and sulfate from 100 to 120 mg/L.

4.1.2 Distribution System and Treated Water Quality. The distribution system for Climax, MN is supplied by two wells, alternating on a monthly basis. The distribution system materials are primarily 6-inch polyvinyl chloride (PVC) pipe with ¾-inch PVC or copper pipe used at individual homes. The city conducts quarterly compliance sampling for coliform and fluoride and annual compliance sampling for arsenic. Prior to this demonstration project, the treatment system consisted of only a gas chlorine feed to reach a target chlorine residual level of 0.6 mg/L. The water also was fluoridated to a target level of approximately 1.0 mg/L with fluoride levels in the distribution system ranging from 0.5 to 1.6 mg/L (see Table 4-1). The historic As levels detected within the distribution system at several different sampling points, including residences, businesses, and at the treatment plant effluent, ranged from non-detect to 36 μg/L based on MDH treated water sampling data (see Table 4-1).

4.2 Treatment Process Description

The treatment train for the Climax system includes oxidation, co-precipitation/adsorption, and Macrolite® pressure filtration. Macrolite® is a low-density, spherical, and chemically inert ceramic media that is designed for a high-rate filtration up to 10 gpm/ft^2. The media, manufactured by Kinetico, is approved for use in drinking water applications under NSF Standard 61. The physical properties of Macrolite® are summarized in Table 4-2.

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

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

Figure 4-4 is a schematic and Figure 4-5 a photograph of the Macrolite® FM-236-AS Arsenic Removal System. The primary components consist of a chemical feed system for prechlorination and iron addition (one each), two contact tanks, two pressure filtration vessels, and associated pressure and flow instrumentation. The Macrolite® treatment system is fully automated with an operator interface, programmable logic controller (PLC), and modem housed in a central control panel. The control panel is connected to various instruments used to track system performance, including inlet and outlet pressure after each filter, system flowrate, backwash flowrate, and backwash turbidity with a Hach™ high range turbidimeter. All plumbing for the system is Schedule 80 PVC and the skidded unit is pre-plumbed with the necessary isolation valves, check valves, sampling ports, and other features. A 5-hp, 60-gal vertical air compressor also is included in the system. Table 4-3 summarizes the design features of the Macrolite® pressure filtration system.

Figure 4-6 presents a process flowchart, along with the sampling/analysis schedule, for the 140 gpm Macrolite® system. The major process steps and system components are presented as follows:

- **Oxidation** - The existing gas chlorine system was initially used for the oxidation of As(III) and Fe(II) in source water. Because the existing equipment malfunctioned, the gas chlorine system was replaced with a liquid sodium hypochlorite feed system on January 14, 2005.

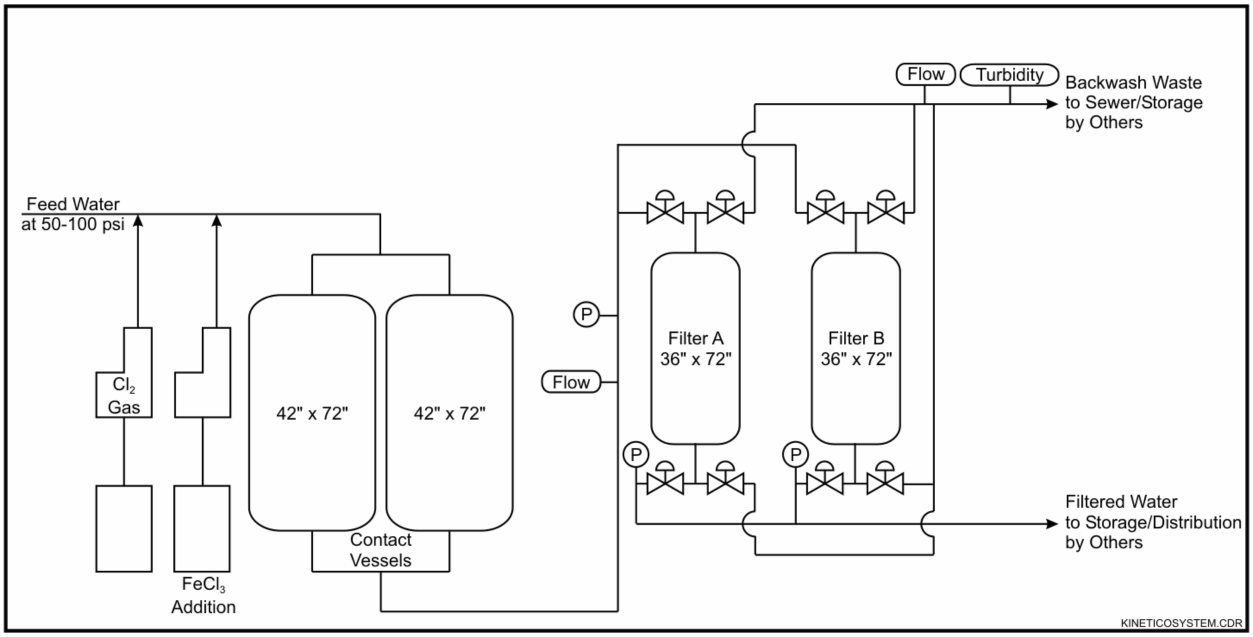

Figure 4-4. Process Schematic of the Macrolite® Pressure Filtration System

Figure 4-5. Photograph of the Macrolite® Pressure Filtration System

Table 4-3. Design Specifications for the Macrolite® FM-236-AS Pressure Filtration System

Parameter	Value	Remarks
Prechlorination Dosage (mg/L [as Cl_2])	1.2	Sodium hypochlorite system installed on 01/14/05. Prior to that date chlorine gas was used. The calculated chlorine demand based on arsenic, iron, and manganese in source water was 0.6 mg/L. Actual demand was higher due to the presence of ammonia in source water. Target free chlorine residual was 0.6 mg/L to distribution.
Iron Dosage (mg/L [as Fe])	0.5	Implemented on January 3, 2005
Contact Vessels		
Vessel Size (inch)	42 D × 72 H	345 gal each tank
No. Vessels	2	—
Contact Time (min/vessel)	5	—
Filtration Vessels		
Vessel Size (inch)	36 D × 72 H	264 gal each tank
No. Vessels	2	—
Configuration	Parallel	—
Media Quantity (ft^3/vessel)	14	24-inch bed depth of 40/60 mesh Macrolite® in each vessel
Media Type	Macrolite®	—
Filtration Rate (gpm/ft^2)	10	—
Pressure Drop (psi)	15	Across a clean bed
Backwash Initiating Pressure (psi)	20	Across bed at end of filter run
Throughput before Backwash (gal)	Variable	Based on PLC settings for pressure, run time, or standby set points.
Backwash Hydraulic Loading (gpm/ft^2)	8 to 10	—
Backwash Duration (min)	Variable	Based on PLC settings for minimum and maximum backwash times (e.g. 7 to 15 min from factory set points).
Wastewater Production (gal)	Variable	See above
System Design Flowrate (gpm)	140	—
Maximum Daily Production (gpd)	201,600	Based on peak flow, 24 hrs per day
Hydraulic Utilization (%)	52	Estimated based on peak daily demand[a]

(a) Based on a historic peak daily demand of 105,000 gpd

- **Co-Precipitation/Adsorption with Supplemental Iron Addition -** The system was operated without supplemental iron addition from August 11, 2004 to January 2, 2005. Beginning on January 3, 2005, an iron addition system was used to inject a target dose of 0.5 mg/L of iron after the prechlorination tap using a ferric chloride solution. The iron addition system included a day tank, a metering pump, and a scale. The working solution was prepared by adding 3 gal of a 35% ferric chloride stock solution into 47 gal of water.

- **Contact -** Two 345-gal contact tanks arranged in parallel were used to provide 5 min of contact time to facilitate the formation of iron flocs prior to filtration. The 42-inch-diameter by 72-inch-height contact tanks were constructed of fiberglass-reinforced plastic (FRP) and had 6-inch top and bottom flanges.

- **Pressure Filtration –** Pressure filtration involved downflow filtration through two vessels arranged in parallel. The 36-inch-diameter and 72-inch-height FRP vessels, equipped with 6-inch top and bottom flanges, were mounted on a polyurethane-coated

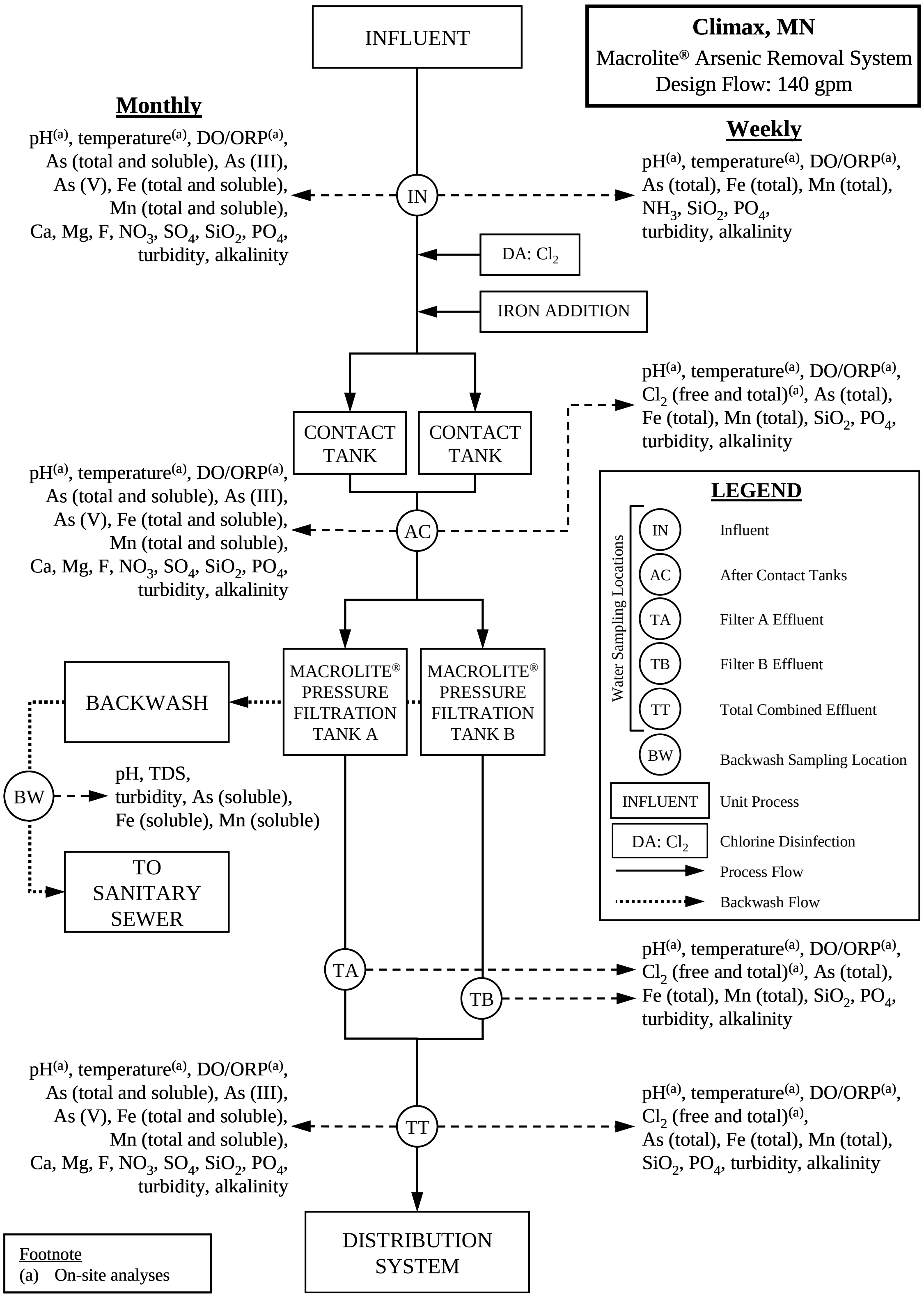

Figure 4-6. Process Flow Diagram and Sampling Locations

steel frame. Each vessel was filled with approximately 24 inches (14 ft^3) of 40/60 mesh Macrolite® media, which was underlain by a fine garnet fill layered 1 inch above the 0.006-inch slotted stainless steel wedge-wire underdrain. The flow through each vessel was regulated to less than 70 gpm using a flow-limiting device to prevent filter overrun or damage to the system. The normal system operation with both tanks would produce a total system flowrate of 140 gpm.

- **Backwash Operations -** At a 10 gpm/ft^2 hydraulic loading rate and 24-inch bed depth, the anticipated pressure drop was 15 pounds per square inch (psi) across a clean bed in service mode. As the pressure drop across the bed had reached 20 psi, the filter was automatically backwashed in an upflow configuration. The backwash might also be triggered by the length of time the unit had been in service and/or in stand-by mode (see Section 4.4.2 for more information). During backwash, the water in one of the filtration vessels was first drained from the vessel and the filter was then sparged with air for 2 min at a pressure of 100 psig. After a 5-min settling period, the filtration vessel was backwashed with treated water at a flowrate of approximately 55 gpm (8 gpm/ft^2) until the turbidity of the backwash water had reached a target threshold level of 6 nephelometric turbidity units (NTU) based on the factory setting. The backwash was conducted one vessel at a time and the resulting wastewater was sent to a sump and then to the sanitary sewer. After backwash, the filtration vessel underwent a filter-to-waste cycle for five min before returning to the service mode.

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 Kinetico and Widseth, Smith, and Nolting. The plans included diagrams and specifications for the Macrolite® FM-236-AS Arsenic Removal System, as well as drawings detailing the connections of the new unit to the pre-existing facility infrastructure. The plans were submitted to the MDH on February 9, 2005. After changes to the design were incorporated related to MDH comments received on March 22 and May 24, 2004, MDH granted its approval of the application on June 22, 2004. On November 23, 2004, an approval also was granted for the installation and startup of a supplemental ferric chloride chemical feed system.

4.3.2 Building Construction. The building construction was initiated on May 19, 2004 and the city was able to accommodate shipping and off-loading of the treatment system by June 21, 2004. A 22-ft × 24-ft building was built as an addition onto the existing concrete block well house. The building walls were constructed with a wood stud frame and 24-gauge pre-fabricated metal wall panels and set on a 6-inch-thick concrete slab floor with footings. The building also was equipped with an insulated, 10-ft-wide overhead door. Because of a shortage of the interior metal wall panels, the treatment system was delivered and installed prior to completing the building interior walls. By July 30, 2005, the city had completed the building along with the sump installation and sanitary sewer connection, and obtained the duplex sump pumps as required by MDH. Figure 4-7 shows the new building adjacent to the pre-existing pump house and water tower.

4.3.3 System Installation, Shakedown, and Startup. The Macrolite® system was shipped on June 17, 2005 and delivered to the site on June 21, 2005. A subcontractor to Kinetico off-loaded and installed of the system, including piping connections to the existing entry and distribution system. The system mechanical equipment installation was completed by July 30, 2004 when the city completed the backwash sump installation. The system shakedown was conducted from August 4 to 7, 2004.

Figure 4-7. New Building Constructed Adjacent to the Pre-Existing Pump House and Water Tower

Shakedown activities included disinfection of the contact and filtration tanks, backwash of Macrolite® filtration media, and troubleshooting of the city's sump pump operation. Issues noted during the shakedown included high system pressure and abnormally low system flowrate caused by the flow restrictors. With the 10 hp pump in Well No. 2, the flowrate ranged from 126 to 130 gpm with an elevated inlet pressure of >125 psi, resulting in seal problems on the pressure vessels. With the 7.5 hp pump in Well No. 1, the flowrate ranged from 105 to 115 gpm at an inlet pressure of approximately 70 psi. These problems were addressed by removing some rubber inserts from the flow restrictors, which reduced the system pressure and resulted in flowrates ranging from approximately 120 gpm for the 7.5 hp pump and 140 gpm for the 10 hp pump. Other action items noted during the system shakedown included installation of a bubble trap to reduce entrained air in the backwash water to alleviate high readings on the backwash turbidimeter, installation of an hour meter, and connection of the PLC to the pump motor starters to coordinate system operation. During the August 5 to August 7, 2004 startup trip, Kinetico conducted operator training of system operations and Battelle conducted operator training for system sampling and data collection. The treated water was sent to the distribution system on August 11, 2004. A Battelle staff member returned to the site on September 1, 2004 to review system operations and to further train the operator on proper operation of the water quality meter and probes.

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters for the first six months of the system operation are summarized in Table 4-4, including operational time, throughput, flowrate, and pressure information. Detailed daily operational information also is attached as Appendix A. The plant operational data were recorded beginning August 16, 2004 and the system continued to operate through February 28, 2005 with only a few operational problems for the first six months of the demonstration period.

