

**Arsenic Removal from Drinking Water  
by Process Modifications to Coagulation/Filtration  
U.S. EPA Demonstration Project at Lidgerwood, ND  
Final Evaluation Report**

by

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## ABSTRACT

This report documents the activities performed and the results obtained for the arsenic removal treatment technology demonstration project at the Lidgerwood, North Dakota, site. The objectives of the project were to evaluate: (1) the effectiveness of process modifications to an existing coagulation/gravity filtration plant in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 µg/L, (2) the reliability of the treatment system, (3) the required system operation and maintenance (O&M) and operator skills, and (4) the capital and O&M cost of the technology. The project also characterized water in the distribution system and process residuals produced by the treatment system.

The pre-existing 250 gal/min (gpm) treatment system consisted of pre-chlorination, forced draft aeration, KMnO<sub>4</sub> oxidation, polymer addition, detention, gravity filtration, post-chlorination, and fluoridation. Chemicals were added into a rapid mix tank ahead of a 15,000-gal baffled detention tank, which provided about 60 min of detention time. Afterwards, water flowed into four 7.0 ft × 4.3 ft gravity filter cells, each containing a 24-in deep bed of manganese dioxide (MnO<sub>2</sub>)-coated anthrasand filter media manufactured by General Filter Products. The pre-existing treatment plant reduced total arsenic concentrations to an average level of 31 µg/L in the treated water, thus requiring process modifications to achieve arsenic levels below the new arsenic MCL.

The process modifications included the installation of an iron addition system and a supplemental polymer addition system. A series of jar and full-scale process tests were conducted to determine a set of optimum process conditions, which consisted of the addition of 1.2 mg/L (as Fe) of ferric chloride, 0.3 mg/L of Aqua Hawk 9207 PWG polymer (note that 0.1 mg/L of Aqua Hawk 9207 PWG polymer had already been added to the rapid mix tank prior to the demonstration study), and 0.5 mg/L of Aqua Hawk 127 polymer. These process conditions were implemented on January 1, 2005, and lasted until July 31, 2005, for the demonstration study.

During the seven-month demonstration study period, the system operated for a total of 1,300 hr with an average daily operating time of 6.1 hr/day. Based on wellhead totalizer readings, the system treated approximately 22,102,000 gal of water with an average daily water demand of 89,788 gal during this time period. The treatment system processed approximately 283 gpm of raw water from the wellhead and 26 gpm of reclaim water from the backwash recovery basin. This is equivalent to a hydraulic loading rate of about 2.6 gpm/ft<sup>2</sup> to the filters.

The gravity filters were backwashed automatically every Monday, Wednesday, and Friday. The median filter run time was 13.3 hr with durations of run time ranging from 8.7 hr to 27.2 hr between two consecutive backwash cycles. This is equivalent to a median throughput of 225,834 gal of raw water without reclaim and a range of 147,726 to 461,856 gal of raw water throughput without reclaim. The longer filter run times up to 27.2 hr were associated with operations over the weekends (between Fridays and Mondays). Based on headloss measurements, it was determined that the rate of differential pressure ( $\Delta p$ ) buildup across the filters was 2.7 in of H<sub>2</sub>O/hr. Therefore, in order not to exceed 50 in of H<sub>2</sub>O headloss during the filter runs, the filter run times should be limited to no longer than 15 hr with a wellhead flowrate of 283 gpm and a reclaim flowrate of 26 gpm.

Total arsenic levels in raw water ranged from 113 to 158 µg/L with an average value of 129 µg/L. Arsenic was present primarily in the As(III) form at an average value of 125 µg/L. Total iron levels in source water averaged 1,344 µg/L and existed primarily in the soluble form. This amount of soluble iron corresponded to an iron:arsenic ratio of 9:1 given the average soluble iron and soluble arsenic levels in raw water. Because this was below the target ratio of 20:1 for effective arsenic removal, supplemental iron addition was required at an average dose of 1.2 mg/L (as Fe) using a ferric chloride solution.

After detention and prior to the filter, approximately 38% of arsenic was removed through settling within the baffled detention tank. Based on the average iron dose of 1.2 mg/L and the total iron levels in the raw water, approximately 37% of the iron particulates also were removed within the baffled detention tank.

After the filters, total arsenic levels were reduced to 6.3 to 14.3 µg/L and averaged 8.5 µg/L. Arsenic in the treated water was present primarily as As(V) at an average of 5.7 µg/L. Particulate arsenic levels ranged from <0.1 to 4.9 µg/L and averaged 1.1 µg/L. Total iron levels in the treated water (existing solely as particulates) ranged from <25 to 64 µg/L.

Due to particulate arsenic breakthrough (up to 14.3 µg/L) from the filters, an increase in backwash frequency would be required to maintain the filter performance to achieve levels consistently below the 10 µg/L MCL. Additional process modifications were implemented based on recommendations developed from this demonstration study. The modifications included: (1) installing a 40-gpm backwash reclaim pump to provide additional capacity for daily backwash, (2) implementing a more frequent backwash schedule, and (3) reducing the wellhead pump flowrate to lower the hydraulic loading rate to the filters. The 40-gpm reclaim pump was installed at the plant on October 18, 2005. The wellhead flowrate was reduced to an average value of 239 gpm, which after including the 40 gpm reclaim flowrate, would yield a hydraulic loading rate of 2.3 gpm/ft<sup>2</sup> to the filters. The operator also performed filter backwash over the weekends in October 2005 and anticipated performing daily backwash as the water demand increased in the spring and summer.

The existing plant was backwashed automatically on Mondays, Wednesdays, and Fridays. This backwash schedule was maintained during the demonstration study period due to the limited capacity for backwash reclaim given the original plant infrastructure. The rate of backwash water production was approximately 5.5% of the amount of treated water produced. The backwash water contained relatively low levels of soluble arsenic (i.e., 9.8 µg/L on average) and soluble iron (i.e., <25 µg/L on average). The solids in the backwash water contained 7.63E+03 to 1.15E+04 µg/g of arsenic and 1.99E+05 to 3.07E+05 µg/g of iron. The backwash solids passed the Toxicity Characteristic Leaching Procedure (TCLP) test with arsenic in the leachate at <0.5 mg/L. Only barium at 0.069 mg/L and chromium at 0.054 mg/L were detected in the leachate. The TCLP regulatory limit set by EPA is 5 mg/L for arsenic, 100 mg/L for barium, and 5 mg/L for chromium. As such, the backwash solids were non-hazardous and could be accumulated and disposed of at a landfill.

Arsenic levels in water samples collected from the distribution system averaged 12.1 µg/L after process modifications, which was higher than the average arsenic level of 8.5 µg/L in the treated water. The higher levels in the distribution system might be due to longer filter runs over the weekends or solubilization, destabilization, and/or desorption of arsenic-laden particles/scales within the distribution system. More frequent backwash as implemented in October 2005 would help to eliminate the longer filter run times over the weekends. Since the process modifications, iron levels in the distribution system remained at non-detectable levels at <25 µg/L. Manganese levels were generally lower in the distribution system samples at 6.7 µg/L compared to 17.9 µg/L in the treated water. Lead and copper levels in the distribution system were not affected by the process modifications.

The capital investment cost was \$57,038 which included \$32,452 for equipment, \$5,786 for engineering, and \$18,800 for installation. The capital cost was solely for the new equipment required for the iron addition system, second polymer mixer, and reclaim pump. This does not include the cost for the second polymer feed system because an existing spare chemical feed pump and tank were used. The incremental O&M cost was estimated at \$0.04/1,000 gal based on the supplemental iron and polymer dosages required to achieve the target process conditions. Including the O&M cost for all chemical supplies (i.e., chlorine, potassium permanganate, Aqua Hawk 9207 PWG polymer, Aqua Hawk 127 polymer, and fluoride), electrical usage, and labor, the total O&M cost was estimated at \$0.52/1000 gal of treated water.

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## ABBREVIATIONS AND ACRONYMS

AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
As	arsenic
BL	baseline sampling
Ca	calcium
C/F	coagulation/filtration
Cl	chlorine
Cu	copper
DO	dissolved oxygen
EF	Extraction Fluid
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
GFH	granular ferric hydroxide
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IX	ion exchange
LCR	Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MDWCA	Mutual Domestic Water Consumer's Association
Mg	magnesium
Mn	manganese
mV	millivolts
Na	sodium
NA	not available
ND	non-detect
NDDH	North Dakota Department of Health
NRMRL	National Risk Management Research Laboratory
NS	not sampled
NTU	nephelometric turbidity units

O&M	operation and maintenance
ORD	Office of Research and Development
ORP	oxidation-reduction potential
P&ID	pipng and instrumentation diagrams
PM	process modifications
QA	quality assurance
QAPP	quality assurance project plan
QA/QC	quality assurance/quality control
RPD	relative percent difference
RPM	rotations per minute
Sb	antimony
SDWA	Safe Drinking Water Act
STMGID	South Truckee Meadows General Improvement District
STS	Severn Trent Services
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
V	vanadium
WRWC	White Rock Water Company

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## Section 1.0: INTRODUCTION

### 1.1 Background

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

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

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the 17 host sites. EPA received 70 technical proposals for the 17 host sites, with each site receiving from one to six proposals. In April 2003, an independent technical 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. Process modifications to the existing gravity filtration plant with supplemental iron and polymer additions were selected for the Lidgerwood, North Dakota, facility. The performance evaluation of the system began on January 1, 2005, and was completed on July 31, 2005.

### 1.2 Treatment Technologies for Arsenic Removal

The technologies selected for the 12 Round 1 EPA arsenic removal demonstration host sites include nine adsorptive media systems, one anion exchange system, one coagulation/filtration (C/F) system, and one C/F process modifications with iron addition. Table 1-1 summarizes the locations, technologies, vendors, and key source water quality parameters (including arsenic, iron, and pH) of the 12 demonstration sites. An overview of the technology selection and system design for the 12 demonstration sites and associated capital cost is provided in two EPA reports (Chen et al., 2004; Wang et al., 2004), which are posted on the EPA Web site at <http://www.epa.gov/ORD/NRMRL/arsenic/resource.htm>.

### 1.3 Project Objectives

The objective of the Round 1 arsenic demonstration program is to conduct 12 full-scale arsenic treatment technology demonstration studies on the removal of arsenic from drinking water supplies. The specific objectives are to:

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

This report summarizes the performance of the process modifications at the gravity filtration plant at Lidgerwood, North Dakota, from January 1, 2005, through July 31, 2005. The types of data collected include system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and O&M cost.

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

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

AM = adsorptive media process; C/F = coagulation/filtration; GFH = granular ferric hydroxide; IX = ion exchange; PM = process modifications; MDWCA = Mutual Domestic Water Consumer's Association; STMGID = South Truckee Meadows General Improvement District; STS = Severn Trent Services; WRWC = White Rock Water Company

(a) System reconfigured from parallel to series operation due to a reduced flowrate of 40 gal/min (gpm).

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

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

## Section 2.0: SUMMARY AND CONCLUSIONS

The following conclusions were made relating to the overall objectives of the treatment technology demonstration study:

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

- With supplemental iron and polymer additions (i.e., 1.2 mg/L [as Fe] of ferric chloride, 0.3 mg/L of Aqua Hawk 9207 PWG polymer, and 0.5 mg/L of Aqua Hawk 127 polymer), the MnO<sub>2</sub>-coated anthrasand gravity filtration system was able to remove arsenic to <10 µg/L.
- Chlorine and potassium permanganate (KMnO<sub>4</sub>) were effective in oxidizing As(III) to As(V), reducing As(III) concentrations from 125 µg/L (on average) in raw water to 1.8 µg/L (on average) after the rapid mix and detention tanks. It was also noted that approximately 38% of total arsenic was removed through settling in the detention tank.
- Because occasional particulate arsenic breakthrough was observed in the filter effluent, several operational changes were made including more frequent filter backwash (such as daily), higher reclaim rates (from 9.2% to 16.7%), and lower hydraulic loading rates (from 2.6 to 2.3 gpm/ft<sup>2</sup>), were implemented after the demonstration study period.
- Retrofitting the filters with Macrolite<sup>®</sup> filter media was not recommended because of the potential for higher rates of pressure buildup and shorter run times than observed in the full-scale plant.

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

- There was no unscheduled downtime during the demonstration study period from January 1, 2005, to July 31, 2005. However, operational issues were experienced related to headloss buildup on the filter cells and the need for more frequent backwash. Therefore, several operational changes were implemented in October 2005.
- The weekly demand for operator labor was approximately 11 hr and the O&M of the system required a significant level of mechanical and electrical skills to ensure proper operation of pumps, controls, and other system components. The operator also required a strong working understanding of chemical feed system O&M for the six chemicals used in pre- and post-treatment.

### *Process residuals produced by the technology:*

- The rate of backwash water generation was 5.5% of the amount of treated water produced. The backwash solids generated showed no detectable arsenic concentrations in the leachate from the Toxicity Characteristic Leaching Procedure (TCLP) and, therefore, were suitable for landfill disposal. Due to the increased solids loading from the iron addition, the frequency of sludge removal from the detention tank increased from annually to biannually.

*Cost-effectiveness of the technology:*

- The capital investment cost was \$57,038 which included \$32,452 for equipment, \$5,786 for engineering, and \$18,800 for installation.
- The incremental O&M cost was \$0.04/1,000 gal based on supplemental iron and polymer dosages required to achieve the target process conditions. The total O&M cost was estimated to be \$0.52/1000 gal for all chemical supplies (i.e., chlorine, potassium permanganate, ferric chloride, Aqua Hawk 9207 PWG polymer, Aqua Hawk 127 polymer, and fluoride), electrical consumption, and labor.

## Section 3.0: MATERIALS AND METHODS

### 3.1 General Project Approach

Prior to the commencement of the performance evaluation study, a number of pre-demonstration activities were performed as summarized in Table 3-1. Among the activities performed were a series of jar and process tests that were carried out to establish a process modification approach that evolved to comprise supplemental iron and polymer additions to the coagulation/gravity filtration system. The performance evaluation of the process modifications began on January 1, 2005, and ended on July 31, 2005. Table 3-2 summarizes the types of data collected and/or considered as part of the technology evaluation process. The overall performance of the process modifications was evaluated based on its ability to consistently remove arsenic to the target MCL of 10 µg/L through the collection of weekly and monthly water samples across the treatment train. The reliability of the process modifications was evaluated by tracking the unscheduled system downtime and frequency and extent of equipment repair and replacement. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

**Table 3-1. Completion Dates of Pre-Demonstration Study Activities**

Activity	Date
Introductory Meeting Held	07/31/03
Request for Quotation Issued to Vendor	08/01/03
Vendor Quotation Received by Battelle	09/29/03
Purchase Order Completed and Signed	10/16/03
Letter of Understanding Issued	08/22/03
Letter Report Issued	10/20/03
Engineering Package Submitted to NDDH	11/17/03
Installation Approved by NDDH	12/08/03
Iron Addition System Installed	01/14/04
Iron Addition Jar Tests Completed	01/15/04
Baseline Process Testing Completed	03/09/04
Iron Addition Process Testing Completed	07/31/04
Polymer Addition Jar Tests Completed	08/13/04

NDDH = North Dakota Department of Health

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

The 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 the tracking of capital cost for equipment, engineering, and installation, as well as the O&M cost for chemical supply, electrical power use, and labor.



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

<b>Evaluation Objectives</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 preventive maintenance including number, frequency, and complexity of tasks -Chemical handling and inventory requirements -General knowledge needed of relevant chemical processes and health and safety practices
Cost-Effectiveness	-Capital cost for equipment, engineering, and installation -O&M cost for chemical usage, electricity consumption, and labor
Residual Management	-Quantity of residuals generated by process -Characteristics of aqueous and solid residuals

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

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

The plant operator performed daily, weekly, and monthly system O&M and data collection according to instructions provided by the vendor and Battelle. On a daily basis, the plant operator recorded system operational data, such as pressure, flowrate, totalizer, and hour meter readings on a Daily System Operation Log Sheet; the operator also checked levels of various chemicals and conducted visual inspections to ensure normal system operations. In the event of problems, the plant operator would contact the Battelle Study Lead, who then would determine if the vendor should be contacted for troubleshooting. The plant operator recorded all relevant information, including the problem encountered, course of action taken, materials and supplies used, and associated cost and labor on the Repair and Maintenance Log Sheet. On a weekly basis, the plant operator measured pH, temperature, dissolved oxygen (DO), and oxidation-reduction potential (ORP), and recorded the data on a Weekly On-site Water Quality Parameters Log Sheet.

The capital cost for the process modifications included the cost for equipment, site engineering, and system installation. The incremental O&M cost consisted primarily of expenses for additional chemicals. Consumption of ferric chloride and polymer was tracked on the Daily System Operation Log Sheet. Labor for various activities, such as the routine system O&M, troubleshooting and repair, and demonstration-related work, was traced using an Operator Labor Hour Log Sheet. The routine O&M included activities such as completing field logs, replenishing chemical solutions, ordering supplies, performing system inspections, and others as recommended by the vendor. The labor for demonstration-related work, including activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead and the vendor, was recorded, but not used for cost analysis.

### 3.3 Sample Collection Procedures and Schedules

To evaluate the effectiveness of the process modifications, samples were collected at the wellhead, across the treatment plant, during filter backwash, and from the distribution system. Table 3-3 provides the sampling schedules and analytes measured during each sampling event (Battelle, 2004). Specific requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2003). The procedure for arsenic speciation is described in Appendix A of the QAPP.

**Table 3-3. Sample Collection Schedule and Analyses**

Sample Type	Sample Locations <sup>(a)</sup>	No. of Samples	Frequency	Analytes	Date(s) Samples Collected
Source Water	At Wellhead (IN)	1	Once (during initial site visit)	As(total), particulate As, As(III), As(V), Fe (total and soluble), Mn (total and soluble), Al (total and soluble), Na, Ca, Mg, V, Mo, Sb, Cl, F, SO <sub>4</sub> , SiO <sub>2</sub> , PO <sub>4</sub> , TOC, turbidity, and alkalinity	07/31/03
Treatment Plant Water	At Wellhead (IN), Before Filter (BF), After Filter (AF), Post-Chlorination (PC) <sup>(c)</sup>	4	Weekly	On-site: pH, temperature, DO/ORP, and Cl <sub>2</sub> (free and total) (at PC location) Off-site: As (total), Fe (total), Mn (total), SiO <sub>2</sub> , PO <sub>4</sub> , turbidity, and alkalinity	01/11/05, 01/18/05, 01/25/05, 02/08/05, 02/15/05, 02/22/05, 03/08/05, 03/15/05, 03/22/05, 03/29/05, 04/12/05, 04/18/05, 04/26/05, 05/11/05, 05/17/05, 05/24/05, 05/31/05, 06/07/05, 06/21/05, 06/28/05, 07/06/05, 07/19/05, 07/25/05
	At Wellhead (IN), Before Filter (BF), After Filter (AF) Post-Chlorination (PC) <sup>(c)</sup>	3	Monthly	On-site: pH, temperature, DO/ORP, and Cl <sub>2</sub> (free and total) (at PC location). Off-site: As(total and soluble) particulate As, As(III), As(V), Fe (total and soluble), Mn (total and soluble), Ca, Mg, F, NO <sub>3</sub> , SO <sub>4</sub> , SiO <sub>2</sub> , PO <sub>4</sub> , turbidity, and alkalinity	01/04/05, 02/01/05, 03/01/05, 04/05/05, 05/03/05, 06/14/05, 07/12/05
Distribution Water	Three LCR Residences	3	Monthly	pH, alkalinity, As (total), Fe (total), Mn (total), Pb (total), and Cu (total)	Baseline Sampling <sup>(b)</sup> 12/02/03, 12/17/03 01/06/04, 01/22/04 Monthly Sampling: 01/18/05, 02/22/05 03/22/05, 04/06/05 05/03/05, 06/14/05 07/12/05
Backwash Water	At Backwash Discharge Line from Two Filters	2	Monthly	TDS, turbidity, pH, As (soluble), Fe (soluble), and Mn (soluble)	03/23/05, 04/18/05 05/25/05, 06/21/05 07/25/05
Residual Sludge	From Backwash Water Reclaim Tank	2	Once	TCLP Metals As(Total)	11/02/05

(a) Abbreviation corresponding to sample location in Figure 4-6.

(b) Four baseline sampling events performed before system became operational.

(c) PC location analysis only for pH, temperature, Cl<sub>2</sub> (free and total), turbidity, and ICP-MS total and soluble metals. No monthly arsenic speciation samples.

LCR = Lead and Copper Rule

**3.3.1 Source Water Sample Collection.** During the initial visit to the site, one set of source water samples was collected and speciated using an arsenic speciation kit (see Section 3.4.1). The source water also was measured for pH, temperature, DO, and ORP on site. 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 Jar Test and Process Test Procedures.** Prior to the start of the performance evaluation study, a series of jar and process tests were conducted to determine the process conditions needed to achieve below 10 µg/L of arsenic in the treated water. To determine the supplemental iron dosage, four jar tests were conducted, each consisting of an iron salt (i.e., ferric chloride [FeCl<sub>3</sub>] or ferrous sulfate [FeSO<sub>4</sub>]) and a water sample taken either at the wellhead or after the rapid mix tank. The water taken from the rapid mix tank had already been dosed with sodium hypochlorite (NaOCl), potassium permanganate (KMnO<sub>4</sub>), and a non-ionic polymer, Aqua Hawk 9207 PWG. Each test consisted of dosing an iron salt with increasing dosages into a series of six 1-L jars placed on a Phipps & Byrd overhead stirrer/jar tester with an illuminated base. Table 3-4 summarizes the experimental conditions for these jar tests. For Tests 1 and 2, NaOCl was added at a dosage of approximately 2.3 mg/L to oxidize As(III) and Fe(II) in raw water (and Fe[II] added as supplemental iron in Test 2). For Test 4, NaOCl also was added up to 0.3 mg/L to oxidize Fe(II) added as supplemental iron. pH values were monitored at the beginning and end of each jar test, but not adjusted during the test. After the specified contact time, the supernatant in each jar was filtered with 0.45-µm disc filters and analyzed for arsenic, iron, and manganese. The results of the jar tests are summarized in Section 4.3.2.

**Table 3-4. Summary of Jar Test Parameters**

Parameter	Jar 1	Jar 2	Jar 3	Jar 4	Jar 5	Jar 6
<i>Jar Tests with Raw Water</i>						
Mix Time (min)	30	30	30	30	30	30
Test 1: Ferric Chloride, mg/L (as Fe)	0	0.18	0.36	0.54	0.72	0.91
Test 2: Ferrous Sulfate, mg/L (as Fe)	0	0.20	0.41	0.61	0.81	1.02
<i>Jar Tests with Rapid Mix Tank Water</i>						
Mix Time (min)	60	60	60	60	60	60
Test 3: Ferric Chloride, mg/L (as Fe)	0	0.09	0.18	0.27	0.36	0.45
Test 4: Ferrous Sulfate, mg/L (as Fe)	0	0.10	0.20	0.30	0.41	0.51

EPA subsequently conducted four jar tests using water collected from the clearwell. These jar tests consisted of varying dosages of ferrous sulfate (FeSO<sub>4</sub>) and ferric sulfate (Fe<sub>2</sub>[SO<sub>4</sub>]<sub>3</sub>). The ferrous iron dosages ranged from 0.2 to 1.2 mg/L (as Fe) and the ferric iron dosages ranged from 0.2 to 1.2 mg/L (as Fe). The jars were mixed for 30 min at 20 rotations per minute (RPM). The supernatant was filtered with both 0.45 and 0.20 µm disc filters and analyzed for arsenic, iron, and manganese. The results of the jar tests are summarized in Section 4.3.2.

After the jar tests were completed, full-scale process tests began with supplemental iron addition to the treatment plant. During this timeframe, effluent from Filter Cell No. 4 was monitored on-line on a daily basis for turbidity and total and soluble arsenic, iron, and manganese to further assess the process conditions. The results of the process testing are summarized in Section 4.3.2.

Subsequent to the supplemental iron addition process testing, eight jar tests were conducted to select a supplemental polymer using the Phipps & Byrd jar test apparatus described above. Five polymers, i.e.,

Aqua Hawk 927, Aqua Hawk 9207 PWG, Aqua Hawk 2757, Aqua Hawk 6427, and Aqua Hawk 127, were tested at concentrations ranging from 0.2 to 10 mg/L. The polymers were dosed into 1-L jars and mixed with the Phipps & Byrd overhead stirrer/jar tester. The supernatant was filtered with 0.45 µm disc filters to simulate the performance of the gravity filter media and with 0.22 µm disc filters to analyze for soluble metals in the gravity filter effluent. The results of these jar tests are presented in Section 4.3.3. On September 21, 2004, the operator set up an additional polymer feed system to test full-scale plant operations with the addition of the second polymer selected from the jar tests.

**3.3.3 Macrolite® Pilot Testing.** A pilot test was performed by the selected equipment vendor, Kinetico, from March 28 to April 11, 2005, to determine if a potential retrofit of the existing gravity filter cells with Macrolite® media would result in improved arsenic removal. Macrolite® is a low-density, spherical, and chemically inert ceramic media. It is designed for high-rate filtration up to 10 gpm/ft<sup>2</sup> and typically used in treatment systems configured with pressurized filter tanks. However, Kinetico has used Macrolite® media in gravity filter plants for surface water treatment. The pilot test was conducted on-site using Kinetico's 1-ft<sup>2</sup> pilot plant apparatus loaded with 24-in of Macrolite® media. The flowrate to the pilot plant apparatus was approximately 2.0 gpm, resulting in a 2.0 gpm/ft<sup>2</sup> hydraulic loading rate similar to that (i.e., 2.1 gpm/ft<sup>2</sup>) of the full-scale gravity filters.

Two different pilot tests were conducted. The first pilot test from April 1 to 3, 2005, consisted of three individual runs (with Well No. 3 running during the test). Water for the first pilot test was taken from the top of the filters with the same chemical dosages used on the full-scale plant (e.g. NaOCl, KMnO<sub>4</sub>, FeCl<sub>3</sub>, Aqua Hawk 9207 PWG, and Aqua Hawk 127). The second pilot test from April 8 to 10, 2005, also consisted of three individual runs and used raw water from Well No. 1 with the addition of only KMnO<sub>4</sub> to oxidize iron and arsenic. The test was conducted in order to determine if improved arsenic removal could be achieved by a Macrolite® filter without the use of supplemental polymers, i.e., Aqua Hawk 9207 PWG, and Aqua Hawk 127, required for the full-scale plant. The pilot unit was backwashed at the end of the day after each individual run.

**3.3.4 Treatment Plant Water Sample Collection.** During the system performance evaluation study, the plant operator collected weekly samples across the treatment train, on a four-week cycle, for on- and off-site analyses. For the first three weekly events, samples were collected at four locations (i.e., at the wellhead [IN], before filter [BF], after filter [AF], and post-chlorination from clearwell [PC]) and analyzed for the analytes listed under the weekly treatment plant analyte list in Table 3-3. For the fourth weekly event, samples taken at four locations (i.e., IN, BF, AF, PC) were speciated on-site and analyzed for the analytes listed under the monthly treatment plant analyte list in Table 3-3.

**3.3.5 Backwash Water Sample Collection.** Backwash water samples were collected monthly from two of the four gravity filters. Unfiltered samples were measured on-site for pH and off-site for total dissolved solids (TDS) and turbidity. Filtered samples using 0.45-µm disc filters were analyzed for soluble As, Fe, and Mn.

**3.3.6 Backwash Solid Sample Collection.** Backwash solid samples were collected from 1-gal plastic jars containing backwash water/solid mixtures collected during a backwash event on October 6, 2005. After solids in the jar were settled and the supernatant was carefully decanted, one aliquot of the solids/water mixture was taken for TCLP testing. The remaining solid/water mixture was air-dried, acid-digested, and analyzed for Mg, Al, Si, P, Ca, Fe, Mn, Ni, Cu, Zn, As, Cd, and Pb.

**3.3.7 Distribution System Water Sample Collection.** Samples were collected from the distribution system by the plant operator to determine the impact of the process modifications on the water chemistry in the distribution system – specifically, lead and copper levels. From December 2003 to January 2004, prior to the startup of the process modifications, four bi-monthly baseline distribution

system sampling events were conducted at three locations within the distribution system. Following the start-up of the process modifications, distribution system sampling continued on a monthly basis at the same three locations.

The three homes selected for sampling had been included in the City's Lead and Copper Rule (LCR) sampling. The samples collected at the LCR locations were taken following an instruction sheet developed according to the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The first draw sample was collected from a cold-water faucet that had not been used for at least 6 hr to ensure that stagnant water was sampled. The sampler recorded the date and time of last water use before sampling and the date and time of sample collection for calculation of the stagnation time. Analytes for the baseline samples coincided with the monthly distribution system water samples as described in Table 3-3. Arsenic speciation was not performed for the distribution system water samples.

### **3.4 Sampling Logistics**

All sampling logistics, including arsenic speciation kits preparation, sample cooler preparation, and sample shipping and handling, are discussed below.

**3.4.1 Preparation of Arsenic Speciation Kits.** The arsenic field speciation method used an anion exchange resin column to separate the soluble arsenic species, As(V) and As(III) (Edwards et al., 1998). Resin columns were prepared in batches at Battelle laboratories according to the procedures detailed in Appendix A of the EPA-endorsed QAPP (Battelle, 2003).

