

**Arsenic Removal from Drinking Water by Coagulation/Filtration  
U.S. EPA Demonstration Project at City of Three Forks, MT  
Final Performance Evaluation Report**

by

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**Contract No. 68-C-00-185  
Task Order No. 0029**

for

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Sally Gutierrez, Director  
National Risk Management Research Laboratory

## ABSTRACT

This report documents the activities performed during and the results obtained from the arsenic removal treatment technology demonstration project at the City of Three Forks, MT facility. The objectives of the project were to evaluate: 1) the effectiveness of Kinetico's FM-248-AS Arsenic Removal System using Macrolite<sup>®</sup> media in removing arsenic to meet the maximum contaminant level (MCL) of 10 µg/L, 2) the reliability of the treatment system for use at small water facilities, 3) the required system operation and maintenance (O&M) and operator skill levels, and 4) the capital and O&M cost of the technology. The project also characterized water in the distribution system and residuals generated by the treatment process. The types of data collected included system operation, water quality, process residuals, and capital and O&M cost.

After review and approval of the engineering plan by the State, the FM-248-AS treatment system was installed and became operational on October 30, 2006. The system consisted of two 63-in × 86-in fiber reinforced plastic (FRP) contact tanks and two 48-in × 72-in FRP pressure filtration vessels, both configured in parallel. Each pressure filtration vessel was loaded with 25 ft<sup>3</sup> of Macrolite<sup>®</sup> media to which filtration rates up to 10.0 gpm/ft<sup>2</sup> was applied. During the performance evaluation study from November 27, 2006, and February 8, 2008, the system operated at an average flowrate of 206 gal/min (gpm) for 8.9 hr/day, producing 30,499,000 gal of water. This average flowrate corresponded to an average contact time of 6.2 min and an average filtration rate of 8.0 gpm/ft<sup>2</sup>.

Problems encountered during the performance evaluation study included programmable logic controller (PLC) settings, arsenic and iron particulate breakthrough, and increased differential pressure across the media beds, which led to shorter useful run lengths and more frequent backwashing. The actions taken to address these problems are detailed in this report.

Source water from Well 2 had an average pH value of 7.5 and contained 59.8 µg/L to 96.7 µg/L of total arsenic, 46.8 to 50.8 mg/L of silica (as SiO<sub>2</sub>), and 17.1 to 53.7 µg/L of phosphorus (as P). The predominant soluble arsenic species was As(V) with an average concentration of 74.5 µg/L. Total iron concentrations were below the method reporting limit, therefore, in order to make the planned coagulation/filtration process work, an iron addition system was installed to provide iron for soluble As(V) removal. The amounts of iron added ranged from 1.1 to 2.5 mg/L (as Fe), compared to the target dosage of 2.0 mg/L (as Fe).

After the contact tanks, most soluble As(V) was converted to particulate arsenic, presumably via adsorption and coprecipitation. As much as 10.6 µg/L of soluble As(V), however, remained in the contact tank effluent. Higher iron dosages appear to have very little effect on additional soluble As(V) removal. Silica and phosphorus in the raw water might have competed with arsenic for available adsorptive sites, thus rendering the coagulation process less effective. The use of higher iron dosages also increased solid loading to the pressure filters, causing premature breakthrough of arsenic-laden particles within 2 to 4 hr of filter runs.

Filter effluent samples taken during the first three weeks of system operation contained 17.3 to 30.6 µg/L of total arsenic and 236 to 936 µg/L of total iron. Of the total amount of total arsenic measured, 23.5 µg/L, on average, existed as particulate arsenic. All iron existed in the particulate form. These results suggest that arsenic-laden particles broke through the pressure filters during the filter runs. To examine breakthrough characteristics and methods to improve the filter performance, several special studies, including some jar tests, were conducted, which included the use of a higher iron dose, implementation of a finer Macrolite<sup>®</sup> media size fraction, and addition of a polymer/coagulant aid. However, only a

blending scheme using water from Wells 5, 6, 8, and 9 was successful in reducing arsenic concentrations to below the MCL.

In general, filter backwash was triggered manually three times a week (i.e., Monday, Wednesday, and Friday) for the first five months and then automatically 5 times a week by the 8 hr run time setpoint. Approximately 1,173,000 gal of wastewater, or 3.8% of the amount of water treated, was generated during the study. However, because the useful filter run length (i.e., the maximum filter run length that consistently yielded  $<10\text{ }\mu\text{g/L}$  total arsenic and  $<300\text{ }\mu\text{g/L}$  total iron in the effluent) was much shorter than the actual filter run lengths observed during the study, the percentage of processed water used for backwashing would have been much higher than 3.8% had the useful filter run length been implemented throughout the study. The backwash wastewater contained between 310 mg/L and 388 mg/L of total dissolved solids (TDS) and between 130 mg/L and 328 mg/L of total suspended solids (TSS). On average, approximately 0.06 lb of arsenic, 1.6 lb of iron, and 0.006 lb of manganese were discharged during each backwash event.

The capital investment for the treatment system was \$305,447, consisting of \$168,142 for equipment, \$53,435 for site engineering, and \$83,870 for installation, shakedown, and startup. Using the system's rated capacity of 250 gpm (or 360,000 gal/day [gpd]), the capital cost was \$1,222/gpm (or \$0.85/gpd). This calculation does not include the cost of the building to house the treatment system. O&M cost, estimated at \$0.18/1,000 gal, included only the incremental cost for chemicals, electricity, and labor.

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## ABBREVIATIONS AND ACRONYMS

$\Delta p$	differential pressure
$\mu\text{g/L}$	micrograms per liter
$\mu\text{m}$	micrometers
AAL	American Analytical Laboratories
AL	polyaluminum hydroxychloride
AM	adsorptive media
Al	Aluminum
As	arsenic
ATS	Aquatic Treatment Systems
bgs	below ground surface
C/F	coagulation/filtration
Ca	calcium
$\text{CaCO}_3$	calcium carbonate
Cd	cadmium
Cl	chlorine
Cu	copper
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
$\text{FeCl}_3$	ferric chloride
FRP	fiberglass reinforced plastic
FTW	filter-to-waste
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
HDPE	high-density polyethylene
HIX	hybrid ion exchanger
hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IN	wellhead sampling location
IX	ion exchange
LCR	(EPA) Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MEI	Magnesium Elektron, Inc.

Mg	magnesium
Mn	manganese
MT DEQ	Montana Department of Environmental Quality
mV	millivolts
Na	sodium
NA	not analyzed
NaOCl	sodium hypochlorite
ND	not detected
Ni	nickel
NTU	nephelometric turbidity units
O&M	operation and maintenance
OIP	operator interface panel
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
P	phosphorus
P&ID	pipng and instrumentation diagram
Pb	lead
PD	polydiallyldimethylammonium chloride
psi	pounds per square inch
psig	pounds per square inch gauge
PLC	programmable logic controller
PO <sub>4</sub>	phosphate
POU	point-of-use
PVC	polyvinyl chloride
PY	polyquaternary amine
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RPD	relative percent difference
rpm	rotations per minute
RO	reverse osmosis
SCADA	system control and data acquisition
SDWA	Safe Drinking Water Act
SiO <sub>2</sub>	silica
SMCL	secondary maximum contaminant level
SO <sub>4</sub>	sulfate
SOC	synthetic organic compounds
STS	Severn Trent Services
TA	Vessel A sampling location
TB	Vessel B sampling location
TCLP	toxicity characteristics leaching procedure
TDH	total dynamic head
TDS	total dissolved solids

TOC	total organic carbon
TSS	total suspended solids
TT	combined Vessel A and Vessel B sampling location
U	uranium
UPS	uninterruptible power supply
V	vanadium
VOC	volatile organic compounds
Zn	zinc

## **ACKNOWLEDGMENTS**

The authors wish to extend their sincere appreciation to Mr. Randy Johnson of the City of Three Forks, MT. Mr. Johnson monitored the treatment system and collected samples from the treatment and distribution systems on a regular schedule throughout the study. This performance evaluation would not have been possible without his support and dedication.

Ms. Julia Valigore was the Battelle Study Lead from the inception of this demonstration project through July 2007. She is currently pursuing a doctoral degree at the University of Canterbury in New Zealand.

## 1.0 INTRODUCTION

### 1.1 Background

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

In October 2001, EPA announced an initiative for additional research and development of cost-effective technologies to help small community water systems (<10,000 customers) meet the new arsenic standard and to provide technical assistance to operators of small systems 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, onsite demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems. Shortly thereafter, an announcement was published in the *Federal Register* requesting water utilities interested in participating in Round 1 of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 out of 115 sites to host the demonstration studies.

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

In 2003, EPA initiated Round 2 arsenic technology demonstration projects that were partially funded with Congressional add-on funding to the EPA budget. In June 2003, EPA selected 32 potential demonstration sites, and the community water system in the City of Three Forks, MT was one of those selected.

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

As of September 2009, 39 of the 40 systems were operational, and the performance evaluation of 33 systems was completed.

## **1.2 Treatment Technologies for Arsenic Removal**

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

## **1.3 Project Objectives**

The objective of the arsenic demonstration program is to conduct full-scale arsenic treatment technology demonstration studies on the removal of arsenic from drinking water supplies. The specific objectives are to:

- Evaluate the performance of the arsenic removal technologies for use on small systems.
- Determine the required system operation and maintenance (O&M) and operator skill levels.
- Characterize process residuals produced by the technologies.
- Determine the capital and O&M cost of the technologies.

This report summarizes the performance of the Kinetico system at the City of Three Forks in Montana from November 27, 2006, to February 8, 2008. The types of data collected include system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and preliminary O&M cost.

**Table 1-1. Summary of Arsenic Removal Demonstration Sites**

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

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

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

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

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

(a) Arsenic existing mostly as As(III).

(b) Design flowrate reduced by 50% due to system reconfiguration from parallel to series operation.

(c) Iron existing mostly as Fe(II).

(d) Withdrew from program in 2007. Selected originally to replace Village of Lyman, NE site, which withdrew from program in June 2006.

(e) Facilities upgraded systems in Springfield, OH from 150 to 250 gpm, Sandusky, MI from 210 to 340 gpm, and Arnaudville, LA from 385 to 770 gpm.

(f) Including nine residential units.

(g) Including eight under-the-sink units.

## 2.0 SUMMARY AND CONCLUSIONS

Based on the information collected from November 27, 2006, to February 8, 2008, the following summary and conclusions are provided relating to the overall objectives of the treatment technology demonstration study.

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

- Operating at 8 gpm/ft<sup>2</sup>, Kinetico's FM-248-AS Arsenic Removal System with Macrolite<sup>®</sup> media can remove arsenic to below its MCL of 10 µg/L. However, above MCL levels of arsenic, present in both soluble and particulate forms, can break through the filters within 2 hr of service time, rendering the filtration process ineffective.
- The use of ferric chloride (FeCl<sub>3</sub>) coagulant can reduce levels of soluble arsenic, present predominantly as As(V), after the contact tanks. However, close to or above MCL levels of soluble arsenic remain untreated in the contact tank effluent. Increasing the iron dosage to as much as 2.5 mg/L (at 31:1 Fe:As ratio) does not appear to be effective in improving the treatment results. The poor treatment results might have been caused by the presence of silica (at 48.5 mg/L [as SiO<sub>2</sub>]) and phosphorus, which competed with As(V) for available adsorptive sites on iron solids.
- Increasing iron dosage also increases solids loading to the pressure filters, causing premature breakthrough of arsenic-laden iron solids from the pressure filters. The use of an organic polymer, C-05 FeCl<sub>3</sub>/polymer blend, does not appear to be effective in improving the filter performance. The use of C-05 caused clogging to the filters, as evidenced by an increase in differential pressure (Δp) buildup rate (i.e., 1.4 to 1.6 psi/hr versus 1.0 psi/hr with the use of FeCl<sub>3</sub> alone) and several backwash alarms (resulting from the inability to achieve a preset turbidity threshold within the maximum backwash time).
- The use of a smaller media size fraction (70/80 mesh vs. 40/60 mesh) does not appear to be effective in improving the filter's ability to remove arsenic-laden iron particles.
- Blending with water from other available wells is capable of reducing arsenic concentrations to below MCL levels.

### *Required system O&M and operator skill levels:*

- The daily demand on the operator was short, averaging 30 min for routine O&M.
- A significant amount of time and effort was required to adjust and monitor the chemical feed system for coagulation/filtration.

### *Characteristics of residuals produced by the technology:*

- Approximately 3,700 gal of wastewater were produced during each backwash event for both vessels. The wastewater contained 0.06 lb of arsenic, 1.6 lb of iron, and 0.006 lb of manganese, most of which existed in the particulate form as part of the 4.6 lb of solids discharged to the sewer.
- Soluble arsenic and iron concentrations in the backwash wastewater were high (i.e., 10.5 to 50.4 µg/L for arsenic and 120 to 846 µg/L for iron) when compared with those measured at the rest of the arsenic demonstration sites. The soluble metals measured may include dispersed colloidal particles due to the presence of elevated silica in water.

*Capital and O&M cost of the technology:*

- The capital investment for the system was \$305,447, consisting of \$168,142 for equipment, \$53,435 for site engineering, and \$83,870 for installation, shakedown, and startup.
- The unit capital cost was \$1,222/gpm (or \$0.85/gpd) based on a 250-gpm design capacity. This calculation does not reflect the building cost as it was funded by the City.
- The O&M cost was \$0.18/1,000 gal including incremental cost for chemicals, electricity, and labor.

### 3.0 MATERIALS AND METHODS

#### 3.1 General Project Approach

Following the predemonstration activities summarized in Table 3-1, the performance evaluation study of the Kinetico treatment system began on November 27, 2006, and operational data collection ended on February 8, 2008. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall system performance was based on its ability to consistently remove arsenic to below the target MCL of 10 µg/L through the collection of water samples across the treatment train, as described in the Study Plan (Battelle, 2006). The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

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

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

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

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

Activity	Date
Introductory Meeting Held	November 30, 2004
Project Planning Meeting Held	April 5, 2005
Draft Letter of Understanding Issued	April 12, 2005
Final Letter of Understanding Issued	April 22, 2005
Request for Quotation Issued to Vendor	April 22, 2005
Vendor Quotation Received	May 19, 2005
Purchase Order Established	June 8, 2005
Letter Report Issued	June 15, 2005
Engineering Package Submitted to MT DEQ	November 2, 2005
Study Plan Issued	September 14, 2005
System Permit Granted by MT DEQ	January 26, 2006
Building Construction Permit Granted by MT DEQ	April 7, 2006
Building Construction Began	April 13, 2006
FM-248-AS System Shipped/Delivered	May 24/30, 2006
System Installation Completed	June 5, 2006
Building Completed	July 31, 2006
System Shakedown Completed	October 30, 2006
Performance Evaluation Began	November 27, 2006

MT DEQ = Montana Department of Environmental Quality

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

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

### **3.2 System O&M and Cost Data Collection**

The plant operator performed daily, weekly, and monthly system O&M and data collection according to instructions provided by the vendor and Battelle. As long as possible, the plant operator recorded daily system operational data, such as pressure, flowrate, totalizer, and hour meter readings on a Daily System Operation Log Sheet, checked the sodium hypochlorite (NaOCl) and FeCl<sub>3</sub> levels, and conducted visual inspections to ensure normal system operations. If any problem occurred, the plant operator contacted the Battelle Study Lead, who determined if the vendor should be contacted for troubleshooting. The plant operator recorded all relevant information, including the problem encountered, course of actions taken, materials and supplies used, and associated cost and labor incurred, on the Repair and Maintenance Log Sheet. On a weekly basis, the plant operator measured several water quality parameters onsite, including temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and residual chlorine, and recorded them on a Weekly Onsite Water Quality Parameters Log Sheet. Monthly backwash data also were recorded on a Backwash Log Sheet.

The capital cost for the arsenic removal system consisted of the cost for equipment, site engineering, and system installation. The O&M cost consisted of the cost for chemical usage, electricity consumption, and labor. Consumption of NaOCl and FeCl<sub>3</sub> was tracked on the Daily System Operation Log Sheet. Electricity consumption was determined from utility bills. Labor for various activities, such as routine system O&M, troubleshooting and repairs, and demonstration-related work, was tracked using an Operator Labor Hour Log Sheet. The routine system O&M included activities such as completing field logs, replenishing chemical solutions, ordering supplies, performing system inspections, and others as recommended by the vendor. Labor hours for demonstration-related work, including activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead and the vendor, were recorded, but not used for the cost analysis.

### **3.3 Sample Collection Procedures and Schedules**

To evaluate system performance, samples were collected at the wellhead, across the treatment plant, during Macrolite<sup>®</sup> filter backwash, and from the distribution system. Table 3-3 provides the sampling schedule and analytes measured during each sampling event. Figure 3-1 presents a flow diagram of the

**Table 3-3. Sampling Schedule and Analyses**

<b>Sample Type</b>	<b>Sample Locations<sup>(a)</sup></b>	<b>No. of Samples</b>	<b>Frequency</b>	<b>Analytes</b>	<b>Collection Date(s) and Results</b>
Source Water	IN	1	Once	Onsite: pH, temperature, DO, and ORP  Offsite: As(III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, Cl, F, NO <sub>2</sub> , NO <sub>3</sub> , NH <sub>3</sub> , SO <sub>4</sub> , SiO <sub>2</sub> , PO <sub>4</sub> , alkalinity, turbidity, TDS, and TOC	Table 4-1
Treatment Plant Water	IN, AC, TA, and TB	4	Weekly (non-speciation sampling)	Onsite: pH, temperature, DO, ORP, and Cl <sub>2</sub> (total and free)  Offsite: As (total), Fe (total), Mn (total), SiO <sub>2</sub> , P (total), alkalinity, and turbidity	Appendix B
	IN, AC, and TT	3	Monthly (speciation sampling)	Onsite: pH, temperature, DO, ORP, and Cl <sub>2</sub> (total and free)  Offsite: As(III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), Ca, Mg, F, NO <sub>3</sub> , SO <sub>4</sub> , SiO <sub>2</sub> , P (total), alkalinity, and turbidity	Appendix B
Backwash Wastewater	Discharge Line	2	Monthly	As (total and soluble), Fe (total and soluble), Mn (total and soluble), TDS, TSS, and pH	Table 4-13
Residual Sludge	Discharge Area	2-3	Once	TCLP metals and total Al, As, Ca, Cd, Cu, Fe, Mg, Mn, Ni, P, Pb, Si, and Zn	Not Sampled
Distribution Water	One Residence and Two Non-Residences	3	Monthly	As (total), Fe (total), Mn (total), Cu, Pb, pH, and alkalinity	Table 4-15

(a) IN = at wellhead; AC = after contact tanks; TA = after Vessel A; TB = after Vessel B;  
TT = after filter effluent combined

TCLP = toxicity characteristics leaching procedure; TDS = total dissolved solids; TOC = total organic carbon; TSS = total suspended solids

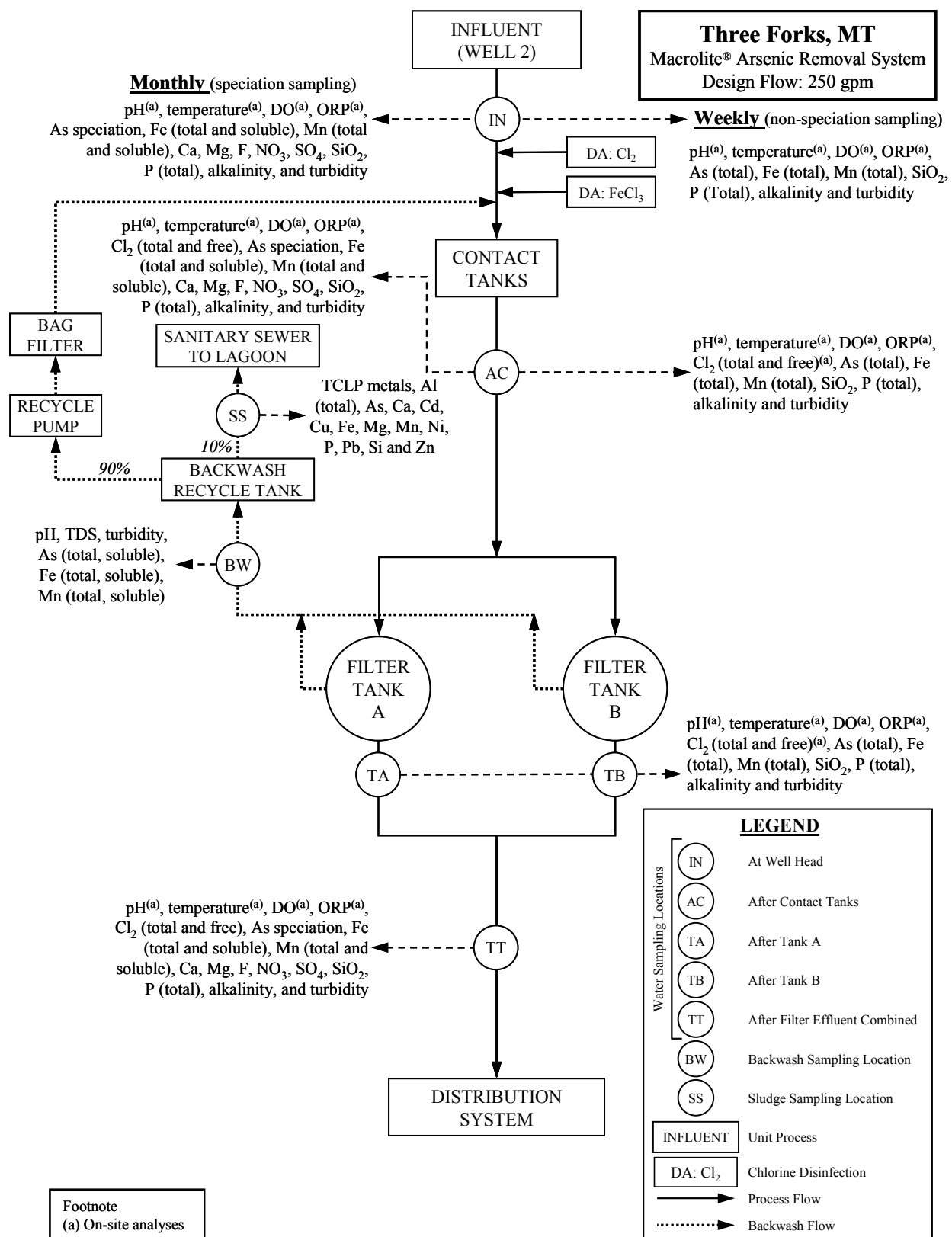


Figure 3-1. Process Flow Diagram and Sampling Schedule and Locations

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

**3.3.1 Source Water.** During the initial site visit, one set of source water samples was collected and speciated using an arsenic speciation kit (Section 3.5.1). The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Analytes for the source water samples are listed in Table 3-3.

**3.3.2 Treatment Plant Water.** The initial plan was for the plant operator to collect treatment plant water samples weekly, on a four-week cycle, for on- and offsite analyses. For the first week of each four-week cycle, samples were collected at the wellhead (IN), after the contact tanks (AC), and after the effluent from the two filtration vessels combined (TT), and speciated onsite and analyzed for the analytes listed under speciation sampling in Table 3-3. On the second, third, and fourth weeks of the four-week cycle, samples were collected at IN, AC, after Vessel A (TA), and after Vessel B (TB) and analyzed for the analytes listed under non-speciation sampling in Table 3-3. Sampling following this schedule was only conducted in November to December 2006, and March to April 2007. Due to earlier-than-expected particulate iron and arsenic breakthrough in the filter effluent, this sampling schedule was discontinued and a series of special studies under varying process conditions was conducted as described in Section 3.4.

**3.3.3 Backwash Wastewater.** Five sets of backwash water samples were collected by the plant operator from December 2006 to April 2007. Tubing, connected to the tap on the discharge line of each vessel, directed a portion of backwash wastewater at about 1 gpm into a clean, 32-gal container over the entire backwash duration from each vessel. After the content in the container was thoroughly mixed, composite samples were collected and/or filtered onsite with 0.45- $\mu$ m disc filters. Analytes for the backwash samples are listed in Table 3-3.

**3.3.4 Distribution System Water.** Prior to system startup from June to September 2005, four monthly baseline distribution water samples were collected from two non-residences and one residence that had been included in the City's Lead and Copper Rule (LCR) sampling. Among others, the samples were analyzed for arsenic, lead, and copper. Following system startup, distribution system water sampling continued on a monthly basis at the same three locations from December 2006 to January 2008.

Homeowners collected samples following an instruction sheet developed according to the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The dates and times of last water usage before sampling and of actual sample collection were recorded for calculation of the stagnation time. All samples were collected from a cold-water faucet that had not been used for at least 6 hr to ensure that stagnant water was sampled.

The distribution system water sampling might not achieve the intended results because the Well 2 treated water had been blended with source water from Wells 5, 6, 8, and 9, which contained little or no arsenic. Nonetheless, the sampling proceeded as planned.

**3.3.5 Residual Solids.** Residual solids produced by the treatment process consisted of only backwash wastewater solids. Residual solids were not sampled due to the request of the operator to end the study after February 8, 2008 prior to sample collection.

### 3.4 Special Studies

A series of special studies was conducted to improve the performance of the pressure filters for iron and arsenic removal. The studies were necessary because the analytical results from the first three weeks of treatment plant sampling (i.e., from November 29 through December 12, 2006) indicated significantly elevated arsenic and iron concentrations in the filter effluent. The studies performed involved:

- ***Filter run-length with the use of higher iron doses.*** A filter run length study was conducted on December 20, 2006, and then on January 10, 2007. The December 20 study involved collecting treatment plant water samples from all four sampling locations at 1 and 4 hr of service time and analyzing the samples for total arsenic, iron, and manganese. The January 10 study encompassed the collection of similar water samples at approximately 1.0, 2.0, and 4.0 hr and the analysis of the samples for all five onsite analytes (Table 3-3) and total and/or soluble arsenic, iron, and manganese. The iron dosages applied during the two studies were 1.8 and 2.2 mg/L (as Fe), respectively. Regular sampling as outlined in Table 3-3 was temporarily suspended from December 12, 2006, to March 21, 2007.
- ***Use of a finer filter media size fraction.*** Because a significant amount of arsenic-laden iron particles continued to prematurely break through the pressure filters, the top 6-in of the filter media at 40/60 mesh was replaced with a 6-in layer of finer media at 70/80 mesh. Upon completion of the media replacement on March 13, 2007, regular sampling as outlined in Table 3-3 resumed on March 21, 2007, and lasted until April 25, 2007.
- ***Use of an iron/organic polymer blend.*** Analytical results collected between March 21 and April 25, 2007, revealed that the media bed modification failed to produce the anticipated result and that a significant amount of particulate iron and arsenic continued to penetrate through the pressure filters. Efforts were then made to determine if the use of a coagulant aid might help form more filterable flocs, thereby improving the filter performance. An iron/polymer mixture (C-05, a blend of 38%  $\text{FeCl}_3$  with an organic polymer; the amount and type of the polymer were unknown) was recommended by Kinetico to replace the  $\text{FeCl}_3$ , so that no additional feed equipment would be needed for separate polymer addition.

To evaluate iron and polymer dosages, 12 jar tests were performed by Kinetico on June 4, 2007. Source water collected from the IN location was dosed with three free chlorine dosages, i.e., 0.5, 1.0, and 1.5 mg/L (as  $\text{Cl}_2$ ), and four C-05 dosages, i.e., 1.0, 1.5, 2.0, and 2.5 mg/L (as Fe). After mixing for 8 min, supernatant in each jar was filtered with 0.45- $\mu\text{m}$  disc filters before being analyzed for arsenic and iron.

