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Arsenic Removal from Drinking Water by Adsorptive Media USEPA Demonstration Project at Brown City, MI Six-Month Evaluation Report

by

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Sally Gutierrez, Director
National Risk Management Research Laboratory

ABSTRACT

This report documents the activities performed during and the results obtained from the first six months of the arsenic removal treatment technology demonstration project in Brown City, MI. The objectives of the project are to evaluate the effectiveness of Severn Trent Services (STS) Arsenic Package Unit-300 (APU-300) SORB 33™ media in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 micrograms per liter (µg/L), the reliability of the treatment system, the simplicity of required system operation and maintenance (O&M) and operator's skills, and the cost-effectiveness of the technology. The project also is characterizing water in the distribution system and process residuals produced by the treatment system.

The STS treatment system started up on May 11, 2004, and continued to operate through November 30, 2004 with an average operational time of approximately 4.8 hrs/day or a 20% utilization rate. The design capacity of the treatment system with two APU-300 units in parallel is 640 gallons per minute (gpm). During this time frame, approximately 29,711,000 gallons or 13,096 bed volumes of water were treated. The system continued to operate through the six-month demonstration period with only a few minor repairs and adjustments. The flowrate and pressure data and other operational parameters were within the vendor specifications after a system retrofit that was performed in late April to early May of 2004. The system continues to operate within the vendor equipment specifications.

Arsenic in the source water existed primarily as As(III) (i.e., 79% at 11.2 µg/L), with a small amount also present as As(V) (i.e., 0.8 µg/L) and particulate As (i.e., 2.2 µg/L). Per vendor's recommendations, raw water was fed directly through the adsorption vessels without pre-chlorination to evaluate the capacity of the SORB 33™ media for As(III) adsorption.

Over the six-month period, total arsenic concentrations in raw water ranged from 9.5 to 28.7 µg/L and in treated water from 0.5 to 8.7 µg/L. In early November, as the treatment system throughput was approaching 12,500 bed volumes, a spike up to 8.7 µg/L of total arsenic was measured in the treated water. However, by November 30, 2005, the total arsenic concentrations dropped to 2.4 to 4.1 µg/L in the treated water. The treated water remained below 10 µg/L for approximately 20,000 bed volumes, which will be further discussed in the final evaluation report.

Comparison of the distribution system sampling results before and after the operation of the APU-300 system showed a decrease in arsenic concentrations at each of the sampling locations. Total aresnic levels in the distribution system decreased from 7.2 to 13.3 µg/L before treatment to 3.0 to 6.1 µg/L after treatment. Iron levels decreased to non-detect levels, while manganese levels increased slightly. Lead and copper concentrations did not appear to have been affected by the operation of the system.

Four backwash water samples were collected during the first six months of system operation. With the exception of one event, dissolved arsenic concentrations in the backwash water were significantly lower than the raw water and ranged from 4.9 to 9.9 µg/L, indicating removal of arsenic by the media during backwash. Soluble iron levels were typically lower than the raw water, while manganese concentrations correlated more closely with the influent concentrations.

The capital investment cost of $305,000 includes $218,000 for equipment, $35,500 for site engineering, and $51,500 for installation. Using the system's rated capacity of 640 gpm (921,600 gallons per day [gpd]), the capital cost was $477 per gpm ($0.33 per gpd) and equipment-only cost was $340 per gpm ($0.24 per gpd). These calculations do not include the cost of a building addition to house the treatment system.

O&M costs included only incremental costs associated with the APU-300 system, such as media replacement and disposal, chemical supply, electricity, and labor. Although not incurred during the first six months of system operation, the media replacement cost would represent the majority of the O&M cost and was estimated to be $53,600 for both APU-300 units (e.g., 320 ft^3 of media). This cost was used to estimate the media replacement cost per 1,000 gallons of treated water as a function of the projected media run length to the 10 μg/L arsenic breakthrough. O&M costs will be refined once the actual throughput and cost at the time of the media replacement become available.

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ABBREVIATIONS AND ACRONYMS

AA	activated alumina
AAL	American Analytical Laboratories
Al	aluminum
APU	arsenic package unit
As	arsenic
bgs	below ground surface
BV	bed volume(s)
Ca	calcium
Cl	chlorine
CRF	capital recovery factor
Cu	copper
DO	dissolved oxygen
EBCT	empty bed contact time
EDR	electrodialysis reversal
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
FEATS	Field Evaluation and Technical Support
FRP	fiberglass reinforced plastic
GFH	granular ferric hydroxide
gpd	gallons per day
gpm	gallons per minute
HCl	hydrochloric acid
HDPE	high-density polyethylene
HP	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IX	ion exchange
KWh	kilowatt hours
LCR	Lead and Copper Rule
LOU	Letter of Understanding
MCL	maximum contaminant level
MDL	method detection limit
MDEQ	Michigan Department of Environmental Quality
MDWCA	Mutual Domestic Water Consumers Association
Mg	magnesium
Mn	manganese
Mo	molybdenum

Na	sodium
NA	not applicable
NaOCl	sodium hypochlorite
NR	no reading
NTU	nephelometric turbidity units
O&M	operation and maintenance
ORD	Office of Research and Development
ORP	oxidation-reduction potential
PLC	process logic controller
psi	pounds per square inch
psig	pounds per square inch (gage)
POE	point-of-entry
PVC	polyvinyl chloride
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
RDP	relative percent difference
RFQ	Request for Quotation
Sb	antimony
SDWA	Safe Drinking Water Act
SOC	synthetic organic compound
SOW	scope of work
STS	Severn Trent Services
TBD	to be determined
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
TO	Task Order
TOC	total organic carbon
TSS	total suspended solids
V	vanadium
VOC	volatile organic compounds

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1.0 INTRODUCTION

1.1 Background

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

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

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the 17 host sites. EPA received 70 technical proposals for the 17 host sites, with each site receiving from one to six proposals. In April 2003, an independent technical review panel reviewed the proposals and provided its recommendations to EPA on the technologies that it determined were acceptable for the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration project. Using the information provided by the review panel, EPA in cooperation with the host sites and the drinking water programs of the respective states, selected one technical proposal for each site. Severn Trent Services' (STS's) arsenic package unit (APU), using the Bayoxide E33 media developed by Bayer AG, was selected for the Brown City, MI facility. STS has given the E33 media the designation "SORB 33™."

1.2 Treatment Technologies for Arsenic Removal

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

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

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

AM = adsorptive media process; C/F = coagulation/filtration process; IX = ion exchange process; GFH = granular ferric hydroxide, MDWCA = Mutual Domestic Water Consumer's Association; SM = system modification; STMGID = South Truckee Meadows General Improvement District; STS = Severn Trent Services.

(a) Due to system reconfiguration from parallel to series operation, the design flowrate is reduced by 50%.

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

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

1.3 Project Objectives

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

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

This report summarizes the results gathered during the first six months of the STS treatment system operation from May 11, 2004 through November 30, 2004. The types of data collected include system operational data, water quality data (both across the treatment train and in the distribution system), residuals characterization data, and capital and preliminary O&M cost data.

2.0 CONCLUSIONS

Based on the information collected during the first six months of system operation, the following conclusions were made relating to the overall objectives of the treatment technology demonstration study.

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

- By the end of the first six months of system operation, the treatment system treated approximately 29,711,000 gallons of water, which was equivalent to 13,096 bed volumes. During this time period, the As(III) concentration in the treated water increased from 1.9 mg/L on May 25, 2004 to 5.3 µg/L on November 16, 2004. The arsenic concentrations in the treated water remained below 10 µg/L after approximately 20,000 bed volumes of total throughput, which will be further discussed in the final evaluation report. Switching from post- to prechlorination would then be implemented to determine the effect of chlorination on arsenic adsorption.

- Total iron concentrations varied from 101 to 228 µg/L at the influent, and the majority of the iron was present in the soluble form. After 13,096 bed volumes of treated water, the total iron concentrations in the treated water have been well below the detection limit of <25 µg/L.

- Total manganese concentrations in the treated water were reduced initially, but reached 100% breakthrough after 6,000 bed volumes of water treated. After 6,000 bed volumes, the total manganese levels were slightly higher in the treated water than the influent raw water.

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

- Operational issues were experienced during system shakedown related to higher than expected pressure drops across the treatment system. The system was retro-fitted by replacing the 3-inch-diameter pipe with 4-inch-diameter pipe; removing the diaphragm valves, restrictive orifices, and valve controllers; and installing a nested system of fully ported actuated butterfly valves. The flowrate and pressure data and other operational parameters were within the vendor specifications after the system retrofit.

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

- Under normal operating conditions, the skill requirements to operate the system were minimal, with a typical daily demand on the operator of 15 to 20 minutes. Normal operation of the system did not appear to require additional skills beyond those necessary to operate the existing water supply equipment.

Process residuals produced by the technology:

- Residuals produced by the operation of the treatment system included spent media and backwash water. The media was not exhausted during the first six months of system operation; therefore, the only residual produced was backwash wastewater.

- Soluble arsenic concentrations in the backwash water ranged from 4.9 to 9.9 μg/L. In most cases, arsenic and iron concentrations were lower than those in the raw water (backwash was performed using raw water from the supply wells), indicating some removal of these metals by the media during backwash.

Cost-effectiveness of the technology:

- Using the system's rated capacity of 640 gpm (921,600 gpd), the capital cost was $477 per gpm ($0.33 per gpd) and equipment-only cost was $340 per gpm ($0.24 per gpd). These calculations do not include the cost of a building addition to house the treatment system.

- The estimated media changeout cost is $53,600 for both APU-300 units. Media changeout did not occur during the first six months of operation. O&M costs will be refined once the actual throughput and cost at the time of the media replacement become available.

3.0 MATERIALS AND METHODS

3.1 General Project Approach

Following the pre-demonstration activities summarized in Table 3-1, the performance evaluation study of the STS treatment system began on May 11, 2004. Table 3-2 summarizes the types of data collected and/or considered as part of the technology evaluation process. The overall performance of the system was determined based on its ability to consistently remove arsenic to the target MCL of 10 μg/L. This was monitored by collecting biweekly water samples across the treatment train. The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

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

The cost-effectiveness of the system was evaluated based on the capital cost per gpm of design capacity and the O&M cost per 1,000 gallons of water treated. This required tracking capital costs such as equipment, engineering, and installation costs, as well as O&M costs for media replacement and disposal, chemical supply, electrical power use, and labor hours. The capital costs have been reported in an EPA report (Chen et al., 2004) posted on an EPA Web site (http://www.epa.gov/ORD/NRMRL/arsenic/resource.htm). Data on O&M costs were limited to chemicals, electricity, and labor because media replacement did not take place during the six months of system operation.

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

Activity	Date
Introductory Meeting Held	07/24/03
Request for Quotation Issued to Vendor	07/28/03
Vendor Quotation Submitted to Battelle	08/26/03
Purchase Order Completed and Signed	09/24/03
Letter of Understanding Issued	08/15/03
Letter Report Issued	10/20/03
Engineering Package Submitted to Michigan Department of Environmental Quality (MDEQ)	11/26/03
Building Construction Initiated	12/01/04
Permit Issued by MDEQ	02/11/04
Final Study Plan Issued	02/12/04
Building Construction Completed	02/12/04
APU-300 Unit Shipped by STS	02/18/04
APU-300 Unit Delivered to Brown City	02/23/04
System Installation Completed (Before Media Loading)	03/18/04
Initial Hydraulic System Shakedown Performed	03/19/04
System Retrofit Completed	05/05/04
Media Loading and Initial Backwash Events Performed	05/07/04
Final Hydraulic System Shakedown Performed	05/07/04
Performance Evaluation Begun	05/11/04

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

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

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

3.2 System O&M and Cost Data Collection

The plant operator performed daily, weekly, and monthly system O&M and data collection following the instructions provided by STS and Battelle. On a daily basis, the plant operator recorded system operational data, such as pressure, flowrate, totalizer, and hour meter readings on the Daily Field Log Sheet and conducted visual inspections to ensure normal system operations. In the event of problems, the plant operator contacted the Battelle Study Lead, who then determined if STS should be contacted for troubleshooting. The plant operator recorded all relevant information on the Repair and Maintenance Log Sheet. On a biweekly basis, the plant operator measured temperature, pH, dissolved oxygen (DO), and oxidation-reduction potential (ORP) across the treatment train and recorded the data on a Weekly Water Quality Parameters Log Sheet. During the six-month study period, the system was backwashed manually to capture the backwash samples on a 45 day time interval.