**3.4.2 Preparation of Sampling Coolers.** 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, and waterproof label, consisting of the sample identification (ID), date and time of sample collection, collector's name, site location, sample destination, analysis required, and preservative. The sample ID consisted of a two-letter code for the specific water facility, sampling date, a two-letter code for a specific sampling location, and a one-letter code designating the arsenic speciation bottle (if necessary). The sampling locations at the treatment plant were color-coded for easy identification. The pre-labeled bottles for each sampling location were placed separate in ziplock bags and packed in the cooler.

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

**3.4.3 Sample Shipping and Handling.** After sample collection, samples for off-site analyses were packed carefully in the original coolers with wet ice and shipped to Battelle. Upon receipt, sample custodians verified that all samples indicated on the chain-of-custody forms were included and intact. Sample 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 water quality analyses were packed in separate coolers and picked up by couriers from American Analytical Laboratories (AAL) in Columbus, Ohio, and TCCI Laboratories in New Lexington, Ohio, both of which were under contract with Battelle for this demonstration study. Samples for metal analyses were stored at Battelle's Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) Laboratory. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

### **3.5 Analytical Procedures**

Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a WTW Multi 340i handheld meter, which was calibrated for pH and DO prior to use following the procedures provided in the user's manual. The ORP probe also was checked for accuracy by measuring the ORP of a standard solution and comparing it to the expected value. The plant operator collected a water sample in a clean 400-mL plastic beaker and placed the Multi 340i 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.

The analytical procedures described in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2003) were followed by Battelle's ICP-MS Laboratory, AAL, and TCCI Laboratories. Laboratory quality assurance/quality control (QA/QC) of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection limit (MDL), and completeness met the criteria established in the QAPP, i.e., relative percent difference (RPD) of 20%, percent recovery of 80% to 120%, and completeness of 80%. The quality assurance (QA) data associated with each analyte will be presented and evaluated in a quality assurance/quality control (QA/QC) Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project.

## Section 4.0: RESULTS AND DISCUSSION

### 4.1 Facility Description and Pre-Existing Treatment System Infrastructure

The water treatment system at Lidgerwood, North Dakota, supplies drinking water to approximately 750 community members. Located on Highway 18 North, the system has a design capacity of 250 gpm to meet the peak daily demand of 180,000 gpd. Source water is pumped from two 98-ft deep wells (one each north and south side) alternating on a monthly basis. The pre-existing treatment system housed in the building shown in Figure 4-1 consists of pre-chlorination, forced draft aeration,  $\text{KMnO}_4$  oxidation, polymer coagulant addition, detention, gravity filtration, post-chlorination, and fluoridation. There are four gravity filter cells filled with  $\text{MnO}_2$ -coated anthrasand. Figure 4-2 shows the top of two of the four gravity filter cells. The system also is equipped with a backwash reclaim system consisting of an 18,000-gal backwash water reclaim basin and a ½-horsepower (hp) reclaim pump. The sludge removed from the reclaim basin gets stored in a 20-ft diameter by 9-ft and 5-in tall sludge holding tank and excess water filtered off of the sludge is returned for treatment (Figure 4-3). The treated water is stored in a 30,000-gal clearwell before being pumped to the 50,000-gal water tower located in town. A detailed description of the pre-existing treatment plant and subsequent process modifications is provided in Section 4.2.



**Figure 4-1. Pre-Existing Water Treatment Facility at Lidgerwood, ND**





**Figure 4-2. Top View of Pre-Existing Gravity Filter Cells (with Two of Four Cells Shown)**



**Figure 4-3. Pre-Existing Backwash Sludge Holding Tank**



**4.1.1 Source Water Quality.** Source water samples were collected on July 31, 2003, and subsequently analyzed for the analytes listed in Table 3-3. Table 4-1 presents the results of the source water analyses, along with those provided by the facility to EPA for the demonstration site selection and those independently collected and analyzed by EPA, North Dakota Department of Health (NDDH), and the vendor.

As shown in Table 4-1, total arsenic concentrations in source water ranged from 108 to 146.2 µg/L. Based on Battelle's July 31, 2003, sampling results, 82% of total arsenic existed as As (III) at 120.6 µg/L, and 14% as particulate As at 20.3 µg/L. Iron concentrations in source water ranged from 1,310 to 1,620 µg/L existing almost completely as soluble iron. A general rule is that the soluble iron concentration should be at least 20 times the soluble arsenic concentration for effective removal of arsenic onto iron solids (Sorg, 2002). The results from the July 31, 2003, sampling event indicated that the soluble iron level was approximately 10 times the soluble arsenic level. Because the natural iron content in source water was below the target 20:1 Fe:As ratio, the system would require supplemental iron addition to achieve below 10 µg/L treatment results. The manganese levels were elevated, ranging from 111 to 675 µg/L and existed mainly as soluble manganese. The pH values ranged from 7.2 to 7.5. Hardness ranged from 435 to 520 mg/L, silica from 27.8 to 32.1 mg/L, and sulfate from 341 to 390 mg/L. Although, silica and sulfate can compete with arsenic for removal onto iron solids, these concentrations were not high enough to show significant impact on arsenic removal.

**4.1.2 Treated Water Quality.** Tables 4-1 and 4-2 summarize the results of treated water samples collected by Battelle, EPA, and NDDH. In general, treated water samples had lower arsenic, iron, and manganese concentrations than source water samples, while other parameters remained within the range of source water concentrations. Table 4-1 shows that arsenic concentrations in the treated water ranged from 25.7 to 31.1 µg/L from 1998 through 2003. Iron concentrations ranged from below the method detection limit of µg/L to 109 µg/L (which is below the secondary MCL of 300 µg/L for iron, but suggests particulate breakthrough from the gravity filters). Manganese concentrations ranged from <10 to 101 µg/L (the secondary MCL for manganese is 50 µg/L).

Table 4-2 presents the analytical results of the water samples collected across the treatment train by EPA in April 2003. These samples were collected at the wellhead, after aeration/oxidation, before the filters, after the filters, and after the post-chlorination point. Total arsenic and iron concentrations in source water were 129 µg/L and 1,390 µg/L, respectively. After prechlorination and aeration, approximately 20% of total arsenic, or 19 µg/L, was present in the soluble form with the remainder existing as particulate. Iron was present entirely in particulate form after aeration with total iron concentration at 924 µg/L. After the detention tank and before the filters, total arsenic and total iron levels decreased by approximately 32% and 38%, respectively, indicating that significant settling of particles had been taking place within the detention tank. After the filters, the total arsenic level was 18 µg/L, which was present only in the soluble form and somewhat lower than historic levels (i.e., 25.7 to 31.1 µg/L) obtained by NDDH. There was no particulate arsenic observed in the water sample collected after the filters. Based on these treated water sampling results, it was determined that supplemental iron would be needed for further removal of soluble arsenic to reach the arsenic MCL of 10 µg/L.

**Table 4-1. Lidgerwood, ND Raw and Treated Water Quality Results**

Parameter	Unit	Raw Water				Treated Water	
		Utility Data	EPA Data	Vendor Data	Battelle Raw Water Data	Battelle Treated Water Data	NDDH Treated Water Data
Date	-	NA	09/03/02	NA	07/31/03	07/31/03	1998 to 2003
pH	S.U.	7.5	NS	7.3	7.2	NS	6.9 - 7.4
Alkalinity (as CaCO <sub>3</sub> )	mg/L	385	NS	368	344	NS	364 - 403
Hardness (as CaCO <sub>3</sub> )	mg/L	444	435	520	513	510	477 - 481
Chloride	mg/L	36	NS	81	82	NS	58 - 66
Fluoride	mg/L	NS	NS	0.5	0.8	NS	1.3
Sulfide	mg/L	NS	114	NS	NS	NS	NS
Sulfate	mg/L	344	341	350	390	NS	373 - 384
Silica (as SiO <sub>2</sub> )	mg/L	27.8	28.5	32.1	29.4	NS	NS
Orthophosphate (as PO <sub>4</sub> )	mg/L	<0.065	NS	<0.1	<0.10	NS	NS
TOC	mg/L	NS	NS	NS	<1.0	NS	NS
As (total)	µg/L	108	129	128	146.2	30.5	25.7 - 31.1
As (soluble)	µg/L	NS	NS	NS	125.9	17.6	NS
As (particulate)	µg/L	NS	NS	NS	20.3	12.8	NS
As (III)	µg/L	NS	NS	NS	120.6	<0.1	NS
As (V)	µg/L	NS	NS	NS	5.3	17.6	NS
Fe (total)	µg/L	1,310	1,390	1,620	1,325	69	<10 - 109
Fe (soluble)	µg/L	NS	NS	NS	1,316	54	NS
Al (total)	µg/L	NS	<25	NS	<10	<10	<50
Al (soluble)	µg/L	NS	NS	NS	<10	<10	NS
Mn (total)	µg/L	544	111	660	675	101	<10 - 46
Mn (soluble)	µg/L	NS	NS	NS	665	14.8	NS
V (total)	µg/L	NS	NS	NS	<0.1	<0.1	NS
V (soluble)	µg/L	NS	NS	NS	<0.1	<0.1	NS
Mo (total)	µg/L	NS	NS	NS	2.7	5.1	NS
Mo (soluble)	µg/L	NS	NS	NS	2.5	5.3	NS
Sb (total)	µg/L	NS	<25	NS	<0.1	<0.1	<0.1
Sb (soluble)	µg/L	NS	NS	NS	<0.1	<0.1	NS
Na (total)	mg/L	142	147	148	131	130	160 - 168
Ca (total)	mg/L	128	125	147	148	147	136 - 138
Mg (total)	mg/L	29	30	38	35	35	33

NA = not available; ND = non-detect; NS = not sampled

**Table 4-2. Lidgerwood, ND Treated Water Quality Data Collected by EPA on April 30, 2003**

Sample Location	As (total) (µg/L)	As (soluble) (µg/L)	Fe (total) (µg/L)	Fe (soluble) (µg/L)
At Wellhead	129	NS	1,390	NS
After Aeration	97	19	924	<25
Before Filters	88	15	863	<25
After Filters	18	22	<25	<25
After Post-Chlorination	21	18	<25	<25

NS = not sampled

## 4.2 Treatment Process Description

Figure 4-4 is a process schematic of the treatment train for the Lidgerwood, North Dakota, plant. The pre-existing treatment system consisted of pre-chlorination, forced draft aeration,  $\text{KMnO}_4$  oxidation, polymer coagulant addition, detention, gravity filtration, post-chlorination, and fluoridation. Table 4-3 summarizes the major components and design parameters. The process modifications included the use of supplemental iron and polymer additions to enhance arsenic removal by the filters. Figure 4-5 presents a process flowchart, along with the sampling/analysis schedule, for the process modifications. The major process steps and system components are presented as follows:

- Pre-Chlorination.** A gas chlorine feed system was used to maintain chlorine residuals and prevent biological growth across the treatment train and oxidize As(III), Fe(II), and Mn(II) in raw water prior to aeration. The pre-chlorination dosage was targeted at 1.8 mg/L (as  $\text{Cl}_2$ ).
- Aeration.** Forced-draft aeration with a 1-hp blower was used to promote the transfer of oxygen from air to water to further oxidize iron and manganese within the tray aeration unit.
- Rapid Mixing with  $\text{KMnO}_4$  Oxidation and Iron and Polymer Additions.** A rapid mix tank was used prior to the detention tank to provide for  $\text{KMnO}_4$ ,  $\text{FeCl}_3$ , and polymer addition into the aerated water. A supplementary oxidation step was provided by the addition of  $\text{KMnO}_4$ , which was stored in a 50-gal tank and added at a dosage of approximately 0.7 mg/L.  $\text{KMnO}_4$  also was used to continuously regenerate the  $\text{MnO}_2$ -coated anthrasand in the filters. The new  $\text{FeCl}_3$  addition system consisted of a 1.75 gal/hr (gph) chemical metering pump, a 60-gal chemical day tank, a tank mixer, and a secondary containment skid. Figure 4-6 shows the new chemical feed system for  $\text{FeCl}_3$  that was installed as part of the process modifications.

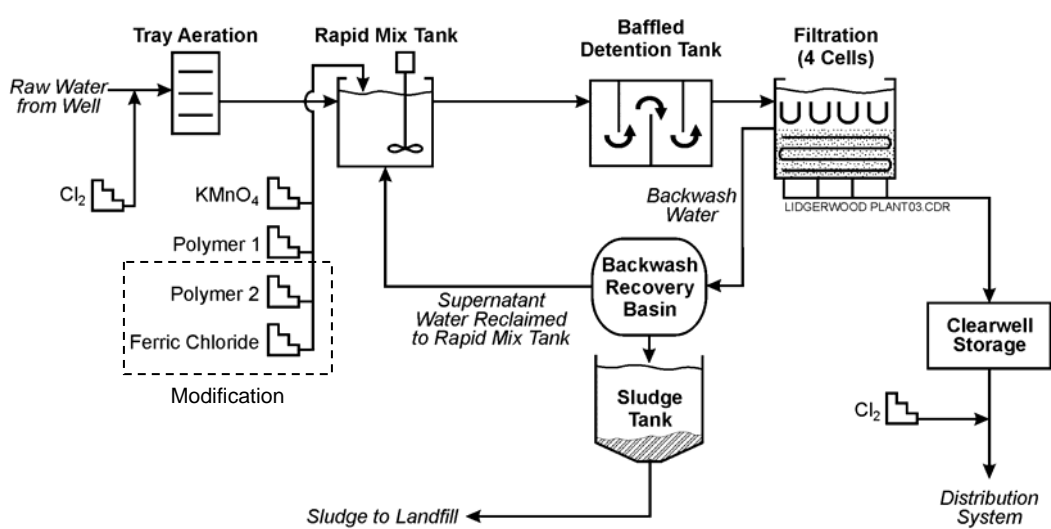


Figure 4-4. Process Schematic of Coagulation/Gravity Filtration Plant at Lidgerwood, ND

**Table 4-3. Design Specifications for Lidgerwood, ND Coagulation/Gravity Filtration Plant**

Parameter	Value	Remarks
<i>Pre-Treatment</i>		
Prechlorination Dosage (mg/L [as Cl <sub>2</sub> ])	1.8	
Potassium Permanganate Dosage (mg/L)	0.7	
Iron Dosage (mg/L [as Fe])	1.0-1.2	Based on Jar Test Results
Aqua Hawk 9207 PWG Polymer Dosage (mg/L)	0.3	Based on Jar Test Results
Aqua Hawk 127 Polymer Dosage (mg/L)	0.5	Based on Jar Test Results
<i>Contact</i>		
Capacity (gal)	15,000	
Contact Time (min)	60	At 250 gpm design flowrate
<i>Filtration</i>		
Cell Size (ft)	7.0 L × 4.3 W	
Cell Area (ft <sup>2</sup> )	30	
Number of Cells	4	
Configuration	Parallel	
Media Quantity (ft <sup>3</sup> /cell)	60	24-in bed depth
Media Type	MnO <sub>2</sub> -coated anthrasand	20/40 mesh
Design Flowrate (gpm)	250	
Filtration Rate (gpm/ft <sup>2</sup> )	2.1	
Δp across Clean Bed (in of H <sub>2</sub> O)	10	
Maximum Daily Production (gpd)	360,000	Based on peak flow; 24 hr/day
Hydraulic Utilization (%)	50	Estimated based on peak daily demand <sup>(a)</sup>
<i>Backwash</i>		
Backwash Frequency	3 time per week	Taking place on Monday, Wednesday, and Friday
Backwash Hydraulic Loading Rate (gpm/ft <sup>2</sup> )	8.0	
Backwash Duration (min/cell)	10	
Wastewater Production (gal/cell)	2,400	Based on 240 gpm backwash flowrate

(a) Based on a historic peak daily demand of 180,000 gpd.

Ferric chloride was added at a target dosage of 1.2 mg/L (as Fe). Two non-ionic polymers also were added. Aqua Hawk 9207 PWG, a polyacrylamide-based polymer, had already been added at the plant at a level of approximately 0.10 mg/L prior to this demonstration study. During this study period, the dosage of this polymer was increased to 0.3 mg/L at a feed rate of 0.90 gph. The second polymer added during this study period was Aqua Hawk 127, which is a blended aluminum-based coagulation chemical/polymer. It was added at a rate of 0.75 gph to reach a target level of 0.5 mg/L. Both polymers are NSF International-certified for use in drinking water applications.

- **Contact Time.** The baffled detention tank had a capacity of 15,000 gal and allowed for approximately 60 min of contact time before gravity filtration.

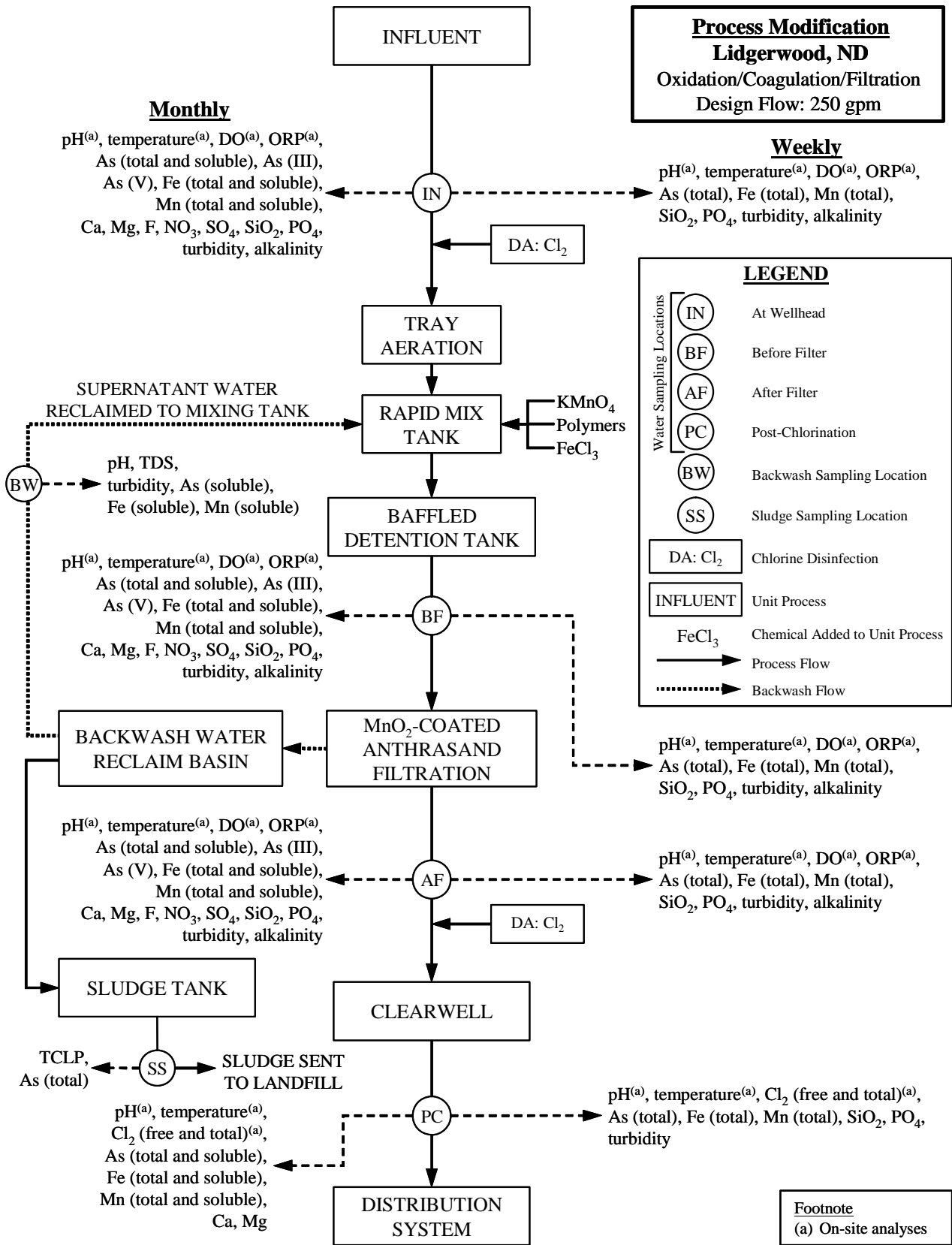


Figure 4-5. Process Flow Diagram and Sampling Locations



**Figure 4-6. New Iron Addition System**

- **Gravity Filtration.** Particulate matter in water was removed using four gravity filter cells, each having a cross-sectional area of 30 ft<sup>2</sup> and filled with 24-in of 20 × 40 mesh MnO<sub>2</sub>-coated anthrasand (General Filter Products) that was changed out on October 31, 2002. The total cross-sectional area of all four cells was 120 ft<sup>2</sup>, which yields a hydraulic loading rate of 2.1 gpm/ft<sup>2</sup> at the design flowrate of 250 gpm. This hydraulic loading rate is consistent with the 2 gpm/ft<sup>2</sup> specification for conventional sand filters in the *Recommended Standards for Water Works or Ten State Standards* (Great Lakes-Upper Mississippi River Board of State Sanitary Engineers, 2003). The pressure drop was 10 in of H<sub>2</sub>O across the clean filter cell in the service mode. As part of the process modifications, each filter cell was outfitted with a Hach 1720D low-range turbidimeter with a power supply and associated interface (see Figure 4-7). In addition, a Foxboro differential pressure ( $\Delta p$ ) cell was placed across the media bed in Filter Cell No. 4 to monitor the filter cell performance. Data from these devices were recorded and stored by a Telog data logging system and downloaded once per week by the operator.
- **Post-Chlorination.** For post-chlorination, free chlorine was targeted at 0.08 mg/L and total chlorine residual was targeted at 3.4 mg/L. In addition, 1.3 mg/L of fluoride was added to the treated water prior to distribution.
- **Backwash Operation and Reclaim.** A clock-based timer was used to trigger a backwash every Monday, Wednesday, and Friday at 3 AM. Each backwash cycle

included an initial air sparging step (air and water) with an air scour pressure of 3.5 lb followed by 12 min of backwash per cell at approximately 240 gpm. The backwash water produced from each backwash cycle was allowed to settle in an 18,000-gal backwash water reclaim basin for 6 hr. After the required settling period, the supernatant was reclaimed to the mixing tank with a ½-hp reclaim pump at a flowrate of 26 gpm. This pump was later replaced by a 1-hp reclaim pump to reach a flowrate of 40 gpm to increase the rate of recycling and allow for daily backwashing of the system, if needed. The sludge accumulated in the bottom of the reclaim basin was pumped to a 20-ft diameter by 9-ft, 5-in tall sludge holding tank and then collected for landfill disposal once every other year. After the process modifications, the frequency of sludge disposal was increased to once per year.



**Figure 4-7. Turbidimeters and DataLogger for Process Measurements**

- **Clearwell Storage.** Before distribution, the treated water was stored in a 30,000-gal clearwell located underneath the treatment building. The original 16,000-gal clearwell installed in 1984 was used as a source for backwash and the 30,000-gal clearwell installed in 1989 was used for distribution water. The treated water was stored in a 50,000-gal water tower in town.

### **4.3 Process Modifications**

Prior to the demonstration study period, several steps were taken to determine a set of process conditions capable of reducing arsenic concentrations to less than the 10 µg/L MCL. These pre-demonstration activities included treatment plant baseline testing, jar tests for iron and polymer additions, and supplemental iron and polymer addition testing to achieve target conditions in the plant. The results of these pre-demonstration activities are discussed below. These activities occurred prior to the commencement of the full-scale performance evaluation study.

**4.3.1 Treatment Plant Baseline Sampling.** Prior to the process modifications, speciation samples were collected across the treatment train on January 14, 2004. The speciation results presented in Table 4-4 showed that the ratio of soluble iron to soluble arsenic concentration in raw water was 8:1, which was well below the target level of 20:1 for effective arsenic removal (EPA, 2001; Sorg, 2002). Iron and manganese existed entirely in the soluble form. After prechlorination, aeration, and  $\text{KMnO}_4$  addition, arsenic, iron, and manganese were present primarily in the particulate form. The soluble arsenic fraction consisted primarily of As(V) at 19.6  $\mu\text{g/L}$ , suggesting effective oxidation of As(III) to As(V). Upon exiting the baffled detention tank, 19.4%, 16.7%, and 16.9% of particulate arsenic, iron, and manganese, respectively, were removed through settling within the detention tank. The total arsenic level in the filter effluent was 38.2  $\mu\text{g/L}$ , which was present primarily as As(V). There also was 5.5  $\mu\text{g/L}$  of particulate arsenic in the filter effluent. The total arsenic level in the filtered effluent was consistent with those in the treated water samples collected by Battelle on July 31, 2003, and by NDDH from 1998 through 2003.

**Table 4-4. Analytical Results of Baseline Speciation Samples Taken Across Treatment Train on January 14, 2004**

Parameter	Unit	At Wellhead	After Aeration/ Rapid Mixing	Before Filters	After Filters	Post-Chlorination
As (total)	$\mu\text{g/L}$	153	145	126	38.2	40.2
As (particulate)	$\mu\text{g/L}$	13	124	100	5.5	7.6
As (soluble)	$\mu\text{g/L}$	140	20.6	25.7	32.7	32.6
As (III)	$\mu\text{g/L}$	121	1.0	0.9	0.9	1.0
As (V)	$\mu\text{g/L}$	19.0	19.6	24.8	31.8	31.6
Fe (total)	$\mu\text{g/L}$	1,053	1,025	854	<25	<25
Fe (soluble)	$\mu\text{g/L}$	1,075	<25	<25	<25	<25
Mn (total)	$\mu\text{g/L}$	668	840	698	7.8	6.1
Mn (soluble)	$\mu\text{g/L}$	673	12.7	1.1	2.2	1.4
Free Chlorine (as $\text{Cl}_2$ )	$\text{mg/L}$	NA	1.37 <sup>(a)</sup>	0.92	0.06	0.10 (2.20) <sup>(b)</sup>

(a) Permanganate in water might have interfered with chlorine measurements using Hach meter.

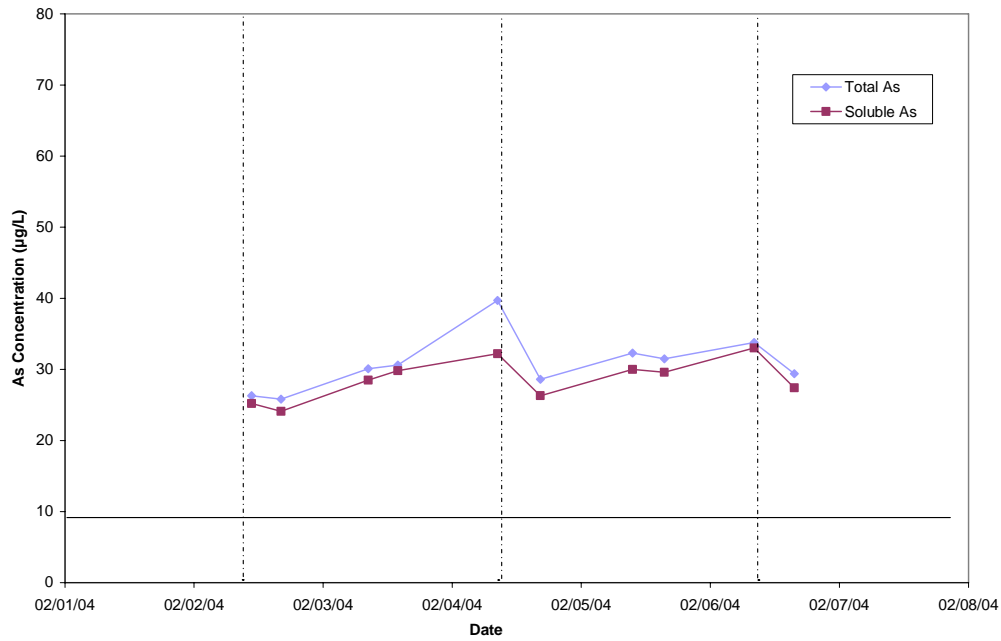
(b) Total chlorine reading in parentheses.

The baseline performance of Filter Cell No. 4 was further evaluated from February 2 through 6, 2004. Figure 4-8 shows total and soluble arsenic concentrations in the Filter Cell No. 4 effluent during this period. The filter run times were 14.9 hr from Monday to Wednesday (February 2 to 4, 2004) and 12.9 hr from Wednesday to Friday (February 4 to 6, 2004).