The use of C-05 in the full-scale system was started on July 6, 2007 with the chlorine and C-05 blend dosages set at 1.5 mg/L (as  $\text{Cl}_2$ ) and 2.5 mg/L (as Fe), respectively. (The C-05 blend was delivered to the injection point by ramping up the feed pump stroke length by about 10% to account for the polymer content in the blend.) A run-length study was carried out on July 17, 2007, with filter effluent samples collected at approximately 3, 6, and 10 hr and analyzed for arsenic and iron. Because of lack of improvement to the filter effluent, the use of C-05 blend was discontinued in August 2007.

While awaiting the implementation of C-05 iron/polymer blend, regular sampling as outlined in Table 3-3 was suspended again from April 25, 2007 to July 17, 2007. Afterwards, regular sampling was suspended indefinitely.

- **Use of other coagulant aids.** On October 30, 2007, eight jar tests were conducted onsite by a chemical supplier, Hawkins, to further investigate the use of coagulant aids, including alum and seven polymer blends, on coagulation of arsenic and iron particulates. The jar tests were performed because the use of the C-05 blend resulted in minimal, if any, improvement to the filter effluent. Water, collected from the AC location containing 2.2 mg/L of iron (as Fe), was dosed with a varying amount of the coagulant aids listed in Table 3-4. After mixing for 20 min, supernatant from each jar was filtered with 0.45- $\mu$ m disc filters before being analyzed for arsenic and iron. The use of these coagulant aids was never implemented at the site because of concerns over media fouling by the facility operator.

For each run length study, rise of  $\Delta p$  across the pressure filters was carefully monitored, along with particulate iron and arsenic concentrations, against incremental filter run times. These studies allowed for the evaluation of filter performance between consecutive backwash events. The results of the run length studies and associated jar tests are discussed in Section 4.5.2.

During the special study period, the City began to increase the blending ratio between treated water from Well 2 and raw water from other wells to meet the 10- $\mu$ g/L arsenic MCL within the distribution system.

**Table 3-4. Coagulant Aids Jar-Tested by Hawkins**

Polymer	Description	Unit Cost (\$/gal)	Dosage (mg/L)
Aqua Hawk 427	Polymer blend (AL/PD/PY)	\$10.61	1
Aqua Hawk 6527	PD	\$11.33	1
Aqua Hawk 6547	PD	\$16.04	1
Alum	NA	NA	10
Aqua Hawk 9827	Long chain polymer	NA	0.2
Aqua Hawk 9827	Long chain polymer	NA	0.5
Aqua Hawk 9847	Long chain polymer	NA	0.2
Aqua Hawk 9847	Long chain polymer	NA	0.5

AL = Polyaluminum hydroxychloride

PD = Polydiallyldimethylammonium chloride

PY = Polyquaternary amine

### 3.5 Sampling Logistics

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

**3.5.2 Preparation of Sample Coolers.** For each sampling event, a sample cooler was prepared with the appropriate number and type of sample bottles, disc filters, and/or speciation kits. All sample bottles were new and contained appropriate preservatives. Each sample bottle was affixed with a pre-printed, colored-coded label consisting of the sample identification (ID), date and time of sample collection, collector's name, site location, sample destination, analysis required, and preservative. The sample ID consisted of a two-letter code for the demonstration site, the sampling date, a two-letter code for a specific sampling location, and a one-letter code designating the arsenic speciation bottle (if

necessary). The sampling locations at the treatment plant were color-coded for easy identification. The labeled bottles were separated by sampling location, placed in Zip-lock<sup>®</sup> bags, and packed into the cooler.

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

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

Samples for metal analyses were stored at Battelle's inductively coupled plasma-mass spectrometry (ICP-MS) laboratory. Samples for other water quality analyses were packed in separate coolers and picked up by couriers from American Analytical Laboratories (AAL) in Columbus, OH; TCCI Laboratories in New Lexington, OH; and/or Belmont Labs in Englewood, OH, all of which were under contract with Battelle for this demonstration study. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

### **3.6 Analytical Procedures**

The analytical procedures described in Section 4.0 of the QAPP (Battelle, 2004) were followed by Battelle ICP-MS, AAL, TCCI Laboratories, and Belmont Labs. Laboratory quality assurance/quality control (QA/QC) of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection limits (MDLs), and completeness met the criteria established in the QAPP (i.e., relative percent difference [RPD] of 20%, percent recovery of 80% to 120%, and completeness of 80%). The quality assurance data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project.

Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a WTW Multi 340i handheld field meter, which was calibrated for pH and DO prior to use following the procedures provided in the user's manual. The ORP probe also was checked for accuracy by measuring the ORP of a standard solution and comparing it to the expected value. The plant operator collected a water sample in a clean, plastic beaker and placed the probe in the beaker until a stable value was obtained. The plant operator also performed free and total chlorine measurements using Hach chlorine test kits following the user's manual.

## 4.0 RESULTS AND DISCUSSION

### 4.1 Site Description

**4.1.1 Pre-existing Facility.** The City of Three Forks had a population of approximately 2,000 residents. The water system was supplied by five wells (Wells 2, 5, 6, 8, and 9), which had a maximum combined capacity of 1,200,000 gpd. Located near the Jefferson River, Wells 5, 6, 8, and 9 did not contain elevated levels of arsenic and were used by the City to meet the daily water demand of approximately 120,000 gpd. Well 2, located adjacent to an active pasture at Connor's Ranch, drew water from the Madison River, which was rich in arsenic from the upflow of geothermal water at Yellowstone National Park. Therefore, Well 2 was designated for this demonstration study. Prior to startup of the arsenic treatment system, Well 2 had been used only in the summer for cemetery irrigation for 5 to 8 hr/day and 3 day/week. After startup, the treated water from Well 2 also was used to supply water to the distribution system.

Well 2 was 12.5-in in diameter and 150 ft deep with a screened interval extending from 75.5 to 150 ft below ground surface (bgs). The static water table was at 18 ft bgs. Well 2 was equipped with a 30-horsepower (hp) submersible pump rated for 250 gpm at 85 psi of total dynamic head (TDH). Figure 4-1 shows the pre-existing Well 2 pump house, which housed the wellhead piping, a pressure gauge, and a sample tap (Figure 4-2). Raw water from Well 2 was not treated prior to the demonstration study.

An onsite sewer system discharged wastewater into a lagoon and then the Madison River during the summer months. Designed to serve a population of 2,200 people, the lagoon was composed of two 7-acre cells with depths ranging from 3.5 to 5 ft.



**Figure 4-1. Pre-existing Well 2 Pump House**



**Figure 4-2. Interior Piping of Well 2 Pump House**

**4.1.2 Source Water Quality.** Samples of Well 2 water were collected by Battelle on November 30, 2004, during the introductory meeting for this demonstration project. The source water was filtered for soluble arsenic, iron, manganese, uranium, and vanadium, and then speciated for As(III) and As(V) using the field speciation method modified from Edwards (1998) by Battelle (Wang et al., 2000). In addition, pH, temperature, DO, and ORP were measured onsite using a WTW Multi 340i field meter.

Table 4-1 summarizes the analytical results of the Well 2 source water sampling and those provided by the facility for the demonstration site selection and by the selected technology vendor (Kinetico). Historical data collected by MT DEQ from July 1993 through July 1998 also are included in the table. Overall, Battelle's data are comparable to those provided by other parties with the exception of a few parameters provided by the facility. Well 2 had not been sampled by MT DEQ since 1998 as it was not used as a drinking water well nor connected to the City's distribution system.

The treatment system for the Three Forks site included iron addition, adsorption/coprecipitation, and Macrolite® pressure filtration. Several factors, such as arsenic speciation, iron concentration, pH,

**Table 4-1. Three Forks, MT Well 2 Source Water Data**

Parameter	Unit	Facility Data	Kinetico Data	Battelle Data	MT DEQ Data <sup>(a)</sup>
<i>Date</i>		NA	10/22/03	11/30/04	07/07/93–07/21/98
pH	S.U.	7.4	7.4	7.5	NA
Temperature	°C	NA	NA	11.3	NA
DO	mg/L	NA	NA	5.2	NA
ORP	mV	NA	NA	62	NA
Total Alkalinity (as CaCO <sub>3</sub> )	mg/L	NA	236	260	NA
Hardness (as CaCO <sub>3</sub> )	mg/L	246	185	205	NA
Turbidity	NTU	NA	NA	0.2	NA
TDS	mg/L	692	NA	292	NA
TOC	mg/L	65 <sup>(b)</sup>	NA	0.8	NA
Nitrate (as N)	mg/L	11.5	<1.0	0.4	0.42
Nitrite (as N)	mg/L	NA	NA	<0.01	<0.005
Ammonia (as N)	mg/L	NA	NA	<0.05	NA
Chloride	mg/L	19.0	19.7	17.0	NA
Fluoride	mg/L	NA	2.2	2.2	0.2–2.4
Sulfate	mg/L	NA	18	18	23
Silica (as SiO <sub>2</sub> )	mg/L	49.0	49.2	48.7	NA
Orthophosphate (as P)	mg/L	0.86	<0.5	<0.06	NA
As (total)	µg/L	72.0	85.0	64.3	60–78
As (total soluble)	µg/L	NA	NA	63.7	NA
As (particulate)	µg/L	NA	NA	0.6	NA
As(III)	µg/L	NA	NA	1.3	NA
As(V)	µg/L	NA	NA	62.4	NA
Fe (total)	µg/L	<30	<30	<25	NA
Fe (soluble)	µg/L	NA	NA	<25	NA
Mn (total)	µg/L	NA	<10	<0.1	NA
Mn (soluble)	µg/L	NA	NA	<0.1	NA
U (total)	µg/L	NA	NA	3.6	NA
U (soluble)	µg/L	NA	NA	3.8	NA
V (total)	µg/L	NA	NA	8.0	NA
V (soluble)	µg/L	NA	NA	8.4	NA
Na (total)	mg/L	NA	47.0	43.9	NA
Ca (total)	mg/L	NA	52.0	59.3	NA
Mg (total)	mg/L	13.1	13.5	13.7	NA

(a) MT DEQ historical data collected from 1993 through 1998 tabulated in Table 4-2.

(b) Data questionable.

NA = not analyzed

turbidity, total organic carbon (TOC), and competitive anions, may affect the system performance. The results of the source water assessment and implications for water treatment are discussed below.

**Arsenic.** Total arsenic concentrations ranged from 60 to 85 µg/L. Based on the November 30, 2004, speciation results, arsenic existed almost entirely in the soluble form. Of the soluble fraction, 1.3 µg/L existed as As(III) and 62.4 µg/L as As(V). Therefore, As(V) was the predominant species and prechlorination for the oxidation of As(III) to As(V) was not required for treatment. Prechlorination was used for disinfection purposes through the treatment system and to maintain chlorine residuals in the distribution system.

The presence of As(V) as the predominant species is consistent with the relatively high DO level of 5.2 mg/L measured for the same sample. The ORP reading was 62 mV, somewhat lower than what would be expected for an oxidizing water. ORP readings were carefully monitored during the performance evaluation study.

**Iron and Manganese.** The source water did not contain detectable levels of iron or manganese. Therefore, adsorptive media would be ideal candidates for this source water. However, because of concerns over the O&M cost, the City decided to choose coagulation/filtration using FeCl<sub>3</sub> rather than adsorptive media. For effective arsenic removal via the coagulation/filtration process, the iron concentration should be 20 times the arsenic concentration (Sorg, 2002). The treatment process relied upon adsorption and coprecipitation of As(V) onto/with iron solids.

**Other Water Quality Parameters.** The pH range of 7.4 to 7.5 was within the target range of 5.5 to 8.5 for arsenic removal via adsorption/coprecipitation onto/with iron solids. Results of other water quality parameters shown in Table 4-1 are comparable with exception to the results provided by the facility for nitrate (i.e., 11.5 mg/L), orthophosphate (i.e., 0.86 mg/L), total dissolved solids (TDS) (i.e., 692 mg/L), and TOC (i.e., 65 mg/L). These values are all significantly higher than those provided by other parties. The extremely high TOC was believed to be an error.

The raw water also was sampled by MT DEQ for heavy metals, such as antimony, barium, beryllium, cadmium, chromium, mercury, nickel, selenium, and thallium (see Table 4-2). These metals were not detected except for antimony (i.e., 0.003 mg/L) and barium (i.e., 0.02 mg/L) on one occasion.

**Table 4-2. Three Forks, MT Historic Water Quality Data**

Parameter	Unit	Well 2 Raw Water Data					
Date		07/07/93	07/05/94	09/20/94	09/11/95	06/19/96	07/21/98
Nitrate (as N)	mg/L	NA	NA	NA	NA	0.42	NA
Nitrite (as N)	mg/L	NA	NA	NA	NA	ND	NA
Nitrate + Nitrite (as N)	mg/L	0.52	ND	0.13	0.19	0.42	0.44
Fluoride	mg/L	2.4	NA	NA	NA	0.2	NA
Sulfate	mg/L	23	NA	NA	NA	23	NA
Antimony	mg/L	0.003	NA	NA	NA	ND	NA
Arsenic	mg/L	0.06	NA	NA	NA	0.078	NA
Barium	mg/L	0.02	NA	NA	NA	ND	NA
Beryllium	mg/L	ND	NA	NA	NA	ND	NA
Cadmium	mg/L	ND	NA	NA	NA	ND	NA
Chromium	mg/L	ND	NA	NA	NA	ND	NA
Mercury	mg/L	ND	NA	NA	NA	ND	NA
Nickel	mg/L	ND	NA	NA	NA	ND	NA
Selenium	mg/L	ND	NA	NA	NA	ND	NA
Thallium	mg/L	ND	NA	NA	NA	ND	NA

Source: MT DEQ.

NA = not analyzed; ND = not detected

**4.1.3 Distribution System.** The distribution system for the City of Three Forks consisted of an 8-mile closed distribution line supplied by Wells 5, 6, 8, and 9 prior to the demonstration study. The distribution system was extended to include Well 2 after startup of the arsenic treatment system. According to the utility operator, the distribution system piping was a combination of 6-, 8-, 10-, and 12-in ductile iron, polyvinyl chloride (PVC), and asbestos cement. The service lines were galvanized,

copper, and polyethylene piping. Well water was pumped into a 1,000,000-gal water tank (Figure 4-3) immediately adjacent to the treatment building for storage and distribution. The three locations that were selected for monthly baseline and distribution system water sampling were impacted by all five wells.

The City of Three Forks sampled water from the distribution system for several parameters: monthly at two residences for bacterial analysis; once every three years at 10 residences for LCR analysis; and once every nine years for asbestos analysis. Wells 5, 6, 8, and 9 also were sampled yearly for nitrate and nitrite; once every three years for arsenic, volatile organic compounds (VOCs), synthetic organic compounds (SOCs), inorganics, and periodically for radionuclides.



**Figure 4-3. One-million Gallon Water Tank by Treatment Building**

## **4.2 Treatment Process Description**

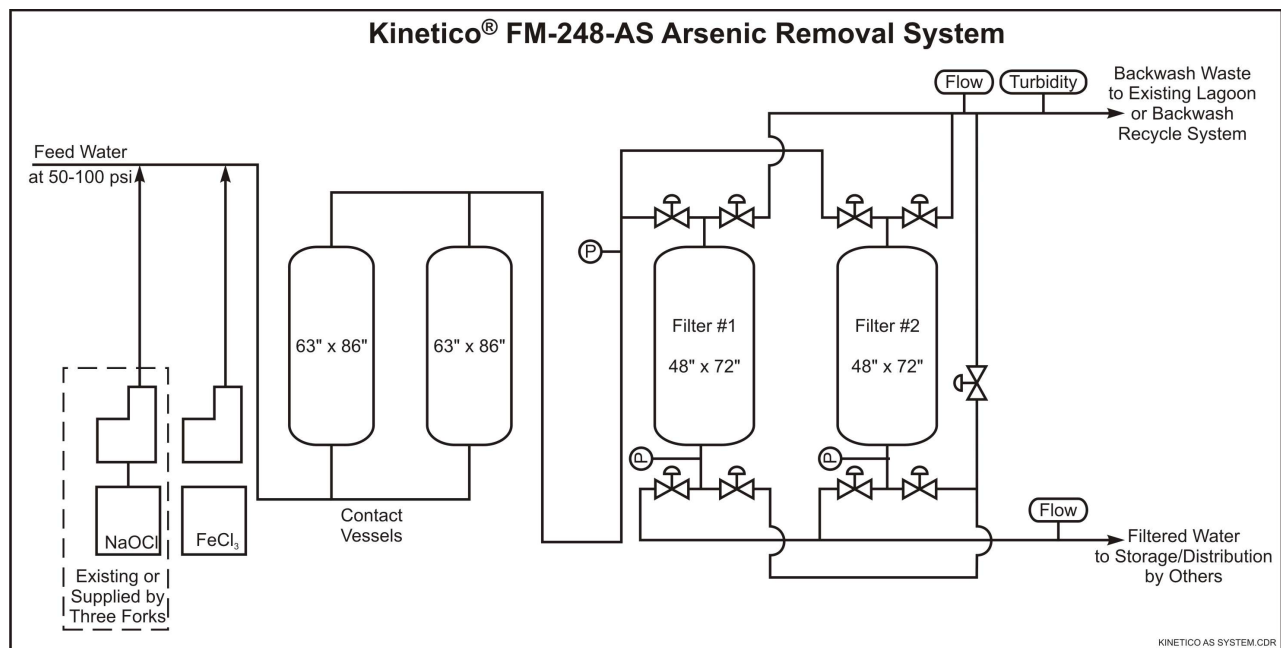
The arsenic treatment system installed was a Kinetico coagulation/filtration system that included Macrolite<sup>®</sup> pressure filtration. Macrolite<sup>®</sup> is a ceramic media manufactured by Kinetico approved for use in drinking water applications under NSF International (NSF) Standard 61. As claimed by the vendor, the spherical, low density and chemically inert media is designed to allow for filtration rates up to 10 gpm/ft<sup>2</sup>. The physical properties of this media are summarized in Table 4-3.

Figure 4-4 is a schematic of the Macrolite<sup>®</sup> FM-248-AS arsenic removal system. The treatment system was composed of two chemical feed systems for chlorine and FeCl<sub>3</sub>, two contact tanks (arranged in parallel), two pressure filtration vessels (arranged in parallel), and associated instrumentation to monitor inlet and outlet pressure, system flowrate, backwash flowrate, and backwash wastewater turbidity. The system also was equipped with a central control panel that housed a touch screen operator

**Table 4-3. Properties of 40/60 Mesh Macrolite® Media**

Property	Value
Color	Taupe, Brown, Grey
Thermal Stability (°F)	2000
Uniformity Coefficient	1.1
Sphere Size Range (in)	0.014–0.009
Bulk Density (g/cm <sup>3</sup> or lb/ft <sup>3</sup> )	0.86 or 54
Specific Gravity	2.05

interface panel (OIP), a programmable logic controller (PLC), a modem, and an uninterruptible power supply (UPS). The Allen Bradley PLC automatically controlled the system by actuating PVC pneumatic valves using a 7.5-hp compressor depending on various inputs and outputs of the system and corresponding PLC setpoints. The system featured schedule 80 PVC solvent bonded plumbing and all necessary isolation and check valves and sampling ports. The system's design specifications are summarized in Table 4-4.



**Figure 4-4. Schematic of Kinetico's Macrolite® Arsenic Removal System**

The treatment technology includes the following major process steps and system components:

- **Intake.** Raw water was pumped from Well 2, which was equipped with a 30-hp submersible pump rated for 250 gpm at 85 psi TDH to the distribution system. The well pump was controlled by a pair of high/low level sensors in the 1,000,000-gal water storage tank.
- **Chlorination.** The prechlorination system was used for disinfection purposes through the treatment system and to maintain a total chlorine residual level of approximately 0.9 mg/L (as Cl<sub>2</sub>) in the distribution system. MT DEQ requires that a minimum of 0.2 to 0.5 mg/L (as Cl<sub>2</sub>)

**Table 4-4. Design Specifications of Macrolite® System**

Parameter	Value	Remarks
<b><i>Influent Specifications</i></b>		
Peak Flowrate (gpm)	250	–
Arsenic Concentration (µg/L)	≤ 90	–
Iron Concentration (µg/L)	<25	–
<b><i>Pretreatment</i></b>		
Chlorine Residual (mg/L [as Cl <sub>2</sub> ])	0.9	From 12.5% NaOCl stock
Iron Addition (mg/L)	2.0	From 35% FeCl <sub>3</sub> stock (diluted 1:4)
<b><i>Contact</i></b>		
Number of Tanks	2	–
Configuration	Parallel	–
Tank Size (in)	63 D × 86 H	–
Contact time (min)	5	–
<b><i>Filtration</i></b>		
Number of Vessels	2	–
Configuration	Parallel	–
Vessel Size (in)	48 D × 72 H	–
Media Volume (ft <sup>3</sup> /vessel)	25	–
Media Bed Depth (in)	24	–
Peak Filtration Rate (gpm/ft <sup>2</sup> )	10	–
<b><i>Backwash</i></b>		
Pressure Drop (psi)	10–12	Across a clean bed
Initiating Pressure (psi)	20	Across bed at end of filter run
Initiating Standby Time (hr)	48	–
Initiating Service Time (hr)	24	–
Hydraulic Loading Rate (gpm/ft <sup>2</sup> )	8–10	100 to 125 gpm
Duration (min/vessel)	10–15	–
Turbidity Setpoint (NTU)	10	To terminate backwash
Wastewater Production (gal/event)	2,000–3,750	From backwashing both vessels
<b><i>Effluent Specifications</i></b>		
Peak Flowrate (gpm)	250	Typically expected
Maximum Daily Production (gpd)	360,000	Based on peak flowrate, 24 hr/day
Hydraulic Utilization (%)	6–21	Estimate based on expected demand <sup>(a)</sup>
Arsenic Concentration (µg/L)	<10	–
Iron Concentration (µg/L)	<25	–

(a) Operation of approximately 10 hr/week during winter and 35 hr/week during summer.

of free chlorine residuals be maintained at distant points of a distribution system. The chlorine feed system (Figure 4-5) consisted of a 55-gal high-density polyethylene (HDPE) day tank containing a 12.5% NaOCl solution, a 0.04-hp chemical feed pump (LMI B711-490HI model) with a maximum flowrate of 1.6 gal/hr (gph), a maximum pressure of 150 psi, and a 66-gal polyethylene spill containment pallet (U.S. Plastic model 2316). The feed pump was energized only when the well pump was on.

- Iron Addition.** FeCl<sub>3</sub> was added at a target dosage of approximately 2.0 mg/L (as Fe) to remove soluble As(V). The FeCl<sub>3</sub> feed system consisted of a 55-gal HDPE day tank containing a solution mixed from a 35% FeCl<sub>3</sub> stock, a 1/20-hp, 1,550 rotations per minute (rpm) overhead mixer (Pulsafeeder model J40456-F-M-TE-H/WRD/Vinyl), and a chemical feed pump (Pulsatron LPH5MA-VTC3-XXX) rated at 3.15 gph nominal flowrate and 150 psi maximum pressure.



**Figure 4-5. Chemical Feed Systems**

The iron and chlorine addition systems shared the same spill containment pallet as shown in Figure 4-5. The chemical feed pump was energized only when the Well 2 pump was on.

- **Adsorption/Coprecipitation.** Two 63-in × 86-in FRP tanks arranged in parallel provided 5 min of contact time to enhance the formation of arsenic-laden iron solids prior to pressure filtration. Each 1,160-gal tank had a 6-in top and a 6-in bottom flange connecting to the exit and inlet piping, respectively, for an upflow configuration. Figure 4-6 shows the two contact tanks along with the inlet and exit piping.
- **Pressure Filtration.** Removal of arsenic-laden iron particles from the contact tank effluent was achieved via downflow filtration through two 48-in × 72-in FRP pressure filtration vessels configured in parallel. The vessels were floor mounted and piped to a valve rack mounted on a welded, stainless steel frame (Figure 4-7). Each filtration vessel was filled with approximately 24 in (or 25 ft<sup>3</sup>) of 40/60 mesh Macrolite<sup>®</sup> media supported by fine garnet underbedding filled to 1 in above a stainless steel wedge-wire underdrain with 0.006-in slots. The flow through each vessel was regulated to 125 gpm with a flow-limiting device. The normal system operation with both vessels online provided a total system flowrate of 250 gpm.



**Figure 4-6. Contact Tanks with Inlet and Exit Piping**



**Figure 4-7. Filtration Vessels and Valve Rack**

- Filter Backwash.** At a 10-gpm/ft<sup>2</sup> loading rate and a 24-in bed depth, the anticipated pressure drop across a clean Macrolite<sup>®</sup> filter bed was 10 to 12 psi. The filters were automatically backwashed in succession in an upflow mode based on a service time, a standby time, or a  $\Delta p$  setpoint. Initial design specified that during each backwash cycle, water was drained from the first filtration vessel, which was then sparged with air at 150 psi for 2 min using a Speedaire Model 1WD61 air compressor. After a 25-min settling period, the filtration vessel was backwashed with treated water from the distribution system until the backwash wastewater reached a desired turbidity threshold setpoint (e.g., 20 nephelometric turbidity units [NTU]) as measured by an inline Hach<sup>™</sup> turbidimeter (Figure 4-8). These design values were altered throughout the course of the demonstration study as discussed in Section 4.4.3.1. The filtration vessel then underwent a filter-to-waste rinse before returning to service, and the second filtration vessel was backwashed thereafter. Shortly after system startup, it was determined that a booster pump needed to be installed to achieve the required backwash pressure from the treated water line due to the treatment system being constructed at the same elevation as the 1,000,000-gallon storage tank. To remedy this, a 7.5-hp booster pump (Blador 11SH model) was installed.



**Figure 4-8. Hach<sup>™</sup> Turbidimeter for Control of Backwash Duration**

As originally designed, the backwash wastewater was discharged to a recycling tank. The backwash recycle system (Figure 4-9) consisted of a 92-in diameter, 3,000 gal cone-shaped-bottom holding tank and a 5-hp Blador G&L pump (Model SSV). Upon completion of a backwash, wastewater in the backwash wastewater tank was allowed to settle for a period of time (Section 4.4.3.1) before the supernatant was pumped at 100 to 120 gpm through a 20-in, 5- $\mu$ m bag filter back to the head of the treatment train. Two weeks after commencement of

the performance evaluation study, the City installed piping and a manual diverter valve to drain the recycle tank supernatant directly to the sewer. This was done to help isolate/identify factors that adversely affected the treatment results (i.e., apparent breakthrough of soluble As[V] and arsenic-laden iron particles from the filters) observed during the first two weeks of system operations. Wastewater recycling was never put back into service throughout the remainder of the evaluation study. Had recycling been implemented as designed, the sludge that settled and accumulated in the recycle tank would be removed periodically from the bottom of the tank through a sludge removal port.



**Figure 4-9. Backwash Recycle System**

- **Water Storage and Distribution.** After leaving the treatment train, the treated water was transferred into the 1,000,000-gal storage tank located next to the treatment building. The stored effluent was allowed to flow to the distribution system based on demand.