Capital costs for the STS system consisted of costs for equipment, site engineering, and system installation. The O&M costs consisted primarily of costs for the media replacement and spent media disposal, electricity, chemicals, and labor. The electricity use was tracked before and after plant installation through a comparison of utility bills. Labor hours for various activities, such as the routine system O&M, system troubleshooting and repair, and demonstration-related work, were tracked using an Operator Labor Hour Record. The routine O&M included activities such as filling field logs and performing system inspections as recommended by STS. The demonstration-related work included activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead. The demonstration-related activities were recorded, but not used for the cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate the performance of the system, samples were collected from the source, treatment plant, distribution system, and adsorptive vessel backwash discharge. Table 3-3 provides the sampling schedules and analytes measured during each sampling event. Specific sampling requirements for analytical

Table 3-3. Sample Collection Schedule and Analyses

Sample Type	Sample Locations[(a)]	No. of Samples	Frequency	Analytes	Date(s) Samples Collected
Source Water	At wellhead (IN)	1	Once during the initial site visit	As(total), particulate and soluble As, As(III), As(V), Fe (total and soluble), Mn (total and soluble), Al (total and soluble), Na, Ca, Mg, V, Mo, Sb, Cl, F, SO_4, SiO_2, PO_4, TOC, and alkalinity.	07/24/03
Treatment Plant Water	At wellhead (IN), after Tank A (TA), after Tank B (TB), after Tank C (TC), and after Tank D (TD)	5	Monthly (Once every four weeks)	On-site: pH, temperature, DO/ORP. Off-site: As (total), Fe (total), Mn (total), SiO_2, PO_4, turbidity, and alkalinity.	05/18/04, 06/08/04, 07/06/04, 08/03/04, 08/31/04, 09/28/04, 11/02/04, 11/30/04
	At wellhead (IN) and after the combined effluent (TT)	2	Monthly (Once every four weeks)	On-site: pH, temperature, DO/ORP, and Cl_2 (free and total) (except at wellhead). Off-site: As(total), particulate As, As(III), As(V), Fe (total and soluble), Mn (total and soluble), Ca, Mg, NO_3, SO_4, SiO_2, PO_4, turbidity, and alkalinity.	05/25/04, 06/24/04, 07/20/04, 08/17/04, 09/14/04, 10/12/04, 11/16/04
Distribution Water	Three homes	3	Monthly	pH, alkalinity, As, Fe, Mn, Pb, and Cu	Baseline sampling[(b)]: 12/04/03, 12/18/03, 01/08/04. Monthly sampling: 06/15/04, 07/13/04, 08/10/04, 09/08/04, 10/05/04, 11/02/04.
Backwash Water	Backwash discharge line from Tanks A, B, C, and D	4	Once every 45 days	TDS, turbidity, pH, As (soluble), Fe (soluble), and Mn (soluble)	06/15/04, 07/28/04, 09/09/04, 10/22/04
Residual Sludge	At backwash discharge point	2-3	TBD	TCLP Metals As(Total)	TBD

(a) The abbreviation in each parenthesis corresponds to the sample location in Figure 4-5.
(b) Three baseline sampling events were performed before the system became operational.
TBD = to be determined.

methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2003).

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

3.3.2 Treatment Plant Water Sample Collection. During the system performance evaluation study, water samples were collected across the treatment train by the plant operator. Samples were collected biweekly on a four-week cycle. For the first biweekly event, treatment plant samples were collected at five locations (i.e., at the wellhead [IN], after Tank [TA], after Tank B [TB], after Tank C [TC], and after Tank D [TD]) and analyzed for the analytes listed in Table 3-3. For the second biweekly event, treatment plant samples were collected for arsenic speciation at two locations (i.e. at the wellhead [IN] and after the combined effluent [TT]) and also analyzed for the analytes listed in Table 3-3. The sampling frequency was reduced from weekly as stated in the Study Plan to biweekly due to the low water demand and the resulting low volume throughput to the system (Battelle, 2004).

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

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

3.3.5 Distribution System Water Sample Collection. Samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically, lead and copper levels. From December 2003 to January 2004, prior to the startup of the treatment system, four baseline distribution system sampling events were conducted at three locations per sampling event within the distribution system. Following the installation of the arsenic adsorption system, distribution system sampling continued on a monthly basis at the same three locations.

Baseline and monthly distribution system samples were collected by the plant operator at three homes that had been included for the Lead and Copper Rule (LCR) sampling. The 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). The first draw sample was collected from a cold-water faucet that had not been used for at least six hours to ensure that stagnant water was sampled. The sampler recorded the date and time of last water use before sampling and the date and time of sample collection for calculation of the stagnation time. The samples were analyzed for the analytes listed in Table 3-3.

3.4 Sampling Logistics

All sampling logistics, including arsenic speciation kit preparation, sample cooler preparation, and sample shipping and handling, were performed by Battelle. Relevant procedures were as follows:

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

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

When appropriate, the sample cooler was packed with bottles for the three distribution system sampling locations and/or the four backwash sampling locations (one for each vessel).

In addition, a packet containing all sampling and shipping-related supplies, such as latex gloves, sampling instructions, chain-of-custody forms, prepaid Federal Express air bills, ice packs, and bubble wrap, also was placed in the cooler. Except for the operator's signature and sampling time, the chain-of-custody forms and prepaid Federal Express air bills had already been completed with the required information. The sample coolers were shipped via Federal Express to the facility approximately one week prior to the scheduled sampling date.

3.4.3 Sample Shipping and Handling. After sample collection, samples for off-site analyses were packed carefully in the original coolers with wet ice and shipped to Battelle. Upon receipt, sample custodians verified that all samples indicated on the chain-of-custody forms were included and intact. Sample IDs were checked against the chain-of-custody forms and the samples were logged into the laboratory sample receipt log. Discrepancies, if noted, were addressed by the field sample custodian (usually the plant operator), and the Battelle Study Lead was notified.

Samples for water quality analyses by Battelle's subcontract laboratories were packed in coolers at Battelle and picked up by a courier from either AAL (Columbus, OH) or TCCI Laboratories (New Lexington, OH). The samples for arsenic speciation analyses were stored at Battelle's ICP-MS Laboratory. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the duration of the required hold time and disposed of properly thereafter.

3.5 Analytical Procedures

The analytical procedures are described in detail in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2003). Field measurements of pH, temperature, and DO/ORP were conducted by the plant operator using a WTW Multi 340i handheld meter, which was calibrated prior to use following the procedures provided in the user's manual. The plant operator collected a water sample in a 400-mL plastic beaker and placed the Multi 340i probe in the beaker until a stable measured value was reached. The plant operator also performed free and total chlorine measurements using Hach chlorine test kits.

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

4.0 RESULTS AND DISCUSSION

4.1 Facility Description

The Brown City water treatment system supplies water to 1,334 community members and has 664 service connections. Figure 4-1 shows a map of the present delivery service area of the plant, which is located at the end of Maple Street. Figure 4-2 shows the former pump house at the facility prior to the installation of the two STS APU-300 systems.

4.1.1 Existing System. The water source is groundwater extracted from three wells. However, the water demand is met primarily from Well No. 3 and Well No. 4 (see Figure 4-1 for the locations). Prior to the demonstration study, Well No. 3 was the primary well in operation, running on an intermittent basis for approximately four hours per day. Only Well No. 4 is currently in use for the demonstration study, and Well No 3. is used as an emergency backup well. Well No. 4 is 16-inches in diameter and installed at a depth of approximately 315 ft below ground surface (bgs). The static water level is approximately at 23 to 27 ft bgs. Well No. 4 is equipped with a 75 horsepower (HP) submersible pump rated for approximately 640 gpm at a discharge pressure of 59 pounds per square inch (psi).

Figure 4-3 shows the pre-existing piping configuration at Well No. 4 including a pump motor, several pressure gauges, a flow totalizer, and a chlorine addition assembly at the wellhead. The treatment system consisted only of disinfection with a sodium hypochlorite addition assembly that included a day tank and a positive displacement pump. Residual chlorine levels were targeted at 0.3 mg/L for free chlorine (as Cl_2) and 0.4 mg/L for total chlorine (as Cl_2). The treated water was stored in a nearby 200,000 gallon water tower.

4.1.2 Source Water Quality. Source water samples were collected from Well No. 4 on July 24, 2003, and subsequently analyzed for the analytes shown in Table 3-3. The results of the source water analyses, along with those provided by the facility to EPA for the demonstration site selection and those independently collected and analyzed by EPA, are presented in Table 4-1.

As shown in Table 4-1, total arsenic concentrations in raw water ranged from 10 to 31 μg/L. Based on the July 24, 2003 sampling results, arsenic existed primarily as As(III) (i.e., 79% at 11.2 μg/L), with a small amount also present as As(V) (i.e., 0.8 μg/L) and particulate As (i.e., 2.2 μg/L). During the first six months of system operation, chlorine was added only after the adsorption vessels so that the capacity of the SORB 33™ media for As(III) adsorption might be evaluated.

Raw water pH values ranged from 7.3 to 7.5, which was within the STS recommended range of between 6.0 and 8.0. Therefore, pH adjustment was not required.

The concentrations of iron (126.7 to 262.5 μg/L) and manganese (13 to 18.7 μg/L) in the raw water were below their respective secondary MCLs of 300 μg/L and 50 μg/L and sufficiently low so that pre-treatment prior to the adsorption process was not required. The maximum levels of phosphate at <0.1 mg/L and silica at 8.1 mg/L were significantly below the levels having the potential to reduce the overall effectiveness of arsenic adsorption onto the SORB 33™ media. Sulfate levels were relatively elevated at 74 to 128 mg/L and approaching the threshold of 150 mg/L, above which the sulfate anions may compete with arsenic for available adsorption sites onto the SORB 33™ media.

4.1.3 Distribution System. The Brown City distribution system is supplied primarily by two wells (Well No. 3 and Well No. 4). Well No. 4 is the designated well for the full duration of the arsenic removal demonstration study. Well No. 3 is currently the emergency backup well and has been operated

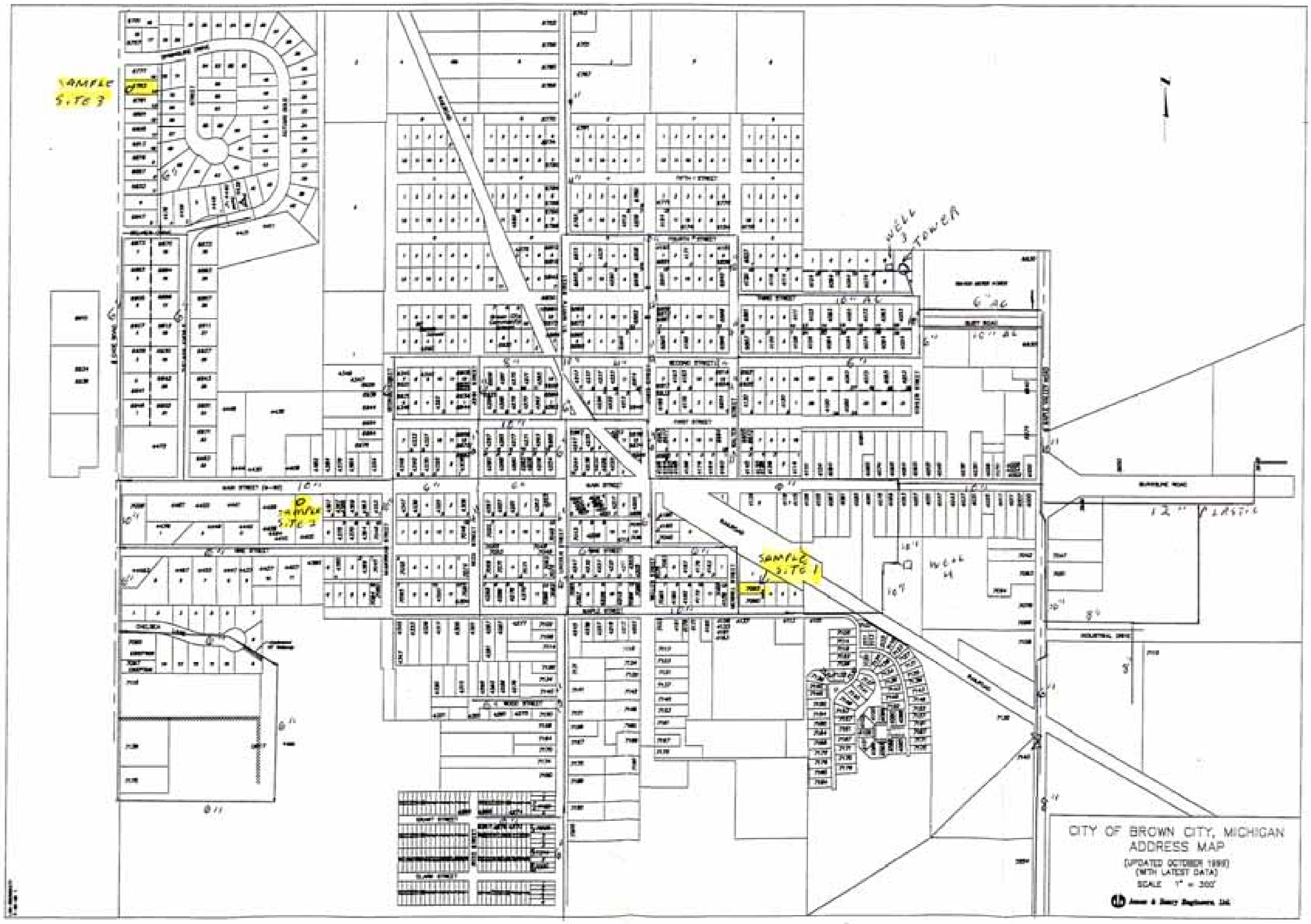


Figure 4-1. Map of the Brown City Service Area

Figure 4-2. Former Pump House at Brown City, MI, Site

Figure 4-3. Pump Motor, System Piping, and Chlorine Addition Assembly at Wellhead No. 4