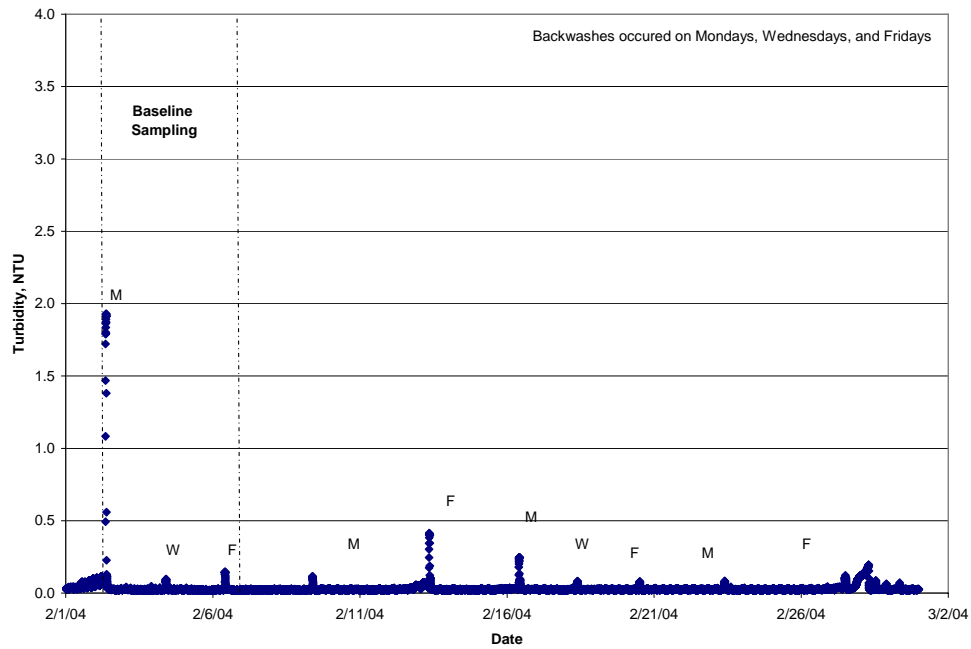
Total arsenic levels in the filter effluent ranged from 25.8 to 39.7  $\mu\text{g/L}$  and existed primarily in the soluble form. Total iron levels were <25  $\mu\text{g/L}$  in all effluent samples. Total manganese concentrations averaged 3.7  $\mu\text{g/L}$  and existed primarily in the soluble form. The presence of soluble arsenic in the filter effluent confirmed the need for supplemental iron addition. The on-line baseline turbidity readings of the Filter Cell No. 4 effluent averaged 0.032 nephelometric turbidity units (NTU), indicating effective particulate removal by the filter (Figure 4-9).

**4.3.2 Jar and Process Testing for Iron Addition.** A series of jar tests was performed on-site by Battelle in January 2004 using water taken from the wellhead and rapid mix tank. The jar test procedure is summarized in Section 3.3.2. The objectives of the jar tests were to: 1) compare the effectiveness of





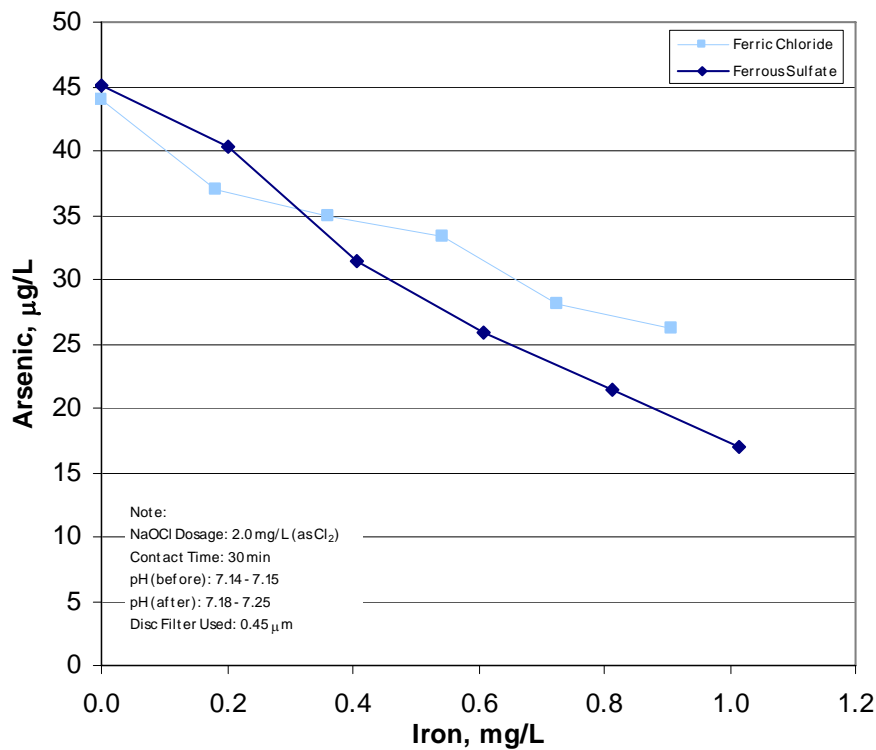
**Figure 4-8. Total and Soluble Arsenic Levels in Filter Cell No. 4 Effluent Under Baseline Conditions in February 2004**



**Figure 4-9. Turbidity Readings of Filter Cell No. 4 Effluent under Baseline Conditions in February 2004**

FeCl<sub>3</sub> and FeSO<sub>4</sub> for arsenic removal; 2) determine the optimal iron salt dosage to enhance arsenic removal to below 10 µg/L; and 3) determine the effect of different iron addition points prior to the gravity filters.

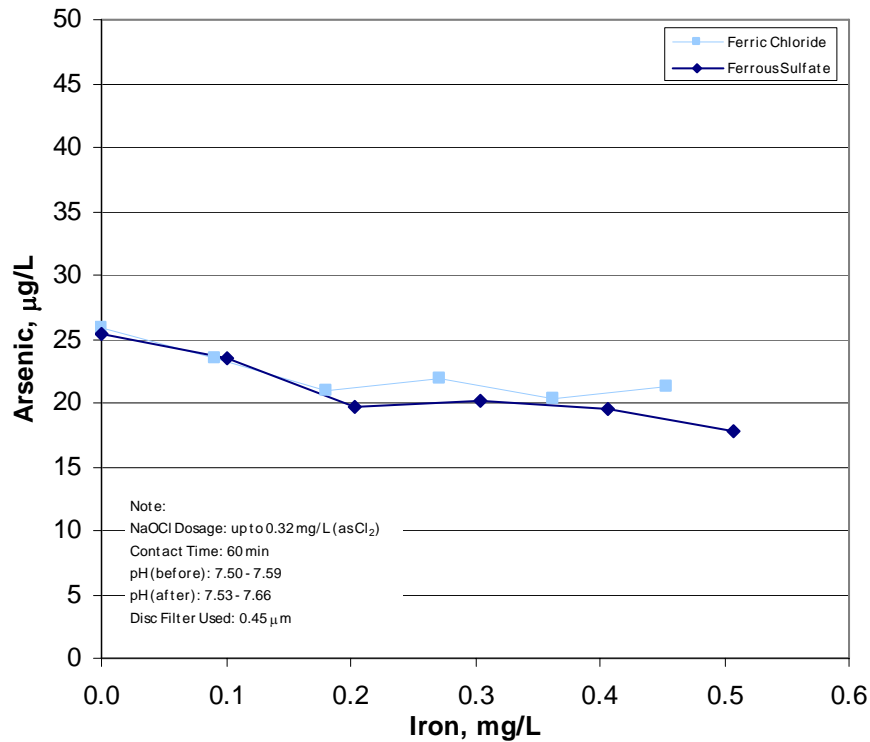
Figure 4-10 shows the results of the first and second jar tests with the addition of FeCl<sub>3</sub> or FeSO<sub>4</sub> to raw water. With 0.9 to 1.0 mg/L (as Fe) of iron addition, arsenic concentrations were reduced to 16.9 to 26.2 µg/L and iron concentrations, unexpectedly, to only 83.9 to 210 µg/L in 0.45 µm-filtered water. Because the contents in the jars were in contact with air for at least 30 min and because chlorine residuals were measured in the jars by the end of tests, it would not have been possible to have soluble iron present in filtered water. It was, therefore, speculated that some iron particles might have passed through 0.45 µm disc filters due to smaller sizes of these particles.



**Figure 4-10. Results of Jar Tests with Addition of FeCl<sub>3</sub> or FeSO<sub>4</sub> to Raw Water (Tests Performed by Battelle)**

Figure 4-11 shows the results of the third and fourth jar tests with the addition of FeCl<sub>3</sub> or FeSO<sub>4</sub> to water collected from the rapid mix tank. With 0.45 to 0.51 mg/L (as Fe) of iron addition, soluble arsenic concentrations were reduced to 17.8 to 21.3 µg/L. In this case, iron levels were reduced to <25 µg/L. Apparently, the amounts of iron added during each of the four jar tests were not sufficient to remove soluble arsenic to below 10 µg/L.

EPA subsequently conducted a series of jar tests off-site using water collected from the clearwell with different dosages of FeSO<sub>4</sub> and Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>. Upon completion of the jar tests, both 0.45 and 0.20 µm disc filters were used to filter the water samples. The results of these jar tests, as shown in Figure 4-12, indicated that about 1.0 to 1.2 mg/L (as Fe) of iron would be needed to reduce soluble arsenic

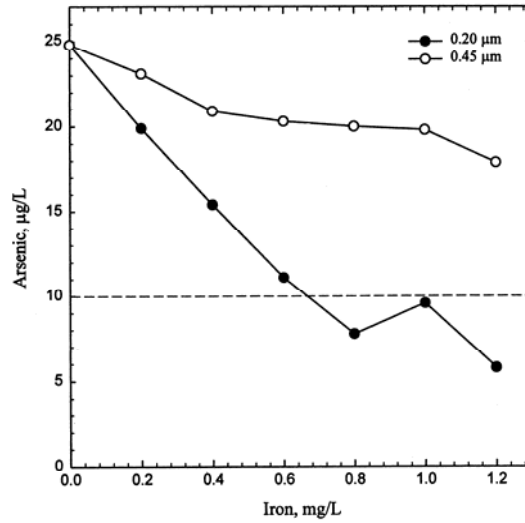


**Figure 4-11. Jar Test Results with Addition of FeCl<sub>3</sub> or FeSO<sub>4</sub> to Water Collected from Rapid Mix Tank (Test Performed by Battelle)**

concentrations to below 10 µg/L. The data also showed that using 0.20 µm disc filters resulted in much lower arsenic concentrations, compared to the data using 0.45 µm disc filters, confirming that some fractions of arsenic particulate were indeed smaller than 0.45 µm (Lytle, 2005).

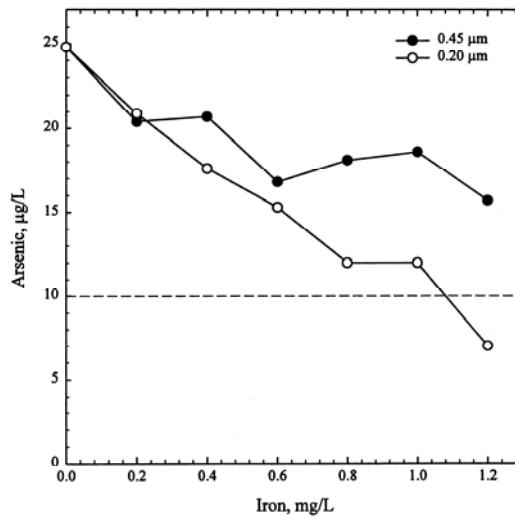
The process conditions for supplemental iron addition were determined based on the jar test results obtained by Battelle and EPA. FeCl<sub>3</sub> was selected as the chemical for supplemental iron addition. FeCl<sub>3</sub> provided comparable arsenic removal performance to FeSO<sub>4</sub> and Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> and was readily available from the City's chemical supplier. FeCl<sub>3</sub> was available in a more concentrated form at 35%, which would be more convenient to use for solution preparation than FeSO<sub>4</sub> at 7%. Moreover, the use of FeSO<sub>4</sub> or Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> would have contributed to the already elevated sulfate levels (i.e. about 390 mg/L) in the treated water. Further, FeSO<sub>4</sub> has an elevated freeze point compared to FeCl<sub>3</sub>, which may add complexity to shipping, storage, and handling, especially under sub-zero ambient conditions in the winter. The supplemental iron dosage was determined to be between 1.0 to 1.2 mg/L (as Fe) to reduce arsenic below 10 µg/L. The rapid mix tank was selected as the point for the FeCl<sub>3</sub> injection.

Supplemental iron addition was tested on the full-scale system from March through July 2004. During this time period, 142 samples were collected approximately twice per day, five days a week. Table 4-5 summarizes total and soluble arsenic and iron concentrations in the Filter Cell No. 4 effluent with the addition of 0.6 to 1.1 mg/L (as Fe) of FeCl<sub>3</sub> and 0.10 to 0.12 mg/L of Aqua Hawk 9207 PWG (i.e., the polymer already used at the plant prior to the demonstration study). All soluble arsenic and iron samples were collected using 0.22 µm disc filters. As shown in the table, average total arsenic levels in the filter effluent ranged from 16.3 to 23.9 µg/L and average total iron levels ranged from 32 to 139 µg/L. When only 0.6 to 0.9 mg/L of iron was added (i.e., from March 9 to June 30, 2004), average soluble arsenic



(pH at 7.67 with 30 min of contact time)

**Figure 4-12a. Jar Test Results for FeSO<sub>4</sub> to Water Collected from Clearwell (Test Performed by EPA)**



(pH at 7.67 with 30 min of contact time)

**Figure 4-12b. Jar Test Results for Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> to Water Collected from Clearwell (Test Performed by EPA)**

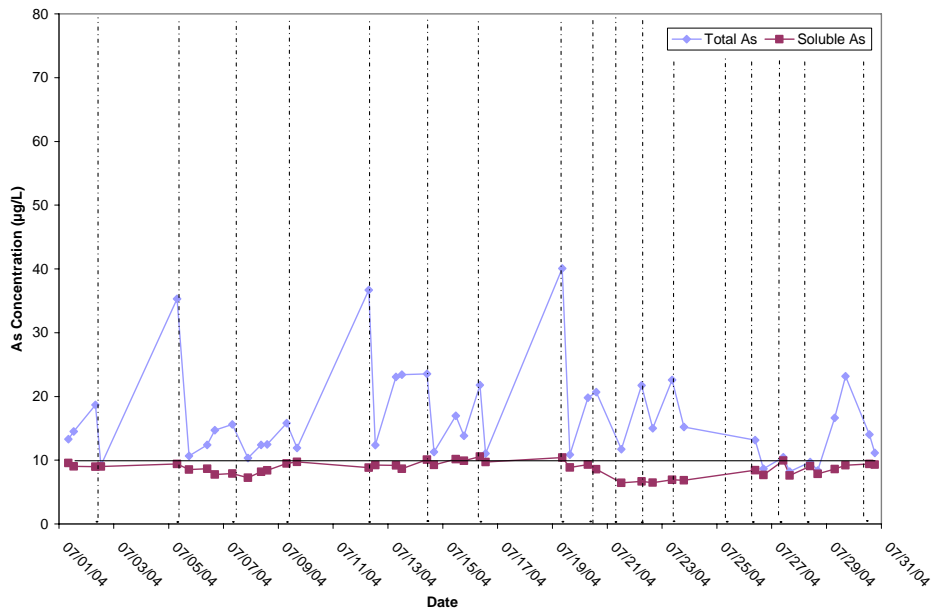
levels remained high, ranging from 14.0 to 16.5 µg/L. From July 1 to 31, 2004, as the iron dosage was increased to 1.1 mg/L (as Fe), the average soluble arsenic level was reduced to 8.7 µg/L. Particulate arsenic and iron breakthrough from the filter apparently had caused total arsenic levels in the filter effluent to exceed the 10 µg/L target level.

**Table 4-5. Arsenic and Iron Levels in Filter Cell No. 4 Effluent During Iron Addition Process Testing**

Test Duration	Average Iron Dosage (mg/L [as Fe])	Average Aqua Hawk 9207PWG Dosage (mg/L)	No. of Samples	Average As (total) (µg/L)	Average As (soluble) (µg/L)	Average Fe (total) (µg/L)	Average Fe (soluble) (µg/L)
03/09/04 – 03/19/04	0.6	0.10	15	18.6	15.1	32	<25
04/07/04 – 05/18/04	0.9	0.10	60	23.9	16.5	81	<25
06/14/04 – 06/30/04 <sup>(a)</sup>	0.9	0.12	24	18.5	14.0	54	<25
07/01/04 – 07/31/04	1.1	0.12	43	16.3	8.7	139	<25

(a) Aqua Hawk 9207 PWG application rate was increased on June 21, 2004 from approximately 0.10 mg/L to 0.12 mg/L.

Figure 4-13 shows total arsenic levels in the Filter Cell No. 4 effluent from July 1 through 31, 2004, when an average of 1.1 mg/L of iron was added. Total arsenic levels ranged from 8.2 to 40.1 µg/L and averaged 16.3 µg/L, with the majority of arsenic present as particulate arsenic with levels ranging from 0.2 to 29.7 µg/L. Total iron concentrations ranged from <25 to 557 µg/L and averaged 139 µg/L, which was present entirely in the particulate form (data not shown). These results further demonstrated that iron particles formed prior to the gravity filters were not effectively removed by the MnO<sub>2</sub>-coated anthrasand. The turbidity readings of the filter effluent (that will be discussed further in Section 4.5.1.4) averaged 0.31 NTU during this time period, compared to the average baseline turbidity value of 0.032 NTU. Nevertheless, the Δp readings recorded just before respective backwash cycles ranged from 25.4 to 44.6 in of H<sub>2</sub>O, which were comparable to the baseline levels of 26.2 to 41.4 in of H<sub>2</sub>O recorded in February 2004. These data will be further discussed in Section 4.4.1.



**Figure 4-13. Total and Soluble Arsenic in Filter Cell No. 4 Effluent with Supplemental Iron Addition in July 2004**

**4.3.3 Jar and Process Testing for Polymer Addition.** A series of jar tests was performed on-site in August 2004 by the Hawkins Water Treatment Group (the City’s chemical supplier) to determine if supplemental polymer addition could provide improved particulate arsenic and iron removal across the MnO<sub>2</sub>-coated anthrasand filters. A total of eight different combinations of polymers were tested. The results presented in Table 4-6 showed total arsenic levels ranging from 5.8 to 7.3 µg/L and soluble arsenic levels ranging from 5.6 to 7.1 µg/L in the treated water. (Note that soluble arsenic samples were filtered with 0.22 µm disc filters.) The combination of Aqua Hawk 127 at 0.5 mg/L and Aqua Hawk 9207 PWG at 0.3 mg/L showed both total and soluble iron levels at non-detectable levels and, therefore, was selected for full-scale plant process testing. The Aqua Hawk 9207 PWG had already been used at the treatment plant prior to the process modifications, but at a lower dose rate of approximately 0.10 mg/L. Based on these jar test results and the iron addition process testing, the target process conditions were set at 1.2 mg/L (as Fe) for supplemental FeCl<sub>3</sub> addition, 0.5 mg/L for Aqua Hawk 127, and 0.3 mg/L for Aqua Hawk 9207 PWG. After the polymer jar tests were completed, the results were shared with the project team and approval was received from NDDH for full-scale plant testing. The operator set up a second polymer feed system on September 21, 2004.

**Table 4-6. Summary of Polymer Jar Test Results Obtained in August 2004**

Jar Test No.	Polymer Mix <sup>(a)(b)(c)(d)</sup>	Total Arsenic (µg/L)	Soluble Arsenic <sup>(e)</sup> (µg/L)	Total Iron (µg/L)	Soluble Iron <sup>(e)</sup> (µg/L)	Total Mn (µg/L)	Soluble Mn (µg/L)
1	Aqua Hawk 927 at 0.2 mg/L	7.1	7.1	79	<25	12.0	5.3
2	Aqua Hawk 2757 at 1.0 mg/L	5.8	5.6	44	<25	2.8	0.6
3	Aqua Hawk 2757 at 5.0 mg/L	6.1	6.0	34	<25	2.5	0.9
4	Aqua Hawk 6427 at 0.5 mg/L with Aqua Hawk 9207 PWG at 0.3 mg/L	6.3	6.2	62	<25	3.5	1.4
5	Aqua Hawk 2757 at 10.0 mg/L	6.2	6.2	80	<25	6.7	1.6
6	Aqua Hawk 127 at 1.0 mg/L with Aqua Hawk 9207 PWG at 0.3 mg/L	6.0	6.0	64	<25	2.9	1.6
7	Aqua Hawk 127 at 0.5 mg/L with Aqua Hawk 9207 PWG at 0.3 mg/L	6.8	6.5	<25	<25	1.2	0.6
8	Aqua Hawk 6427 at 1.0 mg/L with Aqua Hawk 9207 PWG at 0.3 mg/L	7.3	6.6	77	<25	6.3	1.6

(a) Aqua Hawk 927 and Aqua Hawk 9207 PWG are polyacrylamide-based polymers.

(b) Aqua Hawk 2757 is a blended aluminum-based coagulation chemical, poly dialkyldimethylammonium chloride (pDADMAC) polymer, and polyamine polymer.

(c) Aqua Hawk 6427 is a pDADMAC-based polymer.

(d) Aqua Hawk 127 is a blended aluminum-based coagulation chemical/polymer.

(e) Soluble samples were obtained using 0.22 µm disc filters.

**4.3.4 Macrolite<sup>®</sup> Pilot Test Results.** The procedures for the Macrolite<sup>®</sup> pilot tests are summarized in Section 3.3.3. The first pilot test used water taken from the top of the filters with the same chemical dosages used on the full-scale plant (e.g., NaOCl, KMnO<sub>4</sub>, FeCl<sub>3</sub>, Aqua Hawk 9207 PWG, and Aqua Hawk 127). The second pilot test was conducted with raw water and KMnO<sub>4</sub> used to oxidize iron and arsenic. Table 4-7 summarizes the analytical results for arsenic, iron, and manganese removal from the first and second pilot tests. Figure 4-14 shows the total and soluble arsenic levels in the influent and effluent of the Macrolite<sup>®</sup> filter during both tests.

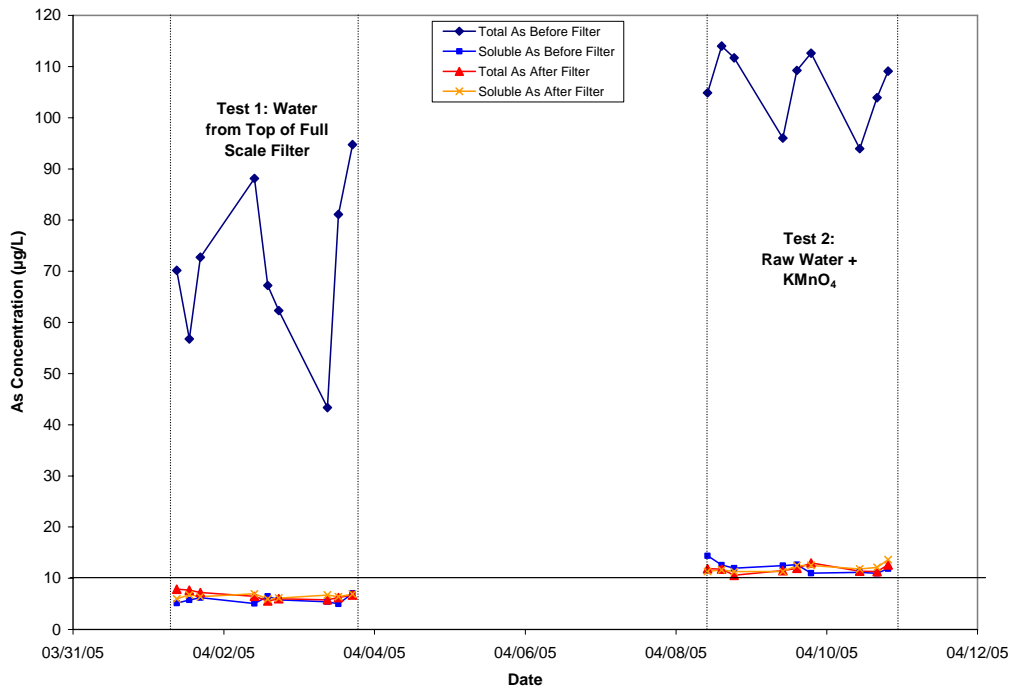
**Table 4-7. Summary of Macrolite® Pilot Test Analytical Results**

Test	Run Time (hr)	Average Flowrate (gpm)	Average Total As Influent (µg/L)	Average Total As Effluent (µg/L)	Average Total Fe Influent (µg/L)	Average Total Fe Effluent (µg/L)	Average Total Mn Influent (µg/L)	Average Total Mn Effluent (µg/L)
<i>Test 1: Water before filter with NaOCl, KMnO<sub>4</sub>, FeCl<sub>3</sub>, and polymers</i>								
Run 1	8.4	2.00	66.5	7.6	1,287	<25	60.8	75.4
Run 2	8.6	1.98	72.6	6.0	1,371	<25	61.2	20.5
Run 3	9.1	2.00	73.1	6.3	1,381	<25	61.6	28.0
Ave	8.7	1.99	70.7	6.6	1,346	<25	61.2	41.3
<i>Test 2: Raw water with KMnO<sub>4</sub> only</i>								
Run 1	10.3	1.99	110	11.4	1,610	<25	1,786	29.2
Run 2	10.2	1.99	106	12.1	1,508	<25	1,637	12.3
Run 3	10.0	1.99	102	11.8	1,396	<25	1,502	43.1
Ave	10.1	1.99	106	11.8	1,505	<25	1,642	28.2

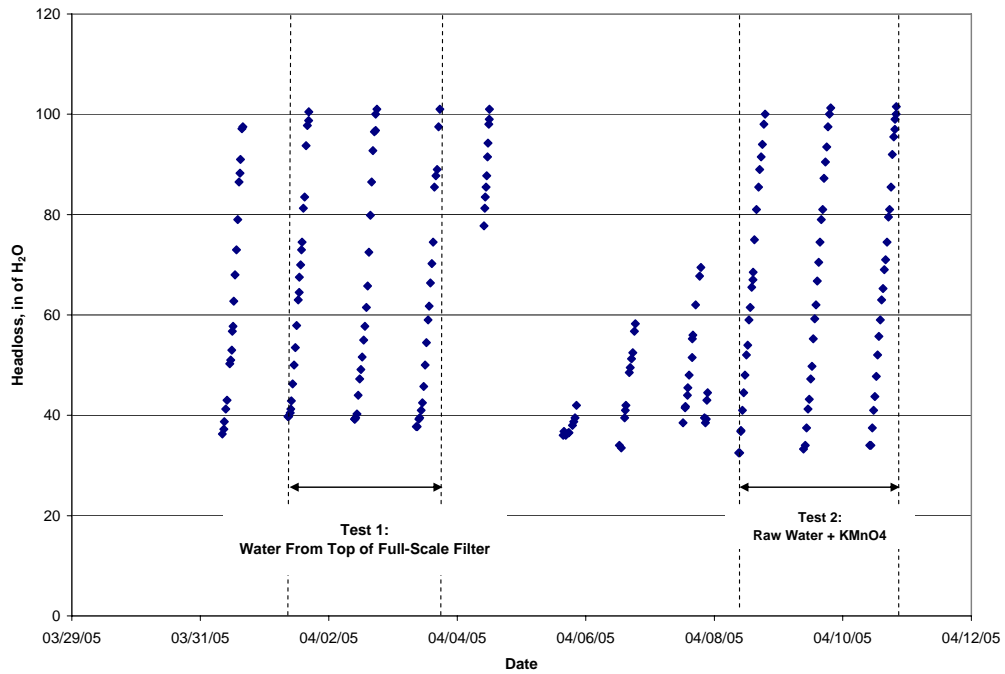
During the first pilot test, influent total arsenic levels averaged 70.7 µg/L and the effluent total arsenic levels averaged 6.6 µg/L. Arsenic in the filter effluent was present almost entirely in the soluble form with an average value of 6.5 µg/L. There were no detections of total iron in the filter effluent. Total manganese averaged 61.2 µg/L in the influent and 41.3 µg/L in the effluent. Manganese was present in both the particulate and soluble form. Soluble manganese levels averaged 38.5 µg/L in the influent and 35 µg/L in the effluent. Only particulate manganese was removed by the Macrolite® filter. These data indicate that the Macrolite® filter media was effective in removing arsenic, iron, and manganese particulates at 91%, 100%, and 33%, respectively. Soluble manganese was not removed across the filter as observed with the MnO<sub>2</sub>-coated anthrasand media.

Figure 4-15 shows the headloss versus time for each of the three runs during the first and second pilot test. During the first pilot test, the Δp readings across a clean filter (right after backwash) ranged from 37.8 to 39.8 in of H<sub>2</sub>O and the Δp readings across a loaded filter just before backwash ranged from 100.5 to 101 in of H<sub>2</sub>O. This represents an average increase of 62 in of H<sub>2</sub>O over the duration of filter runs, which averaged 8.7 hr between consecutive backwash events. Based on the Δp measurements and run length, the average rate of Δp buildup was 7.1 in of H<sub>2</sub>O/hr, which was more than 2.5 times higher than the rate of Δp buildup observed, i.e., 2.7 in of H<sub>2</sub>O/hr, in the full-scale plant (see Section 4.4.1). If the system was retrofit with the use of Macrolite® filter media, this higher rate of Δp buildup would have resulted in the need for more frequent backwashing than already employed at the treatment plant.

During the second pilot test, influent total arsenic levels averaged 106 µg/L (see Table 4-7), which was significantly higher than the influent arsenic level in the first pilot test, due to the particulate arsenic removal that occurred within the baffled detention tank in the full-scale treatment plant (see Figure 4-14). Total arsenic levels in the Macrolite® filter effluent averaged 11.8 µg/L, which was present entirely in the soluble form. Supplemental iron was needed to achieve an arsenic level below 10 µg/L, but was not used during the pilot test due to the vendor's time and equipment constraints. There were no detections of total iron in the filter effluent. Total manganese levels averaged 1,642 µg/L in the influent and 28.2 µg/L in the effluent. The vendor encountered difficulty in controlling the KMnO<sub>4</sub> dosage to the pilot test apparatus and adjustments were made during the pilot test to the KMnO<sub>4</sub> dosages. Soluble manganese levels averaged 50 µg/L in the influent and 26.5 µg/L in the effluent. These data indicated that the Macrolite® filter was effective in retaining arsenic, iron, and manganese particulates. However, supplemental iron addition was required to achieve arsenic levels below 10 µg/L.