### **4.3 Treatment System Installation**

**4.3.1 System Permitting.** The system engineering package, prepared by Kinetico and its subcontractor, Morrison Maierle, Inc., included a system design report, a general arrangement and piping and instrumentation diagram (P&ID), electrical and mechanical drawings and component specifications,

and building construction drawings detailing connections from the system to the inlet piping and the City's water and sanitary sewer systems. The engineering package was certified by a Professional Engineer registered in the State of Montana and submitted to MT DEQ for review and approval on November 2, 2005. A water supply construction permit was issued by MT DEQ on January 26, 2006. The permit approval letter required that a complete set of record drawings be signed, stamped, certified (that the system was constructed in accordance with approved plans and specifications), and submitted to MT DEQ within 90 days following completion of the construction.

**4.3.2 Building Construction.** A permit for building construction was approved by MT DEQ on April 7, 2006. Construction began on April 13, 2006 and was completed on July 31, 2006. The building was 15 ft × 29 ft with sidewall and roof peak heights of 17 and 22 ft, respectively. The foundation had a 102-in-depth overlain with a 6-in concrete slab. Wastewater discharge was facilitated with a 1,500-gal underground sump that emptied by gravity into the sanitary sewer. In addition to electrical and plumbing connections, a phone line also was installed to enable the equipment vendor to dial into the modem in the control panel for any troubleshooting. Figure 4-10 shows photographs of the constructed building.



**Figure 4-10. Treatment System Building**

**4.3.3 System Installation, Startup, and Shakedown.** The treatment system was delivered to the site on May 30, 2006 (see Figure 4-11). The vendor, through its subcontractor, performed the off-loading and installation of the system, including connections to the entry and distribution piping and electrical interlocking. System installation, hydraulic testing, and media loading were completed on June 5, 2006, but system startup and shakedown were delayed due to the absence of power to the building; power connection was completed on June 26, 2006. Startup/shakedown activities began on July 11, 2006, but ended prematurely due to insufficient pressure in the treated waterline for backwash (Section 4.2). A 20-

hp Goulds 11SH model booster pump was then procured and installed by the City under Kinetico's guidance and became operational on October 25, 2006. Kinetico technicians remained onsite to perform system startup and shakedown, which lasted until October 30, 2006. The shakedown and startup activities included PLC testing, instrument calibration, prolonged backwashing to remove Macrolite<sup>®</sup> media fines, chlorine disinfection and residual testing, and operator training on system O&M.

Two Battelle staff members traveled to the site to perform system inspections and operator training on sample and data collection on November 28 and 29, 2006. As a result of the system inspections, several punch-list items were identified and are summarized in Table 4-5.



**Figure 4-11. Treatment System Delivery at Three Forks, MT Site**

#### **4.4 System Operation**

**4.4.1 Service Operation.** System operational parameters are tabulated and attached as Appendix A with key parameters summarized in Table 4-6. The performance evaluation study began on November 27, 2006, and ended on February 8, 2008, with the treatment plant treating approximately 30,499,000 gal of water. The amount of water treated was based on readings from a flow meter/totalizer installed at the effluent side of the pressure filters.

Through the study period, the system operated for a total of 2,543 hr, based on well pump hour meter readings from November 27, 2006, to February 16, 2007, and filter run time from February 16, 2007, to February 8, 2008. The system operated for 2 to 7 days per week for a total of 284 days, excluding some weekends and weekdays when the system was not operating (see Appendix A) and some weekdays when

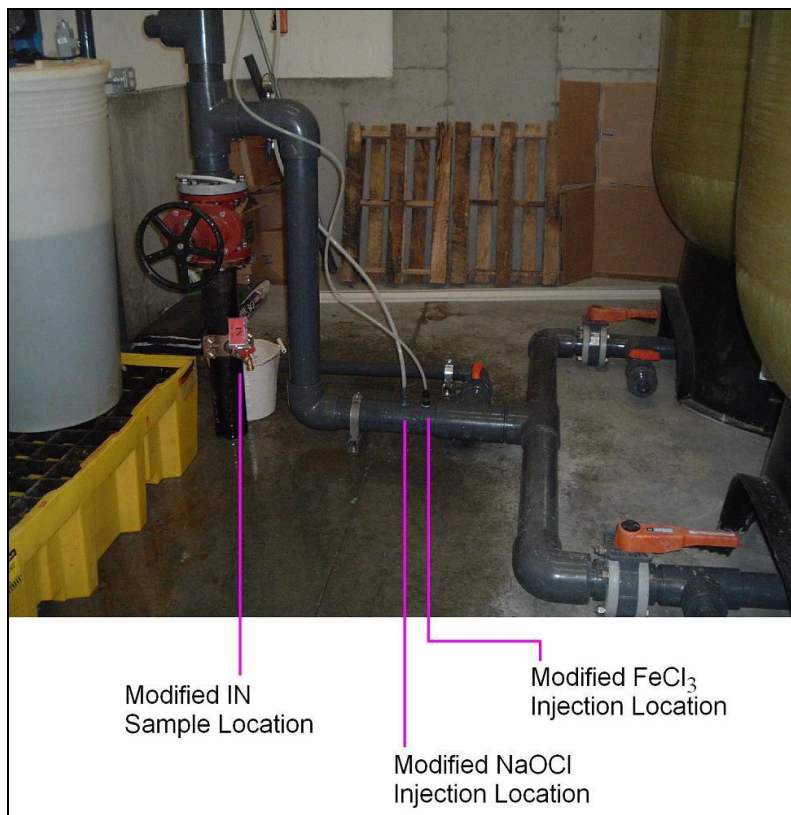
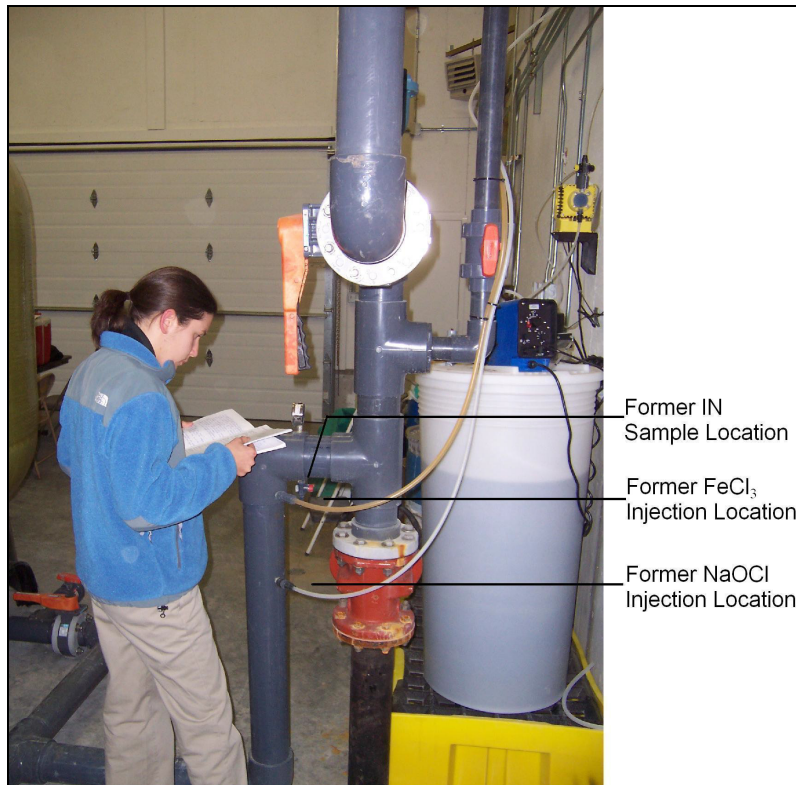
**Table 4-5. System Inspection Punch-List Items**

<b>Item No.</b>	<b>Punch-List Item Description</b>	<b>Corrective Action(s) Taken</b>	<b>Resolution Date</b>
1	Check programming to determine cause for Vessel A's returning to service only after reaching 45 min delay time following backwashing	<ul style="list-style-type: none"> <li>Programming checked; Vessel A returned to service upon completion of backwashing</li> </ul>	12/01/06
2	Check/revise maximum backwash time programming	<ul style="list-style-type: none"> <li>Programming checked, no further action required</li> </ul>	12/01/06
3	Adjust recycle flowrate and low backwash flowrate setpoint to meet State requirements and provide effective backwashing	<ul style="list-style-type: none"> <li>Recycle flowrate reduced from 44 to 20 gpm</li> <li>Low backwash flowrate setpoint increased from 20 to 100 gpm</li> </ul>	12/01/06
4	Adjust delay time for backwash wastewater recycling	<ul style="list-style-type: none"> <li>Increased delay time from 45 to 240 min to allow for settling of backwash solids</li> </ul>	12/08/06
5	Repipe influent piping (Figure 4-12), which was not installed per Drawing 2-1251-01	<ul style="list-style-type: none"> <li>Raw water sample tap relocated to &gt;10 ft from chemical addition points; Chlorine and ferric chloride injection points relocated further downstream (Figure 4-12)</li> </ul>	12/11/06
6	Reset differential pressure setpoint to 25 psi	<ul style="list-style-type: none"> <li>A differential pressure trigger lockout added to allow for increased differential pressure during backwash</li> </ul>	12/11/06
7	Adjust/improve backwash water recycling programming	<ul style="list-style-type: none"> <li>Further explanation given on PLC/alarm interface</li> <li>Total maximum backwash time reduced to 20 min</li> </ul>	12/15/06
8	Repair air relief valves, which leaked water constantly	<ul style="list-style-type: none"> <li>Gaskets of air relief valves replaced</li> </ul>	12/15/06
9	Repair leaky recycle piping	<ul style="list-style-type: none"> <li>Piping repaired by City</li> </ul>	12/15/06

the system or Well 2 was taken offline for repair and/or maintenance (see Table 4-7). To curb the elevated arsenic concentrations in the pressure filter effluent, the City implemented an increased blending scenario by reducing the operating schedule for Well 2 from 5–7 day/week to only 3 day/week on Mondays, Wednesdays, and Fridays. The average daily operating time was 8.9 hr/day, representing a daily use rate of 37%. With 30,499,000 gal of water treated, the average daily demand was 107,400 gpd, compared to 120,000 gpd reported by the facility prior to this demonstration study.

System flowrates were tracked by both instantaneous readings of the flow meter/totalizer installed at the effluent side of the pressure filters and calculated values based on readings of the flow totalizer and well hour meter or filter run time. As shown in Table 4-6, instantaneous flowrate readings ranged from 140 to 216 gpm and averaged 202 gpm, which is comparable to the calculated value of 206 gpm, but 19.2% lower than the design value of 250 gpm. As a result, the average contact time in the two contact tanks increased from the design value of 5 to 6.2 min and the average filtration rate through each pressure filter decreased from the design value to 10.0 to 8.0 gpm/ft<sup>2</sup>.

Contact time was initially recommended by the vendor for 5 min, which was determined to be sufficient to contact arsenic with precipitating iron particles and allow iron flocs to form. However, competition from silicates for available adsorptive sites as well as interaction of Fe(III) with silicates that cause the formation of soluble polymers and highly dispersed colloids (Iler, 1979; Robinson, et al., 1992) might have led to greater contact time needs than provided by the treatment system design. In addition, despite lower than the designed hydraulic loading at 8.0 gpm/ft<sup>2</sup> (compared to the design value of 10 gpm/ft<sup>2</sup>), breakthrough of both iron and arsenic particulates was experienced (see Section 4.5.2).



**Figure 4-12. Relocation of IN Sampling Location and Chemical Inject Points**

**Table 4-6. Treatment System Operational Parameters**

Parameter	11/27/06–02/08/08 Average [Range]
<b>Pretreatment</b>	
NaOCl Dosage (mg/L [as Cl <sub>2</sub> ])	2.4 [0.3–7.1]
FeCl <sub>3</sub> Dosage (mg/L [as Fe])	2.1 [0.2–6.1]
<b>Coagulation/Filtration</b>	
Total Operating Time (hr)	2,543
Total Operating Days (day)	284
Average Daily Operating Time (hr)	8.9
Throughput (gal)	30,499,000
Average Daily Demand (gal)	107,400
Instantaneous Flowrate (gpm)	202 [140–216]
Calculated Flowrate (gpm)	206 [77–261]
Contact Time (min)	6.2 [5.8–8.9]
Filtration Rate (gpm/ft <sup>2</sup> )	8.0 [5.6–8.6]
Δp across Each Filtration Vessel (psi)	12 [5.0–31]
Δp across System (psi)	25 [19–44]
Filter Run Time between Backwash Cycles (hr)	8.3 [0.1–21.1]
Throughput between Backwash Cycles (gal/event)	101,325 [1,128–580,376]
<b>Backwash</b>	
Frequency (occurrence/vessel/day)	1 [0–5]
Number of Cycles (Vessel A/Vessel B)	301/303
Flowrate (gpm) <sup>(a,b)</sup>	114 [85–133]
Hydraulic Loading Rate (gpm/ft <sup>2</sup> )	9.1 [6.7–10.6]
Duration (min/vessel)	10 [9–13]
Backwash Volume (gal/vessel/cycle)	1,167 [1,100–1,300]
Filter to Waste Volume (gal/vessel/cycle)	700
Wastewater Produced (gal/vessel/cycle)	1,867 [1,800–2,000]

(a) Average of both vessels' calculated backwash flowrate. Outlier of 44 gpm on 12/11/06 removed from calculations.

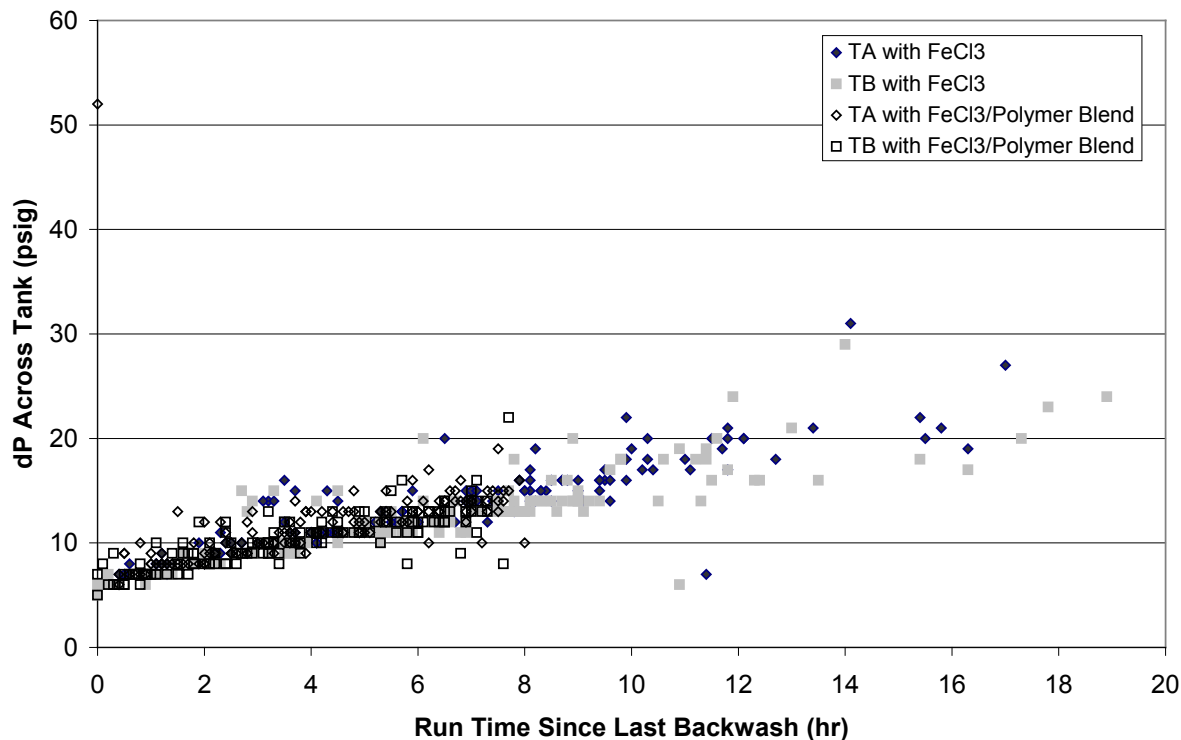
(b) Outlier of 44 gpm backwash lasting for 27 and 25 min for Vessels A and B, respectively, removed from average calculation.

**Table 4-7. Unscheduled System Downtime**

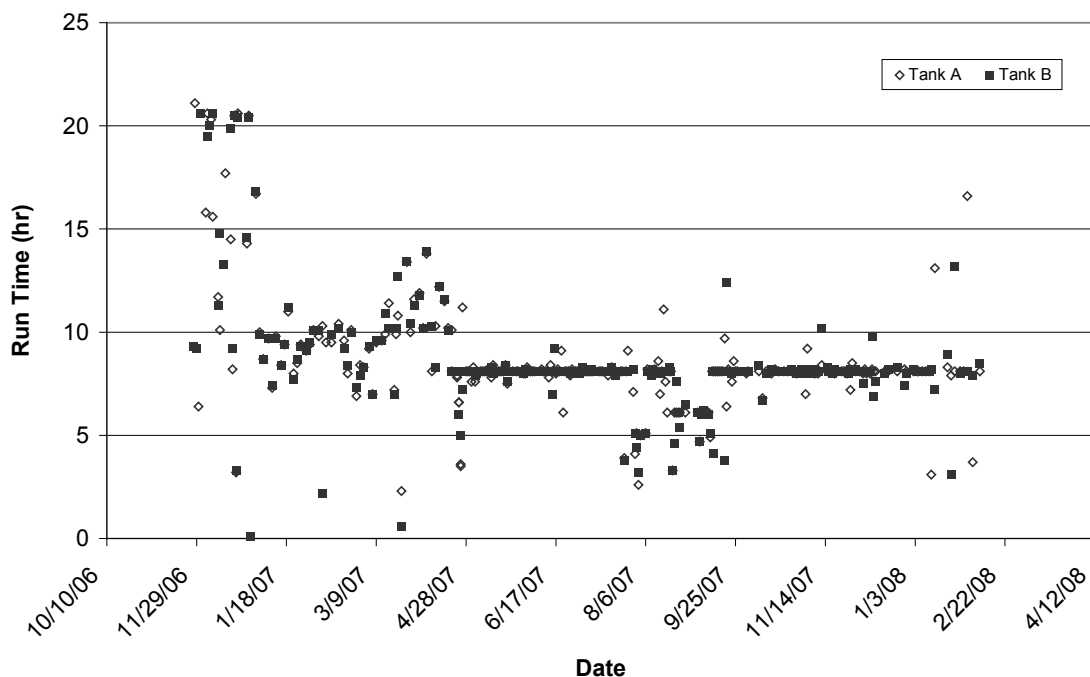
Date	Number of Days with System off/down	Cause(s) of System off/down
12/13/06	1	Influent piping modifications and recycling tank piped to sewer
02/14/07	1	Communication between plant and well down
02/15/07	0	Coaxial cable replacement and hand switches added to well (system remained online)
05/22–23/07	2	Well 2 offline for repairs
05/28–29/07	2	Well 2 offline for repairs
07/08–09/07	2	A 480 V, 65 amp breaker at Well 2 broken due to storm
08/25–27/07	3	Plant and Well 2 shut down due to low backwash flow alarm
01/14–21/08	7	Well 2 offline for repairs
Total	18	

$\Delta p$  readings ranged from 5 to 31 psi across each filter and from 19 to 44 psi across the system. As expected,  $\Delta p$  readings increased with increasing duration of the filter runs (Figure 4-13), presumably caused by the buildup of arsenic-laden iron solids within the filter media. Figure 4-13 also presents data for the  $\Delta p$  behavior with the filter runs using polymer amended systems (Section 4.5.2). It does not appear from these data that polymer addition significantly altered the trend of pressure drop with filter run time during the filter service cycles. Data in Figure 4-13 also indicate that backwash was effective in restoring the filters, as evidenced by the relatively low differential pressure readings, i.e., 5 to 8 psi, immediately after backwashing. Backwash will be further discussed in Section 4.4.3.

Filter run times between backwash cycles ranged from 0.1 to 21.1 hr and averaged 8.3 hr (Figure 4-14). The corresponding throughputs ranged from 1,128 to 580,376 gal/event and averaged 101,325 gal/event. Each backwash cycle consumed an average of 3,734 gal of treated water, which represents 3.8% of the average throughput between backwash cycles. These numbers are based on the time in service between backwash cycles and the average daily flowrate (taken from the totalizer) from that day.



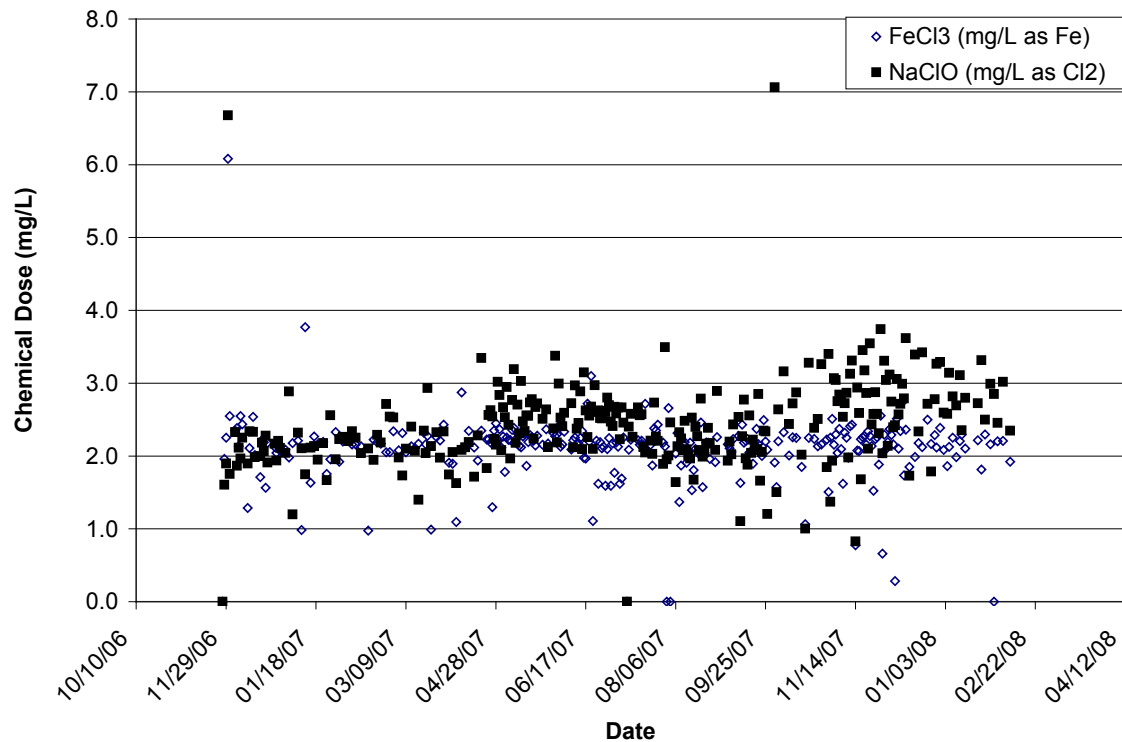
**Figure 4-13. Differential Pressure vs. Filter Run Time**



**Figure 4-14. Vessels A and B Service Time between Backwash Cycles**

**4.4.2 Chlorine and Iron Additions.** Chemical pretreatments consisted of prechlorination and iron addition. Prechlorination was used for disinfection purposes; chlorine dosages ranged from 0.3 to 7.1 mg/L (as  $\text{Cl}_2$ ) and averaged 2.4 mg/L (as  $\text{Cl}_2$ ) (Table 4-6 and Figure 4-15). Iron addition was used for As(V) removal. A 35%  $\text{FeCl}_3$  stock solution was diluted with a volume ratio of 1:4 and then fed prior to the contact tanks. Throughout the study period, iron dosages ranged from 0.2 to 6.1 mg/L (as Fe) and averaged 2.1 mg/L (as Fe), compared to the target dosage of 2.0 mg/L (as Fe) (Table 4-6 and Figure 4-15). Chlorine and iron dosages were calculated based on daily chemical consumption (by changes of solution levels in the respective chemical day tanks) and daily flow.

As shown in Figure 4-15, extensive scattering of chemical dosages was observed during both NaOCl and  $\text{FeCl}_3$  additions. Because the speed and stroke length settings of the chemical feed pumps were seldom adjusted, more consistent dosages should have been achieved especially with relatively constant system flowrates experienced during the study period. Therefore, the scattering observed was believed to be due mainly to inconsistencies or inaccuracies in solution level measurements, which could significantly impact the calculated dosages. Chemical consumption and dosage data could be better obtained by the use of a drum scale.



**Figure 4-15. Chlorine and Ferric Chloride Dosages Over Time**

**4.4.3 Backwash Operation.** As noted in Section 4.2, backwash could be initiated by a service run time, a standby time, or a  $\Delta p$  setpoint. The vendor recommended in the original design documentation that backwash be initiated: (1) when  $\Delta p$  across a single filter had reached 20 psi, (2) after the system had achieved 24 hr of service time, or (3) after the system had sat idle for 48 hr, whichever occurred first. Since system startup, these and several other settings had been adjusted a number of times based on system performance and filter effluent water quality data. Further, backwash cycles were manually initiated during the first five months of system operation and manual backwash was discontinued on April 16, 2007. Table 4-8 summarizes adjustments to PLC settings throughout the study period.

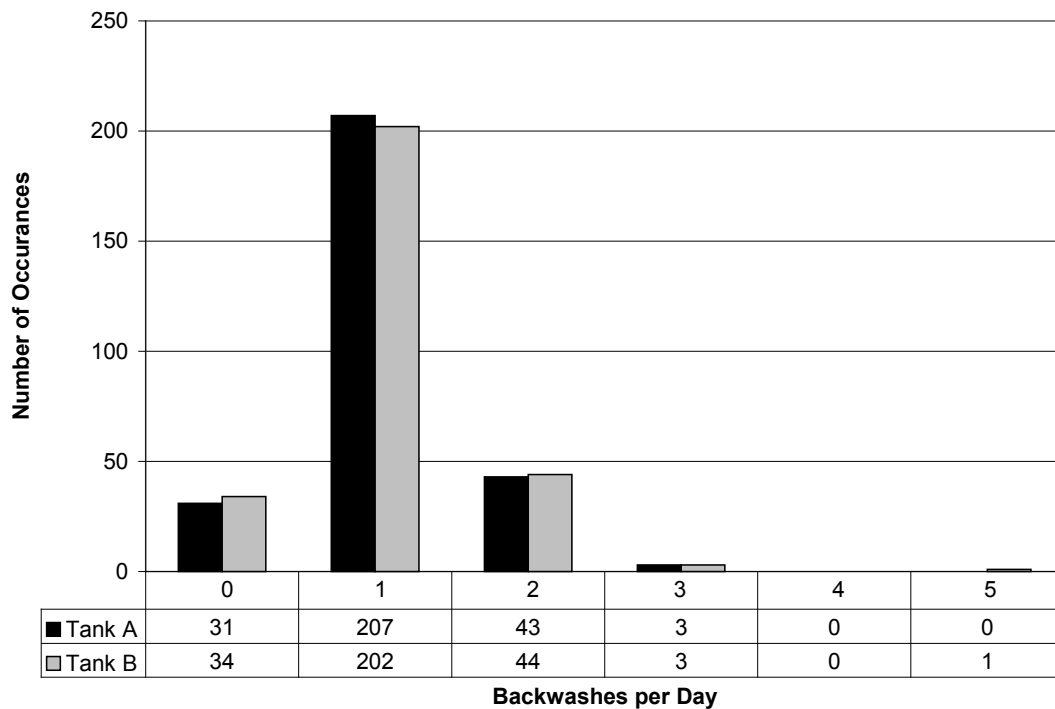
Since system startup, Vessels A and B were backwashed 301 and 303 times, respectively. Among the 284 days when the system was operational, Vessels A and B were backwashed once a day for 207 and 202 days, respectively. There were days when the vessels were either not backwashed (31 and 34 days, respectively), or backwashed two times a day (43 and 44 days, respectively) or even three times a day (three days each). On February 5, 2007 when the operator tried to initiate backwash from offsite, Vessel B was backwashed consecutively for five times due to unknown control issues with the City's system control and data acquisition (SCADA) system. The system had to be restarted to resume normal operations. Figure 4-16 shows a backwash frequency histogram.