Table 4-4. Summary of Macrolite® FM-26-AS System Operation at the Climax, MN, Site

Parameter	Values	
Operational Period	August 16, 2004 - February 28, 2005	
Total Operating Time (hr)	1,075	
Average Daily Operating Time (hr)	5.3	
Throughput to Distribution (kgal)	6,758	
Average Daily Demand (gpd)	34,850	
Peak Daily Demand (gpd)	92,730	
Number of Backwash Cycles[(a)]	96	
Run Time Between Backwash Cycles (hrs)	3 -16	
Throughput Between Backwash Cycles (gal)	22,600 - 101,700	
	Well No. 1 (7.5 HP)	**Well No. 2 (10 HP)**
Average Flowrate (gpm)	122	141
Range of Flowrates (gpm)	104 – 131	134 – 148
Contact Time (min)	5.3 – 6.6	4.7 – 5.1
Hydraulic Loading to Macrolite® Filters (gpm/ft^2)	7.4 – 9.3	9.5 – 10.5
Pressure Differential across Filtration Vessels A/B (psi)	5 – 17	8 – 21
Pressure Differential across Entire System (psi)	19 to 30	25 to 34

(a) Backwash was triggered by 48-hr standby, 24-hr run time, or pressure loss of 20 psi. Only three pressure-initiated backwashes occurred during this study period.

Between August 16, 2005 and February 28, 2005, the treatment system operated for approximately 1,075 total hrs, based on the PLC hour meter readings with an average daily operating time of 5.3 hrs per day. The total system throughput was approximately 6,758,000 gal based on the flow totalizer readings. The average daily demand was approximately 34,850 gal and the peak daily demand occurred on August 31, 2004 at 92,750 gal. During this time period, a total number of 96 backwashes took place. The run time between backwash cycles ranged from approximately 3.0 to 16 hrs and the throughput between two consecutive backwash cycles ranged from approximately 22,600 to 101,700 gal. The median value of run time was 10 hrs and the median throughput was 71,000 gal. The throughput varied based on the amount of run time required to meet demand and the corresponding amount of time that the system was in standby mode. The filter run ended when the system had been in service mode for 24 hrs or in standby mode for 48 hrs, unless a pressure-initiated backwash was triggered.

The flowrate through the system varied slightly based on which well pump was operational. When the Well No. 1 pump (7.5 hp) was operational, the flowrates ranged from 104 to 131 gpm with an average value of 122 gpm. This corresponded to a contact time of 5.3 to 6.6 min compared to a design value of 5 min. At these flowrates, the hydraulic loading rates to the filter ranged from 7.4 to 9.3 gpm/ft^2 compared to the design value of 10 gpm/ft^2. When the Well No. 2 pump (10 hp) was operational, the flowrates ranged from 134 to 148 gpm with an average value of 141 gpm. This corresponded to a contact time of 4.7 to 5.1 min and a hydraulic loading rate to the filter of 9.5 to 10.5 gpm/ft^2, which was much closer to the respective design values.

Figure 4-8 illustrates differential pressure readings across the system and pressure vessels A and B. With Well No. 1 operating and before iron addition, the differential pressure readings ranged from 19 to 30 psi across the system and from 5 to 13 psi across the pressure vessels A and B. With Well No. 2 operating

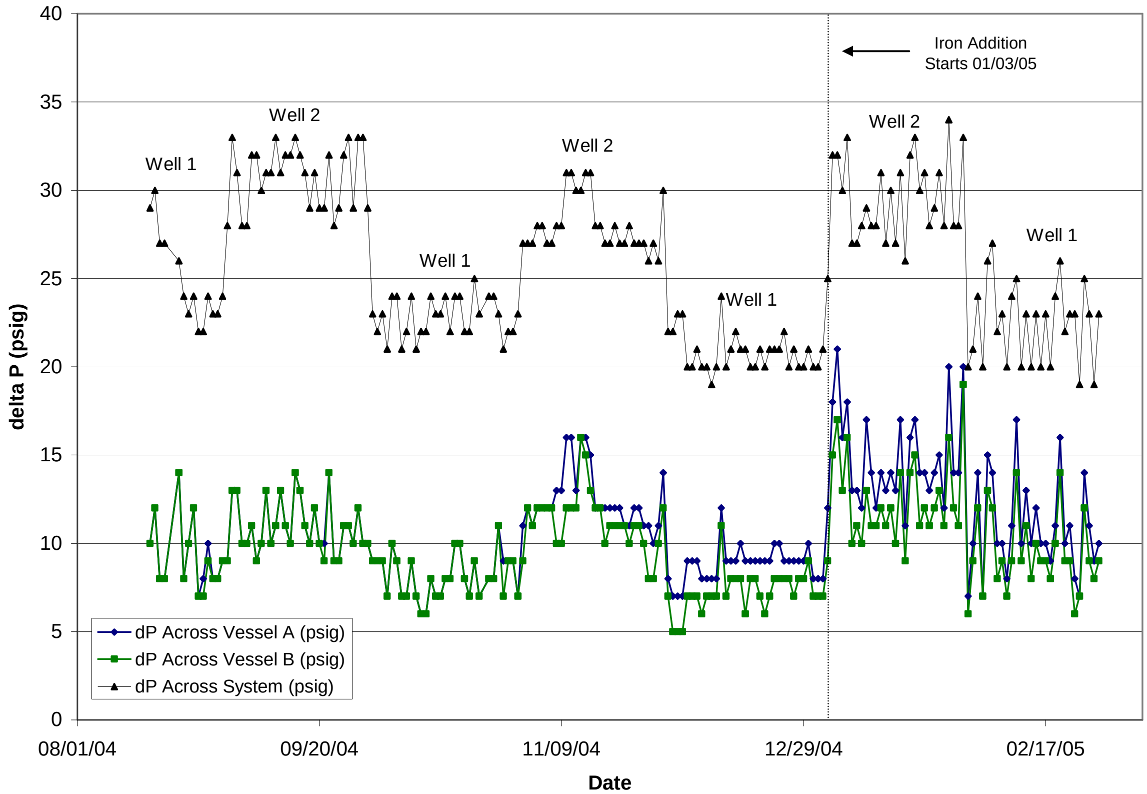

Figure 4-8. Differential Pressure Readings across the Macrolite® System and Pressure Vessels A and B

and before iron addition, the differential pressure readings ranged from 26 to 33 psi across the system and from 8 to 16 psi across pressure vessels A and B.

Iron addition did not appear to have impacted the pressure drop across the system with values ranging from 19 to 33 psi before iron addition and from 19 to 34 psi after iron addition. There was a slight increase in the differential pressure readings across vessels A and B after iron addition, but only three pressure-initiated backwashes were noted after the start of iron addition from January 3, 2005 through February 28, 2005. The majority of backwashes during the six-month time frame occurred as a result of the elapse of the 48-hr standby time. After each backwash event, a filter-to-waste cycle occurred for five min to flush water through the filter bed in the downflow mode before returning to service.

4.4.2 Backwash. The system PLC was set to initiate a backwash based on four potential triggers: 1) high differential pressure, 2) standby time, 3) run time, or 4) manual initiation. Table 4-5 summarizes the programming set points associated with these automatic backwash triggers (20 psi differential pressure, 48 hr of standby time, or 24 hr system run time) and the backwash duration. The backwash duration was controlled by the minimum and maximum backwash time per vessel and the backwash water turbidity measured by a Hach™ turbidimeter. Under the factory settings, if the turbidity threshold of 6 NTU was reached before the minimum backwash time set point, backwash would end at the minimum backwash time of 7 min. Otherwise, it would continue until the target turbidity threshold was reached. If the turbidity threshold was not reached at the end of the maximum backwash time of 15 min, then a backwash failure would be indicated and the operator had to acknowledge the alarm. This would result in a repeat backwash before the pressure filter could resume service. The use of turbidity as one of the backwash set points was designed as a potential water-saving measure.

Table 4-5 also provides a comparison of the factory settings to the initial field settings at startup of the treatment system and the modified field settings were set on January 14, 2005.

Table 4-5. Summary of PLC Settings for Automated Backwash Operations at Climax, MN

Parameter	Factory Setting	Initial Field Settings (From 08/11/04 through 01/14/05)	Modified Field Settings (From 01/14/05 through 02/28/05)
Differential Pressure Trigger (psi)	20	20	20
Standby Time Trigger (hrs)	48	48	48
Run Time Trigger (hrs)	24	24	24
Minimum Backwash Time Per Vessel (min)	7	18[(a)]	5
Maximum Backwash Time Per Vessel (min)	15	15	15
Turbidity Threshold (NTU)	6	45	20
Low Backwash Flow Set Point (gpm)	75	75	75

(a) Kinetico's initial field setting for the minimum backwash time was longer than the maximum backwash time. This was corrected in the January 14, 2005 modified field settings.

Several issues associated with the automated backwash process arose during the first six months of system operation, including correction of initial field set points and operational issues associated with the Hach™ turbidimeter. These issues are discussed as follows:

4.4.2.1 Backwash Settings. Table 4-6 summarizes data related to the backwash duration and backwash water quantity produced under the initial and modified field settings from August 11, 2005 through January 14, 2005 and from January 14, 2005 through February 28, 2005, respectively. The backwash flowrate for both time periods was approximately 50 gpm or 7 gpm/ft^2, which is lower than the 8 to 10 gpm/ft^2 design flowrate. The backwash flowrate was lowered in the field at startup to avoid media loss that was observed when a higher flowrate was used such as the factory set point of 75 gpm.

Between August 11, 2005 and January 14, 2005, each backwash event lasted for at least 18 min per vessel with one event that lasted for up to 53 min per vessel. The median backwash time was 18 min per vessel. The wastewater generated from backwash was 900 to 2,650 gal per vessel. The median value was 900 gal corresponding to an 18 min duration at the 50-gpm backwash flowrate. From January 14, 2005 to February 28, 2005, each backwash event lasted for at least 5 to 10 min per vessel with a median value at 10.5 min per vessel. The quantities of backwash water generated ranged from 250 to 3,000 gal per vessel with a median value of 525 gal per vessel.

Since the startup through January 14, 2005, the system produced 126,900 gal of backwash water (including the initial backwash events after media loading). This amount was equivalent to 2.4% of the total amount of water treated (i.e., 5,275,950 gal) during this time period. The time to backwash each vessel was at least 18 min, which was the minimum backwash time set by the vendor at the system startup. This 18-min backwash time was 3 min longer than the factory-set maximum backwash time or 2.6 times longer than the factory-set minimum backwash time (see Table 4-5). In addition, because of

Table 4-6. Summary of Backwash Parameters

Backwash Parameters	Minimum	Median	Maximum
Initial Field Settings (From 08/11/04 through 01/14/05)[a]			
Backwash Duration Per Vessel (min)	18	18	53[c]
Backwash Water Quantity Generated Per Vessel (gal)	800	900	2,650[c]
Modified Field Setting (From 01/14/05 through 02/28/05)[b]			
Backwash Duration Per Vessel (min)	5	10.5	60[c]
Backwash Water Quantity Generated Per Vessel (gal)	250	525	3,000[c]

(a) Seventy-one backwash events recorded during this time period (70 Vessel A; 71 Vessel B).
(b) Twenty-six backwash events recorded during this time period (26 Vessel A; 22 Vessel B).
(c) Repeat backwash cycles occurred on the same day due to failure to reach the turbidity threshold or other malfunction.

entrained air in the backwash water, the turbidity threshold was reset at an elevated level of 45 NTU at the system startup (instead of the 6 NTU factory setting). Since system startup through January 14, 2005, at least five backwash events occurred where repeat backwash cycles were required on the same day as a result of failure to reach the turbidity threshold of 45 NTU.

Figure 4-9 includes six backwash water turbidity profiles. Four of the profiles were collected prior to the start of iron addition. These four profiles included two recorded manually by the plant operator over one backwash event for each vessel and two recorded remotely by the vendor using a dial-in modem over a separate backwash event with the minimum backwash time set at 18 min and the turbidity threshold set at 45 NTU. As shown in the figure, the data collected manually by the operator were comparable to those collected remotely by the vendor and most particles as reflected by high turbidity values (>40 NTU) were removed from the Macrolite® filters in the first 7 min. The turbidity values in the backwash water were below 20 NTU after approximately 9 min of backwashing. For the remaining 9 min of the 18 min minimum set time, the turbidity values leveled off at 8 to 16 NTU. These results indicate that the 18 min minimum backwash time and the 45 NTU turbidity threshold settings were overly conservative and could be significantly reduced to save water. (Note that approximately 900 gal of wastewater was produced per vessel under these field settings.)

As noted above, the turbidity readings of the backwash water remained at levels higher than 45 NTU during five backwash events for both vessels A and B. The elevated NTU readings were first addressed through the installation of a bubble trap on the turbidimeter line (on August 11, 2005), repair of a leaking air-actuated valve (on September 15, 2004), and testing of the compressed air supply to ensure that it did not contribute to entrained air in the backwash water. After these repairs and during troubleshooting of backwashing operations in December 2004, it was noted that the NTU readings at the end of a backwash cycle ranged from 7.9 to 33.1 NTU with 7 out of 9 readings below 12.5 NTU.

On January 14, 2005, the backwash settings were modified to more closely match the factory settings. The minimum backwash time was changed from 18 to 5 min and the turbidity threshold was lowered from 45 to 20 NTU. Also presented in Figure 4-9 are two backwash water turbidity profiles with the modified PLC settings. Even after iron addition that resulted in turbidity readings much higher than 100 NTU, the time to reach 20 NTU remained at approximately 9 to 10 min for Vessel A and B. As shown in Table 4-6, under these modified settings, the treatment system produced 32,300 gal of backwash water from January 14, 2005 through February 28, 2005. This is equivalent to approximately 2.2% of the total

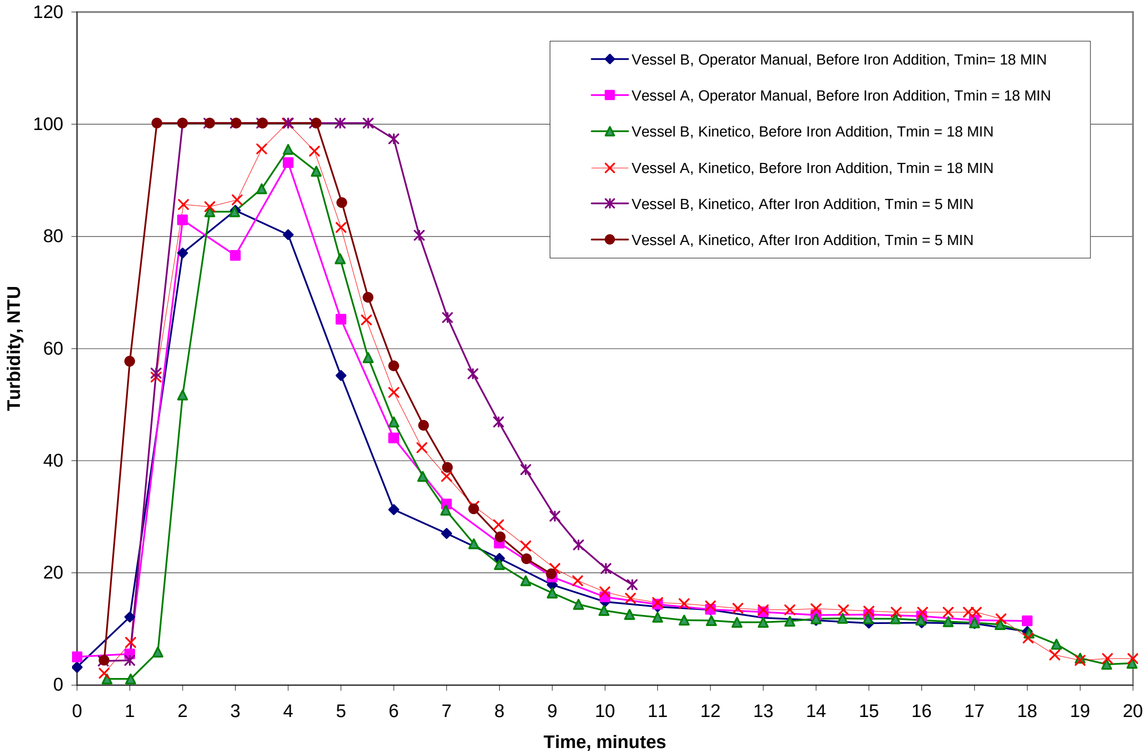

Figure 4-9. Backwash Water Turbidity versus Time Plot for Climax, MN

amount of water treated and this represents 0.2% of water savings compared to the initial field settings with a 2.4% backwash water generation rate from August 11, 2004 to January 14, 2005. The water savings potentially could have been higher, but backwash problems were experienced from January 14, 2005 to February 28, 2005 that significantly elevated the quantity of backwash water generated.