**Figure 4-14. Total and Soluble Arsenic Concentrations During Macrolite<sup>®</sup> Pilot Tests**



**Figure 4-15. Headloss Across Macrolite<sup>®</sup> Filter During Pilot Tests**



During the second pilot test, the  $\Delta p$  readings across a clean filter ranged from 32.5 to 34.0 in of H<sub>2</sub>O and across a loaded filter from 100 to 101.5 in of H<sub>2</sub>O. This represents an average increase of 67.7 in of H<sub>2</sub>O over the duration of filter runs, which averaged 10.1 hr between consecutive backwash events. The run length achieved was only 1.4 hr longer in duration than the first pilot test with supplemental additions of both iron and polymer. Based on the  $\Delta p$  measurements and run length, the average rate of  $\Delta p$  buildup was 6.7 in of H<sub>2</sub>O/hr, which was still significantly higher than the rate of  $\Delta p$  buildup observed (i.e., 2.7 in of H<sub>2</sub>O/hr) in the full-scale plant.

Based on the pilot test results, it was determined that a retrofit to the existing gravity filtration plant with the Macrolite<sup>®</sup> media would not benefit the system operations. The rate of  $\Delta p$  buildup from 6.7 to 7.1 in of H<sub>2</sub>O/hr across the Macrolite<sup>®</sup> bed represented a significant increase in headloss, which would require much more frequent backwashing of the filters than already necessitated for the full-scale treatment plant. Further, the initial headloss at 36 in of H<sub>2</sub>O across the clean Macrolite<sup>®</sup> bed was higher than the 10 in of H<sub>2</sub>O initial headloss across the MnO<sub>2</sub>-coated anthrasand bed. The final headloss at 101 in of H<sub>2</sub>O was also higher than observed in the full-scale plant with the final headloss ranging from 29.2 to 91.7 in of H<sub>2</sub>O at the end of the filter run cycles. Therefore, the increased rate and magnitude of headloss buildup would necessitate more frequent backwashing with Macrolite<sup>®</sup> media.

**4.3.5 Summary of Process Modifications.** The initial process modifications included the installation of an iron addition system (including a drum scale to measure FeCl<sub>3</sub> solution consumption), four turbidimeters to monitor the turbidity of the effluent from the four filter cells, and a differential pressure transducer to monitor headloss across Filter Cell No. 4. The engineering package for the initial process modifications, including a process design report, a piping and instrumentation diagram (P&ID), a general arrangement diagram, a turbidity meter interconnect schematic, and an electrical schematic, was submitted to NDDH for review on November 17, 2003. A letter from NDDH providing approval to install the iron addition system was received on December 8, 2003. The primary installation activities included placing the FeCl<sub>3</sub> tank on the drum scale and spill containment deck, mounting the tank mixer and pump to a wall bracket, and connecting the tubing from the chemical metering pump to the injection point at the rapid mix tank. The installation activities also included all electrical connections and calibration of the associated instrumentation including the drum scale, turbidimeters, and differential pressure transducer. The iron addition system installation was completed on January 14, 2004.

After the iron addition process testing and polymer jar tests were completed in August 2004, a second polymer addition system was installed on September 21, 2004, for the Aqua Hawk 127 polymer addition. An existing spare chemical feed pump and tank were used and a new tank mixer was purchased for the second polymer feed system. Additional changes were later made at the treatment plant based on recommendations developed from the demonstration study results. These changes included: 1) installing a larger 1-hp backwash reclaim pump to provide a 40 gpm capacity to facilitate daily backwash events, 2) implementing a more frequent backwash schedule, and 3) reducing the wellhead pump rate to more closely match the design specification for the hydraulic loading rate to the filters. The 40-gpm reclaim pump was installed at the plant on October 18, 2005. The wellhead flowrate was reduced to an average value of 239 gpm, which, after including the 40 gpm reclaim flowrate, would yield a hydraulic loading rate of 2.3 gpm/ft<sup>2</sup>. The operator also implemented backwashing over the weekends in October 2005 with daily backwashing to be used as water demand increased in the spring and summer months.

## 4.4 System Operation

**4.4.1 Operational Parameters.** Table 4-8 summarizes the operational parameters including operational time, throughput, flowrate, and differential pressure readings. Detailed daily operational data are attached as Appendix A. The plant operational data were recorded from January 1, 2005, through July 31, 2005.

**Table 4-8. Summary of System Operation at Lidgerwood, ND**

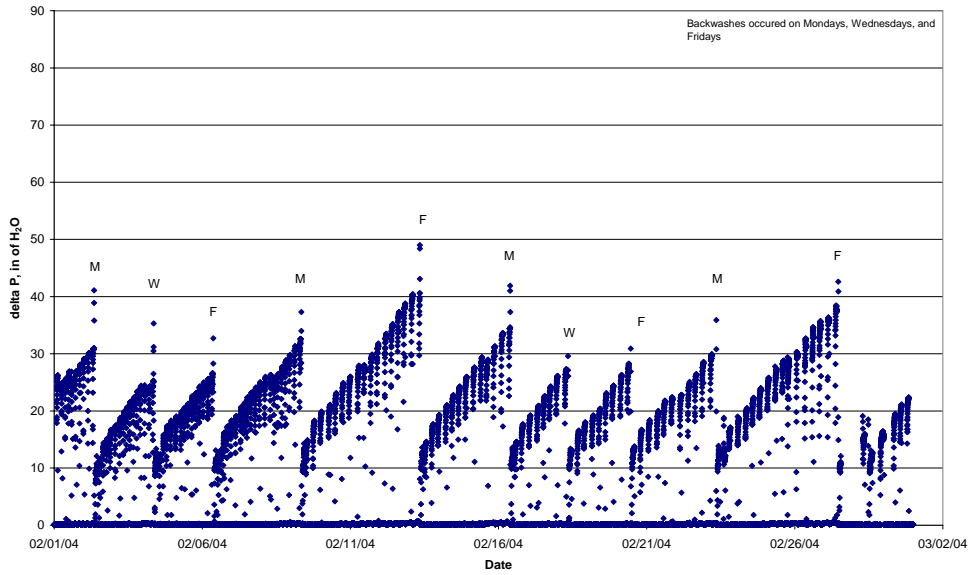
<b>Parameter</b>	<b>Values</b>
Operational Period	01/01/05 – 07/31/05
Total Operating Time (hr)	1,300
Average Daily Operating Time (hr)	6.1
Range of Daily Operating Times (hr)	2.3 – 12.3
Throughput from Wells (gal)	22,102,000
Average Daily Demand to Distribution (gpd)	89,788
Peak Daily Demand to Distribution (gpd)	173,000
Average Well Flowrate (gpm)	283
Range of Well Flowrates (gpm)	217 – 298
Average Reclaim Flowrate (gpm)	26
Range of Contact Times in Detention Tank (min) <sup>(a)</sup>	46 – 62
Range of Hydraulic Loading Rates to Filters (gpm/ft <sup>2</sup> ) <sup>(a)</sup>	2.0 – 2.7
Number of Backwash Events	97
Median Run Time between Backwash Cycles (hr)	13.3
Median Throughput between Backwash Cycles (gal)	225,834
Range of Run Times between Backwash Cycles (hr)	8.7 – 27.2
Range of Throughputs between Backwash Cycles (gal)	147,726 – 461,856
Range of $\Delta p$ Readings at Beginning of Filter Run (in of H <sub>2</sub> O)	6.4 – 13.2
Range of $\Delta p$ Readings at End of Filter Run (in of H <sub>2</sub> O)	29.2 – 91.7

(a) Well flowrate and reclaim flowrate included for calculations.

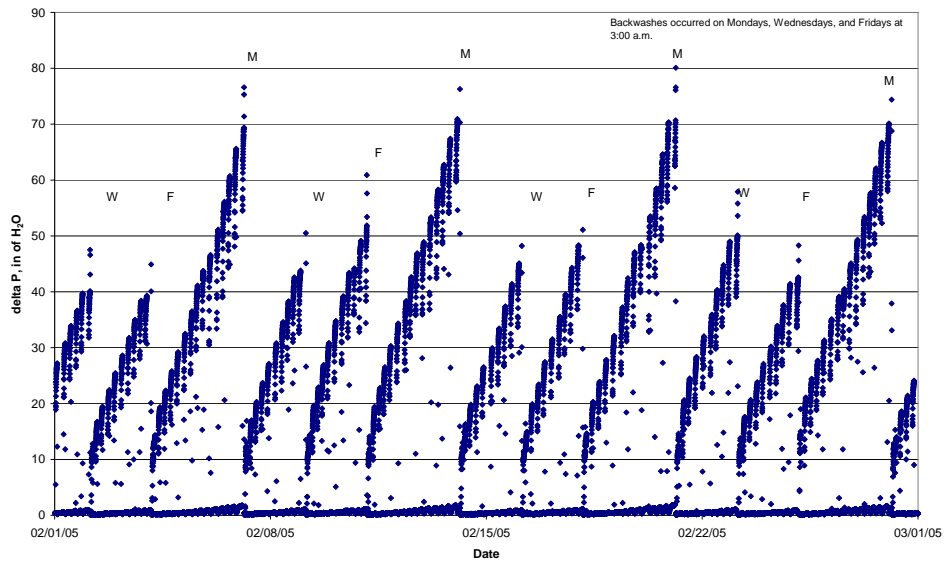
From January 1, 2005, through July 31, 2005, the treatment system operated for approximately 1,300 hr, with an average daily operating time of 6.1 hr/day based on the treatment plant hour meter readings. The total system throughput was approximately 22,102,000 gal based on the flow totalizer readings. The average daily demand was approximately 89,788 gal and the peak daily demand occurred on July 22, 2005, at 173,000 gal, which was very close to the historic peak daily demand of 180,000 gal. The flowrates from the wells ranged from 217 to 298 gpm and averaged 283 gpm based on the plant totalizer and hour meter readings. The average reclaim rate was 26 gpm for the recovery of backwash water. These flowrates corresponded to 46 to 62 min, with an average value of 49 min, of contact time within the baffled detention tank. At these flowrates, the hydraulic loading rates to the filters ranged from 2.0 to 2.7 gpm/ft<sup>2</sup>, compared to the 2.1 gpm/ft<sup>2</sup> design value for the plant. One of the recommendations of the demonstration study was to decrease the flowrate from the wells to provide for a lower hydraulic loading rate to the filters.

During the seven-month demonstration period, a total of 97 backwash events took place. The run times between two consecutive backwash events ranged from 8.7 to 27.2 hr and the corresponding throughputs from 147,726 to 461,856 gal of raw water (e.g. without reclaim). The median run time value was 13.3 hr and the corresponding median value of raw water throughput was 225,834 gal between two consecutive backwash cycles.

**4.4.1.1 Differential Pressure and Filter Run Time.** A differential pressure transducer was used to monitor  $\Delta p$  across Filter Cell No. 4 during the filter service cycles. Typical on-line  $\Delta p$  readings are shown: (1) in Figure 4-16 for baseline conditions before the process modifications in February 2004; and (2) in Figure 4-17 for conditions after the process modifications (i.e., with supplemental iron and polymer additions) in February 2005. The data in Figure 4-16 and Figure 4-17 are summarized in part of Table 4-9.



**Figure 4-16. Typical  $\Delta p$  Readings Across Filter Cell No. 4 Under Baseline Conditions in February 2004**



**Figure 4-17. Typical  $\Delta p$  Readings across Filter Cell No. 4 After Process Modifications in February 2005**

**Table 4-9. Summary of  $\Delta p$  Buildup Across Filter Cell No. 4**

Time	Range of $\Delta p_{\text{initial}}$ (in of H <sub>2</sub> O)	Median $\Delta p_{\text{initial}}$ (in of H <sub>2</sub> O)	Range $\Delta p_{\text{final}}$ (in of H <sub>2</sub> O)	Median $\Delta p_{\text{final}}$ (in of H <sub>2</sub> O)	Median $\Delta p$ Buildup (in of H <sub>2</sub> O)	Range of Filter Run Times (hr)	Median Filter Run Time (hr)	Average Rate of $\Delta p$ Buildup (in of H <sub>2</sub> O/hr)
<i>Under Baseline Conditions in February 2004</i>								
02/04	9.8-10.7	10.3	26.2-41.4	29.7	19.0	11.7-23.9	15.2	1.3
<i>After Process modifications from January to July 2005</i>								
01/05	9.8-12.5	9.9	29.2-66.5	40.4	30.5	11.6-20.0	12.6	2.2
02/05	9.5-12.9	10.0	38.9-71.4	51.4	41.3	12.0-20.3	14.5	2.8
03/05	6.4-12.9	10.0	32.5-60.0	42.3	31.9	11.5-19.6	12.7	2.4
04/05	9.8-13.2	10.2	33.4-89.0	60.8	49.2	10.0-21.0	13.1	3.3
05/05	9.4-12.9 <sup>(a)</sup>	10.1	33.5-55.2	42.3	32.5	8.7-17.2	11.7	2.7
06/05	9.4-28.7 <sup>(a,b)</sup>	9.9	41.2-68.8	49.3	39.0	8.8-16.2	13.6	2.8
07/05	9.3-12.6	10.0	38.3-91.7	55.2	45.3	10.4-27.2	16.8	2.7

(a) Data from May 20 to 30, 2005, June 8 to June 19, 2005, and June 22 to 30, 2005, were not available due to problems with downloading files from datalogger.

(b) Including data from June 20 to 21, 2005, during which filter plugging occurred after a run time of 8.8 hr due to an incomplete filter backwash. These data were not included in the median calculations for the month of June 2005.

These figures show changes in  $\Delta p$  over time with initial  $\Delta p$  readings ( $\Delta p_{\text{initial}}$ ) starting at a low level of approximately 10 in of H<sub>2</sub>O across a clean bed. Subsequently,  $\Delta p$  increased steadily with each filter run (note that low level at the water tower triggered three to four filter runs per day) as particulates were accumulating in the filter bed. The highest  $\Delta p$  readings occurred at the end of the final filter runs just prior to backwash every Monday, Wednesday, and Friday. As expected, the additional filter runs over the weekends (i.e., from Fridays to Mondays) resulted in elevated final  $\Delta p$  readings ( $\Delta p_{\text{final}}$ ), compared to those during the weekdays.

To further dissect the  $\Delta p$  data shown in Figure 4-16 and summarized in Table 4-9, 10 sets of  $\Delta p$  readings representing 10 sets of consecutive filter runs were included under baseline conditions. The  $\Delta p_{\text{initial}}$  readings across the filter ranged from 9.8 to 10.7 in of H<sub>2</sub>O (with a median value of 10.3 in of H<sub>2</sub>O) immediately after backwash and at the start of subsequent filter runs. The  $\Delta p_{\text{final}}$  readings ranged from 26.2 to 41.4 in of H<sub>2</sub>O (with a median value of 29.7 in of H<sub>2</sub>O) at the end of filter runs. Slightly higher  $\Delta p_{\text{final}}$  readings were associated with filter runs over the weekends (between Mondays to Fridays). During February 2004, the filter run times ranged from 11.7 to 23.9 hr. As such, the rate of  $\Delta p$  buildup across the filter was approximately 1.3 in of H<sub>2</sub>O/hr of operation under baseline conditions.

Table 4-9 also summarizes the  $\Delta p$  readings across Filter Cell No. 4 during the demonstration study with supplemental iron and polymer additions from January to July 2005 including the February 2005 data presented in Figure 4-17. The  $\Delta p_{\text{initial}}$  readings ranged from 6.4 to 13.2 in of H<sub>2</sub>O (with a median value of 10.0 in of H<sub>2</sub>O), suggesting that backwash was effective in returning the filter to the initial low headloss conditions. These data also were comparable to those under baseline conditions with a median initial  $\Delta p_{\text{initial}}$  reading of 10.3 in of H<sub>2</sub>O in February 2004. There was one event on June 20, 2005, when the operator reported an incomplete backwash that led to an elevated  $\Delta p_{\text{initial}}$  reading of 28.7 in of H<sub>2</sub>O. After a manual backwash on June 21, 2005, the  $\Delta p_{\text{initial}}$  reading returned to 11.7 in of H<sub>2</sub>O.

The  $\Delta p_{\text{final}}$  readings across the filter cell ranged from 29.2 to 91.7 in of H<sub>2</sub>O. The higher  $\Delta p_{\text{final}}$  values, ranging from 41.5 to 91.7 in of H<sub>2</sub>O, were associated with the additional filter runs and long filter run times over the weekends, ranging from 11.7 to 27.2 hr and averaging 18.1 hr. The median  $\Delta p_{\text{final}}$  readings ranged from 40.4 in of H<sub>2</sub>O in January 2005 to 60.8 in of H<sub>2</sub>O in April 2005. The median value over the entire study period was 47.3 in of H<sub>2</sub>O, compared to a baseline median  $\Delta p_{\text{final}}$  value of 29.7 in of H<sub>2</sub>O in February 2004. During the weekdays, the filter run times ranged from 8.7 to 22.7 hr and averaged 13.0 hr. Using the media  $\Delta p$  buildup and median run time for each month, the average rate of  $\Delta p$  buildup was calculated to be 2.7 in of H<sub>2</sub>O/hr, which was two times higher than that under the baseline conditions in February 2004. The higher rate of  $\Delta p$  buildup suggests that the filter bed may need to be backwashed more often in order to meet the 10  $\mu\text{g/L}$  MCL.

One recommendation was to limit the  $\Delta p_{\text{final}}$  to no higher than 50 in of H<sub>2</sub>O and the filter run time to no longer than 15 hr. The 15-hr maximum filter run time was derived by dividing 40 in of H<sub>2</sub>O (i.e., assuming  $\Delta p_{\text{initial}}$  at 10 in of H<sub>2</sub>O) by 2.7 in of H<sub>2</sub>O/hr (i.e., the average rate of  $\Delta p$  buildup with supplemental iron and polymer additions and at the well and reclaim flowrates of 283 and 26 gpm, respectively). This is equivalent to a raw water throughput from the wellhead of 254,700 gal. The filter run time could be extended to 20.2 hr if the wellhead flowrate was reduced to 210 gpm (with a reclaim flowrate at 40 gpm) to reach the design value of 250 gpm. The shorter filter run times would require an increase in backwash frequency, which would result in better plant performance especially in the spring and summer months as the water demand increases. In order to allow for more frequent (such as daily) backwash, further modifications to the treatment plant were required as discussed in Section 4.3.5.

**4.4.1.2 Filter Backwash.** During the demonstration study, the gravity filters were backwashed at least three times per week using a clock-based timer triggered for Mondays, Wednesdays, and Fridays at 3 AM. The operator could perform a manual backwash, if needed. Backwash samples were collected during manual backwash events performed on March 23, April 18, May 25, June 21, and July 25, 2005. The plant also was manually backwashed on June 23, July 5, July 12, July 19, July 24, and July 30, 2005. The operational parameters associated with the backwash events are summarized in Table 4-10.

From January 1, 2005, to July 31, 2005, 1,206,650 gal of backwash water was generated for reclaim to the head of the treatment train. This represents a backwash water generation rate of approximately 5.5% given the total volume of water pumped from the wells during this time period. Based on the backwash pump hours, the average backwash flowrate was 272 gpm (or 9 gpm/ft<sup>2</sup>), which was higher than the design value of 240 gpm (or 8 gpm/ft<sup>2</sup>). The average duration of each backwash event was 11 min for each cell or 44 min for all four cells, which generated 2,989 gal from each cell or 11,957 gal from all four cells. The backwash water was stored in the 18,000-gal backwash reclaim basin to settle for 6 hr before the supernatant was reclaimed at 26 gpm to the rapid mix tank. At this flowrate, the plant needed over 7.5 hr of filter run time to recycle the approximately 12,000 gal backwash water produced from each backwash cycle. Recall that the average daily run time of the system was only 6.1 hr, along with the 6-hr settling time required; this essentially eliminated the possibility of having daily backwash as the plant. The ½-hp reclaim pump was replaced on October 18, 2005, with a 1-hp, 40 gpm-rated pump. The increased flowrate would complete the recycling in 5 hr, thus giving the plant needed flexibility for more frequent backwash (such as daily) during higher demand times. The 40 gpm reclaim flowrate increased the reclaim ratio from 9.2% to 16.7%, which was approved by the NDDH on October 5, 2005.

**4.4.2 Residual Management.** Residuals produced by the operation of the coagulation/gravity filtration plant included backwash water and sludge. The backwash water was discharged to the reclaim tank and then reclaimed to the treatment system. As discussed in Section 4.4.1.2, the size of the reclaim basin at 18,000 gal and the capacity of the reclaim pump at 26 gpm limited the treatment system to backwashing every other day. The reclaim pump was later replaced with a 40-gpm pump in October 2005. The sludge from the reclaim tank was accumulated in a sludge holding tank and then collected for

**Table 4-10. Summary of Backwash Parameters**

<b>Backwash Parameters</b>	<b>Value</b>
Number of Backwash Events	97
Backwash Water Generated for Reclaim (gal)	1,206,650
Backwash Water Generation Rate ( % )	5.5
Backwash Pump Operation (hr)	73.9
Average Backwash Flowrate (gpm)	272
Average Backwash Duration Per Cell (min)	11
Average Backwash Water Quantity Generated Per Cell (gal)	3,110
Average Backwash Water Quantity Per Cycle (gal)	12,440
Average Backwash Reclaim Pump Flowrate (gpm)	26

landfill disposal once every other year. In addition, due to significant settling of solids prior to the filters, it was necessary to clean the 15,000-gal baffled detention tank on an annual basis. The frequency of sludge removal from the sludge holding tank also was increased from annually to biannually after the process modifications had been implemented.

**4.4.3 System/Operation Reliability and Simplicity.** The major operational issue encountered was related to the need to increase the backwash frequency to maintain filter performance as described in Section 4.4.1. Neither scheduled nor unscheduled downtime had been required since the start of system operations on January 1, 2005. The required system operation and operator skills are discussed according to pre- and post-treatment requirements, chemical/media handling and inventory, levels of system automation, operator skill requirements, and preventive maintenance activities.

**4.4.3.1 Pre- and Post-Treatment Requirements and Chemical Handling/Inventory Requirements.** Pre-treatment requirements included prechlorination, aeration, and  $\text{KMnO}_4$  addition for oxidation of As(III) and Fe(II), supplemental iron addition to enhance arsenic removal from raw water, and polymer coagulant addition to enhance filterability of the flocs formed. Post-treatment requirements at the site included post-chlorination and fluoridation. Two additional chemicals, i.e.,  $\text{FeCl}_3$  and Aqua Hawk 127, were required as part of the process modifications. The operator checked the usage of the  $\text{FeCl}_3$  chemical consumption with a digital scale each day as part of the routine operational data collection. The use of the Aqua Hawk 127 was checked daily through monitoring the tank level with a yard stick. The  $\text{FeCl}_3$  and second polymer tanks were replenished approximately once per week. Similar to most coagulation/filtration plants, the existing treatment plant had a high level of pre- and post-treatment requirements.

**4.4.3.2 System Automation.** All major functions of the treatment system were automated and would require only minimal operator oversight and intervention if all functions operated as intended. Automated processes included system startup in the forward feed mode when the well energized, backwash cycling based on a calendar frequency, system shutdown when the well pump shut down, and backwash water reclaim. The automated backwash control clock was replaced prior to the demonstration study on November 12, 2004 since the original component was no longer functional at the start of the project. One observation was that the calendar-based backwash clock (e.g. backwash every Monday, Wednesday, and Friday) did contribute to operational issues by limiting the flexibility associated with increasing the backwash frequency. A treatment plant automated with backwash events based on throughput, filter run time, or differential pressure would have been easier to control. The design of the pre-existing treatment plant and controls limited the frequency of the automatic filter backwash events to every Monday, Wednesday, and Friday, which impacted filter performance over the longer weekend filter runs.

**4.4.3.3 Operator Skill Requirements.** The skill set required to operate the gravity filtration system was high and included observation of the process equipment integrity and operating parameters such as headloss, flow, and system alarms. The O&M of the system required a significant level of mechanical and electrical skills to ensure proper operation of pumps, controls, and other system components. The operator needed a strong working understanding of chemical feed system O&M. The plant operator was well versed in the operation of chemical addition systems for prechlorination,  $\text{KMnO}_4$  addition, and polymer addition. These tasks included pump setup, maintenance to ensure the pump kept its prime, and weekly chemical feed solution preparation. These tasks required a solid foundation in water chemistry and calculations related to drinking water processes. However, the process modifications to add two additional chemical feed systems did not significantly increase the daily demand on the operator in plant O&M activities. The additional labor required included replenishing the ferric chloride solution tank and the second polymer solution tank once per week. Other skills needed included performing O&M activities such as cleaning and calibrating the filter cell turbidimeters and downloading files from the Telog data logging system.

**4.4.3.4 Preventive Maintenance Activities.** Preventive maintenance tasks included daily to monthly visual inspection of the piping, valves, filter cells, totalizers, and other system components. No significant repairs were required during the study period. The backwash control clock was replaced prior to the demonstration study on November 12, 2004, since the original component was no longer functional at the start of the project. The hour meter for the reclaim pump was replaced on April 27, 2005.

## **4.5 System Performance after Process Modifications**

The performance of the process modifications was evaluated based on analyses of water samples collected from the treatment plant, backwash lines, and distribution system.

**4.5.1 Treatment Plant Sampling.** After the target process conditions were established, the demonstration study began on January 1, 2005, and ended on July 31, 2005. The treatment plant water was sampled on 31 occasions, including one duplicate sampling event. Field speciation also was performed for seven of the 31 occasions. Table 4-11 summarizes the arsenic, iron, and manganese analytical results. Table 4-12 summarizes the results of the other water quality parameters. Appendix B contains a complete set of analytical results for the seven month duration of system operations. The results of the water samples collected throughout the treatment plant are discussed below.

**4.5.1.1 Arsenic Removal.** Figure 4-18 shows the total arsenic levels across the treatment train over the duration of the study period. Total arsenic levels in raw water ranged from 113 to 158  $\mu\text{g/L}$  and averaged 129  $\mu\text{g/L}$ . As(III) was the predominating species with concentrations ranging from 116 to 130  $\mu\text{g/L}$  and averaged 125  $\mu\text{g/L}$  (see bar charts in Figure 4-19 for speciation results). After the detention tank and prior to the filters, As(III) concentrations ranged from <0.1 to 3.5  $\mu\text{g/L}$  and averaged 1.8  $\mu\text{g/L}$ , suggesting effective oxidation of As(III) to As(V) with chlorine and potassium permanganate. After detention and prior to the filters, total arsenic levels ranged from 59.2 to 105  $\mu\text{g/L}$  and averaged 79.5  $\mu\text{g/L}$ , indicating arsenic removal of 38% through settling within the baffled detention tank. The remaining arsenic after the detention tank was present primarily in the particulate form with levels ranging from 52.7 to 98.0  $\mu\text{g/L}$  and averaged 72.8  $\mu\text{g/L}$ . The As(V) concentrations after the detention tank averaged 4.1  $\mu\text{g/L}$ , which indicated sufficient supplemental iron addition. After Filter Cell No. 4, total arsenic levels were reduced to 6.3 to 14.3  $\mu\text{g/L}$  and averaged 8.5  $\mu\text{g/L}$  in the treated water, which was present primarily in the soluble As(V) form with an average value of 5.7  $\mu\text{g/L}$ . Particulate arsenic levels in the treated water ranged from <0.1 to 4.9  $\mu\text{g/L}$ , indicating some penetration of particulates through the filter bed.

**Table 4-11. Summary of Arsenic, Iron, and Manganese Analytical Results**

Parameter	Sampling Location	Sample Count	Concentration (µg/L)			Standard Deviation
			Minimum	Maximum	Average	
As (total)	IN	31	113	158	129	10.0
	BF	31	59.2	105	79.5	12.8
	AF	31	6.3	14.3	8.5	1.8
	PC	31	6.0	14.0	8.4	1.9
As (soluble)	IN	7	117	146	132	9.3
	BF	7	4.3	7.4	5.9	1.1
	AF	7	3.7	9.0	7.4	1.8
	PC	7	7.5	9.8	8.4	0.9
As (particulate)	IN	7	<0.1	9.3	4.3	4.2
	BF	7	52.7	98.0	72.8	16.6
	AF	7	<0.1	4.9	1.1	1.8
	PC	7	<0.1	0.5	0.1	0.1
As(III)	IN	7	116	130	125	5.1
	BF	7	<0.1	3.5	1.8	1.2
	AF	7	<0.1	3.1	1.7	1.1
As(V)	IN	7	<0.1	15.7	7.0	7.0
	BF	7	2.9	5.6	4.1	1.1
	AF	7	3.6	6.8	5.7	1.1
Fe (total)	IN	31	737	2,606	1,344	331
	BF	31	801	2,389	1,575	284
	AF	31	<25	64.0	<25	11.0
	PC	31	<25	194	<25	44.5
Fe (soluble)	IN	7	532	1,524	1,172	338
	BF	7	<25	<25	<25	0.0
	AF	7	<25	105	25.8	35.1
	PC	6	<25	<25	<25	0.0
Mn (total)	IN	31	567	1,067	694	103
	BF	31	452	1,031	669	144
	AF	31	1.1	146	15.2	30.2
	PC	31	0.9	162	17.9	35.5
Mn (soluble)	IN	7	598	868	707	105
	BF	7	5.8	31.1	17.2	9.8
	AF	7	1.1	52.1	10.5	18.6
	PC	6	1.2	146	28.6	57.8

One-half of the detection limit used for non-detect samples for calculations.