Table 4-1. Brown City Water Quality Data

Parameter	Units	Raw Water				Historic Facility Treated Water Data	
		Facility Data	EPA Data	Battelle Data		Min	Max
Sampling Date		**Not Specified**	**07/23/02**	**07/24/03**	**07/23/02**	**2000-2003**	**2000-2003**
pH	–	7.5	NS	7.3	NS	NS	NS
Total Alkalinity	mg/L (as $CaCO_3$)	267.0[(a)]	244.2	235.0	NS	NS	NS
Hardness	mg/L (as $CaCO_3$)	90.0	108.2	83.2	NS	90.0	144.0
Chloride	mg/L	314	NS	51	NS	ND	314
Fluoride	mg/L	NS	NS	1.9	NS	1.4	1.9
Sulfate	mg/L	128	109	74	NS	50	128
Silica	mg/L (as SiO_2)	7.7	7.4	8.1	NS	NS	NS
Orthophosphate	mg/L	<0.01[(a)]	0.06	<0.10	NS	NS	NS
TOC	mg/L	NS	NS	<0.50	NS	NS	NS
As (total)	μg/L	31	10	14.2	11.9	10	36
As (total soluble)	μg/L	NS	NS	12.0	12.0	NS	NS
As (particulate)	μg/L	NS	NS	2.2	<0.1	NS	NS
As(III)	μg/L	NS	NS	11.2	7.9	NS	NS
As(V)	μg/L	NS	NS	0.8	4.2	NS	NS
Total Fe	μg/L	200[(a)]	193	126.7	262.5	200	400
Soluble Fe	μg/L	NS	NS	117.6	148.0	NS	NS
Total Al	μg/L	NS	NS	<10	12.6	NS	NS
Soluble Al	μg/L	NS	NS	<10	1.3	NS	NS
Total Mn	μg/L	18.0[(a)]	18.7	13.0	16.9	NS	NS
Soluble Mn	μg/L	NS	NS	15.0	16.3	NS	NS
Total V	μg/L	NS	NS	<0.1	NS	NS	NS
Soluble V	μg/L	NS	NS	<0.1	NS	NS	NS
Total Mo	μg/L	NS	NS	7.9	NS	NS	NS
Soluble Mo	μg/L	NS	NS	6.9	NS	NS	NS
Total Sb	μg/L	NS	<25	<0.1	NS	ND	ND
Soluble Sb	μg/L	NS	NS	<0.1	NS	NS	NS
Total Na	mg/L	168[(a)]	240.3	115.4	NS	60	289
Total Ca	mg/L	14[(a)]	30.6	20.6	NS	NS	NS
Total Mg	mg/L	7[(a)]	7.7	7.7	NS	NS	NS

(a) = data provided by EPA.
NS = Not sampled.
ND = Not detected.

only twice on October 13, 2004, and November 7, 2004, in the past six months. The water from the two wells is blended in the nearby water tower. The well pumps are activated by pressure sensors in the water tower, which signals the designated pump to turn on and off when the water level reaches a pre-set low and high setting. As shown in Figure 4-1, the distribution system is constructed primarily of asbestos cement pipe with some ductile iron and plastic piping and water main sizes ranging from 4 to 12 inches in diameter. Table 4-1 provides a summary of the treated water quality from historic samples at several locations within the distribution system. In addition, based on the June 1998 to September 2000 monitoring results, the 90th percentile concentrations for lead and copper were 6 μg/L and 150 μg/L, respectively, which were below the respective action levels of 15 μg/L and 1,300 μg/L.

4.2 Treatment Process Description

The STS APU is designed for arsenic removal for small systems with flowrates greater than 100 gpm. It uses Bayoxide® E33, an iron-based adsorptive media developed by Bayer AG, for the removal of arsenic from drinking water supplies. Bayoxide® E33 is branded as SORB 33™ by STS. Table 4-2 presents physical and chemical properties of the media. The SORB 33™ media is delivered in a dry crystalline form and has NSF 61 approval for use in drinking water.

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

Physical Properties	
Parameter	**Values**
Matrix	Iron oxide composite
Physical form	Dry granular media
Color	Amber
Bulk density (g/cm^3)	0.45
Bulk density (lb/ft^3)	28.1
BET surface area (m^2/g)	142
Attrition (%)	0.3
Moisture content (%)	<15% by weight
Particle size distribution	10 × 35 mesh
Crystal size (Å)	70
Crystal phase	α – FeOOH
Chemical Analysis	
Constituents	**Weight %**
FeOOH	90.1
CaO	0.27
SiO_2	0.06
MgO	1.00
Na_2O	0.12
SO_3	0.13
Al_2O_3	0.05
MnO	0.23
TiO_2	0.11
P_2O_5	0.02
Cl	0.01

Note: BET = Brunauer, Emmett, and Teller Method

The STS APU system is a fixed-bed down-flow adsorption system. When the media reaches breakthrough at 10 μg/L of arsenic, the spent media is removed and disposed after being subjected to the EPA TCLP test.

The Brown City treatment system consists of two APU-300 units arranged in a parallel configuration to meet the design flowrate of 640 gpm (i.e., 320 gpm for each unit). Each APU-300 unit consists of two pressure vessels operating in parallel. The design features of the treatment system are summarized in Table 4-3, and the process schematic is shown in Figure 4-4. A flow diagram along with the sampling/analysis schedule are presented in Figure 4-5. Key process components are discussed below:

- **Adsorption**. Each APU-300 unit consists of two 63-inch-diameter, 86-inch-tall vessels configured in parallel, each containing approximately 80 ft^3 of SORB 33™ media supported by a gravel underbed. The vessels are fiberglass reinforced plastic (FRP) construction, rated for 75 psi working pressure, skid mounted, and piped to a valve rack mounted on a polyurethane coated, welded frame. Empty bed contact time (EBCT) for the system is 3.7 minutes. Hydraulic loading to each vessel based on a design flowrate of 320 gpm is approximately 7.3 gpm/ft^2. Figure 4-6 shows the two APU-300 units that were installed in a parallel configuration at the Brown City, MI, site.

Table 4-3. Design Features of Brown City Treatment System

Parameter	Value	Remarks
Pretreatment/post-treatment	Post-chlorination	
Number of adsorber vessels	4	2 vessels per unit
Vessel configuration	parallel	2 units in parallel; each with 2 vessels in parallel
Vessel size (in)	63 D × 86 H	
Type of media	SORB 33™	
Media volume (ft^3/vessel)	80	320 ft^3 total
Media bed depth (in)	44	
Free board depth (in)	16	Based on a media bed depth of 44 inches
Design flowrate (gpm/vessel)	160	640 gpm total
Hydraulic loading rate (gpm/ft^2)	7.3	Based on vessel cross sectional area of 21.6 ft^2 given an inner diameter of 63 inches
EBCT (min)	3.7	Based on the design flow per vessel
Backwash frequency (per 45 days)	1	
Backwash flowrate (gpm)	200	
Backwash hydraulic loading rate (gpm/ft^2)	9.2	
Backwash duration (min/vessel)	20	
Fast rinse duration (min/vessel)	4	
Backwash water produced (gal/vessel)	4,800	
Average use rate (gal/day)	153,600	Based on 4 hours of daily operation at 640 gpm
Estimated working capacity (bed volume [BV])	80,000[(a)]	Based on an influent As concentration of 31 μg/L and a bed volume of 320 ft^3
Throughput (BV/day)	64	Based on 4 hours of daily operation at 640 gpm
Estimated throughput to 10 μg/L As breakthrough	191,514,000[(a)]	Based on a bed volume of 320 ft^3
Estimated media life (months)	40	Estimated frequency of changeout at 17% utilization

(a) Based on STS Proposal dated January 7, 2003, with an influent As concentration of 31 μg/L.

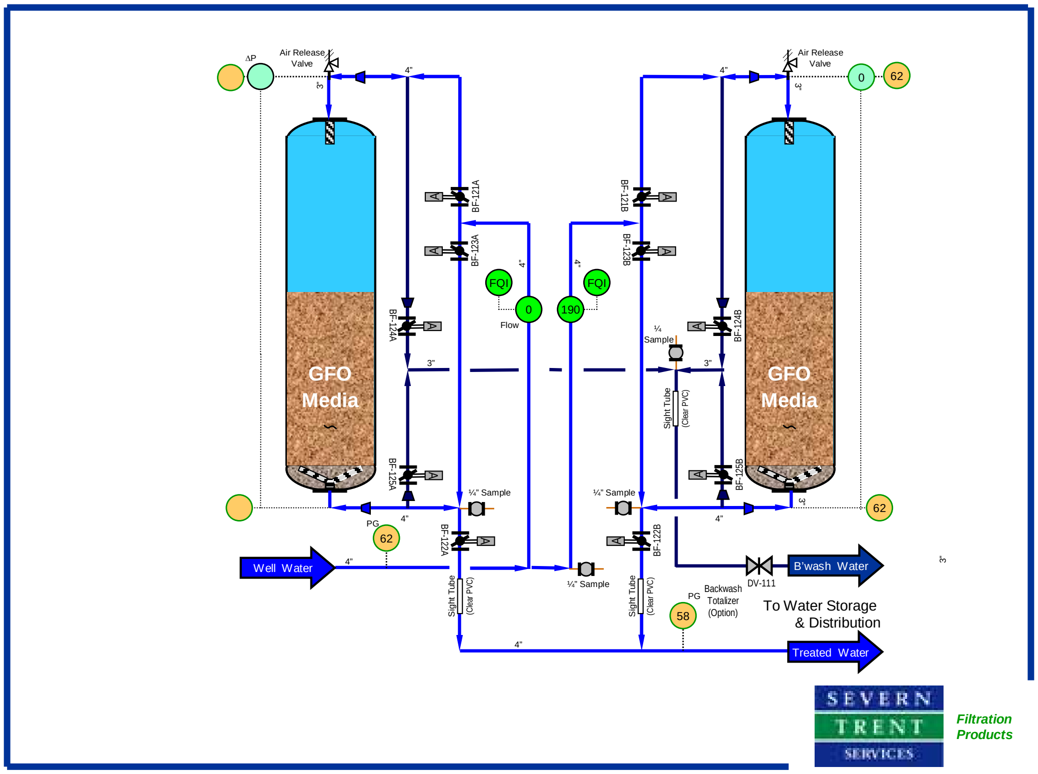


Figure 4-4. Schematic Diagram of an APU-300 Unit at Brown City (After System Retrofit) as Installed in May 2004

- **Backwash**. STS recommends that the SORB 33™ media be backwashed approximately once every 45 days to loosen up the media bed and remove media fines and/or particles accumulated in the beds. Automatic backwash may be initiated either by timer or by differential pressure across the vessels. Controllers for the backwash system include actuated valves for adsorption, backwash and forward flush (fast rinse) cycles, timers, and pressure sensors. The backwash water is directly discharged into a drainage ditch adjacent to the treatment facility.

