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Arsenic Removal from Drinking Water by Iron Removal and Adsorptive Media U.S. EPA Demonstration Project at Stewart, MN Final Performance Evaluation Report

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Sally Gutierrez, Director
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ABSTRACT

This report documents the activities performed and the results obtained from the 1-year U.S. Environmental Protection Agency (EPA) arsenic-removal technology demonstration project at the Stewart, MN, facility. The main objective of the project was to evaluate the effectiveness of Siemens' Type II AERALATER® system for iron removal, as well as AdEdge Technologies' Arsenic Package Unit (APU)-300 system for subsequent arsenic removal, whose effectiveness was evaluated based on its ability to remove arsenic to below the new arsenic maximum contaminant level (MCL) of 10 μg/L. This project also (1) evaluated the reliability of the treatment system for use at small water facilities, (2) determined the required system operation and maintenance (O&M) and operator skill levels, (3) characterized process residuals generated by the treatment process, and (4) determined the capital and O&M cost of the technology. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), process residuals, and capital and O&M cost.

The 250 gal/min (gpm) treatment system consisted of an AERALATER® pretreatment unit and an arsenic package unit (APU)-300 arsenic removal unit. Used for iron removal, the 11-ft × 26-ft carbon-steel AERALATER® package unit was composed of an aeration tower, a detention tank, and a four-cell gravity filter in one stacked circular configuration. The effluent from the gravity filter was subsequently polished with AD-33 media, an iron-based adsorptive media developed by Bayer AG for arsenic removal. The APU-300 system consisted of two skid-mounted 63-in × 86-in fiberglass vessels configured in parallel. Each vessel contained 64 ft^3 of pelletized AD-33 media supported by gravel underbedding.

The treatment system began routine operation on February 2, 2006. Through the end of the performance evaluation study on February 28, 2007, the system treated approximately 20,441,000 gal of water with an average run time of 4.7 hr/day. The average daily demand was 52,418 gal. Water to the treatment system was supplied by two wells (Wells No. 3 and 4), each operating at an average flowrate of 191 and 184 gpm, respectively, on an alternating basis. These reduced flowrates resulted in longer detention times (45 to 46 min versus the design value of 34 min) within the AERALATER® detention tank and lower hydraulic loading rates (2.0 to 1.9 gpm/ft^2 versus the design value of 2.6 gpm/ft^2) to the gravity filter. The corresponding flowrates measured through the APU-300 system also resulted in longer empty bed contact time (EBCT) (5.4 min compared to the design value of 3.8 min) in each vessel. No significant operational or mechanical issues were experienced during the 1-year performance evaluation study period. However, 4 months after the end of the performance evaluation study, the operator reported biofouling of the AERALATER® filter that necessitated the use of chlorine to clean the filter media and re-injection of a previously selected, but later abandoned oxidant (sodium permanganate [$NaMnO_4$]), to oxidize soluble As(III).

The source water contained 31.4 to 56.4 μg/L of total arsenic, with soluble As(III) at an average concentration of 35.3 μg/L as the predominant species. To oxidize soluble As(III), $NaMnO_4$ was selected due to the presence of elevated total organic carbon (TOC) (6.4 mg/L on average) and ammonia levels (1.6 mg/L [as N] on average) in raw water. Based on February 2, 2006, data, 90% of soluble As(III) was oxidized to soluble As(V) when $NaMnO_4$ was added prior to aeration. Soluble As(V) was then adsorbed onto and/or co-precipitated with iron solids, resulting in 57% soluble As(V) removal. The arsenic-laden iron solids were effectively removed by the gravity filter, achieving approximately 60% total arsenic and 100% total iron removal. The remaining arsenic was present mostly as soluble As(V) at 26.4 μg/L (on average), which was subsequently removed by AD-33 media. The elevated soluble As(V) in the gravity filter effluent was most likely caused by the relatively high levels of pH (7.9 on average), competing anions (such as phosphorous [301 μg/L (as P) on average] and silica [25.1 mg/L (as SiO_2) on average]), and TOC in source water.

After one week of operation, $NaMnO_4$ addition was inadvertently discontinued due to problems with the chemical feed pump. It was subsequently decided to operate the system without $NaMnO_4$ addition due to the discovery of microbial-mediated As(III) oxidation processes and elevated manganese levels (e.g., 127 μg/L on February 2, 2006) in the gravity filter effluent. The elevated manganese concentrations in the gravity filter effluent were attributed to the formation of colloidal MnO_2 in the presence of TOC (Knocke et al., 1991). Elevated manganese levels have been shown to be detrimental to AD-33 media based on studies at other EPA demonstration sites, where high manganese loadings were found to coat and/or foul AD-33 media in the presence of chlorine (Oxenham et al., 2005).

Without $NaMnO_4$ addition, the total arsenic removal rate averaged 34%, and the iron removal rate was 100% across the gravity filter. The oxidation of Fe(II) was accomplished through aeration. It also was observed that the oxidation of soluble As(III) to soluble As(V) was occurring at a rate of over 94% across the gravity filter via naturally occurring microbial-mediated processes, with only 1.6 μg/L of soluble As(III) in the filter effluent (on average). Nitrification also was observed within the gravity filter, but was not related to the microbially mediated processes as noted. The soluble As(V) concentration averaged 26.4 μg/L after the gravity filter, which is comparable to the vendor's design estimate of 20 to 27 μg/L of arsenic after the gravity filter and before the AD-33 adsorption system. Therefore, the arsenic removal rate without $NaMnO_4$ was within the vendor's design basis of 30% to 50% across the gravity filter.

With or without the addition of $NaMnO_4$, soluble As(V) remained above 10 μg/L in the gravity filter effluent, thus requiring further treatment with the APU-300 unit. The arsenic concentration in the APU-300 system effluent was below 10 μg/L during the 1-year performance study. Based on compliance samples collected after the end of the study and average daily production values, the AD-33 media run length was estimated at 25,300 bed volumes (BV) of water, which was only 31% of the vendor-projected APU-300 capacity of 82,500 BV. As discussed above, the total arsenic-removal efficiency of the gravity filter was reduced from approximately 60% to 34% after discontinuing $NaMnO_4$ addition, which shifted the burden of arsenic removal from the gravity filter to the downstream adsorption vessels. However, as mentioned above, the average concentration of soluble As(V) (26.4 μg/L) in the gravity filter effluent (without $NaMnO_4$ addition) was close to the design basis of 20 to 27 μg/L in the influent to the APU-300 system. Therefore, the reason for the discrepancy in run length was attributed, in part, to competition from elevated total phosphorous in the source water, which was not accounted for in the vendor's run-length estimate. Biofouling in the adsorption vessels also might have contributed to the short run length.

AERALATER® backwash was manually initiated weekly by the operator. The APU-300 system was backwashed manually four times during the 1-year performance evaluation study. Approximately 406,400 gal of wastewater, or 2% of the quantity of the treated water, was generated during the 1-year performance study from the AERALATER®. The AERALATER® backwash wastewater contained, on average, 87 mg/L of total suspended solids (TSS), 38 mg/L of iron, 343 μg/L of arsenic, and 57 μg/L of manganase, with the majority existing as particulate. The average amount of solids discharged per backwash cycle was approximately 5.5 lb, which was composed of 2.4 lb of elemental iron, 0.002 lb of elemental manganese, and 0.02 lb of elemental arsenic. In addition, 25,415 gal of wastewater were generated by the APU-300 unit, or 0.1% of the quantity of treated water.

Comparison of the distribution system sampling results before and after system startup showed a significant decrease in arsenic concentration from an average of 31.2 to 6.1 μg/L. The arsenic concentrations in the distribution system, however, were generally higher than those following the AD-33 adsorption vessels. Desorption and resuspension of arsenic that previously accumulated on the distribution pipe surfaces was the probable reason for the higher concentration in the distribution system. Iron concentration in the distribution system was significantly reduced, while manganese levels appeared to remain the same after system startup. Both lead and copper concentrations in the distribution system were significantly lower than their action levels.

The capital investment for the system was $367,838: consisting of $273,873 for equipment, $16,520 for site engineering, and $77,445 for installation, shakedown, and startup. Using the system's rated capacity of 250 gpm or 360,000 gal/day (gpd), the capital cost was $1,471 per gpm of design capacity ($1.02/gpd). This calculation did not include the cost of the building to house the treatment system. The O&M cost consisted primarily of the media replacement cost, which was estimated by the vendor at $41,370, to change out the AD-33 media. Media changeout did not occur during the performance evaluation period. The O&M cost is presented as a function of potential media run length in this report.

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FIGURES

TABLES

ABBREVIATIONS AND ACRONYMS

AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
APU	arsenic package unit
As	arsenic
ATS	Aquatic Treatment Systems
BET	Brunauer, Emmett, and Teller Method
bgs	below ground surface
BV	bed volume(s)
Ca	calcium
CAO	chemolithoautotrophic arsenite oxidizer
C/F	coagulation/filtration
cfm	cubic foot per minute
Cl	chlorine
CRF	capital recovery factor
Cu	copper
DBP	disinfection byproducts
DO	dissolved oxygen
DOM	dissolved organic matter
EBCT	empty bed contact time
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
FedEx	Federal Express
GCSP	Greene County Southern Plant
GFH	granular ferric hydroxide
gpd	gallons per day
gpm	gallons per minute
gph	gallons per hour
HAA5	haloacetic acids
HAO	heterotrophic arsenite oxidizers
HIX	hybrid ion exchanger
H_2SO_4	sulfuric acid
hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IX	ion exchange
kgal	kilo gallons
$KMnO_4$	potassium permanganate
LCR	(EPA) Lead and Copper Rule

MCL	maximum contaminant level
MEI	Magnesium Elektron, Inc.
MDH	Minnesota Department of Health
MDL	method detection limit
Mg	magnesium
µm	micrometer
Mn	manganese
mV	millivolts
Na	sodium
NA	not applicable
ND	not detected
NS	not sampled
NSF	NSF International
NTU	nephelometric turbidity units
O&M	operation and maintenance
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
P&ID	process and instrumentation diagram
Pb	lead
pCi	pico curie
psi	pounds per square inch
PLC	programmable logic controller
PO_4	orthophosphate
POE	point of entry
POU	point of use
PVC	polyvinyl chloride
QA	quality assurance
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RO	reverse osmosis
RPD	relative percent difference
Sb	antimony
SDWA	Safe Drinking Water Act
SiO_2	silica
SMCL	secondary maximum contaminant level
SO_4	sulfate
STS	Severn Trent Services
TCLP	Toxicity Characteristic Leaching Procedure
TDH	total dynamic head
TDS	total dissolved solids
THM	trihalomethanes
TOC	total organic carbon
TSS	total suspended solids

V	vanadium
VOC	volatile organic compound

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1.0 INTRODUCTION

1.1 Background

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

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

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

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

In September 2003, EPA again solicited proposals from engineering firms and vendors for arsenic-removal technologies. EPA received 148 technical proposals for the 32 host sites, with each site receiving from two to eight proposals. In April 2004, EPA convened another technical panel to review the proposals and provide recommendations to EPA; the number of proposals per site ranged from none (for two sites) to a maximum of four. Final selection of the treatment technology at sites receiving at least one proposal was made, again through a joint effort by EPA, the state regulators, and the host site. Since then, four sites have withdrawn from the demonstration program, reducing the number of sites to 28. Two technologies were selected for demonstration at the Stewart, MN, facility, including Siemens' (formerly known as USFilter) Type II AERALATER® for iron removal, followed by AdEdge Technologies' AD-33 adsorptive media for arsenic removal.

As of December 2009, 39 of the 40 systems were operational, and the performance evaluation of 34 systems was completed.

1.2 Treatment Technologies for Arsenic Removal

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

1.3 Project Objectives

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

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

This report summarizes the performance of the Siemens' Type II AERALATER® and AdEdge Arsenic Package Unit (APU)-300 systems at Stewart, MN, during February 2, 2006, through February 28, 2007. The types of data collected included 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 Rounds 1 and 2 Arsenic-Removal Demonstration Sites

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

Table 1-1. Summary of Rounds 1 and 2 Arsenic-Removal Demonstration Sites (Continued)

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

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

(a) Arsenic existing mostly as As(III).
(b) Design flowrate reduced by 50% due to system reconfiguration from parallel to series operation.
(c) Iron existing mostly as Fe(II).
(d) Withdrew from program in 2007. Selected originally to replace Village of Lyman, NE site, which withdrew from program in June 2006.
(e) Facilities upgraded systems in Springfield, OH, from 150 to 250 gpm; Sandusky, MI, from 210 to 340 gpm; and Arnaudville, LA, from 385 to 770 gpm.
(f) Including nine residential units.
(g) Including eight under-the-sink units.

2.0 SUMMARY AND CONCLUSIONS

The Siemens AERALATER® and AdEdge Technologies AD-33 APU-300 units were installed and have operated at Stewart, MN, since February 2, 2006. Based on the information collected during the 1-year performance evaluation study from February 2, 2006 to February 28, 2007, the following conclusions were drawn relating to the overall objectives of the treatment technology demonstration study.

Performance of the arsenic removal technology:

- Aeration was effective in oxidizing soluble iron, converting 100% of it to iron solids. However, aeration was only minimally effective in oxidizing soluble As(III), converting 25.8% (on average) of soluble As(III) to soluble As(V) and particulate arsenic.
- $NaMnO_4$ was effective in oxidizing As(III), converting over 90% of soluble As(III) to soluble As(V) and particulate arsenic. Of the As(V) in the contact section of the AERALATER®, only 57% became attached to iron solids formed during the preoxidation step, presumably via adsorption and co-precipitation. The relatively low As(V) removal rate was most likely the result of the relatively elevated pH (i.e., 7.9), competing anions (such as 301 µg/L of total phosphorous [as P] and 25.1 mg/L of Si [as SiO_2]), and total organic carbon [TOC] (6.4 mg/L) in source water.
- $NaMnO_4$ addition resulted in elevated manganese levels in the gravity filter effluent, which were attributed to colloidal MnO_2 formation in the presence of high TOC levels.
- Upon discontinuation of $NaMnO_4$ addition, naturally occurring microbial-mediated pathways were thought to be responsible for the oxidation of over 94% of soluble As(III) within the AERALATER® filter, leaving only 1.6 µg/L of soluble As(III) in the filter effluent. Nitrification also occurred within the gravity filter and AD-33 adsorption vessels. Oxygen, instead of nitrate, was believed to be the electron acceptor for the microbial-mediated As(III) oxidation processes observed.
- The AERALATER® filter was highly effective in removing particulate matter. Without $NaMnO_4$ addition, 34% of total arsenic was removed, compared to 60% removed with $NaMnO_4$ addition. Aeration alone in the AERALATER® system was sufficient to accomplish complete iron removal. No particulate iron breakthrough was observed from the AERALATER® filter, suggesting adequate filter backwash frequency.
- AD-33 media effectively removed arsenic to below 10 µg/L during the 1-year performance study. Based on compliance samples collected after the end of the study and average daily production values, the media run length was estimated at 25,300 bed volumes (BV), which was only 31% of the vendor-projected run length of 82,500 BV. Competition from phosphorous in source water might have contributed, in part, to the short run length.
- Due to biofouling in the gravity filter and APU-300 system, the city used chlorine after the demonstration study to restore the hydraulic capacity of the gravity filter; $NaMnO_4$ addition was re-started, along with a blending scheme to send only a portion of the gravity-filter-treated water to the APU-300 system.
- The treatment system improved the water quality in the distribution system with considerable decreases in arsenic (from 31.2 to 6.1 µg/L) and iron (from 376 to 112 µg/L) concentrations. However, arsenic concentrations were higher in the distribution system than in the treatment plant effluent, suggesting desorption and resuspension of arsenic from pipe surfaces.

Required system operation and maintenance and operator's skill levels:

- Daily operation of the system did not require additional skills beyond those necessary to operate existing water-supply equipment. The daily demand on the operator was only 10 min/day for routine operations.
- Because the system was backwashed only once a week, manual backwash was acceptable to the plant operator. The time required was 31 min per backwash event.
- Biofouling, observed 4 months after the end of the study period, required using chlorine to clean up the gravity filter. $NaMnO_4$ addition alone could not control biofouling and some periodic chlorination would be required. The high TOC and ammonia levels at the site limited the use of chlorine on a continual basis due to the potential for disinfection by-products (DBP) formation.

Characteristics of residuals produced by the technology:

- Residuals produced by operation of the treatment system included only backwash wastewater from the AERALATER® gravity filter and the AD-33 adsorption vessels. The media was not replaced during the 1-year performance evaluation study.
- The amount of wastewater produced was equivalent to about 2.1% of the amount of water treated (406,400 gal or 2% from the AERALATER® and 25,415 gal or 0.1% from the APU-300 unit).
- The amount of solids produced per filter backwash cycle was 5.5 lb, which included 2.4 lb of elemental iron, 0.02 lb of elemental arsenic, and 0.002 lb of elemental manganese.

Cost-effectiveness of the technology:

- The capital investment for the system was $367,838: $273,873 for equipment, $16,520 for site engineering, and $77,445 for installation, shakedown, and startup. The building cost incurred by the City of Stewart was not included in the capital investment cost.
- Using the system’s rated capacity of 250 gpm, or 360,000 gpd, the capital cost was $1,471/gpm ($1.02/gpd) of design capacity.
- Although not incurred during the 1-year performance study, the AD-33 media replacement cost would be the majority of the O&M cost for the system and was estimated to be $41,370.

3.0 MATERIALS AND METHODS

3.1 General Project Approach

Table 3-1 summarizes the pre-demonstration and demonstration study activities and completion dates. Following the pre-demonstration activities, the performance evaluation study of the treatment system began on February 2, 2006. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall system performance was evaluated based on its ability to consistently remove arsenic to below the target MCL of 10 μg/L through the collection of water samples across the treatment train. The reliability of the system was evaluated by tracking the unscheduled system downtime and the frequency and extent of repair and replacement. The plant operator recorded unscheduled downtime and repair information on a Repair and Maintenance Log Sheet.

Table 3-1. Pre-demonstration and Demonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	08/30/04
Draft Letter of Understanding Issued	11/18/04
Final Letter of Understanding Issued	12/10/04
Request for Quotation Issued to Vendor	01/21/05
Vendor Quotation Received	03/15/05
Purchase Order Established	03/29/05
Letter Report Issued	03/09/05
Engineering Package Submitted to MDH	03/21/05
System Permit Granted by MDH	06/20/05
Building Construction Permit Granted	06/13/05
Building Construction Begun	07/01/05
APU-300 Unit Shipped/Arrived	09/06/05
AERALATER® Shipped/Arrived	09/16/05
System Installation/Shakedown Completed	01/18/06
Study Plan Issued	01/24/06
Performance Evaluation Begun	02/02/06
Building Construction Completed	02/09/06
Performance Evaluation Ended	02/28/07

MDH = Minnesota Department of Health.

The O&M and operator skill requirements were evaluated based on a combination of quantitative data and qualitative considerations, including the need for pre- and/or post-treatment, level of system automation, extent of 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 system staffing requirements were recorded on an Operator Labor Hour Log Sheet.

The quantity of aqueous and solid residuals generated was estimated by tracking the volume of backwash wastewater produced during each backwash cycle and the need to replace the media upon arsenic breakthrough. Backwash wastewater was sampled and analyzed for chemical characteristics.

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

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

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

3.2 System O&M and Cost Data Collection

The plant operator performed daily, weekly, and monthly system O&M and data collection following the instructions provided by the vendor and Battelle. On a daily basis (including Saturdays and Sundays), the plant operator recorded system operational data, such as pressure, flowrate, totalizer, and hour meter readings on a Daily System Operation Log Sheet and conducted visual inspections to ensure normal system operations. If any problem occurred, the plant operator contacted the Battelle Study Lead, who determined if the vendor needed to be contacted for troubleshooting. The plant operator recorded all relevant information, including the problems encountered, course of action taken, materials and supplies used, and associated cost and labor incurred, on a Repair and Maintenance Log Sheet. On a weekly basis, the plant operator measured several water quality parameters onsite, including temperature, pH, dissolved oxygen (DO), and oxidation-reduction potential (ORP), and recorded the data on a Weekly Onsite Water Quality Parameters Log Sheet. Weekly backwash data also were recorded on a Backwash Log Sheet.

The capital cost for the arsenic-removal system consisted of the expenditure for equipment, site engineering, and system installation. The O&M cost consisted of the expenditure for media replacement, electricity consumption, and labor. Electricity consumption was determined from utility bills. Labor for various activities, such as routine system O&M, troubleshooting and repairs, and demonstration-related work, were tracked using an Operator Labor Hour Log Sheet. Routine system O&M included activities such as completing field logs, ordering supplies, performing system inspections, and others as recommended by the vendor. The labor for demonstration-related work, including activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead and the vendor, was recorded, but not used for the cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected from the wellhead, across the treatment plant, during backwash of Type II AERALATER® and AD-33 adsorption vessels, and from the distribution system. Table 3-3 provides the sampling schedules and analytes measured during each sampling event. Figure 3-1 presents a flow diagram of the treatment system along with the analytes and schedules at each sampling location. Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2004). Appendix A of the QAPP describes the procedure for arsenic speciation.

3.3.1 Source Water. During the initial visit to the site, source-water samples were collected and speciated using an arsenic speciation kit as described in Section 3.4.1. The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Table 3-3 lists analytes for the source-water samples.

3.3.2 Treatment Plant Water. During the system performance evaluation study, the plant operator collected samples weekly, on a 4-week cycle, for onsite and offsite analyses. For the first week of each 4-week cycle, samples taken at the wellhead (IN), after the contact tank (AC), after AERALATOR® gravity filter (AF), and at the combined effluent of Vessels A and B (TT), were speciated onsite and analyzed for the analytes listed in Table 3-3. For the next 3 weeks, samples were collected at IN, AC, AF, and after Vessels A (TA) and B (TB) and were analyzed for the analytes listed in Table 3-3. Over the 1-year demonstration study, two changes were made to the sampling schedules as follows:

- Before April 25, 2006, the monthly speciation sample at the TT location was collected from either the TA or TB sampling tap due to absence of a combined effluent sample tap at the time.
- After December 18, 2006, the sampling frequency was reduced to monthly speciation sampling at IN, AC, AF, and TT locations through the end of the performance evaluation study.

3.3.3 Backwash Wastewater. AERALATER® backwash wastewater samples were collected monthly by the plant operator. Grab samples were collected monthly from March 1, 2006, to August 23, 2006. Because of the absence of a sampling tap on the backwash wastewater discharge line, grab samples were taken directly from the backwash wastewater discharge sump. One aliquot was collected as is and the other filtered onsite with 0.45-µm disc filters. Since September 20, 2006, composite samples were collected monthly, using a revised procedure to allow collection of more representative samples during backwash. A 1/40-horsepower (hp) recirculation submersible water pump was used to collect a slipstream of water from the backwash wastewater sump to a 50-gal container over the duration of backwash for filter cells 1 and 2, respectively. At the end of each backwash cycle, the content in the container was mixed thoroughly, and composite samples were collected and filtered onsite with 0.45-µm disc filters. Table 3-3 lists analytes for the backwash wastewater samples.

The APU-300 system was backwashed manually four times during the performance evaluation study period, with one set of composite backwash wastewater samples collected. Tubing connected to the tap on the discharge line of each adsorption vessel directed a portion of backwash wastewater from each vessel at about 1 gpm into a clean, 32-gal container throughout the entire backwash. After the content in the container was thoroughly mixed, composite samples were collected and/or filtered onsite with 0.45-µm disc filters. Table 3-3 lists analytes for the adsorption vessels backwash samples.

Table 3-3. Sampling Locations, Schedules, and Analyses

Sample Type	Sample Locations[a]	No. of Samples	Frequency	Analytes	Sampling Date
Source Water	IN	1	Once (during initial site visit)	Onsite: pH, temperature, DO, and ORP Offsite: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, Cl, F, NO_3, NO_2, NH_3, SO_4, SiO_2, PO_4, Ra-226, Ra-228, TDS, TOC, alkalinity, and turbidity	08/30/04
Treatment Plant Water	IN, AC, AF, TA, and TB	5	Weekly	Onsite: pH, temperature, DO, and ORP Offsite: As (total), Fe (total), Mn (total), P (total), SiO_2, alkalinity, and turbidity	Appendix B
	IN, AC, AF, and TT	4	Monthly	Same as weekly analytes shown above plus the following: Offsite: As (soluble), As(III), As(V), Fe (soluble), Mn (soluble), Ca, Mg, F, NO_3, NH_3, SO_4, and TOC	Appendix B[b]
AERALATER® Filter Backwash Wastewater	At backwash discharge sump	2	Monthly	As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, TDS, and TSS	Table 4-8
AERALATER® Filter Backwash Solids	At backwash discharge sump	2	Once	TCLP metals and total Al, As, Ba, Ca, Cd, Cu, Fe, Mg, Mn, Ni, P, Pb, Sb, Si, V, and Zn	02/28/07
APU-300 Backwash Wastewater	At backwash discharge line	2	Once	As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, TDS, and TSS	01/17/07
Distribution Water	Three non-LCR residences	3	Monthly	Total As, Fe, Mn, Cu, and Pb, pH, and alkalinity	Table 4-11[c]

(a) Abbreviation corresponding to sample locations in Figure 3-1: IN = at wellhead; AC = after contact tank; AF = after gravity filter; TA = after Vessel A; TB = after Vessel B; TT = after Vessels A and B combined; and BW = at backwash wastewater discharge line.
(b) Sampling events before 04/25/06 were taken from TA or TB tap due to the absence of combined effluent sample tap.
(c) Four sampling events were performed before system startup.
LCR = Lead and Copper Rule; TCLP = toxicity characteristic leaching procedure

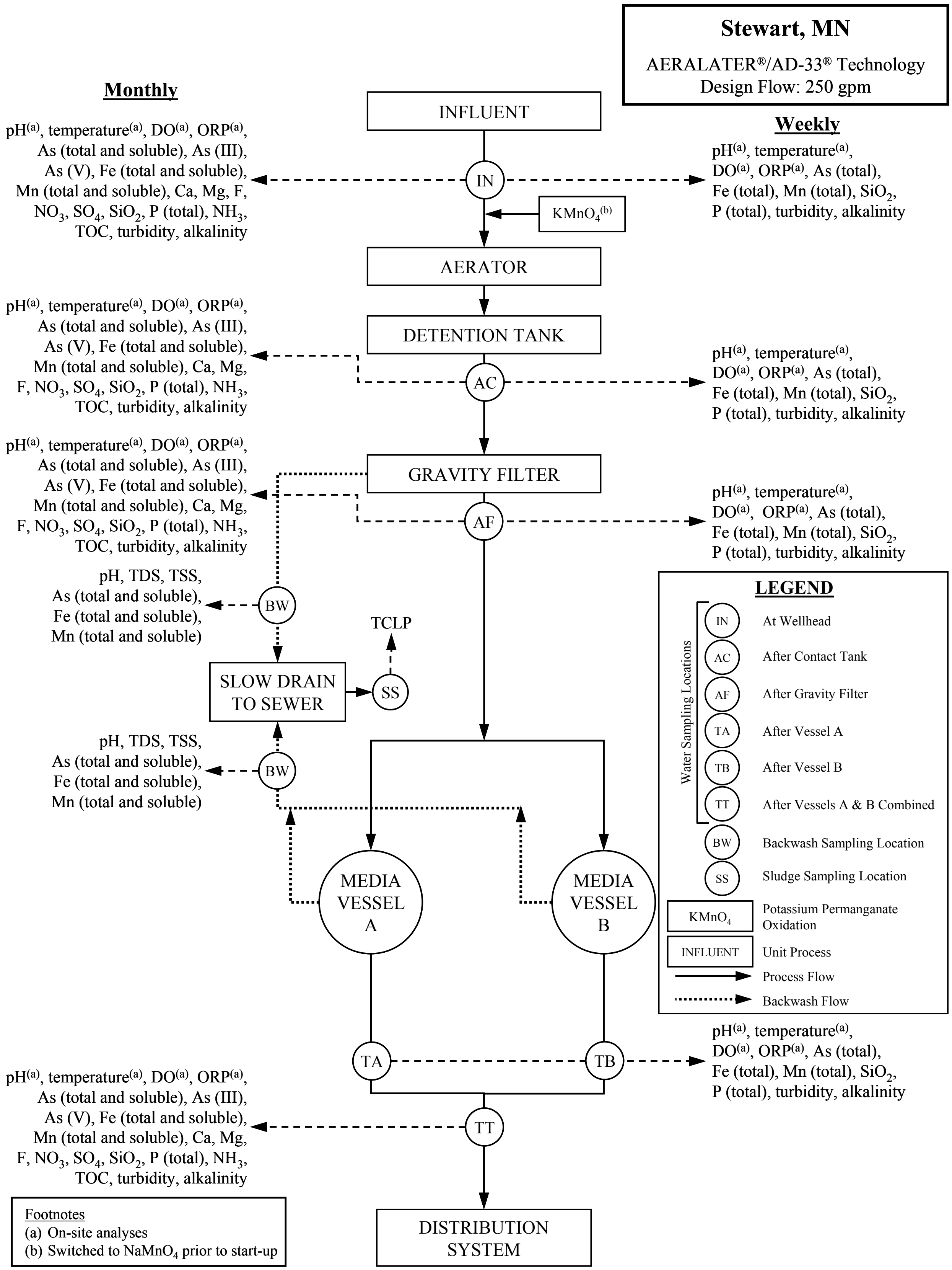

Figure 3-1. Process Flow Diagram and Sampling Schedule and Locations

3.3.4 Distribution System Water. Samples were collected from the distribution system to determine the impact of the arsenic treatment system on its water chemistry, specifically, the arsenic, lead, and copper levels. Prior to system startup from February to May 2005, four sets of baseline distribution water samples were collected from three residences within the distribution system. Following system startup, distribution system sampling continued monthly at the same three locations.

The distribution system water samples were taken following an instruction sheet developed by Battelle according to the *Lead and Copper Rule Reporting Guidance for Public Water Systems* (EPA, 2002). First-draw samples were collected from cold-water faucets that had not been used for at least 6 hours to ensure that stagnant water was sampled. The sampler recorded the date and time of last water use before sampling, as well as the date and time of sample collection for calculation of the stagnation time. The samples were analyzed for the analytes listed in Table 3-3. Arsenic speciation was not performed on the distribution water samples.

3.3.5 Residual Solids. Residual solids included backwash solids and spent-media samples. AERALATER® backwash solids samples were collected once on February 28, 2007, after the solids settled in the 32-gal backwash containers and the supernatant carefully decanted. The samples were air-dried, acid-digested, and analyzed for Al, As, Ba, Ca, Cd, Cu, Fe, Mg, Mn, Ni, P, Pb, Sb, Si, V, and Zn.

No backwash solids samples were collected during the backwash of the APU-300 unit, since the unit was only backwashed four times during the 1-year performance evaluation study. Because the adsorption media was not changed out during the performance evaluation study, no media samples were collected and analyzed.

3.4 Sampling Logistics

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

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

3.4.2 Preparation of Sample Coolers. For each sampling event, a sample cooler was prepared with the appropriate number and type of sample bottles, disc filters, and/or speciation kits. All sample bottles were new and contained appropriate preservatives. Each sample bottle was affixed with a pre-printed, colored-coded, 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, the sampling date, a two-letter code for a specific sampling location, and a one-letter code designating the arsenic speciation bottle (if necessary). The sampling locations at the treatment plant were color-coded for easy identification. The labeled bottles for each sampling location were placed separately in a Ziplock® bag (each corresponding to a specific sample location) and packed in the cooler. When needed, the sample cooler also included bottles for the distribution system sampling.

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

3.4.3 Sample Shipping and Handling. After sample collection, samples for offsite analyses were packed carefully in the original coolers with wet ice and shipped to Battelle. Upon receipt, the sample custodian checked sample IDs against the chain-of-custody forms and verified that all samples indicated on the forms were included and intact. The Battelle Study Lead addressed discrepancies noted by the sample custodian with the plant operator. The shipment and receipt of all coolers by Battelle were recorded on a cooler tracking log.

Samples for metal analyses were stored and analyzed at Battelle's inductively coupled plasma-mass spectrometry (ICP-MS) laboratory. Samples for other water quality parameters 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 to Battelle for this demonstration study. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

3.5 Analytical Procedures

The analytical procedures described in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2003) were followed by Battelle 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 (20% relative percent difference [RPD], 80 to 120% percent recovery, and 80% completeness). The QA data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project.

Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a VWR Symphony SP90M5 handheld multimeter, which was calibrated for pH and DO prior to use following the procedures provided in the user's manual. The ORP probe also was checked for accuracy by measuring the ORP of a standard solution and comparing it to the expected value. The plant operator collected a water sample in a clean, plastic beaker and placed the SP90M5 probe in the beaker until a stable value was obtained.

4.0 RESULTS AND DISCUSSION

4.1 Facility Description

The water treatment system at Stewart, MN, supplies drinking water to approximately 600 community members. The water source is groundwater from two wells (Wells No. 3 and 4). Wellheads 3 and 4 are shown in Figures 4-1 and 4-2, respectively. The static water level of the wells ranges from 20 to 30 ft below ground surface (bgs). Each well is 8 in in diameter and extends to a depth of approximately 370 ft bgs. Well No. 3 has a 50-ft screen length and is equipped with a 20-hp submersible pump with a capacity of approximately 350 gpm. Well No. 4 has a 52-ft screen length and a 15-hp submersible pump with a capacity of approximately 275 gpm. Prior to the performance evaluation study, the average daily demand was 52,420 gpd. Use of these two wells was alternated automatically based on the water tower level. Typically, each well ran for about 12,000 to 15,000 gal per cycle.

The pre-existing treatment consisted of chlorination, fluoridation, and polyphosphate addition. Chlorination was accomplished with a gas chlorine feed system to provide chlorine residuals in the distribution system. The target residual level was 1.1 mg/L for total chlorine (as Cl_2). The water also was fluoridated to a target level of 1.3 mg/L. Blended polyphosphates were added for iron sequestration and corrosion control. Figure 4-3 shows the chemical feed pumps and associated tanks within the pump house. Figure 4-4 shows the entry piping from Wells No. 3 and 4 and the tubing from the chemical feed pumps. As described in Section 4-2, the pre-existing equipment shown in Figures 4-3 and 4-4 was replaced with new equipment of similar sizes as part of the pre- and post-treatment. The treated water was stored in a nearby 65,000-gal water tower, as shown in Figure 4-5.