Duplicate samples included in calculations

IN = at wellhead; BF = before filter; AF = after filter; PC = post-chlorination from clear well

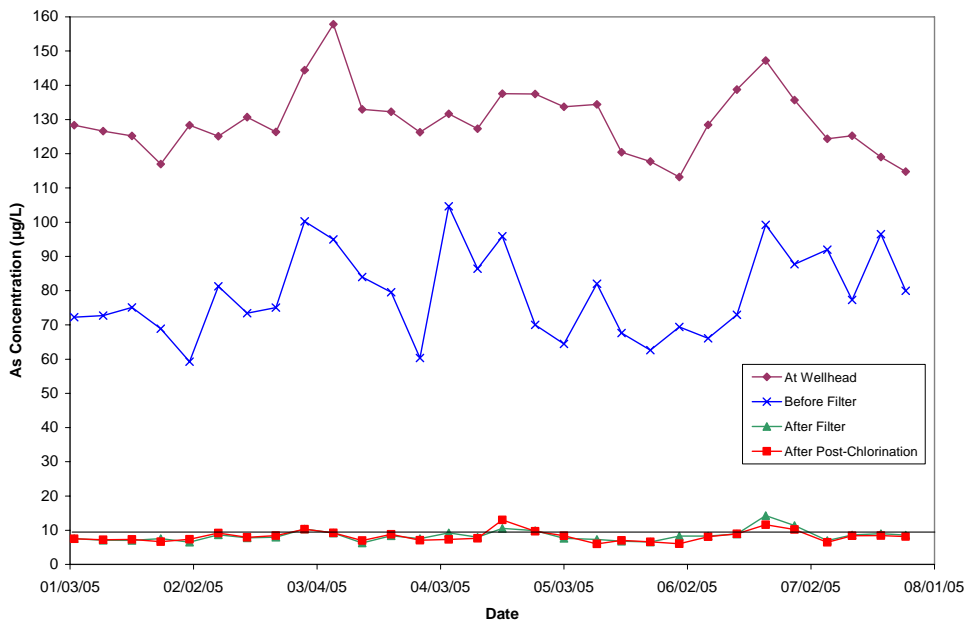
Figure 4-20 shows a close up plot of the treated water results from samples taken after the filter (AF) and after post-chlorination point from the clearwell (PC). The AF samples represent the filter effluent at the time the sample was taken, while the PC samples represent the composite of the filter effluent in the clearwell. Total arsenic levels in the treated water ranged from 6.3 to 14.3 µg/L and averaged 8.5 µg/L after the filter. Total arsenic levels after post-chlorination ranged from 6.0 to 14.0 µg/L and averaged 8.4 µg/L. There were four exceedances of arsenic above the 10 µg/L MCL during the study period, which occurred on March 1, April 18, June 21, and June 28, 2005 (Table 4-13). Two of the four samples were taken when Δp across Filter Cell No. 4 was elevated at 68.3 to 68.8 in of H<sub>2</sub>O. The data suggested that a more frequent backwash schedule would be required in order to maintain the filter performance for



**Table 4-12. Summary of Other Water Quality Parameter Analytical Results**

Parameter	Sampling Location	Unit	Sample Count	Minimum	Maximum	Average	Standard Deviation
Alkalinity (as CaCO <sub>3</sub> )	IN	mg/L	31	352	714	402	63
	BF	mg/L	31	334	682	390	59
	AF	mg/L	31	339	691	388	61
	PC	mg/L	24	348	413	379	19
Fluoride	IN	mg/L	7	<0.1	0.2	0.2	0.1
	BF	mg/L	7	0.2	0.6	0.3	0.1
	AF	mg/L	7	0.2	0.4	0.3	0.1
Sulfate	IN	mg/L	7	323	385	353	22
	BF	mg/L	7	309	352	336	16
	AF	mg/L	7	309	367	338	23
Orthophosphate (as PO <sub>4</sub> )	IN	mg/L	29	<0.05	<0.06	<0.05	0.0
	BF	mg/L	29	<0.05	<0.06	<0.05	0.0
	AF	mg/L	29	<0.05	<0.06	<0.05	0.0
	PC	mg/L	25	<0.05	<0.06	<0.05	0.0
Silica (as SiO <sub>2</sub> )	IN	mg/L	31	29.0	34.2	31.2	1.0
	BF	mg/L	31	24.9	33.3	30.5	1.8
	AF	mg/L	31	28.8	33.2	30.5	0.9
	PC	mg/L	24	28.6	33.1	31.1	0.9
Nitrate (as N)	IN	mg/L	7	<0.04	<0.05	<0.05	0.00
	BF	mg/L	7	<0.04	0.06	<0.05	0.02
	AF	mg/L	7	<0.04	0.15	<0.05	0.05
Turbidity	IN	NTU	31	3.5	23.0	15.7	3.8
	BF	NTU	31	3.1	14.0	5.2	1.9
	AF	NTU	31	<0.1	7.1	0.6	1.3
	PC	NTU	24	<0.1	16.0	1.6	3.9
pH	IN	S.U.	29	7.2	7.6	7.3	0.1
	BF	S.U.	29	7.2	7.5	7.4	0.1
	AF	S.U.	29	6.4	7.5	7.4	0.2
	PC	S.U.	29	7.4	7.9	7.5	0.1
Temperature	IN	°C	29	9.3	11.2	10.0	0.4
	BF	°C	29	9.9	12.1	10.7	0.4
	AF	°C	29	10.6	12.2	11.1	0.4
	PC	°C	29	10.5	12.3	11.5	0.4
Dissolved Oxygen	IN	mg/L	21	1.3	4.1	2.6	0.8
	BF	mg/L	21	4.3	6.4	5.4	0.7
	AF	mg/L	21	4.3	6.4	5.4	0.7
ORP	IN	mV	28	-37	-11	-28	6.3
	BF	mV	28	189	463	334	75
	AF	mV	28	163	393	259	64
Free Chlorine (as Cl <sub>2</sub> )	PC	mg/L	28	0.0	0.6	0.1	0.1
Total Chlorine (as Cl <sub>2</sub> )	PC	mg/L	28	0.3	8.0	3.4	1.4
Total Hardness (as CaCO <sub>3</sub> )	IN	mg/L	7	451	552	499	39.9
	BF	mg/L	7	416	585	498	67.8
	AF	mg/L	7	403	567	489	62.3
	PC	mg/L	6	404	591	497	71.6
Ca Hardness (as CaCO <sub>3</sub> )	IN	mg/L	7	321	392	356	27.8
	BF	mg/L	7	290	414	354	48.7
	AF	mg/L	7	273	401	345	48.2
	PC	mg/L	6	274	418	352	52.8
Mg Hardness (as CaCO <sub>3</sub> )	IN	mg/L	7	118	159	144	14.4
	BF	mg/L	7	113	171	144	20.5
	AF	mg/L	7	124	165	144	15.1
	PC	mg/L	6	125	173	145	20.8

One-half of the detection limit used for non-detect samples for calculations. Duplicate samples included in calculations. Detections of orthophosphate removed due to detections in laboratory blank.

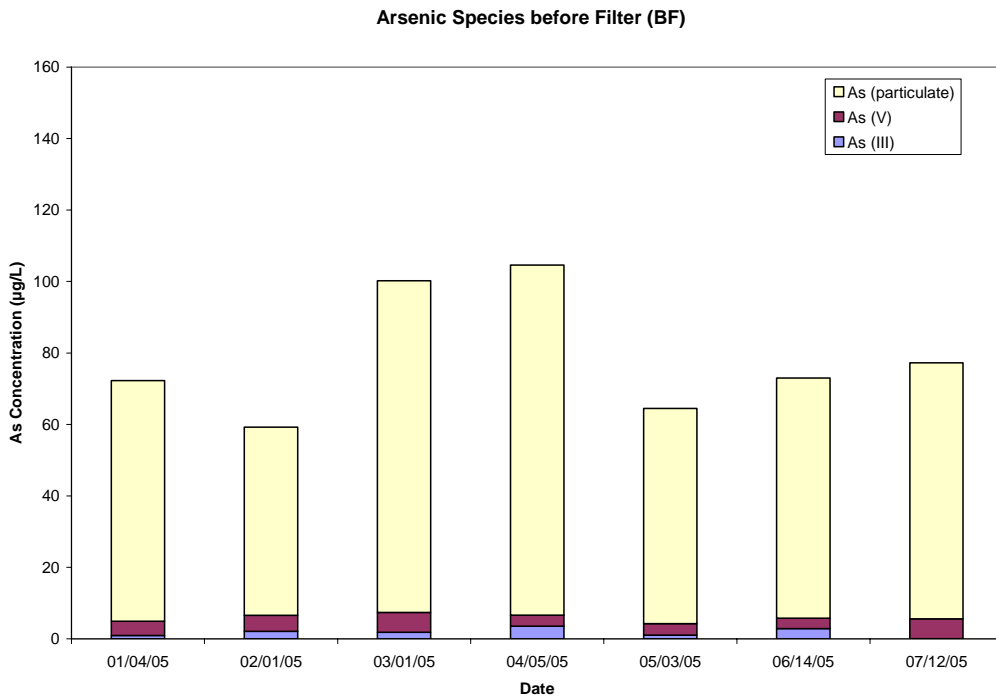
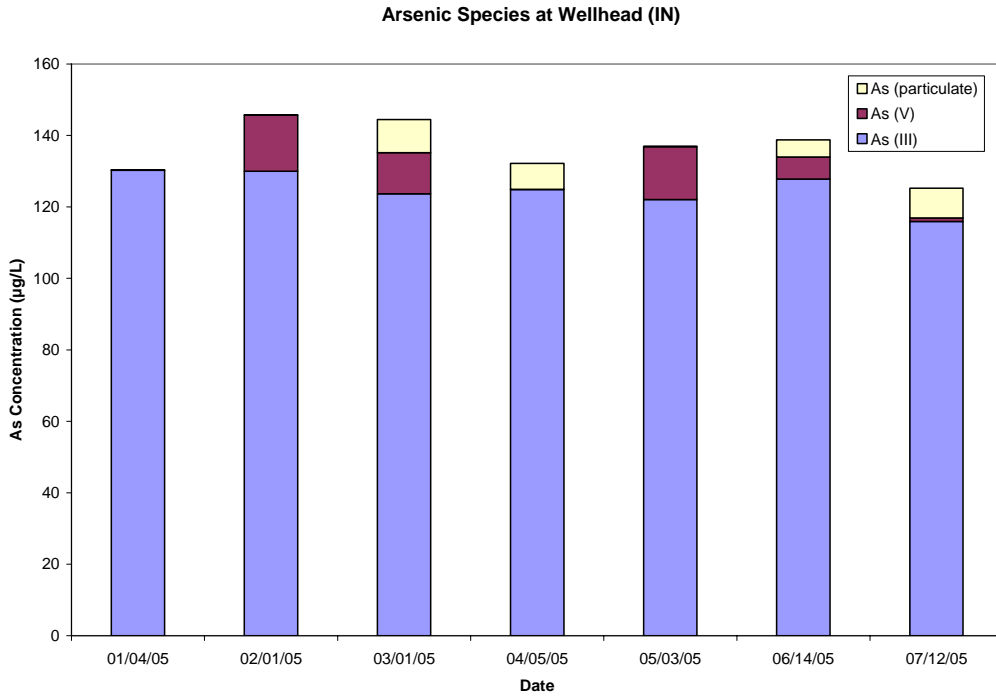


**Figure 4-18. Total Arsenic Concentrations Across Treatment Train**

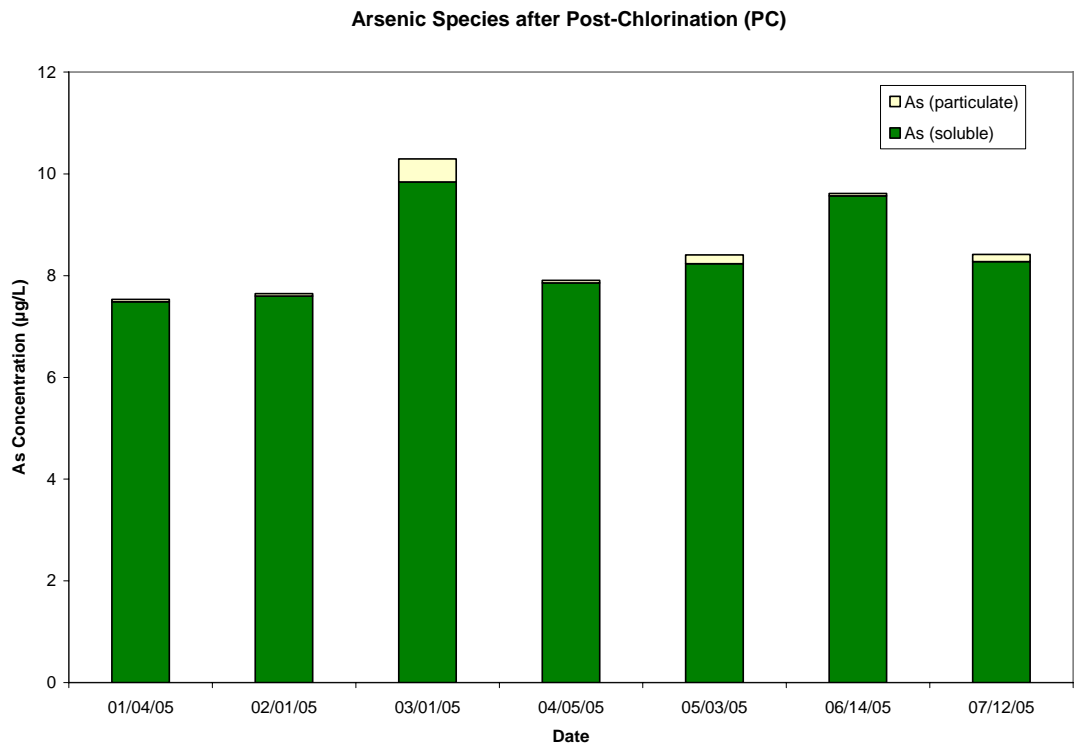
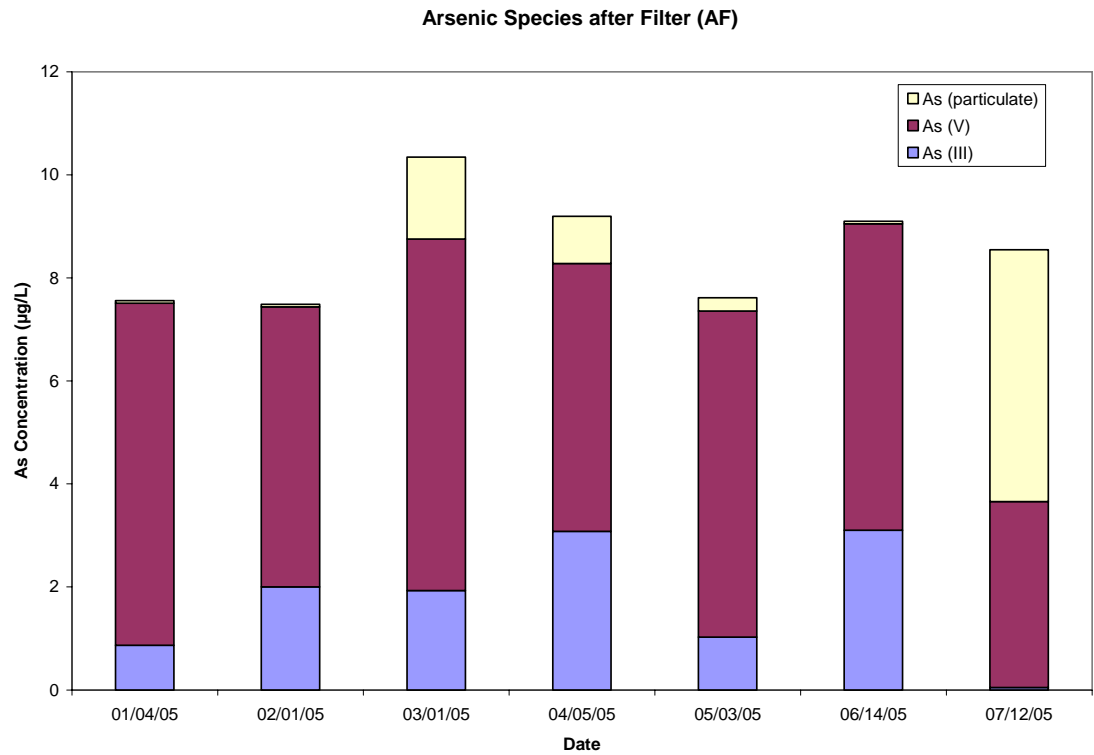
arsenic removal. Further process modifications were required to allow for more frequent backwash at the treatment plant as discussed in Section 4.3.5.

**4.5.1.2 Iron Removal.** Figure 4-21 shows the total iron levels across the treatment train over the duration of the study period. Total iron levels in raw water ranged from 737 to 2,606 µg/L and averaged 1,344 µg/L. As shown in Table 4-11, iron in raw water existed primarily in the soluble form with an average value of 1,172 µg/L. Given the average soluble iron and soluble arsenic levels in the source water, this corresponded to an Fe:As ratio of 9:1, which was below the target ratio for effective arsenic removal of 20:1. Supplemental iron addition was implemented at an average dose of 1.2 mg/L (as Fe) using a FeCl<sub>3</sub> solution. Including the 1.2 mg/L of iron added to raw water, the average iron concentration of 1,575 µg/L after the detention tank would represent about 38% of iron removed in the baffled detention tank. This removal percentage was about two times higher than the 16.7 to 19.47% removal observed under the baseline conditions on January 14, 2004. The use of dual polymers might have formed more settleable and filterable particles during treatment. Total iron levels after the filters and after the post-chlorination point ranged from <25 to 64 µg/L and <25 to 194 µg/L, respectively, suggesting leakage of some iron particles through the filters. However, these iron levels were below the secondary MCL of 300 µg/L.

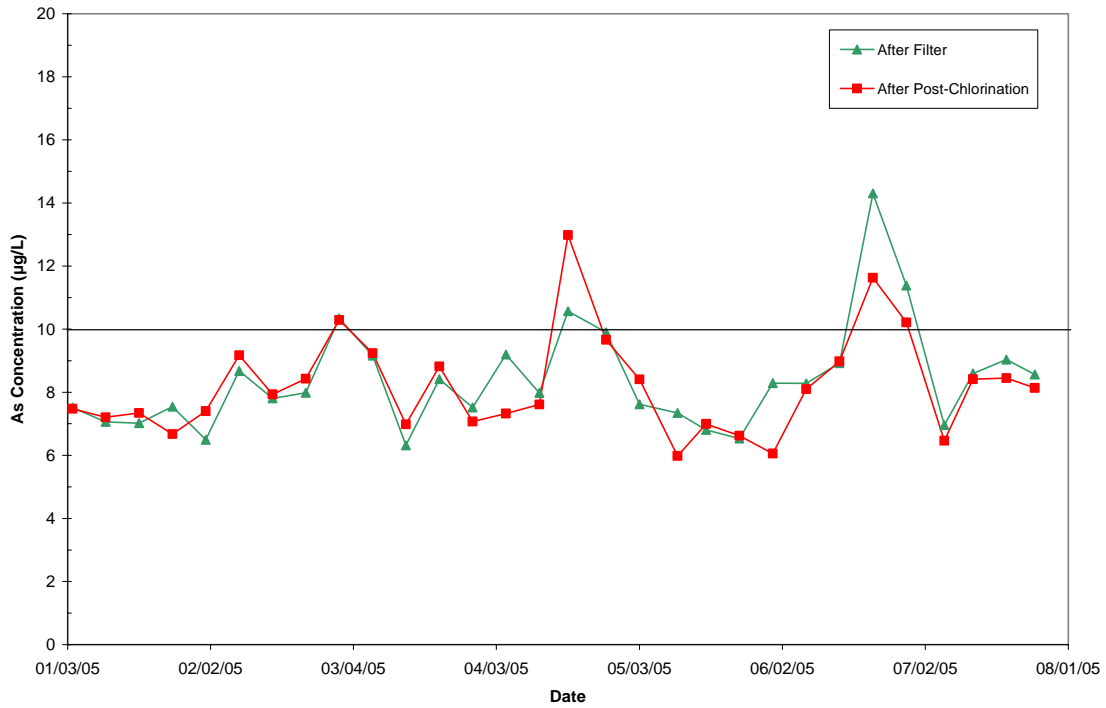
**4.5.1.3 Manganese Removal.** Total manganese levels in raw water ranged from 567 to 1,067 µg/L with an average value of 694 µg/L (see Table 4-11 and Figure 4-22). Manganese in raw water existed primarily in the soluble form at levels ranging from 598 to 868 µg/L and averaging 707 µg/L. After prechlorination, KMnO<sub>4</sub> addition, and the detention tank, soluble manganese concentrations decreased to 5.8 to 31.1 µg/L with an average value of 17.2 µg/L. An average of 98% of the soluble manganese in raw water was converted to particulate manganese after the detention tank and before the filters. Total manganese concentrations before the filter ranged from 452 to 1,031 µg/L, which was present primarily as particulate manganese. Total and particulate manganese was effectively removed by the filters with its concentration reduced to an average of 15.2 µg/L (with 10.5 µg/L as soluble manganese).



**Figure 4-19. Concentrations of Arsenic Species Across Treatment Train**



**Figure 4-19. Concentrations of Arsenic Species across Treatment Train (Continued)**



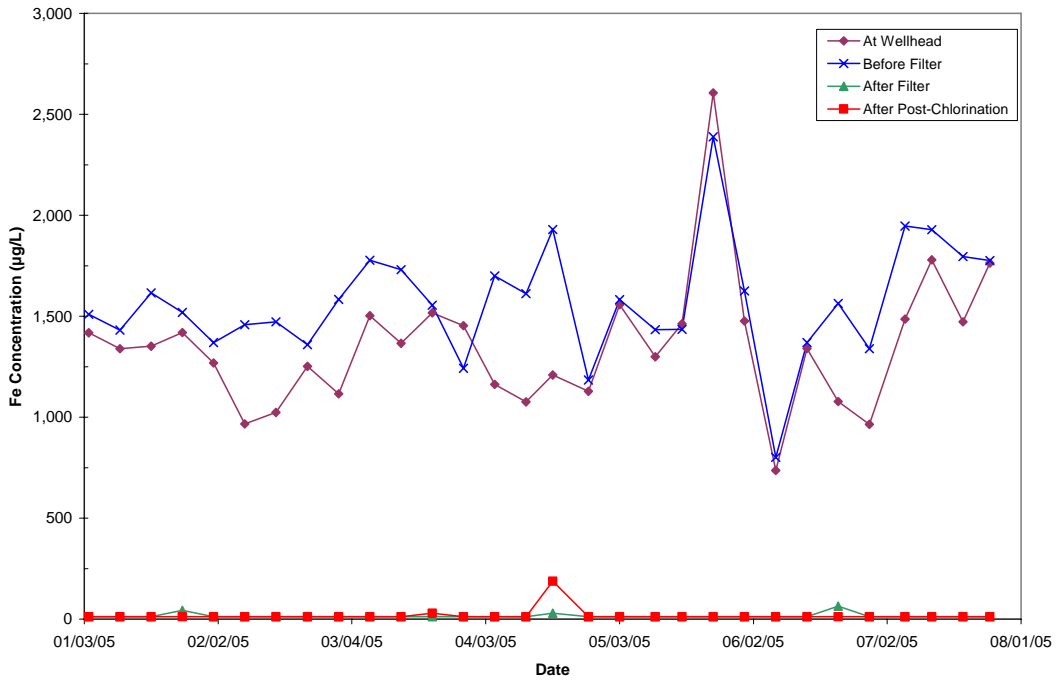
**Figure 4-20. Total Arsenic Concentrations in Treated Water**

**Table 4-13. Summary of Exceedances of 10 µg/L during Performance Evaluation Study**

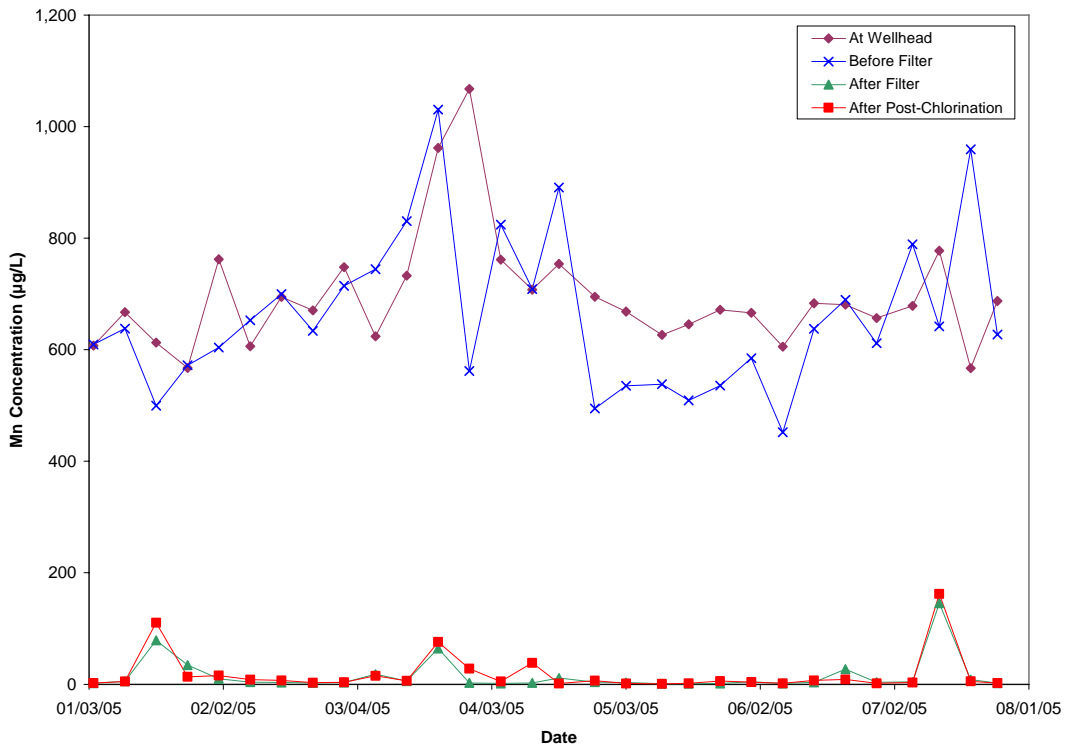
Date	Total Arsenic Concentration (µg/L)	Δp at Sampling Event (in of H <sub>2</sub> O)	Filter Run Time at Sampling Event (hr)	Throughput at Sampling Event (gal)	Total Filter Run Time (hr)
03/01/05	10.3	20.6	7.3	123,954	12.0
04/18/05 <sup>(a)</sup>	10.6 [12.5]	68.3	20.4	346,392	21.0
06/21/05 <sup>(b)</sup>	14.3	68.8	7.8	132,444	8.8
06/28/05	11.4	45.1	10.4	176,592	14.1

(a) Duplicate sample result in parentheses.

(b) On June 20, 2005, an incomplete backwash led to filter plugging after a run time of 8.8 hr. The June 21, 2005, sample was taken prior to manual backwash of filters on June 21, 2005.