4.4.2.2 Hach™ Turbidimeter and Related Backwashes. The backwash event on February 12, 2005 produced 6,700 gal of backwash water apparently caused by calcium deposits on the photocell of the Hach™ turbidimeter. The amount of wastewater produced represented over 20% of the total quantity of backwash water discharged between January 14 and February 28, 2005. The deposits occurred because of the evaporation of water in contact with the hot glass surface, preventing the turbidimeter from detecting accurate turbidity levels, which in turn led to backwash problems. To minimize this problem, the glass lens was periodically inspected and cleaned as part of the routine maintenance of the system.

4.4.3 Residual Management. Residuals produced by the operation of the Macrolite® system included only backwash water, which was discharged to an underground sump and then pumped to a nearby sanitary sewer line for disposal.

4.4.4 System/Operation Reliability and Simplicity. No major operational problems were encountered in the service mode. The only major operational issues encountered were related to the Macrolite® filter backwash as described in Section 4.4.2. Neither scheduled nor unscheduled downtime had been required since the start of system operations. The simplicity of system operation and operator skill requirements are discussed according 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. Pre-treatment at the site included prechlorination for the oxidation of arsenic and iron and supplemental iron addition to enhance the arsenic removal from raw water. Specific chemical handling requirements are further discussed below under chemical handling and inventory requirements.

System Automation. All major functions of the treatment system are automated and would require only minimal operator oversight and intervention if all functions are operating as intended. Automated processes include system startup in the forward feed mode when the well energizes, backwash cycling based on time or pressure triggers, fast rinse cycling, and system shutdown when the well pump shuts down. However, as noted in Section 4.4.2, a number of operational issues did arise with the automated system backwash and associated equipment.

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, flow, and system alarms. The PLC interface was intuitive and all major system operations were automated as described above. The daily demand on the operator was about 30 min to visually inspect the system and record the operating parameters on the log sheets. Other skills needed including performing O&M activities such as cleaning the turbidimeter photo cell, monitoring backwash operational issues, and working with the vendor to troubleshoot and perform minor on-site repairs.

Preventive Maintenance Activities. Preventive maintenance tasks recommended by the vendor included daily to monthly visual inspection of the piping, valves, tanks, flowmeters, and other system components. Routine maintenance also may be required on an as-needed basis for the air compressor motor and the replacement of o-ring seals or gaskets on automated or manual valves (Kinetico, 2004). During this reporting period, maintenance activities performed by the operator included the repair of a leaky fitting and removal of plugs on the flow restrictors for each pressure vessel upon startup of the system. On September 15, 2004, the operator repaired an air leak associated with an air-actuated valve on the bottom of Tank B. It also was found that cleaning of the turbidimeter photocell was required to prevent the buildup of deposits. Other maintenance and troubleshooting activities were conducted as described in Section 4.4.2 related to the malfunction of automated backwash operations.

Chemical/Media Handling and Inventory Requirements. Prechlorination was implemented since the system startup and supplemental iron addition was initiated on January 3, 2005. The iron addition required only minimal effort (10 min as reported by the operator) to prepare the iron solution approximately once every two weeks. The sodium hypochlorite and ferric chloride chemical consumption was checked each day as part of the routine operational data collection.

4.5 System Performance

The performance of the Macrolite® FM-236-AS 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 through the treatment train: at the inlet (IN), after the contact tanks (AC), after pressure vessels A and B (TA and TB), and after vessels A and B combined (TT). Field-speciated samples from the IN, AC, and TT locations were collected once every four weeks throughout this reporting period. Table 4-7 summarizes the arsenic, iron, and manganese analytical results. Table 4-8 summarizes the results of the other water quality parameters. Appendix B contains a complete set of analytical results through the first six months of system operation. The results of the water samples collected throughout the treatment plant are discussed below.

Arsenic and Iron. The key parameter for evaluating the effectiveness of the Macrolite® pressure filtration process was the concentration of total arsenic in the treated water. The treatment plant water was sampled on 28 occasions (including two duplicate sampling events) during the first six months of system operation, with field speciation performed on samples collected from the IN, AC, and TT locations for 7 of the 28 occasions. Figure 4-10 shows the arsenic speciation results.

Total arsenic concentrations in raw water ranged from 32.1 to 51.4 μg/L and averaged 37.2 μg/L (Table 4-7). As(III) was the predominant species in the raw water, ranging from 32.6 to 39.8 μg/L and averaging 35.5 μg/L. Only trace amounts of particulate As and As(V) existed, with concentrations averaging 1.2 and 3.2 μg/L, respectively. The arsenic concentrations measured during this six-month period were consistent with those in the raw water sample collected on July 30, 2003 (Table 4-1). Total iron concentrations in the raw water ranged from 361 to 1,002 μg/L and averaged 551 μg/L, which existed primarily as the soluble form with an average value of 456 μg/L. This amount of soluble iron corresponded to an iron:arsenic ratio of 12:1 given the average soluble iron and soluble arsenic levels in the source water.

After prechlorination and the contact tanks, the As(III) concentrations ranged from 0.9 to 3.0 μg/L (except one data point at 6.2 μg/L), suggesting effective oxidation of As(III) to As(V) with chlorine. The particulate arsenic concentrations after the contact tanks ranged from 15.3 to 28.4 μg/L. After prechlorination and the contact tanks, iron existed solely in the particulate form, ranging from 363 to 1,002 μg/L. The corresponding total and free chlorine measurements after the contact tanks averaged 2.4 mg/L and 1.0 mg/L, respectively (see Table 4-8). The chlorine demand was elevated due to the presence of ammonia in the raw water at 0.6 to 0.8 mg/L, which leads to the formation of combined chlorine.

Prior to the start of supplemental iron addition, total arsenic concentrations in the combined effluent (TT) ranged from 9.7 to 19 μg/L and averaged 14.1 μg/L, of which 8.1 to 11.8 μg/L existed as As(V). The particulate arsenic levels in the treated water were relatively low and ranged from 0.1 to 3.3 μg/L. Additional data were collected to observe the total and soluble arsenic and iron concentrations over the span of one filtration run. As shown in Figure 4-11a, over the 8-hr filtration run, arsenic concentrations in the treated water existed primarily in the soluble form (at 11.2 to 14.6 μg/L) and there was very little particulate arsenic (at <1 to 1.1 μg/L) in the treated water, indicating little particulate As leakage through the Macrolite® filters. This observation was further supported by the low levels of particulate iron in the treated water (<25 to 186 μg/L). The presence of arsenic over the MCL in the treated water throughout the 8-hr filtration run confirmed the need for supplemental iron addition for further As(V) removal.

On January 3, 2005, the supplemental iron addition was started at a target dosage of 0.5 mg/L of iron using a ferric chloride solution. Figure 4-12 shows the increase in iron levels after the contact tanks once iron addition was initiated. Based on the daily use rate of the iron solution and the mix ratio, between 0.6 and 0.8 mg/L of iron was added into the raw water depending on the system flowrate. Since January 3, 2005, total As concentrations at the TT location averaged 6.0 μg/L. The As(V) concentrations in the combined effluent ranged from 3.6 to 4.0 μg/L and averaged 3.8 μg/L. The particulate As levels ranged from 0.6 to 1.2 μg/L and averaged 0.9 μg/L. Figure 4-12 also shows a slight increase in the iron leakage from the Macrolite® filters after the start of supplemental iron addition, with total iron levels (existing solely as particulates) in the treated water ranging from <25 to 122 μg/L.

Table 4-7. Summary of Arsenic, Iron, and Manganese Analytical Results Before and After Supplemental Iron Addition[(a)]

Parameter	Sampling Location	Units	Number of Samples	Minimum Concentration	Maximum Concentration	Average Concentration	Standard Deviation
As (total)	IN	μg/L	28	32.1	51.4	37.2	5.2
	AC	μg/L	28	33.4 [18.5]	72 [37.9]	39.4 [32.5]	9.0 [5.9]
	TA	μg/L	21	9.3 [5.3]	17.9 [7.1]	11.3 [5.9]	2.3 [0.6]
	TB	μg/L	21	9.9 [5.6]	18.3 [7.4]	12.1 [6.5]	2.5 [0.7]
	TT	μg/L	7	9.7 [6.0]	19.0 [6.0]	14.1 [6.0]	4.1 [0.0]
As (soluble)	IN	μg/L	7	33.3	51.3	38.7	5.9
	AC	μg/L	7	11.0 [4.5]	19.5 [18.3]	14.7 [11.4]	3.8 [9.8]
	TT	μg/L	7	9.7 [4.8]	16.1 [5.4]	12.6 [5.1]	3.0 [0.4]
As (particulate)	IN	μg/L	7	<0.1	6.7	1.2	2.4
	AC	μg/L	7	20.9 [15.3]	28.4 [28.3]	24.1 [21.8]	3.1 [9.2]
	TT	μg/L	7	0.1 [0.6]	3.3 [1.2]	1.5 [0.9]	1.5 [0.4]
As(III)	IN	μg/L	7	32.6	39.8	35.5	2.4
	AC	μg/L	7	1.0 [0.9]	6.2 [1.4]	2.6 [1.2]	2.2 [0.4]
	TT	μg/L	7	1.0 [1.2]	5.1 [1.4]	2.5 [1.3]	1.7 [0.1]
As(V)	IN	μg/L	7	<0.1	11.5	3.2	3.8
	AC	μg/L	7	9.9 [3.6]	14.8 [16.9]	12.2 [10.3]	2.1 [9.4]
	TT	μg/L	7	8.1 [3.6]	11.8 [4.0]	10.1 [3.8]	1.6 [0.3]
Fe (total)	IN	μg/L	28	361	1,209	551.1	149.4
	AC	μg/L	28	363 [515]	1,002 [1,791]	563 [1,354]	145 [394]
	TA	μg/L	21	<25 [<25]	66.4 [107]	<25 [44.6]	20.2 [36.6]
	TB	μg/L	21	<25 [<25]	66.0 [122]	<25 [65.8]	16.3 [40]
	TT	μg/L	7	<25 [<25]	36.8 [26.3]	<25 [<25]	12.2 [9.8]
Fe (soluble)	IN	μg/L	7	342	520	455.6	75.2
	AC	μg/L	7	<25 [<25]	<25 [<25]	<25 [<25]	0.0 [0.0]
	TT	μg/L	7	<25 [<25]	<25 [<25]	<25 [<25]	0.0 [0.0]
Mn (total)	IN	μg/L	28	113	505	138.5	72.3
	AC	μg/L	28	109 [110]	156 [143]	125.7 [128.1]	11.9 [11.8]
	TA	μg/L	21	65.6 [65.1]	85.7 [92.3]	74.3 [79.8]	5.9 [11.0]
	TB	μg/L	21	66.0 [62.9]	82.6 [104]	73.3 [84.6]	5.3 [15.6]
	TT	μg/L	7	62.6 [57.2]	86.8 [70.3]	70.6 [63.8]	9.4 [9.3]
Mn (soluble)	IN	μg/L	7	112	145	121.3	11.5
	AC	μg/L	7	61.7 [59]	78.9 [67.1]	69.1 [63.1]	7.4 [5.7]
	TT	μg/L	7	61.8 [55.5]	80.9 [68.3]	69.1 [61.9]	7.1 [9.1]

*Number in parentheses is data complied after the start of iron addition on January 3, 2005.
One-half of the detection limit was used for non-detect samples for calculations.
Duplicate samples are included in the calculations.

Figure 4-11b shows the arsenic concentrations in the treated water collected over the span of two filtration runs following the start of iron addition on January 3, 2005. After 3 to 4 hrs into the filtration runs, total arsenic levels were well below 10 μg/L and the particulate arsenic concentrations increased only slightly from <1 to 1.4 μg/L at the start of the run to 2.0 to 2.2 μg/L about 3 to 4 hrs into the run. Additional data will be collected on the run time performance of the treatment system with iron addition over the next six months of the study.

Table 4-8. Summary of Other Water Quality Parameter Sampling Results

Parameter	Sampling Location	Units	Number of Samples	Minimum Concentration	Maximum Concentration	Average Concentration	Standard Deviation
Alkalinity	IN	mg/L	28	294	360	316.9	13.9
	AC	mg/L	28	284	355	310.6	14.6
	TA	mg/L	21	288	355	312.5	15.1
	TB	mg/L	21	292	337	311.2	11.8
	TT	mg/L	7	284	334	301.6	17.2
Ammonia	IN	mg/L	12	0.6	0.8	0.7	0.1
Fluoride	IN	mg/L	7	0.2	0.7	0.4	0.2
	AC	mg/L	7	0.2	0.7	0.4	0.2
	TT	mg/L	7	0.6	1.5	1.1	0.3
Sulfate	IN	mg/L	7	110	154	123.4	15.1
	AC	mg/L	7	110	155	122.1	15.2
	TT	mg/L	7	110	155	122.1	15.2
Orthophosphate (as PO_4)	IN	mg/L	28	<0.05	<0.1	<0.1	0.01
	AC	mg/L	28	<0.05	<0.1	<0.1	0.01
	TA	mg/L	21	<0.05	<0.1	<0.1	0.01
	TB	mg/L	21	<0.05	<0.1	<0.1	0.01
	TT	mg/L	7	<0.05	<0.1	<0.1	0.01
Silica	IN	mg/L	28	16.8	30.5	28.2	2.3
	AC	mg/L	28	27.1	30.5	28.6	0.7
	TA	mg/L	21	27.3	29.9	28.4	0.6
	TB	mg/L	21	27.3	30.6	28.5	0.7
	TT	mg/L	7	28.0	29.8	28.7	0.6
Nitrate (as N)	IN	mg/L	7	<0.04	<0.05	<0.05	0.00
	AC	mg/L	7	<0.04	<0.05	<0.05	0.00
	TT	mg/L	7	<0.04	<0.05	<0.05	0.00
Turbidity	IN	NTU	28	3.0	8.6	6.2	1.1
	AC	NTU	28	0.4	1.4	0.8	0.3
	TA	NTU	21	<0.1	1.0	0.3	0.2
	TB	NTU	21	<0.1	1.1	0.3	0.2
	TT	NTU	7	<0.1	0.6	0.3	0.2
pH	IN	S.U.	25	7.5	7.7	7.6	0.05
	AC	S.U.	25	7.4	7.6	7.4	0.06
	TA	S.U.	19	7.3	7.6	7.4	0.08
	TB	S.U.	19	7.3	7.6	7.4	0.09
	TT	S.U.	6	7.3	7.4	7.4	0.04
Temperature	IN	ºC	25	8.1	12.4	9.1	0.9
	AC	ºC	25	8.1	10.7	8.9	0.7
	TA	ºC	19	8.1	10.7	8.9	0.8
	TB	ºC	19	8.1	11.0	8.9	0.8
	TT	ºC	6	8.3	9.1	8.6	0.3

Table 4-8. Summary of Water Quality Parameter Sampling Results (Continued)

Parameter	Sampling Location	Units	Number of Samples	Minimum Concentration	Maximum Concentration	Average Concentration	Standard Deviation
Dissolved Oxygen	IN	mg/L	25	1.0	4.1	1.9	0.7
	AC	mg/L	25	0.9	2.6	1.6	0.5
	TA	mg/L	19	0.7	2.2	1.4	0.4
	TB	mg/L	19	1.0	4.9	1.9	0.8
	TT	mg/L	6	1.0	2.5	1.6	0.5
ORP	IN	mV	19	-128	-63	-78	14
	AC	mV	19	121	382	274	65
	TA	mV	13	222	379	292	44
	TB	mV	13	228	364	292	39
	TT	mV	5	258	347	312	34
Free Chlorine	AC	mg/L	25	0.2	3.0	1.0	0.6
	TA	mg/L	19	0.2	3.0	1.0	0.6
	TB	mg/L	19	0.2	3.0	1.0	0.6
	TT	mg/L	6	0.6	1.6	1.1	0.4
Total Chlorine	AC	mg/L	25	0.9	3.0	2.4	0.6
	TA	mg/L	19	0.9	3.0	2.4	0.7
	TB	mg/L	19	0.9	3.0	2.4	0.7
	TT	mg/L	6	2.2	3.0	2.5	0.4
Total Hardness (as $CaCO_3$)	IN	mg/L	7	210	283	239	26.3
	AC	mg/L	7	208	279	237	25.6
	TT	mg/L	7	204	278	239	25.1

One-half of the detection limit was used for non-detect samples for calculations.
Duplicate samples are included in the calculations.

Manganese. Total Mn levels in the influent ranged from 113 to 146 μg/L with an outlier at 505 μg/L (see Table 4-7). The Mn in the raw water existed primarily as soluble Mn at levels ranging from 112 to 145 μg/L. After prechlorination and the contact tanks, the soluble Mn concentrations were decreased to 59 to 78.9 μg/L. An average of 43% of the soluble Mn was converted to particulate Mn. Only particulate Mn was filtered out by the Macrolite® filters, leaving soluble Mn in the treated water at levels ranging from 55.5 to 80.9 μg/L.