Figure 4-1. Wellhead 3 at Stewart, Minnesota (near orange flag in center of photo)

Figure 4-2. Wellhead 4 at Stewart, Minnesota (in front of small brown shed)

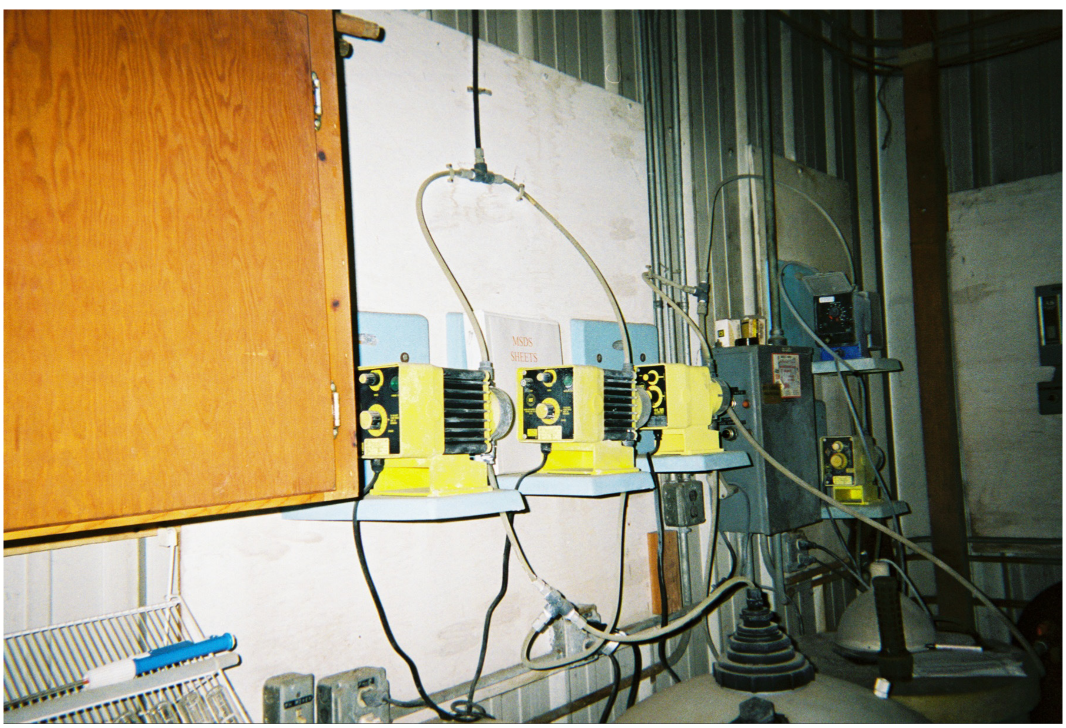

Figure 4-3. Existing Chemical Addition Equipment at Stewart, Minnesota

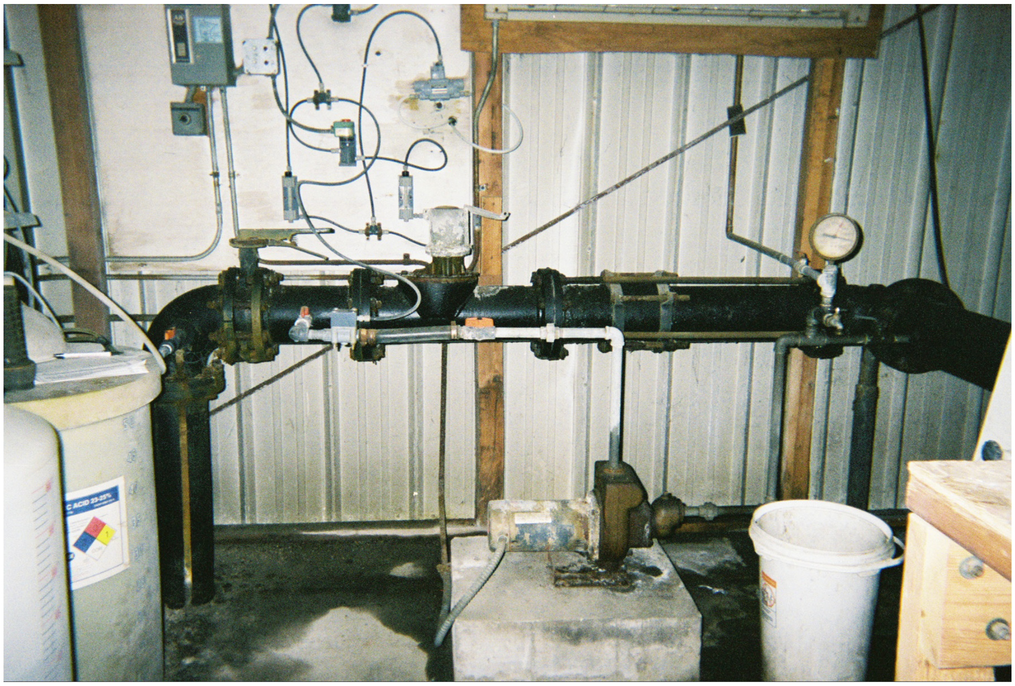

Figure 4-4. Existing Chemical Addition and Entry Piping with Flow Totalizer and Pressure Gauge at Stewart, Minnesota

Figure 4-5. A 65,000-gal Water Tower at Stewart, Minnesota

4.1.1 Source-Water Quality. Battelle collected source-water samples from Well No. 3 on August 30, 2004 for detailed water quality characterization; Table 3-3 shows the analytes of interest. In addition, pH, temperature, DO, and ORP were measured onsite using a VWR Symphony SP90M5 handheld multimeter. The source water also was filtered for soluble arsenic, iron, manganese, uranium, and vanadium and speciated for As(III) and As(V) using the field speciation method modified by Battelle from Edwards, et al. (1998). Table 4-1 presents the analytical results from the source-water sampling event and compares them to historic data taken by the facility.

The proposed treatment train for the City of Stewart included oxidation with potassium permanganate ($KMnO_4$), iron removal using gravity filtration, and arsenic adsorption with AD-33 media. Several factors were anticipated to play a role in the pretreatment process for iron removal, including natural iron concentration, pH, turbidity, natural organic matter, ammonia, anions, and cations. Factors that may affect arsenic removal via adsorption include arsenic concentration, arsenic speciation, pH, and other competing anions.

Arsenic. Total arsenic concentrations in source water ranged from 39.0 to 41.7 μg/L. Based on August 30, 2004, sampling results from Well No. 3, out of 41.7 μg/L of total arsenic, 31.9 μg/L existed as soluble As(III), 1.0 μg/L as soluble As(V), and 8.8 μg/L as particulate As. Therefore, soluble As(III) was the predominating species (about 76%) in groundwater. The proposed treatment process was to use $KMnO_4$, as originally designed, but was switched to $NaMnO_4$ just before system startup by the city in order to oxidize soluble As(III) to soluble As(V) prior to iron removal and AD-33 adsorption. Oxidant addition was discontinued after the discovery of a naturally occurring oxidation process developed within the AERALATER® filter (see detailed discussion in Section 4.5.1.1). Upon oxidation, soluble As(V) was removed via adsorption onto and/or co-precipitation with iron solids during the iron-removal pretreatment step. The remaining As(V) was then removed via adsorption onto the AD-33 media.

Iron and Manganese. In general, adsorptive media technologies are best suited to source water with relatively low iron levels (i.e., less than 300 μg/L, which is the secondary maximum contaminant level [SMCL] for iron). Above 300 μg/L, taste, odor, and color problems can occur in treated water, along with an increased potential for fouling of the adsorption system. The proposed treatment process at Stewart, MN, relied on aeration and gravity filtration to remove elevated levels of iron in source water. This iron removal process also resulted in the removal of some As(V) in the water. Iron concentrations in source water ranged from 1,344 to 1,400 μg/L, which existed almost entirely as soluble iron. Total manganese in source water ranged from 24 to 27 μg/L, which was below the SMCL of 50 μg/L.

pH. pH values of source water ranged from 7.7 to 7.8, which were near the upper end of the target range of 6.0 to 8.0 for optimal arsenic adsorption onto the AD-33 media.

TOC and Ammonia. The source water contained elevated levels of TOC (ranging from 6.8 to 7.2 mg/L) and ammonia (at 1.7 mg/L). To avoid the formation of DBPs and high chlorine consumption, the treatment process used $NaMnO_4$, instead of chlorine, for As(III) oxidation. However, as mentioned above, oxidant addition was later discontinued because iron removal was accomplished through aeration and As(III) oxidation was attained via a naturally occurring process.

Competing Anions. The adsorption of arsenic onto iron solids and AD-33 media also may be influenced by the presence of competing anions such as silica, sulfate, and phosphate. At the Stewart, MN, site, silica levels ranged from 24.0 to 26.6 mg/L (as SiO_2) and sulfate levels ranged from <5 to 7.4 mg/L. These concentrations were low enough that they did not pose a significant problem for effective arsenic adsorption. The orthophosphate level was 0.02 mg/L; however, as discussed in Section 4.5.1.6, the total phosphorous

Table 4-1. City of Stewart, Minnesota, Water Quality Data

Parameter	Unit	Source Water		Historic Utility Distribution Water Data[c]
		Utility Data[a]	Battelle Data[b]	
Sampling Date		Not Specified	08/30/04	10/16/01-10/18/04
pH	S.U.	7.8	7.7	7.7–7.8
DO	mg/L	NS	2.2	NS
ORP	mV	NS	-86	NS
Alkalinity (as $CaCO_3$)	mg/L[a]	415	424	410–420
Hardness (as $CaCO_3$)	mg/L[a]	230	246	<240
Turbidity	NTU	NS	7	<1–7.2
TDS	mg/L	NS	462	NS
TOC	mg/L	6.8	7.2	6.7–6.8
Total N (Nitrate + Nitrite)	mg/L	NS	NS	<0.05
Nitrate (as N)	mg/L	NS	<0.04	NS
Nitrite (as N)	mg/L	NS	<0.01	NS
Ammonia (as N)	mg/L	NS	1.7	NS
Chloride	mg/L	6.5	7.2	6.3–6.8
Fluoride	mg/L	NS	0.4	0.5–4.0
Sulfate	mg/L	7.4	<5.0	7.0–14.0
Silica (as SiO_2)	mg/L	24.0	26.6	23.0–24.0
Orthophosphate (as PO_4)	mg/L	0.02	<0.1	NS
As (total)	μg/L	39.0	41.7	34.0–43.0
As (soluble)	μg/L	NS	32.9	NS
As (particulate)	μg/L	NS	8.8	NS
As(III)	μg/L	39	31.9	NS
As(V)	μg/L	<0.1	1.0	NS
Fe (total)	μg/L	1,400	1,344	1,200–1,500
Fe (soluble)	μg/L	NS	1,359	NS
Mn (total)	μg/L	24.0	27.0	22.0–25.0
Mn (soluble)	μg/L	NS	28.0	NS
U (total)	μg/L	NS	<0.1	NS
U (soluble)	μg/L	NS	<0.1	NS
V (total)	μg/L	NS	<0.1	NS
V (soluble)	μg/L	NS	<0.1	NS
Na	mg/L	87	87	84–89
Ca	mg/L	46	56	44–48
Mg	mg/L	28	26	26–29
Ra-226	pCi/L	NS	<1.0	NS
Ra-228	pCi/L	NS	<1.0	<0.77[d]
Gross-Alpha	pCi/L	NS	NS	1.6–2.7[d]
Gross-Beta	pCi/L	NS	NS	<1.1–1.5[d]
Radon	pCi/L	NS	NS	358–531[d]

(a) Provided to EPA for demonstration study site selection.
(b) Water from Well No. 3.
(c) Water from Wells No. 3 and 4 after chlorine, fluoride, and polyphosphate addition.
(d) Radiochemistry based on data collected from 12/14/92 through 10/18/04.
NS = Not Sampled; MDH= Minnesota Department of Health; TDS = total dissolved solids; TOC = total organic carbon.

level was elevated at 0.90 mg/L (as PO_4) and could compete with arsenic for available adsorption sites onto iron solids and AD-33 media.

Other Water Quality Parameters. Alkalinity, hardness, sodium, and total dissolved solids (TDS) levels in source water were all elevated. Alkalinity values ranged from 415 to 424 mg/L (as $CaCO_3$); hardness values ranged from 230 to 246 mg/L (as $CaCO_3$); and sodium and TDS concentrations (in the August 30, 2004, sample) were 87 and 462 mg/L. Other water quality parameters, including nitrate, nitrite, chloride, fluoride, uranium, and vanadium, were below their respective detection limits or SMCLs. Radium was measured at less than the detection limit of <1.0 pCi/L.

4.1.2 Treated-Water Quality and Distribution System. Historic water samples were taken from both Wells No. 3 and 4, but following chlorination, fluoridation, and polyphosphate addition; therefore, the analytical results obtained from the Minnesota Department of Health (MDH) are included in Table 4-1 as distribution water data. These water samples were collected from residences, businesses (stores), city hall, and the treatment plant from October 16, 2001, through October 18, 2004.

Historic arsenic levels detected within the distribution system ranged from 34.0 to 43.0 µg/L; iron levels ranged from 1,200 to 1,500 µg/L, and manganese levels ranged from 22 to 25 µg/L. These concentrations were similar to those measured in source water. Results of other water quality parameters measured historically also were very close to those found in the source-water samples collected by the facility and Battelle.

The distribution system at Stewart, MN is supplied only by Wells No. 3 and 4. Water from Wells No. 3 and 4 is blended within the distribution system and the 65,000-gal water tower. Based on the distribution system blueprint, the mains for the water distribution system are primarily constructed of 6-in to 8-in cast iron. Other connections within the distribution system include ¾-in to 2-in galvanized iron, 2-in copper, and 2-in polyvinyl chloride (PVC) piping. Three locations were selected for both baseline and distribution system sampling after system startup. The locations were selected as part of the city's historic sampling network for LCR. Compliance samples also included quarterly sampling for arsenic, coliform, total chlorine residual, and fluoride and annual sampling for nitrate, volatile organic compounds (VOCs), trihalomethanes (THMs), haloacetic acids (HAA5), turbidity, TOC, alkalinity, and radionuclides.

4.2 Treatment Process Description

The 250-gpm treatment system at Stewart, MN, consisted of pre-treatment for iron removal, followed by adsorption with AD-33 media for arsenic removal (Figure 4-6). This section provides a detailed description of the Siemens Type II AERALATER® system for iron removal and AdEdge APU-300 system for arsenic adsorption.

Due to elevated iron levels in source water, the adsorption system was preceded by a Siemens Type II AERALATER® system for iron (and some arsenic) removal via oxidation and filtration. Figure 4-7 shows the 11-ft-diameter AERALATER® system, which is a packaged unit for oxidation, detention, and gravity filtration. The AERALATER® system included an aeration chamber, a detention tank, and four filter cells. The treatment processes were permanganate oxidation (with the oxidant added at inlet piping to the AERALATER® system), aeration, adsorption/co-precipitation of As(V) onto/with iron solids, and gravity filtration with anthracite and silica sand. The filtration media are approved for use in drinking-water applications under NSF International (NSF) Standard 61. More details on the Siemens' Type II AERALATER® system are provided below.

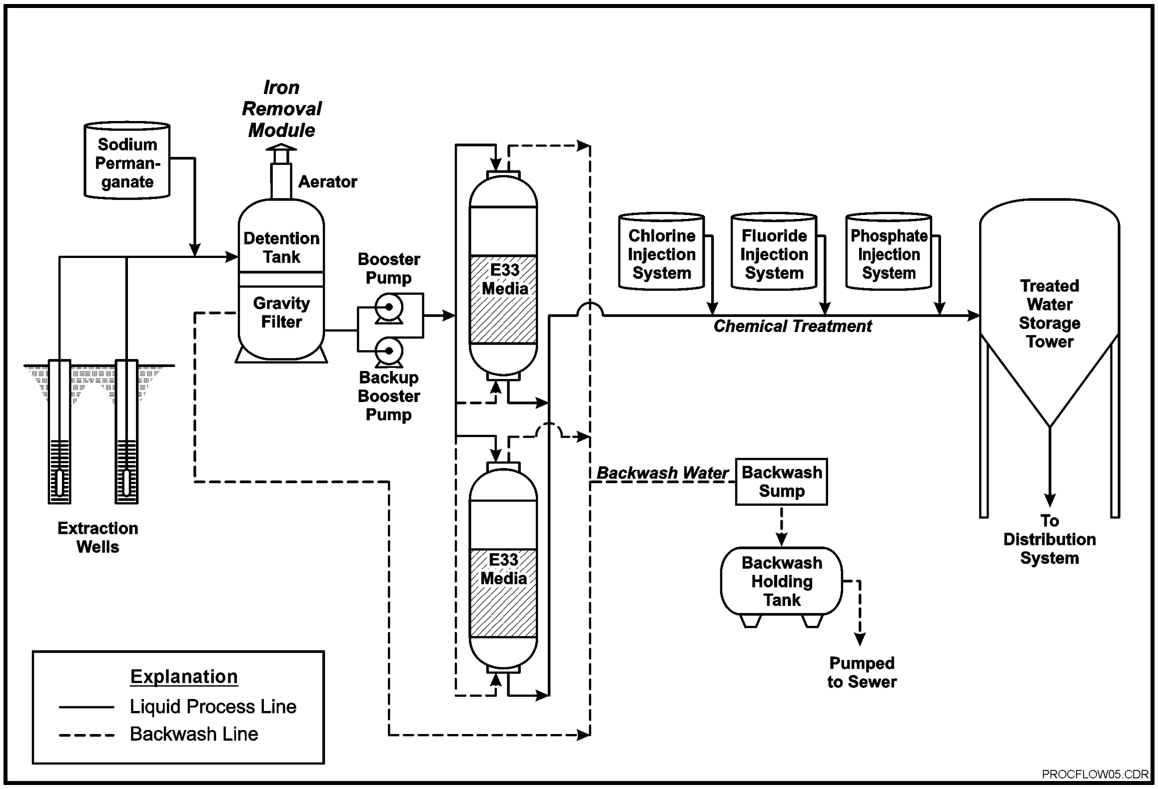

Figure 4-6. Schematic of AERALATER® and APU-300 Systems at Stewart, Minnesota

Figure 4-7. AERALATER® (left) and APU-300 Systems (right) at Stewart, Minnesota

The soluble As(V) that remained in the treated water after the AERALATER® system was further treated by the AdEdge APU-300 system. Designed for arsenic removal for small systems in the flow range of 10 to 300 gpm, the APU series is a fixed-bed adsorption system. As groundwater is pumped through fixed-bed pressure vessels, soluble arsenic is adsorbed onto the media, thus reducing the soluble arsenic concentration to below 10 µg/L MCL. The APU-300 adsorption system consisted of two 63-in-diameter, 86-in-tall vessels configured in parallel (see Figure 4-7). Each vessel contained 64 ft^3 of pelletized Bayoxide® E33 media (branded as AD-33 by AdEdge). This iron-based adsorptive media was developed by Bayer AG for the removal of arsenic from drinking-water supplies. Table 4-2 presents the physical and chemical properties of the media. The AD-33 media is delivered in a dry crystalline form and listed by NSF under Standard 61 for use in drinking water applications. AD-33 is available in both granular and pelletized forms. The pelletized media used at the Stewart, MN site is 25% denser than the granular media (35 vs. 28 lb/ft^3). Both media are reported by the vendor to have similar arsenic adsorption capacities on a per pound basis. After reaching its capacity, the spent media would be removed and disposed of as nonhazardous waste after passing EPA's toxicity characteristic leaching procedure (TCLP) test. The media life depends on the arsenic concentration, pH, and concentrations of interfering ions in the influent water.

Table 4-2. Physical and Chemical Properties of AD-33 Media

Parameter	Value
Physical Properties	
Matrix	Iron oxide/Hydroxide
Physical Form	Dry pelletized media
Color	Amber/rust
Bulk Density (lb/ft^3)	35
BET Surface Area (m^2/g)[(a)]	142
Attrition (%)[(a)]	0.3
Moisture Content (%)	5% by weight
Particle Size Distribution (U.S. Standard Mesh)	14 × 18
Crystal Size (Å)[(a)]	70
Crystal Phase[(a)]	α-FeOOH
Chemical Analysis[(a)]	
Constituents	**Weight (%)**
FeOOH	90.1
CaO	0.27
MgO	1.00
MnO	0.11
SO_3	0.13
Na_2O	0.12
TiO_2	0.11
SiO_2	0.06
Al_2O_3	0.05
P_2O_5	0.02
Cl	0.01

Note: BET = Brunauer, Emmett, and Teller Method.
(a) For dry granular media.
Data Source: Bayer AG.

Table 4-3 presents design features of the treatment system at Stewart, MN. The major process components of the treatment system are described as follows:

- **Intake**. Source water was pumped from Wells No. 3 and 4 alternately, and fed into the entry piping of the Siemens Type II AERALATER® unit. The well pumps were turned on and off based on the low- and high-level settings of 23 and 27 ft of water, respectively, in the water tower.

- **Oxidation**. The original design called for the use of a 2% $KMnO_4$ solution at a target dosage of 0.5 mg/L (as Mn) to oxidize As(III) and Fe(II). Before system startup, modifications were made by the city to use a 20% $NaMnO_4$ solution instead. The $NaMnO_4$ solution was fed into the system with a 1 gal/hr (gph) electronic positive displacement metering pump. In addition to the metering pump with adjustable stroke length and speed, the chemical feed system included a 150-gal polyethylene day tank and a 1/3-hp propeller tank mixer. The addition of $NaMnO_4$ was discontinued at the initial stage of the performance evaluation study (around February 14, 2006) because oxidation of As(III) was accomplished via naturally mediated processes without the use of any oxidant.

- **Iron Removal.** Siemens' Type II AERALATER® was used as a pretreatment step for iron removal. Constructed of carbon steel, the 11-ft-diameter package unit was designed to allow oxidation, detention, and gravity filtration to all occur in a single unit. The system components were assembled in a stacked circular configuration, with an aeration chamber on the top, a detention tank in the middle, and four filter cells in the base (Figure 4-8). Details of these process components are described below:

    - **Aeration.** Air for the aluminum aeration unit was supplied by a ½-hp induced-draft air blower with a capacity of 855 ft^3/min (cfm) at a 3/8-in static pressure. The influent water was aerated as it passed over a network of 1¼-in PVC slats supported by a stainless-steel grid.

    - **Contact.** The 11-ft-diameter by 11.5-ft-high steel detention tank provided 34 min of contact time to improve the formation of filterable iron flocs. The total detention time of 34 min was based on the total volume of 8,550 gal in the detention tank, the freeboard above the filter, and the design flowrate of 250 gpm.

    - **Filtration.** The four filter cells sitting at the base of the circular unit had a total cross-sectional area of 95 ft^2. Therefore, operating the system at the design flowrate of 250 gpm would result in a hydraulic loading rate of 2.6 gpm/ft^2. The filtration bed in each filter cell consisted of one each 12-in layer of 0.6 to 0.8 mm anthracite and 0.45 to 0.55 mm sand, which were supported by a 14-in layer of gravel underbedding. A steel plate underdrain with media-retaining strainers was located under the gravel.

    - **Backwash.** The filter cells were backwashed manually once per week to remove filtered particles from the filter media (the system did not have automatic backwash capabilities). Each cell was backwashed individually at 285 gpm (or 12 gpm/ft^2) using filtered water from the other cells. To initiate the manual backwash, the influent valve on the first cell was closed and the corresponding backwash valve was opened. The backwash was continued until visual observation indicated that the backwash wastewater had reached a "light straw" color. As a result, the duration of the backwash varied based on operator observations. Upon completion, the backwash valve was closed and the influent valve on the first cell was re-opened. The same procedure was followed for the remaining filter

Table 4-3. Design Specifications of Type II AERALATER® and APU-300 Systems

Parameter	Value	Remarks
Preoxidation		
Oxidant	2% $KMnO_4$	Changed to 20% $NaMnO_4$ by city before system startup
AERALATER® System		
Design Flowrate (gpm)	250	–
AERALATER® Diameter (ft)	11	–
AERALATER® Height (ft)	26	
Aerator Cross-Sectional Area (ft^2)	95	–
Detention Tank Size (ft)	11 D × 11.5 H	–
Detention Tank Volume (gal)	8,550	Including freeboard above filter
Detention Time (min)	34	–
Media Volume (ft^3)	190	24-in bed depth (12-in anthracite and 12-in sand)
Hydraulic Loading Rate to Filter (gpm/ft^2)	2.6	–
Backwash Flowrate (gpm)	285	
Backwash Hydraulic Loading (gpm/ft^2)	12	–
Backwash Frequency (time/week)	1	–
Backwash Duration (min)	~8	Variable based on visual observation
Wastewater Production (gal/filter cell)	2,250	Per vendor estimate
APU-300 Adsorbers		
Vessel Size (in)	63 D × 86 H	–
Cross-Sectional Area (ft^2/vessel)	21.6	Based on 62-in inner diameter
Number of Vessels	2	–
Configuration	Parallel	–
Media Type	AD-33	Pelletized media
Media Volume (ft^3)	128	36-in bed depth or 64 ft^3/vessel
Pressure Drop (psi)	4 psi	Across a clean bed
APU-300 Service		
Design Flowrate (gpm)	250	–
Hydraulic Loading (gpm/ft^2)	5.8	–
EBCT (min)	3.8	–
Estimated Working Capacity (BV)	82,500	Projected by vendor, 1 BV = 958 gal
Throughput to Breakthrough (gal)	79,000,000	–
Average Use Rate (gal/day)	48,600	–
Estimated Media Life (month)	53	Estimated frequency of change-out at 13.5% utilization
APU-300 Backwash		
Pressure Differential Setpoint (psi)	10	–
Backwash Flowrate (gpm)	200	
Backwash Hydraulic Loading Rate (gpm/ft^2)	9.3	–
Backwash Frequency (per quarter)	1	Per vendor recommendations
Backwash Duration (min/vessel)	15	–
Fast Rinse Duration (min/vessel)	5	–
Wastewater Production (gal/vessel)	4,000	–

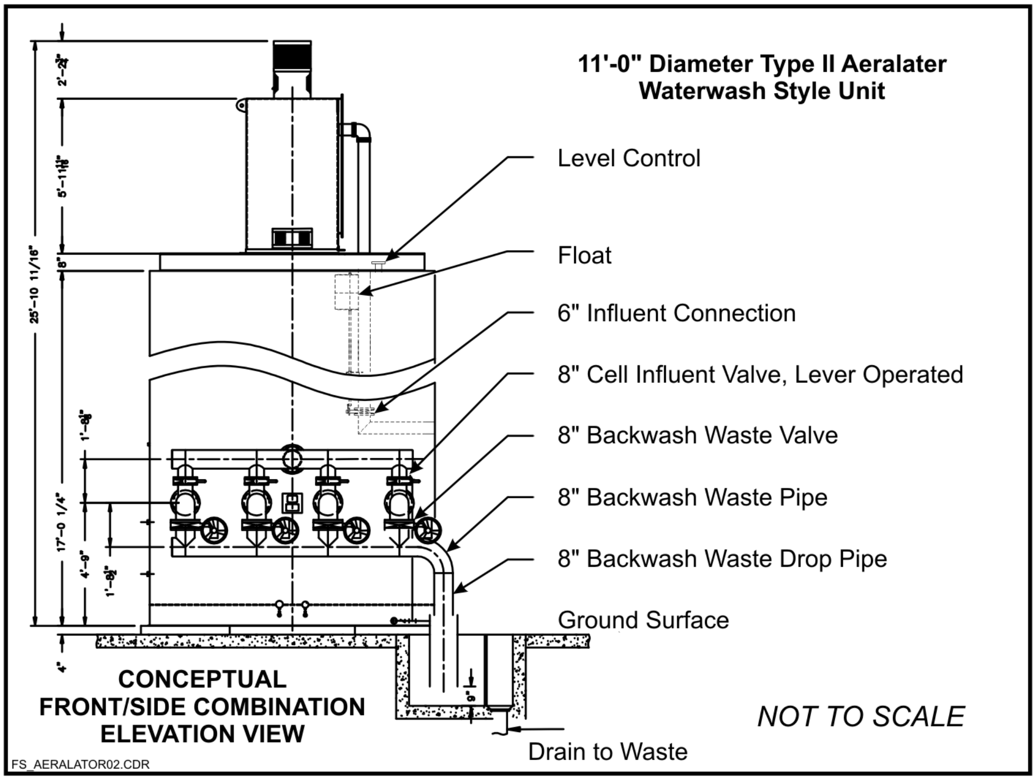

Figure 4-8. Schematic of Type II AERALATER® System (based on general arrangement drawing provided by Siemens)

cells. All filter cells had to be backwashed on the same day to ensure consistent filter performance. After all four cells were backwashed, the system effluent valve was re-opened and the system returned to service. The backwash wastewater produced was discharged to a sump and then drained by gravity to two backwash wastewater holding tanks before being pumped to the sewer system.

- **Adsorption**. The AdEdge APU-300 system was fed by two 15-hp vertical end suction high-service pumps to provide pressurized flow to the water tower rated at 210 gpm at 145 ft total dynamic head (TDH). The high-service pumps were controlled to start and stop operations based on the water level in the AERALATER® detention tank. The APU-300 adsorption system consisted of two 63-in-diameter, 86-in-tall vessels configured in parallel, each containing 64 ft^3 of pelletized AD-33 media supported by gravel underbedding. Figure 4-9 shows the schematic of the APU-300 system. The adsorption vessels were constructed of composite fiberglass with a polyethylene liner and rated for 150 pounds per square inch (psi) working pressure. The system was skid-mounted and piped to a valve rack mounted on a polyurethane-coated, welded frame. The service, backwash, and media replacement are described in more detail below.

  - **Service.** Water flowed downward through the packed AD-33 media beds. Flow to each vessel was measured and totalized to record the volume of water treated. The pressure differential through each vessel also was monitored. Based on a design flowrate of 250 gpm, the empty bed contact time (EBCT) for each vessel was 3.8 min, and the hydraulic loading to each vessel was approximately 5.8 gpm/ft^2.

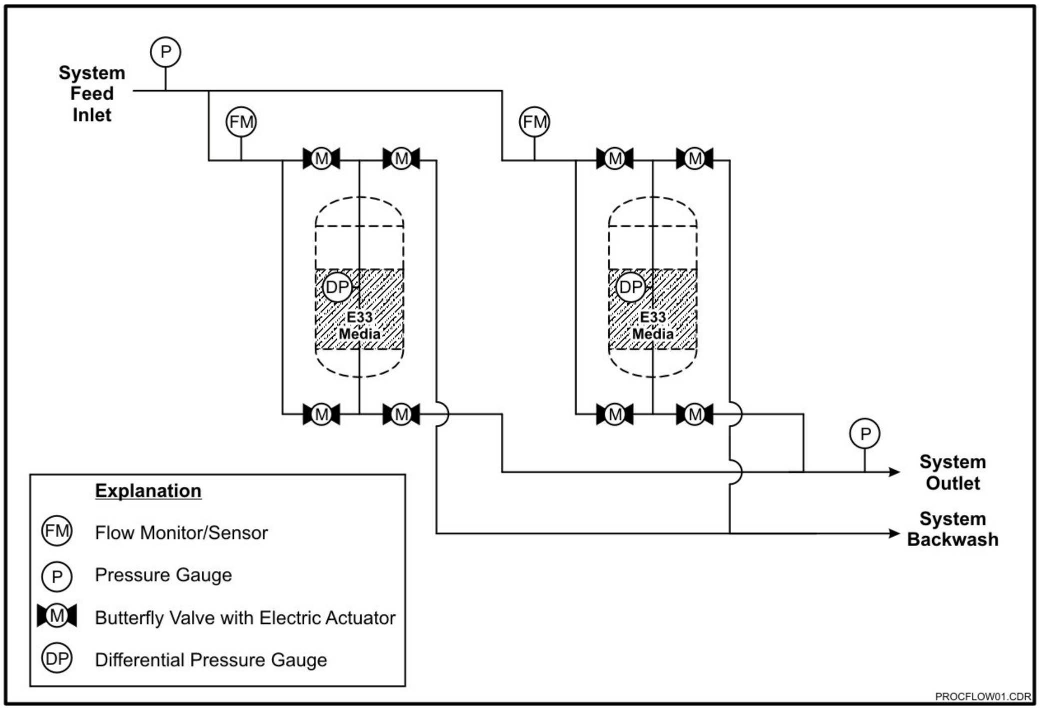

Figure 4-9. Schematic of APU-300 System (Based on Process and Instrumentation Diagram Provided by AdEdge)

- **Backwash.** Based on a set time period or a set pressure differential, the adsorption vessels were taken off-line one at a time for a manual backwash, using source water from the wells. The system was equipped with an automatic backwash trigger based on time or differential pressure, but this feature was disabled. The purpose of the backwash was to remove particulates and media fines built up in the beds and to uncompress the media beds. While one vessel was backwashed, the other vessel remained in service. Each vessel was backwashed at a flowrate of approximately 200 gpm (or 9.3 gpm/ft^2). The backwash wastewater generated was discharged to a sump and then drained by gravity to two 13,000-gal backwash wastewater holding tanks before being pumped to the sewer system. Each holding tank was equipped with a 3-hp submersible centrifugal sludge pump rated for 50 gpm at 20 ft TDH.
- **Media Replacement**. During the performance evaluation study, the adsorption media was not exhausted, so the media was not replaced. When the AD-33 media arsenic removal capacity is exhausted, the spent media will be removed from the vessels and disposed offsite. Virgin media is then loaded back into each vessel. Based on the vendor's estimate, the media will be changed out after treating approximately 79 million gal or 82,500 BV, given influent arsenic concentrations from 20 to 27 µg/L.

- **Post-Treatment Chemical Feed.** After the APU-300 system, the treated water underwent post-chlorination, fluoridation, and polyphosphate addition. Post-chlorination was carried out with a gas chlorine injection system, which consisted of two 150-lb chlorine gas cylinders, a digital, dual-cylinder scale rated for a capacity of 349 lb, a flow controller, and a 3-hp chlorine booster pump. Post-chlorination helped maintain a target total chlorine residual level of 1.1 mg/L (as Cl_2) in the distribution system. Fluoride was added at a target level of 1.3 mg/L, using a 0.58-gph maximum capacity, electronic, positive-displacement metering pump and a 65-gal polyethylene storage tank. Blended polyphosphates were added with a

0.58-gph maximum capacity, electronic, positive-displacement metering and a 50-gal polyethylene storage tank for corrosion control.

4.3 Treatment System Installation

4.3.1 Permitting. The system engineering package, prepared by AdEdge and Bolton & Menk, Inc., included (1) a system design report and associated general arrangement as well as piping and instrumentation diagrams (P&IDs) for the Type II AERALATER® and APU-300 systems; (2) electrical and mechanical drawings and component specifications, and (3) building construction drawings detailing connections from the system to the entry piping and the city's water and sanitary sewer systems. The engineering package was certified by a Professional Engineer registered in the State of Minnesota and submitted to MDH for review and approval on March 21, 2005. After MDH's review comments were incorporated, the revised package was resubmitted on May 20, 2005. MDH issued a water supply construction permit on June 20, 2005, and system fabrication began thereafter.

4.3.2 Building Construction. The city applied for building construction permit, which was issued on June 13, 2005. Building construction began on July 1, 2005, and was completed on February 9, 2006. The concrete block building had a 55.3-ft × 24.7-ft footprint with a sidewall height of 14 ft (see Figure 4-10). The AERALATER® aeration tower protrudes through the building roof where two 16-in-diameter access hatches also were installed for adsorptive media loading. In addition to housing the treatment system, the building contains a fluoride room, a chemical room, a bathroom, and some office/laboratory space. Wastewater discharge is facilitated with a 4-ft × 2-ft × 2-ft (120 gal) underground sump that empties by gravity into two 12,500-gal, pre-cast concrete holding tanks. Each holding tank is equipped with a 2-hp sump pump with a design capacity of 50 gpm for transferring backwash wastewater to the sanitary sewer system.

4.3.3 System Installation, Shakedown, and Startup. Although building construction was ongoing, the site was prepared for delivery of the treatment systems by September 2005. Both units were shipped and arrived prior to roof construction to facilitate placement of the units in the building. The APU-300 system arrived on September 6, 2005, and the AERALATER® system arrived on September 16, 2005. The vendor, through its subcontractor, off-loaded and installed the systems, including connections to the entry and distribution piping and electrical interlocks. Figure 4-11 shows the off-loading of the AERALATER® unit by crane.