**Figure 4-21. Total Iron Concentrations Across Treatment Train**



**Figure 4-22. Total Manganese Concentrations Across Treatment Train**

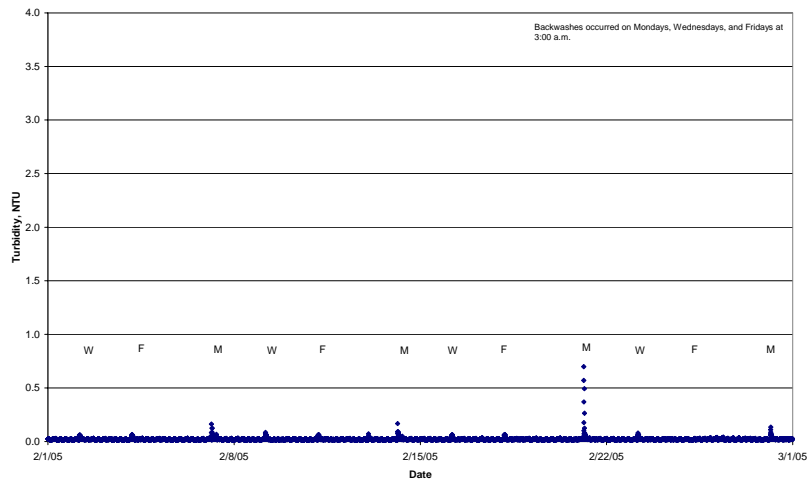
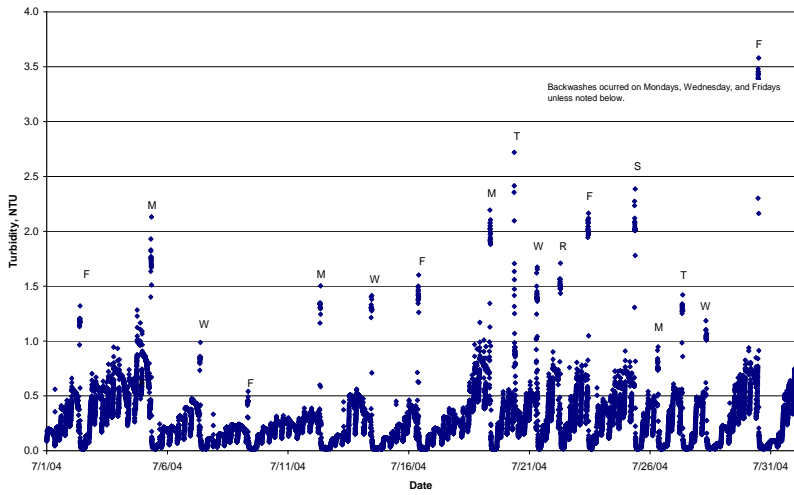
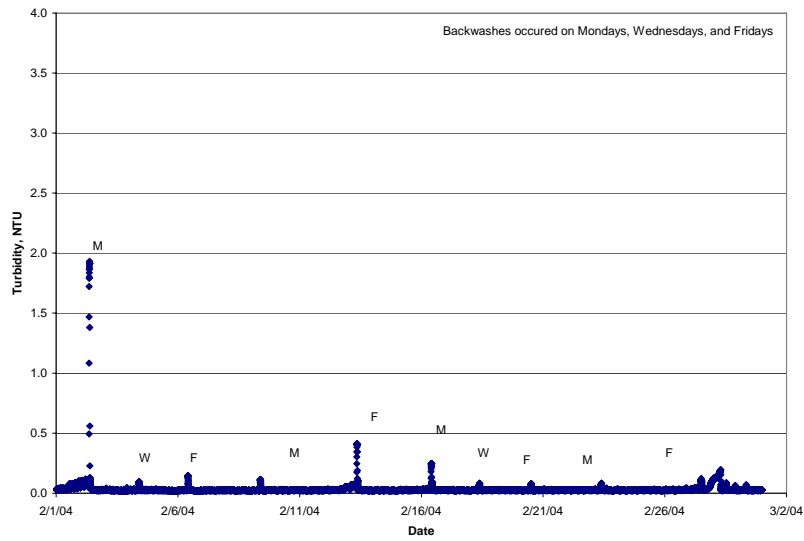
Approximately 77% to 100% of the total manganese was removed across the treatment train with an average 98% removal rate. Among the 30 sampling events, three had total manganese levels above 50 µg/L in filter effluent including January 18, 2005, at 79.1 µg/L, March 22, 2005, at 64.2 µg/L, and July 12, 2005, at 146 µg/L. On July 12, 2005, the sample was speciated: out of 146 µg/L total manganese, 64% or 93.9 µg/L was present as particulate manganese. Soluble manganese after the filter ranged from 1.1 to 10.7 µg/L with one outlier at 52.1 µg/L on July 12, 2005. Removal of soluble manganese was observed across the MnO<sub>2</sub>-coated anthrasand filter ranging from 52% to 96% based on the speciation results.

**4.5.1.4 Other Water Quality Parameters.** As shown in Table 4-12, DO levels were low in raw water with an average value of 2.6 mg/L. As expected, DO levels increased significantly to an average value of 5.4 mg/L after aeration, rapid mixing, and detention. ORP values also increased significantly after chlorine addition, aeration, and potassium permanganate addition. The ORP values averaged -28 mV in raw water, 334 mV after chemical addition and detention, and 259 mV after filtration. The post-chlorination free chlorine levels averaged 0.1 mg/L (as Cl<sub>2</sub>) and the total chlorine levels averaged 3.4 mg/L (as Cl<sub>2</sub>). The average pH value of raw water was 7.3 and the average pH value of the treated water was 7.4, so no significant change in pH occurred across the treatment train. Average alkalinity values ranged from 379 to 402 mg/L (as CaCO<sub>3</sub>) across the treatment train. Average total hardness values ranged from 489 to 499 mg/L (as CaCO<sub>3</sub>) across the treatment train (the total hardness is the sum of calcium hardness and magnesium hardness). The water had predominantly calcium hardness. Fluoride concentrations averaged 0.2 mg/L in raw water and were not affected by the MnO<sub>2</sub>-coated anthrasand filtration. No significant levels of nitrate or orthophosphate were detected in raw water. Average sulfate concentrations ranged from 336 to 353 mg/L across the treatment train. The silica (as SiO<sub>2</sub>) concentration remained at approximately 30.5 to 31.2 mg/L across the treatment train.

Figure 4-23 shows the results of turbidity measurements of Filter Cell No. 4 effluent under three sets of process conditions: 1) baseline conditions before process modifications in February 2004; 2) iron addition (along with 0.12 mg/L of Aqua Hawk 9207 PWG addition that had been practiced at the plant as part of the baseline conditions) in July 2004; and 3) supplemental iron (at 1.2 mg/L) and polymer (at 0.3 mg/L of Aqua Hawk 9207 PWG and 0.5 mg/L of Aqua Hawk 127) additions in February 2005. The average effluent turbidity was 0.032 NTU under the baseline conditions in February 2004 with little to no particulate breakthrough from the filter. With the addition of about 1.1 mg/L (as Fe) in July 2004, effluent turbidity readings increased significantly to 0.015 to 3.58 NTU (averaged 0.31 NTU), which represented one to two orders of magnitude increase over the baseline readings. The data confirmed incomplete filtration of particles and, along with the analytical results, further supported the need for supplemental polymer addition to improve particle filterability by the filter. After second polymer addition, the removal of particles improved significantly with an average effluent turbidity reading of 0.021 NTU in February 2005, comparable to the baseline value of 0.032 NTU in February 2004.

The effluent turbidity readings averaged 0.030 NTU over the entire study period from January 2005 to July 2005, suggesting effective particulate removal throughout the duration of all filter runs. However, the use of the supplemental polymer did result in an increased rate of Δp buildup and filter backwash as discussed in Section 4.4.1.1.

**4.5.2 Backwash Water Sampling.** Table 4-14 summarizes the analytical results from five backwash water sampling events, which took place prior to the October 21, 2005, modification of the backwash water sampling procedure for inclusion of total suspended solids (TSS) and total metals. The backwash water samples were analyzed for pH, turbidity, TDS, and soluble As, Fe, and Mn from grab samples taken during the backwash of two out of the four filter cells. Soluble arsenic concentrations in the backwash water ranged from 7.5 to 11.9 µg/L and averaged 9.8 µg/L.



**Figure 4-23. Turbidity Readings from Filter Cell No. 4 Effluent in February 2004 (Baseline), July 2004 (Iron Addition), and February 2005 (Supplemental Iron and Polymer Additions)**



Table 4-15 presents the results of total metals analysis for two backwash water solid samples (with three replicates for each sample) collected on October 6, 2005. The iron levels in the solids ranged from  $1.99\text{E}+05$  to  $3.07\text{E}+05$   $\mu\text{g/g}$  and the arsenic levels from  $7.63\text{E}+03$  to  $1.15\text{E}+04$   $\mu\text{g/g}$ . This yields an Fe:As ratio of 26:1, which is slightly higher than the 20:1 ratio for effective arsenic removal (EPA, 2001; Sorg, 2002). These data suggest that natural iron solids may have a greater As(V) adsorptive capacity than iron solids formed from supplemental iron addition.

Table 4-16 shows the TCLP results of the backwash water solids. The samples were filtered through  $0.7\ \mu\text{m}$  glass fiber filters. The solid-liquid compositions were 13.8% solid and 86.2% liquid for Sample BW1 and 16.2% solid and 83.8% liquid for Sample BW2. The filtrates were preserved with  $\text{HNO}_3$  until they could be digested for metal analyses. Both samples were found to require Extraction Fluid No. 1 (EF1), which contains 5.7 mL of acetic acid and 64.3 mL of NaOH with a pH of 4.93. Two 10 gram solid portions of each sample were extracted with EF1 on a rotary agitation device for 18 hr. The solids were filtered off and discarded. The extracts were digested along with the initial filtrates for metal analyses according to EPA Methods 200.7 for As, Ba, Cd, Cr, Pb, Se, and Ag and 245.1 for Hg. The results for each sample were obtained by adding the filtrate and extract results based on their percentage of the sample. The TCLP results of the backwash solids showed below the detection level of arsenic in the leachate at  $<0.5$  mg/L. Barium was in the leachate at 0.068 to 0.070 mg/L. Chromium was in the leachate at 0.052 to 0.055 mg/L. The TCLP regulatory limit set by EPA is 5 mg/L for arsenic, 100 mg/L for barium, and 5 mg/L for chromium. Therefore, the backwash solids can be disposed of in a landfill.

**4.5.3 Distribution System Water Sampling.** The results of the distribution system sampling are summarized in Table 4-17. The duration of the stagnation time before the sampling ranged from 6 to 14 hr and averaged 8 hr. The baseline sample DS3 collected on December 1, 2003, had an extended stagnation time of 264 hr. Therefore, the results from this sample are not included in the discussion below.

There was no major change in pH values, which ranged from 7.3 to 7.7 before and 7.4 to 8.2 after the process modifications. Alkalinity levels ranged from 353 to 403 and from 333 to 401 mg/L (as  $\text{CaCO}_3$ ) before and after process modifications, respectively.

Arsenic concentrations in samples collected before the process modifications ranged from 26.6 to 59.1  $\mu\text{g/L}$  and averaged 39.0  $\mu\text{g/L}$ . After the process modifications, arsenic concentrations decreased significantly to 6.0 to 18.8  $\mu\text{g/L}$  (averaged 12.1  $\mu\text{g/L}$ ) in the samples collected from Events 1 to 7. These concentrations were higher than those in treated water (i.e. 6.3 to 14.3  $\mu\text{g/L}$  and averaged 8.5  $\mu\text{g/L}$ ) as shown in Table 4-11. The higher levels of arsenic in the distribution system may be due to: 1) longer filter runs over the weekends with durations ranging from 18.5 to 20.3 hr might have contributed to elevated levels of particulate arsenic in the treated water sent to the distribution system, and/or 2) solubilization, destabilization, and/or desorption of arsenic-laden particles/scales might have occurred in the distribution system (Lytle, 2005). More frequent backwashing as described in Section 4.4.1.2 should help to eliminate the longer filter runs over the weekend.

Iron concentrations in the baseline samples ranged from  $<25$  to 41  $\mu\text{g/L}$ . Since the process modifications, iron levels in the distribution system remained at  $<25$   $\mu\text{g/L}$ . Manganese levels in the distribution system samples averaged 12.3  $\mu\text{g/L}$  in the baseline samples and decreased to an average of 6.7  $\mu\text{g/L}$  after the process modifications. In general, total manganese levels in the distribution samples were lower than those in the treated water from the post-chlorination point (averaged 17.9  $\mu\text{g/L}$ ). Manganese in the treated water was present primarily in the soluble form. The lower levels in the distribution system may be due to further oxidation of Mn(II) after post-chlorination and adsorption and/or coating onto metal oxide scales in the distribution system.

**Table 4-14. Backwash Water Sampling Results**

Sampling Event		BW1						BW2					
		Vessel No. 1						Vessel No. 2					
		pH	Turbidity	TDS	As (Soluble)	Fe (Soluble)	Mn (Soluble)	pH	Turbidity	TDS	As (Soluble)	Fe (Soluble)	Mn (Soluble)
No.	Date	S.U.	NTU	mg/L	µg/L	µg/L	µg/L	S.U.	NTU	mg/L	µg/L	µg/L	µg/L
1	03/23/05	7.6	160	1,050	7.5	<25	46.6	7.5	31	1,130	7.7	<25	37.2
2	04/18/05	7.6	130	1,020	11.8	<25	8.2	7.6	150	1,540	10.6	<25	20.1
3	05/25/05	7.2	110	928	8.5	<25	8.9	7.3	120	946	7.6	<25	0.8
4	06/21/05	7.4	160	986	11.9	<25	2.6	7.4	200	976	11.4	<25	1.8
5	07/25/05	7.4	200	1,010	10.2	<25	2.4	7.4	160	984	10.5	<25	0.8

TDS = total dissolved solids

**Table 4-15. Backwash Solid Sample Total Metal Results**

Metals Units	BW1-Solids A (µg/g)	BW1-Solids B (µg/g)	BW1-Solids C (µg/g)	Average (µg/g)	BW2-Solids A (µg/g)	BW2-Solids B (µg/g)	BW2-Solids C (µg/g)	Average (µg/g)
Al	3.05E+03	2.56E+03	3.24E+03	<b>2.95E+03</b>	2.82E+03	2.50E+03	2.99E+03	<b>2.77E+03</b>
As	1.15E+04	7.65E+03	9.10E+03	<b>9.42E+03</b>	8.02E+03	7.63E+03	1.05E+04	<b>8.73E+03</b>
Ca	5.49E+04	3.98E+04	5.05E+04	<b>4.84E+04</b>	4.32E+04	3.95E+04	4.62E+04	<b>4.29E+04</b>
Cd	2.80E-01	2.30E-01	3.10E-01	<b>2.70E-01</b>	2.20E-01	2.10E-01	2.40E-01	<b>2.20E-01</b>
Cu	2.26E+01	1.83E+01	2.36E+01	<b>2.15E+01</b>	1.97E+01	1.84E+01	2.14E+01	<b>1.98E+01</b>
Fe	3.07E+05	2.00E+05	2.38E+05	<b>2.49E+05</b>	2.06E+05	1.99E+05	2.73E+05	<b>2.26E+05</b>
Mg	5.51E+03	4.55E+03	5.82E+03	<b>5.29E+03</b>	5.16E+03	4.61E+03	5.48E+03	<b>5.08E+03</b>
Mn	1.25E+05	8.02E+04	9.97E+04	<b>1.02E+05</b>	8.55E+04	8.72E+04	1.14E+05	<b>9.55E+04</b>
P	3.50E+03	2.99E+03	3.61E+03	<b>3.37E+03</b>	3.18E+03	2.89E+03	3.26E+03	<b>3.11E+03</b>
Pb	3.19E+00	2.70E+00	3.52E+00	<b>3.14E+00</b>	2.94E+00	2.81E+00	3.19E+00	<b>2.98E+00</b>
Ni	9.53E+00	7.78E+00	9.53E+00	<b>8.95E+00</b>	8.74E+00	7.66E+00	9.36E+00	<b>8.59E+00</b>
Si	2.14E+02	1.02E+02	5.84E+02	<b>3.00E+02</b>	1.49E+02	1.21E+02	1.47E+02	<b>1.39E+02</b>
Zn	1.78E+02	1.38E+02	1.71E+02	<b>1.62E+02</b>	1.49E+02	1.35E+02	1.57E+02	<b>1.47E+02</b>

**Table 4-16. Backwash Solids Sample TCLP Results**

Parameter	Unit	BW1-10/06/05	BW2-10/06/05
As	mg/L	<0.5	<0.5
Ba	mg/L	0.068	0.070
Cd	mg/L	<0.05	<0.05
Cr	mg/L	0.055	0.052
Pb	mg/L	<0.1	<0.1
Ag	mg/L	<0.05	<0.05
Se	mg/L	<0.3	<0.3
Hg	mg/L	<0.003	<0.003

**Table 4-17. Distribution Sampling Results**

Sampling Location	Sampling Date	DS1								DS2							DS3 <sup>(a)</sup>								
		Stagnation Time (hr)	pH (S.U.)	Alkalinity (mg/L as CaCO <sub>3</sub> )	As (µg/L)	Fe (µg/L)	Mn (µg/L)	Pb (µg/L)	Cu (µg/L)	Stagnation Time (hr)	pH (S.U.)	Alkalinity (mg/L as CaCO <sub>3</sub> )	As (µg/L)	Fe (µg/L)	Mn (µg/L)	Pb (µg/L)	Cu (µg/L)	Stagnation Time (hr)	pH (S.U.)	Alkalinity (mg/L as CaCO <sub>3</sub> )	As (µg/L)	Fe (µg/L)	Mn (µg/L)	Pb (µg/L)	Cu (µg/L)
BL1	12/02/03 <sup>(b)</sup>	7.0	7.6	353	32.5	<25	11.8	2.1	104	7.0	7.3	370	35.2	26	47.1	56.8	198	264 <sup>(c)</sup>	8.1	404	41.5	31	33.9	4.4	384
BL2	12/17/03	7.0	7.4	377	33.4	<25	6.1	2.0	89.3	6.7	7.7	371	32.4	<25	5.6	2.0	76.2	8.5	7.6	371	26.6	<25	6.2	3.2	367
BL3	01/06/04	7.0	7.5	387	40.7	<25	3.6	3.3	111	14.0	7.7	393	41.9	<25	9.4	8.2	142	7.3	7.7	379	33.5	<25	1.2	1.8	333
BL4	01/22/04	7.0	7.5	379	47.3	<25	3.1	4.1	126	8.0	7.5	399	46.3	<25	1.4	2.0	102	7.5	7.8	403	59.1	41	39.4	4.3	287
1	01/18/05	7.8	7.5	338	13.9	<25	2.9	2.9	161	10.0	7.5	351	11.5	<25	4.4	1.7	68.4	7.0	7.5	359	6.7	<25	17.2	5.9	121
2	02/22/05	7.5	7.8	392	15.1	<25	0.8	2.4	243	10.8	7.4	400	9.8	<25	1.9	1.0	63.2	7.0	7.8	382	9.9	<25	1.9	5.1	279
3	03/22/05	NS	NS	NS	NS	NS	NS	NS	NS	9.0	7.4	355	11.2	<25	36.3	3.1	93.0	7.0	7.4	333	6.0	<25	5.9	12.5	574
4	04/06/05	7.0	7.7	397	18.8	<25	8.0	4.4	352	8.8	7.8	388	14.8	<25	16.6	2.5	115	7.5	7.8	401	7.5	<25	6.6	2.9	132
5	05/03/05	7.0	7.4	382	13.9	<25	1.0	2.7	251	9.5	7.4	395	10.6	<25	1.1	1.2	78.8	7.5	7.7	377	8.8	<25	2.0	5.0	263
6	06/14/05	7.5	7.5	374	17.8	<25	1.0	2.5	241	6.0	7.4	392	12.7	<25	5.8	1.0	54.2	8.5	8.2	387	9.8	<25	4.9	1.7	125
7	07/12/05	7.0	7.4	352	18.1	<25	5.3	0.8	107	10.8	7.4	352	13.4	<25	6.9	0.2	13.9	7.9	7.7	352	12.3	<25	3.2	2.9	307

(a) Water softener present at this location.

(b) Sample DS3 collected on December 1, 2003.

(c) Stagnation time high due to sample tap not being used over an extended period of time.

NA = not analyzed; BL = baseline sampling

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

µg/L as units for all analytical parameters except for pH (S.U.) and alkalinity (mg/L [as CaCO<sub>3</sub>]).

Lead levels in the distribution system during the baseline sampling events ranged from 1.8 to 8.2 µg/L with one outlier at 56.8 µg/L exceeding the action level of 15 µg/L for lead. After the process modifications, lead levels ranged from 0.2 to 12.5 µg/L with an average value of 3.1 µg/L. Lead levels in the distribution system did not appear to have been significantly affected by the process modifications. The copper concentrations in the distribution system averaged 178 µg/L before and 182 µg/L after process modifications. The process modifications did not appear to have an impact on copper levels in the distribution system and no samples exceeded the 1,300 µg/L action level for copper.

#### 4.6 System Cost

The cost of the system was evaluated based on the capital cost per gpm (or gpd) of design capacity and the O&M cost per 1,000 gal of water treated. This included the tracking of capital cost for equipment, engineering, and installation and O&M cost for chemical supply, electrical power consumption, and labor. However, the cost associated with the building, sanitary sewer connections, and other discharge-related infrastructure was not included in the treatment system cost, because it was not included in the scope of the demonstration project, and was funded previously by the demonstration site.

**4.6.1 Capital Cost.** The capital investment for the process modifications at Lidgerwood, North Dakota, was \$57,038 (Table 4-18), which included \$32,452 for equipment, \$5,786 for engineering, and \$18,800 for installation. The capital equipment cost also included freight and sales tax.

**Table 4-18. Summary of Capital Cost for the Lidgerwood, ND Process Modifications**

Description	Quantity	Cost	% of Capital Investment Cost
<i>Equipment Cost</i>			
Chemical Feed System	1	\$5,570	–
Turbidimeter	4	\$9,567	–
dP Transmitter	1	\$1,894	–
Data Logger	1	\$3,703	–
Drum Scale	1	\$3,940	–
Other Miscellaneous	–	\$1,177	–
Reclaim Pump		\$844	
Polymer Tank Mixer		\$454	
Labor	–	\$2,020	–
Warranty	–	\$3,283	–
<b>Equipment Total</b>	–	<b>\$32,452</b>	<b>57%</b>
<i>Engineering Cost</i>			
<b>Engineering Total</b>	–	<b>\$5,786</b>	<b>10%</b>
<i>Installation Cost</i>			
Material	–	\$1,493	–
Labor	–	\$12,307	–
Travel	–	\$5,000	–
<b>Installation Total</b>	–	<b>\$18,800</b>	<b>33%</b>
<b>Total Capital Investment</b>	–	<b>\$57,038</b>	<b>100%</b>

The equipment cost was \$32,452, or 57% of the total capital investment. The primary equipment for the iron addition system included a 60-gal chemical day tank with secondary containment, a tank mixer, a chemical metering pump, associated materials such as tubing and fasteners, and warranty. In addition,

on-line instrumentation including a Scaleton low-profile drum scale, four Hach 1720D low-range turbidimeters, a Foxboro differential pressure cell, and a Telog data logging system, was installed at the plant to track filter cell performance both before and after process modifications. The system warranty included repair and/or replacement of any equipment or installation workmanship for a period of 12 months after system start-up. The equipment cost also includes the cost of a second polymer mixer and a new reclaim pump. It does not include the cost of the second polymer feed system since an existing spare chemical feed pump and tank were used.

The engineering cost (\$5,786, or 10% of the total capital cost) included the costs for labor for the preparation of a process design report and engineering plans including a P&ID, general assembly drawing, turbidity meter interconnect, and electrical schematics.

The installation cost included the costs for equipment and labor to ship, install, and shakedown the FeCl<sub>3</sub> addition system. The primary installation activities included placing the ferric chloride tank on the drum scale and spill containment deck, mounting the tank mixer and pump to a wall bracket, and connecting the tubing from the chemical metering pump to the injection point at the rapid mix tank. The installation also included labor for all electrical connections, as well as connection and calibration of the associated instrumentation including the drum scale, turbidimeters, and differential pressure cell. The installation cost was \$18,800, or 33% of the total capital cost.

The total capital cost of \$57,038 was normalized to the system's rated capacity of 250 gpm (360,000 gpd), which resulted in \$228 per gpm (\$0.16 per gpd). The total capital cost of \$57,038 was converted to an annualized cost of \$5,384/year using a capital recovery factor of 0.09439 based on a 7% interest rate and a 20-year return. Assuming that the system was operated 24 hours a day, seven days a week at the design flowrate of 250 gpm to produce 131.4 million gal of water per year, the unit capital cost would be \$0.04/1,000 gal. However, the system was operated an average of 6.1 hr/day and produced 22.1 million gal of water during the seven-month study period. The corresponding annual production would be approximately 38.2 million gal of water. The unit capital cost was increased to \$0.14/1,000 gal at this reduced rate of production.

**4.6.2 Operation and Maintenance Cost.** The incremental O&M cost for the process modifications included primarily costs associated with additional chemical supply for FeCl<sub>3</sub> and Aqua Hawk 127 polymer. The incremental O&M cost from the process modifications was \$0.04/1,000 gal as summarized in Table 4-19. The treatment plant was pre-existing and the process modifications did not contribute significantly to the operator's labor hours and/or the electrical demand for the entire treatment plant. The total O&M cost also was estimated to include all chemical supply costs (e.g. NaOCl, KMnO<sub>4</sub>, Aqua Hawk 9207 PWG polymer, Aqua Hawk 127 polymer, and fluoride), electrical usage, and labor. The total O&M was estimated at \$0.52/1000 gal of treated water.

**Table 4-19. O&M Cost for the Lidgerwood, ND Treatment System**

<b>Cost Category</b>	<b>Value</b>	<b>Assumptions</b>
Volume Processed (kgal)	22,012	From 01/01/05 to 07/31/05
<b><i>Incremental Chemical Usage for Process Modifications</i></b>		
FeCl <sub>3</sub> Unit Price (\$/lb)	\$0.40	35% FeCl <sub>3</sub> in a 600 lb drum; fuel surcharge included.
FeCl <sub>3</sub> Consumption Rate (lb/1,000 gal)	0.08	—
FeCl <sub>3</sub> (\$/1,000 gal)	\$0.03	—
Aqua Hawk 127 Unit Price (\$/gal)	\$25.93	Includes fuel surcharge and container recycle charge
Aqua Hawk 127 Consumption Rate (gal/1,000 gal)	5x10 <sup>-4</sup>	—
Aqua Hawk 127 (\$/1,000 gal)	\$0.01	—
<b>Total Incremental Chemical Cost/1,000 gal</b>	<b>\$0.04</b>	<b>—</b>
<b><i>Chemical Usage for Pre-Existing Chemical Feed Systems</i></b>		
Aqua Hawk 9207 PWG Unit Price (\$/lb)	\$4.37	—
Aqua Hawk 9207 PWG Consumption Rate (lb/1,000 gal)	0.003	—
Aqua Hawk 9207 PWG Chemical cost (\$/1,000 gal)	\$0.01	—
Potassium Permanganate Unit Price (\$/lb)	\$3.36	—
Potassium Permanganate Consumption Rate (lb/1,000 gal)	0.010	—
Potassium Permanganate Chemical cost (\$/1,000 gal)	\$0.03	—
Chlorine Unit Price (\$/lb)	\$1.63	—
Chlorine Consumption Rate (lb/1,000 gal)	0.041	—
Chlorine Chemical cost (\$/1,000 gal)	\$0.07	—
Fluoride Unit Price (\$/gal)	\$9.11	—
Fluoride Consumption Rate (lb/1,000 gal)	0.005	—
Fluoride Chemical cost (\$/1,000 gal)	\$0.04	—
<b>Total Pre-Existing Chemical Cost/1,000 gal</b>	<b>\$0.15</b>	<b>—</b>
<b><i>Electricity</i></b>		
Power use (\$/1,000 gal)	\$0.03	—
<b><i>Labor</i></b>		
Average weekly labor (hr)	10.7	—
Labor cost (\$/1,000 gal)	\$0.29	Labor rate = \$20/hr
<b>Total O&amp;M Cost/1,000 gal</b>	<b>\$0.52</b>	<b>—</b>

## Section 5.0: REFERENCES

- Battelle. 2003. *Revised Quality Assurance Project Plan for Evaluation of Arsenic Removal Technology*. Prepared under Contract No. 68-C-00-185, Task Order No. 0019, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Battelle. 2004. *Final System Performance Evaluation Study Plan: U.S. EPA Demonstration of Arsenic Removal Technology at Lidgerwood, ND*. Prepared under Contract No. 68-C-00-185, Task Order No. 0019 for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Chen, A.S.C., L. Wang, J. Oxenham, and W. Condit. 2004. *Capital Costs of Arsenic Removal Technologies: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1*. EPA/600/R-04/201. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Edwards, M., S. Patel, L. McNeill, H. Chen, M. Frey, A.D. Eaton, R.C. Antweiler, and H.E. Taylor. 1998. "Considerations in As Analysis and Speciation." *J. AWWA* 90(3): 103-113.
- EPA. 2003. Minor Clarification of the National Primary Drinking Water Regulation for Arsenic. *Federal Register*, 40 CFR Part 141.
- EPA. 2002. *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems*. EPA/816/R-02/009. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.
- EPA. 2001. National Primary Drinking Water Regulations: Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring. *Federal Register*, 40 CFR Parts 9, 141, and 142.
- Great Lakes-Upper Mississippi River Board of State Sanitary Engineers. 2003. *Recommended Standards for Water Works*. Health Education Services. Albany, New York.
- Lytle, D. 2005. Coagulation/Filtration: Iron Removal Processes Full-Scale Experience. U.S. Environmental Protection Agency Workshop on Arsenic Removal from Drinking Water, Cincinnati, Ohio.
- Sorg, T.J. 2002. "Iron Treatment for Arsenic Removal Neglected." *Opflow*, AWWA, 28(11):15.
- Wang, L., W. Condit, and A.S.C. Chen. 2004. *Technology Selection and System Design: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1*. EPA/600/R-05/001. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.