Other Water Quality Parameters. In addition to arsenic, iron, and manganese analyses, other water quality parameters were analyzed to provide insight into the chemical processes occurring within the treatment system. The results of the water quality parameters are included in Appendix B and are summarized in Table 4-8. DO levels remained low across the treatment train (with average values ranging from 1.4 to 1.9 mg/L), but ORP values increased after chlorine addition (ranging from -63 to -128 mV before chlorination versus 121 to 382 mV after chlorination). The pH in the raw water had an average value of 7.6 and the pH in the treated water had an average value of 7.4. Average alkalinity results ranged from 302 to 317 mg/L (as $CaCO_3$) across the treatment train. Average total hardness results ranged from 237 to 239 mg/L (as $CaCO_3$) across the treatment train (the total hardness is the sum of calcium hardness and magnesium hardness). The water had predominantly calcium hardness.

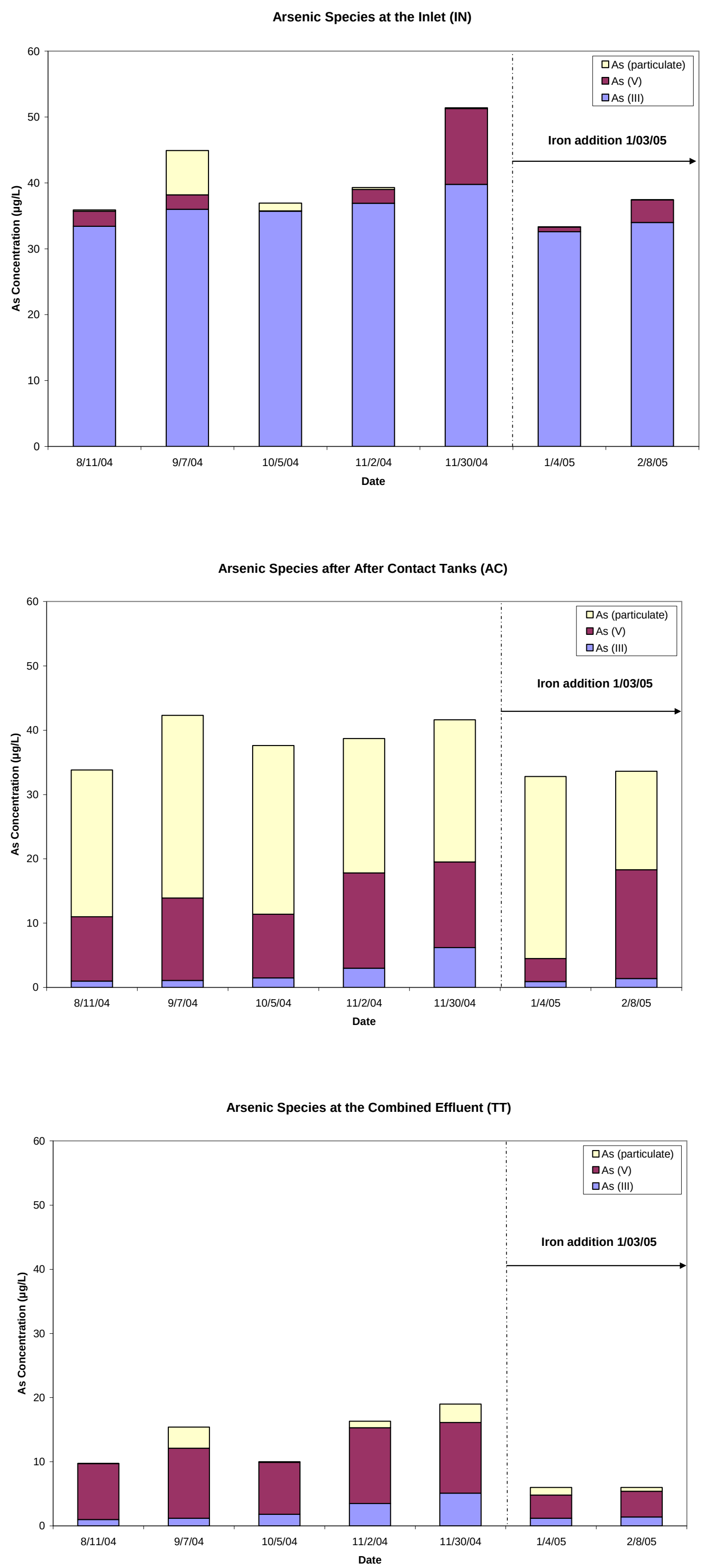

Figure 4-10. Concentrations of Arsenic Species at the Inlet (IN), after Contact Tanks (AC), and after Combined System Effluent (TT) Sampling Locations

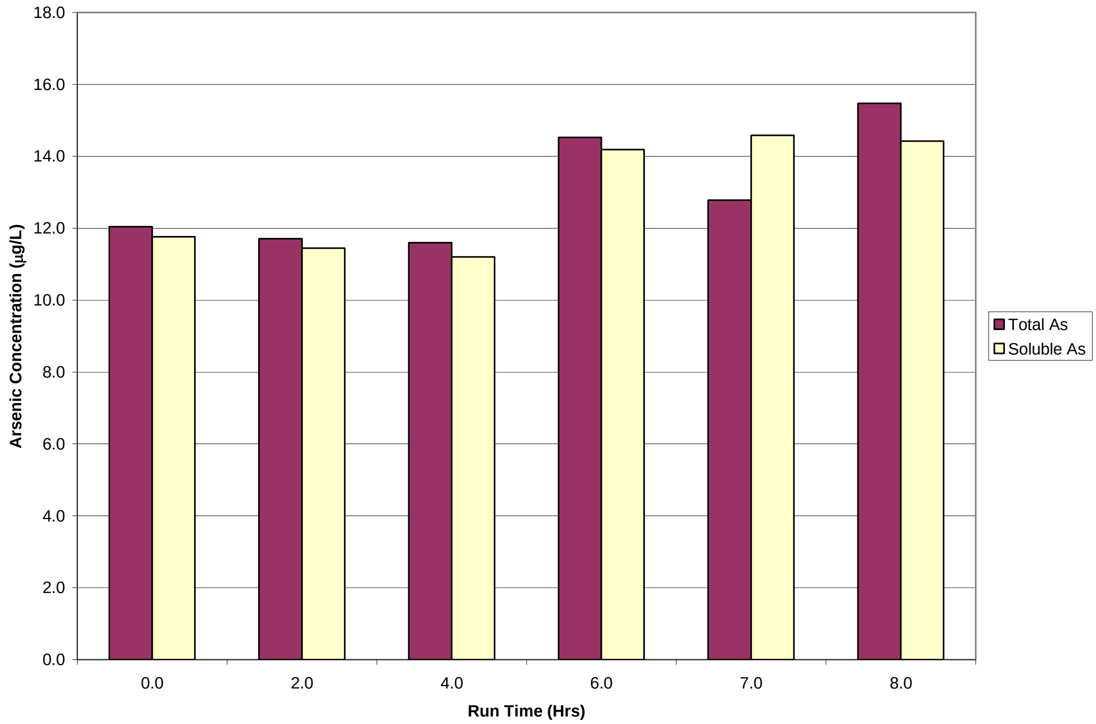

Figure 4-11a. Arsenic in Treated Water before Iron Addition versus Run Time

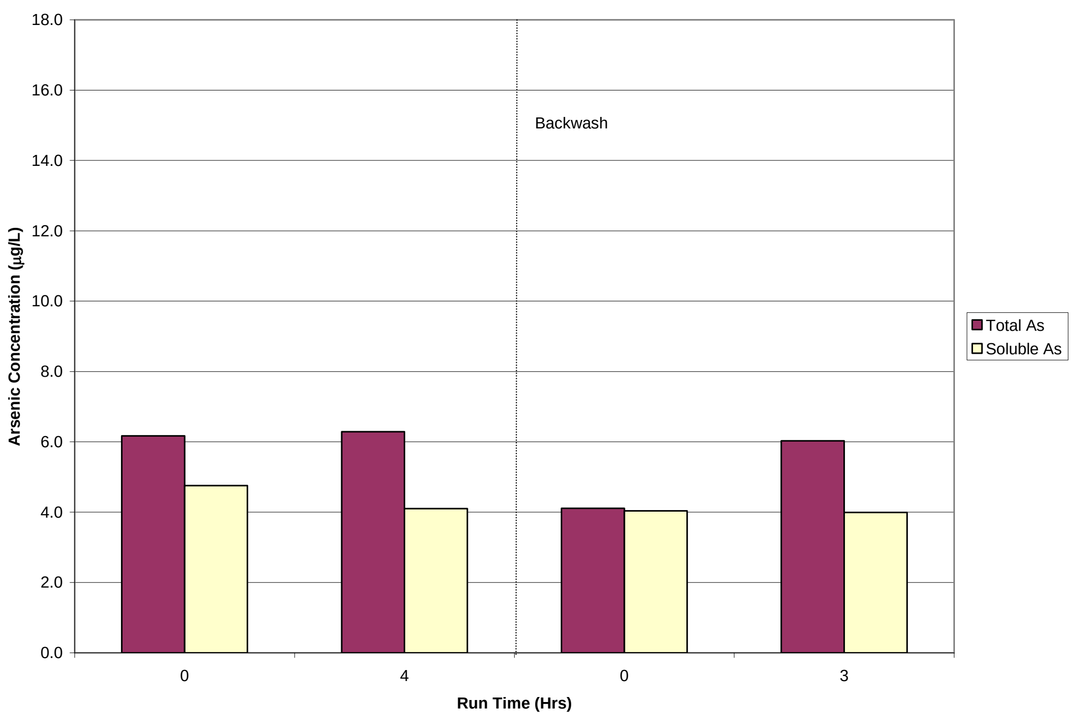

Figure 4-11b. Arsenic in Treated Water after Iron Addition versus Run Time

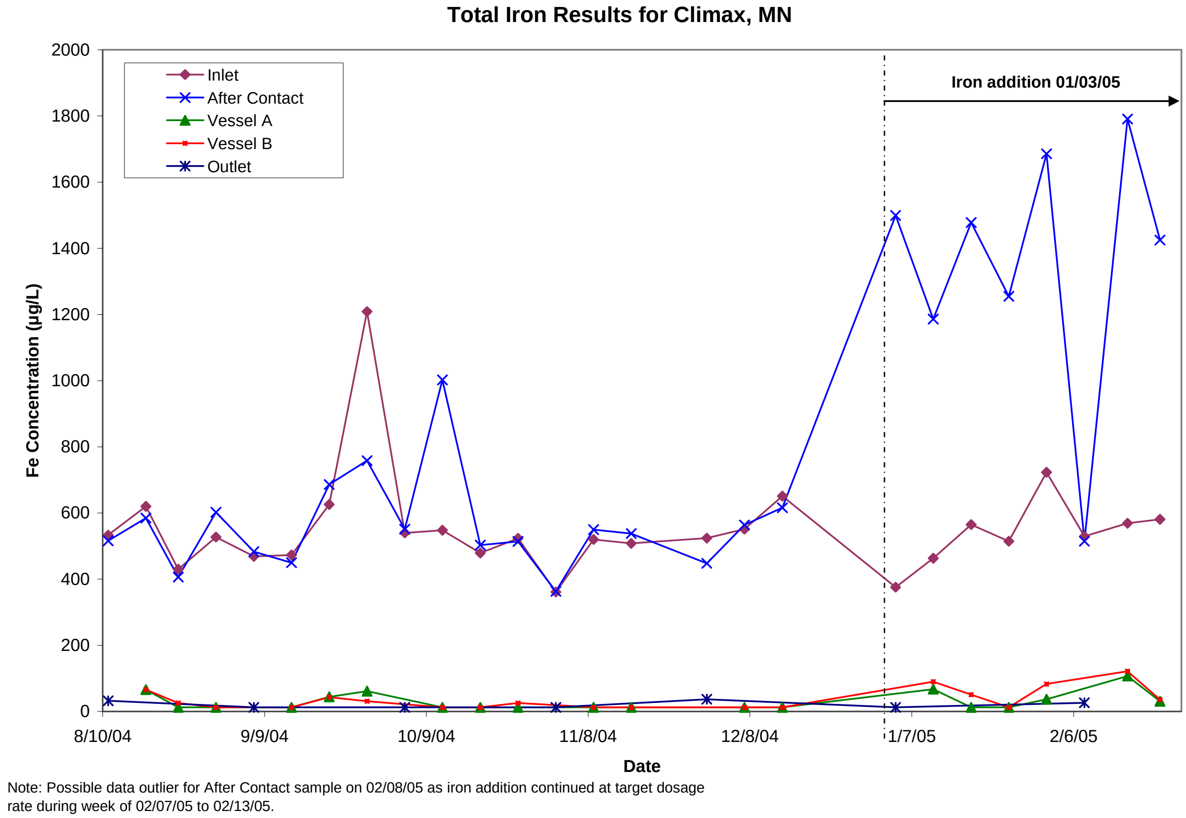

Figure 4-12. Total Iron Concentrations versus Time

Fluoride concentrations ranged from 0.2 to 0.7 mg/L in the raw water and after contact tanks and were not affected by the Macrolite® filtration. Fluoride averaged 1.1 mg/L in the combined effluent samples after the fluoridation step. No nitrate or phosphate was detected in the raw water. Average sulfate concentrations ranged from 122 to 123 mg/L across the treatment train. The silica (as SiO_2) concentration remained at approximately 28 mg/L across the treatment train.

4.5.2 Backwash Water Sampling. Backwash of the Macrolite® filters was performed using treated water. The analytical results from the six backwash water sampling events are summarized in Table 4-9. Samples collected from the sample ports located in the backwash water discharge lines from each vessel were analyzed for pH, turbidity, TDS, and soluble As, Fe, and Mn. Prior to the iron addition, the soluble arsenic concentrations in the backwash water ranged from 12.3 to 21.6 µg/L and the soluble iron concentrations ranged from <25 to 39.9 µg/L. After iron addition, the soluble arsenic concentrations decreased and ranged from 6.4 to 9.2 µg/L, while the soluble iron concentrations increased and ranged from 27.3 to 148 µg/L.

4.5.3 Distribution System Water Sampling. Distribution system samples were collected to determine the impact of the arsenic removal system on the lead and copper level and water chemistry in the distribution system. Prior to the installation and operation of the system, baseline distribution water samples were collected monthly at three LCR residences from January to April 2004. Following the installation of the system, distribution water sampling continued on a monthly basis at the same three locations. The samples were analyzed for pH, alkalinity, and total arsenic, iron, manganese, lead, and copper. The results of the distribution system sampling are summarized in Table 4-10.

Table 4-9. Backwash Water Sampling Results

Sampling Event		Vessel A						Vessel B					
		pH	Turbidity	TDS	As (soluble)	Fe (soluble)	Mn (soluble)	pH	Turbidity	TDS	As (soluble)	Fe (soluble)	Mn (soluble)
No.	Date	S.U.	NTU	mg/L	µg/L	µg/L	µg/L	S.U.	NTU	mg/L	µg/L	µg/L	µg/L
1	09/24/04	7.1	45	908	14.8	<25	37.4	7.2	52	990	17.9	<25	24.9
2	10/20/04[(a)]	7.6	54	824	21.6	<25	413.0	7.5	29	774	19.5	30.7	235.0
3	11/16/04	7.9	60	826	15.6	<25	49.6	7.9	48	840	14.1	<25	54.8
4	12/13/04	7.7	38	798	12.3	34.6	69.8	7.6	7	758	12.5	39.9	72.7
5	01/12/05	7.5	140	648	9.2	148.0	86.7	7.5	120	646	7.8	87.1	81.8
6	02/16/05	7.5	14[(b)]	808	7.2	83.4	73.1	7.5	14[(b)]	798	6.4	27.3	68.7

TDS = total dissolved solids.
(a) Soluble Mn was re-run to give similar results for both samples for this date.
(b) Low turbidity on 02/16/05 might have been caused by analytical errors.

The main difference observed before and after the operation of the system was a decrease in the arsenic concentrations at each of the sampling locations. Arsenic concentrations in the baseline samples ranged from 21.8 to 52.3 µg/L. The arsenic levels measured since the treatment system started ranged from 11.3 to 17.0 µg/L before iron addition and 5.9 to 11.8 µg/L after iron addition. One exception occurred on August 31, 2004 when the operator reported a "red water" slug from the Distribution Sample 1 (DS1) tap, which contained signficiant solids and elevated levels of arsenic, iron, manganese, lead, and copper. Iron concentrations in the baseline samples were high and ranged from 25.1 to 579.8 µg/L before the system installation. Since system startup, iron levels in the distributed water decreased with an average of 48.4 µg/L before iron addition and an average of 90.9 µg/L after iron addition. The manganese levels in the distribution system samples averaged 65.7 µg/L in the baseline samples collected before startup and decreased to an average of 35.4 µg/L after the treatment system began operation.

There was no major change in measured pH values in the distribution system, which ranged from 7.4 to 7.6 before the system became operational and 7.3 to 7.7 after the system became operational. Alkalinity levels in the distribution system ranged from 198 to 331 mg/L as $CaCO_3$ before, and 294 to 339 as $CaCO_3$ after.