Subsequent to the treatment system delivery, construction work to finish the building and associated piping and electrical infrastructure continued through February 9, 2006. Siemens arrived onsite for mechanical checkout of the AERALATER® installation on January 4, 2006. AdEdge was onsite from January 4 to 11, 2006, for mechanical checkout of the APU-300 installation and startup activities, including hydraulic testing, media loading, initial backwashing, and system disinfection. After the bacteriological test results were received and passed, the systems began to operate manually, with the treated water sent to the distribution system starting on January 18, 2006. Manual operation of the systems continued until the city's contractor completed the electrical wiring and control setpoints for the well pumps and high-service pumps. The operator began to record operational data on January 30, 2006.

Battelle staff traveled to Stewart, MN to perform system inspections and operator training from February 1 to 3, 2006, with the first set of treatment plant samples taken on February 2, 2006. A punch list was identified during the trip and later forwarded to AdEdge on February 16, 2006. The issues to be addressed included replacement of a headloss gauge on the AERALATER® system; installation of a combined effluent sample tap downstream of the APU-300 system and upstream of post-chlorination; disabling of the APU-300 system automatic backwash; calibration of flow meters for the APU-300

Figure 4-10. Building with AERALATER® Tower (top), Backwash Sump (bottom left), and Backwash Wastewater Holding Tanks (bottom right) at Stewart, Minnesota

Figure 4-11. Off-Loading and Placement of AERALATER® Unit at Stewart, Minnesota

System; and changes of combined flow totalizer programmable logic controller (PLC) programming for the APU-300 system. The vendor subsequently resolved these issues by August 2006.

4.4 System Operation

System operation data were tabulated and are attached as Appendix A. Key parameters are summarized in Table 4-4. From February 2, 2006, to February 28, 2007, the system operated for 1,821 hr, producing 20,441,000 gal based on wellhead flow totalizer readings. The wells were operated on an alternating basis, with Well No.3 operating for 908 hr and Well No. 4 for 913 hr. The average daily demand was 52,418 gal, and the average operation time was 4.7 hr/day. Given the full design capacity of 250 gpm (360,000 gpd), this represents an average hydraulic utilization rate of 15% on a daily basis. The system operation is discussed below in terms of the hydraulic performance of the AERALATER® and APU-300 systems.

Table 4-4. Summary of Treatment System Operation at Stewart, Minnesota

Operational Parameter	Values		
Operational Period	February 2, 2006 to February 28, 2007		
Wellhead Operations	**Well No.3**	**Well No.4**	**Total**
Total Operating Time (hr)	908	913	1821
Average Operating Time (hr/day)	2.33	2.34	4.7
Throughput (kgal)	10,421	10,020	20,441
Average Demand (gpd)	26,700	25,718	52,418
AERALATER® Iron Removal Operations	**Well No.3**	**Well No.4**	**Total**
Average Flowrate [Range] (gpm)[(a)]	191 [100–217]	184 [127–248]	–
Average Detention Time [Range] (min)	45 [39–86]	46 [34–67]	–
Average Filtration Rate [Range] (gpm/ft^2)	2.0 [1.1–2.3]	1.9 [1.3–2.6]	–
Average Δp across Filter (ft H_2O)	–	–	<1.5
Average Throughput Between Backwash [Range] (kgal)	–	–	368 [138–739]
Average Run Time Between Backwash [Range] (hr)	–	–	33 [13–68]
Average Backwash Frequency [Range] (day/backwash)	–	–	7 [3–15]
APU-300 Adsorption Operations	**Tank A**	**Tank B**	**Total**
Throughput (kgal)	10,181	10,289	20,470
Throughput (BV)	21,264	21,489	21,377
Average Flowrate [Range] (gpm)[(b)]	88 [66–104]	88 [62–103]	176 [128–207]
Average EBCT [Range] (min)	5.4 [4.6–7.2]	5.4 [4.6–7.7]	5.4 [4.6–7.5]
Δp across tank/system (psi)	0	0	1 to 2

(a) Average flowrate based on readings of individual wellhead mechanical flow totalizers and hour meter.
(b) Average flowrate based on weekly readings of instantaneous flowrate from each vessel using digital paddlewheel flow meters.

4.4.1 AERALATER® Operations. With an average flowrate of 188 gpm between the two wells, the AERALATER® system was run at approximately 75% of its full design capacity of 250 gpm. The flowrate to the AERALATER® system varied slightly, based on which well pump was operational. When Well No. 3 was operational, flowrate readings ranged from 100 to 217 gpm and averaged 191 gpm. At these flowrates, the detention times ranged from 39 to 86 min and averaged 45 min (compared to a design value of 34 min); the hydraulic loading rates to the filter ranged from 1.1 to 2.3 gpm/ft^2 and averaged 2.0 gpm/ft^2 (compared to the design value of 2.6 gpm/ft^2). When Well No. 4 was operational, the flowrate readings ranged from 127 to 248 gpm and averaged 184 gpm. This corresponded to a detention time of

34 to 67 min (averaged 46 min) and a hydraulic loading rate of 1.3 to 2.6 gpm/ft^2 (averaged 1.9 gpm/ft^2). In general, the detention time was longer and the hydraulic loading rate was lower than the respective design values.

During the 1-year performance study, 54 backwash events took place. The operator manually backwashed the AERALATER® system approximately once per week, with the number of days per backwash ranging from 3 to 15. During the filter run cycles, less than 1.5 ft of water head loss was measured across the filter media beds. The run times between two consecutive backwash events ranged from 13 to 68 hr, and the average run time was 33 hr. The throughput between two consecutive backwash events ranged from 138,100 to 739,000 gal, and the average throughput was 368,000 gal. The throughput to the filter varied, based on the amount of run time required to meet the water demand during the week.

4.4.2 APU-300 Operations. The APU-300 system processed approximately 20,470 kgal, or 21,377 BV of water, from February 2, 2006, through February 28, 2007, based on readings from the individual digital paddle-wheel flow totalizers installed on the effluent piping downstream from the adsorption vessels. In general, the throughput readings obtained via the paddle-wheel flow totalizers were consistent with those from the totalizers at the wellheads, with relative error within 2.1%, given the wellhead throughput and estimated backwash wastewater volume. Based on the readings for the individual vessels, Vessel A processed 21,264 BV (10,181,000 gal) of water and Vessel B processed 21,489 BV (10,289,000 gal).

Each week, the operator recorded the instantaneous flowrates through Vessels A and B based on the digital paddlewheel flow meter for each vessel. As shown in Figure 4-12, the flowrates through Vessels A and B were generally at the same level. The average flowrate was 88 gpm for both Vessels A and B, indicating balanced flow between them. According to the flowrates measured, the system operated at approximately 70% of its design capacity. The EBCTs for both Vessels A and B averaged 5.4 min, which is higher than the design value of 3.8 min. Throughout the performance evaluation study, the differential pressure across the adsorption system remained low at 1.0 to 2.0 psi, indicating effective particulate removal by the AERALATER® system. The four manual backwash events conducted during the performance evaluation study are discussed in detail below.

4.4.3 Backwash Operations. Both the AERALATER® and APU-300 systems required backwash. Because the AERALATER® system was used as pre-treatment to remove iron particles, it was backwashed as often as once per week. The APU-300 system did not experience elevated differential pressures above the 10-psi setpoint; it was, therefore, backwashed only four times during the 1-year performance evaluation study. Both units used treated water for backwash. Table 4-5 summarizes key operational parameters related to system backwash for both systems.

The 54 manual backwash events of the AERALATER® system generated approximately 406,400 gal of backwash wastewater, based on the readings obtained via the wellhead totalizer readings before and after backwash. The amount of wastewater produced represents 2% of the volume of water processed during this time period. The average backwash flowrate was 215 gpm, or 9.1 gpm/ft^2, which was about 25% lower than the design value of 285 gpm or 12 gpm/ft^2. The duration for each backwash event (for all four cells) ranged from 15 to 60 min and averaged 36 min, which is slightly higher than the vendor-provided value of 8 min/cell or 32 min/event. The backwash duration varied because backwash was manually controlled by the operator based on visual observations of the color of backwash wastewater. The backwash was discontinued when the backwash wastewater had reached a "light straw" color. The average amount of wastewater produced was 7,619 gal per backwash event, compared to 9,000 gal per event specified by the vendor.

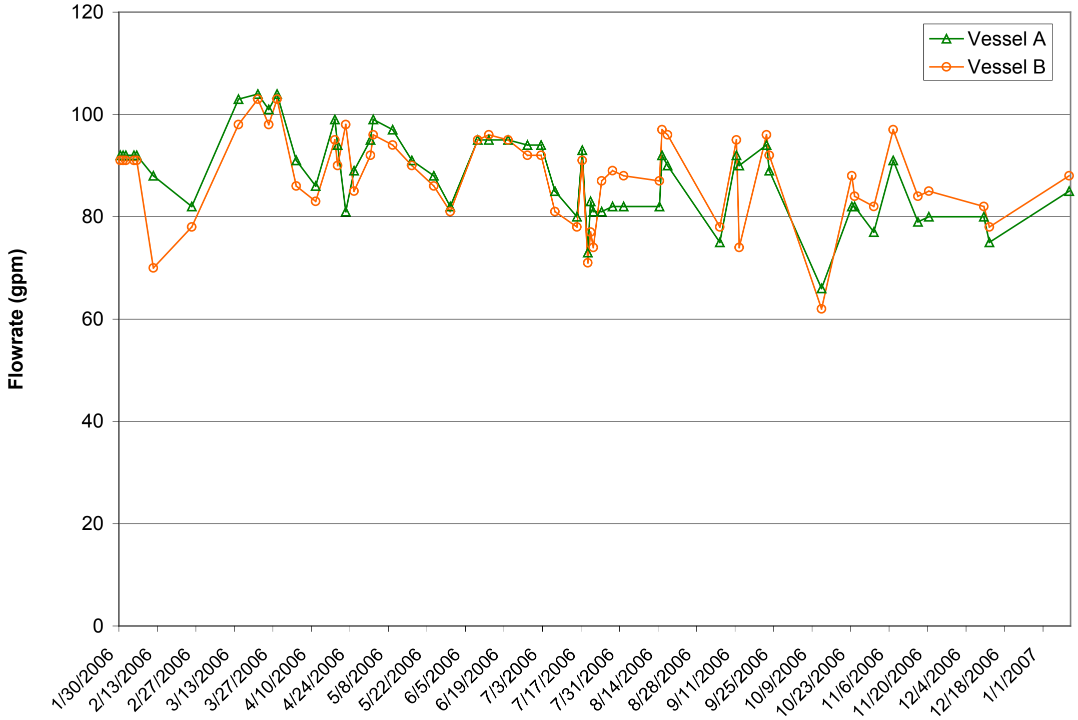

Figure 4-12. Instantaneous Flowrates Through Adsorption Vessels A and B

Table 4-5. Summary of Backwash Operations at Stewart, Minnesota

Parameter	Value
AERALATER® Backwash Operations	
Total Number of Backwash Events	54
Total Volume of Backwash Wastewater Produced (gal)	406,400
Average Frequency of Backwash [Range] (day)	7 [3–15]
Average Flowrate [Range] (gpm)	215 [157–387]
Average Hydraulic Loading Rate [Range] (gpm/ft^2)	9.1 [6.6–16.3]
Average Duration [Range] (min)	36 [15–60]
Average Backwash Wastewater Volume [Range] (gal/event)	7,619 [3,600–12,400]
APU-300 Backwash Operations	
Total Number of Backwash Events	4
Total Volume of Backwash Wastewater (gal)[a]	25,415
Average Backwash Wastewater Volume [Range](gal/vessel)[b]	2,963 [2,578–3,392]

(a) Backwash wastewater volumes, including fast rinse water.
(b) Calculations do not include Vessel A backwash that was initiated and then halted on February 2, 2006.

The recommended AD-33 media backwash frequency was once every 45 days. The system was equipped with an automatic backwash control that initiated backwash either by a 45-day time trigger or by a differential pressure trigger set at 10 psi across each vessel. Because of the process control configuration of the well pumps and high-service pumps, the automatic backwash feature was disabled. Per communication with the operator during the startup trip in February 2006, it was determined that there was no wiring connection between the APU-3 PLC and the city's PLC that controlled the well pumps and high-service pumps. Therefore, if an automatic backwash was called for while the well pumps and high-service pumps were off, adequate flow would not be available to the APU-300 units to accomplish the backwash. For this reason, the automatic backwash capability was disabled in the PLC on February 2, 2006, and the operator performed each backwash of the APU-300 unit with a manual trigger. The four manual backwashes occurred on February 2, February 22, and October 12, 2006, and on January 16, 2007 as described below.

The backwash on February 2, 2006, occurred during startup activities to confirm proper installation and setup of the system. During this event, it was noted that further adjustments were required to the PLC settings and to the backwash flowrate to meet design specifications. During the backwash of Vessel A, a higher than specified backwash flowrate of greater than 275 gpm (or 13 gpm/ft^2) was noted, along with visual observation of media loss discharged through the backwash line. Shortly after initiation of backwash, the operator throttled back the flowrate to approximately 181 gpm (or 8.6 gpm/ft^2), a value below the design flowrate of 200 gpm (or 9.5 gpm/ft^2). It also was noted that the backwash and fast rinse time setpoints required adjustment in the PLC. Therefore, the backwash of Vessel A was halted after 28 min to make these adjustments. The backwash time was changed from 1,200 sec (20 min) to 900 sec (15 min) to match the design value of 15 min. The fast rinse time also was adjusted from 1,500 sec (25 min) to 180 sec (3 min) to be closer to the 5-min design value. During this backwash, Vessels A and B generated 4,668 and 2,979 gal of wastewater, respectively. The operator subsequently performed manual backwash events on February 22, 2006, October 12, 2006, and January 16, 2007 that generated 3,026, 2,857, and 2,578 gal of wastewater from Vessel A, respectively, and 2,799, 3,392, and 3,116 gal of wastewater from Vessel B, respectively. Except for Vessel A on February 2, 2006, backwash produced smaller amounts of wastewater than the design value of 4,000 gal/vessel. During the 1-year system operation, backwash of the adsorption vessels produced 25,415 gal of wastewater, which represents 0.12% of the total amount of water processed.

4.4.4 Residual Management. The residuals produced by the treatment system at Stewart, MN included backwash wastewater produced from the gravity filter and adsorption vessels. The wastewater produced was discharged to the building sump, which emptied by gravity to two holding tanks before being pumped to the sanitary sewer. The total volume of wastewater produced was 431,815 gal, which represents a wastewater generation rate of approximately 2.1%. The AD-33 media was not exhausted during the 1-year performance evaluation study, so there were no residuals associated with spent media.

4.4.5 Reliability and Simplicity of Operation. No significant scheduled or unscheduled downtime was required during the 1-year performance evaluation study. The simplicity of system operation and operator skill requirements is discussed, including pre- and post treatment requirements, levels of system automation, operator skill requirements, preventive maintenance activities, and frequency of chemical/media handling and inventory requirements.

4.4.5.1 Pre- and Post-Treatment Requirements. Due to the high TOC and ammonia levels in source water, $KMnO_4$, instead of chlorine, was originally selected to oxidize As(III) and Fe(II). However, prior to system startup, the operator indicated his preference of using liquid $NaMnO_4$ instead of powdered $KMnO_4$. Subsequently, a modification of the initial design was implemented by the city in December 2005 to include the use of a 20% liquid $NaMnO_4$ solution with a 1-gph chemical-metering pump. To achieve the target dosage, the chemical-metering pump operated with a 25% stroke and 2.5% speed settings. Based on measurements with a calibration cylinder, these settings corresponded to a 0.092-gph application rate, equivalent to only 9.2% of the pump's maximum capacity. The pump size and low settings contributed to difficulties in controlling the $NaMnO_4$ dose, and the pump appeared to have lost prime after February 2, 2006. Without $NaMnO_4$ injection, it was observed that iron continued to be removed, presumably by aeration and that As(III) continued to be oxidized to As(V) via unidentified processes within the AERALATER® gravity filter (see Section 4.5.1.1). No post-treatment requirements existed related to the arsenic-removal system.

4.4.5.2 System Automation. The wellhead and high-service pumps were automatically controlled by a PLC installed by the city. The AERALATER® system did not require significant automation other than the level sensors in the detention tank that controlled operation of the high-service pumps. The AERALATER® system did not include automatic backwash triggers, which could be added as a system upgrade. Because the system needed to be backwashed only weekly, the lack of automation for the gravity filter backwash was not a significant inconvenience. However, this lack of automation would likely be an issue at a site requiring more frequent backwash. As noted in Section 4.4.3, it was necessary to disable the automatic backwash capability of the APU-300 system. It was determined that there was no wiring connection between the APU-300 PLC and the city's PLC that controlled the well pumps and high-service pumps. Therefore, if an automatic backwash was called for while the well pumps and high-service pumps were off, there would not be adequate flow to the adsorption vessels to accomplish the backwash. The city decided not to pursue a change to the control system and to manually backwash the adsorption vessels when required.

4.4.5.3 Operator Skill Requirements. Under normal operating conditions, the daily demand on the operator was approximately 10 min for visual inspection of the system and recording on filed log sheets of operational data such as pressure, volume, and flowrate. The manual backwash operations required an average of 31 min of the operator's time once per week. This is equivalent to approximately 1.7 hr of labor per week. The operator also performed routine weekly and monthly maintenance according to the users' manual to ensure proper system operation. Normal operation of the system did not appear to require additional skills beyond those necessary to operate the existing water supply equipment.

The state of Minnesota has five water operator certificate class levels (A, B, C, D, and E with A being the highest). The certificate levels are based on education, experience, and system characteristics, such as water source, treatment processes, water storage volume, number of wells, and population affected. The water operator for the City of Stewart has a Class C certificate. Class C requires a high school diploma or equivalent with at least 3 years of experience in operating Class A, B, or C system or a bachelor's degree from an accredited institution with at least 1 year of experience in operating a Class A, B, C, or D system.

4.4.5.4 Preventive Maintenance Activities. Recommended maintenance activities for the AERALATER® system include annual inspection of the aerator internals and slats to monitor iron build-up and perform cleaning if necessary; a complete interior inspection every 2 years by Siemens; and mechanical and electrical aerator blower checks if performance issues arise. Preventive maintenance tasks for the APU-300 system recommended by the vendor include monthly inspection of the control panel; quarterly checking and calibration of flow meters; biannual inspection of actuator housings, fuses, relays, and pressure gauges; and annual inspection of the butterfly valves. The vendor recommended checking the actuators at each backwash event to ensure that the valves were opening and closing in the proper sequence. Further, inspection of the adsorber laterals and replacement of the underbedding gravel were recommended to be concurrent with the media replacement. During the 1-year performance evaluation study, two relays that controlled the electrically actuated values on the APU-300 system were replaced, using spare relays in the PLC panel. No other significant repair and maintenance activities were reported during the period.

4.4.5.5 Chemical-Handling and Inventory Requirements. No chemical-handling requirements were necessary because iron removal occurred by aeration, and because oxidation of As(III) to As(V) was occurring within the AERALATER® filter (see Section 4.5.1.1). Chemical handling of $NaMnO_4$ was required only initially from January 18 to February 2, 2006, during the system shakedown stage.

4.5 System Performance

The performance of the AERALATER® and APU-300 systems was evaluated based on analyses of water samples collected from the treatment plant, system backwash, and distribution system.

4.5.1 Treatment Plant. The treatment plant water was sampled at six locations (IN, AC, AF, TA, TB, and TT) on 49 occasions (including three duplicate events) with field speciation performed during 13 of the 49 occasions. Field-speciation samples were collected at the IN, AC, AF, and TT sampling locations monthly. Table 4-6 summaries analytical results for arsenic, iron, and manganese. Table 4-7 summarizes results of the other water quality parameters. These tables include data from all 49 sampling occasions, except for those collected at AC, AF, TA, TB, and TT on February 2, 2006, when $NaMnO_4$ was added. The February 2, 2006, results are included in Appendix B, which contains a complete set of analytical data. Results of the water samples collected throughout the treatment plant are discussed below.

4.5.1.1 Arsenic. Figure 4-13 contains four bar charts showing the concentrations of total As, particulate As, soluble As(III), and soluble As(V) at the IN, AC, AF, and TT sampling locations for each speciation sampling event. Total arsenic concentrations in source water ranged from 31.4 to 56.4 µg/L with 27.6 to 44.0 µg/L existing as soluble As(III). Therefore, As(III) was the predominant species. Lower levels of soluble As(V) and particulate arsenic also were present, averaging 5.1 and 6.4 µg/L, respectively. Total arsenic concentrations measured during the performance evaluation study varied in a wider range than those measured historically (39.0 to 41.7 µg/L), as shown in Table 4-1.

Arsenic Removal with $NaMnO_4$ Addition. Upon completion of shakedown, the treatment system was operated with $NaMnO_4$ addition for soluble As(III) and Fe(II) oxidation. However, the addition was disrupted due to loss of prime within 1 week after the first sampling and speciation event on February 2, 2006, based on the measurements of solution level and consumption rate in the chemical day tank.

For the sampling event on February 2, 2006, out of 52.3 µg/L of total arsenic in source water, 39.8 µg/L were present as soluble As(III). At 1,240 µg/L, iron existed almost entirely as soluble iron. The soluble As(III) and Fe(II) concentrations were decreased to 4.2 and < 25 µg/L, respectively, following $NaMnO_4$ preoxidation, aeration, and detention. About 0.51 mg/L of $NaMnO_4$ (as Mn) was believed to have been added to source water based on the difference in total manganese concentrations between the IN and AC sampling locations. This amount was close to the stoichiometrically estimated dosage of 0.42 mg/L (as Mn) based on the February 2, 2006, source-water data. Therefore, the amount of $NaMnO_4$ added should be sufficient to oxidize most, if not all, As(III) and Fe(II) in source water. It should be noted, however, that the $NaMnO_4$ target dosage was estimated based mainly on the levels of soluble As, Fe, and Mn in source water (see data in Appendix B) and that the elevated TOC level at 6.7 mg/L could add to the oxidant demand (see Section 4.5.1.3). The As(V) thus formed, along with the pre-existing As(V), was adsorbed onto and/or co-precipitated with the iron solids formed during the preoxidation step, resulting in 31.1 µg/L of particulate arsenic after the detention tank.

The February 2, 2006, results also showed the presence of 17.0 µg/L of soluble As(V) after the detention tank, indicating incomplete As(V) removal by the naturally occurring iron in source water. The concentration ratio of soluble iron to soluble arsenic in source water was 26:1 on February 2, 2006, which was over the 20:1 target ratio for more effective As(V) removal via the iron-removal process (Sorg, 2002). The relatively inefficient As(V) removal observed might have been caused by the relatively high pH value (8.2) and the presence in source water of competing anions (1.0 mg/L of total phosphorous [as PO_4] and 27.6 mg/L of Si [as SiO_2]) and TOC (6.7 mg/L). All could adversely impact the soluble As(V) removal by natural iron solids.

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

Parameter	Sampling Location[a,c]	Number of Samples	Concentration (µg/L) Minimum	Maximum	Average	Standard Deviation
As (total)	IN	49	31.4	56.4	44.8	7.1
	AC	48	29.9	56.9	43.8	6.3
	AF	48	19.8	42.7	29.0	5.2
	TA	38	0.4	7.4	-[b]	-[b]
	TB	36	0.3	9.2	-[b]	-[b]
	TT	10	<0.1	9.8	-[b]	-[b]
As (soluble)	IN	13	34.1	48.9	40.4	4.7
	AC	12	32.5	44.9	36.6	3.8
	AF	12	21.9	37.4	28.0	3.9
	TA	2	0.4	0.5	-[b]	-[b]
	TB	0	NA	NA	NA	NA
	TT	10	<0.1	8.6	-[b]	-[b]
As (particulate)	IN	13	0.5	14.0	6.4	3.9
	AC	12	<0.1	14.8	10.2	4.1
	AF	12	<0.1	12.3	4.2	4.2
	TA	2	<0.1	0.3	0.2	0.2
	TB	0	NA	NA	NA	NA
	TT	10	<0.1	1.2	0.3	0.4
As (III) (soluble)	IN	13	27.6	44.0	35.3	5.6
	AC	12	21.7	30.8	26.2	2.6
	AF	12	<0.1	6.6	1.6	1.8
	TA	2	0.6	1.7	-[b]	-[b]
	TB	0	NA	NA	NA	NA
	TT	10	<0.1	1.1	-[b]	-[b]
As (V) (soluble)	IN	13	1.4	11.7	5.1	2.9
	AC	12	6.1	23.2	10.4	4.2
	AF	12	21.8	30.8	26.4	2.9
	TA	2	<0.1	<0.1	-[b]	-[b]
	TB	0	NA	NA	NA	NA
	TT	10	<0.1	7.5	-[b]	-[b]
Fe (total)	IN	49	993	1,491	1,188	110
	AC	48	919	1,309	1,142	88.8
	AF	48	<25	29.2	<25	3.2
	TA	38	<25	337	<25	52.6
	TB	36	<25	524	26.7	85.3
	TT	10	<25	<25	<25	NA
Fe (soluble)	IN	13	412	1,335	922	283
	AC	12	<25	68.5	<25	16.9
	AF	12	<25	<25	<25	NA
	TA	2	<25	<25	<25	NA
	TB	0	NA	NA	NA	NA
	TT	10	<25	<25	<25	NA
Mn (total)	IN	49	19.6	44.3	23.6	3.5
	AC	48	20.3	31.4	23.7	1.9
	AF	48	21.9	47.8	27.5	5.7
	TA	38	10.7	31.2	24.8	4.2
	TB	36	7.2	33.2	25.8	5.2
	TT	10	22.9	34.2	26.5	3.4
Mn (soluble)	IN	13	20.3	29.7	24.0	2.4
	AC	12	20.3	25.6	23.4	1.7
	AF	12	22.0	41.3	26.5	5.2
	TA	2	17.5	26.0	21.8	6.1
	TB	0	NA	NA	NA	NA
	TT	10	23.5	35.1	26.8	3.3

(a) See Table 3-3.
(b) Average and standard deviation not meaningful for arsenic breakthrough data.
(c) Not including results for AC, AF, TA, TB, and TT from the February 2, 2006, sampling event with $NaMnO_4$ addition.
NA = not applicable.

Table 4-7. Summary of Other Water Quality Parameter Measurements

Parameter	Sampling Location[a,b]	Unit	Sample Count	Concentration Minimum	Concentration Maximum	Concentration Average	Standard Deviation
Alkalinity (as $CaCO_3$)	IN	mg/L	49	408	485	435	18.8
	AC	mg/L	48	410	487	436	19.3
	AF	mg/L	48	403	476	436	17.1
	TA	mg/L	38	400	474	431	18.1
	TB	mg/L	36	367	470	430	21.0
	TT	mg/L	10	416	469	438	20.0
Ammonia (as N)	IN	mg/L	29	1.0	1.9	1.6	0.2
	AC	mg/L	28	1.1	1.9	1.6	0.2
	AF	mg/L	28	0.9	1.7	1.4	0.2
	TA	mg/L	19	0.6	1.4	1.1	0.2
	TB	mg/L	17	0.4	1.3	1.1	0.2
	TT	mg/L	9	1.0	2.3	1.2	0.4
Fluoride	IN	mg/L	13	0.3	1.0	0.5	0.2
	AC	mg/L	12	0.3	0.6	0.5	0.1
	AF	mg/L	12	0.2	0.6	0.5	0.1
	TA	mg/L	2	0.4	0.4	0.4	0.0
	TT	mg/L	10	0.2	0.8	0.5	0.2
Sulfate	IN	mg/L	13	<1	<1	<1	NA
	AC	mg/L	12	<1	<1	<1	NA
	AF	mg/L	12	<1	<1	<1	NA
	TA	mg/L	2	<1	<1	<1	NA
	TT	mg/L	10	<1	<1	<1	NA
Nitrate (as N)	IN	mg/L	30	<0.05	<0.05	<0.05	0.0
	AC	mg/L	29	<0.05	0.1	<0.05	0.0
	AF	mg/L	29	<0.05	1.5	0.3	0.3
	TA	mg/L	19	<0.05	1.7	0.5	0.4
	TB	mg/L	17	0.2	1.6	0.5	0.3
	TT	mg/L	10	0.3	1.4	0.5	0.4
Total P (as P)	IN	µg/L	49	80.9	350	301	40.9
	AC	µg/L	48	247	344	295	24.1
	AF	µg/L	48	89.3	158	112	13.2
	TA	µg/L	38	<10	246	26.4	40.1
	TB	µg/L	36	<10	336	33.0	55.0
	TT	µg/L	10	<10	111	37.2	32.8
Silica (as SiO_2)	IN	mg/L	49	23.1	28.3	25.1	1.1
	AC	mg/L	48	23.1	28.2	25.0	0.9
	AF	mg/L	47	23.0	28.1	24.9	1.1
	TA	mg/L	38	23.3	28.3	25.1	1.0
	TB	mg/L	36	23.5	28.6	25.0	1.1
	TT	mg/L	10	23.7	27.0	25.2	1.0
Turbidity	IN	NTU	49	4.1	15.0	6.5	2.0
	AC	NTU	48	7.1	15.0	9.2	1.5
	AF	NTU	48	0.3	8.3	0.9	1.1
	TA	NTU	38	0.2	2.2	0.8	0.4
	TB	NTU	36	0.2	3.5	0.9	0.7
	TT	NTU	10	0.4	1.3	0.8	0.3
TOC	IN	mg/L	11	6.2	6.7	6.4	0.2
	AC	mg/L	11	6.2	7.0	6.5	0.3
	AF	mg/L	11	3.8	7.0	6.2	0.9
	TA	mg/L	1	6.1	6.1	6.1	NA
	TT	mg/L	9	3.1	6.7	6.1	1.2
pH	IN	S.U.	46	7.4	8.2	7.9	0.2
	AC	S.U.	45	7.8	8.6	8.3	0.2
	AF	S.U.	45	7.7	8.9	8.1	0.2
	TA	S.U.	35	7.8	8.4	8.2	0.1

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

Parameter	Sampling Location[(a,b)]	Unit	Sample Count	Concentration Minimum	Maximum	Average	Standard Deviation
pH (Con't)	TB	S.U.	33	7.9	8.4	8.2	0.1
	TT	S.U.	10	7.7	8.3	8.1	0.2
Temperature	IN	°C	46	10.1	16.6	11.7	1.2
	AC	°C	45	10.1	13.8	11.4	0.9
	AF	°C	45	10.5	19.3	12.0	1.5
	TA	°C	35	10.6	14.3	12.0	1.1
	TB	°C	33	10.5	15.4	12.3	1.2
	TT	°C	10	10.8	13.5	11.9	0.7
DO	IN	mg/L	45	0.5	2.2	1.2	0.5
	AC	mg/L	43	3.8	7.2	5.0	0.7
	AF	mg/L	43	1.6	4.9	2.6	0.8
	TA	mg/L	33	1.5	6.2	2.7	0.9
	TB	mg/L	31	1.7	5.7	2.7	0.8
	TT	mg/L	10	2.2	6.8	3.0	1.4
ORP	IN	mV	46	-36.6	404	216	129
	AC	mV	45	39.7	360	207	82.0
	AF	mV	45	36.6	386	186	78.0
	TA	mV	35	24.9	323	158	72.0
	TB	mV	33	23.5	321	150	68.8
	TT	mV	10	80.0	297	173	68.9
Total Hardness (as $CaCO_3$)	IN	mg/L	13	200	238	218	13.0
	AC	mg/L	12	189	236	216	14.4
	AF	mg/L	12	206	242	219	10.3
	TA	mg/L	2	209	210	210	0.6
	TT	mg/L	10	205	247	222	13.3
Ca Hardness (as $CaCO_3$)	IN	mg/L	13	88.2	127	112	10.6
	AC	mg/L	12	94.8	130	111	11.7
	AF	mg/L	12	97.2	134	113	10.0
	TA	mg/L	2	103	104	104	0.1
	TT	mg/L	10	95.2	137	115	11.5
Mg Hardness (as $CaCO_3$)	IN	mg/L	13	94.0	118	107	8.6
	AC	mg/L	12	93.9	118	105	8.1
	AF	mg/L	12	92.7	117	107	6.6
	TA	mg/L	2	105	106	106	0.7
	TT	mg/L	10	94.9	119	107	6.9

(a) See Table 3-3.
(b) Not including results for AC, AF, TA, TB, and TT from the February 2, 2006, sampling event with $NaMnO_4$ addition.
NA = not applicable.

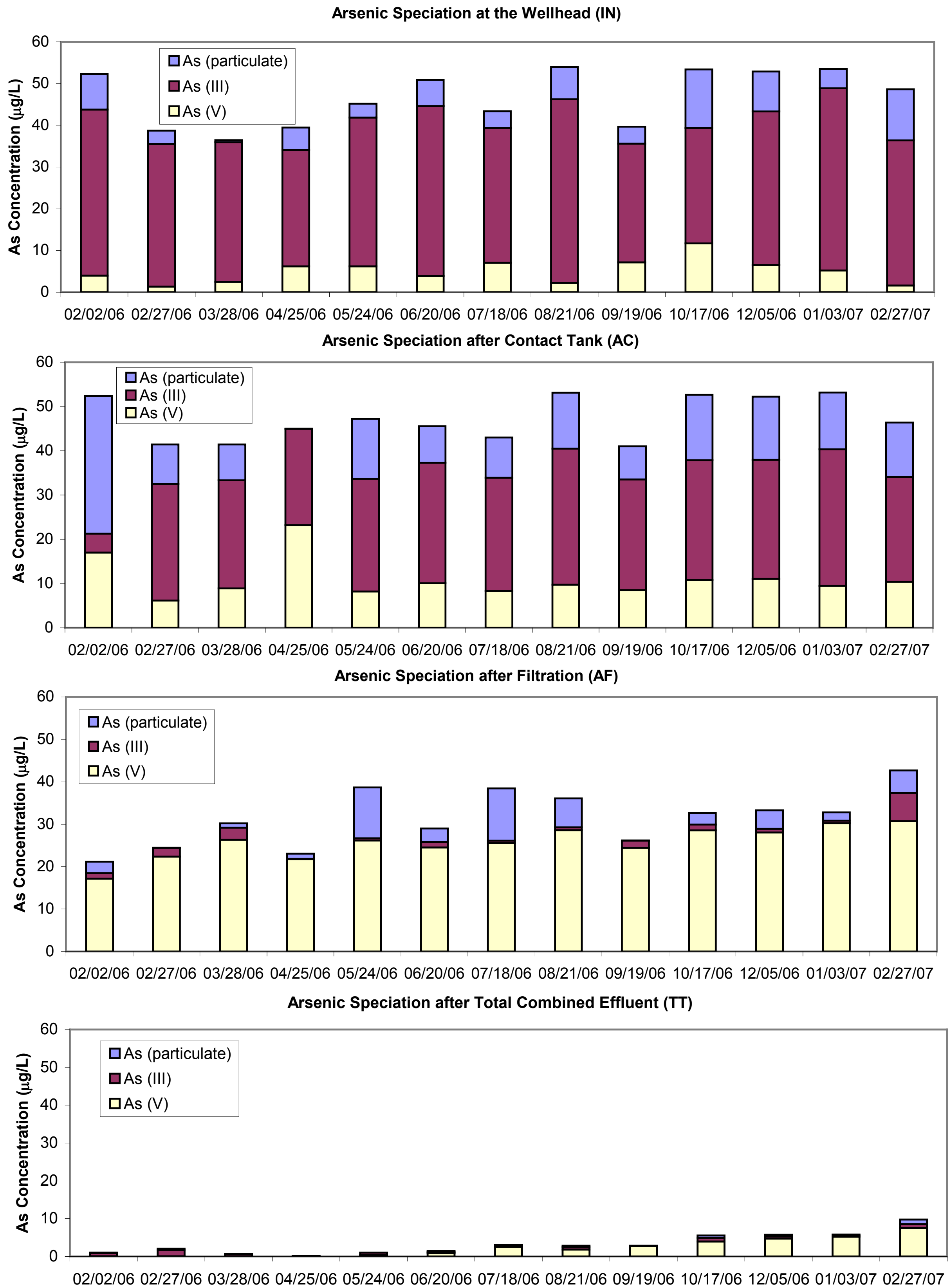

Figure 4-13. Concentrations of Arsenic Species at Wellhead (IN), After Contact Tank (AC), After Filtration (AF), and After Vessels A and B Combined (TT)

The results on February 2, 2006, also indicated that the gravity filter was highly effective in removing particulate matter, leaving only 2.7 μg/L of particulate arsenic and less than the detection limit of iron in the filter effluent. Also present in the filter effluent were 17.2 μg/L of soluble As(V) and 1.3 μg/L of soluble As(III). As expected, soluble As(V) in the filter influent was left essentially untreated. However, soluble As(III) concentrations were reduced from 4.2 to 1.3 μg/L across the filter bed. Conversion of soluble As(III) to soluble As(V) in the gravity filter also was observed during the subsequent sampling events after the addition of $NaMnO_4$ had been inadvertently discontinued due to a pump issue. This unexpected finding is discussed in the following paragraphs. With $NaMnO_4$ addition, the gravity filter achieved removal of approximately 60% total arsenic and nearly 100% total iron.