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



**Table A-1. Daily System Operation Log for Lidgerwood, ND (Page 1 of 5)**

Date	Daily Plant Hours (hrs)	Well #1 (hrs)	Well #3 (hrs)	Backwash Pump #1 (hrs)	Backwash Pump #2 (hrs)	Reclaim Pump (hrs)	Raw Water		Reclaim Water		Treated Water	FeCl <sub>3</sub> (mg/L)	Aqua Hawk 9207 PWG (mg/L)	Aqua Hawk 127 (mg/L)
							(gal)	(gpm)	(gal)	(gpm)	(kgal)			
01/01/05	NA	NA	NA	NA	NA	NA	98721600	NA	6806100	NA	290730	1.41	0.29	0.51
01/02/05	5.6	NA	5.7	0	0	3	98814200	270.8	6810790	26.1	290815	1.54	0.31	0.52
01/03/05	5.4	NA	5.4	0	0.8	0.3	98902300	271.9	6811190	22.2	290882	1.42	0.15	0.49
01/04/05	5.2	5.2	NA	0	0	5.2	98987000	271.5	6819390	26.3	290959	1.33	0.29	0.49
01/05/05	6.3	6.4	NA	0.5	0	3.2	99092700	275.3	6824490	26.6	291046	1.37	0.29	0.45
01/06/05	5.3	5.3	NA	0	0	5.4	99181200	278.3	6832910	26.0	291133	1.38	0.28	0.51
01/07/05	6.7	6.7	NA	0	0.7	1.4	99291700	274.9	6835050	25.5	291217	1.24	0.28	0.52
01/08/05	5.1	5	NA	0	0	5	99376000	281.0	6843100	26.8	291305	1.33	0.29	0.50
01/09/05	4.7	4.9	NA	0	0	3.8	99456700	274.5	6848840	25.2	291376	1.48	0.27	0.48
01/10/05	6.7	6.7	NA	0.8	0	0.3	99569100	279.6	6849470	35.0	291468	1.46	0.31	0.51
01/11/05	5	5	NA	0	0	5	99650500	271.3	6857330	26.2	291541	1.14	0.28	0.47
01/12/05	6.4	6.4	NA	0	0.8	3.4	99757700	279.2	6862640	26.0	291626	1.24	0.29	0.64
01/13/05	5.6	NA	NA	0	0	5.7	99852000	NA	6871670	26.4	291718	1.18	0.31	0.51
01/14/05	5.4	NA	NA	0.8	0	3.1	99942200	NA	6876650	26.8	291793	1.26	0.30	0.52
01/15/05	5.8	6.5	NA	0	0	5.9	39600	249.7	6885830	25.9	291888	1.36	0.24	0.54
01/16/05	6.2	6.2	NA	0	0	3	144400	281.7	6890510	26.0	291984	1.37	0.28	0.46
01/17/05	5.7	5.8	NA	0	0.8	0.5	239500	273.3	6891320	27.0	292053	1.30	0.26	0.52
01/18/05	5.2	5.2	NA	0	0	5.2	326700	279.5	6899640	26.7	292138	1.21	0.27	0.51
01/19/05	6.5	6.5	NA	0.7	0	3.1	435400	278.7	6904330	25.2	292218	1.26	0.27	0.52
01/20/05	5.7	5.7	NA	0.1	0	5.7	530800	278.9	6913420	26.6	292310	1.19	0.26	0.50
01/21/05	7	7	NA	0	0.9	3.1	647400	277.6	6918110	25.2	292407	1.12	0.20	0.48
01/22/05	6.2	6.3	NA	0	0	6.3	752400	277.8	6928160	26.6	292505	1.12	0.22	0.50
01/23/05	7.4	7.4	NA	0	0	2.9	875100	276.4	6932670	25.9	292617	1.34	0.25	0.48
01/24/05	5.9	5.9	NA	0.8	0	0	974400	280.5	6932670	NA	292689	1.25	0.25	0.49
01/25/05	5.5	5.6	NA	0	0	5.5	1066000	272.6	6941450	26.6	292778	1.12	0.23	0.53
01/26/05	5.6	5.6	NA	0	0.8	3.3	116000	NA	6946590	26.0	292852	1.18	0.25	0.47
01/27/05	5.6	5.7	NA	0	0	5.7	1255100	NA	6955600	26.3	292943	1.15	0.29	0.46
01/28/05	7.2	7	NA	0.7	0	3.3	1372100	278.6	6960700	25.8	293036	1.14	0.24	0.46
01/29/05	5.6	5.8	NA	0	0	5.8	1468600	277.3	6970030	26.8	293136	1.22	0.27	0.50
01/30/05	6.9	6.9	NA	0	0	3.2	1584900	280.9	6974770	24.7	293243	1.15	0.25	0.45
01/31/05	6.5	6.5	NA	0	0.7	0.3	1694600	281.3	6975350	32.2	293317	1.13	0.27	0.46
02/01/05	4.5	4.5	NA	0	0	4.5	1770500	281.1	6982620	26.9	293396	1.17	0.26	0.55
02/02/05	6.5	1.0	5.6	0.7	0	4.4	1876700	268.2	6989320	25.4	293476	1.24	0.23	0.47
02/03/05	5.7	NA	5.7	0	0	5.7	1969400	271.1	6998420	26.6	293567	1.25	0.26	0.48
02/04/05	6.8	NA	6.8	0	0.8	3.4	2081400	274.5	7003700	25.9	293656	1.18	0.24	0.45
02/05/05	5.6	NA	5.7	0	0	5.6	2173400	269.0	7012660	26.7	293745	1.13	0.27	0.50
02/06/05	6	NA	6	0	0	NA	2272500	275.3	7017570	NA	293843	1.11	0.23	0.48
02/07/05	6.5	NA	6.5	0.8	0	NA	2378900	272.8	7017570	NA	293918	1.21	0.25	0.46
02/08/05	5.7	NA	5.8	0	0	5.8	2473300	271.3	7026760	26.4	294006	1.15	0.24	0.47
02/09/05	7	NA	6.9	0	0.8	3.5	2587700	276.3	7032210	26.0	294098	1.30	0.25	0.46
02/10/05	6.3	NA	6.5	0	0	6.4	2693500	271.3	7042460	26.7	294206	1.34	0.28	0.50
02/11/05	6.8	NA	6.7	0.8	NA	2.4	2804000	274.9	7046110	25.3	294293	1.17	0.26	0.50
02/12/05	6.9	NA	7	0	0	7	2916300	267.4	7057100	26.2	294396	1.34	0.22	0.56
02/13/05	4.9	NA	4.9	0	0	2.2	2997900	277.6	7060620	26.7	294478	1.43	0.26	0.50
02/14/05	7.6	NA	7.6	0	0.7	0.4	3120800	269.5	7061170	22.9	294565	1.45	0.24	0.48
02/15/05	4.5	NA	4.5	0	0	4.5	3194300	272.2	7068390	26.7	294637	1.52	0.26	0.51
02/16/05	6.6	NA	6.7	0.7	0	4.4	3303600	271.9	7075190	25.8	294725	1.27	0.26	0.46
02/17/05	4.5	NA	4.5	0	0	4.5	3377700	274.4	7082430	26.8	294796	1.14	0.23	0.48
02/18/05	6.6	NA	6.6	0	0.8	4.4	3486100	273.7	7089210	25.7	294885	1.15	0.26	0.46
02/19/05	4.7	NA	4.4	0	0	2	3563200	292.0	7096760	62.9	294965	1.04	0.27	0.53
02/20/05	7.4	NA	7.5	0	0	NA	3684000	268.4	7103280	NA	295072	1.13	0.25	0.50
02/21/05	4.9	NA	5	0.8	0	NA	3765600	272.0	7103280	NA	295132	1.21	0.26	0.52
02/22/05	5.9	NA	6.1	0	0	5.7	3861900	263.1	7112690	27.5	295221	1.35	0.25	0.49

**Table A-1. Daily System Operation Log for Lidgerwood, ND (Continued) (Page 2 of 5)**

Date	Daily Plant Hours (hrs)	Well #1 (hrs)	Well #3 (hrs)	Backwash Pump #1 (hrs)	Backwash Pump #2 (hrs)	Reclaim Pump (hrs)	Raw Water		Reclaim Water		Treated Water (kgal)	FeCl <sub>3</sub> (mg/L)	Aqua Hawk 9207 PWG (mg/L)	Aqua Hawk 127 (mg/L)
							(gal)	(gpm)	(gal)	(gpm)				
02/23/05	5.7	NA	5.9	0	0.8	3.5	3958500	272.9	7118120	25.9	295301	1.08	0.28	0.46
02/24/05	7.3	NA	7.2	0	0	7.2	4076800	273.8	7129590	26.6	295416	1.11	0.27	0.51
02/25/05	3.9	NA	3.9	0.6	0	1.9	4141100	274.8	7132410	24.7	295462	1.13	0.24	0.43
02/26/05	5.5	NA	5.5	0	0	5.5	4231800	274.8	7141060	26.2	295549	1.16	0.27	0.53
02/27/05	6.2	NA	6.3	0	0	1.4	4334700	272.2	7143260	26.2	295640	1.23	0.28	0.53
02/28/05	7.4	NA	7.4	0	0.7	0	4458100	277.9	7143260	NA	295732	1.23	0.30	0.48
03/01/05	5.8	NA	5.9	0	0.1	5.8	4554000	270.9	7152520	26.6	295826	1.20	0.28	0.49
03/02/05	5.6	5.4	0.1	0.7	0	3.4	4646000	284.0	7157680	25.3	295895	1.17	0.27	0.46
03/03/05	5.1	5.3	NA	0	0	5.4	4734300	277.7	7166120	26.0	295984	1.27	0.29	0.53
03/04/05	5.8	5.8	NA	0	0.7	3.4	4830200	275.6	7171640	27.1	296055	1.15	0.28	0.51
03/05/05	5.7	5.7	NA	0	0	5.7	4925200	277.8	7180800	26.8	296141	1.18	0.28	0.50
03/06/05	6.5	6.5	NA	0	0	6.5	5034000	279.0	7191140	26.5	296236	1.19	0.27	0.49
03/07/05	6.1	6.1	NA	0.8	0	NA	5136500	280.1	7196480	NA	296309	1.11	0.27	0.51
03/08/05	4.8	4.8	NA	0	0	NA	5217900	282.6	7204260	NA	296392	1.24	0.17	0.46
03/09/05	6.3	6.3	NA	0	0.8	4.9	5223400	14.6	7211850	25.8	296470	1.21	0.35	0.50
03/10/05	5.4	5.5	NA	0	0	5.4	5414300	578.5	7220550	26.9	296558	1.25	0.26	0.42
03/11/05	4.5	4.6	NA	0	0	4	5491900	281.2	7226760	25.9	296638	1.31	0.28	0.55
03/12/05	6.8	6.7	NA	0.8	0	3.7	5608100	289.1	7232570	26.2	296723	1.22	0.27	0.45
03/13/05	5.9	6.0	NA	0	0	5.4	5705900	271.7	7240990	26.0	296817	1.31	0.29	0.54
03/14/05	6.2	6.2	NA	0	NA	NA	5810200	280.4	7240990	NA	296893	1.27	0.30	0.46
03/15/05	5.9	5.9	NA	0	NA	NA	5910500	283.3	7250470	NA	296989	1.26	0.27	0.47
03/16/05	5.6	5.7	NA	0.7	0	2.8	6005400	277.5	7255130	27.7	297062	1.23	0.29	0.48
03/17/05	5.9	5.9	NA	0	0	5.2	6104700	280.5	7264230	29.2	297157	1.21	0.29	0.48
03/18/05	5.7	5.7	NA	0	0.6	3.4	6202900	287.1	7269820	27.4	297242	1.28	0.28	0.51
03/19/05	6.1	6.1	NA	0	0	6	6303600	275.1	7279130	25.9	297337	1.18	0.28	0.50
03/20/05	6.4	6.5	NA	0	0	1.1	6413100	280.8	7280840	25.9	297430	1.21	0.29	0.52
03/21/05	6.1	6.1	NA	0.8	0	0	6515400	279.5	7280840	NA	297504	1.15	0.28	0.50
03/22/05	5.7	5.8	NA	0	0	5.8	6613200	281.0	7290100	26.6	297598	1.16	0.32	0.52
03/23/05	6	6.0	NA	0	0	3.4	6715100	283.1	7295340	25.7	297692	1.13	0.27	0.47
03/24/05	7	6.9	NA	0	0.8	4.6	6831700	281.6	7302650	26.5	297785	1.09	0.25	0.54
03/25/05	6.8	7.0	NA	0.7	0	4.4	6948300	277.6	7309550	26.1	297879	1.23	0.27	0.51
03/26/05	6	5.9	NA	0	0	6	7049400	285.6	7319020	26.3	297982	1.36	0.27	0.49
03/27/05	5.3	5.4	NA	0	0	2.9	7139200	277.2	7323490	25.7	298059	1.35	0.26	0.54
03/28/05	6.1	6.1	NA	0.1	0.5	0	7242600	282.5	7323490	NA	298141	1.30	0.25	0.48
03/29/05	5.6	5.6	NA	0	0	4.2	7337200	281.5	7330090	26.2	298226	1.22	0.33	0.51
03/30/05	6.8	6.8	NA	0.8	0	0	7451800	280.9	7330090	NA	298311	1.11	0.26	0.53
03/31/05	5.7	5.8	NA	0	0	5.8	7546900	273.3	7339100	25.9	298409	1.18	0.26	0.50
04/01/05	7.2	7.2	NA	0	0.7	0.5	7671000	287.3	7339810	23.7	298491	1.18	0.26	0.53
04/02/05	5	NA	5	0	0	5	7754800	279.3	7347850	26.8	298569	1.21	0.25	0.53
04/03/05	5.3	NA	5.4	0	0	5.4	7843600	274.1	7356090	25.4	298648	1.27	0.26	0.49
04/04/05	5.4	NA	5.4	0.8	0	3.5	7933900	278.7	7361440	25.5	298728	1.24	0.28	0.46
04/05/05	7.5	NA	7.6	0	0	6.2	8057900	271.9	7371350	26.6	298827	1.19	0.25	0.47
04/06/05	3.9	9.2	2.7	0	0	2.6	8105500	293.8	7375290	25.3	298881	1.25	0.27	0.56
04/07/05	6.3	6.5	6.3	0	0.9	4.5	8212800	283.9	7382470	26.6	298960	1.27	0.26	0.51
04/08/05	8.3	11.6	6.9	0.7	0	2.2	8329400	281.6	7385760	24.9	299050	1.31	0.24	0.50
04/09/05	6.6	11.0	6.1	0	0	6.5	8434300	286.6	7396090	26.5	299153	1.25	0.25	0.48
04/10/05	5.5	11.1	6.5	0	0	5.6	8546000	286.4	7404930	26.3	299253	1.20	0.25	0.52
04/11/05	6.8	12.2	6.4	0	0.8	2.5	8653600	280.2	7408720	25.3	299332	1.20	0.26	0.49
04/12/05	9.7	7.9	9.5	0	0	6.6	8816200	285.3	7422700	35.3	299496	1.16	0.25	0.50
04/13/05	7	1.8	7	0.6	0	NA	8936700	286.9	7422700	NA	299579	1.12	0.23	0.47
04/14/05	5.8	NA	5.8	0	0	NA	9036000	285.3	7431500	NA	299674	1.12	0.24	0.52
04/15/05	7	NA	7	0	0.7	NA	9156600	287.1	7431500	NA	299772	1.08	0.26	0.47
04/16/05	5.6	NA	5.7	0	0	NA	9252300	279.8	7439940	NA	299856	1.07	0.25	0.50

**Table A-1. Daily System Operation Log for Lidgerwood, ND (Continued) (Page 3 of 5)**

Date	Daily Plant Hours (hrs)	Well #1 (hrs)	Well #3 (hrs)	Backwash Pump #1 (hrs)	Backwash Pump #2 (hrs)	Reclaim Pump (hrs)	Raw Water		Reclaim Water		Treated Water (kgal)	FeCl <sub>3</sub> (mg/L)	Aqua Hawk 9207 PWG (mg/L)	Aqua Hawk 127 (mg/L)
							(gal)	(gpm)	(gal)	(gpm)				
04/17/05	7.1	NA	4.4	0	0	NA	9362300	416.7	7443680	NA	299962	1.06	0.23	0.44
04/18/05	5.4	NA	8.2	0	0	NA	9469000	216.9	7443680	NA	300048	1.31	0.28	0.56
04/19/05	6.6	NA	6.6	0.8	0	NA	9580700	282.1	7449690	NA	300135	1.13	0.25	0.50
04/20/05	6.5	NA	6.5	0	0.6	NA	9692500	286.7	7449760	NA	300223	1.17	0.27	0.50
04/21/05	6.3	NA	6.3	0	0	NA	9800800	286.5	7457660	NA	300323	1.16	0.26	0.50
04/22/05	6.9	NA	6.9	0.8	0	NA	9920600	289.4	7459650	NA	300421	1.18	0.25	0.50
04/23/05	5.4	NA	5.5	0	0	NA	10013800	282.4	7467710	NA	300506	1.18	0.26	0.50
04/24/05	4.8	NA	4.8	0	0	NA	10096200	286.1	7473480	NA	300588	1.19	0.24	0.47
04/25/05	7.1	NA	7.1	0	0.8	NA	10217600	285.0	7473480	NA	300672	1.16	0.24	0.49
04/26/05	3.9	NA	4	0	0	NA	10285500	282.9	7479780	NA	300742	1.20	0.24	0.47
04/27/05	5.5	NA	5.4	0.7	0	NA	10377500	284.0	7485960	NA	300806	1.11	0.25	0.53
04/28/05	4.4	NA	4.4	0	0	4.1	10453500	287.9	7492590	NA	300881	1.26	0.24	0.55
04/29/05	5.8	NA	5.9	0	0.8	2.8	10554400	285.0	7497860	31.4	300959	1.26	0.24	0.48
04/30/05	4.5	NA	4.5	0	0	5.2	10632100	287.8	7505110	23.2	301033	1.38	0.28	0.51
05/01/05	5.1	NA	5.2	0	0	3.8	10720200	282.4	7510960	25.7	301115	1.28	0.23	0.48
05/02/05	6.7	6.6	NA	0.8	0	0	10835700	291.7	7510960	NA	301198	1.29	0.26	0.50
05/03/05	4.8	4.9	NA	0	0	4.2	10921000	290.1	7517600	26.3	301287	1.29	0.24	0.48
05/04/05	6.3	6.3	NA	0	0	4.7	11029900	288.1	7524590	24.8	301370	1.43	0.24	0.50
05/05/05	6	6.0	NA	0	0	5.1	11132900	286.1	7532630	26.3	301463	1.37	0.25	0.51
05/06/05	7.4	7.5	NA	0.8	0	2.9	11261900	286.7	7536890	24.5	301566	1.19	0.25	0.52
05/07/05	5.1	5.1	NA	0	0	3.2	11352200	295.1	7545020	42.3	301652	1.16	0.25	0.48
05/08/05	3.8	3.8	NA	0	0	4.8	11415600	278.1	7549220	14.6	301711	1.15	0.24	0.48
05/09/05	6.7	6.7	NA	0	0	0	11532600	291.0	7549220	NA	301800	1.20	0.24	0.50
05/10/05	4.6	4.7	NA	0	0	4.7	11613900	288.3	7556450	25.6	301877	1.14	0.23	0.55
05/11/05	4.5	4.5	NA	0	0	1.8	11692100	289.6	7559180	25.3	301955	1.18	0.26	0.50
05/12/05	5.3	5.3	NA	0.7	0	3.7	11783300	286.8	7564930	25.9	302017	1.11	0.24	0.50
05/13/05	5.5	5.6	NA	0	0.8	3.4	11880600	289.6	7570120	25.4	302092	1.20	0.21	0.51
05/14/05	4.3	4.2	NA	0	0	2.3	11955800	298.4	7576880	49.0	302169	1.20	0.24	0.49
05/15/05	4.1	4.2	NA	0	0	6.1	12027200	283.3	7583150	17.1	302231	1.19	0.25	0.50
05/16/05	6.1	6.0	NA	0.8	0	0.1	12133600	295.6	7583200	8.3	302313	1.17	0.25	0.49
05/17/05	4.3	4.4	NA	0	0	3.8	12209000	285.6	7589280	26.7	302385	1.14	0.24	0.50
05/18/05	5.8	5.8	NA	0	0.7	4.1	12309500	288.8	7595450	25.1	302454	1.20	0.24	0.71
05/19/05	4.8	4.8	NA	0	0	4.8	12392600	288.5	7602900	25.9	302536	1.15	0.24	0.51
05/20/05	6.2	6.3	NA	0.6	0	4.8	12502300	290.2	7609930	24.4	302630	1.18	0.26	0.53
05/21/05	7.9	8.0	NA	0	0	7	12640800	288.5	7620530	25.2	302757	1.15	0.25	0.50
05/22/05	10.2	10.2	NA	0	0	0.3	12818500	290.4	7620960	23.9	302908	1.14	0.25	0.49
05/23/05	5.8	5.8	NA	0	0.8	4	12920200	292.2	7626920	24.8	302977	1.14	0.24	0.49
05/24/05	6.7	6.7	NA	0	0	6.4	13037200	291.0	7636910	26.0	303090	1.18	0.26	0.50
05/25/05	3.8	3.8	NA	0	0	2.5	13103300	289.9	7640630	24.8	303151	1.12	0.21	0.46
05/26/05	6.8	6.8	NA	0.8	0	4	13223000	293.4	7647040	26.7	303245	1.15	0.26	0.53
05/27/05	4.7	4.8	NA	0	0.8	1.6	13305700	287.2	7652470	56.6	303313	1.17	0.25	0.48
05/28/05	6.3	6.3	NA	0	0	7.9	13416200	292.3	7661760	19.6	303412	1.19	0.24	0.48
05/29/05	2.3	2.4	NA	0	0	2.4	13457300	285.4	7665310	24.7	303451	1.23	0.25	0.51
05/30/05	6.7	6.7	NA	0.7	0	0.6	13574200	290.8	7666240	25.8	303538	1.24	0.24	0.54
05/31/05	5	5.0	NA	0	0	5	13662000	292.7	7674120	26.3	303621	1.28	0.23	0.54

**Table A-1. Daily System Operation Log for Lidgerwood, ND (Continued) (Page 4 of 5)**

Date	Daily Plant Hours (hrs)	Well #1 (hrs)	Well #3 (hrs)	Backwash Pump #1 (hrs)	Backwash Pump #2 (hrs)	Reclaim Pump (hrs)	Raw Water		Reclaim Water		Treated Water	FeCl <sub>3</sub> (mg/L)	Aqua Hawk 9207 PWG (mg/L)	Aqua Hawk 127 (mg/L)
							(gal)	(gpm)	(gal)	(gpm)	(kgal)			
06/01/05	5.1	5.1	NA	0	0.7	3.7	13752800	296.7	7679690	25.1	303696	1.28	0.27	0.47
06/02/05	5.5	0.9	4.6	0	NA	4.6	13846900	340.9	7686950	26.3	303784	1.23	0.21	0.51
06/03/05	5.4	NA	5.3	0.8	0.9	4.2	13938600	288.4	7693310	25.2	303847	1.11	0.24	0.50
06/04/05	4.9	NA	5	0	0	5	14023900	284.3	7701090	25.9	303931	1.16	0.24	0.46
06/05/05	5.2	NA	5.2	0	0	5.2	14113400	286.9	7707800	21.5	304015	1.19	0.27	0.49
06/06/05	5.9	NA	6	0	0.8	0	14216600	286.7	7707800	NA	304096	1.22	0.24	0.46
06/07/05	6.2	NA	6.2	0	0	5.1	14321900	283.1	7716280	NA	304188	1.18	0.24	0.51
06/08/05	6.6	NA	6.7	0.8	0	4.5	14437600	287.8	7721360	18.8	304282	1.26	0.25	0.47
06/09/05	4.1	NA	4	0	0	3.8	14506100	285.4	7727370	26.4	304344	1.17	0.23	0.47
06/10/05	7.5	NA	7.5	0	0.8	4.7	14635100	286.7	7734690	26.0	304449	1.25	0.23	0.50
06/11/05	4.4	NA	4.5	0	0	4.7	14713000	288.5	7741770	25.1	304529	1.19	0.26	0.46
06/12/05	4.3	NA	4.2	0	0	4.2	14785500	287.7	7748140	25.3	304593	1.13	0.22	0.50
06/13/05	6.1	NA	6.2	0.7	0	4.3	14892800	288.4	7748200	0.2	304677	1.25	0.28	0.47
06/14/05	5.6	NA	5.6	0	0	5.2	14989100	286.6	7756150	25.5	304761	1.15	0.25	0.57
06/15/05	4.6	NA	4.6	0	0.6	3.6	15067900	285.5	7761530	24.9	304820	1.11	0.23	0.48
06/16/05	5.2	NA	5.2	0	0	5.2	15157600	287.5	7769500	25.5	304908	1.04	0.22	0.50
06/17/05	6.5	NA	6.5	0.8	0	5.3	15270100	288.5	7772860	10.6	304991	1.14	0.25	0.45
06/18/05	4.7	NA	4.8	0	0	4.8	15352400	285.8	7772970	0.4	305073	1.23	0.25	0.52
06/19/05	5.8	NA	5.8	0	0	4.1	15451300	284.2	7773090	0.5	305165	1.22	0.24	0.48
06/20/05	5.8	NA	5.9	0	0.7	0	15553300	288.1	7773090	NA	305258	1.21	0.24	0.50
06/21/05	5.8	NA	5.8	0	0	3.5	15652200	284.2	7773190	0.5	305341	1.19	0.22	0.51
06/22/05	7.5	NA	7.5	1.5	0.2	1.4	15782200	288.9	7773230	0.5	305423	1.20	0.25	0.50
06/23/05	6.2	NA	6.2	0	0.8	3.8	15889500	288.4	7773320	0.4	305513	1.19	0.24	0.51
06/24/05	7	NA	NA	0.8	0	4.8	16010700	NA	7780340	24.4	305620	1.17	0.25	0.50
06/25/05	6.4	NA	13.5	0	0.7	3.8	16120100	135.1	7786560	27.3	305708	1.16	0.23	0.50
06/26/05	5.3	NA	5.3	0	0	NA	16211600	287.7	7795040	NA	305795	1.22	0.26	0.47
06/27/05	6.6	NA	NA	0.6	0	NA	16327000	NA	7795460	NA	305884	1.21	NA	0.51
06/28/05	6	NA	NA	0	0	7.9	16429400	NA	7795460	NA	305971	1.14	0.25	0.51
06/29/05	6.6	NA	6.6	0	0.8	5.5	16543400	287.9	7804270	26.7	306062	1.15	0.25	0.48
06/30/05	6	NA	6.2	0	0.9	3.8	16650400	287.6	7810580	27.7	306147	1.22	0.25	0.52
07/01/05	5.8	NA	5.7	0	0	5.7	16749100	288.6	7812850	6.6	306234	1.20	0.24	0.48
07/02/05	5.5	5.5	NA	0.8	0	3.7	16846100	293.9	7818870	27.1	306313	1.23	NA	0.49
07/03/05	4.8	4.8	NA	0	0	4.8	16929300	288.9	7826590	26.8	306386	1.18	NA	0.47
07/04/05	5.6	5.6	NA	0	0.8	2.6	17027800	293.2	7830260	23.5	306474	1.26	0.23	0.48
07/05/05	6.2	6.3	NA	0.7	0	3.9	17137500	290.2	7836640	27.3	306561	1.09	0.24	0.53
07/06/05	5.3	5.3	NA	0	0	5.3	17230700	293.1	7844950	26.1	306650	1.11	0.24	0.47
07/07/05	6.2	6.3	NA	0	0.7	3.1	17340200	289.7	7850010	27.2	306734	1.18	0.25	0.51
07/08/05	6.4	6.3	NA	0.8	0	3.1	17450800	292.6	7858300	44.6	306820	1.22	0.23	0.50
07/09/05	4.8	4.8	NA	0	0	6.9	17536700	298.3	7866340	19.4	306911	1.25	0.24	0.44
07/10/05	6.7	6.8	NA	0	0	4.9	17654300	288.2	7873270	23.6	307013	1.17	0.24	0.58
07/11/05	6.2	6.2	NA	0	0.8	0	17765900	300.0	7873270	NA	307105	1.16	0.22	0.50
07/12/05	7	7.0	NA	0.8	0	4.5	17886400	286.9	7880860	28.1	307204	1.13	0.25	0.49
07/13/05	7.8	7.9	NA	0	0.8	6	18023500	289.2	7888770	22.0	307316	0.42	0.24	0.50
07/14/05	5.7	5.7	NA	0	0	5.7	18124100	294.2	7898130	27.4	307412	0.95	0.24	0.49
07/15/05	10.2	10.2	NA	0.6	0	2.2	18302700	291.8	7904250	46.4	307561	0.87	0.23	0.50
07/16/05	7.3	NA	NA	0	0	7.9	18432100	NA	7913330	19.2	307683	0.86	0.24	0.52
07/17/05	8.7	16.1	NA	0	0	0	18584500	291.7	7913330	NA	307812	0.86	0.25	0.49
07/18/05	9.8	9.8	NA	0	0.8	2.3	18757700	294.6	7920120	49.2	307949	0.86	0.24	0.52
07/19/05	9.3	9.4	NA	0.6	0	7.1	18920200	288.1	7928150	18.8	308082	0.82	0.24	0.50
07/20/05	10.9	10.9	NA	0	0.7	0	19113900	296.2	7928280	NA	308240	0.88	0.24	0.53
07/21/05	10.1	10.2	NA	0	0	8.3	19290600	288.7	7941500	26.5	308400	0.84	0.26	0.50
07/22/05	12.3	12.3	NA	0	0	0	19507200	293.5	7941500	NA	308573	0.84	0.26	0.50
07/23/05	8.7	8.7	NA	0	0	8.5	19659800	292.3	7955190	26.8	308720	0.85	0.27	0.50