- **Post-chlorination.** Sodium hypochlorite is added to the treated water for disinfection. The target residual levels are 0.3 mg/L (as Cl_2) for free chlorine and 0.4 mg/L (as Cl_2) for total chlorine in the distribution system.

4.3 System Installation

The building was completed by the City in early February 2004 and the two STS APU-300 units were installed in March 2004 by a subcontractor to STS. However, hydraulic shakedown and startup activities continued into late April 2004, and the system was retrofitted in early May 2004.

4.3.1 Permitting. Engineering plans for the system permit application were prepared by Boss Engineering, a subcontractor to STS located in Howell, MI. The plans included diagrams of and specifications for the treatment system, as well as drawings detailing the connection of the new units to the pre-existing facility infrastructure. After incorporating comments on the plans from STS and Battelle,

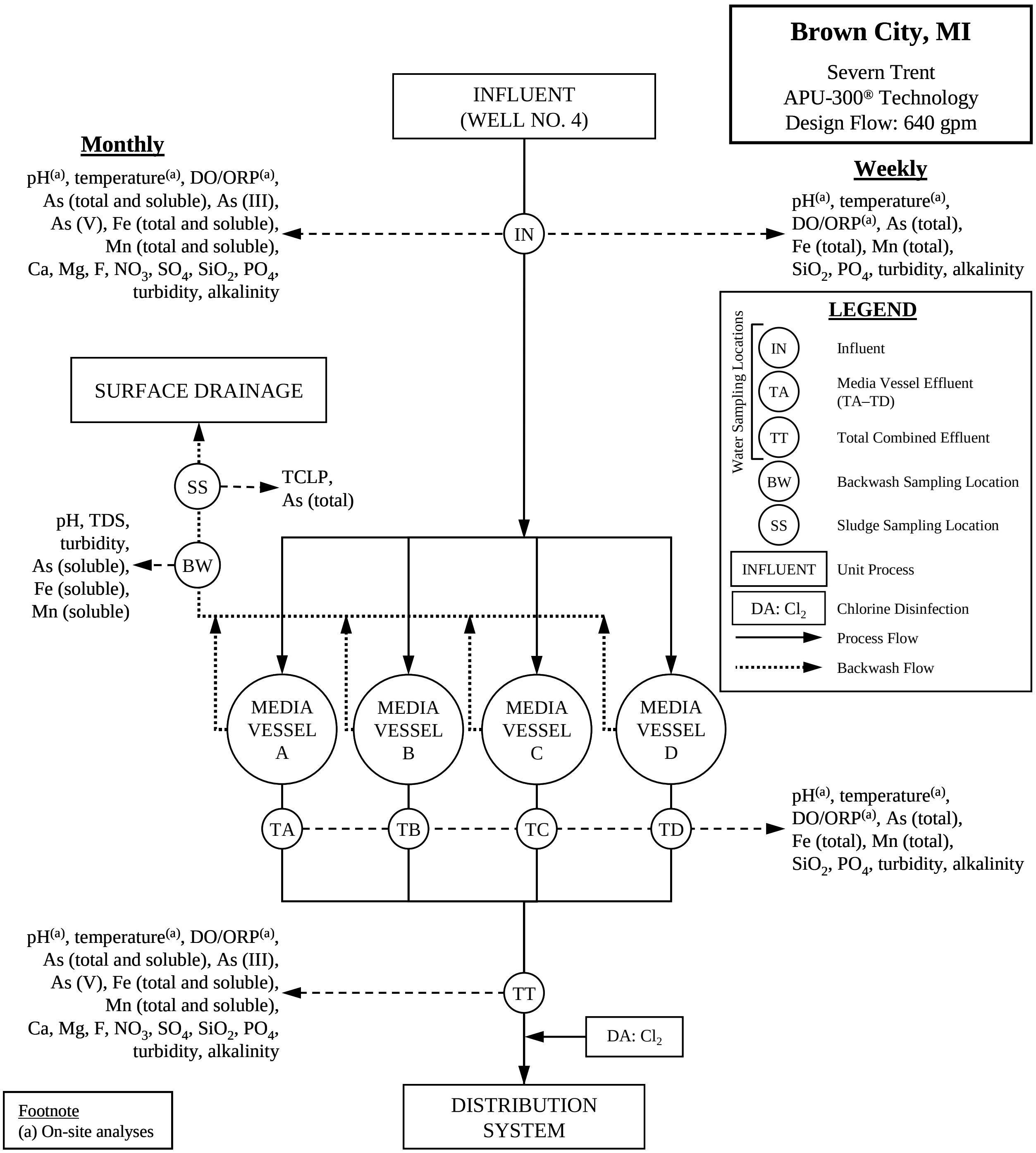


Figure 4-5. Process Flow Diagram and Sampling Locations

Figure 4-6. Photograph of the Two APU-300 Units at the Brown City Site

the permit application was submitted by the City to the MDEQ for review on November 26, 2003. The MDEQ approved the permit application package on February 11, 2004.

4.3.2 Building Construction. The City constructed an addition to its existing pump house at Well No. 4 to house the two APU-300 units. The addition is a 28 ft × 28 ft concrete block structure with a 10-ft-wide roll-top metal door and access hatches in the roof for media loading. A photograph of the new structure adjacent to the pre-existing block pump house is shown in Figure 4-7. The scope of work for the building construction included excavation, masonry, carpentry, concrete floor pouring, building trim and painting, and associated heating and electrical work. Also, included in the building construction was installation of an overhead door, roof deck, and roofing, including overhead roof hatches. Building construction started in December of 2003 with the installation of building footers and walls and was completed by February of 2004.

4.3.3 System Installation, Shakedown, and Startup. The two APU-300 units were delivered to the site on February 23, 2004. A subcontractor to STS, off-loaded and installed the system, including piping connections to the existing entry and distribution piping. Installation was completed on March 18, 2004, and the system hydraulic shakedown before media loading was initiated on March 19, 2004. The original system configuration as delivered included several components such as the piping inlet, an automatic variable diaphragm valve (to control flow), a strainer, a programmable Fleck valve controller (to switch flow from a service to a backwash mode), an FRP vessel with top diffuser and bottom laterals, a restrictive orifice, and an outlet. This configuration was later modified to a valve-tree configuration, as described below in this subsection, to address pressure loss and flow issues with the APU-300 units.

Figure 4-7. New Building at Brown City Adjacent to the Pre-Existing Pump House (on the left)

STS began hydraulic testing of the two APU-300 units on March 19, 2004, with no media loaded in the vessels to troubleshoot several issues related to flow restriction, flow imbalance, and excessive pressure losses noted on an identical APU-300 unit installed at Desert Sands Mutual Domestic Water Consumers Association (MDWCA) in Anthony, New Mexico, in December 2003. The Desert Sands MDWCA system had experienced low and imbalanced flow and elevated pressures as described in the Desert Sands MDWCA Six-Month Report (Coonfare et al., 2005).

On March 19, 2004, water from Well No. 4 was pumped through the two empty APU-300 units with flowrates ranging from 105 to 115 gpm per vessel, which were well below the design flowrate of 160 gpm. The corresponding pressure losses at this flowrate were 7 to 8 psi across each empty vessel and 24 to 26 psi across the entire system. These results suggested that the system components and plumbing most likely were the sources of the high pressure losses.

To address these issues, STS performed a series of systematic hydraulic tests at its Torrance, CA, fabrication shop and at the Brown City, MI, site. A summary of the hydraulic test results are provided in the Six-Month Report on the Deserts Sands MDWCA performance evaluation study (Coonfare et al., 2005). The results of the Brown City testing performed on April 6, 2004, showed that, after removing the restrictive orifice, strainer, and top diffuser, pressure losses were observed across the variable diaphragm valve (from 80 to 71 psi) and valve controller and bottom laterals (from 71 to 58 psi). These results were consistent with those observed during testing at Torrance, CA, except for the 1-psi loss (from 44 to 43 psi) across the variable diaphragm valve. The results of the Brown City, MI, and Torrance, CA, testing were further confirmed during a separate test in Torrance, CA, on April 14, 2004. It was, therefore, evident that the main sources of the pressure losses were the valve controller and restrictive orifice. Upon completion of the hydraulic testing, STS recommended retrofitting the system.

STS developed a revised plumbing design, which included replacing the 3-inch-diameter pipe with 4-inch-diameter pipe; removing the diaphragm valves, restrictive orifices, and valve controllers; and installing a nested system of fully ported actuated butterfly valves and a new control panel. STS completed the system retrofit of the two APU-300 units, and the media was loaded on May 5, 2004. On May 7, 2004, STS conducted operator training for system operations and Battelle conducted operator training for system sampling and data collection. Water samples were taken from the vessels on May 10, 2004, and the system passed the coliform test. The performance evaluation study officially began on May 11, 2004.

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters of the system are tabulated and attached as Appendix A. Key parameters are summarized in Table 4-4. The plant operations were initiated on May 11, 2004, and continued through November 30, 2004.

Table 4-4. Summary of Treatment System Operation at the Brown City, MI, Site

Parameter	Values				
Operating Time (hr)	843.7 hours from June 7, 2004 to November 30, 2004				
Average Daily Operating Time (hr)	5.5 hrs/day Jun to Aug; 4.1 hrs/day Sept to Nov				
	Vessel A	**Vessel B**	**Vessel C(b)**	**Vessel D**	**Total**
Throughput (kgal)	8,000	7,756	6,925	7,030	29,711
Throughput (BV)	14,106	13,674	12,210	12,395	13,096
Average Flowrate (gpm)	165	164	148	148	625
Range of Flowrate (gpm)	133-186	144-188	126-165	131-168	534-707
Average EBCT (min)(a)	3.5	3.5	3.8	3.8	NA
Range of EBCT (min)(a)	3.1-4.3	3.0-3.9	3.4-4.5	3.4-4.3	NA
Differential Pressure across Bed (psi)	2.4-3.2	2.8-5.0	2.2-4.0	1.0-3.0	NA
System Pressure Loss for Each Unit (psi)	2-10		2-8		2-10
Time Between Backwash Events (days)	43	43	43	43	NA

(a) Calculated based on 76 ft^3 of media in each vessel. Also note that the underbedding in each vessel was 15 ft^3 and that the free boards in Vessels A, B, C, and D were 16, 14, 16, and 16 inches, respectively.
(b) Actual bed volumes may vary due to malfunction of flowmeter noted on November 20, 2004.
NA = not applicable.

An hour meter was installed on June 7, 2004. From June 7 to November 30, 2004, Well No. 4 operated for 843.7 total hours based on the well pump hour meter readings, which is equal to an average daily operating time of 4.8 hrs per day. This operating time represented a utilization rate of approximately 20% over that time period. The water demand was only slightly higher in the summer, with an average operating time of 5.5 hrs/day from June to August compared to 4.1 hrs/day from September to November.

The total system throughput from May 11 to November 30, 2004, was approximately 29,711,000 gallons based on the digital flow totalizer readings from the APU-300 units. This corresponds to 13,096 bed volumes of water processed through the entire system. Based on the readings for the individual vessels, the throughput values were 8,000, 7,756, 6,925, and 7,030 kilogallons through Vessels A, B, C, and D, respectively (or 14,106, 13,674, 12,210, and 12,395 BV, respectively). The variance was due largely to the minor flow discrepancy between the vessels as described below.

The average flowrates through the vessels ranged from 148 to 165 gpm, which corresponded well with the 160 gpm design flowrate for each vessel. There was a slight imbalance in flow between Unit 1 (A/B) and Unit 2 (C/D). As a result, the EBCT for the vessels in Unit 1 averaged 3.5 minutes and in Unit 2 averaged 3.8 minutes, both of which were very close to the target value of 3.7 minutes. Although, the flowrate difference primarily accounted for the variance in bed volumes of water treated, another contributing factor was the malfunction of the flow totalizer/meter on Vessel C on November 20, 2004 (see Section 4.4.4).

Since the commencement of system operations on May 11, 2004, the differential pressure across each adsorption vessel varied from 1.0 to 5.0 psi and remained low throughout the six-month duration of system operations. The pressure drop across each APU-300 unit was low, ranging from 2 to 10 psi. No significant pressure related problems were noted, with the exception of malfunctioning of the differential pressure gauge on Vessel A, which was replaced on July 21, 2004.