Arsenic Removal Without $NaMnO_4$ Addition. As noted above, after the sampling event on February 2, 2006, the $NaMnO_4$ metering pump lost prime, thus inadvertently discontinuing $NaMnO_4$ addition for soluble As(III) oxidation. The disruption of chemical addition was confirmed by both the lack of chemical consumption in the $NaMnO_4$ day tank and the decrease in Mn concentrations in the AC samples taken after the detention tank starting from the second sampling event on February 14, 2006.

As typified by the results of the first speciation event on February 27, 2006, since discontinuation of $NaMnO_4$ addition, very little soluble As(III) conversion occurred via aeration, with 34.2 μg/L in source water and 26.4 μg/L following aeration and detention. This observation was consistent with the general notion that aeration was not effective in oxidizing soluble As(III) (Ghurye and Clifford, 2001). Nonetheless, some soluble As(III) oxidation still occurred, with soluble As(V) concentrations increasing from 1.4 to 6.1 μg/L and particulate arsenic concentrations from 3.2 to 8.9 μg/L after aeration and detention. The amount of particulate arsenic formed via aeration was 5.7 μg/L (i.e., the difference of 3.2 and 8.9 μg/L on February 27, 2006), compared to 22.6 μg/L (i.e., the difference of 8.5 and 31.1 μg/L) formed following $NaMnO_4$ preoxidation and aeration on February 2, 2006. Note that the levels of soluble iron in the February 2 and 27, 2006, source-water samples were comparable at 1,159 and 855 μg/L, respectively.

As discussed in the *Design Manual for the Removal of Arsenic from Drinking Water Supplies by Iron Removal Process* (Hoffman, et al., 2006), the use of a chemical oxidant and the point of chemical oxidant addition are critical to optimize arsenic removal via the iron-removal process. Research has shown that iron particles formed in the presence of soluble As(V), like the case of preoxidation with $NaMnO_4$, had more capacity to remove soluble As(V) than pre-formed iron particles, as with the case of aeration. Edwards (1994) reported that pre-formed iron hydroxides only reached one-fifth to one-sixth of the maximum adsorption density for iron hydroxides formed in the presence of soluble As(V). The differences in adsorption densities were attributed to certain mechanisms (i.e., strictly surface adsorption versus adsorption and co-precipitation). Lytle and Snoeyink (2003) also observed that arsenic removal was lower with pre-formed iron solids, as opposed to the ideal case of oxidizing both soluble Fe(II) and As(III) at the same time. Consequently, the oxidation of iron and arsenic should occur at the same time to achieve optimal arsenic removal.

The February 27, 2006, speciation results also showed that even without the use of $NaMnO_4$, most soluble As(III) in the filter influent was oxidized to soluble As(V) within the gravity filter, with the soluble As(V) concentration elevated to 22.4 μg/L and particulate arsenic reduced to <0.01 μg/L in the filter effluent. The amount of soluble As(V) in the filter effluent suggested that a portion of the soluble As(V) formed in the filter, along with that already existing in the filter influent, was removed, presumably by attaching to the iron solids accumulating in the filter. Removal of soluble As(V) also was observed during all but one (on February 27, 2007) subsequent speciation event, with removal rates ranging from 13% to 51% and averaging 26%. These soluble As(V) removal rates were lower than the 57% As(V) removal rate achieved on February 2, 2006, following $NaMnO_4$ preoxidation. Adsorption of As(V) on pre-formed iron solids, as discussed above, probably explains why the removal rates were lower.

The gravity filter was effective in removing particulate iron, as indicated by less than the MDL of iron in the filter effluent throughout the performance evaluation study (except for one sampling event on June 6, 2006). The gravity filter removed approximately 59% of particulate arsenic, leaving only 4.2 µg/L (on average) in the filter effluent (Table 4-6). Because soluble As(III) was oxidized to soluble As(V) in the filter under natural conditions and due to elevated manganese levels in the filter effluent in the presence of high TOC, it was decided to continue the study without $NaMnO_4$ addition (see Section 4.5.1.3).

In summary, after the use of $NaMnO_4$ was discontinued, the average soluble As(III) and soluble As(V) concentrations following the detention tank (AC) were 26.2 and 10.4 µg/L, respectively (Table 4-6). The average soluble As(III) level after the gravity filter (AF) decreased to 1.6 µg/L, and As(V) increased to 26.4 µg/L. The aeration step in the AERALATER® unit converted approximately 26% (on average) of As(III) to As(V). Across the gravity filter, approximately 94% of As(III) was oxidized to As(V) via naturally occurring microbial-mediated processes. As shown by Figure 4-14, approximately 34% (on average) of total arsenic was removed by the gravity filter, lower than the 60% from the single sampling event on February 2, 2006, with $NaMnO_4$ addition. Arsenic exiting the gravity filter was removed by the AD-33 media in the APU-300 system.

The arsenic breakthrough curves for the two adsorption vessels and the entire system are presented in Figure 4-14, with total arsenic concentrations plotted against throughput in BV at the IN, AC, AF, TA, TB, and TT locations. As expected, arsenic concentrations in the adsorption vessel effluent (TA, TB, and TT) increased gradually (except for one measurement at approximately 10,000 BV), with total arsenic concentrations measured below the MCL of 10 µg/L during the 1-year performance evaluation study.

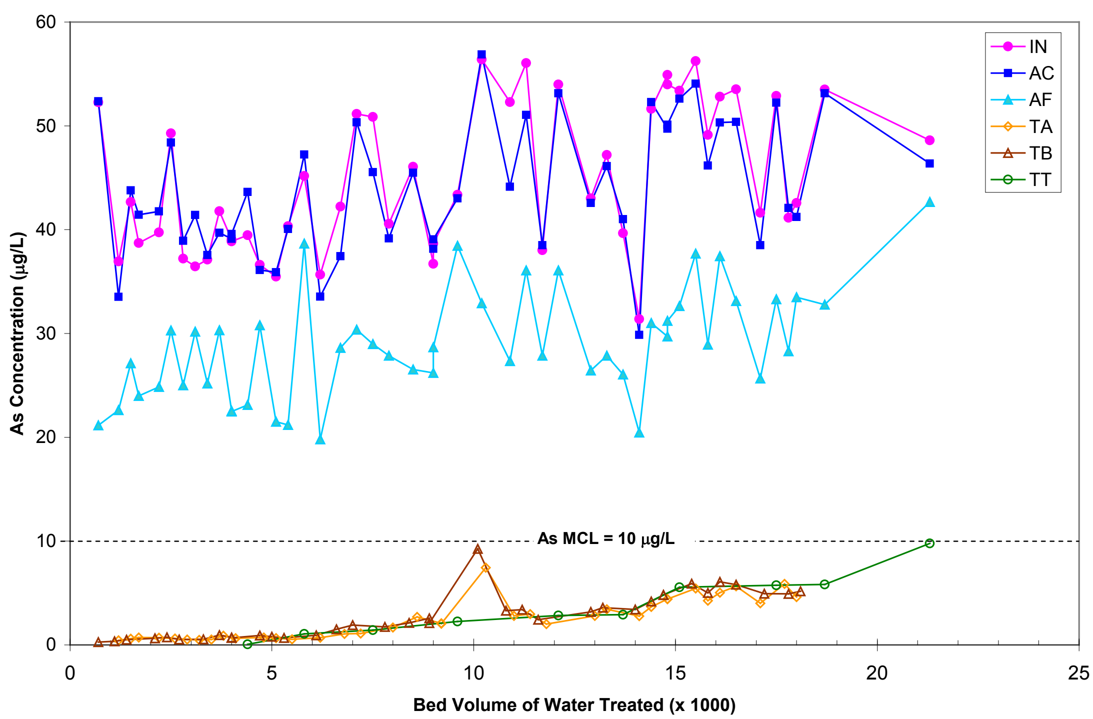

Figure 4-14. Total Arsenic Concentrations vs. Throughput

At the end of the study, the total arsenic concentration was 9.8 µg/L in system effluent (February 27, 2007). The city took two more compliance samples after the end of the study, with total arsenic concentrations at 7.0 µg/L at around 22,400 BV on March 19, 2007, and at 11 µg/L at around 26,300 BV on May 29, 2007. Extrapolating from the average daily production of 52,418 gpd, the arsenic breakthrough above 10 µg/L most likely occurred at 25,300 BV, which was only 31% of the vendor's projected capacity of 82,500 BV (Table 4-3).

As discussed above, the total arsenic removal efficiency of the gravity filter was reduced from approximately 60% to 34% after stopping $NaMnO_4$ injection, which shifted the burden of arsenic removal from the gravity filter to the downstream adsorption vessels. The vendor's estimate of 82,500 BV was based on expected removal across the gravity filter of 30% to 50%, which would result in influent arsenic concentrations of 22 to 31 µg/L to the APU-300 treatment system. This design basis is comparable to the 26.4-µg/L As(V) concentration from the filter effluent (without $NaMnO_4$ addition). Therefore, the discrepancy observed in media run length would have been caused by factors such as competing ions (like total phosphorous) in the source water, which were not accounted for in the vendor's run-length estimate (see Section 4.5.1.6).

Microbial-Mediated As(III) Oxidation. Since the $NaMnO_4$ addition ended, soluble As(III) was unexpectedly oxidized to soluble As(V) in the gravity filter, apparently via certain natural pathways. Figure 4-15 shows the biogeochemical cycle of arsenic as it is transformed between the As(III) and As(V) states in the environment. This transformation often is mediated by microbial activities. Several researchers have reported the presence of As(III)-oxidizing bacteria in surface and groundwater (Oremland and Stolz, 2003; Battaglia-Brunet et al., 2002; Hambsch et al., 1995), with over 30 strains of microorganisms identified. These microorganisms are categorized in two groups (heterotrophic arsenite oxidizers [HAOs] and chemolithoautotrophic arsenite oxidizers [CAOs]) based on the pathways involved in arsenite oxidation. The term heterotroph means that the microbe uses organic carbon substrates for its biomass growth, while the term autotroph means that the microbe uses inorganic carbon (e.g. CO_2) for its biomass growth. These two types of microorganisms oxidize As(III) through the following mechanisms (Oremland and Stoltz, 2003):

- **Heterotrophic Arsenite Oxidizers**. The HAOs primarily oxidize As(III) as a detoxification reaction that converts As(III) to As(V) at the cell membrane. This helps inhibit its entry into the cellular structure. This reaction does not create energy or biomass for the HAO microbe.
- **Chemolithoautotrophic Arsenite Oxidizers.** The CAOs use As(III) as an electron donor to reduce oxygen or nitrate and use the energy to fix CO_2 into biomass. The term chemolithoautotroph refers to the microbe that uses chemical reactions for energy ("chemo") and uses inorganic electron donors ("litho") to fix CO_2 into biomass ("autotroph").

Under a separate task order, researchers at EPA and Battelle observed similar naturally-occurring As(III) oxidation processes in a gravity sand filter following aeration at the Greene County Southern Plant (GCSP) in Beaver Creek, OH. Source water at the plant contained 45.9 and 2,280 µg/L of total arsenic and iron, both existing almost entirely in the soluble form. Upon aeration and filtration, As(III) concentrations were reduced from 37.2 µg/L (on average) in the filter influent to 1.2 µg/L (on average) in the filter effluent. As(V) removal across the filter bed was 77%, much higher than the 26% observed at the Stewart, MN facility without $NaMnO_4$ preoxidation (Wang, 2006a). Higher As(V) removal at the GCSP was likely due to the lower pH value at 7.5, which is more favorable for As(V) adsorption onto iron solids, and the <10 µg/L of total phosphorous, which eliminated a source of competing species for As(V) removal. At the GCSP, the oxidation of As(III) occurred concurrently with nitrification in the filter bed, which converted almost 100% of the 1.2 mg/L of NH_3 (as N) (on average) in the filter influent to NO_3^- in the filter effluent (Wang, 2006a; Lytle et al., 2007). However, nitrification

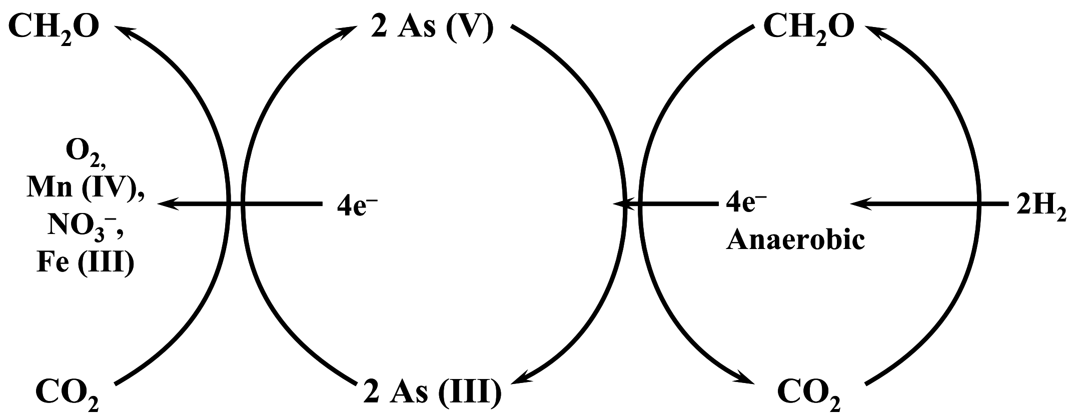

Figure 4-15. Biogeochemical Cycle of Arsenic (Oremland et al., 2002)

was determined not to be directly responsible for As(III) oxidation under an internally funded research project at Battelle. The results of this study will be further discussed under Section 4.5.1.5.

At the Stewart, MN site, the average As(III) levels declined from 26.2 μg/L in the filter influent to 1.6 μg/L in the filter effluent. The reduction of DO concentrations from 5.0 mg/L after aeration to 2.6 mg/L after the filter suggested that oxygen was the most likely electron donor in a biologically mediated process and that aerobic conditions persist throughout the filter. A portion of DO removal also might be attributed to the nitrification process that occurred, although this process was shown to be unrelated to the As(III) oxidation at the GCSP, as described below in Section 4.5.1.5.

4.5.1.2 Iron. Figure 4-16 presents total iron concentrations measured across the treatment train. Total iron concentrations in source water ranged from 993 to 1,491 μg/L and averaged 1,188 μg/L, existing primarily in the soluble form at 922 μg/L (on average). The average soluble iron and soluble arsenic concentrations in source water corresponded to a ratio of 23:1, which was just over the 20:1 target ratio for more effective arsenic removal (Sorg, 2002). As discussed above, relatively high pH values and/or high concentrations of competing anion and TOC in source water might affect the arsenic-removal capacity of the natural iron solids.

Aeration alone in the AERALATER® unit was sufficient to accomplish complete Fe(II) oxidation. Soluble iron concentrations after aeration and the detention tank were <25 μg/L; complete conversion of soluble iron to particulate iron was achieved. The AERALATER® filter was effective in removing particulate iron, reducing the iron concentrations to be close to or below the MDL of 25 μg/L over the 1-year study period. No particulate iron breakthrough was observed from the gravity filter, indicating adequate filtration rate and filter backwash frequency.

Following the APU-300 adsorption vessels, iron levels remained at <25 μg/L, with the exception of one outlier taking place on July 25, 2006, when total iron (as particulate) appeared to break through from Vessels A and B at 337 and 524 μg/L, respectively. It was not clear what had caused the elevated iron concentrations observed. The system appeared to operate properly at the time, with differential pressure across the system remaining as low as 1 psi. On the subsequent sampling events, the total iron levels from Vessels A and B returned to <25 μg/L.

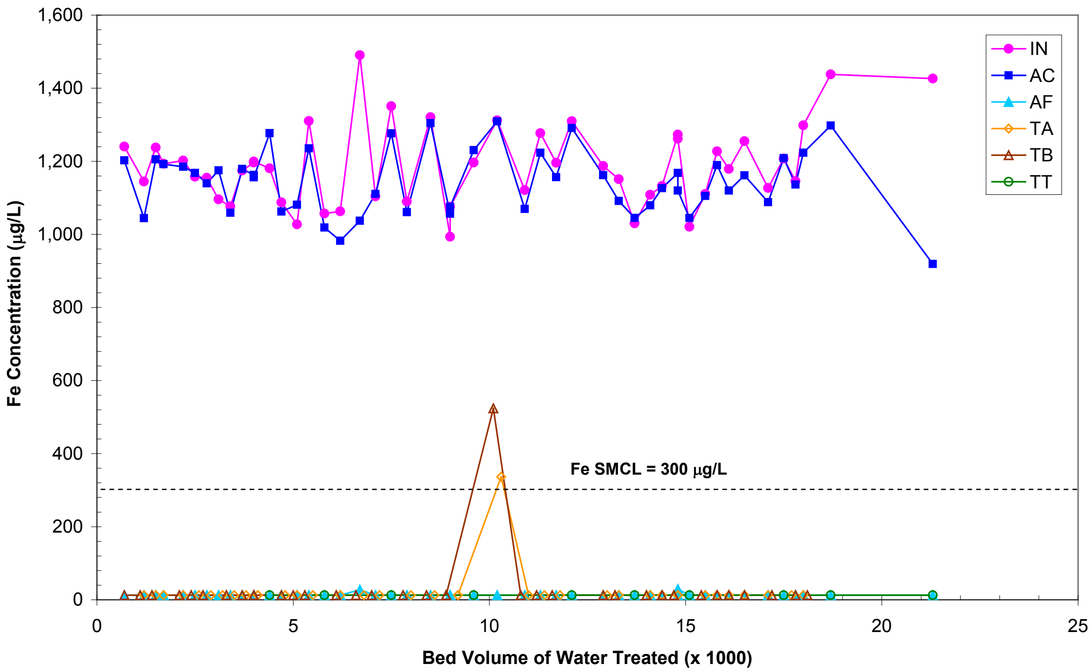

Figure 4-16. Total Iron Concentrations vs. Bed Volumes

4.5.1.3 Manganese. Manganese concentrations in source water ranged from 19.6 to 44.3 µg/L and averaged 23.6 µg/L. Manganese existed primarily in the soluble form at an average concentration of 24.0 µg/L. Manganese removal is discussed below for treatment system performance, both with and without $NaMnO_4$ addition. For the first sampling event on February 2, 2006, the $NaMnO_4$ feed pump was operational and a total manganese concentration of 541 µg/L was measured after preoxidation, aeration, and detention. The total manganese concentration following the gravity filter (AF) was elevated at 127 µg/L, existing entirely as soluble manganese. The presence of elevated soluble manganese in the filter effluent was unexpected, because the amount of $NaMnO_4$ added was very close to the stoichiometric dosage of 0.42 mg/L (as Mn) for the February 2, 2006, source water, and should have been completely consumed and converted to MnO_2 solids during the preoxidation step.

The detection of "soluble manganese" was probably caused by the presence of high TOC levels in source water. It is possible that the "soluble manganese" exiting the filter was present in the colloidal form that penetrated through the gravity filter and the 0.45-µm disc filters during speciation sampling. Researchers have reported that high levels of dissolved organic matter (DOM) in source water can form fine colloidal MnO_2 particles not filterable by conventional gravity or pressure filters (Knocke et al., 1991). Similar observation also was made at another EPA arsenic demonstration site at Sauk Centre, MN, where elevated levels of "soluble manganese" up to 1,062 µg/L were observed following the contact tank and Macrolite® pressure filters as the $KMnO_4$ dosage was progressively decreased from 3.8 to 1.4 mg/L (as Mn) due to concerns with overdosing. (Note that similar to the Stewart, MN system, permanganate was used for the Sauk Centre, MN system to preoxidize as much as 23 and 2,691 µg/L of As(III) and Fe(II), respectively, due to the presence of 4.0 mg/L of TOC.) At Sauk Centre, "soluble manganese" eventually was reduced to as low as 2.5 µg/L as the $KMnO_4$ dosage was increased to 5.6 mg/L (as Mn). Increasing the $KMnO_4$ dosage probably helped diminish the effect of DOM on Mn(II) oxidation and helped form more filterable MnO_2 particles (Shiao, et al., 2007).

At Stewart, elevated manganese concentrations in the gravity filter effluent occurred only with $NaMnO_4$ addition, which took place for about a week. The colloidal manganese present in the gravity filter effluent was removed by AD-33 media, with its concentration reduced from 127 to 3.7 µg/L on February 2, 2006. Had $NaMnO_4$ addition continued at the same dose rate as on February 2, 2006, the elevated colloidal manganese levels in the filter effluent could become an issue for media performance. At other EPA demonstration sites with pre-chlorination, such as Rollinsford, NH, elevated manganese levels were found to coat and foul AD-33 media (Cumming et al., 2009), resulting in early arsenic breakthrough and short media run length. The impact of elevated manganese levels on AD-33 media should be minimal because they occurred for only a very short duration.

After the February 2, 2006, sampling event, when the $NaMnO_4$ feed pump lost prime, manganese levels after the detention tank (AC) decreased significantly to those in raw water (e.g., at 21 µg/L by the next sampling event on February 14, 2006 [see Figure 4-17]). Total Mn levels exiting the AERALATER® filter continued to be somewhat elevated relative to filter influent levels during most of the sampling events throughout the study. From February 14 to April 4, 2006, some manganese was removed by AD-33 media, and the removal continued for approximately 3,400 BV. Since then, the effluent values have become equal to, or somewhat higher than, the influent values. These results suggest that AD-33 media had only a limited capacity for Mn removal (present as Mn^{2+} ions). As discussed in Section 4.5.1.1, the $NaMnO_4$ addition was not resumed during the remainder of the performance evaluation study.

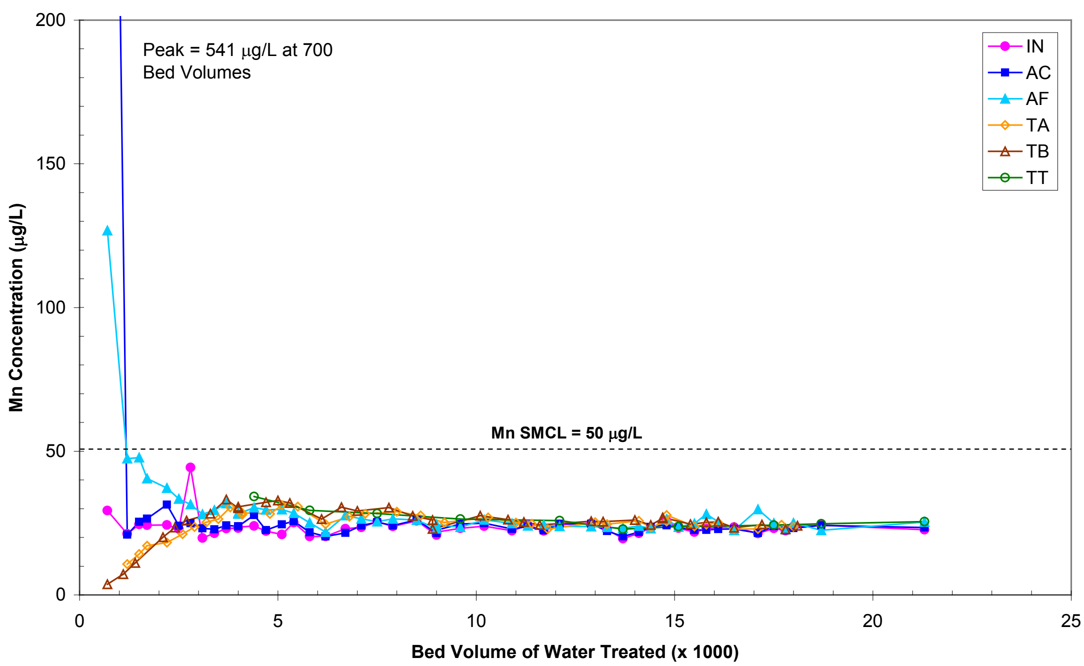

Figure 4-17. Total Manganese Concentrations vs. Bed Volumes

4.5.1.4 pH, DO, and ORP. pH values of source water ranged from 7.4 to 8.2 and averaged 7.9. pH values increased slightly from an average value of 7.9 at the wellhead to 8.3 after the AERALATER® filter. Aeration probably contributed to this increase in pH. DO levels averaged 1.2 mg/L in source water and increased to an average value of 5.0 mg/L after aeration. DO concentrations decreased by about 48% to an average value of 2.6 mg/L across the gravity filter. The aerobic biological processes responsible for As(III) oxidation and nitrification processes might have consumed some of the DO in the filter influent

(Sawyer, et al., 2003). The average DO levels after the APU-300 system were 2.7 mg/L, essentially the same as those going into the adsorption system. ORP levels averaged 216 mV in source water and 207 mV after aeration and the detention tank. Again, probably due to the biological processes, ORP readings decreased to 186 mV (on average) after the gravity filter. ORP levels averaged 173 mV in the combined effluent of the APU-300 system.

4.5.1.5 Ammonia and Nitrate. Twenty-nine sampling events took place for ammonia and 30 for nitrate during the 1-year performance evaluation study. In source water, ammonia concentrations ranged from 1.0 to 1.9 mg/L (as N) and averaged 1.6 mg/L (as N); nitrate concentrations were consistently less than the MDL of 0.05 mg/L (as N). Following aeration and detention, ammonia concentrations remained essentially unchanged, although up to 0.3 mg/L (as N) concentration differences were observed between the IN and AC sampling locations. Nitrate concentrations also remained unchanged following aeration and detention, with all measurements less than 0.05 mg/L (as N), except for one outlier of 0.1 mg/L (as N) measured at the AC location on December 12, 2006.

Figure 4-18 shows the decreases in ammonia concentration and increases in nitrate concentration across the gravity filter and AD-33 adsorption vessels versus volume throughput in bed volumes by the system. After treating 3,100 BV of water (or 69 days after system startup on January 18, 2006), some ammonia began to be removed by the gravity filter and AD-33 adsorption vessels. Decreases in ammonia concentration across the gravity filter ranged from 0 to 0.6 mg/L (as N) and averaged 0.3 mg/L (as N). Decreases in ammonia concentration across the AD-33 adsorption vessels ranged from 0 to 1 mg/L (as N) and averaged 0.3 mg/L (as N). Nitrate concentrations remained below 0.05 mg/L (as N) until 4,400 BV of water had been treated (or 97 days after system startup), and then started to increase. Increases in nitrate concentration across the gravity filter ranged from 0 to 1.5 mg/L (as N) and averaged 0.2 mg/L (as N). Increases in nitrate concentration across the AD-33 adsorption vessels ranged from 0 to 1.6 mg/L (as N) and averaged 0.3 mg/L (as N). The concentration changes between ammonia and nitrate across the gravity filter and AD-33 adsorption vessels appear to follow a stoichiometric relationship.

The decreasing ammonia and DO concentrations and increasing nitrate concentrations indicate that nitrification was occurring within the gravity filter and AD-33 adsorption vessels approximately 69 to 97 days into system operation. The 69-day timeframe was based on the observation of ammonia removal, while the 97-day timeframe was based on detectable levels of nitrate in the gravity filter effluent.

Under the aerobic conditions in the AERALATER® filter, nitrifiers, including Nitrosomonas and Nitrobacters, can convert ammonia to nitrite and then to nitrate following the reaction equations (Sawyer et al., 2003) as follows:

$$2NH_3 + 3O_2 = 2NO_2^- + 2H^+ + 2H_2O \ [\textit{Nitrosomonas}]$$

$$2NO_2^- + O_2 = 2NO_3 \ [\textit{Nitrobacter}]$$

Through research efforts funded separately by EPA and Battelle, researchers have observed similar nitrification processes occurring in gravity filters at the GCSP in Beaver Creek, OH, that have a similar treatment train (i.e., aeration and gravity filtration) to the Stewart, MN, system (Lytle et al., 2007; Wang, 2006). In addition, As(III) to As(V) oxidation also was observed, possibly through biologically-mediated processes. Based on laboratory column tests conducted with filtered source water and filter media obtained from the GCSP, it was observed that As(III) oxidation continued to occur even after the nitrification processes had been completely inhibited by lowering the influent pH values to < 5.0 (Clark et al., 1977). This suggests that nitrification is not necessary for the microbial-mediated As(III) oxidation to occur (Wang et al., 2006). The same study also showed that, after the filter media in the column had been

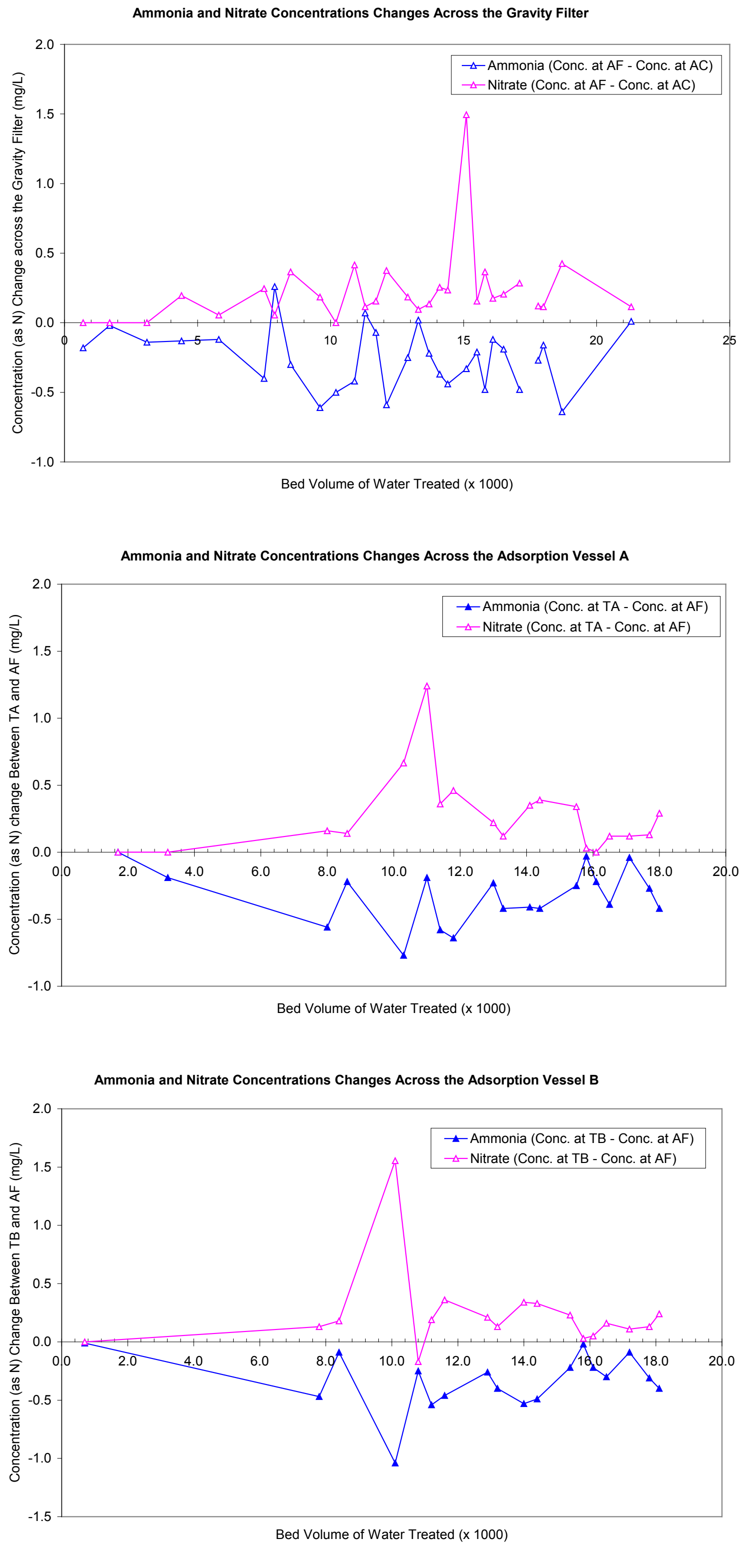

Figure 4-18. Decreases/Increases in Ammonia/Nitrate Across AERALATER® Filter and AD-33 Adsorption Vessels

sterilized with $HgCl_2$, the pathways responsible for As(III) oxidation apparently were disrupted, thus allowing As(III) to break through from the column, with the same amount of As(III) measured in both the column influent and effluent. Furthermore, because significant nitrification was not observed for 97 days compared to 40 days for As(III) oxidation, it was very likely that oxygen, instead of nitrate, was the electron acceptor for the microbial-mediated As(III) oxidation process. As discussed above, there was a 48% DO removal rate across the gravity filter, with approximately 2.6 mg/L of O_2 in the filter effluent, suggesting the persistence of aerobic conditions through the filter.

4.5.1.6 Other Water Quality Parameters. Alkalinity, fluoride, sulfate, silica, TOC, temperature, and hardness levels remained consistent across the treatment train and were not significantly affected by the treatment process (Table 4-7). TOC levels were elevated at 6.4 mg/L in source water, and no significant change was observed across the treatment train. Although high TOC levels might have contributed to the oxidant demand, they did not appear to have been adsorbed onto iron solids. The orthophosphate level in the source water was 0.02 mg/L (as PO_4) based on historic sampling, and was not considered by the vendor as a factor impacting the media run length, which was estimated at 82,500 BV. However, the study results indicate that total phosphorus (as P) was present in source water at levels that lowered the effectiveness of arsenic removal in both the gravity filter and APU-300 treatment systems. Total P decreased from an average concentration of 301 μg/L (or 0.92 mg/L as PO_4) in source water to an average concentration of 112 and 37.2 μg/L, following the AERALATER® filter and APU-300 system, respectively. Turbidity also decreased from 6.5 nephelometric turbidity units (NTU) in source water to <1.0 NTU after the AERALATER® filter and APU-300 system.