Lead levels in the distribution system ranged from 0.3 to 4.7 µg/L with no samples exceeding the action level of 15 µg/L (with the excpetion of the August 31, 2004 sample collected at the DS1 location). Lead levels in the distribution system did not appear to have been affected by the operation of the arsenic treatment unit. Copper concentrations in the distribution system ranged from 19.7 to 401.8 µg/L in the baseline samples. Copper concentrations in the distribution system ranged from 53.4 to 1,027 µg/L after the system was started (with no samples exceeding the 1,300 µg/L action level with the exception of the August 31, 2004 event noted above).

Table 4-10. Distribution Sampling Results

No. of Sampling Events	Location ID	DS1									DS2									DS3								
	Sampling Date	Stagnation Time (hrs)	pH (S.U.)	Alkalinity (mg/L as $CaCO_3$)	Flouride (mg/L)	As (µg/L)	Fe (µg/L)	Mn (µg/L)	Pb (µg/L)	Cu (µg/L)	Stagnation Time (hrs)	pH (S.U.)	Alkalinity (mg/L as $CaCO_3$)	Flouride (mg/L)	As (µg/L)	Fe (µg/L)	Mn (µg/L)	Pb (µg/L)	Cu (µg/L)	Stagnation Time (hrs)	pH (S.U.)	Alkalinity (mg/L as $CaCO_3$)	Flouride (mg/L)	As (µg/L)	Fe (µg/L)	Mn (µg/L)	Pb (µg/L)	Cu (µg/L)
BL1	01/28/04	7.5	7.4	292	1.2	37.2	372	89.1	2.5	61.9	8.9	7.5	282	NA	39.2	371	65.8	4.1	208	6.0	7.4	286	1.1	52.3	580	111	4.7	402
BL2	02/23/04	6.3	7.5	198	1.1	34.1	212	86.5	0.3	26.0	8.8	7.6	298	1.2	49.0	417	45.4	3.9	195	15.5	7.6	300	1.1	41.7	321	82.4	0.9	230
BL3	03/22/04	6.3	7.5	331	0.9	40.4	276	81.6	0.3	28.8	10.0	7.6	307	1.0	35.0	260	42.3	4.6	215	6.9	7.5	323	1.0	45.8	472	89.0	3.0	335
BL4	04/27/04	6.7	7.6	307	1.0	21.8	39.5	37.3	0.6	19.7	8.0	7.6	299	1.0	22.9	36.6	17.0	0.5	55.8	6.8	7.6	299	1.1	25.1	71.0	40.8	0.7	86.6
1	08/31/04[(a)]	6.8	7.4	314	0.5	483	13,903	1,291	142	6,605	12.0	7.5	314	0.6	15.9	<25	12.7	1.9	122	7.5	7.5	306	0.6	13.9	<25	25.0	1.0	110
2	09/28/04	8.3	7.3	304	0.9	14.6	70.7	76.6	2.2	62.5	12.0	7.4	304	0.9	15.0	74.6	47.4	3.3	145	18.0	7.4	308	0.9	12.9	<25	51.5	2.2	119
3	10/26/04	5.8	7.5	316	0.6	14.9	58.3	29.7	1.7	53.4	6.4	7.6	316	0.5	13.5	35.4	12.6	1.2	110	18.5	7.7	316	0.5	12.0	31.7	25.1	1.2	213
4	11/30/04[(b)]	7.0	7.5	309	1.4	15.6	54.5	37.1	3.4	281	12.0	7.5	317	1.3	17.0	81.0	49.9	4.2	187	7.2	7.6	309	1.4	16.0	61.6	27.9	3.3	593
5	12/14/04	6.8	7.6	305	0.7	12.1	<25	26.2	2.8	297	8.0	7.6	301	1.0	13.1	52.6	23.4	1.6	121	17.0	7.6	301	0.6	11.3	35.0	23.0	3.5	1,027
6	01/11/05[(c)]	7.0	7.6	298	1.2	10.7	71.5	45.4	2.0	233	24.0	7.6	294	1.2	11.8	109	25.1	2.4	106	16.3	7.6	328	1.0	7.4	180	33.0	2.9	407
7	02/08/05	7.0	7.5	334	1.0	8.0	69.4	26.2	2.3	241	12.0	7.6	326	1.0	9.3	69.6	13.9	1.6	112	16.3	7.7	339	1.0	5.9	46.1	46.9	3.3	108

(a) Homeowner at DS1 noticed a flush of red water during sample collection.
(b) DS2 was taken on 12/7/04 for this sampling event.
(c) DS3 was taken on 1/12/05 for this sampling event.
NA = not analyzed; BL = baseline sampling.
Lead action level = 15 µg/L; copper action level = 1.3 mg/L
The unit for analytical parameters is µg/L except for pH (S.U.) alkalinity (mg/L [as $CaCO_3$])

4.6 System Costs

The cost-effectiveness 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 included the tracking of capital costs such as equipment, engineering, and installation costs and O&M costs such as media replacement and disposal, chemical supply, electrical power use, and labor.

4.6.1 Capital Costs. The capital investment for the Climax system was $249,081 (Table 4-11), which included $137,970 for equipment, $39,344 for engineering, and $71,767 for installation. The equipment costs include the costs for the Macrolite® media, contact tanks, filtration skid, instrumentation and controls, labor (including activities for the system shakedown), and system warranty. The equipment costs were 55% of the total capital investment. The engineering cost included the costs for preparing a process design report and the required engineering plans, including a general arrangement drawing, piping and instrumentation diagrams (P&IDs), interconnecting piping layouts, tank fill details, a schematic of the PLC panel, an electrical on-line diagram, and other associated drawings. After certified by a Minnesota-registered professional engineer (PE), the plans were submitted to the MDH for permit review and approval. The engineering costs were 16% of the total capital investment.

Table 4-11. Summary of Capital Investment for the Climax, MN, Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
Media, Filter Skid, and Tanks	1	$66,210	–
Air Compressor	1	$2,346	–
Control Panel	1	$11,837	–
Additional Flowmeter/Totalizers	1	$2,622	–
Labor	–	$43,005	–
Warranty	–	$11,950	–
Equipment Total	–	**$137,970**	**55%**
Engineering Costs			
Labor	–	$38,094	–
Subcontractor	–	$1,250	–
Engineering Total	–	**$39,344**	**16%**
Installation Costs			
Labor	–	$12,914	–
Travel	–	$6,163	–
Subcontractor	–	$52,690	–
Installation Total	–	**$71,767**	**29%**
Total Capital Investment	–	**$249,081**	**100%**

The installation costs included the costs for labor and materials for system unloading and anchoring, plumbing, and mechanical and electrical connections. The installation costs were 29% of the total capital investment.

The total capital cost of $249,081 and equipment cost of $137,900 were converted to a unit cost of $0.23/1,000 gal and $0.13/1,000 gal, respectively, using a capital recovery factor (CRF) of 0.06722 based on a 3% interest rate and a 20-year return period (Chen et al., 2004). These calculations assumed that the system operated 24 hrs a day, 7 days a week, at the system design flowrate of 140 gpm. The system operated only 5.3 hrs a day and produced 6,758,000 gal of water during the six month period. At this reduced usage rate, the total unit cost and equipment-only unit cost were increased to $1.32/1,000 gal and $0.73/1,000 gal, respectively. Using the system's rated capacity of 140 gpm (201,600 gpd), the capital cost was $1,779 per gpm ($1.24 per gpd) and equipment-only cost was $986 per gpm ($0.68 per gpd). These calculations did not include the cost of the building construction.

A 22-ft × 24-ft building was built as an addition onto the existing concrete block well house for $88,256. The building walls were constructed with a wood stud frame and 24-gauge pre-fabricated metal wall panels and set on a 6-inch-thick concrete slab floor with footings. The building also was equipped with an insulated, 10-ft-wide overhead door. The building construction cost includes all of the required insulation, mechanical, and electrical work. The building was heated with a 60,000 British Thermal Units per hour (BTU-hr) heater. The connection to the existing water main required 16 linear ft of 6-inch-diameter C900 pipe and cost $4,650. The initial budget called for $6,730 for connection to the sanitary sewer with 145 ft of 6-inch-diameter PVC pipe. However, after plan review by the MDH, a code requirement was identified to complete the sanitary sewer connection at a distance greater than 50 ft from the wellhead. An underground storage tank was placed at a distance of 50 ft from the well house to hold the backwash water prior to pumping to the sewer. The cost for this change was approximately $12,000.

4.6.2 Operation and Maintenance Costs. O&M costs include primarily costs associated with chemical supply, electricity, and labor. These costs are summarized in Table 4-12. Since chlorination was performed prior to this demonstration study, the incremental cost for the sodium hypochlorite (NaOCl) solution was assumed to be negligible. The usage rate for the ferric chloride stock solution was approximately 75 gal or 853 pounds per year. Incremental electrical power consumption associated with the increased total dynamic head was assumed to be negligible. The power demand was based on vendor specifications for the PLC and air compressor and will be verified with utility bills from the site during the next reporting period. The routine, non-demonstration related labor activities consumed about 30 min per day, as noted in Section 4.4.4. Based on this time commitment and a labor rate of $21/hr, the labor cost was $0.22/1,000 gal of water treated. In sum, the total O&M cost was approximately $0.27/1,000 gal. The O&M costs included estimates of the projected chemical usage, electrical usage, and labor rates and will be verified during the next reporting period.

Table 4-12. O&M Costs for the Climax, MN, Treatment System

Cost Category	Value	Assumptions
Projected volume processed (kgal)	6,758	From 08/11/04 through 02/28/05 (see Table 4-4)
Chemical Usage		
Projected chemical cost ($/1,000 gal)	$0.03	Ferric chloride usage of 75 gal or 853 pounds per year; Unit cost was $0.40/lbs for 35% ferric chloride in a 600 lb drum.
Electricity		
Projected power use ($/1,000 gal)	$0.02	Based on estimate of power usage for PLC and air compressor
Labor		
Average weekly labor (hrs)	2.5	30 min/day; Five days a week
Projected labor cost ($/1,000 gal)	$0.22	Labor rate = $21/hr
Total O&M Cost/1,000 gal	**$0.27**	–

5.0 REFERENCES

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APPENDIX A

OPERATIONAL DATA

US EPA Arsenic Demonstration Project at Climax, MN - Daily System Operation Log Sheet

Daily System Operation																								
		Well #1		Well#2		Volume to Treatment			Pressure Filtration							Volume to Distribution				Backwash				Iron Solution
Week No.	Date	Hour Meter (hr)	Daily Operational (hr)	Hour Meter (hr)	Daily Operational (hr)	Totalizer (kgal)	Daily Volume (kgal)	Ave. Flowrate (gpm)	IN (psig)	TA (psig)	TB (psig)	OUT (psig)	ΔP across Tank A (psig)	ΔP across Tank B (psig)	ΔP across System (psig)	Flowrate (gpm)	Totalizer (kgal)	Daily Volume (kgal)	Ave. Flowrate (gpm)	TA No.[a]	TB No.[a]	Wastewater Produced (kgal)	Time Since Last BW (hr)	Weight (lbs)
	08/16/04	NA	5.0	NA	NA	307	NA	NA	70	60	60	41	10	10	29	110	NA	NA	NA	NA	NA	NA	NA	NA
	08/17/04	57:10	NA	NA	NA	348	41	NA	71	59	59	41	12	12	30	104	367	NA	NA	NA	NA	NA	NA	NA
	08/18/04	64:56	7.8	NA	NA	395	47	100	68	60	60	41	8	8	27	107	414	47	101	NA	NA	NA	NA	NA
2	08/19/04	68:54	4.0	NA	NA	418	23	98	68	60	60	41	8	8	27	108	439	24	103	NA	NA	NA	NA	NA
	08/20/04	76:33	7.6	NA	NA	466	48	104	65	65	62	41	0	3	24	124	488	50	108	NA	NA	NA	NA	NA
	08/21/04	85:14	8.7	NA	NA	523	57	109	65	65	65	41	0	0	24	122	550	61	118	NA	NA	NA	NA	NA
	08/22/04	95:52	10.6	NA	NA	591	68	106	67	53	53	41	14	14	26	120	623	73	115	NA	NA	NA	NA	NA
	08/23/04	105:04	9.2	NA	NA	645	55	99	64	56	56	40	8	8	24	119	680	58	104	NA	NA	NA	NA	NA
	08/24/04	114:27	9.4	NA	NA	705	60	107	64	54	54	41	10	10	23	117	745	65	115	NA	NA	NA	NA	NA
	08/25/04	119:40	5.2	NA	NA	737	32	103	65	53	53	41	12	12	24	118	780	35	112	NA	NA	NA	NA	NA
3	08/26/04	124:11	4.5	NA	NA	765	28	103	62	55	55	40	7	7	22	118	809	29	107	NA	NA	NA	NA	NA
	08/27/04	129:03	4.9	NA	NA	797	32	109	63	55	56	41	8	7	22	117	843	34	116	NA	NA	NA	NA	NA
	08/28/04	135:06	6.0	NA	NA	836	39	107	65	55	56	41	10	9	24	118	884	42	114	NA	NA	NA	NA	NA
	08/29/04	142:02	6.9	NA	NA	880	45	107	63	55	55	40	8	8	23	119	931	47	112	NA	NA	NA	NA	NA
	08/30/04	145:20	3.3	NA	NA	902	21	107	64	56	56	41	8	8	23	119	953	22	111	NA	NA	NA	NA	NA
	08/31/04	160:06	14.8	NA	NA	994	93	105	65	56	56	41	9	9	24	117	1053	100	113	NA	NA	NA	NA	NA
	09/01/04	NA	NA	166:07	6.0	1037	43	119	69	60	60	41	9	9	28	139	1098	45	124	NA	NA	24.5	NA	NA
4	09/02/04	NA	NA	175:42	9.6	1109	72	125	74	61	61	41	13	13	33	135	1175	77	134	NA	NA	24.5	NA	NA
	09/03/04	NA	NA	180:04	4.4	1142	32	124	72	59	59	41	13	13	31	138	1208	34	129	NA	NA	24.5	NA	NA
	09/04/04	NA	NA	183:52	3.8	1167	25	110	69	59	59	41	10	10	28	144	1237	29	126	NA	NA	26.2	NA	NA
	09/05/04	NA	NA	189:11	5.3	1211	44	138	69	59	59	41	10	10	28	143	1281	44	136	NA	NA	26.2	NA	NA
	09/06/04	NA	NA	192:56	3.8	1239	28	125	73	62	62	41	11	11	32	138	1310	30	132	NA	NA	26.2	NA	NA
	09/07/04	NA	NA	199:11	6.2	1285	46	122	73	64	64	41	9	9	32	136	1359	49	131	NA	NA	27.8	NA	NA
	09/08/04	NA	NA	202:33	3.4	1310	26	126	71	61	61	41	10	10	30	144	1386	27	133	NA	NA	27.8	NA	NA
5	09/09/04	NA	NA	206:25	3.9	1339	29	125	72	59	59	41	13	13	31	136	1416	30	127	NA	NA	27.8	NA	NA
	09/10/04	NA	NA	212:00	5.6	1382	43	128	72	62	62	41	10	10	31	139	1460	45	133	NA	NA	29.5	NA	NA
	09/11/04	NA	NA	215:51	3.8	1410	28	122	73	62	62	40	11	11	33	137	1491	31	134	NA	NA	29.5	NA	NA
	09/12/04	NA	NA	219:10	3.3	1435	25	125	72	59	59	41	13	13	31	141	1517	26	131	NA	NA	31.2	NA	NA
	09/13/04	NA	NA	225:08	6.0	1480	45	127	73	62	62	41	11	11	32	139	1565	48	133	NA	NA	31.2	NA	NA
	09/14/04	NA	NA	229:29	4.4	1515	35	134	73	63	63	41	10	10	32	138	1600	35	135	NA	NA	31.2	NA	NA
	09/15/04	NA	NA	234:02	4.6	1547	32	117	74	60	60	41	14	14	33	137	1634	34	124	NA	NA	32.9	NA	NA
6	09/16/04	NA	NA	238:21	4.3	1580	32	124	73	60	60	41	13	13	32	138	1668	34	132	NA	NA	32.9	NA	NA
	09/17/04	NA	NA	241:28	3.1	1603	23	123	72	61	61	41	11	11	31	138	1692	24	128	NA	NA	34.5	NA	NA
	09/18/04	NA	NA	247:07	5.6	1646	43	127	70	60	60	41	10	10	29	139	1737	45	133	NA	NA	34.5	NA	NA
	09/19/04	NA	NA	250:33	3.4	1671	26	124	72	60	60	41	12	12	31	139	1764	27	131	NA	NA	34.5	NA	NA
	09/20/04	NA	NA	254:20	3.8	1700	29	128	70	60	60	41	10	10	29	142	1793	30	130	21	24	36.3	NA	NA
	09/21/04	NA	NA	259:12	4.9	1737	37	127	70	60	61	41	10	9	29	138	1832	38	131	21	24	36.3	NA	NA
	09/22/04	NA	NA	263:29	4.3	1770	32	126	73	59	59	41	14	14	32	140	1865	33	129	22	25	38.1	NA	NA
7	09/23/04	NA	NA	264:55	1.4	1781	11	128	69	60	60	41	9	9	28	144	1876	11	124	22	25	38.1	NA	NA
	09/24/04	NA	NA	272:07	7.2	1836	55	128	70	61	61	41	9	9	29	140	1934	58	135	22	25	38.1	NA	NA
	09/25/04	NA	NA	276:53	4.8	1872	36	125	73	62	62	41	11	11	32	139	1971	37	129	22	25	38.1	NA	NA
	09/26/04	NA	NA	281:45	4.9	1908	37	125	74	63	63	41	11	11	33	138	2009	38	130	23	26	39.8	NA	NA
	09/27/04	NA	NA	286:28	4.7	1944	36	127	70	60	60	41	10	10	29	143	2046	37	131	23	26	39.8	NA	NA
	09/28/04	NA	NA	291:15	4.8	1980	36	125	73	61	61	40	12	12	33	138	2082	36	126	23	26	39.8	NA	NA
	09/29/04	NA	NA	296:02	4.8	2016	36	126	74	64	64	41	10	10	33	136	2118	36	127	24	27	41.5	NA	NA
8	09/30/04	NA	NA	300:41	4.6	2052	35	127	70	60	60	41	10	10	29	138	2154	36	128	24	27	41.5	NA	NA
	10/01/04	306:14	5.6	NA	NA	2087	35	106	64	55	55	41	9	9	23	118	2190	36	108	24	27	41.5	NA	NA
	10/02/04	310:51	4.6	NA	NA	2117	30	110	63	54	54	41	9	9	22	123	2221	31	113	25	28	43.3	NA	NA
	10/03/04	314:27	3.6	NA	NA	2132	15	69	64	55	55	41	9	9	23	122	2252	31	144	25	28	43.3	NA	NA
	10/04/04	320:54	6.5	NA	NA	2172	40	103	62	55	55	41	7	7	21	124	2287	35	90	26	29	45.0	NA	NA
	10/05/04	327:28	6.6	NA	NA	2225	53	135	65	55	55	41	10	10	24	118	2332	45	114	26	29	45.0	NA	NA
	10/06/04	332:55	5.5	NA	NA	2260	35	107	65	56	56	41	9	9	24	118	2368	36	111	26	29	45.0	NA	NA
9	10/07/04	337:44	4.8	NA	NA	2291	31	107	62	55	55	41	7	7	21	124	2400	32	110	27	30	46.7	NA	NA
	10/08/04	343:48	6.1	NA	NA	2329	38	103	63	56	56	41	7	7	22	122	2439	39	107	27	30	46.7	NA	NA
	10/09/04	349:09	5.3	NA	NA	2365	37	114	65	56	56	41	9	9	24	118	2477	38	119	27	30	46.7	NA	NA
	10/10/04	354:45	5.6	NA	NA	2402	37	110	62	55	55	41	7	7	21	123	2516	38	113	28	31	48.5	NA	NA
	10/11/04	360:22	5.6	NA	NA	2439	37	108	62	56	56	40	6	6	22	122	2553	38	112	28	31	48.5	NA	NA
	10/12/04	366:52	6.5	NA	NA	2481	43	110	62	56	56	40	6	6	22	122	2596	43	110	29	32	50.2	NA	NA
	10/13/04	371:34	4.7	NA	NA	2512	30	107	64	56	56	40	8	8	24	119	2628	31	111	29	32	50.2	NA	NA
10	10/14/04	376:17	4.7	NA	NA	2541	30	105	63	56	56	40	7	7	23	123	2658	30	107	30	33	51.9	NA	NA
	10/15/04	382:48	6.5	NA	NA	2584	43	110	63	56	56	40	7	7	23	121	2702	44	113	30	33	51.9	NA	NA
	10/16/04	388:00	5.2	NA	NA	2610	26	83	64	56	56	40	8	8	24	121	2728	26	83	30	33	51.9	NA	NA
	10/17/04	425:34	37.6	NA	NA	2621	11	5	62	54	54	40	8	8	22	124	2740	12	5	31	34	53.6	NA	NA
	10/18/04	434:34	9.0	NA	NA	2679	58	107	65	55	55	41	10	10	24	124	2801	61	113	32	35	55.3	NA	NA
	10/19/04	441:57	7.4	NA	NA	2693	15	33	65	55	55	41	10	10	24	122	2816	15	34	32	35	55.3	NA	NA
	10/20/04	448:30	6.6	NA	NA	2735	42	107	62	54	54	40	8	8	22	125	2859	43	109	33	36	57.0	NA	NA
11	10/21/04	451:25	2.9	NA	NA	2755	19	110	63	56	56	41	7	7	22	120	2879	20	114	33	36	57.0	NA	NA
	10/22/04	454:22	2.9	NA	NA	2774	19	108	65	56	56	40	9	9	25	120	2899	20	112	34	37	60.2	NA	NA
	10/23/04	456:27	2.1	NA	NA	2784	10	80	63	56	56	40	7	7	23	118	2909	10	80	Fail			NA	NA
	10/24/04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