4.4.2 Backwash. STS recommended that the SORB 33™ media be backwashed manually or automatically approximately once per month to loosen up the media bed and remove media fines and particles accumulated in the beds. Automatic backwash could be initiated either by timer or by differential pressure in the vessels.

Although the automatic backwash was set for every 45 days or when the pressure drop across an adsorption vessel exceeded 10 psi, backwash events were all initiated manually to facilitate backwash water sampling and to allow observation of the backwash events. Also, backwash was never automatically triggered because the differential pressure across each adsorption vessel never exceeded the 10 psi setpoint during this time period. Backwash was initiated manually four times on June 15, July 28, September 9, and October 22, 2004, during the six months of system operations. Backwash was performed at approximately 200 gpm, or 9.2 gpm/ft^2, as set by STS using the manual valves on the backwash discharge line from each unit. Based on the backwash logs, the backwash flowrates for all four vessels ranged from 190 to 229 gpm. Each backwash event lasted for 20 minutes, followed by a four-minute rinse, producing approximately 4,800 gallons of wastewater per vessel during each backwash event. Based on the backwash logs, the amount of backwash water produced ranged from 3,900 to 6,100 gallons per vessel.

An operational issue arose during backwash on October 22, 2004. Tank B did not go into fast rinse and the operator had to manually adjust the valve to put the system back into service. The valve problem was addressed by STS on December 2, 2004, by the repair of a loose limit switch. All four vessels were then backwashed. The backwash water and treatment plant water samples taken after October 22, 2004, appear to have been impacted by the valve problem (see Sections 4.5.2) and Battelle will continue to monitor and assess the impact of this operational issue on the system performance. Note that backwashing problems can potentially impact system performance through mechanisms such as media loss, bed disturbance (such as short circuiting), and/or improper flow patterns.

4.4.3 Residual Management. Residuals produced by the treatment system included spent media and backwash water. The media was not exhausted during the first six months of system operation; therefore, the only residual produced was backwash water. Aboveground piping for backwash water from both APU-300 units is combined before extending outside the building. The pipe emerges from the building and then discharges after an air gap into a small subsurface concrete vault and discharges via an underground pipe to a nearby drainage ditch.

4.4.4 System/Operation Reliability and Simplicity. After the system retrofit, no major operational problems were encountered. The only O&M issues encountered were the temporary failure of a digital flow meter, the failure of a differential pressure gauge, and a loose switch on an automatic valve.

Neither scheduled nor unscheduled downtime had been required since the completion of the system retrofit. The simplicity of system operation and operator skill requirements are discussed according to pre- and post-treatment requirements, levels of system automation, operator skill requirements, preventative maintenance activities, and frequency of chemical/media handling and inventory requirements.

Pre- and Post-Treatment Requirements. Pre-treatment was not implemented at the site in order to evaluate the capacity of the SORB 33™ media for As(III). Post-treatment consisted only of disinfection with the pre-existing sodium hypochlorite chemical feed system. When arsenic reaches breakthrough, pre-chlorination will be initiated to extend the media life.

System Automation. All major functions of the treatment system are automated and it requires only minimal operator oversight and intervention. Automated processes include system startup in the forward feed mode when the well energizes, backwash cycling based on time or pressure triggers, fast rinse cycling, and system shutdown when the well pump shuts down.

Operator Skill Requirements. Under normal operating conditions, the skill set required to operate the treatment system was basic and limited to observation of the process equipment integrity and operating parameters such as pressure, flow, and system alarms. The process logic controller (PLC) interface was intuitive, and all major system operations were automated as described above. The daily demand on the operator was 30 minutes to allow the operator to visually inspect the system and record the operating parameters on the log sheets.

Preventative Maintenance Activities. Preventative maintenance tasks recommended by STS included monthly inspection of the control panel; quarterly checking and calibration of the flow meters; biannual inspection of the actuator housings, fuses, relays, and pressure gauges; and annual inspection of the butterfly valves. STS 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 performed concurrent with the media replacement (STS, 2004). During this reporting period, maintenance activities performed by the operator included cleaning and repairing the flow meter paddle wheels, replacing one differential pressure gauge, and replacing plastic pressure line fittings/elbows on sampling taps. Maintenance also was required on an automated valve to repair a loose limit switch. This repair was made by STS and beyond routine maintenance activities that could be performed by the operator.

Chemical/Media Handling and Inventory Requirements. Pre-chlorination was not implemented at this site. Therefore, chemical use and/or media handling was not required during the first six months of system operations.

4.5 System Performance

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

4.5.1 Treatment Plant Sampling. Water samples were collected at six locations through the treatment train: at the inlet (IN), after Vessels A, B, C, and D (TA, TB, TC, and TD), and at the combined effluent (TT). Field-speciated samples from the IN and TT locations were collected once every four weeks throughout this reporting period. Table 4-5 summarizes the arsenic, iron, and manganese analytical results. Table 4-6 summarizes the results of other water quality parameters. Appendix B contains a complete set of analytical results through the first six months of system operations. The results of the water samples collected throughout the treatment plant are discussed below.

Table 4-5. Summary of Arsenic, Iron, and Manganese Analytical Results

Parameter	Sampling Location	Units	Number of Samples[b]	Minimum Concentration	Maximum Concentration	Average Concentration	Standard Deviation
As (total)	IN	µg/L	17	9.5	28.7	15.0	4.4
	TA	µg/L	10	0.6	5.2	2.1	1.5
	TB	µg/L	10	0.5	8.7	3.1	2.9
	TC	µg/L	10	0.8	7.8	3.2	2.6
	TD	µg/L	10	0.4	8.0	3.4	2.6
	TT	µg/L	7	0.7	7.1	2.8	2.2
As (soluble)	IN	µg/L	7	9.6	15.8	13.0	2.0
	TT	µg/L	7	0.6	6.2	2.5	1.9
As (particulate)	IN	µg/L	7	<0.1	2.2	0.8	0.9
	TT	µg/L	7	0.1	0.9	0.3	0.3
As(III)	IN	µg/L	7	9.0	14.2	12.4	1.8
	TT	µg/L	7	0.5	5.3	2.1	1.7
As(V)	IN	µg/L	7	<0.1	1.6	0.6	0.5
	TT	µg/L	7	<0.1	2.4	0.6	0.9
Fe (total)	IN	µg/L	17	101	228	153	32.5
	TA	µg/L	10	<25	<25	<25	0.0
	TB	µg/L	10	<25	<25	<25	0.0
	TC	µg/L	10	<25	<25	<25	0.0
	TD	µg/L	10	<25	<25	<25	0.0
	TT	µg/L	7	<25	35.0	15.7	8.5
Fe (soluble)	IN	µg/L	7	99	139	121	16.6
	TT	µg/L	7	<25	<25	<25	0.0
Mn (total)	IN	µg/L	17	12.3	18.5	15.0	2.0
	TA	µg/L	10	0.3	20.5	11.0	7.6
	TB	µg/L	10	0.3	21.8	11.9	7.6
	TC	µg/L	10	1.5	22.8	13.3	7.9
	TD	µg/L	10	2.1	25.0	14.2	9.0
	TT	µg/L	7	1.3	22.4	11.7	9.4
Mn (soluble)	IN	µg/L	7	12.7	16.5	14.2	1.5
	TT	µg/L	7	1.6	19.9	11.3	8.7

Notes:

(a) One-half of the detection limit was used for samples with concentrations less than the detection limit for calculations.

(b) Field duplicate samples were included in the calculations.

Table 4-6. Summary of Water Quality Parameter Sampling Results[(a)]

Parameter	Sampling Location	Units	Number of Samples[(b)]	Minimum Concentration	Maximum Concentration	Average Concentration	Standard Deviation
Alkalinity	IN	mg/L	17	218	277	239	12
	TA	mg/L	10	214	246	234	11
	TB	mg/L	10	214	246	233	11
	TC	mg/L	10	202	250	237	13
	TD	mg/L	10	214	256	240	12
	TT	mg/L	7	164	250	229	30
Fluoride	IN	mg/L	7	1.3	3.3	1.7	0.7
	TT	mg/L	7	1.4	1.8	1.6	0.2
Sulfate	IN	mg/L	7	54	120	73	25
	TT	mg/L	7	73	120	85	16
Orthophosphate (as PO_4)	IN	mg/L	17	<0.06	<0.1	0.04	0.01
	TA	mg/L	10	<0.06	<0.1	0.04	0.01
	TB	mg/L	10	<0.06	<0.1	0.04	0.01
	TC	mg/L	10	<0.06	<0.1	0.04	0.01
	TD	mg/L	10	<0.06	<0.1	0.04	0.01
	TT	mg/L	7	<0.06	<0.1	0.04	0.01
Silica (as SiO_2)	IN	mg/L	17	7.7	14.3	8.9	1.5
	TA	mg/L	10	7.2	17.4	8.7	3.1
	TB	mg/L	10	2.3	8.1	7.1	1.7
	TC	mg/L	10	2.7	7.7	7.0	1.5
	TD	mg/L	10	3.1	7.8	7.1	1.4
	TT	mg/L	7	5.0	7.9	7.1	1.0
Nitrate (as N)	IN	mg/L	6	<0.04	<0.04	<0.04	0.00
	TT	mg/L	6	<0.04	<0.04	<0.04	0.00
Turbidity	IN	NTU	17	0.2	2.3	1.0	0.6
	TA	NTU	10	0.2	0.6	0.4	0.2
	TB	NTU	10	0.1	0.7	0.4	0.2
	TC	NTU	10	0.2	0.8	0.4	0.2
	TD	NTU	10	0.1	0.9	0.4	0.3
	TT	NTU	7	0.1	0.8	0.4	0.2
pH	IN	S.U.	14	7.6	8.5	8.0	0.2
	TA	S.U.	7	7.6	8.0	7.9	0.1
	TB	S.U.	7	7.6	7.9	7.8	0.1
	TC	S.U.	7	7.6	7.9	7.8	0.1
	TD	S.U.	7	7.6	7.9	7.8	0.1
	TT	S.U.	7	7.7	7.9	7.9	0.1

Table 4-6. Summary of Water Quality Parameter Sampling Results (Continued)

Parameter	Sampling Location	Units	Number of Samples[(b)]	Minimum Concentration	Maximum Concentration	Average Concentration	Standard Deviation
Temperature	IN	°C	15	10.3	14.3	11.6	0.9
	TA	°C	8	10.8	13.8	11.6	1.0
	TB	°C	8	10.9	12.8	11.5	0.6
	TC	°C	8	10.8	12.3	11.4	0.5
	TD	°C	8	10.7	12.3	11.5	0.6
	TT	°C	7	10.2	13.4	11.5	1.0
Dissolved Oxygen	IN	mg/L	13	1.0	2.5	1.9	0.4
	TA	mg/L	7	1.3	2.0	1.6	0.3
	TB	mg/L	7	1.2	2.0	1.6	0.3
	TC	mg/L	8	0.7	2.7	1.6	0.6
	TD	mg/L	8	1.2	2.3	1.8	0.4
	TT	mg/L	7	0.7	1.9	1.5	0.4
ORP	IN	mV	15	3	106	32	33
	TA	mV	8	3	99	33	34
	TB	mV	8	2	102	32	34
	TC	mV	8	3	104	32	34
	TD	mV	8	2	104	31	34
	TT	mV	7	2	77	26	25
Total Hardness (as $CaCO_3$)	IN	mg/L	7	65.0	111.2	91.8	18.8
	TT	mg/L	7	87.5	131.1	99.3	14.7