4.5.2 Backwash Wastewater Sampling. Table 4-8 presents the analytical results of 13 monthly backwash wastewater sampling from the two AERALATER® filter cells. pH values of the backwash wastewater ranged from 7.8 to 8.1 and averaged 7.9; TDS concentrations ranged from 378 to 468 mg/L and averaged 423 mg/L; TSS concentrations ranged from 28 to 260 mg/L and averaged 87 mg/L. TSS levels appeared to decline after switching from grab to composite sampling, using a sump pump, on September 20, 2006.

Concentrations of total arsenic, iron, and manganese ranged from 168 to 844 μg/L (averaged 343 μg/L), 17 to 111 mg/L (averaged 38 mg/L), and 34 to 109 μg/L (averaged 57 μg/L), respectively, with the majority existing as particulate. Assuming that 87 mg/L of TSS (i.e., the averaged TSS) was produced in 7,619 gal of backwash wastewater from the AERALATER® filter (Table 4-5), approximately 5.5 lb of solids would have been discharged during each backwash event. Based on the average particulate metal data (311 μg/L of particulate arsenic, 38 mg/L of particulate iron, and 34 μg/L of particulate manganese), the solids discharged would have been composed of 0.02 lb of arsenic (0.4% by weight), 2.4 lb of iron (43.6 % by weight), and 0.002 lb of manganese (0.04% by weight).

Backwash solids samples were collected on February 28, 2007, from both AERALATER® filter cells. The samples were analyzed for total metals; results are presented in Table 4-9. Arsenic, iron, and manganese levels in the solids averaged 0.94 mg/g (or 0.09%), 154 mg/g (or 15.4%), and 0.2 mg/g (or 0.02%), respectively. Based on the backwash wastewater samples collected on February 28, 2007, the averaged concentrations of particulate arsenic, iron, and manganese were 206, 22,646, and 15.2 μg/L, respectively. Assuming that 79.5 mg/L of TSS (i.e., the averaged TSS in the backwash wastewater samples collected on February 28, 2007) were produced in 7,619 gal of backwash wastewater from the AERALATER® filter (Table 4-5), arsenic, iron, and manganese contents in the solids were calculated to be 0.26, 28.5, and 0.02%, respectively. While the calculated manganese content was equivalent to that based on the backwash solids analysis, the calculated arsenic and iron contents were about three and two times higher, respectively. The degree of inconsistency is considered reasonable, considering that the results are from two independent sampling systems (wastewater and backwash solids).

Table 4-8. AERALATER® Filter Backwash Wastewater Sampling Results

Sampling Event		BW1										BW2									
		Backwash Filter Cell No. 1										Backwash Filter Cell No. 2									
		pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)	pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)
No.	Date	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
1	03/01/06[(a)]	8.1	426	92	209	NA	NA	25,897	NA	69.2	NA	8.1	416	36	231	NA	NA	28,765	NA	78.2	NA
2	03/22/06	8.0	432	104	255	23.2	232	31,173	33.5	48.8	26.8	8.0	422	46	176	26.8	149	18,262	37.8	42.2	26.3
3	04/12/06	8.0	428	28	215	28.5	187	18,889	25.8	41.2	28.1	8.0	420	38	168	30.2	138	16,691	47.8	42.9	25.3
4	05/31/06	8.0	454	130	654	29.6	624	55,791	245	70.0	19.5	8.0	436	260	844	26.7	817	73,492	143	86.4	19.0
5	06/28/06	7.9	430	214	835	39.7	795	110,886	206	109	24.3	8.0	404	122	538	30.9	507	69,635	158	103	24.3
6	07/26/06	7.9	428	126	456	38.3	417	52,912	76.7	64.9	24.0	7.9	426	100	403	59.1	343	50,511	133	64.2	24.6
7	08/23/06	7.9	468	144	585	43.1	542	73,364	127	74.8	22.7	7.9	432	127	495	27.3	468	67,266	78.4	70.1	21.5
8	09/20/06	7.9	454	54	290	29.9	260	28,455	57.7	41.6	22.5	7.9	464	28	194	27.3	167	19,399	78.3	64.9	26.5
9	10/25/06	7.8	422	54	284	32.5	252	29,772	40.7	44.5	24.2	7.8	418	66	272	29.4	242	30,779	58.3	41.5	22.1
10	11/29/06	7.8	432	60	235	28.4	207	21,541	63.0	40.5	24.5	7.8	418	60	288	28.7	259	27,079	65.7	40.3	21.5
11	01/03/07	7.9	392	50	200	33.3	167	24,234	43.2	42.7	22.5	7.9	402	65	214	33.7	180	28,184	52.5	58.2	22.4
12	01/17/07	7.9	382	58	209	25.1	184	22,112	66.8	37.1	20.5	7.9	378	50	193	29.5	164	20,386	43.6	33.6	21.6
13	02/28/07	8.0	422	71	230	39.4	190	21,075	41.5	39.8	25.6	8.0	402	88	251	29.3	222	24,328	70.3	38.7	22.6

(a) Filtered samples were not collected by the operator.
TDS = total dissolved solids; TSS = total suspended solids; NA = not analyzed

Table 4-9. AERALATER® Filter Backwash Solids Total Metal Results

Analyte	Mg	Al	Si	P	Ca	V	Fe	Mn	Ni	Cu	Zn	As	Cd	Sb	Ba	Pb
Filter Cell No. 1	33,005	318	1,091	19,347	96,155	2.43	162,397	182	10.5	3.3	214	1,310	<0.5	<0.5	4,082	<0.5
Filter Cell No. 2	24,141	132	<250	763	90,867	2.48	145,938	197	4.8	2.9	118	559	<0.5	<0.5	5,210	<0.5

Samples collected on February 28, 2007.
Average compositions calculated from triplicate analyses.
Values in µg/g.

During the 1-year performance evaluation study, the APU-300 adsorption vessels were backwashed four times using the treated water. One set of backwash wastewater samples were collected from the sample ports located in the backwash effluent discharge lines from each vessel on January 17, 2007. Table 4-10 summarizes the analytical results. The backwash wastewater averaged at 7.9 for pH, 380 mg/L for TDS, 54 mg/L for TSS, 201 µg/L for total arsenic, 21 mg/L for total iron, and 35 µg/L for total manganese. Soluble arsenic concentrations averaged 27.3 µg/L, which was higher than that in the treated water used for backwash. Therefore, desorption of arsenic from the adsorptive media might occur during backwash. Soluble iron concentration averaged 55.2 µg/L, which also was higher than that in the treated water (<25 µg/L). In general, the results measured from Vessels A and B were consistent among one another.

Assuming 5,926 gal of backwash wastewater generated from two APU-300 vessels (the average backwash wastewater generated per backwash event; see Table 4-5) and 54 mg/L of TSS (see Table 4-10), approximately 2.7 lb of solids would have been discharged during each backwash event. Based on the average particulate metal data (174 µg/L of particulate arsenic, 21.2 mg/L of particulate iron, and 14.3 µg/L of particulate manganese), the solids discharged would have been composed of 3.9 g of arsenic (0.32% by weight), 476 g of iron (39.6 % by weight), and 0.32 g of manganese (0.03% by weight).

Table 4-10. APU-300 Adsorption Vessels Backwash Wastewater Sampling Results

Sampling Event		pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)
Sample Location	**Date**	**S.U.**	**mg/L**	**mg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**
Backwash Vessel No. 1	1/17/2007	7.9	382	58	209	25.1	184	22,112	66.8	37.1	20.5
Backwash Vessel No. 2	1/17/2007	7.9	378	50	193	29.5	164	20,386	43.6	33.6	21.6

4.5.3 Distribution System Water Sampling. Distribution system water samples were collected to determine if water treated by the arsenic removal system would impact the lead, copper, and arsenic levels and other water chemistry in the distribution system. Prior to system startup, baseline distribution water samples were collected on February 16, March 16, April 13, and May 18, 2005. Since system startup, distribution water sampling continued monthly at the same three locations until January 9, 2007. The samples were analyzed for pH, alkalinity, arsenic, iron, manganese, lead, and copper; Table 4-11 presents the results.

The main differences observed between the baseline samples and samples collected after system startup were decreases in arsenic concentration at each of the three sampling locations. Arsenic concentrations were reduced from a pre-startup average of 31.2 to a post-startup average of 6.1 µg/L. In Figure 4-19, arsenic concentrations measured in the distribution system water were compared to those in the treatment system effluent. In general, total arsenic concentrations in distribution system water were higher than those in the treatment system effluent. Nonetheless, the concentrations in distribution system water were still below the MCL for all samples, except for the first sample collected at DS3. Desorption and resuspension of arsenic previously accumulated on the distribution pipe surface most likely are the reasons for higher arsenic concentration in the distribution system.

Table 4-11. Distribution System Sampling Results

Sampling Event		DS1								DS2							
		Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu
No.	Date	hr	S.U.	mg/L	μg/L	μg/L	μg/L	μg/L	μg/L	hr	S.U.	mg/L	μg/L	μg/L	μg/L	μg/L	μg/L
BL1	02/16/05	9.0	7.6	436	27.0	337	21.4	0.8	130	8.5	7.6	414	37.2	1,317	23.2	19.8	0.5
BL2	03/16/05[b]	8.5	7.7	466	29.3	404	21.6	0.9	159	10.0[a]	7.5	433	37.1	548	23.0	<0.1	56.3
BL3	04/13/05	8.0	7.7	424	30.1	206	26.5	1.1	202	10.0	7.7	424	31.8	174	25.9	0.2	125
BL4	05/18/05	9.0	7.7	428	30.5	169	21.3	0.5	105	9.4[a]	7.9	428	33.8	193	21.4	<0.1	195
1	02/22/06	8.5	7.9	416	7.8	<25	10.7	<0.1	85.4	7.0	7.9	416	9.9	<25	11.7	<0.1	179
2	03/21/06	7.8	7.8	406	2.1	<25	20.9	<0.1	35.9	9.5	7.8	410	4.2	<25	18.0	<0.1	131
3	04/18/06	8.5	8.0	438	3.5	<25	26.4	0.1	70.4	9.5	7.9	438	4.1	62.8	22.9	<0.1	154
4	05/16/06	9.0	7.8	409	3.1	<25	26.9	<0.1	103	9.8	7.8	405	3.5	<25	28.2	<0.1	106
5	06/13/06	Homeowner did not collect sample								7.0	7.7	433	4.1	<25	30.2	<0.1	338
6	07/11/06	8.0	7.6	419	3.2	<25	24.9	<0.1	91.7	7.5	7.7	415	3.9	<25	23.2	0.4	292
7	08/15/06	9.0	7.7	413	5.2	<25	27.6	0.3	135	0.1[c]	7.7	400	5.6	<25	28.5	0.1	241
8	09/12/06	8.3	7.7	451	5.0	<25	25.4	0.3	138	6.5	7.7	446	4.9	<25	25.5	<0.1	144
9	10/10/06	7.5	7.6	444	6.6	<25	25.0	0.3	145	8.8	7.6	437	6.9	<25	27.4	0.2	344
10	11/07/06	9.0	7.7	443	7.2	<25	24.6	<0.1	83.2	10.0	7.7	425	8.5	<25	25.0	<0.1	345
11	12/12/06	8.0	7.4	426	9.0	<25	26.6	0.3	125	9.0	7.6	428	8.5	<25	26.1	<0.1	161
12	01/09/07	9.0	7.7	453	7.4	<25	22.2	0.2	128	8.7	7.8	440	7.3	<25	19.0	<0.1	316

Table 4-11. Distribution System Sampling Results (Continued)

Sampling Event		DS3							
		Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu
No.	Date	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
BL1	02/16/05	9.0	7.6	418	27.2	311	23.6	1.0	130
BL2	03/16/05(b)	8.5	7.7	433	29.8	197	20.1	0.5	143
BL3	04/13/05	8.0	7.7	446	29.7	427	25.7	1.4	162
BL4	05/18/05	8.3	7.7	428	30.4	230	22.3	0.5	118
1	02/22/06	9.8	7.9	420	17.8	<25	17.5	<0.1	103
2	03/21/06	8.0	7.9	419	9.9	250	20.2	0.4	177
3	04/18/06	8.8	7.9	434	4.7	249	25.3	0.3	222
4	05/16/06	11.5	7.7	405	4.7	<25	29.4	<0.1	184
5	06/13/06	8.0	7.6	429	3.7	203	30.1	<0.1	226
6	07/11/06	6.3	7.5	415	3.7	45.4	28.4	0.1	203
7	08/15/06	6.7	7.7	425	4.7	52.1	33.2	0.2	185
8	09/12/06	12.5	7.7	458	5.8	<25	29.6	<0.1	187
9	10/10/06	7.8	7.6	461	6.5	232	32.4	0.2	217
10	11/07/06	8.5	7.6	445	7.0	<25	28.3	<0.1	201
11	12/12/06	10.0	7.5	440	7.5	170	33.5	0.1	188
12	01/09/07	9.0	7.7	438	6.2	138	27.0	<0.1	208

(a) Estimate provided by the homeowner.
(b) DS1 sampled on 03/22/05.
(c) Not first draw sample.
Action levels: 15 µg/L Pb and 1.3 mg/L Cu. BL = baseline sampling; DS = distribution sampling

Measured pH values ranged from 7.4 to 8.0; alkalinity levels ranged from 400 to 466 mg/L (as $CaCO_3$). Iron concentrations measured at DS1 and DS2 were <25 μg/L, except for one sample collected at DS2 on April 18, 2006. Iron concentrations measured at DS3 ranged from <25 to 250 μg/L and averaged 116 μg/L, which was significantly higher than that measured at the system effluent (<25 μg/L). Some corrosion products might have been washed out of the distribution system during DS3 sampling. Manganese concentrations averaged 23.0 and 25.2 μg/L before and after system startup, respectively, which were similar to the levels in the treatment system effluent.

The average lead level was 2.7 μg/L in the baseline samples and 0.2 μg/L in the samples taken after system startup; these concentrations were significantly lower than the action level of 15 μg/L. The average copper level was 127 μg/L in the baseline samples and 177 μg/L in the samples taken after system startup; these concentrations also were significantly lower than the action level of 1,300 μg/L. The treatment did not appear to impact the lead and copper levels in the distribution system.

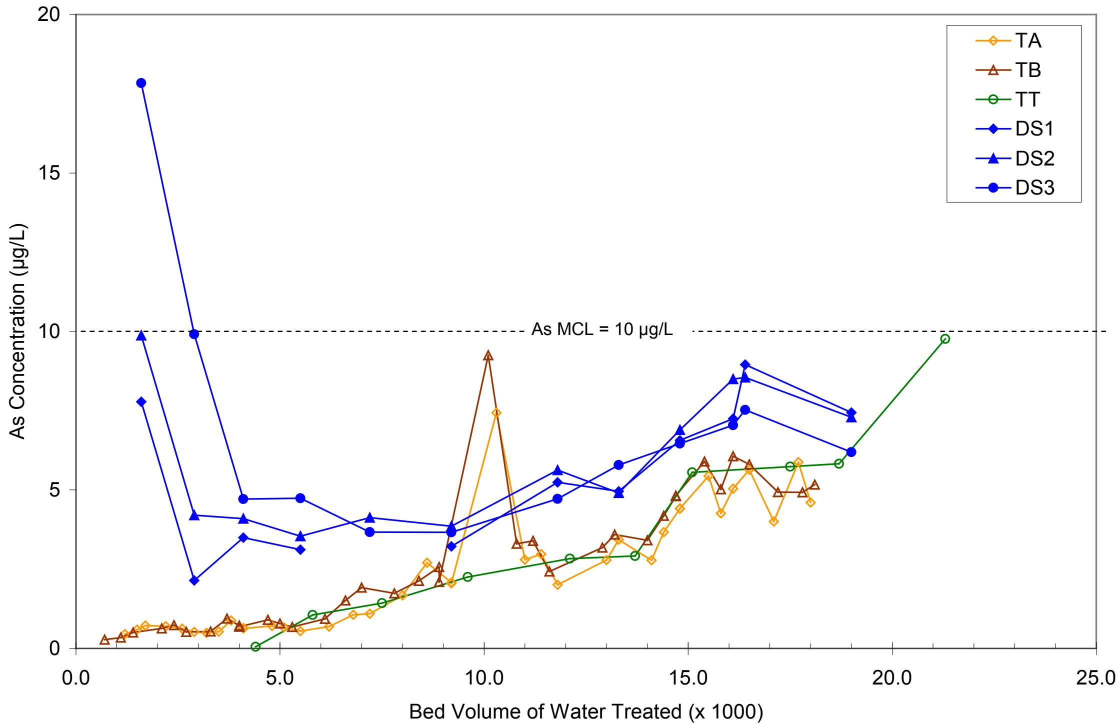

Figure 4-19. Comparsion of Total Arsenic Concentrations in Distribution System Water and APU-300 System Effluent

4.6 System Cost

The cost of the treatment system was evaluated based on the capital cost per gpm (or gpd) of design capacity and the O&M cost per 1,000 gal of water treated. This task required tracking capital cost for the equipment, site engineering, and installation and the O&M cost for media replacement and disposal, replacement parts, chemical supply, electricity consumption, and labor. These costs do not include the building cost or instrumentation and control upgrades installed by the City of Stewart.

4.6.1 Capital Cost. The capital investment for equipment, site engineering, and installation for the 250-gpm treatment system was $367,838. The equipment cost was $273,873 (or 74.4% of the total capital investment), which included $125,555 for a Siemens Type II AERALATER® system; $126,482 for a skid-mounted APU-300 system; $17,952 for ancillary equipment; and $3,884 for freight (as shown in Table 4-12). The Siemens' Type II AERALATER® system included a 11-ft-diameter steel unit (which was composed of an aerator, a fan, a detention tank, and a four-cell filter for a total of $77,000); process valves and piping ($32,060); instrumentation and controls ($7,420); 190 ft^3 of sand ($8,400); and other materials ($675). The APU-300 system included two skid-mounted fiberglass vessels ($45,360); process valves and piping ($19,460); instrumentation and controls ($20,860); 128 ft^3 of AD-33 media ($32,000 or $250/$ft^3$); and $8,802 for other materials.

The engineering cost included the cost for the preparation and submission of an engineering submittal package, including a process flow diagram of the treatment system, mechanical drawings of the treatment equipment, a schematic of the equipment footprint as discussed in Section 4.3.1, and attainment of the required state permit for implementing the system. The engineering cost was $16,520, which was 4.5% of the total capital investment.

The installation cost included the equipment and labor to unload and install the AERALATER® and skid-mounted APU-300 systems, perform piping tie-ins and electrical work, and load and backwash the media in both AERALATER® filter and AD-33 adsorption vessels (see Section 4.3.3). The installation was performed by AdEdge and a local subcontractor. The installation cost was $77,445, or 21.1% of the total capital investment.

The capital cost of $367,838 was normalized to $1,471/gpm ($1.02 per gpd) of design capacity, using the system's rated capacity of 250 gpm (or 360,000 gpd). The capital cost also was converted to an annualized cost of $34,720/yr using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-yr return period. Assuming that the system operated 24 hr/day, 7 day/wk at the design flowrate of 250 gpm to produce 131,400,000 gal/yr, the unit capital cost would be $0.26/1,000 gal. During the performance evaluation study, the system operated only 4.7 hr/day and produced an average of 19,132,570 gal of water in one year (Table 4-4), so the unit capital cost increased to $1.80/1,000 gal at this reduced rate of use. These calculations did not include the building construction cost.

4.6.2 Operation and Maintenance Cost. The O&M cost included items such as AD-33 media replacement and disposal, replacement parts, chemicals, electricity, and labor (see Table 4-13). During the 1-year study period, there was no chemical cost incurred because $NaMnO_4$ addition was discontinued. There was no replacement-part cost incurred either because all parts were covered under a 1-year warranty. Although AD-33 media was not replaced during the 1-year study period, the media replacement cost would represent the majority of the O&M cost. The vendor estimate was $41,370 for replacing 128 ft^3 media in the two APU-300 vessels. This cost includes new media, gravel underbedding, labor, travel, equipment rental, and freight. Although the vendor did not provide a cost breakdown for media profiling and disposal, such cost was assumed to be included in the total cost estimate.

Because media replacement did not take place during the study, the cost per 1,000 gal of water treated was calculated as a function of projected media run length, using the vendor cost estimate (see Figure 4-20). At the end of the performance evaluation study, the total arsenic concentration was 9.8 µg/L in the system effluent on February 27, 2007. Two more compliance samples were taken by the city after the end of the study, with total arsenic concentrations at 7.0 µg/L at about 22,400 BV on March 19, 2007, and at 11 µg/L at about 26,300 BV on May 29, 2007. Extrapolating from the average daily production of 52,418 gpd, the arsenic breakthrough above 10 µg/L most likely would occur at 25,300 BV, which was only 31%

Table 4-12. Capital Investment Cost for Siemens and AdEdge Treatment Systems

Description	Quantity	Cost	% of Capital Investment Cost
Equipment			
Siemens Type II AERALATER®			
11-ft-diameter Steel, Epoxy-Lined Unit, Including Aerator, Fan, Detention Tank, and Filter	1	$77,000	–
Filter Media (ft^3)	190	$8,400	–
Process Valves and Piping	1	$32,060	–
Instrumentation and Controls	1	$7,420	–
Additional Sample Taps	1	$675	–
Subtotal		**$125,555**	–
AdEdge APU-300 System			
63-in-diameter Fiberglass Vessels on Skid	2	$45,360	–
AD-33 Media (ft^3)	128	$32,000	–
Gravel Underbedding	1	$1,540	–
Process Valves and Piping	1	$19,460	–
Instrumentation and Controls	1	$20,860	–
Totalizer for Backwash Line	2	$2,422	–
1-Year O&M Support, O&M Manuals	–	$4,840	–
Subtotal		**$126,482**	–
Ancillary Equipment			
$KMnO_4$ Feed System	1	$4,192	–
Booster Pumps	2	$6,580	–
Motor Controls/MCC/HOA for Pumps	1	$6,850	–
In-Line Mixer	1	$330	–
Subtotal		**$17,952**	
Freight			
Freight–AD33 Media (lb)	4,460	$780	–
Freight–Filter Media (lb)	10,000	$680	–
Freight–System (lb)	26,000	$2,112	–
Freight–Ancillary Equipment	1	$312	
Subtotal		**$3,884**	–
Equipment Total	–	**$273,873**	**74.4%**
Engineering			
Vendor Labor	–	$4,534	
Vendor Travel	–	$2,480	
Vendor Material	–	$98	
Subcontractor Labor	–	$8,400	
Subcontractor Travel		$420	
Subcontractor Material	–	$588	
Engineering Total	–	**$16,520**	**4.5%**
Installation			
Vendor Labor	–	$7,920	
Vendor Travel	–	$3,800	
Subcontractor Mechanical	–	$39,985	
Subcontractor Electrical	–	$21,890	
Subcontractor Other Labor	–	$3,850	
Installation Total	–	**$77,445**	**21.1%**
Total Capital Investment	–	**$367,838**	**100%**

of the vendor-projected capacity of 82,500 BV (Table 4-3). The short media life corresponded to a high medial replacement cost of $1.71/1,000 gal (Figure 4-20).

A comparison of the electrical bills before and after system startup was conducted to estimate the electrical cost. Before the treatment plant was installed, the utility bill totaled $3,643 from January 1 to December 31, 2005. After the treatment plant was operational, the utility bill totaled $5,125 from January 1 to December 31, 2006. Therefore, the incremental electricity cost was approximately $0.08/1,000 gal. Electricity was used mainly for operating the AERALATER® unit.

Routine labor activities for O&M consumed 10 min/day for operational readings and 31 min/week for one manual backwash event. This is equivalent to 101 min/week (or 1.7 hr/week) on a 7 day/week basis. The estimated labor cost is $0.08/1,000 gal of water treated, based on this time commitment and a labor rate of $16.33/hr.

Table 4-13. O&M Cost for City of Stewart, Minnesota Treatment System

Cost Category	Value	Assumptions
Volume Processed (kgal)	20,441	Through February 28, 2007
Media Replacement and Disposal		
Media Cost ($/ft^3)	$250	Vendor quote
Total Media Volume (ft^3)	128	Two vessels
Media Replacement Cost ($)	$32,000	Vendor quote
Gravel Underbedding Cost ($)	$1,650	Vendor quote
Labor, Travel, and Equipment Cost ($)	$6,940	Vendor quote
Freight ($)	$780	Vendor quote
Subtotal	$41,370	Vendor quote
Media Replacement and Disposal Cost ($/1,000 gal)	See Figure 4-20	Based on media run length at 10 µg/L arsenic breakthrough
Replacement Parts		
Replacement Parts Cost ($)	$0.00	Cost related to parts replacement was negligible during 1-year study period
Labor and Travel Cost ($)	$0.00	–
Equipment Replacement Cost ($/1,000 gal)	$0.00	–
Chemical Usage		
Chemical Cost ($)	$0.00	No chemicals required after $NaMnO_4$ oxidation discontinued.
Electricity		
Estimated Incremental Electricity Cost ($/yr)	$1,482	Based on utility bills
Incremental Cost ($/1,000 gal)	$0.08	Annual system throughput = 19,133 kgal
Labor		
Average Weekly Labor (hr)	1.7	10 min/day, plus 31 min manual backwash
Annual Labor Cost ($/yr)	$1,444	Average labor rate = 16.33/hr
Labor Cost ($/1,000 gal)	$0.08	Annual system throughput = 19,133 kgal
Total O&M Cost/1,000 gal	See Figure 4-20	–

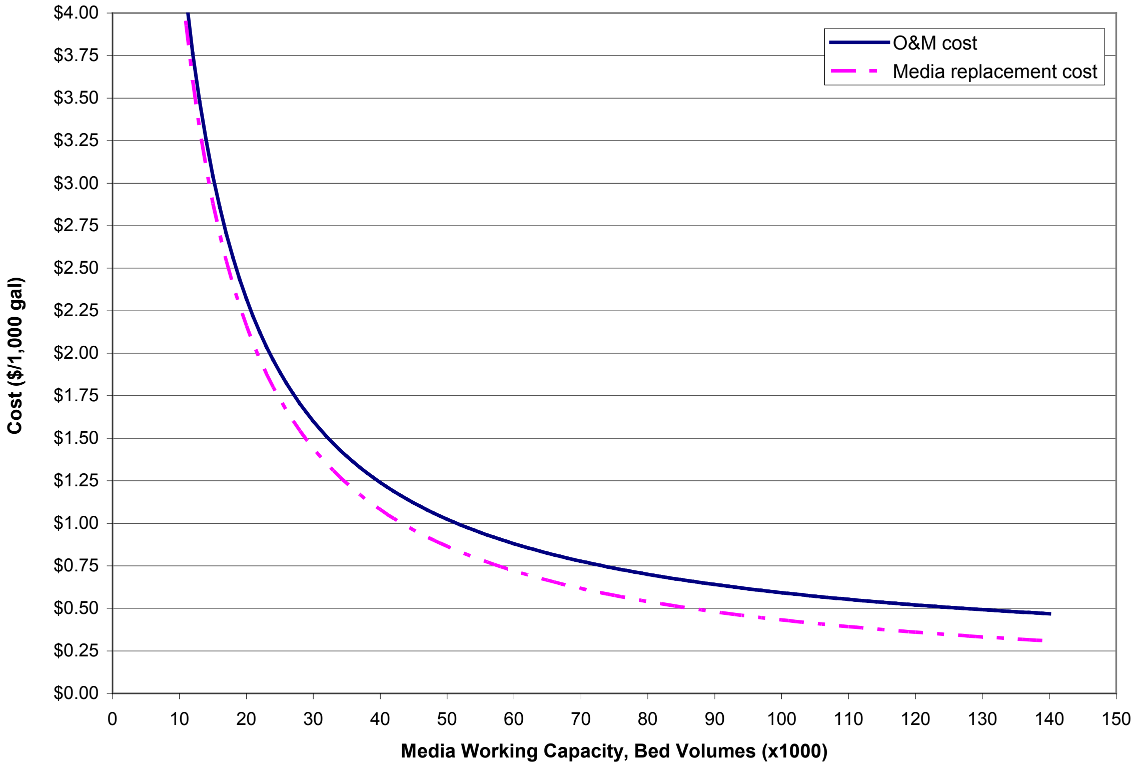

Figure 4-20. Media Replacement and O&M Cost for AERALATER® and APU-300 Systems at Stewart, Minnesota

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APPENDIX A

OPERATIONAL DATA

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

Week No.	Day of Week	Date	Well 3 Op Hours (Hrs)	Well 3 Gallon Usage (gal)	Well 3 Average Flowrate (gpm)	Well 4 Op Hours (Hrs)	Well 4 Gallon Usage (gal)	Well 4 Average Flowrate (gpm)	AERALATER Backwash (Yes/No)	Vessel A Flow Rate (gpm)	Vessel A Service Totalizer (gal)	Cumulative Bed Volumes (BV)	Vessel B Flow Rate (gpm)	Vessel B Service Totalizer (gal)	Cumulative Bed Volumes (BV)	Combined Backwash Totalizer (gal)
	Mon	01/30/06 07:35	NA	NA	NA	NA	NA	NA	No	92	282,600	590	91	275,090	575	0
	Tue	01/31/06 07:00	1.1	12,800	194	0.0	0.0	NA	Yes	92	288,114	602	91	280,488	586	0
	Wed	02/01/06 07:30	3.9	44,400	190	2.1	23,900	190	No	92	318,183	665	91	309,822	647	0
1	Thu	02/02/06 06:30	2.0	23,000	192	1.7	19,800	194	Yes	NA	337,773	705	NA	328,931	687	0
	Fri	02/03/06 08:10	3.2	39,000	203	2.8	12,600	75	No	NA	365,977	764	NA	355,460	742	7,647
	Sat	02/04/06 08:15	1.8	21,700	201	1.5	37,300	414	No	92	384,714	804	91	372,554	778	7,647
	Sun	02/05/06 08:50	2.0	22,700	189	1.9	21,500	189	No	92	406,021	848	91	391,931	819	7,647
	Mon	02/06/06 08:15	2.0	23,700	198	1.8	20,500	190	No	NA	426,860	892	NA	410,436	857	7,647
	Tue	02/07/06 07:10	1.1	11,800	179	1.7	19,300	189	No	NA	442,802	925	NA	424,496	887	7,647
	Wed	02/08/06 08:35	1.9	22,900	201	1.7	20,000	196	No	NA	463,684	968	NA	443,020	925	7,647
2	Thu	02/09/06 08:00	2.0	23,100	193	1.3	15,300	196	No	NA	480,412	1,003	NA	457,596	956	7,647
	Fri	02/10/06 09:10	1.7	20,300	199	2.6	28,300	181	No	NA	502,250	1,049	NA	476,125	994	7,647
	Sat	02/11/06 08:10	1.9	22,000	193	1.0	17,400	290	No	88	532,156	1,111	70	492,894	1,029	7,647
	Sun	02/12/06 08:15	0.9	11,000	204	2.6	21,000	135	No	NA	541,319	1,131	NA	507,614	1,060	7,647
	Mon	02/13/06 07:15	1.8	22,400	207	1.9	22,200	195	No	NA	563,172	1,176	NA	525,767	1,098	7,647
	Tue	02/14/06 07:30	1.9	21,900	192	2.0	22,300	186	No	NA	585,122	1,222	NA	544,109	1,136	7,647
	Wed	02/15/06 07:30	1.7	20,800	204	1.1	12,200	185	No	NA	601,420	1,256	NA	557,855	1,165	7,647
3	Thu	02/16/06 07:35	1.9	22,600	198	2.1	22,800	181	No	NA	623,167	1,302	NA	576,526	1,204	7,647
	Fri	02/17/06 08:00	0.9	11,500	213	2.6	21,600	138	Yes	NA	639,994	1,337	NA	591,015	1,234	7,647
	Sat	02/18/06 09:00	1.8	21,500	199	1.7	26,700	262	No	NA	661,073	1,381	NA	609,618	1,273	7,647
	Sun	02/19/06 08:30	2.0	23,000	192	2.0	22,100	184	No	NA	682,816	1,426	NA	628,969	1,314	7,647
	Mon	02/20/06 09:00	2.0	24,100	201	2.0	21,600	180	No	NA	704,779	1,472	NA	648,622	1,355	7,647
	Tue	02/21/06 08:00	1.8	22,300	206	2.2	23,900	181	No	NA	726,872	1,518	NA	668,540	1,396	7,647
	Wed	02/22/06 08:45	1.8	21,100	195	1.2	14,200	197	No	NA	742,579	1,551	NA	682,802	1,426	7,647
4	Thu	02/23/06 07:30	1.8	21,100	195	2.4	27,400	190	No	NA	763,415	1,594	NA	702,735	1,468	13,472
	Fri	02/24/06 07:50	0.9	11,600	215	1.9	20,900	183	Yes	NA	778,326	1,626	NA	717,060	1,498	13,472
	Sat	02/25/06 08:15	2.8	34,000	202	2.0	22,300	186	No	82	797,262	1,665	78	735,356	1,536	13,472
	Sun	02/26/06 09:30	1.7	20,700	203	1.5	16,600	184	No	NA	814,936	1,702	NA	752,279	1,571	13,472
	Mon	02/27/06 06:30	1.7	20,500	201	1.8	19,200	178	No	NA	835,831	1,746	NA	772,329	1,613	13,472
	Tue	02/28/06 10:15	2.0	23,900	199	1.9	22,100	194	No	NA	856,567	1,789	NA	792,207	1,655	13,472
	Wed	03/01/06 07:15	1.9	22,400	196	0.9	10,400	193	Yes	NA	872,014	1,821	NA	806,985	1,685	13,472
5	Thu	03/02/06 08:15	1.9	21,800	191	2.7	31,400	194	No	NA	971,158	2,028	NA	924,367	1,931	13,472
	Fri	03/03/06 07:45	1.9	22,200	195	1.8	20,100	186	No	NA	992,853	2,074	NA	945,645	1,975	13,472
	Sat	03/04/06 08:30	1.4	16,800	200	1.7	19,200	188	No	NA	1,000,897	2,090	NA	961,433	2,008	13,472
	Sun	03/05/06 08:30	1.7	10,480	103	1.8	14,480	134	No	0	1,031,633	2,155	NA	983,608	2,054	13,472
	Mon	03/06/06 06:40	2.2	33,620	255	1.7	26,320	258	No	NA	1,054,674	2,203	NA	1,006,104	2,101	13,472
	Tue	03/07/06 07:00	2.1	24,900	198	1.9	21,300	187	No	NA	1,007,817	2,105	NA	1,029,016	2,149	13,472
	Wed	03/08/06 08:00	2.0	23,200	193	1.8	21,100	195	No	NA	1,100,817	2,299	NA	1,051,005	2,195	13,472
6	Thu	03/09/06 07:50	2.0	23,400	195	1.7	19,400	190	No	NA	1,119,988	2,339	NA	1,069,653	2,234	13,472
	Fri	03/10/06 07:30	1.9	21,900	192	1.1	12,700	192	Yes	NA	1,140,465	2,382	NA	1,089,401	2,275	13,472
	Sat	03/11/06 10:00	1.8	22,100	205	2.9	33,700	194	No	NA	1,163,976	2,431	NA	1,112,105	2,323	13,472
	Sun	03/12/06 09:15	1.4	16,800	200	2.1	22,500	179	No	NA	1,181,234	2,467	NA	1,128,707	2,357	13,472
	Mon	03/13/06 07:10	1.4	16,500	196	1.9	21,500	189	No	NA	1,203,680	2,514	NA	1,150,212	2,402	13,472
	Tue	03/14/06 06:30	1.8	21,700	201	2.0	22,100	184	No	103	1,226,174	2,561	98	1,171,717	2,447	13,472
	Wed	03/15/06 07:45	1.7	20,500	201	1.0	11,200	187	No	NA	1,242,433	2,595	NA	1,187,240	2,480	13,472
7	Thu	03/16/06 07:15	1.3	16,200	208	2.0	22,400	187	Yes	NA	1,259,485	2,631	NA	1,203,462	2,514	13,472
	Fri	03/17/06 07:50	3.6	44,000	204	2.0	21,500	179	No	NA	1,291,047	2,697	NA	1,233,215	2,576	13,472
	Sat	03/18/06 06:45	1.8	20,700	192	1.0	11,300	188	No	NA	1,307,759	2,731	NA	1,248,624	2,608	13,472
	Sun	03/19/06 07:30	1.6	20,300	211	2.1	23,600	187	No	NA	1,330,633	2,779	NA	1,269,754	2,652	13,472
	Mon	03/20/06 07:30	1.9	22,300	196	2.1	23,000	183	No	NA	1,350,435	2,821	NA	1,291,692	2,698	13,472
	Tue	03/21/06 07:00	0.9	10,800	200	1.9	21,500	189	No	104	16,886	2,856	103	16,535	2,732	0
	Wed	03/22/06 10:00	1.8	21,700	201	2.1	22,800	181	Yes	NA	40,391	2,905	NA	39,553	2,780	0
8	Thu	03/23/06 07:30	1.3	16,100	206	2.4	27,500	191	No	NA	56,671	2,939	NA	55,448	2,814	0
	Fri	03/24/06 07:30	1.8	19,700	182	1.8	20,000	185	No	NA	79,796	2,987	NA	77,927	2,861	0
	Sat	03/25/06 07:30	2.0	23,500	196	1.6	18,400	192	No	101	99,025	3,027	98	96,604	2,900	0
	Sun	03/26/06 09:30	2.0	22,900	191	2.1	23,100	183	No	NA	123,300	3,078	NA	120,078	2,949	0
	Mon	03/27/06 07:30	2.0	23,000	192	1.1	12,700	192	No	NA	144,965	3,123	NA	140,960	2,992	0
	Tue	03/28/06 06:15	2.0	23,700	198	1.8	20,800	193	No	104	168,523	3,173	103	163,674	3,040	0
	Wed	03/29/06 06:55	1.1	12,300	186	1.7	19,400	190	No	NA	185,370	3,208	NA	179,924	3,074	0
9	Thu	03/30/06 08:30	2.0	23,400	195	1.8	20,000	185	No	NA	208,268	3,256	NA	201,978	3,120	0
	Fri	03/31/06 06:55	2.0	23,100	193	1.0	11,400	190	Yes	NA	226,074	3,293	NA	219,063	3,155	0
	Sat	04/01/06 11:30	2.6	30,700	197	2.7	31,400	194	No	NA	254,724	3,353	NA	246,480	3,213	0
	Sun	04/02/06 09:40	2.0	22,700	189	0.9	10,200	189	No	NA	272,088	3,389	NA	263,018	3,247	0
	Mon	04/03/06 07:30	2.1	23,800	189	1.9	21,300	187	No	NA	295,966	3,439	NA	285,813	3,295	0
	Tue	04/04/06 07:30	2.0	23,700	198	1.9	21,400	188	No	91	316,719	3,482	86	305,684	3,336	0
	Wed	04/05/06 07:30	2.3	25,600	186	1.8	21,000	194	No	NA	344,520	3,540	NA	332,196	3,392	0
10	Thu	04/06/06 07:10	1.1	12,300	186	1.8	19,600	181	Yes	NA	361,684	3,576	NA	348,582	3,426	0
	Fri	04/07/06 07:30	1.9	22,600	198	2.9	33,100	190	No	NA	385,893	3,627	NA	371,649	3,474	0
	Sat	04/08/06 07:00	1.7	21,000	206	1.0	11,400	190	No	NA	403,723	3,664	NA	388,618	3,510	0
	Sun	04/09/06 07:30	1.7	19,900	195	2.3	25,300	183	No	NA	427,592	3,714	NA	411,311	3,557	0