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

Daily System Operation																								
		Well #1		Well#2		Volume to Treatment			Pressure Filtration							Volume to Distribution				Backwash				Iron Solution
Week No.	Date	Hour Meter (hr)	Daily Operational (hr)	Hour Meter (hr)	Daily Operational (hr)	Totalizer (kgal)	Daily Volume (kgal)	Ave. Flowrate (gpm)	IN (psig)	TA (psig)	TB (psig)	OUT (psig)	ΔP across Tank A (psig)	ΔP across Tank B (psig)	ΔP across System (psig)	Flowrate (gpm)	Totalizer (kgal)	Daily Volume (kgal)	Ave. Flowrate (gpm)	TA No.[(a)]	TB No.[(a)]	Wastewater Produced (kgal)	Time Since Last BW (hr)	Weight (lbs)
	10/25/04	455:22	NA	NA	NA	2806	NA	NA	64	56	56	40	8	8	24	122	2933	NA	NA	35	38	62.0	NA	NA
	10/26/04	464:32	9.2	NA	NA	2832	25	46	64	56	56	40	8	8	24	121	2960	27	48	35	38	62.0	NA	NA
	10/27/04	478:05	13.6	NA	NA	2859	27	33	63	52	52	40	11	11	23	120	2987	28	34	35	38	62.0	NA	NA
12	10/28/04	486:00	7.9	NA	NA	2909	51	106	61	52	54	40	9	7	21	125	3040	53	111	36	39	63.8	NA	NA
	10/29/04	501:06	15.1	NA	NA	2937	28	31	62	53	53	40	9	9	22	122	3070	30	33	36	39	63.8	NA	NA
	10/30/04	508:00	6.9	NA	NA	2985	47	114	62	53	53	40	9	9	22	121	3120	50	120	36	39	63.8	NA	NA
	10/31/04	512:19	4.3	NA	NA	3013	28	109	63	56	56	40	7	7	23	120	3147	28	106	37	40	65.7	NA	NA
	11/01/04	NA	NA	517:15	4.9	3051	38	128	67	56	58	40	11	9	27	142	3187	40	136	37	40	65.7	NA	NA
	11/02/04	NA	NA	522:51	5.6	3094	43	129	67	55	55	40	12	12	27	144	3232	45	133	38	41	67.5	NA	NA
	11/03/04	NA	NA	526:57	4.1	3127	32	132	67	56	56	40	11	11	27	143	3265	33	135	38	41	67.5	NA	NA
13	11/04/04	NA	NA	531:17	4.3	3160	34	130	68	56	56	40	12	12	28	141	23[(b)]	NA	NA	38	41	67.5	NA	NA
	11/05/04	NA	NA	535:29	4.2	3193	32	128	68	56	56	40	12	12	28	140	56	33	131	39	42	69.4	NA	NA
	11/06/04	NA	NA	541:19	5.8	3240	47	135	67	55	55	40	12	12	27	144	105	48	137	39	42	69.4	NA	NA
	11/07/04	NA	NA	545:37	4.3	3272	32	125	67	55	55	40	12	12	27	143	139	34	132	39	42	69.4	NA	NA
	11/08/04	NA	NA	549:45	4.1	3305	32	130	68	55	58	40	13	10	28	142	171	33	132	40	43	71.2	NA	NA
	11/09/04	NA	NA	554:40	4.9	3343	39	131	68	55	58	40	13	10	28	142	211	40	135	40	43	71.2	NA	NA
	11/10/04	NA	NA	560:18	5.6	3386	43	128	71	55	59	40	16	12	31	142	256	45	132	41	44	73.0	NA	NA
14	11/11/04	NA	NA	563:01	2.7	3408	21	131	71	55	59	40	16	12	31	141	278	22	136	41	44	73.0	NA	NA
	11/12/04	NA	NA	568:34	5.6	3451	43	129	70	57	58	40	13	12	30	140	323	45	134	41	44	73.0	NA	NA
	11/13/04	NA	NA	573:44	5.2	3500	49	159	71	55	55	41	16	16	30	144	364	42	134	42	45	74.8	NA	NA
	11/14/04	NA	NA	576:25	2.7	3513	13	82	71	55	56	40	16	15	31	142	386	22	136	42	45	74.8	NA	NA
	11/15/04	NA	NA	581:38	5.2	3553	40	127	71	56	58	40	15	13	31	140	428	42	135	42	45	74.8	NA	NA
	11/16/04	NA	NA	585:47	4.1	3586	33	133	68	56	56	40	12	12	28	145	462	34	135	43	46	77.7	NA	NA
	11/17/04	NA	NA	590:53	5.1	3626	40	130	68	56	56	40	12	12	28	144	503	41	134	43	46	77.7	NA	NA
15	11/18/04	NA	NA	594:23	3.5	3653	27	130	67	55	57	40	12	10	27	145	530	27	128	45	48	82.9	NA	NA
	11/19/04	NA	NA	600:02	5.6	3699	46	136	67	55	56	40	12	11	27	144	576	46	137	45	48	82.9	NA	NA
	11/20/04	NA	NA	602:56	2.9	3721	22	125	68	56	57	40	12	11	28	143	600	24	136	45	48	82.9	NA	NA
	11/21/04	NA	NA	608:33	5.6	3765	44	131	67	55	56	40	12	11	27	144	608	9	26	45	48	82.9	NA	NA
	11/22/04	NA	NA	611:29	2.9	3788	23	131	67	56	56	40	11	11	27	144	669	61	347	46	49	85.1	NA	NA
	11/23/04	NA	NA	617:06	5.6	3832	44	130	68	57	58	40	11	10	28	142	714	45	134	46	49	85.1	NA	NA
	11/24/04	NA	NA	620:36	3.5	3860	28	134	67	55	56	40	12	11	27	144	743	28	134	47	50	86.8	NA	NA
16	11/25/04	NA	NA	625:37	5.0	3899	39	130	67	55	56	40	12	11	27	143	784	41	138	47	50	86.8	NA	NA
	11/26/04	NA	NA	625:45	0.1	3900	1	137	67	56	57	40	11	10	27	141	784	0	0	47	50	86.8	NA	NA
	11/27/04	NA	NA	629:00	3.2	3925	25	128	67	56	59	41	11	8	26	145	810	26	133	49	51	90.1	NA	NA
	11/28/04	NA	NA	633:41	4.7	3962	37	132	67	57	59	40	10	8	27	142	848	38	135	49	51	90.1	NA	NA
	11/29/04	NA	NA	638:16	4.6	3998	36	131	66	55	56	40	11	10	26	145	885	37	135	50	52	91.9	NA	NA
	11/30/04	NA	NA	646:47	8.5	4041	44	86	70	56	58	40	14	12	30	141	927	42	82	50	52	91.9	NA	NA
	12/01/04	649:11	2.4	NA	NA	4077	36	249	62	54	55	40	8	7	22	123	963	36	249	50	52	91.9	NA	NA
17	12/02/04	655:02	5.9	NA	NA	4117	39	112	62	55	57	40	7	5	22	121	1002	39	111	51	53	93.7	NA	NA
	12/03/04	660:49	5.8	NA	NA	4156	39	113	63	56	58	40	7	5	23	124	1040	39	112	51	53	93.7	NA	NA
	12/04/04	665:04	4.2	NA	NA	4184	28	111	63	56	58	40	7	5	23	121	1068	28	110	51	53	93.7	NA	NA
	12/05/04	668:25	3.3	NA	NA	4207	23	115	60	51	53	40	9	7	20	128	1091	23	114	52	54	95.5	NA	NA
	12/06/04	674:11	5.8	NA	NA	4247	39	114	60	51	53	40	9	7	20	125	1132	41	117	52	54	95.5	NA	NA
	12/07/04	678:46	4.6	NA	NA	4277	31	112	61	52	54	40	9	7	21	123	1163	31	113	53	55	97.2	NA	NA
	12/08/04	684:43	6.0	NA	NA	4318	41	115	60	52	54	40	8	6	20	125	1206	42	119	53	55	97.2	NA	NA
18	12/09/04	690:37	5.9	NA	NA	4358	40	112	60	52	53	40	8	7	20	124	1247	41	116	53	55	97.2	NA	NA
	12/10/04	693:44	3.1	NA	NA	4379	21	110	59	51	52	40	8	7	19	126	1277	30	161	54	56	99.0	NA	NA
	12/11/04	699:36	5.9	NA	NA	4420	41	118	60	52	53	40	8	7	20	123	1310	33	93	54	56	99.0	NA	NA
	12/12/04	705:29	5.9	NA	NA	4458	38	109	64	52	53	40	12	11	24	119	1350	41	116	54	56	99.0	NA	NA
	12/13/04	708:32	3.0	NA	NA	4480	21	116	60	51	53	40	9	7	20	128	1372	22	119	55	57	100.7	48	NA
	12/14/04	713:36	5.1	NA	NA	4514	35	114	61	52	53	40	9	8	21	124	1408	36	117	55	57	100.7	32	NA
	12/15/04	721:00	7.4	NA	NA	4563	49	111	62	53	54	40	9	8	22	121	1459	51	116	55	57	100.7	47.5	NA
19	12/16/04	726:20	5.3	NA	NA	4600	37	116	61	51	53	40	10	8	21	125	1497	38	119	56	58	102.5	17	NA
	12/17/04	731:21	5.0	NA	NA	4634	34	113	61	52	55	40	9	6	21	121	1532	35	116	56	58	102.5	35	NA
	12/18/04	735:00	3.7	NA	NA	4659	25	114	60	51	52	40	9	8	20	126	1556	24	110	57	59	104.2	8	NA
	12/19/04	741:03	6.0	NA	NA	4701	42	115	60	51	52	40	9	8	20	123	1601	45	124	57	59	104.2	24	NA