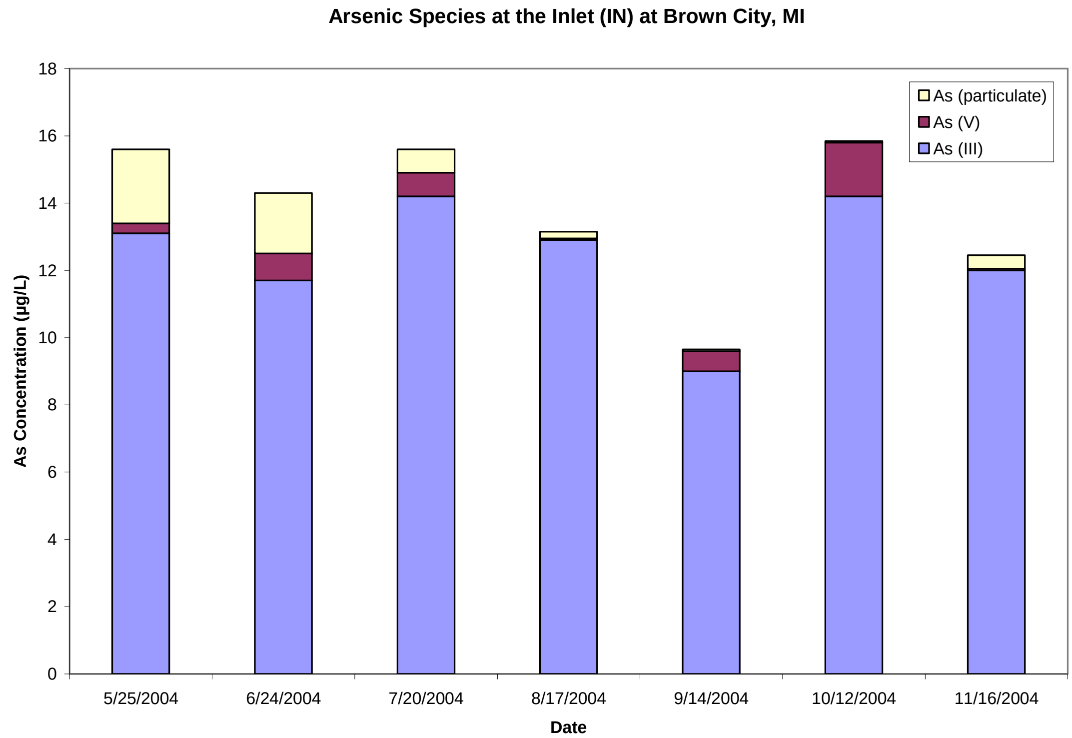
NTU = nephelometric turbidity unit
SU = standard units
Notes:
(a) One-half detection limit was used for samples with concentrations less than detection limit for calculations.
(b) Field duplicate samples were included in the calculations except for field parameters (pH, temperature, DO, and ORP).

Arsenic. The key parameter for evaluating the effectiveness of the SORB 33™ media was the concentration of arsenic in the treated water. The treatment plant water was sampled on 15 occasions during the first six months of system operations, with field speciation performed on samples collected from the IN and TT locations for 7 of the 15 sampling occasions.

Figure 4-8 shows the arsenic speciation results over time including the concentrations of total As, particulate As, As(III), and As(V) at the IN and TT locations.

Total arsenic concentrations in raw water ranged from 9.5 to 28.7 μg/L and averaged 15.0 μg/L (Table 4-5). As(III) was the predominant species in the raw water, ranging from 9.0 to 14.2 μg/L and averaging 12.4 μg/L. Only trace amounts of particulate As and As(V) existed, with concentrations averaging 0.8 and 0.6 μg/L, respectively. The arsenic concentrations measured during this six-month period were consistent with those in the raw water sample collected on July 24, 2003 (Table 4-1).

Total As concentrations in the combined effluent (TT) ranged from 0.7 to 7.1 μg/L and averaged 2.8 μg/L (Table 4-5). As(III) levels in the combined effluent ranged from 0.5 to 5.3 μg/L. The average particulate and As(V) concentrations in the combined effluent were relatively low at 0.3 and 0.6 μg/L, respectively.



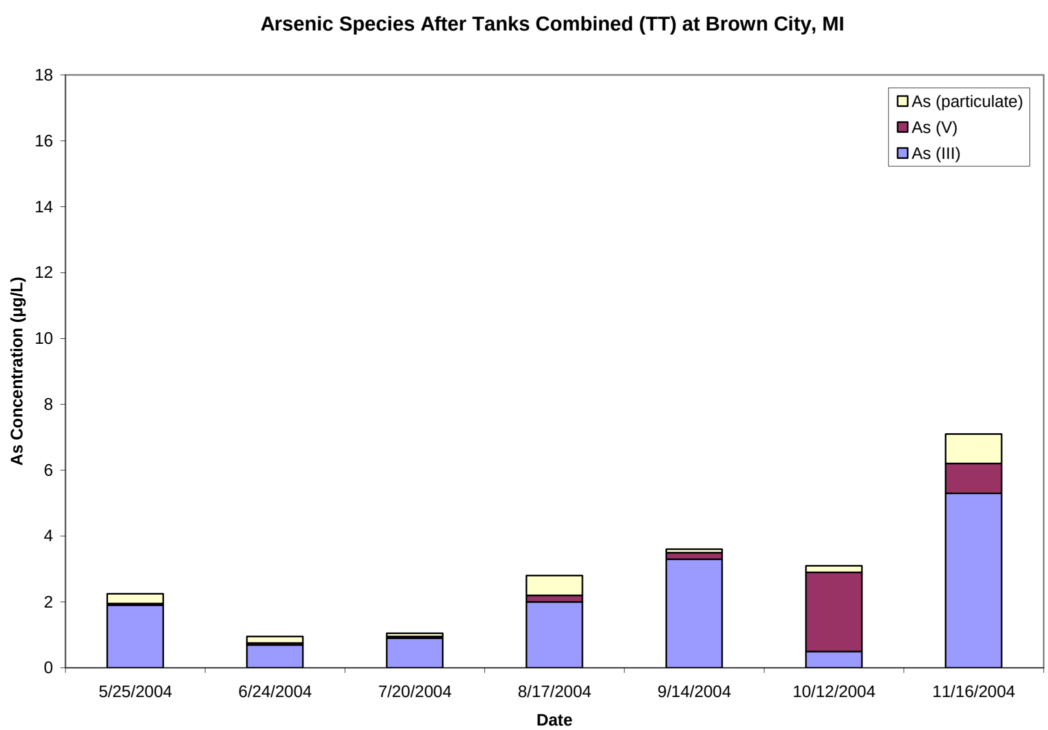


Figure 4-8. Concentrations of Arsenic Species at the Influent and Combined System Effluent

The increase of the As(III) concentration in the combined effluent (TT) from 1.9 µg/L on May 25, 2004, to 5.3 µg/L on November 16, 2004, indicated that SORB 33™ media might be reaching its capacity for As(III) adsorption (see Figure 4-8). Although the total arsenic levels in the effluent of the system have increased gradually over time, a spike up to 8.7 µg/L of total arsenic was measured in the treated water in early November, as the treatment system throughput was approaching 12,500 bed volume (see Figure 4-9). However by November 30, 2005, the total arsenic concentrations had decreased to 2.4 to 4.1 µg/L in the treated water and remained below 10 µg/L for approximately 20,000 bed volume, which will be further discussed in the final evaluation report.

By the end of the first six months of system operation, the APU-300 system treated approximately 29,711,000 gallons of water, which was equivalent to 13,096 bed volumes. The results of the total arsenic analyses at each sampling location are plotted against the bed volumes of treated water in Figure 4-9. For the first six months of system operation, the treatment system removed arsenic from the influent water to levels below the 10 µg/L level. However, the plot shows the gradual increase in total arsenic concentrations in the treated water over time.

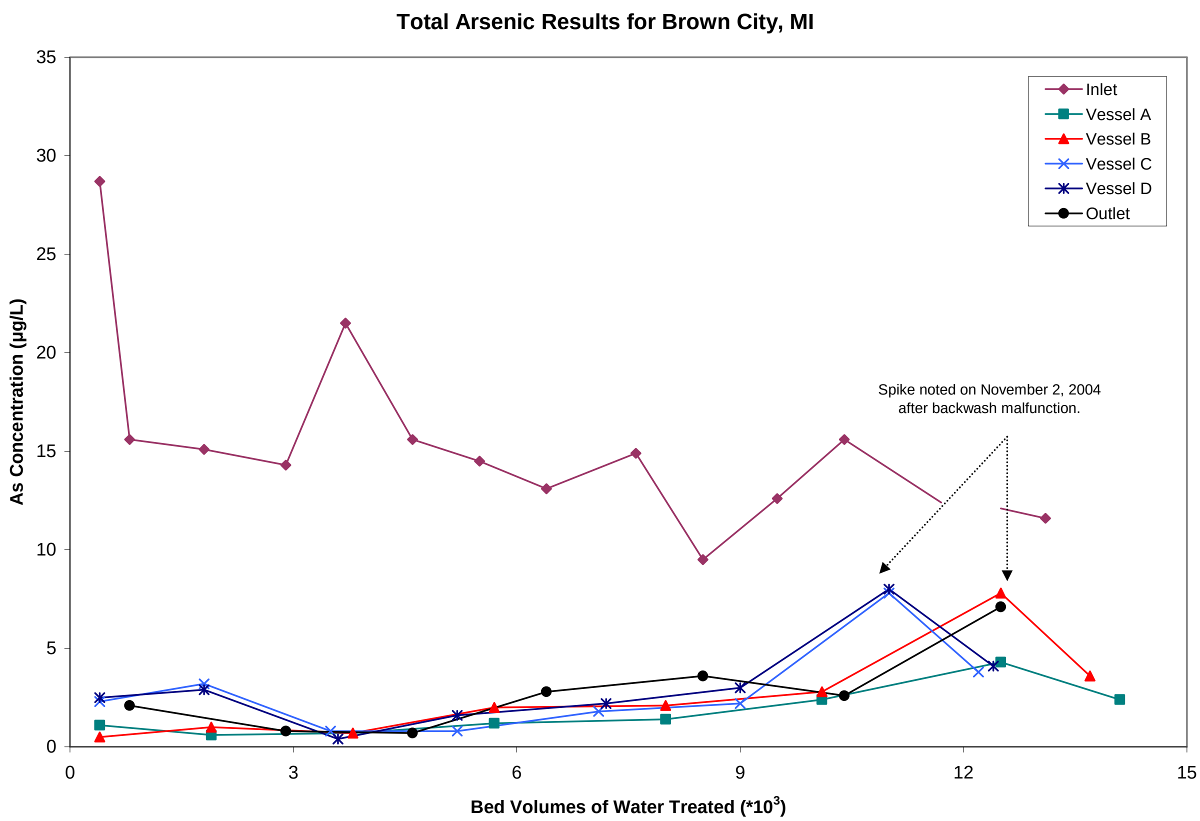


Figure 4-9. Total Arsenic Concentration Versus Bed Volumes

Iron. Total iron concentrations in raw water varied from 101 to 228 µg/L, which existed primarily in the soluble form ranging from 99 to 139 µg/L (see Table 4-5). Figure 4-10 shows that the total iron concentrations in the treated water were below the detection limit of <25 µg/L with the exception of September 14, 2004, when the total iron effluent level was 35 µg/L. This data indicated that mechanisms may exist for the removal of soluble iron within the SORB 33™ media bed, which will be further discussed in the final evaluation report.