The backwash duration for each filter was affected by the minimum and maximum backwash time settings and the ability of backwash wastewater to meet the turbidity threshold setting as measured by the in-line Hach<sup>TM</sup> turbidimeter. If backwash wastewater failed to meet the set threshold value prior to reaching the maximum backwash time, the backwash failure alarm had to be acknowledged and a successful backwash cycle completed before the vessel could return to the service mode. Each backwash was followed by a 3-min filter-to-waste (FTW) step to rinse off any left-over particles from the filter.

**Table 4-8. Summary of PLC Settings for Backwash Operations**

Parameter (for Each Vessel)	Date of Adjustments												
	11/03/06 <sup>(a)</sup>	11/14/06	11/22/06	11/29/06	12/01/06	12/07/06	12/08/06	04/16/07	07/17/07	07/24/07	07/30/07	08/08/07	08/20/07
Drain Time (min)	5	5	5	5	5	5	5	5	5	5	5	5	5
Service Time Trigger (hr)	24	20	20	20	20	20	20	8	24	24	5	8	6
Standby Time Trigger (hr)	48	72	80	80	80	80	96	96	96	96	96	96	96
$\Delta p$ Trigger (psi)	40	40	40	40	40	25	25	25	25	25	25	25	25
Minimum Backwash Time (min)	15	10	10	10	10	10	10	10	10	10	10	10	10
Maximum Backwash Time (min)	45	25	25	25	25	20	20	20	20	20	20	20	20
Turbidity Threshold (NTU)	12	12	15	15	15	15	20	20	20	25	30	30	30
Low Flowrate Threshold (gpm)	20	20	100	100	100	100	100	100	100	100	100	100	100
Filter-to-Waste Time (min)	3	3	3	3	3	3	3	3	3	3	3	3	3
Recycle Pump Run Time Delay (min)	25	25	45	45	240	45	240	240	240	240	240	240	240
Recycle Pump Flowrate (gpm)	44	44	44	20	44	20	20	20	20	20	20	20	20

(a) Initial field settings set by vendor technicians during system shakedown and startup.



**Figure 4-16. Backwash Frequency Histogram**

The amount of backwash wastewater produced ranged from 1,100 to 1,300 gal/vessel and averaged 1,167 gal/vessel. This amount reflects an average backwash flowrate of 114 gpm and an average backwash duration of 10 min (compared to the design values of 100 to 125 gpm and 10 to 15 min, respectively). Including an additional 700 gal/vessel produced during the 3-min FTW step, the total amount of

wastewater produced was 1,867 gal/vessel or 3,734 gal for both vessels. One backwash occurred on February 11, 2007 and lasted for 27 and 25 min for Vessels A and B, respectively and, therefore, was not included in the average calculation for the wastewater produced. The total amount of wastewater produced was equivalent to 3.8% of the amount of water treated. However, as discussed in Section 4.5.2, because the useful filter run length (i.e., the maximum filter run length which consistently yielded <10 µg/L total arsenic and <300 µg/L total iron in the effluent) was much shorter than the actual filter run lengths observed during the study, the percentage of processed water used for backwashing would have been much higher than 3.8% had the useful filter run length been implemented throughout the study.

**4.4.3.1 PLC Settings.** As shown in Table 4-8, the initial backwash PLC settings set by vendor technicians on November 3, 2006 during system shakedown and startup were quite different from those in the original design documentation and those for several similar Macrolite® pressure filtration systems already operational at other arsenic demonstration sites (Condit and Chen, 2006; Condit and Chen, 2008; Valigore et al., 2008a). Six subsequent modifications were made on November 14, 22, and 29, 2006, as well as December 1, 7, and 8, 2006, by the facility operator and the vendor based on Battelle's punch-list items summarized during the November 28 and 29, 2006, trip to the facility. The modifications made included:

- Decreasing the setpoint for the  $\Delta p$  trigger to 25 psi to more closely match the original design value.
- Decreasing the setpoint for the service time trigger to 20 hr to reduce particulate breakthrough from the filters.
- Increasing the setpoint for the standby time trigger to 96 hr to reduce the number of backwash cycles triggered based on standby time.
- Decreasing the maximum backwash time to 20 min and increasing the turbidity threshold to 20 NTU to reduce wastewater production.
- Increasing the low flowrate threshold to 100 gpm to more closely match the intended backwash flowrate of 100 to 125 gpm.

The facility operator decided to manually initiate backwash on a daily basis during the first five months of system operation; automatic backwash triggers were utilized only after April 16, 2007. On November 29, 2006, it was noticed that Vessel A after a backwash cycle would not return to service until it had reached the 45-min recycle pump delay time. This programming problem was resolved by the vendor through dialing to the PLC.

Since April 16, 2007, other changes to the PLC were made, including 1) temporarily increasing the setpoint for the service time trigger to 24 hr to accommodate a special study on the use of the C-05 iron/organic polymer blend, and then decreasing the setpoint to 5 to 6 hr to continue to address issues with particulate breakthrough, and 2) increasing the turbidity threshold from 20 to 30 NTU due to filter clogging caused by C-05 dosing.

**4.4.3.2 Backwash Flowrates.** Backwash flowrates ranged from 85 to 133 gpm and averaged 114 gpm, which was within the range of the design values of 100 to 125 gpm. There were only two backwash instances where the backwash times were over 13 min and thus, the backwash flowrates were considered sufficient for the backwash operation.

**4.4.4 Residual Management.** Residuals produced by the Macrolite® Arsenic Removal System included backwash wastewater and FTW rinse water, which contained arsenic-laden solids. Backwash

wastewater was analyzed for metals. As originally designed, 10% of the wastewater would be discharged via the sewer to a lagoon used for irrigation and the other 90% of the wastewater would be reclaimed after being passed through a bag filter. In June 2006, Battelle considered installing an additional totalizer after a three-way valve on the backwash recycle line in order to quantify the amounts of recycled water. Because the City decided to discharge the backwash wastewater directly to the lagoon via the sewer, the totalizer was not installed.

**4.4.5 Reliability and Simplicity of Operation.** Inability to achieve acceptable arsenic removal due to inefficient coagulation/filtration of arsenic-laden particles, and backwash-related issues including PLC settings were the primary sources of concern during the study. The filter performance issues were not successfully resolved and the treatment system was not able to achieve the 10- $\mu\text{g/L}$  arsenic MCL within reasonable service run lengths. Therefore, the City relied primarily on a blending scheme to meet the 10- $\mu\text{g/L}$  MCL prior to entering the distribution system.

**4.4.5.1 Pre- and Post-Treatment Requirements.** Pretreatment consisted of the addition of chlorine and ferric chloride. Although unnecessary due to the oxidizing nature of source water, prechlorination was used for disinfection and maintaining a total chlorine residual in the distribution system. Iron addition, using a 35%  $\text{FeCl}_3$  stock (diluted 1:4) solution, was required to remove arsenic. Iron was added upstream of the contact tank within the treatment plant where solution levels were tracked daily.

**4.4.5.2 System Automation.** The treatment system was automatically controlled by the PLC in the central control panel. The control panel contained a modem and a touch screen OIP that facilitated monitoring of system parameters, changing of system setpoints, and checking the alarm status. Service time, standby time, and  $\Delta p$  settings (Table 4-8) automatically determined when the filters were backwashed. The touch screen OIP also enabled the operator to manually initiate the backwash sequence.

**4.4.5.3 Operator Skill Requirements.** Under normal operating conditions, the daily demand on the operator was about 30 min for visual inspection of the system and recording of operational parameters, such as pressure, volume, flowrate, and chemical usage on field log sheets. After receiving proper training during the system startup, the operator understood the PLC, knew how to use the touch screen OIP, and was able to work with the vendor to troubleshoot problems and perform minor onsite repairs.

MT DEQ has five certification classes for water system operators (first to fifth class). First class covers all operators in operation of a system treating surface water using chemical coagulation, filtration and disinfection serving more than 20,000 people. Fifth class covers operators in operation of a system treating well water serving fewer than 100 people, with or without disinfection. The Three Forks operator possesses the third class certification, which covers operation of a system treating well water serving greater than 2,500 people with or without disinfection.

**4.4.5.4 Preventative Maintenance Activities.** The vendor recommended several routine maintenance activities to prolong the integrity of the treatment system (Kinetico, 2006). Daily preventative maintenance tasks included recording pressures, flowrates, chemical drum levels, and visually checking for leaks, overheating components, proper manual valve positioning and pumps lubricant levels, and any unusual conditions. The vendor recommended weekly checking for trends in the recorded data that might indicate a decline in system performance, and semi-annually servicing and inspecting ancillary equipment and replacing worn components. Cleaning and replacement of sensors and replacement of o-ring seals and gaskets of valves were performed as needed.

**4.4.5.5 Chemical Handling and Inventory Requirements.** Chlorine and iron addition were required for disinfection and effective arsenic removal, respectively. The operator tracked the use of the chemical solutions daily (by volume), coordinated the supplies, and refilled the day tanks as needed. A 15%

NaOCl solution, supplied in 55-gal drums by Hawkins, was transferred to the day tank and injected without dilution. A 35% FeCl<sub>3</sub> stock solution, supplied in 350 lb drums by Hawkins, was diluted 1:4 in the 55-gal day tank prior to injection into raw water. The speed and stroke settings of the chemical pumps were adjusted, as needed, to acquire the target chlorine residuals (as measured regularly with a Hach pocket colorimeter) and iron concentrations after the contact tanks.

## 4.5 System Performance

The performance of the Macrolite<sup>®</sup> FM-248-AS Arsenic Removal System was evaluated based on analyses of water samples collected from the treatment plant, backwash line, and distribution system.

**4.5.1 Treatment Plant Sampling.** The treatment plant water was sampled on 11 occasions, including one duplicate and three speciation sampling events, during the study. A complete set of the analytical results is tabulated and included in Appendix B. Table 4-9 summarizes the results for arsenic, iron, and manganese. Table 4-10 summarizes the results for other water quality parameters. The results of the water samples collected across the treatment plant are discussed below.

**4.5.1.1 Arsenic and Iron.** Figure 4-17 presents the results of three speciation events taken across the treatment train (at IN, AC, and TT locations). Figure 4-18 shows total arsenic concentrations measured across the treatment train. Total arsenic concentrations in raw water ranged from 59.8 to 96.7 µg/L and averaged 84.0 µg/L. Of the soluble fraction, As(V) was the predominant species averaging 74.5 µg/L with low levels of As(III) also present at 0.7 µg/L (on average). Comparatively low levels of particulate arsenic were present, averaging 4.2 µg/L.

Similar to the observation made during the initial site visit on November 30, 2004, source water from Well 2 was rather oxidizing, with DO concentrations ranging from 2.1 to 3.3 mg/L and averaging 2.6 mg/L and ORP readings ranging from 239 to 334 mV and averaging 272 mV. These DO and ORP data support the speciation results, which indicate the presence of primarily soluble As(V). DO levels remained relatively constant throughout the treatment plant at 2.2 to 2.4 mg/L (on average). ORP readings increased significantly to 342 mV (on average) after chlorination and remained relatively constant thereafter at 330 to 400 mV.

Soluble As(V) and As(III) after the contact tanks averaged 8.7 µg/L and 0.8 µg/L, respectively. Following iron addition (Figure 4-19) and contact tanks, the majority of arsenic was present, as expected, in the particulate form at 71.3 µg/L as a result of adsorption and/or coprecipitation of As(V) with iron solids. The close-to-10 µg/L soluble As(V) concentrations measured after the contact tanks suggest the need for more iron, which, presumably, would produce more iron solids and shorten already short filter run times, as discussed in Section 4.5.2.

The results of the first three weeks of treatment plant sampling indicated that total arsenic concentrations were only reduced to the range of 17.3 to 30.6 µg/L, significantly higher than the 10 µg/L MCL. Based on the November 29, 2006 speciation results, of the 28.3 µg/L total arsenic, 23.5 µg/L existed as particulate arsenic and 4.8 as soluble arsenic. This, together with the 936 µg/L particulate iron measured in the same sample, suggests breakthrough of arsenic-laden iron particles from the pressure filters. In light of the unsatisfactory treatment results, the regular sampling schedule was temporarily suspended and a series of special studies was carried out to determine the needs for process modifications to improve the filter performance. The results of the special studies are described in Section 4.5.2, including filter media run length, use of a higher iron dosage, use of a finer filter media size fraction, use of a C-05 iron/polymer blend, and use of other coagulant aids.

**Table 4-9. Summary of Arsenic, Iron, and Manganese Analytical Results**

Parameter	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
As (total)	IN	µg/L	11	59.8	96.7	84.0	12.4
	AC	µg/L	11	61.2	95.0	_(a)	_(a)
	TA	µg/L	8	8.4	22.4	_(a)	_(a)
	TB	µg/L	8	8.2	30.6	_(a)	_(a)
	TT	µg/L	3	16.8	28.3	_(a)	_(a)
As (soluble)	IN	µg/L	4	59.7	85.5	76.8	11.6
	AC	µg/L	4	5.9	11.7	_(a)	_(a)
	TA	µg/L	1	4.4	4.4	_(a)	_(a)
	TB	µg/L	1	3.8	3.8	_(a)	_(a)
	TT	µg/L	3	4.8	7.2	_(a)	_(a)
As (particulate)	IN	µg/L	4	0.1	10.3	4.2	5.0
	AC	µg/L	4	55.4	79.8	_(a)	_(a)
	TA	µg/L	1	4.0	4.0	_(a)	_(a)
	TB	µg/L	1	4.5	4.5	_(a)	_(a)
	TT	µg/L	3	9.6	23.5	_(a)	_(a)
As (III)	IN	µg/L	3	0.1	1.4	0.7	0.7
	AC	µg/L	3	0.1	1.3	_(a)	_(a)
	TT	µg/L	3	0.1	1.6	_(a)	_(a)
As (V)	IN	µg/L	3	59.0	85.4	74.5	13.7
	AC	µg/L	3	5.0	10.6	_(a)	_(a)
	TT	µg/L	3	3.2	6.0	_(a)	_(a)
Fe (total)	IN	µg/L	11	<25	<25	<25	0
	AC	µg/L	11	1,153	2,502	_(a)	_(a)
	TA	µg/L	8	111	323	_(a)	_(a)
	TB	µg/L	8	96.1	561	_(a)	_(a)
	TT	µg/L	3	225	936	_(a)	_(a)
Fe (soluble)	IN	µg/L	4	<25	<25	<25	0
	AC	µg/L	4	<25	41.5	_(a)	_(a)
	TA	µg/L	1	<25	<25	_(a)	_(a)
	TB	µg/L	1	<25	<25	_(a)	_(a)
	TT	µg/L	3	<25	<25	_(a)	_(a)
Mn (total)	IN	µg/L	10	<0.1	0.1	<0.1	0.0
	AC	µg/L	10	8	15	10	2.2
	TA	µg/L	7	0.5	6	3	1.5
	TB	µg/L	7	0.6	7	3	2.1
	TT	µg/L	3	3.2	9	5	3
Mn (soluble)	IN	µg/L	3	<0.1	0.4	0.2	0.2
	AC	µg/L	3	3.1	6	4	1.8
	TT	µg/L	3	2.6	5	3	1

(a) Statistics not meaningful for data obtained under three separate sets of process conditions.

**Table 4-10. Summary of Other Water Quality Parameter Results**

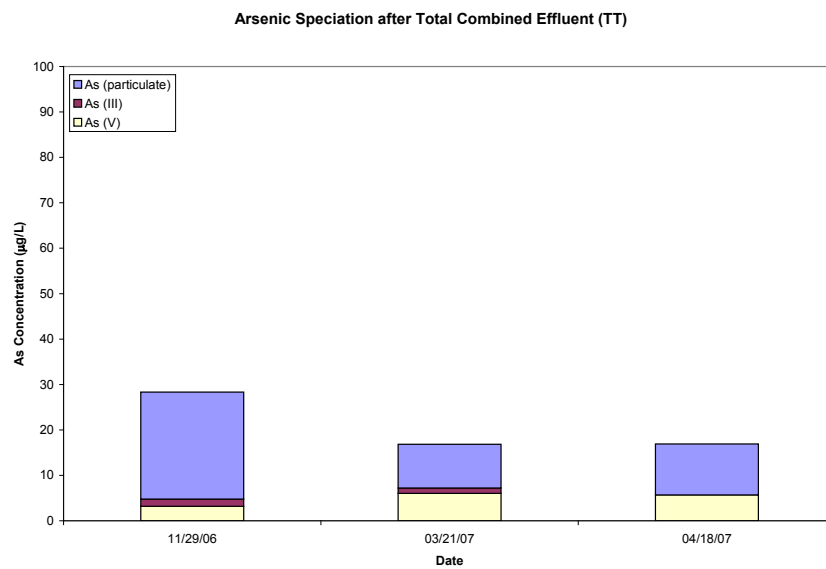
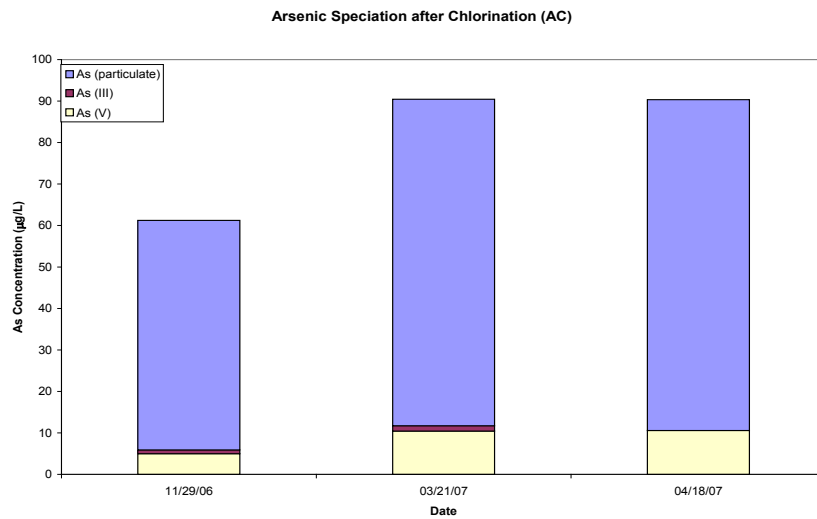
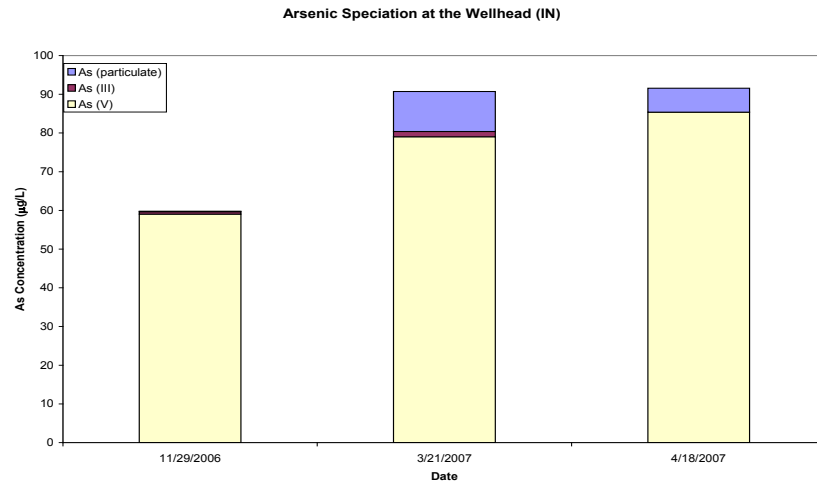
Parameter	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as CaCO <sub>3</sub> )	IN	mg/L	10	266.0	297.0	284.5	10.4
	AC	mg/L	10	267.0	302.0	280.8	11.1
	TA	mg/L	7	265.0	295.0	281.0	9.6
	TB	mg/L	7	267.0	291.0	279.9	10.1
	TT	mg/L	3	262.0	288.0	278.0	14.0
Fluoride	IN	mg/L	3	2.1	3.0	2.4	0.5
	AC	mg/L	3	2.1	3.1	2.5	0.6
	TA	mg/L	0	NS	NS	NS	NS
	TB	mg/L	0	NS	NS	NS	NS
	TT	mg/L	3	2.2	3.0	2.5	0.5
Sulfate	IN	mg/L	3	20.0	22.0	21.0	1.0
	AC	mg/L	3	20.0	22.0	20.7	1.2
	TA	mg/L	0	NS	NS	NS	NS
	TB	mg/L	0	NS	NS	NS	NS
	TT	mg/L	3	20.0	22.0	21.0	1.0
Nitrate (as N)	IN	mg/L	3	0.3	0.4	0.3	0.0
	AC	mg/L	3	0.3	0.4	0.4	0.1
	TA	mg/L	0	NS	NS	NS	NS
	TB	mg/L	0	NS	NS	NS	NS
	TT	mg/L	3	0.3	0.3	0.3	0.0
Total P (as P)	IN	µg/L	9	17.1	53.7	32.8	12.3
	AC	µg/L	10	5.0	53.5	29.9	14.2
	TA	µg/L	7	5.0	15.6	_(a)	_(a)
	TB	µg/L	7	5.0	14.8	_(a)	_(a)
	TT	µg/L	3	11.0	18.6	_(a)	_(a)
Silica (as SiO <sub>2</sub> )	IN	mg/L	10	46.8	50.8	48.5	1.3
	AC	mg/L	10	46.4	51.0	48.7	1.4
	TA	mg/L	7	45.6	49.2	47.4	1.4
	TB	mg/L	7	45.6	49.1	47.1	1.3
	TT	mg/L	3	47.8	50.3	49.2	1.3
Turbidity	IN	NTU	9	0.1	1.1	0.5	0.3
	AC	NTU	10	0.6	3.3	_(a)	_(a)
	TA	NTU	7	0.3	1.5	_(a)	_(a)
	TB	NTU	7	0.3	0.9	_(a)	_(a)
	TT	NTU	3	0.4	0.9	0.7	0.3
Total Organic Carbon	IN	mg/L	1	1.7	1.7	NA	NA
	AC	mg/L	1	0.5	0.5	NA	NA
	TA	mg/L	0	NS	NS	NS	NS
	TB	mg/L	0	NS	NS	NS	NS
	TT	mg/L	1	0.5	0.5	0.5	-
pH	IN	S.U.	10	7.3	7.8	7.5	0.2
	AC	S.U.	10	7.1	7.9	7.5	0.3
	TA	S.U.	7	7.1	7.9	7.5	0.3
	TB	S.U.	7	7.1	8.0	7.5	0.4
	TT	S.U.	3	7.2	7.9	7.6	0.4
Temperature	IN	°C	10	10.7	15.7	12.6	1.4
	AC	°C	10	10.5	15.7	12.3	1.6
	TA	°C	7	10.3	13.4	11.8	1.1
	TB	°C	7	10.4	13.3	11.8	1.1

**Table 4-10. Summary of Other Water Quality Parameter Results (Continued)**

Parameter	Sample Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Temperature (Cont)	TT	°C	3	11.1	15.8	13.2	2.4
Dissolved Oxygen	IN	mg/L	9	2.1	3.3	2.6	0.4
	AC	mg/L	9	1.7	3.9	2.4	0.7
	TA	mg/L	6	1.6	2.9	2.4	0.4
	TB	mg/L	6	1.5	2.8	2.2	0.6
	TT	mg/L	3	2.0	3.1	2.4	0.6
ORP	IN	mV	10	239.1	334.6	272.3	36.7
	AC	mV	10	280.7	506.9	341.9	80.1
	TA	mV	7	313.6	523.1	389.3	87.6
	TB	mV	7	312.7	548.1	400.1	96.3
	TT	mV	3	307.6	362.6	330.4	28.7
Free Chlorine (as Cl <sub>2</sub> )	AC	mg/L	10	0.4	3.2	0.9	0.8
	TA	mg/L	7	0.4	3.1	1.0	1.0
	TB	mg/L	7	0.5	2.7	1.0	0.8
	TT	mg/L	3	0.6	0.8	0.7	0.1
Total Chlorine (as Cl <sub>2</sub> )	AC	mg/L	10	0.4	3.2	0.9	0.8
	TA	mg/L	7	0.4	2.8	0.9	0.9
	TB	mg/L	7	0.5	3.1	1.0	1.0
	TT	mg/L	3	0.6	1.0	0.8	0.2
Total Hardness (as CaCO <sub>3</sub> )	IN	mg/L	3	180.7	222.2	199.4	21.1
	AC	mg/L	3	183.7	247.6	211.2	32.9
	TA	mg/L	0	NS	NS	NS	NS
	TB	mg/L	0	NS	NS	NS	NS
	TT	mg/L	3	177.8	255.7	215.4	39.0
Ca Hardness (as CaCO <sub>3</sub> )	IN	mg/L	3	128.4	167.4	146.8	19.6
	AC	mg/L	3	131.6	195.9	159.7	32.9
	TA	mg/L	0	NS	NS	NS	NS
	TB	mg/L	0	NS	NS	NS	NS
	TT	mg/L	3	128.5	204.1	163.4	38.1
Mg Hardness (as CaCO <sub>3</sub> )	IN	mg/L	3	50.6	54.8	52.6	2.1
	AC	mg/L	3	51.0	52.1	51.6	0.6
	TA	mg/L	0	NS	NS	NS	NS
	TB	mg/L	0	NS	NS	NS	NS
	TT	mg/L	3	49.3	55.1	52.0	2.9

NA = not available; NS = not sampled

Figure 4-19 presents total iron concentrations measured across the treatment train. Iron was required because the facility decided to use the coagulation/filtration process rather than adsorptive media to remove arsenic. The addition of FeCl<sub>3</sub> before the contact tanks resulted in total iron concentrations ranging from 1,153 µg/L to 2,502 µg/L and averaging 1,834 µg/L. Of the total iron, more than 98% was in the insoluble form based on the use of 0.45 µm disc filters during speciation sampling. Care must be taken in evaluating these data, however, since the presence of silica can cause the formation of dispersed colloidal material, which may penetrate through the 0.45 µm disc filters and be considered as particulates (Meng et al., 2000). Silica was present in the Three Forks source water at, on average, 48.5 mg/L (as SiO<sub>2</sub>).