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

Daily System Operation																								
		Well #1		Well#2		Volume to Treatment			Pressure Filtration							Volume to Distribution				Backwash				Iron Solution
Week No.	Date	Hour Meter (hr)	Daily Operational (hr)	Hour Meter (hr)	Daily Operational (hr)	Totalizer (kgal)	Daily Volume (kgal)	Ave. Flowrate (gpm)	IN (psig)	TA (psig)	TB (psig)	OUT (psig)	ΔP across Tank A (psig)	ΔP across Tank B (psig)	ΔP across System (psig)	Flowrate (gpm)	Totalizer (kgal)	Daily Volume (kgal)	Ave. Flowrate (gpm)	TA No.[a]	TB No.[a]	Wastewater Produced (kgal)	Time Since Last BW (hr)	Weight (lbs)
	12/20/04	746:19	5.3	NA	NA	4737	36	112	61	52	54	40	9	7	21	122	1638	37	116	57	59	104.2	42	NA
	12/21/04	751:09	4.8	NA	NA	4770	34	116	60	51	54	40	9	6	20	125	1671	33	115	58	60	106.0	17	NA
	12/22/04	755:21	4.2	NA	NA	4800	30	118	61	52	54	40	9	7	21	123	1701	30	119	58	60	106.0	36	NA
20	12/23/04	761:00	5.6	NA	NA	4839	39	115	61	51	53	40	10	8	21	125	1740	39	116	59	61	107.8	10	NA
	12/24/04	766:25	5.4	NA	NA	4875	36	112	61	51	53	40	10	8	21	124	1778	38	117	59	61	107.8	28	NA
	12/25/04	770:48	4.4	NA	NA	4905	30	112	62	53	54	40	9	8	22	122	1808	30	114	59	61	107.8	46	NA
	12/26/04	775:10	4.4	NA	NA	4935	31	116	60	51	52	40	9	8	20	125	1839	31	118	60	62	109.5	16	NA
	12/27/04	779:52	4.7	NA	NA	4969	34	119	61	52	54	40	9	7	21	123	1873	33	118	60	62	109.5	36	NA
	12/28/04	785:36	5.7	NA	NA	5007	38	111	60	51	52	40	9	8	20	126	1912	39	114	61	63	111.3	11	NA
	12/29/04	789:43	4.1	NA	NA	5035	28	114	60	51	52	40	9	8	20	123	1941	29	116	61	63	111.3	31	NA
21	12/30/04	795:57	6.2	NA	NA	5077	41	111	62	52	53	41	10	9	21	121	1982	42	111	61	63	111.3	46	NA
	12/31/04	799:06	3.2	NA	NA	5099	22	118	60	52	53	40	8	7	20	130	2005	23	122	63	64	112.2	0	NA
	01/01/05	804:00	4.9	NA	NA	5134	35	119	60	52	53	40	8	7	20	124	2041	35	120	63	64	113.9	23	NA
	01/02/05	809:14	5.2	NA	NA	5169	35	111	61	53	54	40	8	7	21	122	2076	35	113	63	64	113.9	34	NA
	01/03/05	NA	NA	811:31	2.3	5188	19	139	65	53	56	40	12	9	25	148	2092	16	118	64	65	115.6	7	388
	01/04/05	NA	NA	817:14	5.7	5233	45	132	72	54	57	40	18	15	32	143	2139	47	136	64	65	115.6	24	279
	01/05/05	NA	NA	820:43	3.5	5258	25	122	72	51	55	40	21	17	32	140	2165	26	126	64	65	115.6	43	212
22	01/06/05	NA	NA	826:02	5.3	5298	40	125	70	54	57	40	16	13	30	141	2204	38	120	65	66	117.6	17	106
	01/07/05	NA	NA	830:17	4.3	5331	33	130	73	55	57	40	18	16	33	140	2236	33	128	66	67	119.3	1	52
	01/08/05	NA	NA	836:19	6.0	5378	47	129	67	54	57	40	13	10	27	143	2284	47	130	66	67	119.3	31	362
	01/09/05	NA	NA	840:39	4.3	5408	30	115	67	54	56	40	13	11	27	139	2313	30	114	67	68	122.6	8	332
	01/10/05	NA	NA	844:48	4.2	5441	33	133	68	56	58	40	12	10	28	143	2346	32	130	68	69	124.2	17	306
	01/11/05	NA	NA	848:12	3.4	5468	26	129	69	52	56	40	17	13	29	141	2371	26	125	68	69	124.2	37	290
	01/12/05	NA	NA	854:40	6.5	5519	51	133	68	54	57	40	14	11	28	143	2423	52	134	69	70	126.0	15	254
23	01/13/05	NA	NA	859:03	4.4	5552	33	126	68	56	57	40	12	11	28	141	2457	34	131	69	70	126.0	34	228
	01/14/05	NA	NA	863:07	4.1	5583	31	127	71	57	59	40	14	12	31	139	2489	31	128	70	71	126.9	5	228
	01/15/05	NA	NA	866:18	3.2	5608	25	132	67	54	56	40	13	11	27	142	2514	25	131	71	72	127.6	18	216
	01/16/05	NA	NA	871:16	5.0	5648	40	134	70	56	58	40	14	12	30	139	2553	39	132	71	72	127.6	36	188
	01/17/05	NA	NA	876:31	5.3	5688	40	127	67	54	57	40	13	10	27	144	2595	42	133	72	73	128.6	16	158
	01/18/05	NA	NA	881:34	5.1	5727	39	130	71	54	57	40	17	14	31	138	2634	39	129	72	73	128.6	32	132
	01/19/05	NA	NA	885:06	3.5	5754	27	126	66	55	57	40	11	9	26	144	2661	27	129	73	74	129.6	4	113
24	01/20/05	NA	NA	891:35	6.5	5806	52	133	72	56	58	40	16	14	32	138	2714	53	135	73	74	129.6	20	78
	01/21/05	NA	NA	894:34	3.0	5828	22	121	73	56	58	40	17	15	33	138	2737	23	130	73	74	129.6	43	61
	01/22/05	NA	NA	900:45	6.2	5873	46	124	70	56	59	40	14	11	30	140	2783	46	124	74	75	131.4	16	456
	01/23/05	NA	NA	904:19	3.6	5901	28	129	71	57	59	40	14	12	31	140	2811	28	132	74	75	131.4	35	436
	01/24/05	NA	NA	908:35	4.3	5934	33	129	68	55	57	40	13	11	28	144	2845	33	130	75	76	132.4	0	412
	01/25/05	NA	NA	913:30	4.9	5972	38	130	69	55	57	40	14	12	29	140	2885	40	136	75	76	132.4	24	384
	01/26/05	NA	NA	917:03	3.6	5999	27	126	71	56	58	40	15	13	31	137	2912	28	131	75	76	132.4	44	366
25	01/27/05	NA	NA	920:18	3.2	6025	26	133	68	56	57	40	12	11	28	143	2939	27	137	76	77	133.3	16	348
	01/28/05	NA	NA	926:20	6.0	6072	47	128	74	54	58	40	20	16	34	134	2987	48	132	76	77	133.3	35	316
	01/29/05	NA	NA	930:17	3.9	6102	30	129	68	54	56	40	14	12	28	144	3018	32	133	78	79	134.4	0	294
	01/30/05	NA	NA	933:46	3.5	6130	28	134	68	54	57	40	14	11	28	141	3047	29	137	78	79	135.3	19	275
	01/31/05	NA	NA	936:44	3.0	6153	23	127	73	53	54	40	20	19	33	138	3070	23	128	79	79	136.3	#1:0; #2:38	256
	02/01/05	944:35	7.9	NA	NA	6206	53	113	60	53	54	40	7	6	20	131	3124	55	116	82	81	140.9	0	213
	02/02/05	948:26	3.8	NA	NA	6232	26	112	61	51	52	40	10	9	21	127	3152	28	119	82	81	140.9	19	192
26	02/03/05	952:56	4.5	NA	NA	6262	30	112	64	50	52	40	14	12	24	120	3182	30	112	82	81	140.9	37	168
	02/04/05	959:14	6.3	NA	NA	6304	42	110	60	53	53	40	7	7	20	130	3226	44	116	83	82	141.9	6	135
	02/05/05	964:36	5.4	NA	NA	6339	36	110	66	51	53	40	15	13	26	115	3262	36	112	83	82	141.9	25	106
	02/06/05	968:30	3.9	NA	NA	6364	25	106	67	53	55	40	14	12	27	113	11[b]	25	106	83	82	141.9	43	85
	02/07/05[c]	973:47	5.3	NA	NA	6399	35	111	62	52	54	40	10	8	22	122	47	36	112	84	83	143.0	13	58
	02/08/05	978:58	5.2	NA	NA	6433	34	111	63	53	54	40	10	9	23	119	82	35	113	84	83	143.0	30	476
	02/09/05	983:41	4.7	NA	NA	6566	NA	NA	60	52	53	40	8	7	20	131	115	33	116	85	84	143.9	1	451
27	02/10/05	987:30	3.8	NA	NA	6591	NA	NA	64	53	55	40	11	9	24	126	141	27	116	85	84	143.9	21	430
	02/11/05	990:46	3.3	NA	NA	6513	NA	NA	65	48	51	40	17	14	25	117	163	21	108	85	84	143.9	42	411
	02/12/05	997:15	6.5	NA	NA	6555	43	110	60	50	51	40	10	9	20	130	208	45	115	89	86	150.6	14	377
	02/13/05	1001:48	4.5	NA	NA	6585	30	110	63	50	52	40	13	11	23	121	239	32	115	89	86	150.6	32	352
	02/14/05	1009:43	7.9	NA	NA	6635	50	104	60	50	52	40	10	8	20	131	291	52	110	90	87	151.6	7	311
	02/15/05	1014:10	4.4	NA	NA	6667	32	120	63	51	53	40	12	10	23	122	324	33	122	90	87	151.6	20	286
	02/16/05	1018:34	4.4	NA	NA	6697	30	115	60	50	51	40	10	9	20	130	355	31	119	91	88	152.6	17	262
28	02/17/05	1023:15	4.7	NA	NA	6728	31	109	63	53	54	40	10	9	23	121	387	32	114	91	88	152.6	37	238
	02/18/05	1027:57	4.7	NA	NA	6760	32	112	60	51	52	40	9	8	20	131	421	34	120	92	89	153.6	8	211
	02/19/05	1032:50	4.9	NA	NA	6792	32	110	64	53	54	40	11	10	24	127	451	30	103	92	89	153.6	27	184
	02/20/05	1038:07	5.3	NA	NA	6825	33	103	66	50	52	40	16	14	26	114	489	37	118	92	89	153.6	44	156
	02/21/05	1043:22	5.3	NA	NA	6859	35	110	62	52	53	40	10	9	22	123	524	35	112	93	90	154.6	14	128
	02/22/05	1047:14	3.9	NA	NA	6880	21	90	63	52	54	40	11	9	23	120	545	21	89	93	90	154.6	32	108
	02/23/05	1051:22	4.1	NA	NA	6907	27	108	63	55	57	40	8	6	23	115	572	28	111	94	91	155.7	3	85
29	02/24/05	1055:01	3.7	NA	NA	6932	25	114	59	52	52	40	7	7	19	130	598	26	119	94	91	155.7	23	66
	02/25/05	1058:55	3.9	NA	NA	6958	26	111	65	51	53	40	14	12	25	115	625	27	115	94	91	155.7	43	45
	02/26/05	1066:00	7.1	NA	NA	7005	48	112	63	52	54	40	11	9	23	122	673	48	114	95	92	157.6	10	436
	02/27/05	1070:27	4.5	NA	NA	7036	31	115	59	50	51	40	9	8	19	130	705	32	120	96	93	159.2	20	411
30	02/28/05	1074:47	4.3	NA	NA	7065	29	111	63	53	54	40	10	9	23	124	735	30	115	96	93	159.2	38	388

Note:
(a) Cumulative count of number of backwashes for vessel A and B.
(b) Digital totalizer meter re-set itself automatically to zero.
(c) From 02/07/05 forward corrected labeling of well numbers by operator.

APPENDIX B

ANALYTICAL DATA

Table B-1. Analytical Results from Long-Term Sampling, Climax, Minnesota

Sampling Date		08/11/04			08/18/04[c]				08/24/04[d]				08/31/04[f]			
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Alkalinity	mg/L[a]	323	311	295	303	299	295	299	316	308	304	312	314	310	310	310
Ammonia	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fluoride	mg/L	0.5	0.5	1.4	–	–	–	–	–	–	–	–	–	–	–	–
NO_3-N	mg/L	<0.04	<0.04	<0.04	–	–	–	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L[b]	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Silica (as SiO_2)	mg/L	28.6	28.2	28.8	29.1	29.1	29.1	28.9	28.5	28.1	28.5	28.4	28.7	28.5	29.1	28.4
Sulfate	mg/L	110	110	110	–	–	–	–	–	–	–	–	–	–	–	–
Turbidity	NTU	6.1	0.6	0.2	6.7	0.8	0.4	0.4	4.9	0.5	0.2	0.3	6.5	1.1	0.6	0.5
pH	S.U.	–	–	–	7.6	7.5	7.6	7.6	7.6	7.5	7.5	7.5	7.6	7.5	7.4	7.4
Temperature	°C	–	–	–	10.1	10.0	10.0	10.1	9.1	10.7	8.8	8.8	8.6	8.9	10.7	11.0
DO	mg/L	–	–	–	2.6	2.6	2.2	2.2	4.1[e]	1.0	1.8	1.8	2.2	2.3	2.1	1.3
ORP	mV	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Free Chlorine	mg/L	–	–	–	–	0.6	0.6	0.6	–	0.6	0.6	0.6	–	0.6	0.6	0.6
Total Chlorine	mg/L	–	–	–	–	3.0	3.0	3.0	–	3.0	3.0	3.0	–	3.0	3.0	3.0
Total Hardness	mg/L[a]	261.6	259.2	259.5	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L[a]	170.1	168.1	168.4	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L[a]	91.5	91.1	91.1	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	35.9	33.8	9.7	37.2	36.9	10.3	10.0	34.0	34.0	9.6	10.1	42.2	44.6	12.0	12.2
As (total soluble)	µg/L	35.7	11.0	9.7	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	0.2	22.8	<0.1	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	33.4	1.0	1.0	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	2.3	10.0	8.7	–	–	–	–	–	–	–	–	–	–	–	–
Total Fe	µg/L	533	516	32.6	620	585	66.4	66.0	430	406	<25	25.5	527	602	<25	<25
Dissolved Fe	µg/L	469	<25	<25	–	–	–	–	–	–	–	–	–	–	–	–
Total Mn	µg/L	117	114	66.2	131	127	75.5	73.0	128	126	68.1	71.9	130	129	77.7	74.0
Dissolved Mn	µg/L	123	65.1	67.1	–	–	–	–	–	–	–	–	–	–	–	–

(a) as $CaCO_3$.
(b) as PO_4.
(c) On-site water quality measurements taken on 8/20/04.
(d) On-site water quality measurements for TA and TB taken on 8/23/04.
(e) Sample possibly aerated during collection.
(f) On-site WQ measurements were taken on 9/03/04.
IN =at the inlet; AC = after contact tanks; TA = after Tank A; TB = after Tank B; TT = after Tanks A and B combined.

Table B-1. Analytical Results from Long-Term Sampling, Climax, Minnesota (Continued)

Sampling Date		09/07/04			09/14/04[c]				09/21/04				09/28/04			
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Alkalinity	mg/L[a]	314	302	302	323	303	307	307	304	304	304	304	316	308	308	308
Ammonia	mg/L	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fluoride	mg/L	0.3	0.3	1.1	–	–	–	–	–	–	–	–	–	–	–	–
NO_3-N	mg/L	<0.04	<0.04	<0.04	–	–	–	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L[b]	<0.1	<0.1	<0.1	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Silica (as SiO_2)	mg/L	28.5	29.0	29.1	29.0	29.3	29.1	28.8	16.8	28.7	28.6	28.4	28.8	28.7	28.4	28.8
Sulfate	mg/L	120	120	120	–	–	–	–	–	–	–	–	–	–	–	–
Turbidity	NTU	4.8	0.6	0.6	6.1	0.9	0.4	0.1	6.5	1.0	0.3	0.6	5.6	0.7	0.3	0.3
pH	S.U.	7.6	7.5	7.4	7.7	7.4	7.4	7.6	7.6	7.5	7.4	7.5	7.5	7.4	7.4	7.4
Temperature	ºC	9.8	9.7	8.6	12.4	10.7	10.6	10.8	9.3	9.3	9.3	9.3	8.4	8.4	8.3	8.3
DO	mg/L	2.8	2.6	1.6	2.5	0.9	0.8	4.9	2.1	1.1	0.7	1.0	1.9	1.1	1.2	1.9
ORP	mV	–	–	–	–	–	–	–	–	–	–	–	-76	121	–	–
Free Chlorine	mg/L	–	0.6	0.6	–	0.8	0.8	0.8	–	1.0	1.0	1.0	–	1.0	1.0	1.0
Total Chlorine	mg/L	–	3.0	3.0	–	3.0+	3.0+	3.0+	–	3.0	3.0	3.0	–	3.0	3.0	3.0
Total Hardness	mg/L[a]	209.8	207.9	203.8	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L[a]	130.2	129.7	128.0	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L[a]	79.6	78.2	75.8	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	44.9	42.3	15.4	34.5	34.3	10.6	12.5	47.0	46.5	13.8	15.1	51.0	39.0	11.1	11.4
As (total soluble)	µg/L	38.2	13.9	12.1	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	6.7	28.4	3.3	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	36.0	1.1	1.2	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	2.2	12.8	10.9	–	–	–	–	–	–	–	–	–	–	–	–
Total Fe	µg/L	469	483	<25	473	450	<25	<25	626	686	44	43	1,209	758	61.6	30.8
Dissolved Fe	µg/L	492	<25	<25	–	–	–	–	–	–	–	–	–	–	–	–
Total Mn	µg/L	146	138	86.8	127	126	73.8	72.2	135	139	81.9	82.6	505	156	85.7	82.6
Dissolved Mn	µg/L	145	78.9	80.9	–	–	–	–	–	–	–	–	–	–	–	–

(a) as $CaCO_3$.
(b) as PO_4.
(c) On-site water quality parameters taken on 9/15/04 for locations IN and AC.
IN =at the inlet; AC = after contact tanks; TA = after Tank A; TB = after Tank B; TT = after Tanks A and B combined.