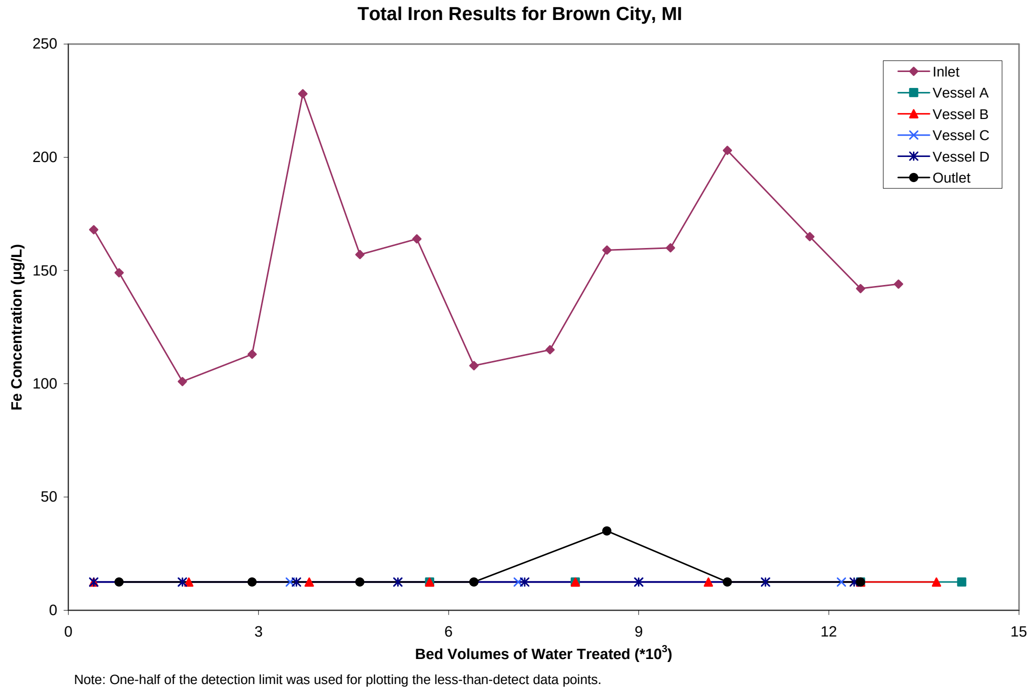


Figure 4-10. Total Iron Concentrations vs. Bed Volumes

***Manganese*.** Total Mn concentrations at the various sampling locations are plotted versus bed volume in Figure 4-11. Total and soluble Mn concentrations over time are also shown in Figure 4-12. Total Mn levels in the influent ranged from 12.3 to 18.5 µg/L (Table 4-5), with the majority being soluble Mn(II). Total Mn concentrations in the treated water sampled after the adsorption vessels were reduced initially,

Figure 4-11. Total Manganese Concentrations Versus Bed Volumes

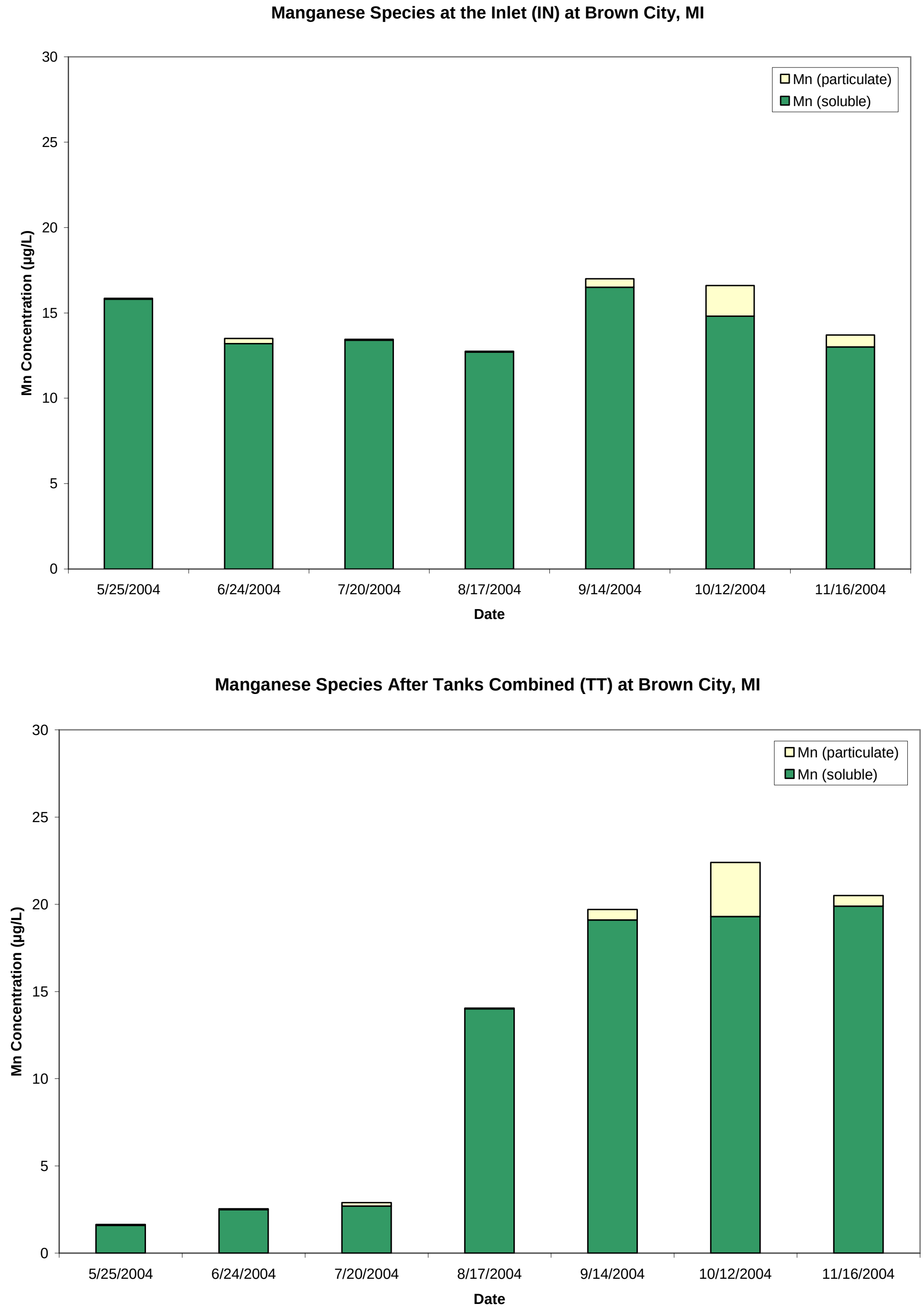


Figure 4-12. Concentrations of Manganese Species Versus Time

but reached 100% breakthrough with about 6,000 bed volumes of water treated. The soluble manganese levels were initially lower in the treated water than those in the raw water until breakthrough at about 6,000 bed volumes. After this point, the soluble manganese levels in the treated water were higher than those in the raw water. The mechanisms responsible for the manganese removal during the first 6,000 bed volumes of treatment are unclear.

Other Water Quality Parameters. In addition to arsenic, iron, and manganese, other water quality parameters were analyzed to provide insight into the chemical processes occurring within the treatment system. The results of the water quality parameters are included in Appendix B and are summarized in Table 4-6.

On-site measurements of pH remained consistent at all sampling locations, with average values ranging from 7.8 to 8.0 across the treatment train. Average alkalinity results ranged from 229 to 240 mg/L (as $CaCO_3$) across the treatment train. The average value of total hardness was 92 mg/L (as $CaCO_3$) in raw water and 99 mg/L (as $CaCO_3$) in the treated water. The samples had predominantly calcium hardness (approximately 59% to 77%).

Fluoride concentrations ranged from 1.3 to 3.3 mg/L in all samples and were not affected by the SORB 33™ media. Sulfate concentrations ranged from 54 to 120 mg/L at the system influent and 73 to 120 mg/L at the effluent. In 5 out of 7 events, the sulfate levels were higher in the effluent than the influent. Orthophosphate was below the detection limit in all samples. The average silica (as SiO_2) concentrations across the treatment train ranged from 7.1 to 8.9 mg/L. Silica was partially removed by the SORB 33™ media, with the amount of removal declining significantly after approximately 2,000 BV.

DO levels ranged from 1.0 to 2.5 in the raw water, with an average value of 1.9 mg/L. The DO levels ranged from 0.7 to 1.9 mg/L in the treated water, with an average value of 1.5 mg/L. The DO levels were not affected by the media. The average ORP readings across the treatment train ranged from 26 to 33 millivolts. The ORP readings showed an increasing trend over time.

4.5.2 Backwash Water Sampling. Backwash was performed one vessel at a time using raw water. The analytical results from the four backwash water sampling events are summarized in Table 4-7. Samples were collected from the sample ports located in the backwash effluent discharge lines from each vessel. Unfiltered samples were analyzed for pH, turbidity, and TDS. Filtered samples (using 0.45-μm disc filters) were analyzed for soluble As, Fe, and Mn. Soluble concentrations measured during the first three backwash events ranged from 4.9 to 9.9 μg/L for arsenic and <25 to 60 μg/L for iron, suggesting removal during backwash. On October 22, 2004, the backwash on Vessel B malfunctioned, and Vessel B did not go into the fast rinse mode. The results from the October 22, 2004 backwash samples on Vessels B, C, and D had relatively elevated levels of soluble Fe and As. The arsenic levels ranged from 15.6 to 19.5 μg/L, close to the influent values. However, there was no change in the manganese levels. As discussed in Section 4.4.2, the backwash problem was caused by a malfunctioning valve that was repaired on December 2, 2004. The system backwash will be carefully monitored to assess the effect of the malfunction on the system performance in both the feed and backwash modes.

4.5.3 Distribution System Water Sampling. Distribution system samples were collected to determine if the arsenic removal system had any impact on the lead and copper level and water chemistry in the distribution system. Prior to the installation and operation of the system, baseline distribution water samples were collected at three locations on December 4 and 18, 2003, and January 8 and 21, 2004. Following the installation of the system, distribution water sampling continued on a monthly basis at the same three locations on June 15, July 13, August 10, September 8, October 5, and November 2, 2004. The samples were analyzed for pH, alkalinity, arsenic, iron, manganese, lead, and copper. The results of the distribution system sampling are summarized in Table 4-8.

Table 4-7. Backwash Water Sampling Results

Sampling Event	Vessel A						Vessel B						Vessel C						Vessel D					
	pH	Turbidity	TDS	As (soluble)	Fe (soluble)	Mn (soluble)	pH	Turbidity	TDS	As (soluble)	Fe (soluble)	Mn (soluble)	pH	Turbidity	TDS	As (soluble)	Fe (soluble)	Mn (soluble)	pH	Turbidity	TDS	As (soluble)	Fe (soluble)	Mn (soluble)
Date	S.U.	NTU	mg/L	µg/L	µg/L	µg/L	S.U.	NTU	mg/L	µg/L	µg/L	µg/L	S.U.	NTU	mg/L	µg/L	µg/L	µg/L	S.U.	NTU	mg/L	µg/L	µg/L	µg/L
06/15/04	7.4	28	648	4.9	<25	11.6	7.6	27	1,010	6.1	<25	13.2	7.6	38	864	7.4	<25	15.2	7.6	39	678	7.0	<25	14.4
07/28/04	7.9	55	770	6.5	<25	15.7	7.9	36	852	8.5	<25	17.2	7.9	50	808	9.1	29	19.0	7.9	62	888	9.9	<25	18.2
09/09/04	7.4	33	392	6.1	<25	16.8	7.7	28	698	8.8	<25	15.8	7.6	28	798	9.7	36	18.0	7.4	25	862	9.7	60	17.9
10/22/04[a]	7.9	24	612	9.1	38.2	17.5	7.9	10	816	15.6	120	15.0	7.9	16	838	18.8	154	17.4	8.1	1.5[b]	410	19.5	225	17.3

(a) Vessel B did not fast rinse properly during backwash, possibly affecting BW2 sample.
(b) Low turbidity reading compared to previous events.

Table 4-8. Distribution Sampling Results

	Location ID	DS1								DS2								DS3							
Sampling Event	Sampling Date	Stagnation Time (hrs)	pH (S.U.)	Alkalinity (mg/L as $CaCO_3$)	As (µg/L)	Fe (µg/L)	Mn (µg/L)	Pb (µg/L)	Cu (µg/L)	Stagnation Time (hrs)	pH (S.U.)	Alkalinity (mg/L as $CaCO_3$)	As (µg/L)	Fe (µg/L)	Mn (µg/L)	Pb (µg/L)	Cu (µg/L)	Stagnation Time (hrs)	pH (S.U.)	Alkalinity (mg/L as $CaCO_3$)	As (µg/L)	Fe (µg/L)	Mn (µg/L)	Pb (µg/L)	Cu (µg/L)
BL1	12/04/03	7	7.9	246	11.5	76	4.9	1.8	44.6	8	7.6	244	9.0	34	6.5	0.5	127.8	15	7.3	252	10.4	71	9.7	2.1	182.7
BL2	12/18/03	7	8.0	254	10.1	89	6.1	1.1	51.4	6.7	7.9	246	7.2	50	6.3	<0.1	217.8	14.5	7.9	282	8.8	95	10.0	1.0	155.8
BL3	01/08/04	7	7.7	268	11.8	45	5.3	1.0	53.9	7	7.6	256	8.8	<25	6.2	0.1	183.0	15	7.3	260	11.7	35	10.2	1.0	194.0
BL4	01/21/04	6	8.1	258	13.3	93	6.7	2.7	72.7	7.5	8.2	249	9.0	31	5.0	0.5	242.1	15	8.2	256	11.8	44	4.1	0.9	56.4
1	06/15/04	6	7.6	232	4.8	<25	1.7	0.5	9.1	6.2	7.6	245	5.5	<25	2.6	<0.1	6.3	14.9	7.6	232	3.8	<25	2.4	0.3	4.9
2	07/13/04	6	7.8	263	3.8	<25	3.4	0.8	27.3	6	7.8	243	4.8	<25	4.7	0.3	93.5	14.9	7.8	239	4.1	<25	4.7	2.3	74.5
3	08/10/04	6	7.8	239	3.0	<25	9.6	0.4	21.4	8.25	7.7	235	3.0	<25	6.5	0.3	62.3	15	7.8	239	3.1	<25	11.5	1.4	70.1
4	09/08/04	6	7.9	234	3.9	<25	11.4	0.4	24.8	6.5	7.9	234	4.3	<25	13.8	<0.1	94.8	15	7.9	242	4.2	<25	14.0	<0.1	73.3
5	10/05/04	6	7.6	244	4.1	<25	16.1	0.9	31.0	6	7.8	244	4.5	<25	17.6	1.7	55.1	15	7.9	244	5.0	<25	20.4	2.2	62.1
6	11/02/04	6	7.8	242	5.3	<25	10.2	1.2	45.0	8.25	8.1	246	6.1	<25	17.8	0.6	33.5	14.9	8.0	246	5.8	<25	16.9	0.9	53.9

Notes:
DS = Distribution Sampling
BL = Baseline Sampling

The results of the distribution sampling indicated a decrease in the arsenic concentrations after treatment at each of the sampling locations. Arsenic concentrations in the baseline samples ranged from 7.2 to 13.3 μg/L, whereas the concentrations measured since the treatment system was started ranged from 3.0 to 6.1 μg/L. The arsenic concentrations measured during system operation were lower than the baseline values, but typically higher than the system effluent results. There also was a slight increasing trend in arsenic concentration over time within the distribution system, corresponding to the increasing concentrations in the treated water over time.