**Figure 4-17. Arsenic Speciation Results**

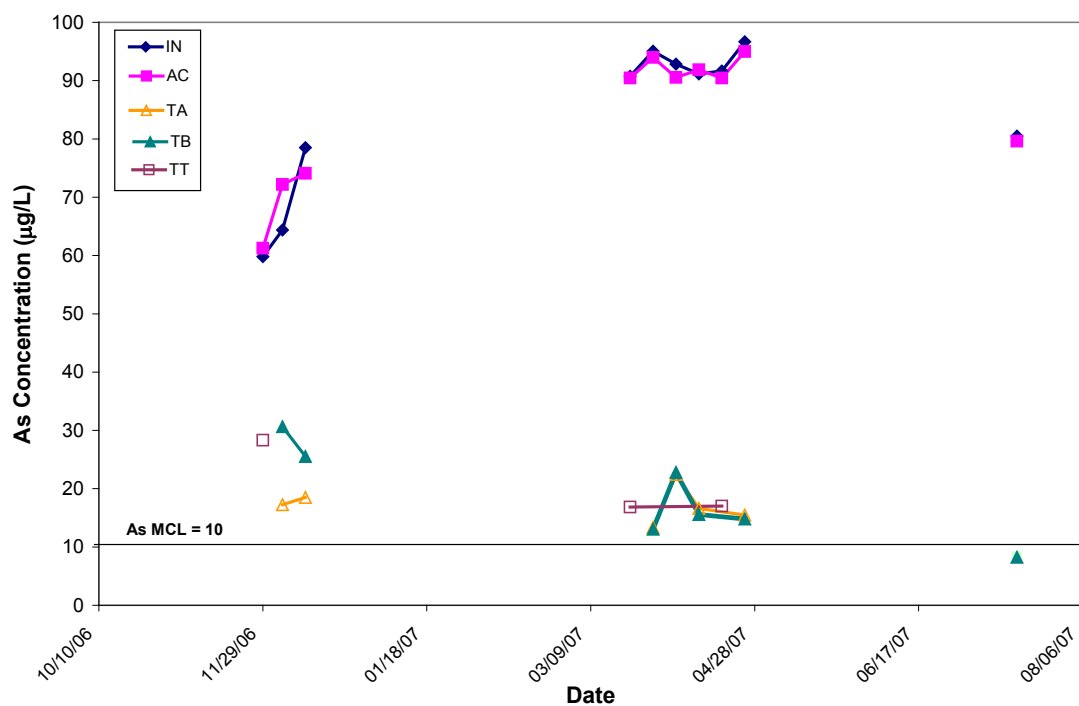


Figure 4-18. Total Arsenic Concentrations across Treatment Train

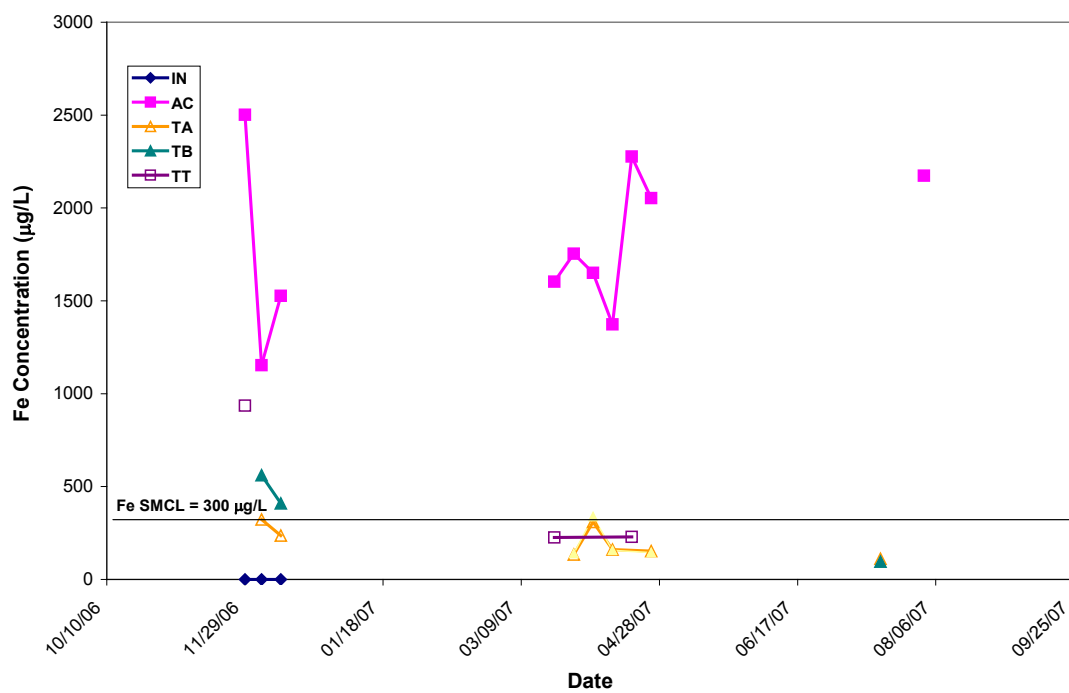


Figure 4-19. Total Iron Concentrations across Treatment Train

The removal of soluble arsenic onto iron solids also can be impacted by elevated pH and the presence of competing anions such as silica and phosphorus. pH values across the treatment train remained relatively constant at 7.5 (on average) (Table 4-10) and thus, should not have any major impact on arsenic removal. Silica begins to inhibit arsenic removal by ferric hydroxide at concentrations above 1 mg/L (Meng et al., 2000). At 48.5 mg/L, silica might have caused lower than expected soluble arsenic removal in the contact tanks. Phosphorus at 32.8 µg/L (as P) also might compete with As(V) for available adsorption sites on iron solids.

**4.5.1.2 Manganese.** Manganese concentrations in raw water were <0.1 µg/L during all sampling events. Both total and soluble manganese (Mn) concentrations increased after the contact tanks, averaging 10 and 4 µg/L, respectively. This is thought to be due to impurities in the chemicals used. Because the pressure filters removed only particulates, manganese levels after the pressure filters were lower on average at 5.0 µg/L. Studies have found that incomplete oxidation of Mn(II) occurs using free chlorine at pH values less than 8.5 (Knocke et al., 1987 and 1990; Condit and Chen, 2006; McCall et al., 2007).

**4.5.1.3 Chlorine Residual.** Total chlorine residuals remained relatively constant at 0.8 to 1.0 mg/L (as Cl<sub>2</sub>) (on average) throughout the treatment train. Of these total chlorine levels, almost all existed as free chlorine, indicating the absence of ammonia in source water.

**4.5.1.4 Other Water Quality Parameters.** Alkalinity, fluoride, sulfate, nitrate, temperature, and hardness levels remained relatively constant across the treatment train and were not affected by the treatment process (Table 4-10). TOC, however, was removed with 1.7 mg/L in raw water, but only 0.5 mg/L after the contact tanks and pressure filters. It is known that TOC can be removed via coagulation/filtration with iron solids.

**4.5.2 Special Studies.** Several special studies were carried out in an attempt to improve the performance of the pressure filters. Key parameters investigated included buildup of  $\Delta p$  across the filters over run time as well as arsenic and iron concentrations in the filter effluent. The studies included the use of a higher iron dosage, a finer filter media size fraction, and various coagulant aids/polymers. For the duration of the special study period, in order to achieve the 10-µg/L MCL, the City implemented a blending scenario with other wells to reduce the effect of high arsenic concentrations from Well 2. This involved reducing the operating schedule for Well 2 to three days per week (i.e., Monday, Wednesday and Friday). The blending resulted in arsenic concentrations between 4.4 and 8.6 µg/L prior to entering the distribution system.

**4.5.2.1 Effect of  $\Delta p$  and Filter Run Time.** A special study was carried out on December 20, 2006 to evaluate buildup of  $\Delta p$  across the filters over run time. With the addition of 1.8 mg/L of iron,  $\Delta p$  values across the pressure filters were 6 to 8 psi at 1 hr and 9 to 11 psi at 4 hr. This corresponds to a buildup rate of 1 psi/hr. Total arsenic concentrations in the filter effluent ranged from 8.1 to 8.3 µg/L at 1 hr and from 12.3 to 15.5 µg/L at 4 hr. Coinciding with the increase in total arsenic concentration was an increase in total iron concentration (i.e., from <25 µg/L at 1 hr to as high as 176 µg/L at 4 hr). These results indicate that the pressure filters can produce treatment effluent that meet the 10-µg/L MCL, but that their useful run lengths can be very short, i.e., <4 hr. Because speciation was not performed during the study, it was not clear if the arsenic that broke through the filters was present in the soluble or particulate form. If a significant amount of arsenic indeed was present in the soluble form (like what was observed during the first three months of regular sampling [Section 4.5.1.1]), there would be value to add more iron to achieve better soluble As(V) removal prior to pressure filtration. Conversely, the use of a higher iron dosage would inevitably produce more iron solids, which could further shorten useful run lengths, thus rendering the pressure filtration process virtually infeasible.

**4.5.2.2 Effect of Higher Iron Dosage.** For this special study (conducted on January 10, 2007) the  $\text{FeCl}_3$  dosage was increased from 1.8 to 2.2 mg/L (as Fe). The objective was to determine the effect of a higher iron dosage on total and soluble arsenic removal as well as particulate iron breakthrough. The increase in iron dosage appears to have very little impact on the  $\Delta p$  buildup rate (data not shown), with a  $\Delta p$  buildup rate of 1 psi/hr observed for both filters. For Vessel A, arsenic levels increased from 7.6 and 6.8  $\mu\text{g/L}$  (at 1.4 hr) to 8.8 and 6.0  $\mu\text{g/L}$  (at 2.4 hr) and to 11.9 and 6.4  $\mu\text{g/L}$  (at 4.4 hr) for total and soluble arsenic, respectively. For Vessel B, arsenic levels increased from 10.8 and 6.2  $\mu\text{g/L}$  (at 1.0 hr) to 11.8 and 6.2  $\mu\text{g/L}$  (at 2.0 hr) and to 17.5 and 6.2  $\mu\text{g/L}$  (at 4.0 hr) for total and soluble arsenic, respectively. The data illustrate that even at a higher iron dose, a significant amount of the total arsenic in the treated water was in the soluble form. As discussed in Section 4.5.1.1, silica and, to a lesser extent, phosphorus, might compete with arsenic for available adsorptive sites on iron solids, making removal of soluble arsenic less effective. Silica is also known to form complexes with arsenic in the colloidal size range, which is small enough to pass through 0.45  $\mu\text{m}$  filters and thus increase the apparent soluble arsenic concentration. As the filter run continued, particulate arsenic began to break through the filters, with concentrations increasing from 0.8 and 4.6  $\mu\text{g/L}$  (at 1.4 hr) to 2.8 and 5.6  $\mu\text{g/L}$  (at 2.4 hr) and to 5.5 and 11.3  $\mu\text{g/L}$  (at 4.4 hr) for Vessels A and B, respectively. The entirety of the iron breakthrough was in the particulate form, illustrating breakthrough of arsenic-laden iron solids.

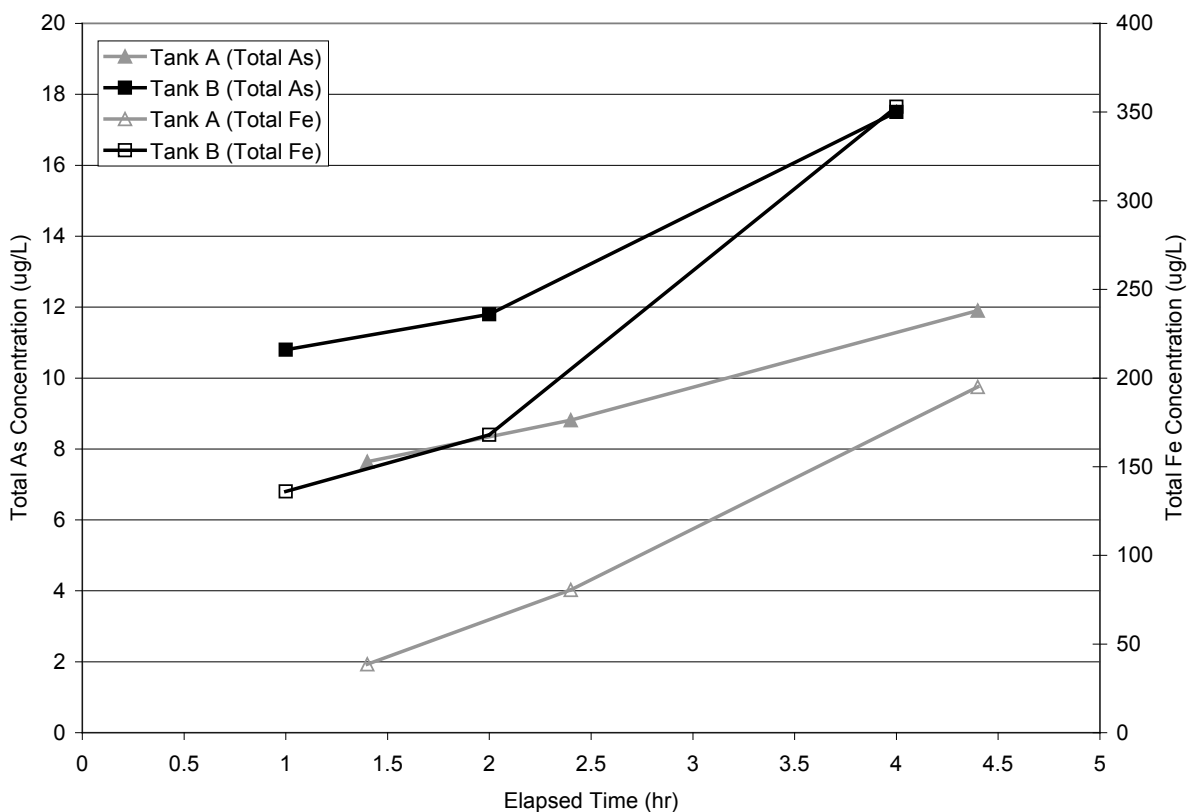


Figure 4-20. Total Arsenic and Iron Levels with Use of a Higher Iron Dosage

While increasing the iron dosage from 1.8 to 2.2 mg/L (as Fe) (or increasing the Fe:As ratio from 22:1 to 27:1) was not particularly effective in completely removing soluble arsenic from the contact tank and pressure filter effluent, it resulted in increased solids loading and increased particulate breakthrough from the pressure filters. A significant amount of particulate iron broke through the filters even within 1 hr of

filter run time and greater than 10 µg/L of arsenic breakthrough occurred within 2 hr of filter run time, thus reducing the useful filter runtime under these operational conditions. As such, it was evident that increasing the iron dosage most likely would not produce better treatment results and that other treatment strategies needed to be developed to improve filter performance.

**4.5.2.3 Effect of Media Size Fraction.** After consulting with the vendor, a decision was made to modify the filter beds by replacing a 6-in layer of the 40/60 mesh Macrolite® media with an equivalent amount of finer media, i.e., 70/80 mesh, in an attempt to achieve better particulate removal by the filters. After the media replacement on March 13, 2007, both vessels were backwashed to <5 NTU. After this, regular sampling as outlined in Table 3-3 resumed, with the treatment plant water samples collected in seven occasions (including one duplicate and two speciation sampling events) during March 21 and April 25, 2007. Regular sampling was suspended again on April 25, 2007 due to poor filter performance. Analytical results as presented in Figures 4-17 through 4-20 and Appendix B indicated the following:

- With the addition of 1.8 mg/L of iron (as Fe) (on average), soluble arsenic concentrations were reduced from 80.4–85.5 at the influent sample tap to 10.7–11.7 µg/L after the contact tanks and to 5.8–7.2 µg/L after the pressure filters, with the soluble arsenic existing primarily as As[V] based on the March 21 and April 18, 2007, speciation sampling results. The speciation results also showed that particulate arsenic concentrations increased significantly to 78.7–79.8 µg/L after the contact tanks. These results were consistent with those obtained during the first three weeks of regular sampling (Section 4.5.1.1) and the above-mentioned special studies (Sections 4.5.2.1 and 4.5.2.2).
- After pressure filtration, total arsenic concentrations were reduced to 12.3–22.8 µg/L (or 16.1 µg/L on average) (Appendix B), which were somewhat lower than those observed during the first three weeks of regular sampling, but very close to those collected at approximately 4 hr during the above-mentioned special studies. Of the 16.9-µg/L (on average) total arsenic measured during the two speciation sampling events, 6.5 µg/L existed as soluble arsenic and 10.4 µg/L as particulate arsenic. These results again were similar to those collected during the above-mentioned special studies. Figure 4-21 displays the total arsenic breakthrough based on the filter run length for regular sampling events before (vessels with only 40/60 mesh) and after (vessels with 40/60 mesh and 70/80 mesh) media replacement. There appears to be no benefit in total arsenic reduction resulting from the media replacement.
- Even after media replacement, >10-µg/L arsenic breakthrough was observed even less than 2 hr. This is similar to what was found during the previous special study. Thus, the useful filter run length was not affected by the media replacement.
- 134 to 338 µg/L of total iron was measured in the filter effluent, with almost all existing in the particulate form. These results also were similar to those collected during the above-mentioned special studies.

The results obtained during this study period clearly suggest that the media bed modification failed to effectively remove arsenic-laden particles to below the MCL levels, which, in conjunction with the soluble arsenic, pushed the arsenic concentrations in the filter effluent well beyond the MCL level.

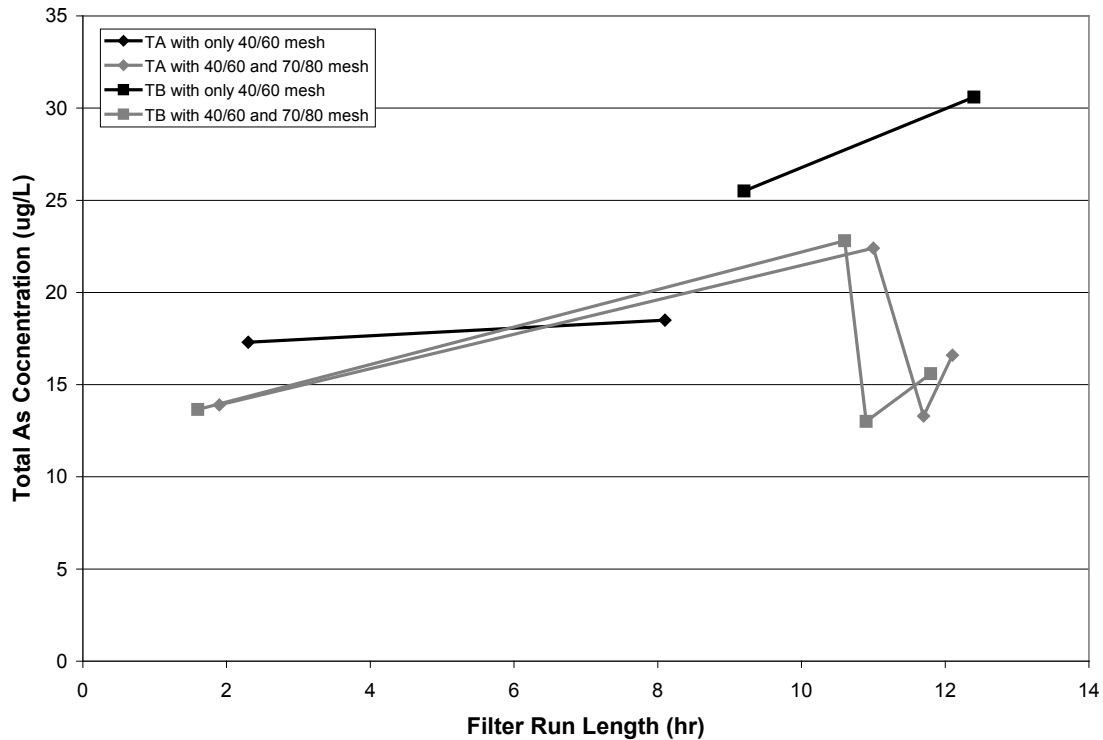


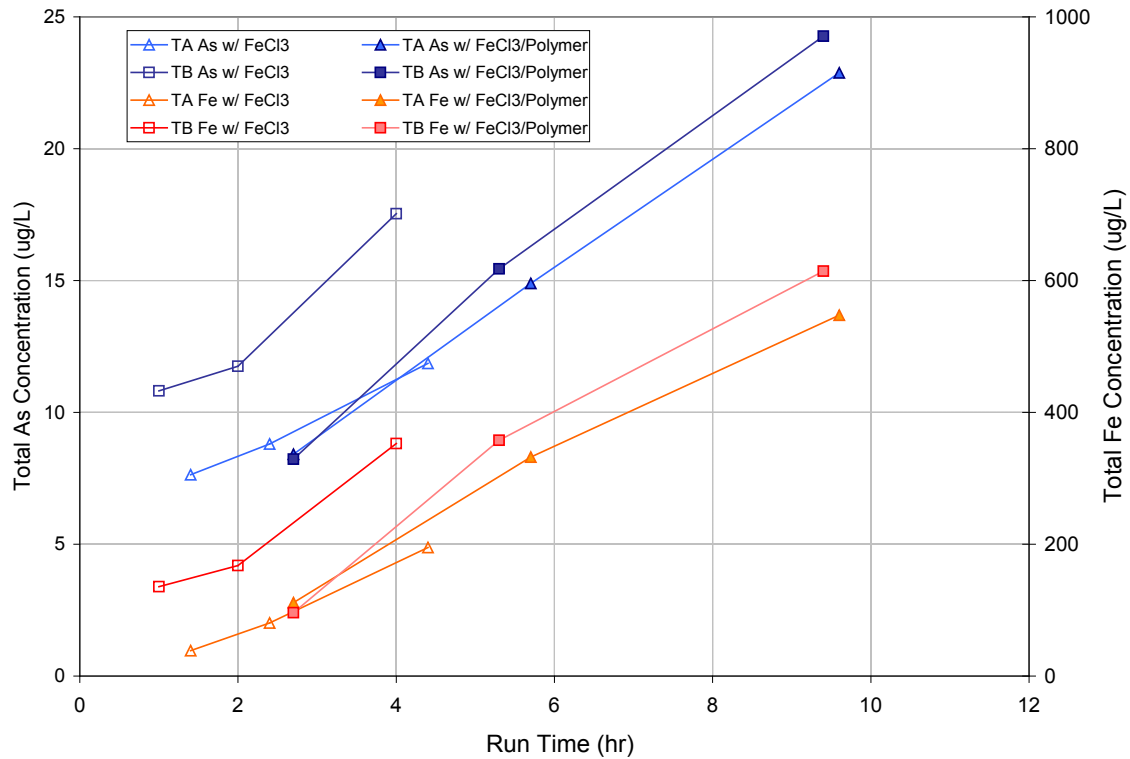
Figure 4-21. Total Arsenic Breakthrough from Filters with 40/60 Mesh Media Only and 40/60 and 70/80 Mesh Amendment

**4.5.2.4 Effect of Polymers/Coagulant Aids.** The use of polymers/coagulant aids was then tested to determine their effects on particulate removal. A series of jar test was carried out by the vendor on June 4, 2007 to determine the optimum chlorine and iron/polymer dose when applying an iron/organic polymer mixture named C-05. The results of the jar tests are presented in Table 4-11. As shown in the table, arsenic removal to below 10 µg/L might be achieved only with the use of 2.5 mg/L (as Fe) of the C-05 blend. (Note that the impact of chlorine dosage on the treatment results appears to be minimal). At this dosage, the Fe:As ratio was 31:1, which is higher than the 22:1 and 27:1 ratios used for the above-mentioned special studies. Not including the particulate arsenic that might break through the filters, the use of the C-05 blend would produce a filter effluent containing 9 µg/L of arsenic, at best.

Nonetheless, the use of the C-05 blend was implemented at the site on July 6, 2007 with a special run length study carried out on July 17, 2007. Figures 4-22 and 4-23 compare the results of this special study with those of an above-mentioned special study discussed in Section 4.5.2.2. By injecting 1.5 mg/L (as Cl<sub>2</sub>) of chlorine and 2.5 mg/L (as Fe) of C-05, total arsenic levels increased from 8.2–8.4 µg/L (at 2.7 hr) to 14.9–15.4 µg/L (at 5.3–5.7 hr) and to 22.9–24.3 µg/L (at 9.4–9.6 hr). Total iron concentrations increased from 96.1–111 µg/L (at 2.7 hr) to 332–358 µg/L (at 5.3–5.7 hr) to 547–614 µg/L (at 9.4–9.6 hr). The results collected at 2.7 and 5.3–5.7 hr were close to those of the previous special study collected at 2.0–2.4 and 4.0–4.4 hr, respectively, indicating little or no improvement in filter performance with the use of the C-05 blend. Throughout the special study, soluble arsenic concentrations in the filter effluent were relatively constant at 3.8–4.5 µg/L and the total iron was in particulate form. These results further support the observation that minimum improvement, if any, was achieved with the use of the C-05 blend, although this special study does show somewhat increased soluble arsenic removal over the previous special study for iron addition.

**Table 4-11. C-05 FeCl<sub>3</sub>/Polymer Blend Jar Test Results**

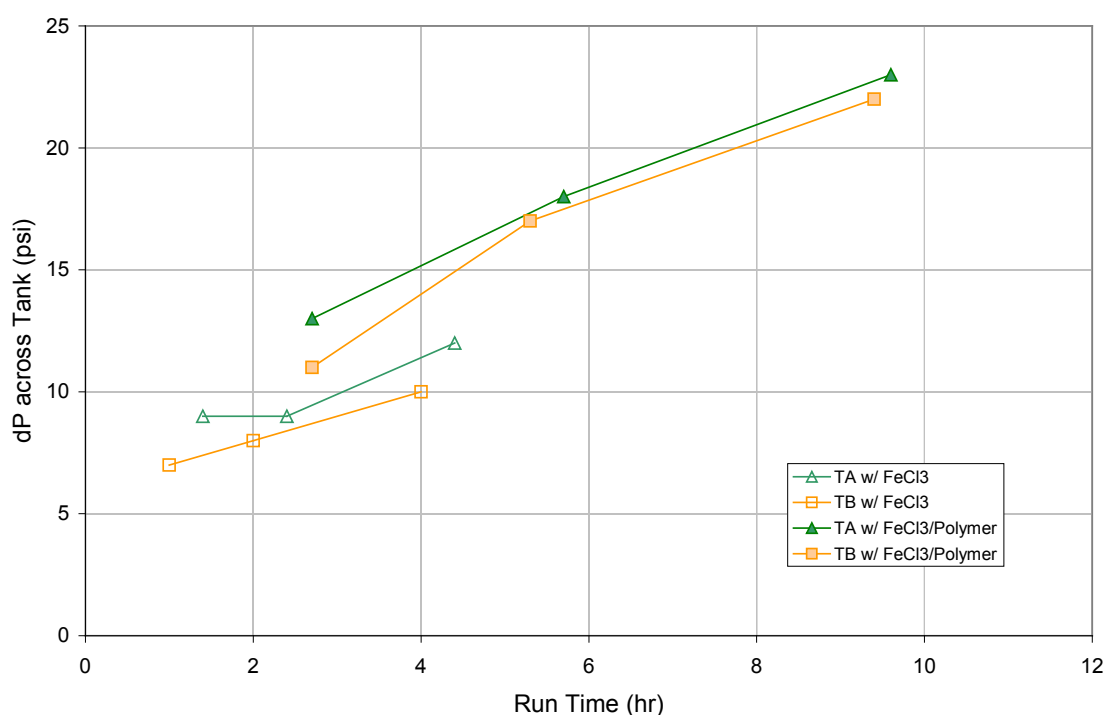
Sample No.	Chlorine Dosage (mg/L as [Cl <sub>2</sub> ])	C-05 Blend Dosage (mg/L [as Fe])	Filtered Concentration	
			Iron (µg/L)	Arsenic (µg/L)
0	0	0	<0.03	81
1	0.5	1.0	<0.03	34
2	0.5	1.5	<0.03	24
3	0.5	2.0	<0.03	14
4	0.5	2.5	<0.03	10
5	1.0	1.0	<0.03	35
6	1.0	1.5	<0.03	21
7	1.0	2.0	<0.03	18
8	1.0	2.5	<0.03	10
9	1.5	1.0	<0.03	33
10	1.5	1.5	<0.03	24
11	1.5	2.0	<0.03	13
12	1.5	2.5	<0.03	9



**Figure 4-22. Total Arsenic and Iron Levels with Use of C-05 Blend**

Figure 4-23 shows the effect of the C-05 blend on  $\Delta p$  buildup over filter run time. For Vessel A,  $\Delta p$  levels increased from 13 to 23 psi after 6.9 hr. For Vessel B,  $\Delta p$  levels increased from 11 to 22 psi after 6.7 hr. This corresponds to a  $\Delta p$  buildup rate of 1.4 to 1.6 psi/hr, which is higher than the 1.0 psi/hr buildup rate with the use of  $\text{FeCl}_3$  alone. The initial  $\Delta p$  levels after 2.7 hr of operation at 11 to 13 psi also were relatively elevated. It was noticed that the use of C-05 not only failed to produce lower levels of arsenic and iron in the filter effluent, but also promoted clogging of the filters. This was evidenced by several backwash alarms resulting from the inability to achieve the 20 NTU turbidity threshold within the maximum backwash time of 20 min. This resulted in a progressive increase in the turbidity threshold setting in the PLC from 20 to 25 and to 30 NTU in late July 2007 (Table 4-8). One disadvantage noted was that the coupled iron and polymer dosing with one chemical feed apparatus provided less flexibility in optimizing the polymer dose to avoid overdosing and clogging of the filters.