Table B-1. Analytical Results from Long-Term Sampling, Climax, Minnesota (Continued)

Sampling Date		10/05/04			10/12/04				10/19/04				10/26/04			
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Alkalinity	mg/L[a]	313	317	313	305	305	301	313	294	290	288	292	312 312	308 308	308 308	308 312
Ammonia	mg/L	–	–	–	–	–	–	–	–	–	–	–	0.8 0.7	–	–	–
Fluoride	mg/L	0.2	0.2	1.0	–	–	–	–	–	–	–	–	–	–	–	–
NO_3-N	mg/L	<0.04	<0.04	<0.04	–	–	–	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L[b]	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06 <0.06	<0.06 <0.06	<0.06 <0.06	<0.06 <0.06
Silica (as SiO_2)	mg/L	28.5	28.5	28.8	28.7	28.2	28.3	27.8	28.4	28.2	28.2	27.9	28.3 28.0	28.2 28.4	28.1 28.3	28.2 28.4
Sulfate	mg/L	110	110	110	–	–	–	–	–	–	–	–	–	–	–	–
Turbidity	NTU	8.6	0.6	0.1	7.7	1.0	0.6	1.1	6.9	0.7	0.5	0.3	6.5 6.5	0.5 0.5	<0.1 0.1	0.1 0.1
pH	S.U.	7.5	7.4	7.3	7.5	7.4	7.4	7.4	7.5	7.4	7.4	7.4	7.5	7.4	7.4	7.4
Temperature	ºC	8.3	8.1	8.3	8.6	8.6	8.6	8.5	8.1	8.2	8.1	8.1	9.6	8.7	8.7	8.6
DO	mg/L	1.0	1.9	1.0	1.6	1.1	1.2	1.6	1.8	1.1	0.9	1.1	1.6	1.4	1.1	2.0
ORP	mV	-80	163	317	-63	170	222	228	-67	382	379	364	-69	349	335	330
Free Chlorine	mg/L	–	1.0	1.0	–	1.0	1.0	1.0	–	1.0	1.0	1.0	–	3.0	3.0	3.0
Total Chlorine	mg/L	–	3.0	3.0	–	3.0	3.0	3.0	–	3.0	3.0	3.0	–	3.0+	3.0+	3.0+
Total Hardness	mg/L[a]	282.8	278.7	278.0	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L[a]	188.4	185.0	185.0	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L[a]	94.4	93.7	93.0	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	36.9	37.6	10.1	35.0	72.0[c]	17.9[c]	18.3[c]	34.0	36.0	12.0	13.0	33.9 34.3	34.1 35.8	10.5 10.9	10.6 11.0
As (total soluble)	µg/L	35.7	11.4	10.0	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	1.2	26.2	0.1	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	35.7	1.5	1.8	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	<0.1	9.9	8.1	–	–	–	–	–	–	–	–	–	–	–	–
Total Fe	µg/L	540	551	<25	548	1,002[c]	<25[c]	<25[c]	479	503	<25	<25	523 495	514 507	<25 <25	26 <25
Dissolved Fe	µg/L	520	<25	<25	–	–	–	–	–	–	–	–	–	–	–	–
Total Mn	µg/L	115	115	62.6	123	124[c]	71.1[c]	69.9[c]	114	113	67	66	121 115	117 116	65.6 66.8	66.3 64.5
Dissolved Mn	µg/L	116	61.7	61.8	–	–	–	–	–	–	–	–	–	–	–	–

(a) as $CaCO_3$.
(b) as PO_4.
(c) Sample re-run due to high Mn and As readings. Both sample sets were similar in value.
IN =at the inlet; AC = after contact tanks; TA = after Tank A; TB = after Tank B; TT = after Tanks A and B combined.

Table B-1. Analytical Results from Long-Term Sampling, Climax, Minnesota (Continued)

Sampling Date		11/02/04			11/09/04				11/16/04				11/30/04		
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT
Alkalinity	mg/L[(a)]	304	304	287	304	304	299	304	328	308	312	324	313	309	296
Ammonia	mg/L	–	–	–	–	–	–	–	0.7	–	–	–	–	–	–
Fluoride	mg/L	0.2	0.2	0.6	–	–	–	–	–	–	–	–	0.6	0.6	1.4
NO_3-N	mg/L	<0.04	<0.04	<0.04	–	–	–	–	–	–	–	–	<0.04	<0.04	<0.04
Orthophosphate	mg/L[(b)]	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Silica (as SiO_2)	mg/L	27.9	28.2	28.5	28.2	28.2	27.8	28.1	28.4	28.6	28.3	28.6	28.1	28.5	28.0
Sulfate	mg/L	120	120	120	–	–	–	–	–	–	–	–	120	120	120
Turbidity	NTU	5.3	0.4	0.1	6.0	0.5	0.5	0.3	6.3	0.9	0.5	0.5	6.8	0.7	0.5
pH	S.U.	7.6	7.4	7.4	7.6	7.4	7.4	7.4	7.6	7.4	7.4	7.4	7.6	7.4	7.4
Temperature	ºC	9.0	8.7	8.6	9.1	9.1	8.7	8.9	9.0	9.1	9.1	9.1	9.3	8.6	8.5
DO	mg/L	1.4	1.9	1.4	1.4	1.8	1.4	1.9	1.5	1.9	1.5	1.9	2.2	2.3	2.5
ORP	mV	-66	309	347	-68	311	332	328	-70	314	326	330	-128	321	333
Free Chlorine	mg/L	–	1.0	1.0	–	1.0	1.0	1.0	–	1.0	1.0	1.0	–	1.0	1.0
Total Chlorine	mg/L	–	2.2	2.2	–	2.2	2.2	2.2	–	2.2	2.2	2.2	–	2.2	2.2
Total Hardness	mg/L[(a)]	237.6	240.2	239.1	–	–	–	–	–	–	–	–	222.1	219.4	241.1
Ca Hardness	mg/L[(a)]	150.6	154.1	153.0	–	–	–	–	–	–	–	–	147.8	146.0	162.0
Mg Hardness	mg/L[(a)]	87.0	86.1	86.1	–	–	–	–	–	–	–	–	74.3	73.4	79.1
As (total)	µg/L	39.3	38.7	16.3	34.1	33.8	9.3	9.9	34.9	35.1	9.9	10.3	51.4	41.6	19.0
As (total soluble)	µg/L	39.0	17.8	15.3	–	–	–	–	–	–	–	–	51.3	19.5	16.1
As (particulate)	µg/L	0.3	20.9	1.0	–	–	–	–	–	–	–	–	0.1	22.1	2.9
As (III)	µg/L	36.9	3.0	3.5	–	–	–	–	–	–	–	–	39.8	6.2	5.1
As (V)	µg/L	2.1	14.8	11.8	–	–	–	–	–	–	–	–	11.5	13.3	11.0
Total Fe	µg/L	361	363	<25	520	550	<25	<25	508	538	<25	<25	524	448	36.8
Dissolved Fe	µg/L	354	<25	<25	–	–	–	–	–	–	–	–	505	<25	<25
Total Mn	µg/L	113	112	69.2	131	135	78.5	78.9	126	128	74.6	74.0	125	109	68.2
Dissolved Mn	µg/L	114	64.9	66.5	–	–	–	–	–	–	–	–	125	75	69.1

(a) as $CaCO_3$.
(b) as PO_4.
IN =at the inlet; AC = after contact tanks; TA = after Tank A; TB = after Tank B; TT = after Tanks A and B combined.

Table B-1. Analytical Results from Long-Term Sampling, Climax, Minnesota (Continued)

Sampling Date		12/07/04				12/14/04				01/04/05[c,d]			01/11/05			
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB
Alkalinity	mg/L[a]	325	325	325	309	318	301	301	305	296	284	284	314	302	310	298
Ammonia	mg/L	0.8	–	–	–	0.7	–	–	–	–	–	–	0.6	–	–	–
Fluoride	mg/L	–	–	–	–	–	–	–	–	0.7	0.7	1.5	–	–	–	–
NO_3-N	mg/L	–	–	–	–	–	–	–	–	<0.04	<0.04	<0.04	–	–	–	–
Orthophosphate	mg/L[b]	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Silica (as SiO_2)	mg/L	27.9	28.5	28.5	29.1	28.9	28.9	28.6	28.8	29.0	29.7	29.8	29.8	29.7	29.3	28.5
Sulfate	mg/L	–	–	–	–	–	–	–	–	130	120	120	–	–	–	–
Turbidity	NTU	6.9	0.6	0.4	0.5	8.3	1.1	1.0	0.3	3.0	1.3	0.4	4.9	1.0	0.2	0.2
pH	S.U.	7.6	7.4	7.3	7.3	7.5	7.4	7.4	7.4	7.6	7.4	7.4	7.6	7.5	7.5	7.4
Temperature	ºC	8.8	8.5	8.4	8.4	8.5	8.8	8.7	8.4	8.4	8.5	8.5	8.4	8.3	8.2	8.4
DO	mg/L	2.5	1.9	1.9	2.2	1.8	1.7	1.5	2.5	1.0	1.8	1.7	1.0	1.3	1.5	2.1
ORP	mV	-68	289	295	298	-89	301	298	304	-77	315	307	-80	242	247	252
Free Chlorine	mg/L	–	0.2	0.2	0.2	–	0.2	0.2	0.2	–	1.5	1.5	–	0.8	0.8	0.8
Total Chlorine	mg/L	–	0.9	0.9	0.9	–	0.9	0.9	0.9	–	2.2	2.2	–	1.4	1.4	1.4
Total Hardness	mg/L[a]	–	–	–	–	–	–	–	–	215.1	214.1	215.2	–	–	–	–
Ca Hardness	mg/L[a]	–	–	–	–	–	–	–	–	138.6	138.3	139.7	–	–	–	–
Mg Hardness	mg/L[a]	–	–	–	–	–	–	–	–	76.5	75.8	75.5	–	–	–	–
As (total)	µg/L	33.4	33.4	10.4	10.3	36.4	35.6	9.5	13.7	32.3	32.8	6.0	35.1	35.5	5.8	7.2
As (total soluble)	µg/L	–	–	–	–	–	–	–	–	33.3	4.5	4.8	–	–	–	–
As (particulate)	µg/L	–	–	–	–	–	–	–	–	<0.1	28.3	1.2	–	–	–	–
As (III)	µg/L	–	–	–	–	–	–	–	–	32.6	0.9	1.2	–	–	–	–
As (V)	µg/L	–	–	–	–	–	–	–	–	0.7	3.6	3.6	–	–	–	–
Total Fe	µg/L	551	564	<25	<25	651	616	<25	<25	376	1,499	<25	463	1186	67.2	63.6
Dissolved Fe	µg/L	–	–	–	–	–	–	–	–	342	<25	<25	–	–	–	–
Total Mn	µg/L	122	120	70.2	69.7	137	135	75.9	71.4	116	118	70.3	125	126	89.0	94.6
Dissolved Mn	µg/L	–	–	–	–	–	–	–	–	112	67.1	68.3	–	–	–	–

(a) as $CaCO_3$.
(b) as PO_4.
(c) Iron addition began on 01/03/05.
(d) Water quality measurements were taken on 01/05/05.
IN =at the inlet; AC = after contact tanks; TA = after Tank A; TB = after Tank B; TT = after Tanks A and B combined.

Table B-1. Analytical Results from Long-Term Sampling, Climax, Minnesota (Continued)

Sampling Date		01/18/05[c]				01/25/05				02/01/05				02/08/05		
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT
Alkalinity	mg/L[a]	308 329	321 299	321 321	317 317	319	324	324	297	337	355	355	337	334	339	334
Ammonia	mg/L	0.7 0.6	–	–	–	0.6	–	–	–	0.8	–	–	–	–	–	–
Fluoride	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	0.4	0.4	0.9
NO_3-N	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	<0.05	<0.05	<0.05
Orthophosphate	mg/L[b]	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silica (as SiO_2)	mg/L	29.3 29.2	28.8 28.2	28.3 28.1	28.5 28.5	27.5	27.7	27.4	27.3	27.8	27.1	27.3	27.3	28	27.8	28
Sulfate	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	154	155	155
Turbidity	NTU	5.8 5.3	0.6 1.0	<0.1 0.2	0.1 0.1	5.6	1.1	<0.1	<0.1	6.4	1.4	0.1	0.1	6.4	0.4	<0.1
pH	S.U.	7.6	7.6	7.6	7.6	7.6	7.5	7.5	7.5	7.5	7.4	7.4	7.3	7.5	7.5	7.4
Temperature	ºC	8.8	8.5	8.5	8.6	8.9	8.7	8.5	8.4	8.8	8.4	8.4	8.4	9.1	9.1	9.1
DO	mg/L	1.2	1.4	1.9	1.7	1.7	1.2	1.2	1.7	1.8	1.5	1.4	1.4	2.5	2.0	1.6
ORP	mV	-86	267	258	259	-74	268	274	279	-79	299	307	305	-81	286	258
Free Chlorine	mg/L	–	1.0	1.0	1.0	–	1.5	1.5	1.5	–	1.6	1.6	1.6	–	1.6	1.6
Total Chlorine	mg/L	–	2.2	2.2	2.2	–	2.2	2.2	2.2	–	2.2	2.2	2.2	–	2.2	2.2
Total Hardness	mg/L[a]	–	–	–	–	–	–	–	–	–	–	–	–	244	236	234
Ca Hardness	mg/L[a]	–	–	–	–	–	–	–	–	–	–	–	–	156	153	153
Mg Hardness	mg/L[a]	–	–	–	–	–	–	–	–	–	–	–	–	88.6	82.9	80.7
As (total)	µg/L	35.0 35.9	35.1 36.3	6.0 7.3	7.2 7.1	33.6	32.8	5.8	5.6	34.9	18.5	5.3	6.4	37.3	33.6	6.0
As (total soluble)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	37.4	18.3	5.4
As (particulate)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	<0.1	15.3	0.6
As (III)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	34.0	1.4	1.4
As (V)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	3.4	16.9	4.0
Total Fe	µg/L	565 523	1,478 1,340	<25 81.4	51.2 81.7	515	1,255	<25	<25	723	1,686	37.1	83.6	529	515[d]	26.3
Dissolved Fe	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	507	<25	<25
Total Mn	µg/L	131 137	143 136	85.8 74.7	104 74.9	121	122	65.1	62.9	132	141	76.8	81.0	114	110	57.2
Dissolved Mn	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	114	59	55.5

(a) as $CaCO_3$.
(b) as PO_4.
(c) Water quality measurements were taken on 01/19/05.
(d) Possible data outlier as iron addition continued at target dosage rate during week of 2/7/05 to 2/13/05.
IN =at the inlet; AC = after contact tanks; TA = after Tank A; TB = after Tank B; TT = after Tanks A and B combined.

Table B-1. Analytical Results from Long-Term Sampling, Climax, Minnesota (Continued)

Sampling Date		02/16/05				02/22/05			
Sampling Location Parameter	Unit	IN	AC	TA	TB	IN	AC	TA	TB
Alkalinity	mg/L[(a)]	334	317	334	334	360	333	328	328
Ammonia	mg/L	0.7	–	–	–	0.7	–	–	–
Fluoride	mg/L	–	–	–	–	–	–	–	–
NO_3-N	mg/L	–	–	–	–	–	–	–	–
Orthophosphate	mg/L[(b)]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silica (as SiO_2)	mg/L	30.5	30.5	29.9	30.6	28.8	29.4	27.6	28.6
Sulfate	mg/L	–	–	–	–	–	–	–	–
Turbidity	NTU	7.2	1.4	0.2	0.2	5.7	1.2	0.2	<0.1
pH	S.U.	7.6	7.5	7.5	7.5	7.6	7.5	7.5	7.5
Temperature	ºC	9.8	8.6	8.4	8.4	9.1	8.8	8.5	8.8
DO	mg/L	1.7	1.2	1.4	1.4	1.9	1.4	1.5	1.5
ORP	mV	-82	240	262	265	-80	252	256	259
Free Chlorine	mg/L	–	1.3	1.3	1.3	–	0.9	0.9	0.9
Total Chlorine	mg/L	–	2.2	2.2	2.2	–	1.9	1.9	1.9
Total Hardness	mg/L[(a)]	–	–	–	–	–	–	–	–
Ca Hardness	mg/L[(a)]	–	–	–	–	–	–	–	–
Mg Hardness	mg/L[(a)]	–	–	–	–	–	–	–	–
As (total)	µg/L	35.5	37.9	7.1	7.4	32.1	33.6	5.5	5.7
As (total soluble)	µg/L	–	–	–	–	–	–	–	–
As (particulate)	µg/L	–	–	–	–	–	–	–	–
As (III)	µg/L	–	–	–	–	–	–	–	–
As (V)	µg/L	–	–	–	–	–	–	–	–
Total Fe	µg/L	569	1,791	107	122	581	1,425	31.1	36.0
Dissolved Fe	µg/L	–	–	–	–	–	–	–	–
Total Mn	µg/L	123	139	69.6	71.8	117	126	92.3	90.8
Dissolved Mn	µg/L	–	–	–	–	–	–	–	–

(a) as $CaCO_3$.
(b) as PO_4.
IN =at the inlet; AC = after contact tanks; TA = after Tank A; TB = after Tank B; TT = after Tanks A and B combined.