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

Week No.	Day of Week	Date	Well 3			Well 4			AERALATER							
			Op Hours	Gallon Usage	Average Flowrate	Op Hours	Gallon Usage	Average Flowrate	Backwash	Vessel A Flow Rate	Vessel A Service Totalizer	Cumulative Bed Volumes	Vessel B Flow Rate	Vessel B Service Totalizer	Cumulative Bed Volumes	Combined Backwash Totalizer
			Hrs	gal	gpm	Hrs	gal	gpm	Yes/No	gpm	gal	BV	gpm	gal	BV	gal
	Mon	04/10/06 08:00	1.7	20,400	200	2.2	23,700	180	No	NA	450,987	3,762	NA	433,564	3,603	0
	Tue	04/11/06 07:30	1.8	22,700	210	2.2	24,000	182	No	86	474,931	3,813	83	456,451	3,651	0
	Wed	04/12/06 07:30	1.0	11,200	187	2.0	22,200	185	Yes	NA	493,225	3,851	NA	473,753	3,687	0
11	Thu	04/13/06 07:00	2.5	30,700	205	1.9	21,800	191	No	NA	517,323	3,901	NA	496,698	3,735	0
	Fri	04/14/06 07:00	1.5	18,400	204	1.9	17,500	154	No	NA	523,009	3,913	NA	528,566	3,802	0
	Sat	04/15/06 07:50	2.3	27,700	201	2.0	19,600	163	No	NA	542,452	3,954	NA	559,093	3,866	0
	Sun	04/16/06 10:30	1.9	22,100	194	2.2	24,600	186	No	NA	567,273	4,005	NA	581,256	3,912	0
	Mon	04/17/06 07:15	0.9	11,500	213	2.1	22,600	179	No	NA	585,508	4,043	NA	598,270	3,947	0
	Tue	04/18/06 06:45	2.6	30,700	197	2.5	28,800	192	No	99	611,098	4,097	95	622,415	3,998	0
	Wed	04/19/06 08:00	2.5	27,400	183	2.2	24,700	187	No	94	639,417	4,156	90	649,110	4,054	0
12	Thu	04/20/06 07:30	2.1	24,600	195	1.4	16,300	194	No	NA	660,342	4,200	NA	668,800	4,095	0
	Fri	04/21/06 07:30	2.0	22,400	187	1.5	16,600	184	No	NA	683,851	4,249	NA	691,123	4,141	0
	Sat	04/22/06 08:00	2.2	24,700	187	1.9	21,400	188	No	81	706,158	4,295	98	712,438	4,186	0
	Sun	04/23/06 08:00	1.1	12,400	188	1.8	20,900	194	No	NA	725,593	4,336	NA	730,996	4,225	0
	Mon	04/24/06 07:30	2.3	25,800	187	1.8	20,100	186	No	NA	749,547	4,386	NA	753,989	4,273	0
	Tue	04/25/06 09:30	3.2	34,700	181	1.8	21,100	195	No	89	778,661	4,447	85	782,073	4,331	0
	Wed	04/26/06 07:30	2.3	25,400	184	1.8	20,900	194	No	NA	802,861	4,497	NA	804,962	4,379	0
13	Thu	04/27/06 07:30	2.2	25,100	190	2.0	22,300	186	Yes	NA	824,698	4,543	NA	825,800	4,423	0
	Fri	04/28/06 06:50	1.8	21,700	201	2.5	27,800	185	No	NA	847,633	4,591	NA	847,801	4,469	0
	Sat	04/29/06 08:50	1.8	21,300	197	2.2	23,800	180	No	NA	871,240	4,640	NA	870,491	4,516	0
	Sun	04/30/06 10:00	1.8	21,200	196	2.3	25,300	183	No	NA	895,354	4,691	NA	893,704	4,564	0
	Mon	05/01/06 07:30	1.9	2,700	24	2.2	24,800	188	No	95	917,086	4,736	92	914,659	4,608	0
	Tue	05/02/06 08:30	1.6	38,800	404	2.2	23,700	180	No	99	939,085	4,782	96	935,859	4,653	0
	Wed	05/03/06 07:30	1.4	16,900	201	2.0	22,800	190	No	NA	962,737	4,831	NA	958,668	4,700	0
14	Thu	05/04/06 07:30	2.0	23,800	198	2.1	22,900	182	Yes	NA	986,918	4,882	NA	982,085	4,749	0
	Fri	05/05/06 07:10	3.0	36,200	201	2.2	23,700	180	No	NA	1,012,484	4,935	NA	1,006,893	4,801	0
	Sat	05/06/06 09:00	2.1	24,100	191	2.0	23,000	192	No	NA	1,036,423	4,985	NA	1,029,783	4,849	0
	Sun	05/07/06 07:30	2.0	24,000	200	2.2	23,700	180	No	NA	1,061,862	5,038	NA	1,054,119	4,900	0
	Mon	05/08/06 07:30	2.4	28,500	198	2.1	23,500	187	No	NA	1,086,995	5,091	NA	1,078,116	4,950	0
	Tue	05/09/06 08:35	1.6	19,500	203	1.9	22,700	199	No	97	1,112,269	5,144	94	1,102,292	5,000	0
	Wed	05/10/06 07:30	2.0	23,600	197	2.2	22,300	169	No	NA	1,134,854	5,191	NA	1,123,876	5,045	0
15	Thu	05/11/06 07:10	2.0	23,900	199	2.1	23,200	184	Yes	NA	1,159,259	5,242	NA	1,147,312	5,094	0
	Fri	05/12/06 07:00	2.9	34,300	197	1.1	12,100	183	No	NA	1,178,114	5,281	NA	1,165,472	5,132	0
	Sat	05/13/06 06:00	1.8	20,300	188	1.9	22,600	198	No	NA	1,197,538	5,322	NA	1,184,169	5,171	0
	Sun	05/14/06 07:50	1.8	19,800	183	1.7	18,400	180	No	NA	1,220,387	5,369	NA	1,206,143	5,217	0
	Mon	05/15/06 08:10	2.0	23,000	192	2.0	24,100	201	No	NA	1,244,073	5,419	NA	1,229,005	5,265	0
	Tue	05/16/06 07:30	2.1	23,500	187	1.9	21,000	184	No	91	1,267,795	5,468	90	1,251,991	5,313	0
	Wed	05/17/06 07:30	2.1	22,800	181	2.0	22,700	189	No	NA	1,291,456	5,518	NA	1,274,925	5,361	0
16	Thu	05/18/06 07:30	2.0	22,700	189	2.1	23,700	188	No	NA	1,315,427	5,568	NA	1,298,223	5,409	0
	Fri	05/19/06 07:30	2.0	22,400	187	2.0	23,000	192	Yes	NA	1,338,976	5,617	NA	1,321,122	5,457	0
	Sat	05/20/06 07:45	1.0	11,600	193	3.7	42,000	189	No	NA	1,361,859	5,665	NA	1,343,381	5,504	0
	Sun	05/21/06 07:15	1.9	23,100	203	2.2	23,200	176	No	NA	1,386,140	5,716	NA	1,367,029	5,553	0
	Mon	05/22/06 07:45	2.6	30,000	192	3.1	35,100	189	No	NA	1,419,448	5,785	NA	1,399,559	5,621	0
	Tue	05/23/06 07:30	2.3	25,700	186	1.8	21,200	196	No	NA	1,443,607	5,836	NA	1,423,099	5,670	0
	Wed	05/24/06 08:00	3.0	33,300	185	1.9	21,000	184	No	88	1,468,540	5,888	86	1,447,450	5,721	0
17	Thu	05/25/06 07:00	2.1	23,100	183	2.0	22,400	187	Yes	NA	1,482,626	5,917	NA	1,470,959	5,770	0
	Fri	05/26/06 07:00	3.1	35,500	191	1.7	19,600	192	No	NA	1,517,547	5,990	NA	1,495,225	5,821	0
	Sat	05/27/06 07:30	3.3	36,500	184	2.0	22,300	186	No	NA	1,545,234	6,048	NA	1,522,268	5,877	0
	Sun	05/28/06 09:00	2.5	28,100	187	3.2	36,700	191	No	NA	1,578,619	6,118	NA	1,554,878	5,945	0
	Mon	05/29/06 09:30	2.8	31,200	186	2.0	22,700	189	No	NA	1,608,016	6,179	NA	1,583,589	6,005	0
	Tue	05/30/06 07:00	3.8	40,600	178	2.2	25,800	195	No	82	1,640,353	6,247	81	1,615,279	6,072	0
	Wed	05/31/06 10:00	3.2	35,800	186	3.5	39,000	186	Yes	NA	NA	NA	NA	NA	NA	0
18	Thu	06/01/06 07:30	3.4	39,400	193	2.3	NA	NA	No	NA	1,710,216	6,393	NA	1,683,814	6,215	0
	Fri	06/02/06 07:00	3.1	36,300	195	2.7	NA	NA	No	NA	1,743,905	6,463	NA	1,716,927	6,284	0
	Sat	06/03/06 07:30	3.2	38,600	201	3.8	40,800	179	No	NA	1,781,981	6,542	NA	1,754,425	6,362	0
	Sun	06/04/06 08:30	3.6	42,600	197	5.8	62,000	178	No	NA	1,838,375	6,660	NA	1,810,012	6,478	0
	Mon	06/05/06 07:15	2.2	25,400	192	1.6	16,300	170	No	NA	1,859,633	6,705	NA	1,831,041	6,522	0
	Tue	06/06/06 07:15	2.7	32,000	198	3.7	40,100	181	No	NA	1,896,516	6,782	NA	1,867,421	6,598	0
	Wed	06/07/06 07:30	2.1	24,100	191	2.1	22,700	180	No	NA	1,920,563	6,832	NA	1,891,195	6,648	0
19	Thu	06/08/06 08:00	3.1	37,100	199	3.5	38,300	182	No	NA	1,956,062	6,906	NA	1,926,446	6,721	0
	Fri	06/09/06 08:00	3.3	39,000	197	3.3	34,400	174	Yes	95	1,993,408	6,984	95	1,963,490	6,799	0
	Sat	06/10/06 09:00	2.8	33,400	199	2.1	23,500	187	No	NA	2,018,564	7,037	NA	1,988,497	6,851	0
	Sun	06/11/06 09:00	2.0	23,500	196	2.1	23,600	187	No	NA	2,042,466	7,086	NA	2,012,255	6,901	0
	Mon	06/12/06 07:30	2.0	23,800	198	2.2	23,800	180	No	NA	2,066,750	7,137	NA	2,036,415	6,951	0
	Tue	06/13/06 07:00	2.4	29,500	205	2.3	24,900	180	No	95	2,092,388	7,191	96	2,061,868	7,004	0
	Wed	06/14/06 07:10	2.9	33,000	190	4.1	43,700	178	No	NA	2,133,607	7,277	NA	2,102,710	7,090	0
20	Thu	06/15/06 07:20	1.9	23,500	206	2.1	23,400	186	Yes	NA	2,157,420	7,327	NA	2,126,215	7,139	0
	Fri	06/16/06 07:00	2.2	23,700	180	2.6	30,700	197	No	NA	2,180,588	7,375	NA	2,149,056	7,186	0
	Sat	06/17/06 07:30	1.4	16,000	190	2.9	32,200	185	No	NA	2,205,255	7,427	NA	2,173,412	7,237	0
	Sun	06/18/06 07:45	3.6	39,800	184	2.3	25,900	188	No	NA	2,238,756	7,496	NA	2,206,522	7,306	0

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

			Well 3			Well 4			AERALATER							
Week No.	Day of Week	Date	Op Hours	Gallon Usage	Average Flowrate	Op Hours	Gallon Usage	Average Flowrate	Backwash	Vessel A Flow Rate	Vessel A Service Totalizer	Cumulative Bed Volumes	Vessel B Flow Rate	Vessel B Service Totalizer	Cumulative Bed Volumes	Combined Backwash Totalizer
			Hrs	gal	gpm	Hrs	gal	gpm	Yes/No	gpm	gal	BV	gpm	gal	BV	gal
21	Mon	06/19/06 07:30	1.2	13,500	188	1.9	19,600	172	No	NA	2,256,658	7,534	NA	2,224,265	7,344	0
	Tue	06/20/06 09:30	3.5	38,800	185	2.0	25,200	210	No	95	2,287,962	7,599	95	2,255,247	7,408	0
	Wed	06/21/06 07:00	2.4	26,600	185	1.9	20,800	182	No	NA	2,312,303	7,650	NA	2,279,162	7,458	0
	Thu	06/22/06 07:00	2.8	29,700	177	3.0	33,700	187	Yes	NA	2,344,847	7,718	NA	2,311,172	7,525	0
	Fri	06/23/06 07:30	3.3	38,700	195	3.3	36,800	186	No	NA	2,378,811	7,789	NA	2,344,822	7,595	0
	Sat	06/24/06 09:30	5.3	38,500	121	4.5	48,600	180	No	NA	2,423,121	7,882	NA	2,388,127	7,686	0
	Sun	06/25/06 08:40	0.2	25,900	2158	2.1	22,600	179	No	NA	2,448,429	7,934	NA	2,412,780	7,737	0
22	Mon	06/26/06 07:00	2.2	26,100	198	2.3	24,200	175	No	NA	2,474,481	7,989	NA	2,438,009	7,790	0
	Tue	06/27/06 07:30	2.9	34,900	201	2.2	24,000	182	No	94	2,501,625	8,046	92	2,464,389	7,845	0
	Wed	06/28/06 07:30	2.2	25,000	189	2.6	27,800	178	Yes	NA	2,531,793	8,109	NA	2,493,682	7,906	0
	Thu	06/29/06 07:00	1.8	22,100	205	3.6	40,200	186	No	NA	2,557,220	8,162	NA	2,518,338	7,958	0
	Fri	06/30/06 07:00	2.1	25,000	198	7.9	87,300	184	No	NA	2,616,173	8,285	NA	2,575,296	8,077	0
	Sat	07/01/06 08:00	2.1	24,700	196	4.0	43,000	179	No	NA	2,651,423	8,358	NA	2,609,067	8,147	0
	Sun	07/02/06 08:00	3.3	40,000	202	2.4	25,400	176	No	94	2,681,050	8,420	92	2,637,568	8,207	0
23	Mon	07/03/06 07:00	2.1	23,500	187	3.1	32,600	175	No	NA	2,714,077	8,489	NA	2,669,270	8,273	0
	Tue	07/04/06 07:00	2.8	32,200	192	3.7	39,400	177	No	NA	2,750,262	8,565	NA	2,703,977	8,345	0
	Wed	07/05/06 07:00	3.1	36,400	196	3.4	36,100	177	No	NA	2,786,863	8,641	NA	2,739,016	8,419	0
	Thu	07/06/06 07:00	2.7	31,300	193	3.4	36,600	179	Yes	NA	2,823,623	8,718	NA	2,774,146	8,492	0
	Fri	07/07/06 07:30	4.4	51,900	197	4.4	45,800	173	No	85	2,865,948	8,806	81	2,814,596	8,576	0
	Sat	07/08/06 07:00	3.5	41,900	200	3.4	35,400	174	No	NA	2,908,966	8,896	NA	2,855,521	8,662	0
	Sun	07/09/06 08:30	2.4	27,100	188	5.6	57,700	172	No	NA	2,953,202	8,989	NA	2,897,540	8,750	0
24	Mon	07/10/06 07:30	5.3	61,700	194	2.6	27,600	177	No	NA	2,998,101	9,082	NA	2,940,264	8,839	0
	Tue	07/11/06 07:30	2.6	29,400	188	4.4	46,900	178	No	NA	3,038,652	9,167	NA	2,978,660	8,919	0
	Wed	07/12/06 07:45	4.4	50,700	192	7.7	77,400	168	Yes	NA	3,105,202	9,306	NA	3,041,629	9,051	0
	Thu	07/13/06 07:00	6.3	66,400	176	4.5	51,900	192	No	NA	3,117,350	9,332	NA	3,091,457	9,155	0
	Fri	07/14/06 07:30	3.3	36,100	182	3.4	36,800	180	No	NA	3,156,849	9,414	NA	3,128,875	9,233	0
	Sat	07/15/06 07:30	2.8	30,900	184	2.9	31,800	183	No	80	3,186,370	9,476	78	3,140,070	9,256	0
	Sun	07/16/06 08:00	4.3	50,000	194	5.0	51,200	171	No	NA	3,241,639	9,591	NA	3,192,592	9,366	0
25	Mon	07/17/06 07:30	3.0	33,600	187	2.1	24,400	194	No	93	3,268,449	9,647	91	3,218,007	9,419	0
	Tue	07/18/06 07:30	3.6	38,100	176	5.8	63,500	182	No	NA	3,320,042	9,755	NA	3,266,629	9,521	0
	Wed	07/19/06 07:00	5.2	55,100	177	3.3	36,700	185	No	73	3,366,506	9,852	71	3,310,241	9,612	0
	Thu	07/20/06 07:00	2.0	22,000	183	2.1	23,400	186	No	83	3,388,565	9,898	77	3,330,963	9,655	0
	Fri	07/21/06 07:00	3.5	36,400	173	4.8	50,800	176	Yes	81	3,433,666	9,992	74	3,373,384	9,744	0
	Sat	07/22/06 09:10	4.0	45,500	190	3.8	39,800	175	No	NA	3,473,299	10,075	NA	3,410,821	9,822	0
	Sun	07/23/06 10:10	3.2	36,500	190	3.2	32,500	169	No	NA	3,506,408	10,144	NA	3,442,266	9,887	0
26	Mon	07/24/06 07:15	2.8	31,400	187	2.9	28,700	165	No	81	3,537,286	10,209	87	3,471,541	9,949	0
	Tue	07/25/06 07:00	3.3	36,400	184	5.9	58,700	166	No	NA	3,589,635	10,318	NA	3,520,970	10,052	0
	Wed	07/26/06 06:20	2.8	33,400	199	4.0	42,400	177	Yes	NA	3,626,432	10,395	NA	3,560,844	10,135	0
	Thu	07/27/06 07:00	3.6	43,200	200	6.6	73,800	186	No	NA	3,678,340	10,503	NA	3,616,274	10,251	0
	Fri	07/28/06 07:00	4.3	49,700	193	6.7	70,800	176	No	82	3,734,103	10,620	89	3,675,770	10,375	0
	Sat	07/29/06 08:15	4.2	50,300	200	5.7	59,800	175	No	NA	3,789,942	10,736	NA	3,735,249	10,499	0
	Sun	07/30/06 08:45	7.4	87,000	196	2.9	30,600	176	No	NA	3,847,814	10,857	NA	3,796,925	10,628	0
27	Mon	07/31/06 06:30	2.6	32,600	209	4.6	48,500	176	Yes	NA	3,887,370	10,940	NA	3,838,985	10,716	0
	Tue	08/01/06 09:30	4.3	48,000	186	5.4	57,600	178	No	82	3,931,228	11,031	88	3,885,665	10,814	0
	Wed	08/02/06 07:30	2.0	22,500	188	2.0	22,500	188	No	NA	3,954,306	11,080	NA	3,910,153	10,865	0
	Thu	08/03/06 07:45	4.0	43,800	183	2.1	24,200	192	Yes	NA	3,987,471	11,149	NA	3,945,340	10,938	0
	Fri	08/04/06 06:30	3.3	37,500	189	3.6	40,800	189	No	NA	4,021,061	11,219	NA	3,980,997	11,013	0
	Sat	08/05/06 10:00	3.4	37,700	185	2.1	23,400	186	No	NA	4,050,664	11,281	NA	4,012,254	11,078	0
	Sun	08/06/06 09:30	2.2	25,000	189	2.2	24,600	186	No	NA	4,074,924	11,332	NA	4,038,023	11,132	0
28	Mon	08/07/06 07:00	2.3	25,600	186	2.2	25,200	191	No	NA	4,099,546	11,383	NA	4,064,110	11,186	0
	Tue	08/08/06 07:00	2.2	24,500	186	2.1	24,400	194	No	NA	4,123,342	11,433	NA	4,089,310	11,239	0
	Wed	08/09/06 07:00	2.4	26,600	185	3.3	36,700	185	No	NA	4,152,384	11,493	NA	4,120,097	11,303	0
	Thu	08/10/06 07:00	2.9	32,300	186	2.1	23,100	183	No	NA	4,179,343	11,550	NA	4,148,629	11,363	0
	Fri	08/11/06 06:45	3.1	33,800	182	2.0	23,600	197	Yes	NA	4,206,219	11,606	NA	4,177,094	11,422	0
	Sat	08/12/06 16:00	4.3	47,600	184	1.5	16,300	181	No	NA	4,233,613	11,663	NA	4,206,006	11,483	0
	Sun	08/13/06 18:00	3.3	37,400	189	3.4	37,600	184	No	NA	4,270,098	11,739	NA	4,244,537	11,563	0
29	Mon	08/14/06 09:00	1.4	17,800	212	1.7	18,000	176	No	82	4,286,018	11,772	87	4,261,380	11,598	0
	Tue	08/15/06 08:00	1.5	17,600	196	2.3	25,300	183	No	92	4,305,719	11,814	97	4,282,131	11,642	0
	Wed	08/16/06 07:15	2.3	25,000	181	1.7	18,100	177	No	NA	4,329,626	11,864	NA	4,307,316	11,694	0
	Thu	08/17/06 07:45	3.0	36,100	201	4.2	45,600	181	No	90	4,366,564	11,941	96	4,346,263	11,776	0
	Fri	08/18/06 07:00	2.3	24,200	175	1.7	19,800	194	Yes	NA	4,389,862	11,989	NA	4,370,755	11,827	0
	Sat	08/19/06 07:30	3.7	42,200	190	2.4	27,100	188	No	NA	4,418,264	12,049	NA	4,400,660	11,889	0
	Sun	08/20/06 08:30	1.6	18,400	192	2.8	30,400	181	No	NA	4,442,142	12,099	NA	4,425,746	11,942	0
30	Mon	08/21/06 07:30	3.1	33,400	180	1.5	18,000	200	No	NA	4,467,129	12,151	NA	4,451,964	11,996	0
	Tue	08/22/06 07:00	1.7	19,900	195	2.7	29,000	179	No	NA	4,491,132	12,201	NA	4,477,139	12,049	0
	Wed	08/23/06 07:30	3.1	36,400	196	3.0	31,900	177	Yes	NA	4,524,068	12,270	NA	4,512,252	12,122	0
	Thu	08/24/06 07:30	3.1	34,500	185	2.0	22,500	188	No	NA	4,547,599	12,319	NA	4,537,138	12,174	0
	Fri	08/25/06 07:00	2.4	26,700	185	2.0	22,500	188	No	NA	4,571,422	12,369	NA	4,562,312	12,227	0
	Sat	08/26/06 11:00	3.5	39,300	187	2.7	30,600	189	No	NA	4,605,023	12,439	NA	4,597,864	12,301	0
	Sun	08/27/06 09:00	2.2	25,100	190	1.2	13,400	186	No	NA	4,623,548	12,477	NA	4,617,376	12,342	0

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

			Well 3			Well 4			AERALATER							
Week No.	Day of Week	Date	Op Hours	Gallon Usage	Average Flowrate	Op Hours	Gallon Usage	Average Flowrate	Backwash	Vessel A Flow Rate	Vessel A Service Totalizer	Cumulative Bed Volumes	Vessel B Flow Rate	Vessel B Service Totalizer	Cumulative Bed Volumes	Combined Backwash Totalizer
			Hrs	gal	gpm	Hrs	gal	gpm	Yes/No	gpm	gal	BV	gpm	gal	BV	gal
	Mon	08/28/06 07:00	2.4	26,500	184	2.3	26,700	193	No	NA	4,649,404	12,531	NA	4,644,690	12,399	0
	Tue	08/29/06 07:00	2.4	26,300	183	3.0	33,300	185	No	NA	4,679,093	12,593	NA	4,676,030	12,464	0
	Wed	08/30/06 07:00	3.1	34,600	186	1.6	18,600	194	No	NA	4,704,979	12,647	NA	4,703,289	12,521	0
31	Thu	08/31/06 07:00	1.5	17,900	199	3.1	32,300	174	Yes	NA	4,729,638	12,699	NA	4,729,279	12,576	0
	Fri	09/01/06 07:00	3.6	41,900	194	1.8	19,300	179	No	NA	4,754,716	12,751	NA	4,755,705	12,631	0
	Sat	09/02/06 10:00	1.9	22,500	197	3.8	40,500	178	No	NA	4,783,164	12,811	NA	4,785,766	12,694	0
	Sun	09/03/06 08:30	1.9	23,500	206	1.3	14,500	186	No	NA	4,803,906	12,854	NA	4,807,442	12,739	0
	Mon	09/04/06 16:20	3.1	36,800	198	3.9	41,200	176	No	NA	4,842,202	12,934	NA	4,847,659	12,823	0
	Tue	09/05/06 07:00	1.0	11,600	193	2.6	27,000	173	No	75	4,859,118	12,969	78	4,865,409	12,860	0
	Wed	09/06/06 07:20	2.0	24,000	200	2.4	25,800	179	No	NA	4,885,510	13,025	NA	4,893,021	12,918	0
32	Thu	09/07/06 07:15	2.1	25,000	198	2.3	25,600	186	No	NA	4,910,069	13,076	NA	4,918,751	12,971	0
	Fri	09/08/06 07:15	2.2	26,500	201	2.3	25,000	181	Yes	NA	4,935,085	13,128	NA	4,944,965	13,026	0
	Sat	09/09/06 09:30	3.8	43,900	193	2.1	23,100	183	No	NA	4,960,553	13,181	NA	4,971,585	13,082	0
	Sun	09/10/06 08:30	2.3	25,400	184	1.5	16,800	187	No	NA	4,978,709	13,219	NA	4,990,503	13,121	0
	Mon	09/11/06 07:30	2.3	25,500	185	2.5	28,300	189	No	92	5,004,872	13,274	95	5,017,808	13,178	0
	Tue	09/12/06 07:30	3.2	37,100	193	1.4	15,900	189	No	90	5,030,173	13,327	74	5,044,147	13,233	0
	Wed	09/13/06 07:30	2.3	27,000	196	2.4	25,700	178	No	NA	5,058,919	13,387	NA	5,074,043	13,296	0
33	Thu	09/14/06 07:30	2.1	25,200	200	2.6	27,000	173	No	NA	5,084,510	13,440	NA	5,100,619	13,351	0
	Fri	09/15/06 07:30	2.1	25,000	198	2.6	27,500	176	Yes	NA	5,110,226	13,494	NA	5,127,319	13,407	0
	Sat	09/16/06 10:00	1.3	40,100	514	2.2	24,200	183	No	NA	5,134,156	13,544	NA	5,152,109	13,459	0
	Sun	09/17/06 08:30	4.2	25,200	100	2.3	25,300	183	No	NA	5,158,965	13,596	NA	5,177,736	13,512	0
	Mon	09/18/06 07:15	2.2	26,400	200	2.4	24,900	173	No	NA	5,184,212	13,648	NA	5,203,764	13,567	0
	Tue	09/19/06 07:45	2.8	33,500	199	2.4	25,600	178	No	NA	5,213,280	13,709	NA	5,233,731	13,629	0
	Wed	09/20/06 07:30	2.9	33,000	190	1.5	17,700	197	Yes	NA	5,238,085	13,761	NA	5,259,243	13,682	0
34	Thu	09/21/06 07:00	2.4	25,800	179	3.3	37,500	189	No	NA	5,264,714	13,817	NA	5,286,536	13,739	0
	Fri	09/22/06 07:30	2.2	24,900	189	2.8	31,400	187	No	94	5,289,585	13,869	96	5,311,932	13,792	0
	Sat	09/23/06 08:45	2.3	25,500	185	2.7	30,000	185	No	89	5,317,432	13,927	92	5,340,316	13,852	0
	Sun	09/24/06 08:00	2.4	26,900	187	2.2	25,300	192	No	NA	5,343,047	13,980	NA	5,366,361	13,906	0
	Mon	09/25/06 07:30	2.7	29,100	180	2.2	24,400	185	No	NA	5,372,295	14,041	NA	5,396,063	13,968	0
	Tue	09/26/06 07:30	2.7	31,000	191	1.9	19,700	173	No	NA	5,397,300	14,093	NA	5,421,417	14,021	0
	Wed	09/27/06 07:30	2.5	27,400	183	1.9	22,500	197	No	NA	5,421,918	14,145	NA	5,446,356	14,073	0
35	Thu	09/28/06 07:05	2.5	27,100	181	2.1	22,800	181	Yes	NA	5,446,642	14,197	NA	5,471,373	14,126	0
	Fri	09/29/06 08:30	3.0	34,800	193	2.5	26,500	177	No	NA	5,469,349	14,244	NA	5,494,310	14,173	0
	Sat	09/30/06 08:30	1.9	23,000	202	1.2	12,700	176	No	NA	5,489,679	14,286	NA	5,514,713	14,216	0
	Sun	10/01/06 08:30	1.9	23,000	202	2.5	26,400	176	No	NA	5,514,331	14,338	NA	5,539,446	14,268	0
	Mon	10/02/06 07:30	2.2	25,100	190	2.6	28,400	182	No	NA	5,540,988	14,394	NA	5,566,197	14,324	0
	Tue	10/03/06 07:30	2.0	23,700	198	2.6	26,600	171	No	NA	5,566,147	14,446	NA	5,591,427	14,376	0
	Wed	10/04/06 07:00	1.9	23,000	202	2.4	25,700	178	No	NA	5,590,525	14,497	NA	5,615,854	14,427	0
36	Thu	10/05/06 07:30	2.1	24,200	192	3.0	31,900	177	No	NA	5,616,794	14,552	NA	5,642,154	14,482	0
	Fri	10/06/06 07:30	2.0	23,300	194	2.2	23,100	175	Yes	NA	5,641,709	14,604	NA	5,667,047	14,534	0
	Sat	10/07/06 08:15	3.2	39,100	204	2.3	24,400	177	No	NA	5,667,122	14,657	NA	5,692,419	14,587	0
	Sun	10/08/06 08:00	2.2	25,800	195	2.4	25,400	176	No	NA	5,692,665	14,710	NA	5,717,853	14,640	0
	Mon	10/09/06 07:30	2.3	26,200	190	2.4	25,400	176	No	NA	5,718,486	14,764	NA	5,743,537	14,694	0
	Tue	10/10/06 08:00	2.1	25,400	202	2.3	24,700	179	No	NA	5,743,486	14,817	NA	5,768,379	14,746	0
	Wed	10/11/06 07:30	2.8	31,800	189	1.6	17,100	178	No	NA	5,767,870	14,867	NA	5,792,618	14,796	0
37	Thu	10/12/06 07:30	2.5	27,100	181	2.0	23,000	192	Yes	66	5,792,876	14,920	62	5,817,482	14,848	0
	Fri	10/13/06 07:35	2.1	23,400	186	3.5	40,800	194	No	NA	5,814,027	14,964	NA	5,839,531	14,894	0
	Sat	10/14/06 09:00	2.8	30,400	181	2.0	21,800	182	No	NA	5,842,318	15,023	NA	5,869,381	14,957	0
	Sun	10/15/06 10:00	2.5	28,100	187	1.9	21,500	189	No	NA	5,863,478	15,067	NA	5,891,781	15,004	0
	Mon	10/16/06 07:30	1.4	14,600	174	2.0	23,200	193	No	NA	5,884,786	15,112	NA	5,914,277	15,051	6,249
	Tue	10/17/06 07:30	2.3	25,400	184	2.0	21,600	180	No	NA	5,905,041	15,154	NA	5,935,705	15,095	6,249
	Wed	10/18/06 07:30	2.3	25,800	187	1.2	13,800	192	No	NA	5,926,979	15,200	NA	5,958,833	15,144	6,249
38	Thu	10/19/06 07:30	2.3	25,100	182	2.1	23,200	184	Yes	NA	5,950,583	15,249	NA	5,983,698	15,196	6,249
	Fri	10/20/06 07:30	3.7	43,800	197	1.0	12,000	200	No	NA	5,969,846	15,289	NA	6,004,074	15,238	6,249
	Sat	10/21/06 08:30	2.3	25,000	181	2.1	22,900	182	No	NA	5,993,082	15,338	NA	6,028,582	15,289	6,249
	Sun	10/22/06 09:30	2.4	26,300	183	2.0	22,600	188	No	NA	6,014,351	15,382	NA	6,051,052	15,336	6,249
	Mon	10/23/06 07:30	1.7	20,200	198	2.0	22,900	191	No	82	6,034,892	15,425	88	6,072,703	15,381	6,249
	Tue	10/24/06 08:00	2.8	30,400	181	1.9	21,500	189	No	82	6,060,136	15,478	84	6,099,276	15,437	6,249
	Wed	10/25/06 07:45	2.0	22,000	183	2.0	21,900	183	Yes	NA	6,082,981	15,526	NA	6,123,298	15,487	6,249
39	Thu	10/26/06 07:45	3.3	37,000	187	2.0	22,100	184	No	NA	6,108,243	15,578	NA	6,150,054	15,543	6,430
	Fri	10/27/06 07:30	2.2	24,800	188	1.3	15,100	194	No	NA	6,126,056	15,616	NA	6,168,942	15,582	6,430
	Sat	10/28/06 08:30	2.2	24,400	185	1.9	21,500	189	No	NA	6,149,901	15,665	NA	6,194,237	15,635	6,430
	Sun	10/29/06 09:00	2.3	25,000	181	2.1	23,100	183	No	NA	6,173,268	15,714	NA	6,219,037	15,687	6,430
	Mon	10/30/06 07:30	2.3	26,000	188	2.1	24,100	191	No	NA	6,197,559	15,765	NA	6,244,816	15,741	6,447
	Tue	10/31/06 07:30	2.4	26,500	184	1.6	22,800	237	No	77	6,218,629	15,809	82	6,267,203	15,788	6,447
	Wed	11/01/06 07:30	1.4	14,200	169	2.6	24,700	158	No	NA	6,240,430	15,854	NA	6,282,890	15,820	6,447
40	Thu	11/02/06 07:30	2.2	24,700	187	1.1	12,400	188	Yes	NA	6,247,805	15,870	NA	6,301,808	15,860	6,447
	Fri	11/03/06 08:30	2.1	25,000	198	3.7	40,600	183	No	NA	6,273,152	15,923	NA	6,328,679	15,916	6,447
	Sat	11/04/06 09:00	1.0	12,300	205	2.3	24,400	177	No	NA	6,290,878	15,960	NA	6,347,436	15,955	6,447
	Sun	11/05/06 08:00	2.1	25,000	198	2.2	24,100	183	No	NA	6,314,727	16,010	NA	6,372,691	16,008	6,447