On August 1, 2007,  $\text{FeCl}_3$  addition was resumed pending investigation into other coagulation approaches.



**Figure 4-23.  $\Delta p$  vs. Run Time with Use of C-05 Blend**

A chemical supplier, Hawkins, was contacted and agreed to perform a series of jar tests to evaluate the effects of alum and several organic polymers on the filter performance. The results summarized in Table 4-12 indicate that the use of alum or organic polymer(s) can achieve below the arsenic MCL-level of treatment results (i.e., 6.2 to 7.3), although any particulate breakthrough can easily push the effluent levels over the MCL. AquaHawk 427 at a 1 mg/L dosage was recommended by Hawkins based upon its lower cost and the lowest soluble arsenic concentration in the jar test supernatant. The polyacrylamide polymers were not considered due to the need for a special make-up system and vendor's concerns over the compatibility of the polymers with Macrolite<sup>®</sup> media. Alum was eliminated from further consideration due to the high dosage at 10 mg/L. In November 2007, the operator elected not to install a separate chemical feed system for polymer dosing and the alternate AquaHawk 427 polymer was not further tested in the treatment plant.

**Table 4-12. Jar Test Results with Alum and Various Polymers**

Polymer	Ingredient (s)	Unit Cost (\$/gal)	Polymer Dosage (mg/L)	Filtered Concentration	
				Iron (µg/L)	Arsenic (µg/L)
AquaHawk 427	Polymer Blend [AL/PD/PY]	\$10.69	1.0	<25	6.2
AquaHawk 6527	PD	\$11.33	1.0	<25	6.7
AquaHawk 6547	PD	\$16.04	1.0	<25	6.7
Alum	NA	NA	10	<25	6.6
Aqua Hawk 9827	Long Chain Polymer	NA	0.2	<25	6.8
Aqua Hawk 9827	Long Chain Polymer	NA	0.5	<25	7.3
Aqua Hawk 9847	Long Chain Polymer	NA	0.2	<25	7.3
Aqua Hawk 9847	Long Chain Polymer	NA	0.5	<25	7.3

AL = Polyaluminum hydroxychloride

PD = Polydiallyldimethylammonium chloride

PY = Polyquaternary amine

**4.5.3 Backwash Wastewater Sampling.** Table 4-13 presents the analytical results from five monthly backwash wastewater sampling events. The backwash wastewater quality was similar for both vessels, indicating that the two vessels performed relatively consistently. For all events, the backwash wastewater had a pH of 7.2 to 7.5, with the majority of metals existing in the particulate form. The backwash wastewater samples collected from Events 1 to 4 were characteristic of normal operating conditions with iron addition. TDS ranged from 310 to 388 mg/L and averaged 350 mg/L; TSS ranged from 130 to 328 mg/L and averaged 235 mg/L. Concentrations of total arsenic, iron, and manganese ranged from 2,162 to 3,672 µg/L, 62,299 to 107,914 µg/L, and 202 to 411 µg/L, respectively. Assuming that these average results existed during the production of 1,167 gal/vessel of backwash wastewater, approximately 0.06 lb of arsenic, 1.6 lb of iron, and 0.006 lb of manganese were discharged from both filtration vessels during each backwash event. Of the amount discharged, some arsenic, iron, and manganese existed in the soluble form, including 10.5 to 50.4 µg/L of arsenic, 120 to 846 µg/L of iron, and 2.3 to 6.2 µg/L of manganese. The soluble arsenic and iron concentrations in the backwash wastewater were high when compared with those measured at most of the arsenic demonstration sites (Table 4-14). Because the presence of elevated silica (at 48.5 mg/L [as SiO<sub>2</sub>] on average in Well 2 water) could cause the formation of dispersed colloidal material, which might penetrate through the 0.45 µm disc filters and be considered as particulate (Meng et al., 2000), some of the “soluble” arsenic and iron might, in fact, exist as colloidal particles.

Table 4-13. Backwash Wastewater Sampling Test Results

Sampling Event		BW1										BW2									
		Filter Vessel A										Filter Vessel B									
		pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)	pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)
No.	Date	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
1	12/11/06	7.2	354	240	2,643	14.3	2,629	63,925	124	247	2.6	7.2	334	328	3,320	15.1	3,305	81,756	147	325	2.6
2	01/17/07 <sup>(a)</sup>	7.4	310	205	3,200	13.4	3,187	93,131	176	327	2.7	7.4	334	130	2,561	21.5	2,540	75,082	370	259	3.3
3	02/21/07	7.4	350	206	2,426	29.7	2,396	69,396	513	225	4.6	7.4	348	192	2,162	50.4	2,112	62,299	846	202	6.2
4	03/20/07	7.4	388	266	3,474	10.5	3,464	96,403	120	349	2.3	7.4	384	312	3,672	22.1	3,650	107,914	391	411	3.7
5	04/25/07 <sup>(b)</sup>	7.5	374	60	679	13.3	666	20,784	147	82.0	3.2	7.5	374	78	964	12.3	952	28,768	123	112	1.9

TDS = total dissolved solids; TSS = total suspended solids

(a) Backwash water recycling discontinued since 12/13/06.

(b) Lower concentrations due to shorter service run.

Note: Sampling generally conducted after 8 to 12 hr run time.

**Table 4-14. Comparison of Soluble Arsenic and Iron Concentrations in Backwash Wastewater**

Demonstration Location	Arsenic Removal Technology	SiO <sub>2</sub> Concentration in Raw Water <sup>(a)</sup> (mg/L)	Soluble Concentration in Backwash Wastewater <sup>(a)</sup>	
			As (µg/L)	Fe (µg/L)
Reno, NV (Cumming et al., 2009)	GFH adsorptive media	72.6 (51.5–95.1)	15.7 (15.4–15.9)	29.7 (<25–34.0)
Three Forks, MT	Coagulation/Macrolite <sup>®</sup> filtration with chlorine and iron addition	48.5 (46.8–50.8)	20.3 (10.5–50.4)	296 (120–846)
Bruni, TX (Williams et al., 2007)	AD-33 adsorptive media	41.9 (40.6–43.9)	NA	NA
Arnaudville, LA	Iron removal/Macrolite <sup>®</sup> filtration with chlorine (or KMnO <sub>4</sub> ) and iron addition	41.0 (38.4–43.5)	18.0 (13.0–28.3)	44.2 (<25–81.2)
Lidgerwood, ND (Condit et al., 2006)	Coagulation/sand filtration with iron/KMnO <sub>4</sub> /polymer addition	31.2 (29.0–34.2)	9.8 (7.5–11.9)	< 25
Sabin, MN (Condit et al., 2008)	Iron removal/Macrolite <sup>®</sup> filtration with chlorine addition	30.3 (28.5–32.5)	15.5 (6.1–27.6)	405 (67.3–827)
Climax, MN (Condit et al., 2006)	Coagulation/Macrolite <sup>®</sup> filtration with chlorine and iron addition	28.7 (16.8–39.2)	12.4 (6.4–25.6)	119 (<25–771)
Sandusky, MI (Valigore et al., 2008b)	Iron removal/AERALATER <sup>®</sup> Type II sand filtration with chlorine addition	12.0 (11.2–13.5)	3.2 (0.7–7.0)	86.1 (<25–196)
Pentwater, MI (Valigore et al., 2008a)	Coagulation/Macrolite <sup>®</sup> filtration with chlorine and iron addition	11.2 (10.1–13.2)	8.8 (6.5–11.4)	157 (48.5–263)

(a) Data presented including average and range (in parentheses).

**4.5.4 Distribution System Water Sampling.** Table 4-15 summarizes the results of the distribution system sampling events. Before system startup, total arsenic concentrations in the baseline samples ranged from 4.0 to 11.6 µg/L and averaged 6.1 µg/L. Because Well 2 was used only for cemetery irrigation, the baseline sampling results reflect mainly the quality of Wells 5, 6, 8, and 9 water, which, as discussed in Section 4.1.1, did not contain elevated levels of arsenic. After system startup, total arsenic concentrations across the three distribution system sampling locations ranged from 0.9 to 14.9 µg/L and averaged 6.8 µg/L, which is much lower than the 17.7 µg/L (on average) of the treated water samples collected during November 29, 2006, and July 17, 2007. This is due to the blending of the treated Well No. 2 water with source water from Wells No. 5, 6, 8, and 9 with low levels of arsenic.

After the treatment system began operation, arsenic concentrations decreased at DS3 from an average baseline value of 5.3 to 4.2 µg/L. In contrast, arsenic concentrations increased slightly at both DS1 (from an average baseline value of 6.3 to 8.3 µg/L) and DS2 (from an average baseline value of 6.8 to 8.2 µg/L). Samples at the DS3 location exhibited lower arsenic concentrations (about half of the average readings at DS1 and DS3), while exhibiting higher iron and manganese levels.

Alkalinity, pH, and lead concentrations remained fairly consistent before and after system startup. Copper concentrations increased significantly from 45.6 to 176 µg/L (on average) at DS1 and from 44.2 to 205 (on average) at DS3. At DS2, its concentrations decreased slightly from 153 to 142 µg/L. All concentrations were lower than the action level of 1.3 mg/L for copper.

## 4.6 System Cost

The system cost was evaluated based on the capital cost per gpm (or gpd) of design capacity and the O&M cost per 1,000 gal of water treated. Capital cost of the treatment system included cost for equipment, site engineering, and system installation, shakedown, and startup. O&M cost included cost

**Table 4-15. Distribution System Sampling Results**

Sampling Event		DS1								DS2								DS3 <sup>(a)</sup>							
		Non-Residence								Non-Residence								LCR							
		Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu
No.	Date	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
BL1	06/20/05 <sup>(b)</sup>	12.8	7.7	308	9.1	33.6	42.0	0.4	54.3	39.8	7.6	308	11.6	74.3	60.7	4.4	284	8.0	7.7	308	7.0	114	88.2	0.2	16.7
BL2	07/19/05	8.5	7.5	299	5.3	106	59.3	0.5	53.3	8.5	7.4	299	4.6	62.4	85.6	0.8	110	7.0	7.6	308	4.5	256	197	0.5	49.9
BL3	08/16/05	9.5	7.7	308	5.2	<25	71.5	0.3	49.2	10.5	7.5	308	5.7	231	103	0.9	116	9.0	7.5	321	5.6	<25	145	0.6	67.7
BL4	09/20/05 <sup>(c)</sup>	10.0	7.5	308	5.7	<25	56.1	0.3	25.6	11.0	7.5	295	5.4	90.0	99.1	0.2	102	6.2	7.6	304	4.0	86.4	147	0.3	42.4
1	12/13/06	9.0	7.4	311	8.9	<25	10.0	0.4	837	NA	7.3	287	11.7	43.8	20.9	0.7	141	9.0	7.3	280	10.8	36.0	18.1	<0.1	5.5
2	01/17/07 <sup>(d)</sup>	11.0	7.5	304	6.9	<25	12.4	0.2	67.7	9.0	7.5	311	8.6	27.0	42.3	0.6	131	7.5	7.7	313	4.4	<25	52.5	0.5	482
3	02/21/07	9.5	7.6	328	10.8	28.0	28.0	0.5	60.6	9.5	7.6	336	13.0	79.8	56.0	0.9	218	7.5	7.7	353	13.0	77.4	82.2	1.9	531
4	03/20/07	11.0	7.6	332	7.0	27.1	31.4	0.3	225	9.0	7.5	322	5.3	<25	49.8	0.5	118	7.0	7.8	335	2.0	39.2	94.9	0.2	163
5	04/17/07	11.5	7.6	319	7.4	39.9	25.9	<0.1	29.9	9.5	7.6	319	6.7	50.7	58.0	<0.1	33.3	7.5	7.8	321	1.2	105	162	0.2	95.2
6	05/23/07	10.3	7.5	312	6.5	<25	18.5	0.2	433	11.5	7.5	310	5.8	<25	34.9	0.4	238	6.5	7.8	310	1.5	38.2	122	0.2	104
7	06/14/07 <sup>(e)</sup>	10.3	7.7	320	8.0	<25	27.6	0.4	278	11.0	7.7	310	9.4	<25	28.4	0.2	45.2	6.5	7.7	310	3.3	<25	59.5	0.2	270
8	07/17/07	10.0	7.7	305	14.9	57.0	115	0.9	80.5	10.0	7.5	293	10.7	28.7	32.2	2.7	333	6.5	7.9	315	5.2	48.8	94.7	<0.1	628
9	09/17/07	12.5	7.6	301	12.8	<25	10.2	0.6	23.8	11.0	7.7	292	1.7	44.5	7.7	0.6	31.5	6.5	7.7	320	2.2	<25	77.6	0.4	20.8
10	10/17/07	11.3	7.5	294	7.2	27.2	17.6	0.2	63.1	11.0	7.6	308	8.7	62.4	55.6	0.5	132	6.5	7.6	300	0.9	<25	0.4	0.5	95.9
11	11/15/07	13.3	7.6	303	8.8	<25	15.5	0.1	81.9	11.0	7.6	287	8.6	<25	8.0	0.5	149	7.5	7.6	313	5.2	<25	18.3	0.2	74.0
12	12/11/07	13.3	7.6	294	7.2	<25	14.9	0.2	99.1	10.8	7.5	287	8.1	28.5	13.8	0.4	177	6.5	7.4	292	2.7	<25	13.2	0.2	44.7
13	01/15/08	13.8	7.5	281	1.7	41.4	22.2	0.6	9.4	10.0	7.8	308	8.9	168	67.8	0.4	93	6.0	7.8	302	2.4	143	142	0.3	154

- (a) BL samples collected at a separate sampling location.  
(b) DS1, DS2, and DS3 samples switched during sampling; correct results displayed.  
(c) DS3 sample collected on 09/19/05.  
(d) Increased distribution system blending scenario initiated since 01/01/07.  
(e) Stagnation time, pH, and alkalinity measured on 06/19/07.  
BL = baseline sampling; NA = data not available  
Lead action level = 15 µg/L; copper action level = 1.3 mg/L  
Alkalinity measured in mg/L (as CaCO<sub>3</sub>).

for chemicals, electricity, and labor. Cost associated with the building including the sump, sanitary sewer connections, and water system telemetry was not included in the capital cost because it was not included in the scope of this demonstration project and was funded separately by the City.

**4.6.1 Capital Cost.** The capital investment for the FM-248-AS system was \$305,447 (Table 4-16). The equipment cost was \$168,142 (or 55% of the total capital investment), which included cost for a chlorine and an iron addition system, two contact tanks, two pressure vessels each loaded with 25 ft<sup>3</sup> of Macrolite<sup>®</sup> media, instrumentation and controls, miscellaneous materials and supplies, labor, and system warranty. The system warranty cost covered the cost for repair and replacement of defective system components and installation workmanship for 12 months after system startup.

**Table 4-16. Capital Investment for FM-248-AS Treatment System**

Description	Cost	% of Capital Investment Cost
<b><i>Equipment</i></b>		
Tanks, Valves, and Piping	\$79,349	—
Macrolite <sup>®</sup> Media (50 ft <sup>3</sup> )	\$10,939	—
Instrumentation and Controls	\$21,970	—
Air Scour System	\$5,373	—
Iron Addition System	\$6,454	—
Additional Sample Taps and Totalizers/Meters	\$1,717	—
Labor	\$35,311	—
Freight	\$7,029	—
<b>Equipment Total</b>	<b>\$168,142</b>	<b>55%</b>
<b><i>Engineering</i></b>		
Labor	\$40,810	—
Subcontractor	\$12,625	—
<b>Engineering Total</b>	<b>\$53,435</b>	<b>18%</b>
<b><i>Installation, Shakedown, and Startup</i></b>		
Labor	\$14,000	—
Subcontractor	\$66,000	—
Travel	\$3,870	—
<b>Installation, Shakedown, and Startup</b>	<b>\$83,870</b>	<b>27%</b>
<b>Total Capital Investment</b>	<b>\$305,447</b>	<b>100%</b>

The site engineering cost covered the cost for preparing the required permit application submittal, including a process design report, a general arrangement drawing, P&IDs, electrical diagrams, interconnecting piping layouts, tank fill details, and a schematic of the PLC panel, and obtaining the required permit approval from MT DEQ. The engineering cost of \$53,435 was 18% of the total capital investment.

The installation, shakedown, and startup cost covered the labor and materials required to unload, install, and test the system for proper operation. All installation activities were performed by the vendor's subcontractor, and startup and shakedown activities were performed by the vendor with the operator's assistance. The installation, startup, and shakedown cost of \$83,870 was 27% of the total capital investment.

The total capital cost of \$305,447 was normalized to \$1,222/gpm (\$0.85/gpd) of design capacity using the system's rated capacity of 250 gpm (or 360,000 gpd). The total capital cost also was converted to an annualized cost of \$28,831/yr using a capital recovery factor of 0.09439 based on a 7% interest rate and a 20-yr return period. Assuming that the system operated 24 hr/day, 7 day/week at the design flowrate of 250 gpm to produce 131,400,000 gal/yr, the unit capital cost would be \$0.22/1,000 gal. During the first year, the system produced approximately 27,234,000 gal of water, so the unit capital cost increased to \$1.06/1,000 gal.

A 37½ ft × 33½ ft building with a sidewall height of 16 ft was constructed by the City to house the treatment system (Section 4.4.2). Not included in the capital cost, the total cost of the building and supporting utilities, which were sized for two treatment systems, was approximately \$120,000.

**4.6.2 O&M Cost.** O&M cost included chemical usage, electricity consumption, and labor for a combined unit cost of \$0.18/1,000 gal (Table 4-17). No cost was incurred for repairs because the system was under warranty. Since chlorination was used only for disinfection purposes, the O&M cost only includes the incremental chemical cost for iron addition at \$0.016/1,000 gal. Electrical power consumption was calculated based on the difference between the average monthly cost from electric bills before and after building construction and system startup. The difference in cost was approximately \$209.50/month or \$0.006/1,000 gal of water treated. Based on this time commitment and a labor rate of \$19.63/hr, the labor cost was \$0.16/1,000 gal of water treated.

**Table 4-17. O&M Cost for FM-248-AS Treatment System**

<b>Category</b>	<b>Value</b>	<b>Remarks</b>
Volume Processed (1,000 gal)	31,147	From 11/27/06 through 2/08/08
<b><i>Chemical Usage</i></b>		
37–42% FeCl <sub>3</sub> Unit Cost (\$/lb)	\$0.34	Supplied in 600 lb drums including tax, surcharges, and drum deposit
FeCl <sub>3</sub> Consumption (lb/1,000 gal)	0.048	
Chemical Cost (\$/1,000 gal)	\$0.016	
<b><i>Electricity Consumption</i></b>		
Electricity Cost (\$/month)	\$209.50	Average incremental consumption after system startup; including building heating and lighting
Electricity Cost (\$/1,000 gal)	\$0.006	
<b><i>Labor</i></b>		
Labor (hr/week)	4.7	30 min/day, 5 day/week
Labor Cost (\$/1,000 gal)	\$0.16	Labor rate = \$19.63/hr
<b>Total O&amp;M Cost (\$/1,000 gal)</b>	<b>\$0.18</b>	Including FeCl <sub>3</sub> usage

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**APPENDIX A**  
**OPERATIONAL DATA**

## US EPA Arsenic Demonstration Project at Three Forks, MT - Daily System Operation

Week No.	Day	Date	Time	Run Time				12.5% Cl <sub>2</sub> Tank Level	35% FeCl <sub>3</sub> Tank Level	Pressure Filtration				Flow rate	Totalizer to Distribution		Backwash			Run Time Since Last BW	
				Totalizer		Daily				Inlet	TA	TB	Outlet		Daily Flow	Cal Flow rate	Tank A	Tank B	Daily Volume	Vessel A	Vessel B
				Vessel A	Vessel B	Vessel A	Vessel B														
				hr	hr	hr	hr														
1	Mon	11/27/06	5:50	NA	NA	9.3	9.3	26.0	14.0	44	17	29	12	188	99	177	14	13	1.0	17.0	4.5
	Tue	11/28/06	7:30	NA	NA	12.3	12.3	31.0	33.0	45	26	21	12	185	141	191	15	13	1.0	8.2	11.9
	Wed	11/29/06	7:30	NA	NA	10.8	10.8	30.0	29.0	45	19	29	12	185	118	182	15	14	1.0	NA	13.5
	Thu	11/30/06	6:30	NA	NA	10.7	10.7	28.5	24.3	43	28	20	12	188	50	NA	16	14	1.3	4.3	17.8
	Fri	12/01/06	7:00	NA	NA	11.3	11.3	27.5	19.0	43	21	27	12	189	125	184	16	15	1.4	15.4	8.5
2	Mon	12/04/06	5:00	NA	NA	10.3	10.3	26.3	14.3	45	23	21	12	186	116	188	17	15	1.0	9.9	18.9
	Tue	12/05/06	4:30	NA	NA	13.0	13.0	25.0	31.0	39	28	23	12	200	143	183	18	16	2.6	2.3	12.4
	Wed	12/06/06	6:00	NA	NA	13.3	13.3	23.3	25.3	41	21	29	12	195	174	218	18	17	1.1	15.5	5.7
	Thu	12/07/06	5:30	NA	NA	11.7	11.7	22.0	19.8	42	27	22	12	191	132	187	19	17	1.3	6.9	17.3
	Fri	12/08/06	4:00	NA	NA	12.2	12.2	20.5	14.0	42	26	22	12	192	136	186	20	18	2.6	3.5	8.9
3	Mon	12/11/06	5:30	NA	NA	13.9	13.9	19.0	32.0	38	25	22	12	200	159	190	21	19	3.2	5.7	11.5
	Tue	12/12/06	7:30	NA	NA	12.5	12.5	17.3	27.3	39	25	25	12	198	148	197	22	20	2.3	8.1	9.2
	Thu	12/14/06	6:00	NA	NA	8.7	8.7	26.5	23.5	40	21	29	12	195	93	178	22	21	1.1	16.3	4.6
	Fri	12/15/06	6:00	NA	NA	11.8	11.8	25.3	19.0	41	24	24	12	193	135	190	23	21	0.9	10.4	16.3
4	Mon	12/18/06	5:00	NA	NA	11.6	11.6	24.0	34.0	37	23	24	12	199	132	190	24	22	NA	7.5	8.0
	Tue	12/19/06	6:00	NA	NA	12.5	12.5	22.5	29.3	40	23	26	12	196	143	191	25	23	4.9	11.8	11.3
	Wed	12/20/06	6:00	NA	NA	11.4	11.4	21.3	25.0	35	25	27	12	207	124	182	26	24	2.4	2.7	2.2
	Thu	12/21/06	6:00	NA	NA	11.6	11.6	19.8	34.0	40	23	26	12	195	133	191	27	25	2.3	11.1	10.5
	Fri	12/22/06	6:30	NA	NA	12.0	12.0	18.5	29.8	35	25	27	12	205	131	181	28	26	2.3	2.5	2.1
5	Tue	12/26/06	5:00	NA	NA	11.9	11.9	17.0	25.3	56	25	27	12	190	136	190	28	26	0.0	14.1	14.0
	Wed	12/27/06	6:00	NA	NA	12.9	12.9	15.5	20.3	41	23	25	12	191	150	193	29	27	2.1	12.7	12.3
	Thu	12/28/06	6:00	NA	NA	11.8	11.8	14.0	15.5	36	25	27	12	204	129	183	30	28	2.3	4.0	3.7
	Fri	12/29/06	7:30	NA	NA	11.8	11.8	12.5	10.5	43	22	25	12	189	133	188	30	28	0.0	15.8	15.4
6	Mon	01/01/07	6:00	NA	NA	10.3	10.3	36.5	34.0	38	22	24	12	200	117	189	31	29	2.3	9.4	8.9
	Wed	01/03/07	7:00	NA	NA	8.9	8.9	35.3	31.0	37	22	24	12	200	102	191	32	30	2.3	8.3	7.9
	Fri	01/05/07	7:00	NA	NA	8.3	8.3	34.8	27.8	38	22	24	12	200	98	196	33	31	2.2	7.9	7.5
7	Mon	01/08/07	7:00	NA	NA	9.9	9.9	33.8	24.3	37	22	24	12	200	100	169	34	32	NA	8.1	7.7
	Wed	01/10/07	6:00	NA	NA	8.2	8.2	32.8	22.5	38	22	24	12	196	109	222	35	33	2.6	9.0	8.5
	Fri	01/12/07	6:00	NA	NA	8.7	8.7	32.0	16.3	38	22	24	12	200	98	188	36	34	4.2	7.9	7.5
8	Mon	01/15/07	5:00	NA	NA	9.2	9.2	31.0	35.0	38	22	24	12	200	107	194	37	35	2.3	8.7	8.3
	Wed	01/17/07	7:00	NA	NA	9.2	9.2	30.0	31.5	37	23	24	12	200	105	190	38	36	2.3	8.5	8.1
	Fri	01/19/07	7:00	NA	NA	10.0	10.0	29.0	27.8	36	22	25	12	200	114	190	39	37	2.2	7.5	6.9
9	Mon	01/22/07	4:30	NA	NA	8.6	8.6	28.0	24.3	38	22	24	12	200	101	196	40	38	2.3	8.1	7.8
	Wed	01/24/07	7:30	NA	NA	9.1	9.1	27.0	20.5	38	22	24	12	198	130	239	41	39	2.4	8.7	8.2
	Fri	01/26/07	6:30	NA	NA	9.2	9.2	25.8	17.0	38	22	24	12	200	105	190	42	40	2.3	8.5	8.1
10	Mon	01/29/07	5:15	NA	NA	9.4	9.4	24.8	12.5	38	22	24	12	200	109	193	43	41	2.3	8.8	8.4
	Wed	01/31/07	7:15	NA	NA	10.2	10.2	23.5	34.0	37	23	24	12	200	118	192	44	42	2.3	9.6	9.1
	Fri	02/02/07	7:00	NA	NA	9.9	9.9	22.3	30.3	38	23	24	12	200	115	193	45	43	2.3	9.4	8.9