**Table A-1. Daily System Operation Log for Lidgerwood, ND (Continued) (Page 5 of 5)**

Date	Daily Plant Hours (hrs)	Well #1 (hrs)	Well #3 (hrs)	Backwash Pump #1 (hrs)	Backwash Pump #2 (hrs)	Reclaim Pump (hrs)	Raw Water		Reclaim Water		Treated Water	FeCl <sub>3</sub> (mg/L)	Aqua Hawk 9207 PWG (mg/L)	Aqua Hawk 127 (mg/L)
							(gal)	(gpm)	(gal)	(gpm)	(kgal)			
07/24/05	9.9	10.0	NA	0	0.8	7.2	19834600	291.3	7966930	27.2	308863	0.86	0.27	0.51
07/25/05	6.8	6.8	NA	0	0	NA	19954600	294.1	7969760	NA	308969	0.85	0.26	0.49
07/26/05	7.8	7.8	NA	0.8	0	4	20092100	293.8	7969760	NA	309078	0.84	0.25	0.49
07/27/05	7.9	7.9	NA	0	0.8	0	20230600	292.2	7969760	NA	309177	0.46	0.26	0.51
07/28/05	5.9	6.0	NA	0	0	NA	20336700	294.7	7979460	NA	309283	0.85	0.25	0.57
07/29/05	9.3	9.3	NA	0.8	0	7.4	20499700	292.1	7981670	5.0	309417	0.82	0.27	0.51
07/30/05	6.4	6.5	NA	0	0	6.4	20612300	288.7	7992110	27.2	309512	0.84	0.27	0.49
07/31/05	10.2	10.1	NA	0	0.7	7.3	20791500	295.7	8003920	27.0	309669	0.84	0.26	0.49

NA = Not Available

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

**Table B-1. Analytical Results from Treatment Plant Sampling at Lidgerwood, ND (Page 1 of 8)**

Sampling Date		01/04/05				01/11/05				01/18/05				01/25/05			
Sampling Location	Parameter	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC
Alkalinity	mg/L <sup>(a)</sup>	360	372	351	–	372	340	344	376	370	366	353	374	388	379	361	384
Fluoride	mg/L	0.2	0.3	0.3	–	–	–	–	–	–	–	–	–	–	–	–	–
Sulfate	mg/L	360	340	330	–	–	–	–	–	–	–	–	–	–	–	–	–
NO <sub>3</sub> (as N)	mg/L	<0.04	<0.04	<0.04	–	–	–	–	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L <sup>(b)</sup>	<0.06	<0.06	<0.06	–	<0.06	<0.06	<0.06	<0.06	0.2 <sup>(e)</sup>	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silica (as SiO <sub>2</sub> )	mg/L	31.5	31.3	31.1	–	31.7	31.2	30.1	31.3	30.0	25.6	29.6	30.2	29.0	29.3	29.4	28.6
Turbidity	NTU	17	4.8	0.4	–	18	5.4	0.4	0.4	18	6.1	<0.1	<0.1	17	5.3	2.0	0.2
pH	–	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	7.3	7.4	7.5	7.5	7.3	7.4	7.5	7.9	7.3	7.4	7.5	7.5
Temperature	°C	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	10.7	9.9	10.8	11.8	10.8	10.6	11.1	11.6	10.2	11.3	12.2	12.2
DO	mg/L	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	–	2.0	5.0	5.2	–	NA <sup>(d)</sup>	NA <sup>(d)</sup>	NA <sup>(d)</sup>	–	3.3	6.3	6.1	–
ORP	mV	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	–	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	–	-11	324	253	–	-26	423	360	–
Free Chlorine (as Cl <sub>2</sub> )	mg/L	–	–	–	NA <sup>(c)</sup>	–	–	–	NA <sup>(c)</sup>	–	–	–	0.1	–	–	–	0.1
Total Chlorine (as Cl <sub>2</sub> )	mg/L	–	–	–	NA <sup>(c)</sup>	–	–	–	NA <sup>(c)</sup>	–	–	–	1.8	–	–	–	4.1
Total Hardness	mg/L <sup>(a)</sup>	534	539	551	561	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L <sup>(a)</sup>	384	387	392	395	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L <sup>(a)</sup>	149	152	160	166	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	128	72.3	7.5	7.5	127	72.7	7.1	7.2	125	75.1	7.0	7.4	117	68.9	7.5	6.7
As (soluble)	µg/L	130	4.9	7.5	7.5	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	<0.1	67.4	<0.1	<0.1	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	130	0.9	0.9	–	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	<0.1	4.0	6.6	–	–	–	–	–	–	–	–	–	–	–	–	–
Fe (total)	µg/L	1,418	1,509	<25	<25	1,340	1,431	<25	<25	1,352	1,616	<25	<25	1,419	1,519	43.3	<25
Fe (soluble)	µg/L	1,356	<25	<25	<25	–	–	–	–	–	–	–	–	–	–	–	–
Mn (total)	µg/L	607	609	2.0	2.2	667	638	5.5	5.2	613	500	79.1	110	567	572	34.7	13.6
Mn (soluble)	µg/L	598	17.7	1.5	1.2	–	–	–	–	–	–	–	–	–	–	–	–

(a) as CaCO<sub>3</sub>; (b) as PO<sub>4</sub>; (c) On-site water quality parameter not measured; (d) DO probe not operational.

IN = at wellhead; BF = before filter; AF = after filter; PC = post-chlorination from clearwell (no speciation or DO/ORP measurements); NA = data not available.

**Table B-1. Analytical Results from Treatment Plant Sampling at Lidgerwood, ND (Page 2 of 8)**

Sampling Date		02/01/05				02/08/05				02/15/05				02/22/05			
Sampling Location	Parameter Unit	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC
Alkalinity	mg/L <sup>(a)</sup>	453	369	355	–	401	415	406	388	401	419	410	401	396	400	400	392
Fluoride	mg/L	0.2	0.3	0.2	–	–	–	–	–	–	–	–	–	–	–	–	–
Sulfate	mg/L	385	324	316	–	–	–	–	–	–	–	–	–	–	–	–	–
NO <sub>3</sub> (as N)	mg/L	<0.05	<0.05	<0.05	–	–	–	–	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L <sup>(b)</sup>	<0.05	<0.05	<0.05	–	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silica (as SiO <sub>2</sub> )	mg/L	29.6	29.1	29.1	–	30.9	30.3	30.5	31.3	32.9	30.0	32.0	31.7	31.0	29.6	30.3	30.8
Turbidity	NTU	14	6.3	<0.1	–	12	5.4	0.1	12	13	4.9	<0.1	0.5	18	4.9	0.2	<0.1
pH	–	7.3	7.4	7.4	7.5	7.3	7.5	7.5	7.6	7.3	7.5	7.5	7.6	7.3	7.5	7.5	7.5
Temperature	°C	11.2	12.1	12.2	12.3	10.5	11.0	11.5	11.0	9.5	10.3	11.3	11.2	9.3	10.3	10.8	11.0
DO	mg/L	1.7	6.1	6.0	–	1.6	6.0	5.8	–	3.4	5.8	5.5	–	1.8	5.7	5.9	–
ORP	mV	-24	395	340	–	-27	440	353	–	-23	366	274	–	-29	339	275	–
Free Chlorine (as Cl <sub>2</sub> )	mg/L	–	–	–	0.0	–	–	–	0.1	–	–	–	0.1	–	–	–	0.1
Total Chlorine (as Cl <sub>2</sub> )	mg/L	–	–	–	1.4	–	–	–	3.5	–	–	–	3.9	–	–	–	3.4
Total Hardness	mg/L <sup>(a)</sup>	552	585	567	591	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L <sup>(a)</sup>	392	414	401	418	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L <sup>(a)</sup>	159	171	165	173	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	151	59.2	7.6	7.4	125	81.3	8.7	9.2	131	73.4	7.8	7.9	126	75.0	8.0	8.4
As (soluble)	µg/L	146	6.6	7.4	7.6	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	4.9	52.7	0.2	<0.1	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	130	2.1	2.0	–	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	15.7	4.4	5.4	–	–	–	–	–	–	–	–	–	–	–	–	–
Fe (total)	µg/L	1,097	1,151	<25	<25	967	1,458	<25	<25	1,024	1,472	<25	<25	1,252	1,359	<25	<25
Fe (soluble)	µg/L	1,032	<25	<25	<25	–	–	–	–	–	–	–	–	–	–	–	–
Mn (total)	µg/L	824	637	10.2	15.7	606	653	3.9	8.4	695	700	3.1	6.9	670	634	2.5	3.0
Mn (soluble)	µg/L	868	31.1	10.7	10.4	–	–	–	–	–	–	–	–	–	–	–	–

(a) as CaCO<sub>3</sub>; (b) as PO<sub>4</sub>; IN = at wellhead; BF = before filter; AF = after filter; PC = post-chlorination from clearwell (no speciation or DO/ORP measurements); NA = data not available.



**Table B-1. Analytical Results from Treatment Plant Sampling at Lidgerwood, ND (Page 3 of 8)**

Sampling Date		03/01/05				03/08/05				03/15/05				03/22/05			
Sampling Location	Parameter	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC
Alkalinity	mg/L <sup>(a)</sup>	714	682	691	–	379	370	370	370	384	366	361	366	377	364	355	369
Fluoride	mg/L	0.1	0.2	0.2	–	–	–	–	–	–	–	–	–	–	–	–	–
Sulfate	mg/L	328	331	332	–	–	–	–	–	–	–	–	–	–	–	–	–
NO <sub>3</sub> (as N)	mg/L	0.05	<0.05	<0.05	–	–	–	–	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L <sup>(b)</sup>	<0.05	<0.05	<0.05	–	<0.05	<0.05	<0.05	<0.05	0.2 <sup>(c)</sup>	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silica (as SiO <sub>2</sub> )	mg/L	31.3	24.9	30.4	–	31.4	31.9	30.8	31.2	34.2	33.3	33.2	33.1	31.7	30.9	30.6	31.5
Turbidity	NTU	12	5.4	0.4	–	19	4.0	0.4	0.4	18	5.1	0.2	0.1	13	4.4	0.9	1.5
pH	–	7.3	7.4	7.5	7.6	7.3	7.4	7.4	7.5	7.3	7.4	7.4	7.5	7.3	7.3	7.3	7.4
Temperature	°C	9.5	10.4	10.8	10.5	9.6	10.3	10.6	10.7	9.7	10.5	10.7	11.0	9.8	10.1	10.6	11.4
DO	mg/L	2.0	5.4	5.7	–	2.7	5.3	5.5	–	2.3	5.1	5.3	–	1.3	5.0	4.8	–
ORP	mV	-22	432	256	–	-29	189	163	–	-29	456	306	–	-33	463	393	–
Free Chlorine (as Cl <sub>2</sub> )	mg/L	–	–	–	0.3	–	–	–	0.1	–	–	–	0.3	–	–	–	0.2
Total Chlorine (as Cl <sub>2</sub> )	mg/L	–	–	–	0.3	–	–	–	2.1	–	–	–	5.2	–	–	–	4.3
Total Hardness	mg/L <sup>(a)</sup>	452	416	425	445	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L <sup>(a)</sup>	321	290	301	317	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L <sup>(a)</sup>	130	126	124	128	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	144	100	10.3	10.3	158	94.9	9.2	9.2	133	84.0	6.3	7.0	132	79.5	8.4	8.8
As (soluble)	µg/L	135	7.4	8.8	9.8	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	9.3	92.8	1.6	0.5	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	124	1.8	1.9	–	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	11.5	5.6	6.8	–	–	–	–	–	–	–	–	–	–	–	–	–
Fe (total)	µg/L	1,116	1,584	<25	<25	1,503	1,777	<25	<25	1,366	1,731	<25	<25	1,517	1,555	<25	29.0
Fe (soluble)	µg/L	1,124	<25	<25	–	–	–	–	–	–	–	–	–	–	–	–	–
Mn (total)	µg/L	748	714	3.4	3.5	624	744	18.2	15.2	733	830	5.7	6.1	962	1,031	64.2	76.0
Mn (soluble)	µg/L	807	7.2	3.5	–	–	–	–	–	–	–	–	–	–	–	–	–

(a) as CaCO<sub>3</sub>; (b) as PO<sub>4</sub>; (c) Orthophosphate levels non-detect based on total phosphorous data from ICP-MS. This value considered as an outlier and not included in review of the water quality. IN = at wellhead; BF = before filter; AF = after filter; PC = post-chlorination from clearwell (no speciation or DO/ORP measurements); NA = data not available.

**Table B-1. Analytical Results from Treatment Plant Sampling at Lidgerwood, ND (Page 4 of 8)**

Sampling Date		03/29/05				04/05/05				04/12/05				04/18/05			
Sampling Location	Parameter	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC
Alkalinity	mg/L <sup>(a)</sup>	376	352	352	354	418	409	405	–	417	404	400	413	424 422	424 400	413 400	401 400
Fluoride	mg/L	–	–	–	–	0.2	0.6	0.4	–	–	–	–	–	–	–	–	–
Sulfate	mg/L	–	–	–	–	323	309	309	–	–	–	–	–	–	–	–	–
NO <sub>3</sub> (as N)	mg/L	–	–	–	–	<0.05	<0.05	<0.05	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L <sup>(b)</sup>	<0.05	<0.05	0.28 <sup>(d)</sup>	<0.05	<0.05	<0.05	<0.05	–	<0.05	<0.05	<0.05	<0.05	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05	<0.05 <0.05
Silica (as SiO <sub>2</sub> )	mg/L	31.4	31.2	29.3	30.6	31.3	32.9	30.5	–	32.0	32.1	31.1	31.6	32.0 31.9	31.4 32.1	31.7 31.3	31.9 31.7
Turbidity	NTU	16	3.1	0.2	1.3	12	5.2	0.2	–	11	4.8	0.2	1.2	13 12	5.4 5.7	0.8 0.2	0.1 0.2
pH	–	7.4	7.4	7.4	7.5	7.6	7.4	7.4	7.5	7.4	7.4	7.4	7.5	7.4	7.5	7.5	7.6
Temperature	°C	10.0	11.2	11.4	11.0	10.2	10.5	11.3	11.7	10.1	10.6	11.0	11.8	9.9	10.5	10.9	11.2
DO	mg/L	3.4	5.1	5.0	–	3.6	4.8	4.7	–	2.8	4.8	4.9	–	3.1	4.6	4.7	–
ORP	mV	-35	387	383	–	-31	378	270	–	-27	248	193	–	-30	391	271	–
Free Chlorine (as Cl <sub>2</sub> )	mg/L	–	–	–	0.1	–	–	–	0.1	–	–	–	0.2	–	–	–	0.1
Total Chlorine (as Cl <sub>2</sub> )	mg/L	–	–	–	8.0 <sup>(c)</sup>	–	–	–	3.3	–	–	–	3.9	–	–	–	3.7
Total Hardness	mg/L <sup>(a)</sup>	–	–	–	–	451	454	483	467	–	–	–	–	–	–	–	–
Ca Hardness	mg/L <sup>(a)</sup>	–	–	–	–	333	322	345	342	–	–	–	–	–	–	–	–
Mg Hardness	mg/L <sup>(a)</sup>	–	–	–	–	118	131	137	125	–	–	–	–	–	–	–	–
As (total)	µg/L	126	60.4	7.5	7.1	132	105	9.2	7.3	127	86.4	8.0	7.6	138 114	95.9 94.0	10.6 12.5	13.0 14.0
As (soluble)	µg/L	–	–	–	–	124	6.6	8.3	7.9	–	–	–	–	–	–	–	–
As (particulate)	µg/L	–	–	–	–	7.3	98.0	0.9	<0.1	–	–	–	–	–	–	–	–
As (III)	µg/L	–	–	–	–	125	3.5	3.1	–	–	–	–	–	–	–	–	–
As (V)	µg/L	–	–	–	–	<0.1	3.1	5.2	–	–	–	–	–	–	–	–	–
Fe (total)	µg/L	1,454	1,243	<25	<25	1,163	1,700	<25	<25	1,076	1,612	<25	<25	1,209 1,065	1,929 1,787	29.2 29.8	188 194
Fe (soluble)	µg/L	–	–	–	–	532	<25	<25	<25	–	–	–	–	–	–	–	–
Mn (total)	µg/L	1,067	562	2.5	28.2	761	824	1.3	5.1	707	709	2.5	38.6	754 658	891 908	11.2 9.9	1.6 2.2
Mn (soluble)	µg/L	–	–	–	–	762	24.6	1.1	4.9	–	–	–	–	–	–	–	–

(a) as CaCO<sub>3</sub>; (b) as PO<sub>4</sub>; (c) Chlorine rotometers plugged during prior operations. Total chlorine levels adjusted higher after repair; (d) Orthophosphate levels non-detect based on total phosphorous data from ICP-MS. This value considered as an outlier and not included in review of the water quality. IN = at wellhead; BF = before filter; AF = after filter; PC = post-chlorination from clearwell (no speciation or DO/ORP measurements); NA = data not available.

**Table B-1. Analytical Results from Treatment Plant Sampling at Lidgerwood, ND (Page 5 of 8)**

Sampling Date		04/26/05				05/03/05				05/11/05				05/17/05			
Sampling Location	Parameter	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC
Alkalinity	mg/L <sup>(a)</sup>	422	405	409	408	408	395	408	–	383	370	378	365	387	374	374	370
Fluoride	mg/L	–	–	–	–	0.2	0.3	0.3	–	–	–	–	–	–	–	–	–
Sulfate	mg/L	–	–	–	–	372	348	367	–	–	–	–	–	–	–	–	–
NO <sub>3</sub> (as N)	mg/L	–	–	–	–	<0.05	<0.05	<0.05	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L <sup>(b)</sup>	0.07 <sup>(d)</sup>	0.07 <sup>(d)</sup>	<0.05	0.07 <sup>(d)</sup>	<0.05	<0.05	<0.05	–	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silica (as SiO <sub>2</sub> )	mg/L	32.6	32.0	30.9	32.4	31.2	30.5	30.1	–	31	31.4	30.0	31.3	30.9	31.1	30.6	31.6
Turbidity	NTU	3.5	3.5	0.2	0.3	15	3.8	0.3	–	17	3.7	0.2	0.7	15	4.0	0.4	0.3
pH	–	7.4	7.4	7.4	7.5	7.2	7.3	7.3	7.4	7.4	7.4	7.4	7.5	7.4	7.3	7.4	7.5
Temperature	°C	10.1	11.0	11.3	11.6	10.1	10.7	11.0	11.4	9.7	10.6	11.6	11.8	10.3	10.9	11.5	12.0
DO	mg/L	2.2	4.6	4.6	–	2.2	4.4	4.3	–	2.5	4.3	4.3	–	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	–
ORP	mV	-32	363	264	–	-34	334	267	–	-33	315	258	–	-37	254	185	–
Free Chlorine (as Cl <sub>2</sub> )	mg/L	–	–	–	0.3	–	–	–	0.1	–	–	–	0.4	–	–	–	0.1
Total Chlorine (as Cl <sub>2</sub> )	mg/L	–	–	–	4.0	–	–	–	4.1	–	–	–	3.7	–	–	–	2.5
Total Hardness	mg/L <sup>(a)</sup>	–	–	–	–	502	504	467	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L <sup>(a)</sup>	–	–	–	–	351	351	326	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L <sup>(a)</sup>	–	–	–	–	151	154	141	–	–	–	–	–	–	–	–	–
As (total)	µg/L	137	70.0	9.9	9.7	134	64.4	7.6	8.4	134	82.0	7.3	6.0	120	67.6	6.8	7.0
As (soluble)	µg/L	–	–	–	–	137	4.3	7.4	8.2	–	–	–	–	–	–	–	–
As (particulate)	µg/L	–	–	–	–	<0.1	60.1	0.3	0.2	–	–	–	–	–	–	–	–
As (III)	µg/L	–	–	–	–	122	1.0	1.0	–	–	–	–	–	–	–	–	–
As (V)	µg/L	–	–	–	–	14.8	3.3	6.3	–	–	–	–	–	–	–	–	–
Fe (total)	µg/L	1,128	1,184	<25	<25	1,557	1,583	<25	<25	1,300	1,433	<25	<25	1,463	1,435	<25	<25
Fe (soluble)	µg/L	–	–	–	–	1,524	<25	<25	<25	–	–	–	–	–	–	–	–
Mn (total)	µg/L	695	495	4.1	6.6	668	535	3.1	1.6	627	538	1.1	0.9	646	509	1.1	1.9
Mn (soluble)	µg/L	–	–	–	–	652	5.8	1.5	1.9	–	–	–	–	–	–	–	–

(a) as CaCO<sub>3</sub>; (b) as PO<sub>4</sub>; (c) DO probe not working properly; (d) Orthophosphate levels non-detect based on total phosphorous data from ICP-MS. This value considered as an outlier and not included in review of the water quality. IN = at wellhead; BF = before filter; AF = after filter; PC = post-chlorination from clearwell (no speciation or DO/ORP measurements); NA = data not available.

**Table B-1. Analytical Results from Treatment Plant Sampling at Lidgerwood, ND (Page 6 of 8)**

Sampling Date		05/24/05				05/31/05				06/07/05				06/14/05			
Sampling Location Parameter	Unit	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC
Alkalinity	mg/L <sup>(a)</sup>	384	366	375	379	390	381	376	372	414	396	427	396	414	409	396	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.1	0.2	0.2	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	355	352	367	-
NO <sub>3</sub> (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	0.1	0.2	-
Orthophosphate	mg/L <sup>(b)</sup>	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-
Silica (as SiO <sub>2</sub> )	mg/L	30.8	30.5	29.8	30.8	31.4	30.6	29.7	30.9	31.5	31.2	31.1	31.7	32.2	31.5	30.8	-
Turbidity	NTU	16	3.8	0.5	0.4	18	4.5	0.3	0.3	23	4.3	<0.1	0.1	14	4.7	0.1	-
pH	-	7.3	7.3	7.3	7.4	7.4	7.3	7.3	7.4	7.3	7.4	7.3	7.5	7.3	7.3	7.3	7.4
Temperature	°C	10.4	11.1	10.8	11.4	9.7	10.6	10.7	11.4	9.8	11.1	11.2	11.4	10.1	10.7	11.3	11.8
DO	mg/L	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	-	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	-	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	-	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	-
ORP	mV	-36	286	179	-	-35	308	197	-	-29	236	294	-	-31	320	233	-
Free Chlorine (as Cl <sub>2</sub> )	mg/L	-	-	-	0.2	-	-	-	0.1	-	-	-	0.1	-	-	-	0.2
Total Chlorine (as Cl <sub>2</sub> )	mg/L	-	-	-	3.0	-	-	-	3.0	-	-	-	3.7	-	-	-	3.5
Total Hardness	mg/L <sup>(a)</sup>	-	-	-	-	-	-	-	-	-	-	-	-	481	426	403	404
Ca Hardness	mg/L <sup>(a)</sup>	-	-	-	-	-	-	-	-	-	-	-	-	335	312	273	274
Mg Hardness	mg/L <sup>(a)</sup>	-	-	-	-	-	-	-	-	-	-	-	-	146	113	130	130
As (total)	µg/L	118	62.7	6.5	6.6	113	69.4	8.3	6.1	128	66.1	8.3	8.1	139	73.0	8.9	9.0
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	134	5.8	9.0	9.6
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	4.8	67.2	<0.1	<0.1
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	128	2.9	3.1	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	6.2	2.9	5.9	-
Fe (total)	µg/L	2,606	2,389	<25	<25	1,476	1,625	<25	<25	737	801	<25	<25	1,341	1,370	<25	<25
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	1,154	<25	<25	<25
Mn (total)	µg/L	672	535	1.6	5.8	666	585	4.5	4.1	606	452	1.6	1.8	683	637	3.8	6.7
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	617	24.2	3.1	6.6

(a) as CaCO<sub>3</sub>; (b) as PO<sub>4</sub>; (c) DO probe not working properly. IN = at wellhead; BF = before filter; AF = after filter; PC = post-chlorination from clearwell (no speciation or DO/ORP measurements); NA = data not available.

**Table B-1. Analytical Results from Treatment Plant Sampling at Lidgerwood, ND (Page 7 of 8)**

Sampling Date		06/21/05				06/28/05				07/06/05 <sup>(d)</sup>				07/12/05			
Sampling Location	Parameter Unit	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC	IN	BF	AF	PC
Alkalinity	mg/L <sup>(a)</sup>	396	387	396	396	396	378	374	374	352	352	352	352	352	352	352	–
Fluoride	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	<0.1	0.2	0.2	–
Sulfate	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	349	348	348	–
NO <sub>3</sub> (as N)	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	<0.05	0.06	0.05	–
Orthophosphate	mg/L <sup>(b)</sup>	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	–
Silica (as SiO <sub>2</sub> )	mg/L	30.4	30.2	30.3	30.0	30.8	30.9	30.2	30.5	31.2	28.8	31.2	31.2	29.5	29.3	28.8	–
Turbidity	NTU	13	4.9	0.7	0.3	19	14	7.1	16	20	6.2	0.3	0.4	20	7.3	1.2	–
pH	–	7.3	7.4	6.4	7.5	7.4	7.3	7.4	7.5	7.4	7.3	7.3	7.4	7.2	7.2	7.2	7.4
Temperature	°C	10.1	10.5	11.2	11.9	10.1	10.7	11.4	11.9	9.8	10.5	11.1	11.9	10.1	11.1	11.0	11.5
DO	mg/L	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	–	NA <sup>(c)</sup>	NA <sup>(c)</sup>	NA <sup>(c)</sup>	–	4.1	6.0	6.0	–	2.2	6.1	6.1	–
ORP	mV	-13	251	186	–	-28	319	213	–	-32	284	172	–	-34	190	260	–
Free Chlorine (as Cl <sub>2</sub> )	mg/L	–	–	–	0.1	–	–	–	0.6	–	–	–	0.1	–	–	–	0.1
Total Chlorine (as Cl <sub>2</sub> )	mg/L	–	–	–	2.0	–	–	–	3.8	–	–	–	4.0	–	–	–	1.4
Total Hardness	mg/L <sup>(a)</sup>	–	–	–	–	–	–	–	–	–	–	–	–	526	564	527	516
Ca Hardness	mg/L <sup>(a)</sup>	–	–	–	–	–	–	–	–	–	–	–	–	374	405	379	369
Mg Hardness	mg/L <sup>(a)</sup>	–	–	–	–	–	–	–	–	–	–	–	–	152	158	148	147
As (total)	µg/L	147	99.2	14.3	11.6	136	87.7	11.4	10.2	124	92.0	7.0	6.5	125	77.3	8.6	8.4
As (soluble)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	117	5.7	3.7	8.3
As (particulate)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	8.3	71.6	4.9	0.1
As (III)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	116	<0.1	<0.1	–
As (V)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	1.0	5.6	3.6	–
Fe (total)	µg/L	1,078	1,563	64.4	<25	965	1,340	<25	<25	1,486	1,947	<25	<25	1,779	1,928	<25	<25
Fe (soluble)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	1,480	<25	105	<25
Mn (total)	µg/L	681	690	27.1	8.7	657	612	3.6	1.9	679	789	4.5	3.3	778	642	146	162
Mn (soluble)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	647	9.9	52.1	146

(a) as CaCO<sub>3</sub>; (b) as PO<sub>4</sub>; (c) DO probe not working properly; (d) Replacement DO probe received. IN = at wellhead; BF = before filter; AF = after filter; PC = post-chlorination from clearwell (no speciation or DO/ORP measurements); NA = data not available.

**Table B-1. Analytical Results from Treatment Plant Sampling at Lidgerwood, ND (Page 8 of 8)**

Sampling Date		07/19/05				07/25/05			
Sampling Location	Parameter	IN	BF	AF	PC	IN	BF	AF	PC
Alkalinity	mg/L <sup>(a)</sup>	361	352	352	352	361	334	339	348
Fluoride	mg/L	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-
NO <sub>3</sub> (as N)	mg/L	-	-	-	-	-	-	-	-
Orthophosphate	mg/L <sup>(b)</sup>	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silica (as SiO <sub>2</sub> )	mg/L	31.3	31.2	30.3	31.0	29.8	28.6	29.2	29.5
Turbidity	NTU	20	5.3	0.3	0.2	20	4.8	<0.1	0.4
pH	-	7.3	7.4	7.5	7.5	7.4	7.5	7.4	7.6
Temperature	°C	9.7	10.4	10.9	11.4	10.2	10.9	11.1	11.7
DO	mg/L	2.5	6.4	6.2	-	3.2	6.4	6.4	-
ORP	mV	-22	320	215	-	-23	330	228	-
Free Chlorine (as Cl <sub>2</sub> )	mg/L	-	-	-	0.1	-	-	-	0.1
Total Chlorine (as Cl <sub>2</sub> )	mg/L	-	-	-	4.0	-	-	-	4.2
Total Hardness	mg/L <sup>(a)</sup>	-	-	-	-	-	-	-	-
Ca Hardness	mg/L <sup>(a)</sup>	-	-	-	-	-	-	-	-
Mg Hardness	mg/L <sup>(a)</sup>	-	-	-	-	-	-	-	-
As (total)	µg/L	119	96.5	9.0	8.4	115	80.0	8.6	8.1
As (soluble)	µg/L	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-
Fe (total)	µg/L	1,472	1,795	<25	<25	1,763	1,776	<25	<25
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-
Mn (total)	µg/L	567	959	8.5	5.4	687	627	2.2	2.3
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-

(a) as CaCO<sub>3</sub>; (b) as PO<sub>4</sub>; I IN = at wellhead; BF = before filter; AF = after filter; PC = post-chlorination from clearwell (no speciation or DO/ORP measurements); NA = data not available.