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

			Well 3			Well 4			AERALATER							
Week No.	Day of Week	Date	Op Hours	Gallon Usage	Average Flowrate	Op Hours	Gallon Usage	Average Flowrate	Backwash	Vessel A Flow Rate	Vessel A Service Totalizer	Cumulative Bed Volumes	Vessel B Flow Rate	Vessel B Service Totalizer	Cumulative Bed Volumes	Combined Backwash Totalizer
			Hrs	gal	gpm	Hrs	gal	gpm	Yes/No	gpm	gal	BV	gpm	gal	BV	gal
41	Mon	11/06/06 08:00	2.3	26,500	192	2.4	25,700	178	No	NA	6,340,012	16,062	NA	6,399,479	16,064	6,447
	Tue	11/07/06 07:30	2.8	33,400	199	2.3	24,300	176	No	91	6,365,280	16,115	97	6,426,258	16,120	6,447
	Wed	11/08/06 07:00	1.9	22,900	201	2.5	26,000	173	Yes	NA	6,390,768	16,168	NA	6,452,897	16,176	6,447
	Thu	11/09/06 08:00	5.0	55,900	186	2.1	23,600	187	No	NA	6,424,924	16,240	NA	6,489,356	16,252	6,447
	Fri	11/10/06 08:00	2.3	25,600	186	2.2	25,400	192	No	NA	6,449,596	16,291	NA	6,515,446	16,306	6,447
	Sat	11/11/06 10:30	2.4	26,000	181	3.4	36,700	180	No	NA	6,480,200	16,355	NA	6,547,814	16,374	6,447
	Sun	11/12/06 10:30	2.3	25,800	187	2.2	24,600	186	No	NA	6,504,631	16,406	NA	6,573,623	16,428	6,447
42	Mon	11/13/06 08:00	2.4	26,300	183	1.8	21,100	195	No	NA	6,524,741	16,448	NA	6,594,873	16,472	6,447
	Tue	11/14/06 08:30	2.4	26,500	184	2.7	29,900	185	No	NA	6,554,910	16,511	NA	6,626,737	16,539	6,447
	Wed	11/15/06 07:30	2.3	25,100	182	1.1	11,900	180	No	NA	6,572,786	16,549	NA	6,645,596	16,578	6,447
	Thu	11/16/06 07:45	1.7	19,900	195	2.1	23,100	183	No	79	6,590,890	16,586	84	6,664,733	16,618	6,447
	Fri	11/17/06 07:30	2.1	23,700	188	2.0	20,000	167	Yes	NA	6,612,353	16,631	NA	6,687,376	16,665	6,447
	Sat	11/18/06 07:45	3.1	36,300	195	1.0	12,000	200	No	NA	6,631,462	16,671	NA	6,707,501	16,707	6,447
	Sun	11/19/06 07:45	2.3	25,100	182	2.2	23,700	180	No	NA	6,653,106	16,716	NA	6,730,357	16,755	6,447
43	Mon	11/20/06 07:30	2.0	23,300	194	2.1	24,000	190	No	80	6,675,241	16,763	85	6,753,700	16,804	6,447
	Tue	11/21/06 07:30	1.8	18,600	172	1.9	21,100	185	No	NA	6,697,361	16,809	NA	6,774,971	16,848	6,447
	Wed	11/22/06 07:30	2.4	26,300	183	1.1	11,800	179	Yes	NA	6,715,751	16,847	NA	6,796,312	16,893	6,447
	Thu	11/23/06 10:30	2.0	23,800	198	4.1	45,100	183	No	NA	6,741,457	16,901	NA	6,823,364	16,949	6,447
	Fri	11/24/06 06:00	1.0	11,500	192	2.1	22,700	180	No	NA	6,759,689	16,939	NA	6,842,510	16,989	6,447
	Sat	11/25/06 14:00	3.2	38,100	198	2.2	24,000	182	No	NA	6,789,513	17,001	NA	6,873,854	17,055	6,447
	Sun	11/26/06 05:00	1.0	11,500	192	1.3	12,800	164	No	NA	6,801,400	17,026	NA	6,886,323	17,081	6,447
44	Mon	11/27/06 07:30	2.0	23,800	198	2.6	27,600	177	No	NA	6,826,262	17,078	NA	6,912,404	17,135	6,447
	Tue	11/28/06 07:00	1.5	17,900	199	2.3	24,800	180	No	NA	6,844,536	17,116	NA	6,931,532	17,175	6,447
	Wed	11/29/06 07:30	2.3	26,000	188	1.7	18,200	178	Yes	NA	6,868,432	17,166	NA	6,956,573	17,228	6,447
	Thu	11/30/06 07:30	3.4	39,400	193	1.2	13,300	185	No	NA	6,886,644	17,204	NA	6,975,600	17,267	6,447
	Fri	12/01/06 07:15	2.3	25,200	183	1.9	21,300	187	No	NA	6,910,219	17,253	NA	7,000,183	17,319	6,447
	Sat	12/02/06 08:30	2.5	27,000	180	2.0	22,200	185	No	NA	6,931,555	17,298	NA	7,022,460	17,365	6,447
	Sun	12/03/06 08:15	1.2	13,500	187	1.9	21,600	189	No	NA	6,951,304	17,339	NA	7,043,023	17,408	6,447
45	Mon	12/04/06 07:30	2.5	27,300	182	2.3	24,500	178	No	NA	6,974,963	17,389	NA	7,067,677	17,460	6,447
	Tue	12/05/06 07:30	2.3	25,400	184	1.0	11,500	192	No	NA	6,994,294	17,429	NA	7,087,749	17,502	6,447
	Wed	12/06/06 07:30	2.8	31,400	187	1.0	11,700	195	No	NA	7,015,027	17,472	NA	7,109,289	17,546	6,447
	Thu	12/07/06 07:30	1.3	14,200	182	2.0	21,500	179	Yes	NA	7,032,541	17,509	NA	7,127,515	17,585	6,447
	Fri	12/08/06 07:30	3.5	39,800	190	1.4	16,400	195	No	NA	7,051,448	17,548	NA	7,147,116	17,626	6,447
	Sat	12/09/06 08:00	2.1	23,900	190	1.8	19,200	178	No	NA	7,074,538	17,597	NA	7,171,010	17,675	6,447
	Sun	12/10/06 09:00	1.9	21,800	191	2.0	23,200	193	No	80	7,093,470	17,636	82	7,190,628	17,716	6,447
46	Mon	12/11/06 07:30	2.0	19,900	166	2.1	22,300	177	No	NA	7,116,957	17,685	NA	7,214,884	17,767	6,447
	Tue	12/12/06 08:30	2.3	25,800	187	2.1	23,400	186	No	75	7,140,603	17,735	78	7,239,317	17,818	6,447
	Wed	12/13/06 07:30	2.3	25,400	184	1.1	12,400	188	No	NA	7,159,335	17,774	NA	7,258,613	17,858	6,447
	Thu	12/14/06 07:30	1.6	18,100	189	2.1	23,200	184	Yes	NA	7,176,913	17,810	NA	7,276,767	17,896	6,447
	Fri	12/15/06 07:30	3.1	35,600	191	2.4	25,500	177	No	NA	7,200,035	17,859	NA	7,300,620	17,946	6,447
	Sat	12/16/06 08:45	1.9	23,300	204	1.3	13,800	177	No	NA	7,220,901	17,902	NA	7,322,035	17,991	6,447
	Sun	12/17/06 08:30	1.6	19,200	200	2.0	26,200	218	No	NA	7,240,063	17,942	NA	7,341,717	18,032	6,447
47	Mon	12/18/06 07:30	1.7	19,300	189	2.8	24,500	146	No	NA	7,264,327	17,993	NA	7,366,572	18,084	6,447
	Tue	12/19/06 07:45	1.1	12,100	183	2.9	31,300	180	No	NA	7,285,802	18,038	NA	7,388,564	18,130	6,447
	Wed	12/20/06 07:45	2.0	24,300	203	1.7	18,100	177	No	NA	7,303,537	18,075	NA	7,406,767	18,168	6,447
	Thu	12/21/06 08:00	2.0	23,300	194	2.0	20,900	174	Yes	NA	7,327,734	18,125	NA	7,431,556	18,220	6,447
	Fri	12/22/06 07:00	1.3	13,900	178	3.2	36,100	188	No	NA	7,346,710	18,165	NA	7,450,993	18,260	6,447
	Sat	12/23/06 09:00	1.4	26,600	317	2.0	22,500	188	No	NA	7,370,532	18,215	NA	7,475,324	18,311	6,447
	Sun	12/24/06 09:00	3.4	25,800	126	1.1	11,700	177	No	NA	7,388,756	18,253	NA	7,493,909	18,350	6,447
48	Mon	12/25/06 10:15	2.5	27,400	183	2.2	23,800	180	No	NA	7,413,759	18,305	NA	7,519,454	18,403	6,447
	Tue	12/26/06 07:45	1.2	13,000	181	2.0	22,600	188	No	NA	7,431,065	18,341	NA	7,537,148	18,440	6,447
	Wed	12/27/06 07:30	2.3	26,700	193	1.2	13,500	188	No	NA	7,449,779	18,380	NA	7,556,249	18,480	6,447
	Thu	12/28/06 07:00	2.3	25,000	181	1.9	22,000	193	Yes	NA	7,473,442	18,430	NA	7,580,422	18,531	6,447
	Fri	12/29/06 07:30	1.1	12,700	192	3.3	36,100	182	No	NA	7,492,463	18,469	NA	7,599,831	18,571	6,447
	Sat	12/30/06 07:00	2.1	24,500	194	1.2	32,700	454	No	NA	7,510,508	18,507	NA	7,618,282	18,610	6,447
	Sun	12/31/06 07:45	2.0	23,300	194	2.4	5,500	38	No	NA	7,534,239	18,557	NA	7,642,535	18,660	6,447
49	Mon	01/01/07 08:00	1.1	13,300	202	2.5	26,000	173	No	NA	7,558,362	18,607	NA	7,662,075	18,701	6,447
	Tue	01/02/07 08:15	2.2	25,400	192	2.5	26,400	176	No	NA	7,578,568	18,649	NA	7,687,901	18,755	6,447
	Wed	01/03/07 07:30	2.1	24,000	190	1.3	13,700	176	Yes	NA	7,596,685	18,687	NA	7,706,492	18,794	6,447
	Thu	01/04/07 07:30	1.2	13,600	189	3.0	33,600	187	No	NA	7,614,782	18,725	NA	7,725,065	18,833	6,447
	Fri	01/05/07 08:00	2.6	28,100	180	2.0	22,500	188	No	NA	7,639,143	18,776	NA	7,750,075	18,885	6,447
	Sat	01/06/07 09:00	2.4	26,000	181	1.5	16,200	180	No	NA	7,657,387	18,814	NA	7,768,803	18,924	6,447
	Sun	01/07/07 09:30	2.3	25,400	184	1.8	19,500	181	No	NA	7,681,237	18,864	NA	7,793,350	18,975	6,447
50	Mon	01/08/07 07:45	2.7	28,800	178	2.3	25,100	182	No	NA	7,706,459	18,916	NA	7,819,370	19,030	6,447
	Tue	01/09/07 07:30	1.1	14,300	217	2.1	23,200	184	No	NA	7,725,499	18,956	NA	7,838,990	19,071	6,447
	Wed	01/10/07 07:30	2.7	26,600	164	1.9	21,000	184	No	85	7,745,624	18,998	88	7,859,768	19,114	6,447
	Thu	01/11/07 07:30	2.3	25,200	183	1.5	16,300	181	Yes	NA	7,768,374	19,046	NA	7,883,250	19,163	6,447
	Fri	01/12/07 08:00	1.3	11,200	144	4.1	46,300	188	No	NA	7,791,514	19,094	NA	7,907,230	19,213	6,447
	Sat	01/13/07 08:06	1.7	22,000	216	1.8	18,000	167	No	NA	7,809,733	19,132	NA	7,926,089	19,252	6,447
	Sun	01/14/07 07:30	2.3	26,000	188	2.3	24,900	180	No	NA	7,834,171	19,183	NA	7,951,464	19,305	6,447

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

Week No.	Day of Week	Date	Well 3 Op Hours (Hrs)	Well 3 Gallon Usage (gal)	Well 3 Average Flowrate (gpm)	Well 4 Op Hours (Hrs)	Well 4 Gallon Usage (gal)	Well 4 Average Flowrate (gpm)	AERALATER Backwash (Yes/No)	Vessel A Flow Rate (gpm)	Vessel A Service Totalizer (gal)	Cumulative Bed Volumes (BV)	Vessel B Flow Rate (gpm)	Vessel B Service Totalizer (gal)	Cumulative Bed Volumes (BV)	Combined Backwash Totalizer (gal)
51	Mon	01/15/07 08:00	2.1	25,200	200	2.7	27,400	169	No	NA	7,856,720	19,230	NA	7,974,918	19,354	6,447
	Tue	01/16/07 08:30	2.0	23,200	193	3.3	25,200	127	No	NA	7,882,406	19,284	NA	8,001,600	19,410	6,447
	Wed	01/17/07 07:30	2.0	23,100	193	2.1	31,300	248	Yes	NA	7,905,111	19,331	NA	8,026,114	19,461	6,447
	Thu	01/18/07 07:00	2.8	34,000	202	1.9	19,800	174	No	NA	7,923,716	19,370	NA	8,045,976	19,503	6,447
	Fri	01/19/07 07:00	3.8	43,700	192	1.5	16,200	180	No	NA	7,951,674	19,429	NA	8,075,798	19,565	6,447
	Sat	01/20/07 07:00	2.3	25,500	185	2.1	23,400	186	No	NA	7,975,078	19,477	NA	8,100,718	19,617	6,447
	Sun	01/21/07 08:00	2.4	25,600	178	2.5	27,800	185	No	NA	8,000,617	19,531	NA	8,127,937	19,674	6,447
52	Mon	01/22/07 08:00	2.4	26,600	185	2.2	24,500	186	No	NA	8,025,044	19,582	NA	8,153,942	19,728	12,141
	Tue	01/23/07 07:30	2.6	28,100	180	2.1	23,300	185	No	NA	8,048,103	19,630	NA	8,178,516	19,780	12,141
	Wed	01/24/07 07:30	1.6	18,100	189	2.0	22,700	189	No	NA	8,066,929	19,669	NA	8,198,537	19,822	12,141
	Thu	01/25/07 07:30	2.2	24,000	182	2.0	22,000	183	Yes	NA	8,090,760	19,719	NA	8,223,881	19,874	12,141
	Fri	01/26/07 07:30	2.5	26,700	178	2.9	33,300	191	No	NA	8,113,365	19,766	NA	8,247,962	19,925	12,141
	Sat	01/27/07 08:00	2.4	26,900	187	2.0	23,100	193	No	NA	8,137,246	19,816	NA	8,273,380	19,978	12,141
	Sun	01/28/07 08:00	2.9	31,000	178	1.6	12,500	130	No	NA	8,159,132	19,862	NA	8,296,642	20,026	12,141
53	Mon	01/29/07 08:00	2.2	25,100	190	1.8	24,500	227	No	NA	8,182,649	19,911	NA	8,321,656	20,079	12,141
	Tue	01/30/07 07:30	2.3	25,400	184	2.2	25,000	189	No	NA	8,206,499	19,961	NA	8,347,013	20,132	12,141
	Wed	01/31/07 07:30	2.3	24,500	178	2.5	26,500	177	No	NA	8,227,971	20,006	NA	8,369,902	20,179	12,141
	Thu	02/01/07 07:10	1.6	18,000	187	1.8	21,800	202	Yes	NA	8,248,826	20,049	NA	8,392,027	20,226	12,141
	Fri	02/02/07 07:30	1.9	21,900	192	3.4	36,700	180	No	NA	8,272,385	20,098	NA	8,417,008	20,278	12,141
	Sat	02/03/07 08:00	1.9	22,700	199	2.3	24,200	175	No	NA	8,293,484	20,143	NA	8,439,166	20,324	12,141
	Sun	02/04/07 09:00	1.9	14,100	124	2.4	25,600	178	No	NA	8,317,470	20,193	NA	8,464,709	20,377	12,141
54	Mon	02/05/07 07:30	2.1	33,100	263	2.2	24,300	184	No	NA	8,338,083	20,236	NA	8,485,921	20,422	12,141
	Tue	02/06/07 10:00	1.6	19,600	204	2.6	26,900	172	No	NA	8,363,100	20,288	NA	8,512,083	20,476	12,141
	Wed	02/07/07 08:00	2.4	27,500	191	2.3	25,000	181	No	NA	8,387,479	20,339	NA	8,537,627	20,530	12,141
	Thu	02/08/07 07:30	2.0	23,500	196	2.4	25,000	174	Yes	NA	8,411,013	20,388	NA	8,562,223	20,581	12,141
	Fri	02/09/07 07:30	1.7	18,500	181	3.2	35,900	187	No	NA	8,430,179	20,428	NA	8,582,259	20,623	12,141
	Sat	02/10/07 07:30	2.7	30,500	188	1.6	17,900	186	No	NA	8,454,253	20,478	NA	8,607,397	20,675	12,141
	Sun	02/11/07 07:30	1.7	19,900	195	2.1	24,400	194	No	NA	8,473,187	20,518	NA	8,627,153	20,717	12,141
55	Mon	02/12/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Tue	02/13/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Wed	02/14/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Thu	02/15/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Fri	02/16/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sat	02/17/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sun	02/18/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
56	Mon	02/19/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Tue	02/20/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Wed	02/21/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Thu	02/22/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Fri	02/23/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sat	02/24/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sun	02/25/07 00:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
57	Tue	02/27/07 07:00	NA	NA	NA	NA	NA	NA	No	NA	8,809,984	21,221	NA	8,976,131	21,446	12,141
	Wed	02/28/07 07:00	1.8	20,500	190	2.0	21,200	177	Yes	NA	8,830,297	21,264	NA	8,996,994	21,489	12,141

Highlighted columns indicate calculated values.
NA = data not available.

APPENDIX B

ANALYTICAL DATA TABLES

Table B-1. Analytical Results from Long-Term Sampling at Stewart, MN (Continued)

Table B-1. Analytical Results from Long-Term Sampling at Stewart, MN

Sampling Date		02/02/06[(c)]				02/14/06					02/21/06					02/27/06[(c)]				03/06/06				
Sampling Location Parameter	Unit	IN	AC	AF	TB	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB	IN	AC	AF	TA	IN	AC	AF	TA	TB
Bed Volume (10^3)	BV	-	-	-	0.7	-	-	-	1.2	1.1	-	-	-	1.5	1.4	-	-	-	1.7	-	-	-	2.2	2.1
Alkalinity (as $CaCO_3$)	mg/L	423 -	432 -	427 -	432 -	421 -	442 -	417 -	438 -	421 -	419 -	419 -	419 -	419 -	414 -	422 -	413 -	434 -	418 -	419 -	410 -	427 -	419 -	419 -
Ammonia (as N)	mg/L	1.7	1.9	1.7	1.7	-	-	-	-	-	-	-	-	-	-	1.0	1.1	1.1	1.1	-	-	-	-	-
Fluoride	mg/L	0.3	0.3	0.3	0.3	-	-	-	-	-	-	-	-	-	-	0.4	0.4	0.4	0.4	-	-	-	-	-
Sulfate	mg/L	<1	<1	<1	<1	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	<1	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-
Total P (as P)	µg/L	317 -	294 -	95.8 -	<10 -	304 -	275 -	89.3 -	<10 -	<10 -	294 -	289 -	106 -	<10 -	<10 -	290 -	306 -	101 -	<10 -	290 -	296 -	101 -	<10 -	<10 -
Silica (as SiO_2)	mg/L	27.6 -	25.6 -	24.9 -	24.1 -	25.6 -	26.9 -	25.7 -	24.4 -	25.4 -	26.3 -	25.7 -	25.0 -	25.3 -	24.8 -	26.5 -	24.6 -	23.0 -	23.8 -	24.6 -	24.6 -	24.2 -	23.7 -	24.1 -
Turbidity	NTU	7.3 -	4.3 -	0.9 -	2.0 -	7.9 -	15 -	1.4 -	1.7 -	1.8 -	6.5 -	15 -	1.1 -	0.8 -	0.9 -	9.2 -	9.6 -	0.7 -	1.0 -	7.1 -	8.9 -	1.5 -	1.6 -	3.5 -
TOC	mg/L	6.7	7.1	6.8	NA[(a)]	-	-	-	-	-	-	-	-	-	-	6.3	6.7	6.3	NA[(a)]	-	-	-	-	-
pH	S.U.	8.2	8.2	8.4	8.2	7.6	7.9	7.9	7.9	7.9	7.6	8.3	8.3	8.2	8.4	7.4	7.9	7.7	7.8	7.7	8.3	8.0	8.0	8.1
Temperature	°C	11.4	11.8	12.4	10.9	11.4	11.4	12.4	13.1	13.4	12.9	10.5	11.7	12.1	12.2	10.6	11.5	11.9	12.5	10.5	10.1	11.6	11.8	11.4
DO	mg/L	1.1	7.9	5.0	4.8	1.1	NA[(b)]	NA[(b)]	NA[(b)]	NA[(b)]	NA[(b)]	NA[(b)]	NA[(b)]	NA[(b)]	NA[(b)]	1.3	6.0	4.0	3.4	1.8	6.3	3.2	3.6	3.4
ORP	mV	-36.6	250	203	256	35.2	128	166	175	179	294	341	333	323	321	271	273	176	177	300	288	281	289	307
Total Hardness (as $CaCO_3$)	mg/L	211	209	206	214	-	-	-	-	-	-	-	-	-	-	226	224	212	210	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	112	113	113	113	-	-	-	-	-	-	-	-	-	-	109	110	105	103	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	98.9	95.4	93.6	101	-	-	-	-	-	-	-	-	-	-	117	114	107	106	-	-	-	-	-
As (total)	µg/L	52.3 -	52.4 -	21.2 -	0.3 -	36.9 -	33.5 -	22.6 -	0.4 -	0.3 -	42.7 -	43.8 -	27.1 -	0.6 -	0.5 -	38.7 -	41.4 -	24.0 -	0.7 -	39.7 -	41.8 -	24.8 -	0.7 -	0.6 -
As (soluble)	µg/L	43.8	21.3	18.5	0.2	-	-	-	-	-	-	-	-	-	-	35.6	32.5	24.4	0.4	-	-	-	-	-
As (particulate)	µg/L	8.5	31.1	2.7	<0.1	-	-	-	-	-	-	-	-	-	-	3.2	8.9	<0.1	0.3	-	-	-	-	-
As (III)	µg/L	39.8	4.2	1.3	0.9	-	-	-	-	-	-	-	-	-	-	34.2	26.4	2.0	1.7	-	-	-	-	-
As (V)	µg/L	4.0	17.0	17.2	<0.1	-	-	-	-	-	-	-	-	-	-	1.4	6.1	22.4	<0.1	-	-	-	-	-
Fe (total)	µg/L	1,240 -	1,202 -	<25 -	<25 -	1,144 -	1,044 -	<25 -	<25 -	<25 -	1,238 -	1,205 -	<25 -	<25 -	<25 -	1,193 -	1,192 -	<25 -	<25 -	1,202 -	1,185 -	<25 -	<25 -	<25 -
Fe (soluble)	µg/L	1,159	<25	<25	<25	-	-	-	-	-	-	-	-	-	-	855	<25	<25	<25	-	-	-	-	-
Mn (total)	µg/L	29.4 -	541 -	127 -	3.7 -	21.3 -	21.0 -	47.4 -	10.7 -	7.2 -	24.5 -	25.4 -	47.8 -	14.2 -	11.2 -	24.3 -	26.5 -	40.5 -	17.1 -	24.3 -	31.4 -	37.2 -	18.2 -	20.1 -
Mn (soluble)	µg/L	29.7	118	138	3.6	-	-	-	-	-	-	-	-	-	-	24.7	24.8	41.3	17.5	-	-	-	-	-

(a) TOC sample bottle broke during transit. (b) Operator recorded DO readings as percentage therefore no reading available. (c) TT sample tap is not present. Sample taken from individual vessel for speciation week.

IN = Influent, AC = after gravity filtration; TA = after tank A; TB = after tank B; TT = after combined effluent
NA = not available.

Table B-1. Analytical Results from Long-Term Sampling at Stewart, MN (Continued)

Sampling Date		03/14/06					03/21/06					03/28/06				04/04/06				
Sampling Location Parameter	Unit	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB	IN	AC	AF	TA	IN	AC	AF	TA	TB
Bed Volume (10^3)	BV	-	-	-	2.6	2.4	-	-	-	2.9	2.7	-	-	-	3.2	-	-	-	3.5	3.3
Alkalinity (as $CaCO_3$)	mg/L	422 -	422 -	422 -	426 -	426 -	419 -	419 -	423 -	423 -	423 -	408 -	416 -	412 -	416 -	414 -	410 -	410 -	414 -	414 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	1.7	1.7	1.6	1.4	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	0.4	0.4	0.4	0.4	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	<1	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-
Total P (as P)	µg/L	296 -	281 -	105 -	<10 -	<10 -	313 -	315 -	116 -	<10 -	<10 -	80.9 -	304 -	117 -	<10 -	297 -	290 -	110 -	<10 -	<10 -
Silica (as SiO_2)	mg/L	23.3 -	23.1 -	23 -	23.3 -	23.5 -	24.5 -	24.5 -	25.1 -	25.1 -	25.2 -	24.8 -	25 -	- -	24.3 -	25.1 -	24.5 -	25.5 -	25.2 -	25.6 -
Turbidity	NTU	6.1 -	8.6 -	0.9 -	0.8 -	1.2 -	11 -	9.3 -	0.9 -	0.7 -	0.6 -	5.9 -	9.9 -	1 -	0.6 -	6.3 -	8.7 -	0.7 -	0.8 -	1.1 -
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	6.2	6.2	6.2	6.1	-	-	-	-	-
pH	S.U.	7.9	8.2	8.1	8.1	8.1	7.9	8.3	8.1	8.2	8.2	8.1	8.3	8.3	8.3	8.0	8.4	8.2	8.2	8.2
Temperature	°C	12.5	10.9	11.3	10.8	11.8	16.6	11.0	12.6	11.5	11.5	12.7	11.0	11.1	11.1	12.2	13.1	13.6	14.3	15.4
DO	mg/L	1.1	6.2	3.1	3.9	3.4	0.8	5.7	2.2	2.4	2.7	0.6	5.5	4.9	4.7	0.5	5.2	1.6	2.4	1.9
ORP	mV	284	291	268	212	188	216	237	249	168	154	281	266	195	158	8.9	146	148	140	146
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	229	213	206	209	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	117	107	102	104	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	112	106	103	105	-	-	-	-	-
As (total)	µg/L	49.3 -	48.4 -	30.3 -	0.6 -	0.7 -	37.2 -	38.9 -	25.0 -	0.5 -	0.5 -	36.5 -	41.4 -	30.2 -	0.5 -	37.1 -	37.6 -	25.2 -	0.5 -	0.5 -
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	36.0	33.3	29.2	0.5	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	0.5	8.1	1.0	<0.1	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	33.4	24.4	2.9	0.6	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	2.5	8.9	26.4	<0.1	-	-	-	-	-
Fe (total)	µg/L	1,157 -	1,168 -	<25 -	<25 -	<25 -	1,155 -	1,139 -	<25 -	<25 -	<25 -	1,096 -	1,176 -	<25 -	<25 -	1,077 -	1,059 -	<25 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	412	<25	<25	<25	-	-	-	-	-
Mn (total)	µg/L	23.0 -	24.1 -	33.4 -	21.2 -	23.4 -	44.3 -	25.0 -	31.5 -	23.6 -	25.8 -	19.8 -	23.2 -	28.0 -	25.3 -	21.5 -	22.9 -	29.5 -	26.4 -	28.3 -
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	22.8	23.2	28.8	26.0	-	-	-	-	-

IN = Influent, AC = after gravity filtration; TA = after tank A; TB = after tank B; TT = after combined effluent
NA = not available.

Table B-1. Analytical Results from Long-Term Sampling at Stewart, MN (Continued)

Sampling Date		04/11/06[(a)]					04/18/06					04/25/06				05/02/06				
Sampling Location / Parameter	Unit	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB	IN	AC	AF	TT	IN	AC	AF	TA	TB
Bed Volume (10^3)	BV	-	-	-	3.8	3.7	-	-	-	4.1	4.0	-	-	-	4.4	-	-	-	4.8	4.7
Alkalinity (as $CaCO_3$)	mg/L	440	440	448	440	435	435	444	440	444	431	423	415	431	427	421	420	432	412	412
		-	-	-	-	-	448	435	431	440	444	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	1.6	1.4	1.3	1.0	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	0.5	0.5	0.4	0.4	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	<1	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	0.2	0.3	-	-	-	-	-
Total P (as P)	µg/L	294	265	94.8	<10	<10	287	289	113	11.5	<10	296	289	107	<10	264	254	97.0	<10	<10
		-	-	-	-	-	289	291	113	10.9	<10	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	24.1	24.4	25.1	25.1	25.2	24.6	25.1	23.3	25.1	24.2	25.9	24.6	25.1	24.8	25.9	25.7	25.5	26.2	26.2
		-	-	-	-	-	24.9	25.5	24.3	24.9	24.5	-	-	-	-	-	-	-	-	-
Turbidity	NTU	9.4	8.9	0.9	1.0	0.7	5.0	8.8	0.7	0.5	0.4	4.3	7.6	0.5	0.6	4.6	8.3	0.6	0.4	0.8
		-	-	-	-	-	5.8	8.6	0.6	0.7	0.6	-	-	-	-	-	-	-	-	-
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	6.2	6.2	6.3	6.1	-	-	-	-	-
pH	S.U.	7.8	8.1	8.1	8.1	8.1	8.0	8.4	8.2	8.2	8.2	8.1	8.4	8.2	8.2	8.0	8.3	8.2	8.2	8.2
Temperature	°C	13.0	11.5	12.9	14.0	14.1	14.2	12.7	13.3	13.8	13.3	12.6	12.1	13.8	11.7	10.2	10.3	10.5	10.8	10.8
DO	mg/L	0.6	4.2	1.8	1.9	2.3	0.7	5.0	2.2	2.9	2.9	0.6	5.1	1.8	2.4	0.5	5.0	1.9	2.5	2.1
ORP	mV	21.4	210	186	168	118	89.7	213	216	164	160	119	161	229	152	16.8	349	251	198	195
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	205	214	218	221	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	111	118	120	122	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	94.0	96.4	99.0	99.8	-	-	-	-	-
As (total)	µg/L	41.8	39.7	30.3	0.9	0.9	39.0	39.1	22.5	0.6	0.7	39.5	43.6	23.1	<0.1	36.6	36.1	30.8	0.7	0.9
		-	-	-	-	-	38.9	39.6	22.5	0.6	0.7	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	34.1	44.9	21.9	<0.1	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	5.4	<0.1	1.2	<0.1	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	27.9	21.7	<0.1	<0.1	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	6.2	23.2	21.8	<0.1	-	-	-	-	-
Fe (total)	µg/L	1,175	1,179	<25	<25	<25	1,197	1,163	<25	<25	<25	1,181	1,277	<25	<25	1,088	1,063	<25	<25	<25
		-	-	-	-	-	1,200	1,156	<25	<25	<25	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	931	<25	<25	<25	-	-	-	-	-
Mn (total)	µg/L	23.1	24.2	31.9	30.5	33.2	23.3	23.8	28.5	27.9	30.2	24.0	27.7	30.4	34.2	22.2	22.6	29.6	28.2	32.3
		-	-	-	-	-	23.6	23.8	28.2	28.5	30.6	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	24.6	25.6	30.9	35.1	-	-	-	-	-

(a) Water quality measurements taken on 04/10/06.

IN = Influent, AC = after gravity filtration; TA = after tank A; TB = after tank B; TT = after combined effluent
NA = not available.