# US EPA Arsenic Demonstration Project at Three Forks, MT - Daily System Operation (Continued)

Week No.	Day	Date	Time	Run Time				12.5% Cl <sub>2</sub> Tank Level	35% FeCl <sub>3</sub> Tank Level	Pressure Filtration				Flow rate	Totalizer to Distribution		Backwash			Run Time Since Last BW	
				Totalizer		Daily				Inlet	TA	TB	Outlet		Daily Flow	Cal Flow rate	Tank A	Tank B	Daily Volume	Vessel A	Vessel B
				Vessel A	Vessel B	Vessel A	Vessel B														
				hr	hr	hr	hr														
11	Mon	02/05/07	5:45	NA	NA	9.9	9.9	21.0	26.3	38	22	24	12	199	116	195	46	44	2.3	9.5	8.7
	Wed	02/07/07	7:20	NA	NA	9.8	9.8	19.8	22.5	37	22	24	12	200	108	184	47	49	5.5	9.0	7.5
	Fri	02/09/07	6:15	NA	NA	9.6	9.6	18.5	18.5	37	23	24	12	200	111	192	48	49	2.3	9.1	8.6
12	Mon	02/12/07	5:30	NA	NA	10.3	10.3	17.3	14.0	39	21	24	12	196	121	195	49	50	2.3	9.9	9.0
	Fri	02/16/07	6:30	NA	NA	10.0	10.0	16.0	27.0	39	22	23	12	197	116	NA	50	51	2.3	9.5	8.8
13	Mon	02/19/07	6:15	8.1	8.0	8.1	8.0	15.0	23.5	37	22	24	12	201	99	NA	51	52	2.2	8.0	7.6
	Wed	02/21/07	6:15	16.5	16.5	8.4	8.5	13.8	19.8	37	22	24	12	200	104	204	52	53	2.2	8.4	7.7
	Fri	02/23/07	6:10	25.2	25.2	8.7	8.7	12.5	15.8	36	22	25	12	202	107	205	53	54	2.2	7.0	6.4
14	Mon	02/26/07	7:15	33.4	33.6	8.2	8.4	11.0	12.0	37	22	24	12	199	102	205	54	55	2.3	8.3	7.5
	Wed	02/28/07	7:00	41.7	41.8	8.3	8.2	21.3	33.5	37	23	24	12	202	101	204	55	56	2.3	8.2	7.8
	Fri	03/02/07	6:15	49.8	49.9	8.1	8.1	20.0	30.0	37	22	24	12	199	100	206	56	57	2.3	8.0	7.6
15	Mon	03/05/07	5:00	58.0	58.2	8.2	8.3	19.0	26.8	37	22	24	12	202	101	204	57	58	2.2	7.0	6.6
	Wed	03/07/07	7:00	67.4	67.6	9.4	9.4	18.0	22.5	38	22	24	12	198	115	203	58	59	2.1	9.4	9.0
	Fri	03/09/07	7:00	77.1	77.2	9.7	9.6	16.8	18.5	38	22	24	12	200	117	201	59	60	2.3	9.6	9.0
16	Mon	03/12/07	5:30	87.0	87.2	9.9	10.0	15.3	14.0	38	22	24	12	198	121	202	60	61	2.4	9.9	9.4
	Wed	03/14/07	7:15	98.4	99.6	11.4	12.4	13.8	31.8	32	25	26	12	212	138	193	61	62	2.2	11.4	10.9
	Fri	03/16/07	7:35	105.1	105.0	6.7	5.4	34.8	29.0	37	23	23	12	201	84	231	62	63	2.4	6.7	6.1
17	Mon	03/19/07	5:30	115.9	115.7	10.8	10.7	33.5	24.5	40	22	22	12	195	124	191	63	64	2.3	10.3	9.8
	Tue	03/20/07	7:25	127.3	127.5	11.4	11.8	32.3	19.5	43	23	25	12	190	141	202	64	65	2.3	11.8	11.4
	Wed	03/21/07	4:00	127.5	129.6	0.2	2.1	32.0	18.8	33	24	26	12	210	19	281	65	66	2.4	1.2	0.8
	Fri	03/23/07	7:00	142.0	142.4	14.5	12.8	30.5	34.8	43	22	22	12	189	158	193	66	67	2.3	13.4	13.0
18	Mon	03/26/07	5:00	152.0	152.4	10.0	10.0	29.3	30.8	40	21	23	12	196	120	200	67	68	2.3	10.0	9.6
	Wed	03/28/07	5:00	163.7	164.1	11.7	11.7	28.0	26.0	41	22	22	12	190	139	198	68	69	2.3	11.7	10.9
	Fri	03/30/07	7:00	175.4	175.9	11.7	11.8	26.5	20.5	42	21	23	12	191	139	197	69	70	2.3	11.8	11.4
19	Mon	04/02/07	5:30	185.7	186.1	10.3	10.2	25.5	16.5	40	23	22	12	194	123	200	70	71	2.2	10.2	9.8
	Wed	04/04/07	6:00	196.7	197.1	11.0	11.0	24.0	11.3	40	22	22	12	194	154	234	71	72	2.3	11.0	10.6
	Fri	04/06/07	7:30	207.6	208.1	10.9	11.0	23.0	35.5	39	22	24	12	197	128	195	72	73	2.3	8.1	7.7
20	Mon	04/09/07	5:00	217.9	218.5	10.3	10.4	21.8	30.3	41	21	23	12	194	124	199	73	74	2.4	10.3	7.8
	Wed	04/11/07	4:30	230.0	230.8	12.1	12.3	20.3	25.5	41	21	24	12	191	144	197	74	75	2.2	12.1	11.8
	Fri	04/13/07	5:30	241.6	242.4	11.6	11.6	18.8	20.3	41	21	23	12	191	137	197	75	76	2.3	11.5	11.2
21	Mon	04/16/07	4:45	253.7	254.4	12.1	12.0	17.5	15.0	42	22	22	12	191	144	199	76	77	2.4	12.1	11.6
	Wed	04/18/07	5:30	264.2	264.9	10.5	10.5	34.0	32.8	33	24	25	12	209	128	203	78	79	4.7	2.3	1.9
	Fri	04/20/07	6:00	277.1	277.8	12.9	12.9	31.8	27.3	37	23	23	12	200	154	199	79	80	2.3	7.1	6.7
22	Mon	04/23/07	5:00	289.2	290.5	12.1	12.7	30.5	21.8	35	23	25	12	205	154	207	81	82	4.8	3.5	3.2
	Tue	04/24/07	7:30	303.1	302.9	13.9	12.4	28.8	16.0	33	22	24	12	205	152	192	83	84	4.9	4.2	3.7
	Wed	04/25/07	7:30	307.9	305.8	4.8	2.9	27.8	12.8	35	25	26	12	204	83	361	84	85	2.2	1.9	1.6
	Thu	04/26/07	11:00	317.6	318.6	9.7	12.8	26.5	34.0	34	27	29	12	207	107	158	86	87	4.8	0.4	0.0
	Fri	04/27/07	11:00	323.7	324.7	6.1	6.1	25.8	31.5	42	22	22	12	196	72	196	86	87	0.0	6.5	6.1
	Sat	04/28/07	10:00	329.8	330.8	6.1	6.1	25.0	28.8	37	23	23	12	198	74	202	87	88	2.3	4.5	4.1
	Sun	04/29/07	11:00	337.1	338.1	7.3	7.3	23.8	25.8	37	22	22	12	201	87	199	88	89	2.4	3.7	3.3

# US EPA Arsenic Demonstration Project at Three Forks, MT - Daily System Operation (Continued)

Week No.	Day	Date	Time	Run Time				12.5% Cl <sub>2</sub> Tank Level	35% FeCl <sub>3</sub> Tank Level	Pressure Filtration				Flow rate gpm	Totalizer to Distribution		Backwash			Run Time Since Last BW	
				Totalizer		Daily				Inlet psig	TA psig	TB psig	Outlet psig		Daily Flow kgal	Cal Flow rate gpm	Tank A No.	Tank B No.	Daily Volume kgal	Vessel A hr	Vessel B hr
				Vessel A	Vessel B	Vessel A	Vessel B														
				hr	hr	hr	hr														
23	Mon	04/30/07	10:30	344.7	345.7	7.6	7.6	22.5	22.3	37	23	24	12	201	92	201	89	90	2.3	3.2	2.8
	Tue	05/01/07	10:45	352.4	353.9	7.7	8.2	21.5	18.8	36	22	22	12	203	99	207	90	91	2.3	3.3	2.9
	Wed	05/02/07	11:00	360.5	361.8	8.1	7.9	20.3	15.0	37	23	22	12	204	95	198	91	92	2.4	3.1	2.7
	Thu	05/03/07	12:00	367.0	368.0	6.5	6.2	19.3	36.3	33	25	26	12	208	79	208	92	93	2.3	2.0	1.0
	Fri	05/04/07	11:30	374.0	375.0	7.0	7.0	18.0	33.5	34	27	28	12	209	84	200	93	94	2.4	1.0	0.0
	Sat	05/05/07	12:15	379.5	380.5	5.5	5.5	17.3	31.5	36	24	25	12	200	61	184	93	94	0.0	5.6	5.2
	Sun	05/06/07	11:25	385.6	386.6	6.1	6.1	16.5	29.0	35	24	26	12	203	74	203	94	95	2.4	3.6	3.2
24	Mon	05/07/07	10:30	395.8	396.8	10.2	10.2	14.8	24.5	37	24	26	12	201	122	199	95	96	1.9	5.7	5.3
	Tue	05/08/07	6:15	404.9	405.9	9.1	9.1	33.8	34.0	37	25	25	12	200	110	201	96	97	2.9	6.7	6.3
	Wed	05/09/07	7:30	413.8	414.8	8.9	8.9	32.8	30.5	38	23	25	12	197	106	198	97	98	2.3	7.5	7.1
	Thu	05/10/07	8:00	424.1	425.1	10.3	10.3	31.3	26.0	33	25	26	12	208	126	204	99	100	4.9	1.6	1.2
	Fri	05/11/07	8:00	430.3	431.4	6.2	6.3	30.5	23.5	37	24	24	12	196	73	195	99	100	0.0	7.8	7.5
	Sat	05/12/07	8:20	436.0	437.5	5.7	6.1	29.5	34.3	37	24	26	12	202	74	208	100	101	2.3	5.7	5.3
	Sun	05/13/07	7:15	445.6	446.7	9.6	9.2	28.3	30.5	37	23	25	12	198	111	198	101	102	2.2	6.9	6.5
25	Mon	05/14/07	7:45	457.1	458.2	11.5	11.5	26.8	25.5	34	25	26	12	205	139	202	103	104	4.6	2.2	1.8
	Tue	05/15/07	8:00	466.6	467.7	9.5	9.5	34.5	32.0	35	25	26	12	204	138	241	104	105	2.4	3.6	3.2
	Wed	05/16/07	7:30	472.2	473.3	5.6	5.6	33.8	29.8	33	25	26	12	209	68	203	105	106	2.4	1.1	0.7
	Thu	05/17/07	8:00	484.5	485.6	12.3	12.3	32.0	24.5	37	24	25	12	200	147	199	106	107	2.4	5.3	4.9
	Fri	05/18/07	8:00	491.3	492.3	6.8	6.7	31.0	21.5	35	24	26	12	205	81	201	107	108	2.4	4.0	3.5
	Sat	05/19/07	8:00	501.8	502.8	10.5	10.5	29.8	33.0	36	24	25	12	198	125	198	108	109	2.4	6.4	5.9
	Sun	05/20/07	8:00	512.7	513.7	10.9	10.9	28.3	29.0	32	25	26	12	208	124	189	110	111	4.7	0.5	0.1
26	Mon	05/21/07	8:00	522.2	523.3	9.5	9.6	27.5	32.5	34	25	26	12	205	121	211	111	112	2.4	2.5	2.1
	Thu	05/24/07	7:00	531.2	532.2	9.0	8.9	26.3	29.0	35	25	26	12	204	108	200	112	113	2.4	3.4	2.9
	Sat	05/26/07	5:00	541.3	542.4	10.1	10.2	24.8	24.5	37	24	25	12	202	121	199	113	114	2.4	5.4	5.0
	Sun	05/27/07	NA	545.3	546.4	4.0	4.0	24.3	22.8	33	25	26	12	206	50	207	114	115	2.3	1.3	0.9
27	Wed	05/30/07	7:00	554.4	555.5	9.1	9.1	23.0	18.5	35	25	26	12	208	110	201	115	116	2.4	2.4	2.0
	Thu	05/31/07	7:00	564.4	565.6	10.0	10.1	21.0	33.0	36	25	26	12	201	122	202	116	117	2.4	4.4	3.9
	Fri	06/01/07	7:30	574.3	575.3	9.9	9.7	19.8	29.0	36	24	25	12	200	116	197	117	118	2.2	6.0	5.5
	Sat	06/02/07	9:00	579.7	580.8	5.4	5.5	18.8	26.5	35	25	26	12	206	67	204	118	119	2.4	3.3	2.9
	Sun	06/03/07	7:30	589.4	590.5	9.7	9.7	17.3	22.5	36	24	26	12	203	117	201	119	120	2.3	4.9	4.5
28	Mon	06/04/07	5:00	599.5	600.6	10.1	10.1	15.8	33.8	38	24	25	12	200	121	199	120	121	2.4	6.9	6.5
	Tue	06/05/07	6:00	610.0	611.2	10.5	10.6	14.0	29.3	33	26	27	12	209	129	203	122	123	4.7	1.3	0.9
	Sat	06/09/07	8:30	620.9	622.0	10.9	10.8	35.3	25.0	36	25	26	12	206	130	200	123	124	2.4	4.0	3.6
	Sun	06/10/07	8:00	632.4	633.4	11.5	11.4	34.0	20.0	38	24	26	12	200	138	200	124	125	2.2	7.4	6.9
29	Mon	06/11/07	9:00	640.4	641.4	8.0	8.0	32.8	16.3	36	24	25	12	206	97	202	125	126	2.4	7.3	6.8
	Tue	06/12/07	7:00	650.1	651.1	9.7	9.7	31.5	33.3	33	26	27	12	212	120	206	127	128	4.2	0.8	0.3
	Wed	06/13/07	7:30	661.2	662.5	11.1	11.4	30.0	28.8	35	25	26	12	206	137	204	128	129	2.9	4.1	3.6
	Thu	06/14/07	8:00	672.6	673.6	11.4	11.1	28.3	24.0	39	24	26	12	200	134	199	129	130	2.3	7.1	6.6
	Fri	06/15/07	6:45	678.8	678.8	6.2	5.2	27.5	21.0	37	25	26	12	205	78	228	130	131	2.3	5.2	4.8
	Sat	06/16/07	8:00	684.4	685.5	5.6	6.7	26.5	32.0	35	25	27	12	211	69	186	131	132	2.4	2.7	2.3
	Sun	06/17/07	9:00	696.4	697.2	12.0	11.7	24.8	27.8	38	24	26	12	204	142	200	132	133	2.4	6.7	5.9

# US EPA Arsenic Demonstration Project at Three Forks, MT - Daily System Operation (Continued)

Week No.	Day	Date	Time	Run Time				12.5% Cl <sub>2</sub> Tank Level	35% FeCl <sub>3</sub> Tank Level	Pressure Filtration				Flow rate	Totalizer to Distribution		Backwash			Run Time Since Last BW	
				Totalizer		Daily				Inlet	TA	TB	Outlet		Daily Flow	Cal Flow rate	Tank A	Tank B	Daily Volume	Vessel A	Vessel B
				Vessel A	Vessel B	Vessel A	Vessel B														
				hr	hr	hr	hr														
30	Mon	06/18/07	7:00	701.7	702.8	5.3	5.6	24.0	24.8	36	26	26	12	207	70	214	133	134	2.3	3.8	3.4
	Tue	06/19/07	7:00	711.7	712.8	10.0	10.0	25.8	33.5	37	25	25	12	205	126	211	134	135	2.3	5.7	5.3
	Wed	06/20/07	5:30	725.4	724.5	13.7	11.7	24.0	27.0	34	26	27	12	214	138	182	136	137	4.6	1.2	0.8
	Thu	06/21/07	6:45	736.2	737.3	10.8	12.8	22.0	23.5	39	24	26	12	201	198	280	137	138	2.4	5.9	5.5
	Fri	06/22/07	4:00	747.6	748.7	11.4	11.4	20.3	18.3	34	26	27	12	215	120	175	139	140	4.7	1.1	0.7
	Sat	06/23/07	4:30	760.3	761.4	12.7	12.7	18.3	12.3	37	25	27	12	205	154	201	140	141	2.2	5.7	5.3
	Sun	06/24/07	6:00	771.4	772.5	11.1	11.1	37.5	32.8	34	26	27	12	216	138	207	142	143	4.6	0.6	0.2
31	Mon	06/25/07	4:30	784.7	786.0	13.3	13.5	35.8	27.3	37	25	26	12	205	165	205	143	144	2.4	6.0	5.7
	Tue	06/26/07	4:00	798.1	799.2	13.4	13.2	34.0	21.8	36	26	27	12	210	163	204	145	146	4.9	3.0	2.7
	Wed	06/27/07	4:00	809.0	810.0	10.9	10.8	32.5	17.0	37	25	26	12	205	132	202	146	147	2.3	5.8	5.4
	Thu	06/28/07	4:00	821.3	822.4	12.3	12.4	30.8	33.5	35	26	27	12	212	152	206	148	149	4.7	2.0	1.6
	Fri	06/29/07	4:00	834.4	835.5	13.1	13.1	28.8	28.5	38	24	26	12	200	159	202	149	150	2.4	7.0	6.6
	Sat	06/30/07	4:00	849.3	850.1	14.9	14.6	26.5	22.0	37	25	26	12	205	182	205	151	152	4.7	5.7	5.3
	Sun	07/01/07	2:30	863.5	864.2	14.2	14.1	24.5	32.3	36	25	26	12	207	173	203	153	154	4.6	3.7	3.3
32	Mon	07/02/07	2:30	877.8	878.9	14.3	14.7	22.5	26.5	34	26	27	12	211	173	199	155	156	4.8	1.8	1.4
	Tue	07/03/07	2:30	896.5	897.7	18.7	18.8	19.5	29.8	37	26	27	12	205	228	203	157	158	4.7	4.3	3.9
	Wed	07/04/07	2:30	913.9	915.0	17.4	17.3	16.8	22.5	37	25	26	12	206	210	202	159	160	4.5	5.5	5.1
	Thu	07/05/07	2:30	928.7	929.8	14.8	14.8	14.3	16.0	36	26	26	12	207	180	203	161	162	4.7	4.1	3.7
	Fri	07/06/07	2:30	948.1	949.2	19.4	19.4	33.0	13.3	39	25	26	12	200	234	201	163	164	4.6	7.3	7.0
	Sat	07/07/07	2:30	971.0	972.1	22.9	22.9	29.8	28.8	41	25	26	12	198	275	200	166	167	7.1	5.9	5.5
	Sun	07/08/07	4:50	993.3	994.3	22.3	22.2	26.8	19.0	39	26	27	12	204	268	200	169	170	7.0	3.9	3.5
33	Tue	07/10/07	2:30	994.0	995.0	0.7	0.7	26.5	37.3	38	25	27	12	203	8	193	169	170	0.0	4.6	4.1
	Wed	07/11/07	2:30	1010.4	1011.5	16.4	16.5	24.0	30.5	39	24	26	12	203	221	224	171	172	4.7	4.8	4.4
	Thu	07/12/07	2:30	1027.2	1028.3	16.8	16.8	21.5	23.5	39	24	26	12	201	201	199	173	174	4.7	5.4	5.0
	Fri	07/13/07	6:00	1032.7	1033.8	5.5	5.5	20.8	21.0	38	26	27	12	205	68	205	174	175	2.4	2.8	2.4
34	Mon	07/16/07	8:30	1043.6	1044.9	10.9	11.1	19.0	16.0	39	25	27	12	199	132	200	175	176	2.2	5.8	5.4
	Tue	07/17/07	4:00	1053.5	1054.7	9.9	9.8	17.5	33.5	42	23	26	12	195	116	196	176	177	2.2	7.5	7.1
	Wed	07/18/07	8:30	1063.0	1064.1	9.5	9.4	16.0	29.8	34	28	29	12	213	113	200	178	179	4.7	0.4	0.0
	Thu	07/19/07	7:30	1068.8	1069.8	5.8	5.7	15.3	27.5	42	25	26	12	195	68	197	178	179	0.0	6.2	5.7
	Fri	07/20/07	6:00	1074.6	1075.5	5.8	5.7	14.5	24.5	39	26	27	12	203	70	202	179	180	2.4	3.9	3.5
35	Mon	07/23/07	7:30	1081.7	1082.6	7.1	7.1	13.5	21.5	37	26	27	12	205	86	201	180	181	2.4	2.9	2.5
	Tue	07/24/07	6:00	1088.2	1089.1	6.5	6.5	34.8	34.5	35	27	28	12	212	78	199	181	182	2.2	1.3	0.9
	Wed	07/25/07	7:30	1098.4	1099.1	10.2	10.0	33.3	30.0	38	26	27	12	204	127	210	183	184	6.2	3.8	3.3
	Thu	07/26/07	6:30	1104.7	1105.4	6.3	6.3	32.5	27.3	36	28	28	12	206	76	201	184	185	2.3	2.0	1.5
	Fri	07/27/07	6:00	1116.5	1116.2	11.8	10.8	31.3	22.3	39	26	27	12	203	129	190	185	186	2.3	4.7	4.2
36	Mon	07/30/07	9:30	1122.8	1123.6	6.3	7.4	30.5	19.0	31	22	23	12	168.7	89	217	186	187	4.1	3.9	3.4
	Tue	07/31/07	8:00	1126.6	1128.5	3.8	4.9	29.8	17.3	37	25	27	12	205	48	184	187	188	2.3	3.6	3.2
	Wed	08/01/07	4:30	1135.6	1136.1	9.0	7.6	28.8	18.8	37	26	27	12	205	113	227	189	190	5.3	2.4	2.1
	Thu	08/02/07	9:00	1137.8	1138.8	2.2	2.7	28.5	17.5	36	27	27	12	206	27	186	190	191	1.7	2.0	1.6
	Fri	08/03/07	6:00	1145.0	1146.0	7.2	7.2	27.5	33.5	36	25	27	12	203	89	206	191	192	2.4	4.2	3.8

# US EPA Arsenic Demonstration Project at Three Forks, MT - Daily System Operation (Continued)

Week No.	Day	Date	Time	Run Time				12.5% Cl <sub>2</sub> Tank Level	35% FeCl <sub>3</sub> Tank Level	Pressure Filtration				Flow rate	Totalizer to Distribution		Backwash			Run Time Since Last BW	
				Totalizer		Daily				Inlet	TA	TB	Outlet		Daily Flow	Cal Flow rate	Tank A	Tank B	Daily Volume	Vessel A	Vessel B
				Vessel A	Vessel B	Vessel A	Vessel B														
				hr	hr	hr	hr														
37	Mon	08/06/07	7:00	1152.0	1152.9	7.0	6.9	26.8	30.5	35	27	28	12	210	99	237	193	194	4.7	1.0	0.5
	Tue	08/07/07	6:00	1163.3	1164.3	11.3	11.4	25.5	26.0	37	26	27	12	203	126	185	194	195	2.2	4.1	3.8
	Wed	08/08/07	6:30	1176.4	1177.4	13.1	13.1	23.8	22.5	35	27	28	12	212	159	202	196	197	4.8	1.1	0.7
	Thu	08/09/07	6:00	1189.8	1190.8	13.4	13.4	22.0	31.3	39	26	26	12	201	162	202	197	198	2.3	6.4	6.2
	Fri	08/10/07	5:30	1201.7	1202.7	11.9	11.9	20.5	26.5	36	27	27	12	210	147	206	199	200	5.3	2.2	1.7
	Sat	08/11/07	8:00	1213.6	1214.5	11.9	11.8	18.8	21.5	39	26	26	12	204	141	199	200	201	2.3	5.9	5.4
	Sun	08/12/07	6:30	1223.4	1224.3	9.8	9.8	17.5	34.0	40	26	26	12	199	118	201	201	202	2.4	7.6	7.1
38	Mon	08/13/07	6:00	1236.3	1236.2	12.9	11.9	16.0	29.5	36	26	27	12	205	146	196	203	204	4.5	3.3	2.8
	Tue	08/14/07	4:00	1247.3	1248.3	11.0	12.1	14.5	24.5	40	25	27	12	199	146	211	204	205	2.2	7.3	6.9
	Wed	08/15/07	6:00	1259.5	1260.5	12.2	12.2	12.5	33.0	36	27	27	12	205	149	203	206	207	4.6	3.3	2.9
	Thu	08/16/07	4:30	1274.3	1272.3	14.8	11.8	11.0	28.5	39	25	26	12	199	165	207	207	208	2.3	7.0	6.6
	Fri	08/17/07	5:30	1285.6	1284.6	11.3	12.3	9.0	23.5	36	26	27	12	205	151	213	209	210	4.7	3.1	2.7
	Sat	08/18/07	7:30	1294.6	1295.6	9.0	11.0	30.0	32.5	39	26	27	12	202	132	221	210	211	2.3	6.0	5.6
	Sun	08/19/07	11:30	1303.2	1304.4	8.6	8.8	29.0	29.3	39	25	27	12	199	107	204	211	212	3.1	6.5	6.1
39	Mon	08/20/07	5:45	1306.3	1307.3	3.1	2.9	28.5	27.8	35	27	28	12	210	40	219	212	213	4.6	1.5	0.9
	Tue	08/21/07	6:00	1317.0	1318.1	10.7	10.8	27.3	34.0	36	26	27	12	207	137	213	215	216	7.2	2.5	2.2
	Wed	08/22/07	6:00	1327.6	1325.7	10.6	7.6	26.0	30.0	35	26	28	12	210	131	240	217	218	4.8	1.0	0.6
	Thu	08/23/07	6:00	1339.4	1340.6	11.8	14.9	24.5	25.0	34	27	28	12	210	147	183	219	220	4.8	0.7	0.3
	Fri	08/24/07	7:00	1351.9	1353.0	12.5	12.4	22.8	19.5	34	27	28	12	209	153	205	221	222	4.7	0.9	0.5
	Sat	08/25/07	8:00	1361.7	1362.1	9.8	9.1	21.5	15.5	37	26	27	12	205	118	208	222	223	2.2	4.6	4.2
40	Tue	08/28/07	13:00	1369.8	1370.8	8.1	8.7	20.5	33.5	35	26	28	12	205	98	194	224	225	4.6	0.5	0.0
	Wed	08/29/07	6:00	1374.4	1375.3	4.6	4.5	19.8	31.8	37	26	26	12	203	52	192	224	225	0.0	5.1	4.5
41	Tue	09/04/07	5:30	1384.8	1385.7	10.4	10.4	18.5	27.5	36	26	27	12	205	129	207	226	227	4.7	3.3	2.7
	Wed	09/05/07	7:00	1393.7	1394.7	8.9	9.0	17.3	23.8	35	26	27	12	205	112	209	228	229	4.7	2.8	2.4
	Thu	09/06/07	6:00	1401.6	1402.5	7.9	7.8	16.3	20.5	37	26	26	12	203	96	204	229	230	2.4	4.6	4.2
	Fri	09/07/07	6:00	1408.0	1409.0	6.4	6.5	15.3	17.5	37	26	26	12	202	79	204	230	231	2.3	4.9	4.5
42	Mon	09/10/07	5:00	1414.0	1415.0	6.0	6.0	14.3	14.5	38	25	27	12	202	75	209	231	232	2.4	4.8	4.5
	Tue	09/11/07	7:00	1421.8	1422.9	7.8	7.9	34.8	34.5	40	25	27	12	200	96	203	232	233	2.4	7.7	7.3
	Wed	09/12/07	7:00	1428.0	1429.1	6.2	6.2	34.0	31.8	38	26	26	12	204	77	206	233	234	2.2	5.8	5.4
	Thu	09/13/07	9:00	1434.8	1435.9	6.8	6.8	33.0	29.0	37	26	27	12	205	83	204	234	236	2.4	4.5	4.1
	Fri	09/14/07	6:00	1441.9	1442.8	7.1	6.9	32.3	26.0	37	26	27	12	207	87	208	235	236	2.3	3.5	2.9
	Sat	09/15/07	7:30	1449.2	1450.2	7.3	7.4	31.5	22.8	36	26	27	12	207	91	205	236	237	2.3	2.7	2.2
	Sun	09/16/07	6:30	1458.2	1459.3	9.0	9.1	30.3	19.0	37	26	27	12	207	110	202	237	238	2.4	3.6	3.2
43	Mon	09/17/07	6:00	1469.5	1470.6	11.3	11.3	29.0	13.8	39	25	27	12	201	136	200	238	239	2.3	6.8	6.4
	Tue	09/18/07	7:00	1477.4	1478.5	7.9	7.9	28.0	35.3	40	25	27	12	200	99	208	239	240	2.4	6.6	6.2
	Wed	09/19/07	7:00	1485.4	1480.5	8.0	2.0	27.3	32.8	38	26	27	12	204	78	261	240	241	2.3	4.9	4.4
	Thu	09/20/07	6:30	1489.9	1491.1	4.5	10.6	26.5	30.0	36	26	28	12	209	77	171	241	242	2.3	3.0	2.6
	Fri	09/21/07	7:00	1496.1	1497.2	6.2	6.1	25.5	27.5	35	27	28	12	211	75	204	242	243	2.4	1.0	0.6
	Sat	09/22/07	7:00	1501.5	1502.6	5.4	5.4	25.0	35.5	39	26	26	12	202	64	198	242	243	0.0	6.4	5.9
	Sun	09/23/07	12:00	1509.4	1511.0	7.9	8.4	24.0	32.5	39	25	27	12	198	103	210	243	244	2.3	6.7	6.3

# US EPA Arsenic Demonstration Project at Three Forks, MT - Daily System Operation (Continued)

Week No.	Day	Date	Time	Run Time				12.5% Cl <sub>2</sub> Tank Level	35% FeCl <sub>3</sub> Tank Level	Pressure Filtration				Flow rate	Totalizer to Distribution		Backwash			Run Time Since Last BW	
				Totalizer		Daily				Inlet	TA	TB	Outlet		Daily Flow	Cal Flow rate	Tank A	Tank B	Daily Volume	Vessel A	Vessel B
				Vessel A	Vessel B	Vessel A	Vessel B														
				hr	hr	hr	hr														
44	Mon	09/24/07	1:00	1515.3	1516.4	5.9	5.4	23.3	30.0	39	26	27	12	202	67	197	244	245	2.3	4.0	3.6
	Tue	09/25/07	6:30	1520.6	1521.8	5.3	5.4	22.5	27.8	35	27	28	12	210	67	207	245	246	2.5	1.2	0.9
	Wed	09/26/07	1:30	1531.2	1532.3	10.6	10.5	21.8	23.5	37	26	27	12	203	128	203	246	247	2.3	3.7	3.3
	Sun	09/30/07	1:30	1534.9	1536.0	3.7	3.7	20.3	37.3	40	25	25	12	196	43	195	246	247	0.0	7.4	7.0
45	Mon	10/01/07	2:30	1538.3	1539.5	3.4	3.5	19.8	35.8	35	26	27	12	207	67	323	247	248	2.4	2.8	2.4
	Tue	10/02/07	6:00	1552.3	1553.4	14.0	13.9	17.5	30.3	35	26	27	12	212	169	202	249	250	4.5	0.5	0.1
	Fri	10/05/07	6:00	1558.8	1559.5	6.5	6.1	16.3	27.5	39	25	25	12	197	77	204	249	250	0.0	7.0	6.5
46	Mon	10/08/07	7:30	1565.2	1566.3	6.4	6.8	15.3	25.0	37	24	26	12	202	79	199	250	251	2.4	5.3	4.9
	Tue	10/10/07	7:00	1575.1	1576.1	9.9	9.8	13.5	20.5	34	26	27	12	207	122	206	252	253	4.4	1.7	1.3
	Fri	10/12/07	7:30	1586.3	1587.3	11.2	11.2	11.5	15.5	37	25	26	12	202	129	193	253	254	2.2	4.8	4.5
47	Mon	10/15/07	5:30	1591.4	1592.5	5.1	5.2	10.8	13.3	34	26	27	12	208	68	220	254	255	2.3	1.9	1.5
	Tue	10/17/07	7:00	1599.9	1600.9	8.5	8.4	31.5	34.3	35	26	26	12	206	102	200	255	256	2.4	2.2	1.8
	Fri	10/19/07	6:00	1609.9	1610.9	10.0	10.0	29.8	30.3	36	25	26	12	202	120	200	256	257	2.2	4.1	3.7
48	Mon	10/22/07	4:00	1619.6	1620.6	9.7	9.7	28.5	26.3	36	24	26	12	200	116	199	257	258	2.3	5.7	5.3
	Tue	10/24/07	6:00	1632.1	1633.1	12.5	12.5	26.8	21.0	34	26	27	12	205	152	203	259	260	4.7	2.0	1.7
	Fri	10/26/07	8:00	1639.0	1640.0	6.9	6.9	25.5	18.0	33	26	27	12	210	82	199	260	261	2.3	0.8	0.4
49	Mon	10/29/07	6:00	1648.4	1649.4	9.4	9.4	24.5	13.5	35	26	27	12	205	115	204	261	262	2.3	2.2	1.8
	Tue	10/30/07	7:30	1658.7	1659.7	10.3	10.3	22.5	33.5	37	25	26	12	200	123	199	262	263	2.2	4.4	4.0
	Wed	10/31/07	6:00	1661.9	1663.0	3.2	3.3	22.3	32.3	39	24	25	12	195	38	193	262	263	0.0	7.6	7.3
	Thu	11/01/07	6:00	1666.1	1667.2	4.2	4.2	21.8	30.3	35	25	25	12	204	53	211	263	264	2.4	3.7	3.3
	Fri	11/02/07	6:00	1673.0	1674.0	6.9	6.8	20.5	27.5	34	25	26	12	206	83	202	264	265	2.3	2.5	2.1
	Sat	11/03/07	6:00	1678.8	1681.0	5.8	7.0	19.3	24.5	33	25	26	12	208	83	215	265	266	2.3	1.3	0.9
	Sun	11/04/07	6:00	1687.3	1688.4	8.5	7.4	18.0	21.5	33	26	27	12	208	90	189	266	267	2.4	0.6	0.2
50	Mon	11/05/07	5:30	1693.1	1694.2	5.8	5.8	17.0	18.8	38	24	26	12	200	69	198	266	267	0.0	6.4	6.0
	Tue	11/06/07	6:00	1698.8	1699.9	5.7	5.7	16.0	16.3	36	25	26	12	201	69	202	267	268	2.3	4.0	3.6
	Wed	11/07/07	6:00	1706.7	1707.7	7.9	7.8	14.8	29.3	35	25	26	12	202	95	201	268	269	2.3	3.8	3.4
	Thu	11/08/07	6:00	1712.4	1713.6	5.7	5.9	13.8	26.8	34	26	27	12	207	70	200	269	270	2.4	1.5	1.1
	Fri	11/09/07	6:00	1716.7	1717.7	4.3	4.1	13.0	25.0	37	25	25	12	199	49	195	269	270	0.0	5.7	5.2
	Sat	11/10/07	6:00	1720.4	1721.6	3.7	3.9	12.5	23.5	34	26	27	12	207	47	207	270	271	2.3	1.4	1.0
51	Sun	11/11/07	6:00	1724.1	1723.4	3.7	1.8	11.8	21.8	37	24	26	12	199	44	269	270	271	0.0	5.3	4.8
	Mon	11/12/07	5:30	1728.7	1729.9	4.6	6.5	10.8	19.5	37	24	27	12	207	55	166	271	272	2.3	1.5	1.1
	Wed	11/14/07	6:00	1733.9	1735.2	5.2	5.3	32.8	35.8	39	24	26	12	196	62	197	271	272	0.0	6.7	6.5
	Thu	11/15/07	6:00	1738.7	1740.0	4.8	4.8	32.0	34.0	36	25	26	12	202	58	202	272	273	2.3	3.4	3.0
	Fri	11/16/07	6:00	1744.2	1745.4	5.5	5.4	31.3	32.0	36	26	27	12	208	66	201	273	274	2.4	0.8	0.3
	Sat	11/17/07	5:30	1749.9	1751.0	5.7	5.6	30.8	29.8	38	24	25	12	196	67	198	273	274	0.0	6.5	5.9
	Sun	11/18/07	5:30	1755.2	1756.3	5.3	5.3	29.8	27.5	39	25	26	12	202	65	203	274	275	2.3	3.7	3.2
52	Mon	11/19/07	5:30	1760.9	1762.2	5.7	5.9	28.8	25.0	34	26	27	12	206	70	200	275	276	2.3	1.4	0.9
	Tue	11/20/07	6:00	1765.8	1767.1	4.9	4.9	28.0	23.0	34	24	26	12	197	57	195	275	276	0.0	6.2	5.8
	Wed	11/21/07	6:00	1770.0	1771.3	4.2	4.2	27.5	21.0	38	26	26	12	204	52	206	276	277	2.3	2.3	1.9
	Thu	11/22/07	5:30	1773.9	1775.2	3.9	3.9	26.8	19.3	38	25	25	12	199	46	196	276	277	0.0	6.2	5.8
	Fri	11/23/07	6:00	1781.2	1782.6	7.3	7.4	25.8	16.0	37	25	26	12	198	88	200	277	278	2.4	5.4	5.1
	Sat	11/24/07	6:30	1788.1	1789.4	6.9	6.8	24.8	34.8	37	24	26	12	198	83	201	278	279	2.3	4.2	3.8

# US EPA Arsenic Demonstration Project at Three Forks, MT - Daily System Operation (Continued)

Week No.	Day	Date	Time	Run Time				12.5% Cl <sub>2</sub> Tank Level	35% FeCl <sub>3</sub> Tank Level	Pressure Filtration				Flow rate	Totalizer to Distribution		Backwash			Run Time Since Last BW	
				Totalizer		Daily				Inlet	TA	TB	Outlet		Daily Flow	Cal Flow rate	Tank A	Tank B	Daily Volume	Vessel A	Vessel B
				Vessel A	Vessel B	Vessel A	Vessel B														
				hr	hr	hr	hr														
	Sun	11/25/07	5:00	1795.7	1797.0	7.6	7.6	23.5	31.8	36	26	26	12	202	91	200	279	280	2.3	3.7	3.3
53	Mon	11/26/07	5:30	1802.4	1803.8	6.7	6.8	22.5	29.0	35	25	27	12	203	81	199	280	281	2.4	2.4	2.0
	Tue	11/27/07	8:00	1815.4	1816.7	13.0	12.9	20.5	23.8	38	25	25	12	197	177	228	281	282	2.0	7.3	6.9
	Wed	11/28/07	6:00	1818.8	1821.1	3.4	4.4	19.5	21.5	35	25	26	12	204	54	230	282	283	2.6	3.5	3.1
	Thu	11/29/07	6:00	1825.4	1827.2	6.6	6.1	18.8	35.0	34	26	27	12	206	73	193	283	284	2.3	1.6	1.1
	Fri	11/30/07	6:00	1829.7	1830.9	4.3	3.7	18.0	33.5	37	25	26	12	197	45	187	283	284	0.0	5.3	4.9
	Sat	12/01/07	6:00	1833.7	1834.9	4.0	4.0	17.3	32.0	34	26	27	12	208	48	202	284	285	2.4	1.2	0.7
	Sun	12/02/07	5:00	1837.5	1838.7	3.8	3.8	16.8	30.5	37	25	25	12	200	46	200	284	285	0.0	5.0	4.5
54	Mon	12/03/07	5:30	1842.6	1843.9	5.1	5.2	15.8	28.3	37	25	27	12	204	62	201	285	286	2.3	2.0	1.6
	Tue	12/04/07	6:00	1848.5	1849.9	5.9	6.0	14.8	25.8	39	23	25	12	194	70	195	285	286	0.0	7.9	7.0
	Wed	12/05/07	6:00	1855.0	1856.4	6.5	6.5	13.8	23.0	37	24	26	12	198	79	203	286	287	2.3	6.4	6.0
	Thu	12/06/07	6:00	1859.8	1861.1	4.8	4.7	13.0	36.8	35	25	26	12	206	58	204	287	288	2.2	3.0	2.6
	Fri	12/07/07	6:00	1866.0	1867.4	6.2	6.3	11.8	34.0	34	25	26	12	208	76	202	288	289	2.3	1.2	0.8
	Sat	12/08/07	6:30	1872.9	1874.2	6.9	6.8	33.3	31.5	33	23	25	12	195	81	196	288	289	0.0	8.0	7.6
	Sun	12/09/07	6:00	1879.8	1881.1	6.9	6.9	32.3	28.5	38	24	25	12	196	84	204	289	290	2.3	6.9	6.4
55	Mon	12/10/07	6:00	1886.1	1889.1	6.3	8.0	31.3	25.3	36	25	25	12	200	76	177	290	291	2.5	5.0	4.6
	Tue	12/11/07	7:00	1892.8	1894.6	6.7	5.5	30.3	23.0	35	25	26	12	202	81	220	291	292	2.2	3.6	3.2
	Wed	12/12/07	6:00	1899.1	1900.4	6.3	5.8	29.0	20.0	35	25	26	12	206	77	211	292	293	2.2	1.8	1.4
	Fri	12/14/07	8:30	1904.5	1905.8	5.4	5.4	28.5	18.0	34	24	25	12	196	64	196	292	293	0.0	7.2	6.8
56	Mon	12/17/07	5:30	1909.8	1911.1	5.3	5.3	27.5	34.2	37	24	26	12	199	64	203	293	294	2.3	4.4	4.1
	Wed	12/19/07	7:00	1915.6	1917.0	5.8	5.9	26.8	32.0	35	25	26	12	203	70	198	294	295	2.3	2.1	1.8
	Fri	12/21/07	7:00	1919.6	1921.0	4.0	4.0	26.0	30.5	38	24	26	12	197	47	196	294	295	0.0	6.1	5.9
57	Mon	12/24/07	5:00	1924.5	1925.8	4.9	4.8	25.3	28.3	38	25	26	12	200	59	202	295	296	2.3	2.9	2.4
	Wed	12/26/07	8:24	1927.0	1929.0	2.5	3.2	25.0	27.3	38	25	25	12	198	30	174	295	296	0.0	5.5	4.9
	Fri	12/28/07	9:00	1933.3	1934.7	6.3	5.7	24.0	24.5	35	24	25	12	201	76	211	296	297	2.5	3.6	3.2
	Sat	12/29/07	11:00	1939.9	1941.3	6.6	6.6	22.8	21.8	34	25	26	12	205	80	202	297	298	2.3	2.1	1.8
58	Mon	12/31/07	9:00	1945.3	1946.8	5.4	5.5	21.8	19.3	37	23	24	12	197	63	191	297	298	0.0	7.5	7.2
	Wed	01/02/08	9:00	1954.9	1956.4	9.6	9.6	20.3	15.0	32	25	26	12	209	118	204	299	300	4.6	0.9	0.5
	Fri	01/04/08	9:00	1964.6	1966.1	9.7	9.7	18.8	33.0	33	24	25	12	205	117	200	300	301	2.4	2.5	2.1
	Sat	01/05/08	14:30	1973.8	1975.3	9.2	9.2	17.0	29.5	35	24	26	12	204	110	199	301	302	2.3	3.6	3.2
59	Mon	01/07/08	10:00	1980.9	1982.4	7.1	7.1	15.8	26.5	33	24	25	12	205	86	202	302	303	2.3	2.6	2.2
	Wed	01/09/08	13:00	1991.3	1992.8	10.4	10.4	14.0	32.8	35	24	24	12	202	124	199	303	304	2.3	4.9	4.5
	Fri	01/11/08	10:30	2001.4	2002.9	10.1	10.1	12.0	28.8	36	23	24	12	200	120	198	304	305	2.2	6.9	6.5
	Sat	01/12/08	15:00	2004.5	2011.1	3.1	8.2	10.8	25.3	36	24	24	12	197	98	288	305	306	2.3	6.9	6.5
60	Mon	01/14/08	13:00	2016.1	2017.6	11.6	6.5	9.5	22.5	36	23	25	12	199	81	149	306	307	2.3	5.4	5.8
61	Mon	01/21/08	9:00	2025.8	2027.2	9.7	9.6	7.8	18.3	38	22	24	12	195	114	198	307	308	2.3	6.8	6.5
	Wed	01/23/08	9:30	2034.4	2030.9	8.6	3.7	29.0	33.8	36	23	25	12	198	105	283	308	309	2.3	7.5	7.1
	Fri	01/25/08	8:00	2042.0	2043.0	7.6	12.1	28.0	30.8	36	23	25	12	198	88	149	309	310	1.9	7.0	6.0
62	Mon	01/28/08	8:00	2049.1	2050.6	7.1	7.6	26.8	27.8	36	23	25	12	202	91	206	310	311	2.7	6.0	5.6
	Wed	01/30/08	8:00	2058.5	2060.0	9.4	9.4	25.3	34.5	36	23	24	12	198.7	113	200	311	312	2.3	7.3	6.9
	Fri	02/01/08	8:00	2067.8	2068.9	9.3	8.9	24.0	31.0	55	3	33	12	140	108	197	312	313	2.3	0.0	7.7

## US EPA Arsenic Demonstration Project at Three Forks, MT - Daily System Operation (Continued)

Week No.	Day	Date	Time	Run Time				12.5% Cl <sub>2</sub> Tank Level	35% FeCl <sub>3</sub> Tank Level	Pressure Filtration				Flow rate gpm	Totalizer to Distribution		Backwash			Run Time Since Last BW	
				Totalizer		Daily				Inlet psig	TA psig	TB psig	Outlet psig		Daily Flow kgal	Cal Flow rate gpm	Tank A No.	Tank B No.	Daily Volume kgal	Vessel A hr	Vessel B hr
				Vessel A	Vessel B	Vessel A	Vessel B														
				hr	hr	hr	hr														
63	Mon	02/04/08	7:30	2075.9	2077.4	8.1	8.5	22.5	27.5	32	25	26	12	212	104	208	314	315	4.5	0.4	0.4
	Fri	02/08/08	6:30	2084.8	2086.3	8.9	8.9	21.0	23.5	32	24	26	12	208	131	245	315	316	2.3	1.2	0.8

Highlighted columns indicate calculated values.

Note: Chemical drums are tapered; Cl<sub>2</sub> and FeCl<sub>3</sub> levels measured from bottom of drum.

Note: Backwash wastewater supernatant recycled until 12/12/06. Afterwards, wastewater discharged to sewer.

Note: Run time until 02/16/07 estimated by Well No. 2 Hour Meter.

NA = data not available

**APPENDIX B**  
**ANALYTICAL DATA TABLES**

# **Analytical Results from Long-Term Sampling at Three Forks, MT**

Sampling Date		11/29/06			12/05/06				12/12/06 <sup>(a)</sup>				03/21/07 <sup>(c)</sup>			03/28/07			
Sampling Location		IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB
Parameter	Unit																		
Alkalinity (as CaCO <sub>3</sub> )	mg/L	266	270	262	271	271	280	272	279	267	265	267	287	280	284	284	271	275	275
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	3.0	3.1	3.0	-	-	-	-	-	-	-	-	2.2	2.1	2.2	-	-	-	-
Sulfate	mg/L	21	20	21	-	-	-	-	-	-	-	-	20	20	20	-	-	-	-
Nitrate (as N)	mg/L	0.4	0.4	0.3	-	-	-	-	-	-	-	-	0.3	0.3	0.3	-	-	-	-
Total P (as P)	µg/L	17.1	21.3	11.7	<10	<10	<10	<10	22.4	20.8	<10	<10	45.2	44.3	18.6	24.8	22.6	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L	48.5	48.8	47.8	47.0	47.1	45.9	45.8	47.5	48.0	47.0	46.7	50.8	51.0	50.3	48.2	48.5	47.5	47.9
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	0.4	1.8	0.9	0.1	1.8	0.8	0.9	<0.1	1.0	0.3	0.3	1.1	1.9	0.7	0.3	1.6	0.6	0.8
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	7.4	7.7	7.8	7.8	7.3	7.8	7.6	7.3	7.2	7.2	7.3	7.4	7.2	7.2	7.3	7.1	7.1	7.1
Temperature	°C	13.3	12.9	12.7	12.7	13.5	12.4	12.5	12.3	12.3	12.4	12.3	15.7	15.7	15.8	12.3	11.8	11.8	11.6
DO	mg/L	3.3	2.4	3.1	2.7	3.9	2.7	2.5	NA <sup>(b)</sup>	NA <sup>(b)</sup>	NA <sup>(b)</sup>	NA <sup>(b)</sup>	2.5	1.8	2.1	2.4	2.1	2.2	2.1
ORP	mV	335	281	321	312	468	503	524	262	295	327	313	249	317	363	251	314	384	390
Free Chlorine	mg/L	-	0.5	0.8	-	0.4	0.4	0.5	-	0.6	0.6	0.5	-	0.6	0.6	-	0.7	0.6	0.7
Total Chlorine	mg/L	-	0.4	1.0	-	0.5	0.5	0.5	-	0.6	0.5	0.5	-	0.7	0.6	-	0.6	0.6	0.6
Total Hardness (as CaCO <sub>3</sub> )	mg/L	181	184	178	-	-	-	-	-	-	-	-	222	248	256	-	-	-	-
Ca Hardness (as CaCO <sub>3</sub> )	mg/L	128	132	129	-	-	-	-	-	-	-	-	167	196	204	-	-	-	-
Mg Hardness (as CaCO <sub>3</sub> )	mg/L	52.3	52.1	49.3	-	-	-	-	-	-	-	-	54.8	51.7	51.6	-	-	-	-
As (total)	µg/L	59.8	61.2	28.3	64.4	72.2	17.3	30.6	78.5	74.1	18.5	25.5	90.7	90.5	16.8	95.1	94.0	13.3	13.0
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	59.7	5.9	4.8	-	-	-	-	-	-	-	-	80.4	11.7	7.2	-	-	-	-
As (particulate)	µg/L	0.1	55.4	23.5	-	-	-	-	-	-	-	-	10.3	78.7	9.6	-	-	-	-
As (III)	µg/L	0.6	0.9	1.6	-	-	-	-	-	-	-	-	1.4	1.3	1.2	-	-	-	-
As (V)	µg/L	59.0	5.0	3.2	-	-	-	-	-	-	-	-	79.0	10.4	6.0	-	-	-	-
Fe (total)	µg/L	<25	2,502	936	<25	1,153	323	561	<25	1,527	236	410	<25	1,604	225	<25	1,754	134	139
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	<25	42	<25	-	-	-	-	-	-	-	-	<25	38	<25	-	-	-	-
Mn (total)	µg/L	<0.1	15.4	8.5	0.1	12.3	5.5	7.2	<0.1	8.5	3.4	4.1	0.1	9.7	3.2	<0.1	7.5	0.5	0.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	<0.1	6.3	4.9	-	-	-	-	-	-	-	-	0.4	3.2	2.7	-	-	-	-

(a) Stroke of iron addition pump reduced from 28 to 21 on 12/08/06. (b) DO probe not operational. (c) Media bed modifications performed 03/13/07.

### Analytical Results from Long-Term Sampling at Three Forks, MT (Continued)

Sampling Date		04/04/07				04/11/07				04/18/07 <sup>(a)</sup>			04/25/07				07/17/07 <sup>(b)</sup>			
Sampling Location		IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB
Parameter	Unit																			
Alkalinity (as CaCO <sub>3</sub> )	mg/L	282	284	279	274	296	288	286	291	288	288	288	297	302	295	290	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	295	287	287	290	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	2.1	2.2	2.2	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	22	22	22	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	0.3	0.4	0.3	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	36.5	34.7	<10	<10	53.7	53.5	15.6	14.8	42.9	43.5	11.0	28.0	28.4	<10	<10	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	25.1	25.0	<10	<10	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L	46.8	46.4	45.6	45.6	47.4	47.9	47.4	47.0	49.7	50.3	49.5	49.1	49.3	49.2	49.1	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	49.5	49.7	49.2	47.9	-	-	-	-
Turbidity	NTU	0.3	1.6	0.8	0.6	0.9	3.3	1.5	0.8	0.5	1.5	0.4	0.3	1.4	0.5	0.4	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	0.4	0.6	0.3	0.7	-	-	-	-
pH	S.U.	7.5	7.2	7.2	7.1	7.7	7.9	7.9	7.9	7.4	7.8	7.9	7.7	7.9	7.8	8.0	7.6	7.7	7.7	7.7
Temperature	°C	11.3	10.5	10.3	10.5	11.9	11.8	11.7	11.7	11.6	11.1	11.1	10.7	10.5	10.6	10.4	13.7	13.3	13.4	13.3
DO	mg/L	3.1	2.7	2.7	2.7	2.2	1.7	1.6	1.7	2.6	2.3	2.0	2.1	1.9	2.5	1.5	3.0	2.6	2.9	2.8
ORP	mV	325	355	348	321	242	294	314	353	239	287	308	258	301	327	353	251	507	523	548
Free Chlorine	mg/L	-	0.5	0.5	0.7	-	0.7	0.6	0.7	-	0.9	0.8	-	1.0	0.9	1.0	-	3.2	3.1	2.7
Total Chlorine	mg/L	-	0.5	0.4	0.5	-	0.6	0.5	0.6	-	0.9	0.8	-	1.0	1.0	1.0	-	3.2	2.8	3.1
Total Hardness (as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-	-	-	195	202	213	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-	-	-	145	151	157	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-	-	-	50.6	51.0	55.1	-	-	-	-	-	-	-	-
As (total)	µg/L	92.8	90.5	22.4	22.8	91.1	91.9	16.6	15.6	91.7	90.4	17.0	96.7	95.0	15.5	14.8	80.5	79.6	8.4	8.2
		-	-	-	-	-	-	-	-	-	-	-	82.9	86.8	12.3	12.5	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	-	-	85.5	10.7	5.8	-	-	-	-	81.7	6.3	4.4	3.8
As (particulate)	µg/L	-	-	-	-	-	-	-	-	6.2	79.8	11.2	-	-	-	-	<0.1	73.3	4.0	4.5
As (III)	µg/L	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	85.4	10.6	5.7	-	-	-	-	-	-	-	-
Fe (total)	µg/L	<25	1,650	309	338	<25	1,373	161	156	<25	2,277	229	<25	2,053	153	145	<25	2,301	111	96
		-	-	-	-	-	-	-	-	-	-	-	<25	1,990	147	155	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	<25	39	<25	-	-	-	-	<25	<25	<25	<25
Mn (total)	µg/L	<0.1	9.2	3.0	3.1	<0.1	9.9	2.9	2.9	0.1	10.7	3.5	<0.1	10.1	2.4	2.4	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	<0.1	9.6	2.2	2.2	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	0.1	3.1	2.6	-	-	-	-	-	-	-	-

(a) Stroke of chlorine addition pump increased from 20 to 30 on 04/16/07. (b) Addition of FeCl<sub>3</sub>/polymer blend began 07/06/07. Stroke of iron addition pump set at 25.

Samples collected 2.7 hr after backwash.