Table B-1. Analytical Results from Long-Term Sampling at Stewart, MN (Continued)

Sampling Date		05/09/06[a]					05/16/06					05/24/06				05/30/06				
Sampling Location Parameter	Unit	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB	IN	AC	AF	TT	IN	AC	AF	TA	TB
Bed Volume (10^3)	BV	-	-	-	5.1	5.0	-	-	-	5.5	5.3	-	-	-	5.8	-	-	-	6.2	6.1
Alkalinity (as $CaCO_3$)	mg/L	410 -	419 -	423 -	423 -	410 -	422 -	434 -	426 -	409 -	422 -	414 -	423 -	423 -	419 -	424 -	420 -	420 -	400 -	367 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	1.6	1.6	1.5	1.2	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	0.5	0.5	0.5	0.5	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	<1	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	0.1	0.3	-	-	-	-	-
Total P (as P)	µg/L	272 -	255 -	90.1 -	<10 -	<10 -	287 -	282 -	93.3 -	<10 -	<10 -	289 -	292 -	128 -	<10 -	292 -	278 -	114 -	25.3 -	26.7 -
Silica (as SiO_2)	mg/L	25.5 -	26 -	25.9 -	26.3 -	26.3 -	26.3 -	26.8 -	25.2 -	26 -	26.2 -	25.2 -	24.5 -	24.9 -	25.2 -	24.5 -	24.4 -	24.2 -	24.5 -	24.1 -
Turbidity	NTU	4.1 -	8.3 -	0.7 -	0.6 -	0.7 -	5.5 -	8.1 -	0.6 -	0.4 -	0.7 -	4.9 -	9.1 -	0.7 -	0.7 -	4.3 -	9.7 -	0.6 -	0.4 -	1.0 -
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	6.3	6.3	6.5	6.6	-	-	-	-	-
pH	S.U.	8.0	8.3	8.2	8.2	8.2	8.0	8.2	8.9	8.1	8.1	7.5	7.8	7.7	7.7	8.2	8.5	8.4	8.4	8.4
Temperature	°C	11.8	11.0	11.0	10.6	10.5	11.0	10.8	11.1	10.9	11.5	12.6	11.6	19.3	11.7	10.9	11.5	11.2	11.4	11.5
DO	mg/L	1.5	4.8	2.5	2.6	2.7	0.8	5.3	2.2	2.0	2.2	1.1	5.0	2.5	2.5	1.9	4.9	3.8	3.6	3.7
ORP	mV	78.1	140	170	168	165	-1.4	140	119	112	117	71.3	248	386	150	265	340	308	300	297
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	200	189	217	222	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	101	95.0	109	110	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	98.8	93.9	108	111	-	-	-	-	-
As (total)	µg/L	35.5 -	35.9 -	21.5 -	0.7 -	0.8 -	40.3 -	40.1 -	21.2 -	0.5 -	0.7 -	45.2 -	47.2 -	38.7 -	1.1 -	35.7 -	33.6 -	19.8 -	0.7 -	0.9 -
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	41.8	33.7	26.7	1.0	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	3.3	13.6	12.0	<0.1	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	35.7	25.5	0.5	0.6	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	6.2	8.2	26.2	0.3	-	-	-	-	-
Fe (total)	µg/L	1,027 -	1,081 -	<25 -	<25 -	<25 -	1,311 -	1,235 -	<25 -	<25 -	<25 -	1,057 -	1,019 -	<25 -	<25 -	1,063 -	983 -	<25 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	784	<25	<25	<25	-	-	-	-	-
Mn (total)	µg/L	21.0 -	24.5 -	29.7 -	31.2 -	32.9 -	25.1 -	25.7 -	28.5 -	30.7 -	32.0 -	20.3 -	21.8 -	25.1 -	29.4 -	20.3 -	20.3 -	21.9 -	24.6 -	26.4 -
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	20.7	20.3	22.0	28.7	-	-	-	-	-

(a) Operator turned off potassium permanganate pump after sampling event on 05/09/06.

IN = Influent, AC = after gravity filtration; TA = after tank A; TB = after tank B; TT = after combined effluent
NA = not available.

Table B-1. Analytical Results from Long-Term Sampling at Stewart, MN (Continued)

Sampling Date		06/06/06					06/13/06					06/20/06[(a)]				06/27/06				
Sampling Location Parameter	Unit	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB	IN	AC	AF	TT	IN	AC	AF	TA	TB
Bed Volume (10^3)	BV	-	-	-	6.8	6.6	-	-	-	7.2	7.0	-	-	-	7.5	-	-	-	8.0	7.8
Alkalinity (as $CaCO_3$)	mg/L	422 -	435 -	431 -	435 -	422 -	429 -	416 -	433 -	454 -	441 -	454 -	416 -	425 -	421 -	421 -	417 -	417 -	417 -	417 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	1.8	1.6	1.2	1.2	1.6	1.3	1.5	1.0	1.1
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	0.6	0.5	0.6	0.6	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	<1	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	0.3	0.5	<0.05	<0.05	0.1	0.2	0.2
Total P (as P)	µg/L	344 -	264 -	122 -	13.4 -	18.1 -	344 -	338 -	125 -	<10 -	14.7 -	318 -	312 -	123 -	14.9 -	289 -	288 -	115 -	14.2 -	17.3 -
Silica (as SiO_2)	mg/L	25.7 -	25.5 -	25.4 -	26.1 -	26.1 -	27.0 -	26.8 -	26.9 -	27.1 -	27.0 -	28.3 -	26.1 -	26.6 -	27.0 -	26.8 -	26.1 -	26.2 -	26.7 -	26.5 -
Turbidity	NTU	15.0 -	9.9 -	0.7 -	1.2 -	1.1 -	6.2 -	8.5 -	0.6 -	0.5 -	1.0 -	7.6 -	8.5 -	0.9 -	0.9 -	4.6 -	8.8 -	0.7 -	0.6 -	0.8 -
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	NA[(b)]	NA[(b)]	NA[(b)]	NA[(b)]	-	-	-	-	-
pH	S.U.	8.0	8.2	8.2	8.2	8.2	8.0	8.3	8.1	8.1	8.1	7.9	8.3	8.3	8.1	8.0	8.3	8.2	8.2	8.2
Temperature	°C	10.9	12.1	11.4	11.3	11.2	11.4	10.6	11.2	11.6	12.6	11.2	11.0	11.2	11.4	10.1	10.4	11.0	11.6	11.5
DO	mg/L	1.9	3.8	4.2	3.1	3.1	0.7	5.6	2.1	2.5	3.0	1.1	4.3	2.4	2.7	0.7	4.7	1.7	2.7	2.6
ORP	mV	316	222	203	137	139	337	319	269	273	259	378	256	190	195	404	209	154	156	154
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	237	236	235	240	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	119	118	118	120	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	117	118	117	119	-	-	-	-	-
As (total)	µg/L	42.2 -	37.4 -	28.6 -	1.1 -	1.5 -	51.1 -	50.3 -	30.4 -	1.1 -	1.9 -	50.9 -	45.5 -	29.0 -	1.4 -	40.6 -	39.2 -	27.9 -	1.7 -	1.7 -
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	44.6	37.3	25.8	1.2	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	6.3	8.2	3.2	0.2	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	40.7	27.3	1.3	0.4	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	3.9	10.0	24.5	0.9	-	-	-	-	-
Fe (total)	µg/L	1,491 -	1,037 -	27 -	<25 -	<25 -	1,104 -	1,111 -	<25 -	<25 -	<25 -	1,351 -	1,276 -	<25 -	<25 -	1,090 -	1,061 -	<25 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	1,335	68	<25	<25	-	-	-	-	-
Mn (total)	µg/L	23.0 -	21.6 -	27.6 -	27.2 -	30.6 -	23.5 -	24.1 -	26.5 -	28.2 -	29.2 -	25.5 -	25.3 -	25.5 -	28.3 -	23.8 -	24.2 -	26.5 -	29.0 -	30.4 -
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	26.1	25.2	24.7	27.6	-	-	-	-	-

(a) Operator no longer taking on-site oxidant measurements. (b) Sample analysis failed laboratory QA/QC check.

IN = Influent, AC = after gravity filtration; TA = after tank A; TB = after tank B; TT = after combined effluent
NA = not available.

Table B-1. Analytical Results from Long-Term Sampling at Stewart, MN (Continued)

Sampling Date		07/05/06					07/11/06					07/18/06				07/25/06				
Sampling Location / Parameter	Unit	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB	IN	AC	AF	TT	IN	AC	AF	TA[b]	TB[b]
Bed Volume (10^3)	BV	-	-	-	8.6	8.4	-	-	-	9.2	8.9	-	-	-	9.6	-	-	-	10.3	10.1
Alkalinity (as $CaCO_3$)	mg/L	431	419	419	410	406	427	423	423	419	423	439	447	439	416	421	421	425	421	417
		-	-	-	-	-	419	419	419	423	419	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	1.2	1.2	0.9	0.7	0.9	NA	NA	NA	NA	NA	1.6	1.9	1.3	1.2	1.7	1.9	1.4	0.6	0.4
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	0.5	0.5	0.5	0.5	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	<1	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	0.4	0.5	0.6	NA	NA	NA	NA	NA	<0.05	<0.05	0.2	0.4	<0.05	<0.05	<0.05	0.7	1.6
Total P (as P)	µg/L	288	288	101	<10	15.8	263	284	107	22.4	29.3	350	307	124	19.9	344	344	126	246	336
		-	-	-	-	-	291	288	115	26.2	22.9	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	24.9	24.4	25.5	25.2	24.3	25.0	24.6	24.6	25.8	25.5	25.0	24.7	25.0	24.8	25.0	25.7	24.9	25.8	25.6
		-	-	-	-	-	25.3	24.1	25.8	25.2	25.4	-	-	-	-	-	-	-	-	-
Turbidity	NTU	5.3	8.4	1.1	0.8	0.6	4.2	8.6	0.5	0.5	0.3	6.9	10.0	1.0	0.4	8.0	12.0	1.0	2.2	3.2
		-	-	-	-	-	5.5	8.6	0.5	0.6	0.5	-	-	-	-	-	-	-	-	-
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	6.4	6.6	6.5	6.5	-	-	-	-	-
pH	S.U.	8.1	8.2	8.2	8.2	8.2	8.0	8.3	8.2	8.1	8.1	8.0	8.2	8.2	8.2	8.0	8.3	8.2	8.2[a]	8.2
Temperature	°C	11.0	10.8	11.0	11.1	11.7	10.9	11.0	11.6	12.1	12.1	10.8	11.5	11.0	10.8	10.2	10.8	10.6	11.7[a]	11.5
DO	mg/L	1.7	5.0	3.8	2.6	2.9	1.0	7.2	3.2	3.3	3.8	1.6	5.2	2.7	2.5	0.5	5.0	1.9	6.2[a]	5.7
ORP	mV	311	170	166	140	134	163	172	236	229	179	343	288	261	264	371	267	156	137[a]	175
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	210	195	224	206	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	116	96.6	113	104	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	94.3	98.0	110	102	-	-	-	-	-
As (total)	µg/L	46.1	45.5	26.5	2.7	2.1	36.7	38.2	26.2	2.1	2.6	43.4	43.0	38.4	2.3	56.4	56.9	32.9	7.4	9.2
		-	-	-	-	-	38.7	39.1	28.7	2.1	2.1	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	39.4	33.9	26.1	3.0	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	4.0	9.1	12.3	<0.1	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	32.3	25.6	0.6	0.5	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	7.0	8.3	25.6	2.5	-	-	-	-	-
Fe (total)	µg/L	1,321	1,305	<25	<25	<25	993	1,056	<25	<25	<25	1,197	1,230	<25	<25	1,312	1,309	<25	337	524
		-	-	-	-	-	1,075	1,076	<25	<25	<25	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	852	<25	<25	<25	-	-	-	-	-
Mn (total)	µg/L	25.8	26.1	26.1	27.7	27.5	20.9	21.5	23.1	25.1	26.0	23.2	24.7	23.6	26.4	23.9	25.0	26.1	26.9	27.5
		-	-	-	-	-	21.9	22.5	24.5	25.2	23.0	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	23.4	24.3	23.5	26.7	-	-	-	-	-

(a) Water quality measurements taken at sampling location TT.

(b) 07/25/06 TA and TB samples rerun with similar results for As, Fe, and Mn

IN = Influent, AC = after gravity filtration; TA = after tank A; TB = after tank B; TT = after combined effluent
NA = not available.

Table B-1. Analytical Results from Long-Term Sampling at Stewart, MN (Continued)

Sampling Date		08/01/06					08/07/06					08/15/06					08/21/06			
Sampling Location Parameter	Unit	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB	IN	AC	AF	TT
Bed Volume (10^3)	BV	-	-	-	11.0	10.8	-	-	-	11.4	11.2	-	-	-	11.8	11.6	-	-	-	12.1
Alkalinity (as $CaCO_3$)	mg/L	416 -	416 -	412 -	407 -	412 -	428 -	424 -	424 -	416 -	416 -	421 -	434 -	442 -	413 -	417 -	422 -	457 -	403 -	424 -
Ammonia (as N)	mg/L	1.9	1.6	1.2	1.0	1.0	1.9	1.6	1.7	1.1	1.2	1.4	1.7	1.7	1.0	1.2	1.8	1.8	1.2	1.0
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	0.4	0.4	0.4
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	<1
Nitrate (as N)	mg/L	<0.05	<0.05	0.4	1.7[(a)]	0.3	<0.05	<0.05	0.1	0.5	0.3	<0.05	<0.05	0.2	0.6	0.5	<0.05	<0.05	0.4	0.5
Total P (as P)	µg/L	322 -	293 -	99.8 -	20.7 -	23.9 -	327 -	315 -	110 -	12.1 -	17.4 -	312 -	313 -	106 -	12.5 -	18.7 -	302 -	298 -	126 -	29.1 -
Silica (as SiO_2)	mg/L	27.8 -	28.2 -	28.1 -	28.3 -	28.6 -	24.2 -	23.9 -	23.9 -	24 -	24.2 -	24.8 -	24.9 -	24.8 -	24.1 -	24.9 -	24.4 -	24.9 -	23.3 -	24.4 -
Turbidity	NTU	5.3 -	7.5 -	0.4 -	0.4 -	0.3 -	5.5 -	9.0 -	0.4 -	0.2 -	0.2 -	6.7 -	8.7 -	0.3 -	0.4 -	0.3 -	7.8 -	8.5 -	8.3 -	1.2 -
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.6	6.6	3.8[(b)]	3.1[(b)]
pH	S.U.	8.1	8.3	8.2	8.2	8.2	8.0	8.3	8.2	8.2	8.2	8.1	8.4	8.2	8.2	8.2	8.1	8.3	8.2	8.2
Temperature	°C	10.7	12.0	11.9	11.5	11.7	11.4	11.3	11.7	12.3	12.2	11.0	10.3	10.9	11.3	11.4	10.4	10.7	11.5	12.2
DO	mg/L	0.6	4.4	3.1	2.1	2.2	1.1	4.0	1.6	1.5	2.0	1.4	4.4	1.8	2.3	2.1	0.8	4.9	2.1	2.4
ORP	mV	111	95.9	108	88.7	83.9	56.1	118	103	94.5	99.7	130	64.5	59.9	65.8	73.7	268	191	113	89.6
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	226	224	219	219
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	123	122	118	115
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	103	102	101	105
As (total)	µg/L	52.3 -	44.1 -	27.3 -	2.8 -	3.3 -	56.0 -	51.1 -	36.1 -	3.0 -	3.4 -	38.0 -	38.5 -	27.9 -	2.0 -	2.4 -	54.0 -	53.1 -	36.1 -	2.8 -
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	46.2	40.5	29.2	2.5
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.8	12.7	6.8	0.4
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	44.0	30.7	0.7	0.7
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.2	9.7	28.6	1.8
Fe (total)	µg/L	1,121 -	1,070 -	<25 -	<25 -	<25 -	1,277 -	1,224 -	<25 -	<25 -	<25 -	1,196 -	1,157 -	<25 -	<25 -	<25 -	1,310 -	1,292 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,325	<25	<25	<25
Mn (total)	µg/L	22.3 -	22.9 -	24.9 -	25.2 -	26.2 -	24.3 -	23.8 -	24.1 -	24.8 -	25.4 -	22.3 -	22.5 -	24.4 -	22.9 -	24.3 -	24.5 -	24.8 -	23.8 -	25.9 -
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24.0	23.9	24.2	25.9

(a) 08/01/06 TA sample was rerun with similar result for nitrate.

(b) Low effluent TOC levels. Results confirmed with laboratory.

IN = Influent, AC = after gravity filtration; TA = after tank A; TB = after tank B; TT = after combined effluent
NA = not available.

Table B-1. Analytical Results from Long-Term Sampling at Stewart, MN (Continued)

Sampling Date		09/05/06					09/12/06					09/19/06				09/26/06				
Sampling Location Parameter	Unit	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB	IN	AC	AF	TT	IN	AC	AF	TA	TB
Bed Volume (10^3)	BV	-	-	-	13.0	12.9	-	-	-	13.3	13.2	-	-	-	13.7	-	-	-	14.1	14.0
Alkalinity (as $CaCO_3$)	mg/L	474 -	476 -	456 -	474 -	460 -	436 -	438 -	441 -	438 -	443 -	434 -	439 -	453 -	448 -	443 -	440 -	454 -	440 -	433 -
Ammonia (as N)	mg/L	1.9	1.8	1.5	1.3	1.3	1.8	1.6	1.7	1.2	1.3	1.6	1.5	1.3	1.1	1.6	1.7	1.3	0.9	0.8
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	0.3	0.3	0.2	0.2	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	<1	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	0.2	0.4	0.4	<0.05	<0.05	0.1	0.2	0.3	<0.05	<0.05	0.2	0.3	<0.05	<0.05	0.3	0.6	0.6
Total P (as P)	µg/L	299 -	295 -	115 -	26.3 -	30.2 -	299 -	288 -	107 -	25.1 -	27.1 -	285 -	292 -	105 -	22.3 -	270 -	264 -	102 -	35.1 -	42.8 -
Silica (as SiO_2)	mg/L	23.8 -	24.0 -	23.6 -	24.2 -	23.7 -	24.3 -	24.7 -	24.2 -	24.5 -	24.2 -	25.9 -	25.8 -	27 -	26.7 -	24.4 -	24.2 -	24.7 -	24.2 -	23.9 -
Turbidity	NTU	5.8 -	11.0 -	0.8 -	0.6 -	0.9 -	5.2 -	9.1 -	0.5 -	0.5 -	0.4 -	6.6 -	7.1 -	0.3 -	0.4 -	6.3 -	7.4 -	0.3 -	0.5 -	0.2 -
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	6.7	7.0	7.0	6.6	-	-	-	-	-
pH	S.U.	8.1	8.3	8.2	8.2	8.2	7.7	8.4	8.2	8.2	8.2	8.0	8.4	8.2	8.2	7.9	8.1	8.2	8.2	8.2
Temperature	°C	11.3	11.3	11.3	11.7	12.4	10.1	10.2	10.8	11.2	11.7	12.0	12.8	11.8	11.8	10.8	10.5	10.6	10.8	11.0
DO	mg/L	1.6	4.0	2.6	2.3	2.4	0.7	5.9	2.0	1.9	1.7	1.3	4.5	2.5	2.2	1.2	4.5	1.7	1.9	2.2
ORP	mV	230	123	77.2	76.1	83.7	337	193	199	104	103	-8.6	78.5	89.3	80	126	121	101	84.1	92.2
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	204	210	218	215	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	101	104	107	106	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	103	106	111	109	-	-	-	-	-
As (total)	µg/L	43.0 -	42.6 -	26.4 -	2.8 -	3.2 -	47.2 -	46.1 -	27.9 -	3.4 -	3.6 -	39.7 -	41.0 -	26.1 -	2.9 -	31.4 -	29.9 -	20.5 -	2.8 -	3.4 -
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	35.6	33.5	26.1	2.8	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	4.1	7.5	<0.1	<0.1	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	28.4	25.0	1.8	0.1	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	7.2	8.5	24.4	2.7	-	-	-	-	-
Fe (total)	µg/L	1,187 -	1,162 -	<25 -	<25 -	<25 -	1,151 -	1,091 -	<25 -	<25 -	<25 -	1,030 -	1,045 -	<25 -	<25 -	1,108 -	1,080 -	<25 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	925	<25	<25	<25	-	-	-	-	-
Mn (total)	µg/L	24.9 -	24.7 -	23.8 -	25.3 -	25.6 -	22.7 -	22.2 -	23.6 -	24.6 -	25.5 -	19.6 -	20.3 -	23.2 -	22.9 -	21.5 -	21.8 -	24.0 -	25.8 -	26.1 -
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	20.3	20.3	23.6	23.5	-	-	-	-	-

IN = Influent, AC = after gravity filtration; TA = after tank A; TB = after tank B; TT = after combined effluent
NA = not available.

Table B-1. Analytical Results from Long-Term Sampling at Stewart, MN (Continued)

Sampling Date		10/03/06					10/10/06					10/17/06				10/24/06				
Sampling Location / Parameter	Unit	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB	IN	AC	AF	TT	IN	AC	AF	TA	TB
Bed Volume (10^3)	BV	-	-	-	14.4	14.4	-	-	-	14.8	14.7	-	-	-	15.1	-	-	-	15.5	15.4
Alkalinity (as $CaCO_3$)	mg/L	438	452	449	429	445	466	448	459	433	452	455	457	446	469	442	470	465	446	470
		-	-	-	-	-	442	450	448	442	463	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	1.7	1.9	1.5	1.1	1.0	NA(a)	NA(a)	NA(a)	NA(a)	NA(a)	1.9	1.9	1.6	2.3(c)	1.5	1.5	1.3	1.1	1.1
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	0.5	0.6	0.5	0.5	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	<1	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	0.3	0.7	0.6	NA(a)	NA(a)	NA(a)	NA(a)	NA(a)	<0.05	<0.05	1.5(b)	1.4(b)	<0.05	<0.05	0.2	0.5	0.4
Total P (as P)	µg/L	322	326	124	43.2	49.1	325	329	117	34.6	42.2	347	341	131	52.5	331	321	123	43.7	49.4
		-	-	-	-	-	339	340	122	39.7	43.1	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	24.3	25.0	24.5	24.6	24.3	25.3	24.4	25.3	24.8	25.2	24.3	25.0	24.4	25.1	23.1	25.2	25.1	25.0	24.8
		-	-	-	-	-	25.9	24.7	25.0	25.9	24.1	-	-	-	-	-	-	-	-	-
Turbidity	NTU	4.4	8.9	0.3	0.5	0.6	7.1	9.2	0.7	0.4	0.5	7.1	11.0	1.2	1.1	7.5	9.5	0.9	1.5	1.1
		-	-	-	-	-	6.9	9.8	0.9	0.6	1.0	-	-	-	-	-	-	-	-	-
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	6.7	6.7	6.9	6.7	-	-	-	-	-
pH	S.U.	8.0	8.4	8.2	8.3	8.3	7.8	8.3	8.2	8.2	8.2	8.0	8.4	8.2	8.3	8.1	8.3	8.3	8.2	8.2
Temperature	°C	10.8	10.7	11.0	11.2	11.3	11.0	10.5	10.8	11.2	11.5	11.9	12.1	13.4	13.5	12.9	11.6	11.6	12.2	12.6
DO	mg/L	1.2	4.6	1.8	3.0	2.4	1.9	4.9	1.9	1.9	1.9	2.0	5.5	3.6	4.0	1.5	4.8	2.7	2.1	1.9
ORP	mV	303	39.7	36.6	24.9	23.5	300	258	239	168	151	303	230	161	154	293	312	273	265	142
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	206	211	211	205	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	88.2	94.8	97.2	95.2	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	118	116	114	110	-	-	-	-	-
As (total)	µg/L	51.6	52.3	31.0	3.7	4.2	54.9	49.7	29.7	4.4	4.8	53.4	52.6	32.6	5.6	56.2	54.1	37.7	5.4	5.9
		-	-	-	-	-	54.0	50.1	31.2	4.4	4.8	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	39.3	37.8	29.9	4.9	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	14.0	14.8	2.7	0.6	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	27.6	27.1	1.3	0.9	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	11.7	10.8	28.6	4.0	-	-	-	-	-
Fe (total)	µg/L	1,132	1,126	<25	<25	<25	1,273	1,168	<25	<25	<25	1,021	1,045	<25	<25	1,110	1,105	<25	<25	<25
		-	-	-	-	-	1,262	1,120	29	<25	<25	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	478	<25	<25	<25	-	-	-	-	-
Mn (total)	µg/L	23.4	23.6	23.1	23.5	24.3	25.7	24.5	26.3	25.6	26.6	23.3	23.5	23.7	23.8	21.9	22.6	24.8	23.9	24.6
		-	-	-	-	-	25.6	24.2	26.2	27.8	26.9	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	23.0	23.2	24.5	24.5	-	-	-	-	-

(a) Sample bottles not included in cooler per COC.

(b) Samples showed non-detect (<0.05 mg/L) during first analyses. Rerun values are reported. (c) Not able to rerun sample due to discard.

IN = Influent, AC = after gravity filtration; TA = after tank A; TB = after tank B; TT = after combined effluent
NA = not available.

Table B-1. Analytical Results from Long-Term Sampling at Stewart, MN (Continued)

Sampling Date		10/31/06					11/07/06					11/14/06					11/28/06				
Sampling Location Parameter	Unit	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB
Bed Volume (10^3)	BV	-	-	-	15.8	15.8	-	-	-	16.1	16.1	-	-	-	16.5	16.5	-	-	-	17.1	17.2
Alkalinity (as $CaCO_3$)	mg/L	463 -	456 -	460 -	469 -	465 -	457 -	447 -	462 -	470 -	466 -	445 -	443 -	445 -	433 -	435 -	474 -	474 -	476 -	442 -	436 -
Ammonia (as N)	mg/L	1.5	1.5	1.0	1.0	1.0	1.6	1.5	1.4	1.2	1.2	1.6	1.7	1.5	1.1	1.2	1.6	1.7	1.2	1.2	1.1
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	0.4	0.4	0.4	<0.05	<0.05	0.2	0.2	0.3	<0.05	<0.05	0.2	0.4	0.4	<0.05	<0.05	0.3	0.4	0.4
Total P (as P)	µg/L	349 -	338 -	131 -	51.8 -	61.2 -	316 -	301 -	120 -	49.0 -	58.9 -	333 -	304 -	118 -	50.4 -	56.7 -	275 -	256 -	99.4 -	38.4 -	49.2 -
Silica (as SiO_2)	mg/L	23.5 -	24.3 -	24.2 -	24.5 -	25.1 -	23.8 -	24.9 -	24.5 -	25.3 -	24.1 -	24.8 -	24.7 -	24.8 -	24.7 -	24.4 -	24.2 -	24.2 -	23.8 -	24.9 -	24.5 -
Turbidity	NTU	6.5 -	9.0 -	1.0 -	1.1 -	2.3 -	11.0 -	9.3 -	1.1 -	1.1 -	1.1 -	5.7 -	10.0 -	1.0 -	1.3 -	1.0 -	6.7 -	9.0 -	0.7 -	1.2 -	1.1 -
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	8.1	8.6	8.2	8.3	8.3	8.0	8.3	8.3	8.2	8.3	7.9	8.3	8.3	8.3	8.3	7.6	8.1	7.9	8.0	8.0
Temperature	°C	11.2	10.6	12.4	12.4	12.7	12.1	12.2	13.0	13.6	14.3	13.8	13.8	13.9	14.1	14.6	11.1	13.0	13.1	12.2	12.3
DO	mg/L	1.7	5.1	2.0	3.5	3.1	0.7	4.5	3.1	2.0	3.0	1.3	5.0	4.0	3.3	3.4	2.0	4.7	1.9	1.8	2.0
ORP	mV	350	146	161	159	145	248	242	90.2	86.8	96.9	114	121	109	90.6	73.1	230	226	216	216	193
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L	49.1 -	46.2 -	28.9 -	4.3 -	5.0 -	52.8 -	50.3 -	37.4 -	5.0 -	6.1 -	53.5 -	50.4 -	33.1 -	5.6 -	5.8 -	41.6 -	38.5 -	25.7 -	4.0 -	4.9 -
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	1,227 -	1,189 -	<25 -	<25 -	<25 -	1,179 -	1,120 -	<25 -	<25 -	<25 -	1,255 -	1,162 -	<25 -	<25 -	<25 -	1,127 -	1,088 -	<25 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	23.0 -	22.6 -	28.1 -	24.5 -	25.3 -	23.7 -	22.9 -	25.4 -	25.1 -	25.4 -	23.6 -	23.0 -	22.5 -	22.9 -	23.4 -	21.4 -	21.5 -	29.8 -	23.0 -	24.5 -
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

IN = Influent, AC = after gravity filtration; TA = after tank A; TB = after tank B; TT = after combined effluent
NA = not available.

Table B-1. Analytical Results from Long-Term Sampling at Stewart, MN (Continued)

Sampling Date		12/05/06				12/12/06					12/18/06					01/03/07				02/27/07			
Sampling Location Parameter	Unit	IN	AC	AF	TT	IN	AC	AF	TA	TB	IN	AC	AF	TA	TB	IN	AC	AF	TT	IN	AC	AF	TT
Bed Volume (10^3)	BV	-	-	-	17.5	-	-	-	17.7	17.8	-	-	-	18.0	18.1	-	-	-	18.7	-	-	-	21.3
Alkalinity (as $CaCO_3$)	mg/L	449 -	455 -	447 -	439 -	457 -	448 -	442 -	446 -	432 -	469 -	461 -	457 -	455 -	455 -	485 -	487 -	463 -	469 -	445 -	445 -	447 -	450 -
Ammonia (as N)	mg/L	NA[(a)]	NA[(a)]	NA[(a)]	NA[(a)]	1.7	1.9	1.6	1.4	1.3	1.6	1.8	1.6	1.2	1.2	1.7	1.7	1.1	1.0	1.8	1.7	1.7	1.2
Fluoride	mg/L	1.0	0.4	0.5	0.8	-	-	-	-	-	-	-	-	-	-	0.5	0.4	0.4	0.5	0.6	0.5	0.6	0.6
Sulfate	mg/L	<1	<1	<1	<1	-	-	-	-	-	-	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	<1
Nitrate (as N)	mg/L	<0.05	<0.05	0.7	0.7	<0.05	0.1	0.2	0.3	0.3	<0.05	<0.05	0.1	0.4	0.4	<0.05	<0.05	0.5	0.6	<0.05	<0.05	0.1	0.3
Total P (as P)	µg/L	340 -	281 -	107 -	48.0 -	252 -	247 -	97.7 -	54.1 -	43.9 -	280 -	270 -	91.8 -	26.6 -	33.3 -	306 -	290 -	119 -	64.0 -	337 -	307 -	158 -	111 -
Silica (as SiO_2)	mg/L	24.0 -	23.6 -	23.4 -	23.7 -	24.4 -	24.9 -	24.0 -	24.2 -	24.1 -	26.1 -	25.4 -	26.0 -	24.6 -	25.3 -	25.1 -	25.2 -	24.8 -	24.8 -	24.6 -	24.6 -	24.5 -	25.1 -
Turbidity	NTU	5.8 -	8.2 -	0.8 -	1.3 -	6.5 -	9.5 -	0.3 -	0.3 -	0.5 -	5.7 -	10.0 -	0.7 -	0.6 -	1.0 -	7.4 -	8.1 -	0.9 -	0.7 -	4.8 -	8.3 -	1.0 -	0.7 -
TOC	mg/L	6.4	6.3	6.3	6.4	-	-	-	-	-	-	-	-	-	-	6.3	6.7	6.3	6.5	6.5	6.6	6.6	6.7
pH	S.U.	7.9	8.2	7.9	8.0	7.9	8.2	8.0	8.0	8.0	7.8	8.2	8.0	7.9	8.0	7.7	8.1	7.9	7.9	7.6	7.8	7.8	7.7
Temperature	°C	10.9	10.3	11.2	11.4	13.4	12.9	13.3	13.7	14.3	12.6	12.6	12.9	13.9	14.1	12.1	12.1	11.5	12.3	11.5	11.5	10.9	12.2
DO	mg/L	2.0	5.0	2.7	2.3	0.8	5.4	2.4	2.3	2.8	1.1	4.5	3.2	2.1	2.6	2.2	5.5	3.6	6.8	1.0	4.3	3.2	2.4
ORP	mV	295	252	235	201	346	93.4	89.1	78.6	84.8	215	171	133	105	114	361	360	299	297	389	186	169	143
Total Hardness (as $CaCO_3$)	mg/L	220	214	213	215	-	-	-	-	-	-	-	-	-	-	226	226	213	227	238	235	242	247
Ca Hardness (as $CaCO_3$)	mg/L	108	118	121	120	-	-	-	-	-	-	-	-	-	-	122	120	107	118	127	130	134	137
Mg Hardness (as $CaCO_3$)	mg/L	112	95.3	92.7	94.9	-	-	-	-	-	-	-	-	-	-	104	106	106	110	112	105	108	110
As (total)	µg/L	52.9 -	52.2 -	33.3 -	5.7 -	41.1 -	42.1 -	28.3 -	5.9 -	4.9 -	42.6 -	41.2 -	33.5 -	4.6 -	5.2 -	53.5 -	53.1 -	32.8 -	5.8 -	48.6 -	46.4 -	42.7 -	9.8 -
As (soluble)	µg/L	43.3	38.0	28.9	5.3	-	-	-	-	-	-	-	-	-	-	48.9	40.3	30.8	5.6	36.4	34.1	37.4	8.6
As (particulate)	µg/L	9.5	14.3	4.4	0.4	-	-	-	-	-	-	-	-	-	-	4.6	12.8	1.9	0.3	12.2	12.3	5.3	1.2
As (III)	µg/L	36.8	26.9	0.9	0.6	-	-	-	-	-	-	-	-	-	-	43.7	30.8	0.6	0.3	34.7	23.7	6.6	1.1
As (V)	µg/L	6.6	11.1	28.0	4.7	-	-	-	-	-	-	-	-	-	-	5.2	9.5	30.2	5.2	1.6	10.4	30.8	7.5
Fe (total)	µg/L	1,208 -	1,209 -	<25 -	<25 -	1,146 -	1,137 -	<25 -	<25 -	<25 -	1,298 -	1,224 -	<25 -	<25 -	<25 -	1,438 -	1,298 -	<25 -	<25 -	1,427 -	919 -	<25 -	<25 -
Fe (soluble)	µg/L	894	<25	<25	<25	-	-	-	-	-	-	-	-	-	-	1,202	36	<25	<25	829	<25	<25	<25
Mn (total)	µg/L	23.2 -	23.9 -	25.0 -	24.2 -	22.4 -	22.4 -	23.0 -	24.4 -	22.8 -	23.8 -	23.2 -	25.1 -	23.8 -	24.1 -	24.3 -	24.2 -	22.5 -	24.7 -	22.7 -	23.5 -	25.4 -	25.5 -
Mn (soluble)	µg/L	24.3	23.4	26.0	25.8	-	-	-	-	-	-	-	-	-	-	24.9	23.7	23.6	24.2	22.9	23.4	25.5	26.3

(a) Operator did not take ammonia samples on 12/05/06.

IN = Influent, AC = after gravity filtration; TA = after tank A; TB = after tank B; TT = after combined effluent
NA = not available.