Measured pH values in the distribution system ranged from 7.3 to 8.2 before treatment and 7.6 to 8.1 after treatment. Alkalinity levels in the distribution system ranged from 244 to 282 mg/L (as $CaCO_3$) before treatment and 232 to 263 (as $CaCO_3$) after treatment. Iron concentrations ranged from <25 to 95 μg/L before treatment and <25 μg/L after treatment. The iron concentrations in the distribution system samples decreased since the treatment system began operation. The concentrations of manganese in the distribution system samples ranged from 4.1 to 10.2 μg/L before treatment. Manganese levels appeared to have decreased initially after the initiation of the system operations, but have since increased to above baseline levels at 10.2 to 17.8 μg/L in the November 2, 2004, samples.

Lead levels in the distribution system ranged from <0.1 to 2.7 μg/L, with no samples exceeding the action level of 15 μg/L. Lead levels in the distribution system did not appear to have been affected by the treatment. Copper concentrations in the distribution system ranged from 44.6 to 242.1 μg/L before treatment, with no samples exceeding the 1,300 μg/L action level. Copper concentrations in the distribution system ranged from 4.9 to 94.8 μg/L after treatment and were generally lower than those before treatment.

4.6 System Costs

The cost-effectiveness of the system was evaluated based on the capital cost per gpm (or gpd) of design capacity and the O&M cost per 1,000 gallons of water treated. This included capital costs such as equipment, engineering, and installation and O&M costs such as media replacement and disposal, chemical supply, electrical power use, and labor.

4.6.1 Capital Costs. The capital investment costs for equipment, site engineering, and installation were $305,000 (see Table 4-9). The equipment costs included the costs for the two skid-mounted APU-300 units ($144,400), SORB 33™ media ($150/$ft^3$ or $5.34/lb to fill four vessels with a total cost of $48,000), miscellaneous materials and supplies ($3,400), and vendor's labor and travel ($22,200) for the system shakedown and startup activities. The equipment costs are 71% of the total capital investment.

The engineering costs included the costs for the design work necessary to develop the final system layout and footprint within the building, design of the piping connections up to the distribution tie-in points in the building, and the design of the electrical connection and conduit plan. The engineering costs also included the cost for the submission of the plans to the MDEQ for permit review and approval. Engineering costs amounted to $35,500 or 12% of the total capital investment.

The installation costs included the cost for labor, equipment, and materials to unload and install the skid-mounted units, perform the piping tie-ins and electrical work, and load and backwash the media. All of the piping tie-ins were completed using ductile iron pipe, valves, and fittings. Installation costs were $51,500 or 17% of the total capital investment.

Table 4-9. Summary of Capital Investment for the Brown City, MI, Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
APU Skid-Mounted System	2	$144,400	–
SORB-33 Media	320 ft^3	$48,000	–
Miscellaneous Equipment and Materials	–	$3,400	–
Vendor Labor	–	$17,500	–
Vendor Travel	–	$4,700	–
Equipment Total	–	**$218,000**	**71%**
Engineering Costs			
Subcontractor	–	$27,740	–
Vendor Labor	–	$6,680	–
Vendor Travel	–	$1,080	–
Engineering Total	–	**$35,500**	**12%**
Installation Costs			
Subcontractor	–	$42,000	–
Vendor Labor	–	$5,600	–
Vendor Travel	–	$3,900	–
Installation Total	–	**$51,500**	**17%**
Total Capital Investment	–	**$305,000**	**100%**

The total capital cost of $305,000 and equipment cost of $218,000 were converted to a unit cost of $0.06/1,000 gallon and $0.04/1,000 gallon, respectively, using a capital recovery factor (CRF) of 0.06722 based on a 3% interest rate and a 20-year return period. These calculations assumed that the system operated 24 hours a day, 7 days a week at the system design flowrate of 640 gpm. The system typically operated only 4.8 hrs/day, producing 29,711,000 gallons of water during the 6-month period, so at this rate of usage the total unit cost and equipment-only unit cost would increase to $0.38/1,000 gallon and $0.27/1,000 gallon, respectively. Using the system's rated capacity of 640 gpm (921,600 gallons per day [gpd]), the capital cost was $477 per gpm ($0.33 per gpd) and equipment-only cost was $340 per gpm ($0.24 per gpd). These calculations did not include the building construction cost.

The total cost for the addition to the existing concrete block well house was $62,602. The primary construction costs totaled $41,468 and included excavation, masonry, carpentry, and concrete floor pouring. The overhead door cost was $1,400. The building costs also included $13,048 for the roof deck work and roofing, including the overhead roof hatches. The building was finished with a wood and aluminum trim and painted white. The cost for painting was $2,135, and the heating and electrical work for the building totaled $4,550.

4.6.2 Operation and Maintenance Costs. O&M costs included only incremental costs associated with the two APU-300 units, such as media replacement and disposal, chemical supply, electricity, and labor. These costs are summarized in Table 4-10. Because media replacement and disposal did not take place during the first six months of operation, its cost per 1,000 gallons of water treated was calculated as a function of projected media run length using the vendor-estimate of $53,600 for media replacement for all four vessels. This replacement cost included costs for new media, freight, labor, travel expenses, and media profiling and disposal fee. At the vendor-estimated media capacity of 80,000 BV for As(V) or a throughput of 192 million gallons (See Table 4-4), the media replacement cost is projected to be $0.28/1,000 gallons (Figure 4-13). This cost, however, will be refined once the actual breakthrough occurs and the cost of media replacement becomes available.

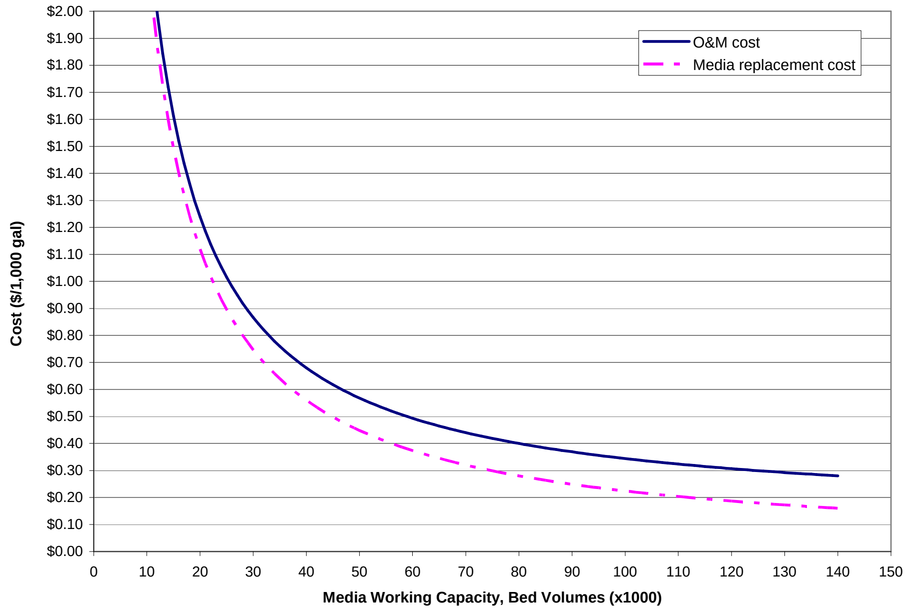


Figure 4-13. Media Replacement and O&M Cost for Brown City, MI, System (Two APU-300 Units)

Table 4-10. O&M Costs for the Brown City, MI, Treatment System

Cost Category	Value	Assumptions
Volume processed (Kgal)	29,711	Through November 30, 2004
Media Replacement and Disposal		
Media cost ($/ft^3)	$150	Vendor quote
Total media volume (ft^3)	320	Four vessels
Media replacement cost ($)	$48,000	Vendor quote
Labor cost ($)	$4,240	Vendor quote
Media disposal fee ($)	$1,360	Vendor quote
Subtotal	$53,600	Vendor quote
Media replacement and disposal cost ($/1,000 gal)	See Figure 4-13	Based upon media run length at 10 μg/L arsenic breakthrough
Chemical Usage		
Chemical cost ($)	$0.00	No additional chemicals required.
Electricity		
Electric utility charge ($/kWh)	$0.0812	Based on 2003 Detroit Edison Rate
Total usage (kWh)	57,251	From May to Nov 2004
Total electricity cost ($)	$4,771	From May to Nov 2004
Electricity cost ($/1,000 gal)	$0.16	–
Incremental cost ($/1,000 gal)	$0.07	Minus Usage from May to Nov 2003
Labor		
Average weekly labor (hrs)	3.5	30 minutes/day
Labor cost ($/1,000 gal)	$0.05	Average Labor rate = $15/hr
Total O&M Cost/1,000 gallons	See Figure 4-13	–

Because pre-chlorination was not implemented, there were no additional chemical costs associated with the installation of the two APU-300 systems. The point of chlorination will be moved before the treatment system, however, when the effluent arsenic level reaches breakthrough. This change could result in an increase in chlorine because of a change in the chlorine demand of the source water.

The incremental electrical power consumption also was reviewed. From May to November of 2003, the utility bill totaled $2,610.45 before the treatment plant was installed. From May to November of 2004, the utility bill totaled $4,770.50 after the treatment plant was installed and operational. The incremental utility cost over running the well alone before treatment is approximately $10.64/day or an additional 131 kilowatt hours (KWh) each day at $0.0812 per KWh. This increased usage may be due to the increased total dynamic head on the well pump, but it is also related to the installation of a heater/air conditioner unit in the building to maintain the building's temperature. The total cost of electricity was approximately $0.16/1000 gallons, and the incremental cost over the before-treatment cost was $0.07/1000 gallons.

The routine, non-demonstration related labor activities consume only 30 minutes per day, as noted in Section 4.4.4. The labor cost was $0.05/1,000 gallons of water treated based on this time commitment and a labor rate of $15/hr.

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APPENDIX A

OPERATIONAL DATA

Table A-1. U.S. EPA Arsenic Demonstration Project at Brown City, MI – Daily System Operation Log Sheet

Week No.	Date	Pump Hour		Well Totalizer		Flow Totalizer TA				Flow Totalizer TB				Head Loss		Pressure A/B		
		Meter	Op Hours	Meter	GAL	GPM	KGAL	Avg GPM	Cumulative Bed Volume	GPM	KGAL	Avg GPM	Cumulative Bed Volume	Tank A psi	Tank B psi	Influent psig	Effluent psig	ΔP
1	05/12/04	NA	NA	NA	NA	NR	107.229	NA	81.6	NR	125.518	NA	78.4	NR	NR	NR	NR	NA
	05/13/04	NA	NA	NA	NA	161	119.759	NA	103.7	157	136.316	NA	97.4	3.1	2.8	61	56	5
	05/14/04	NA	NA	NA	NA	159	178.436	NA	207.2	159	196.577	NA	203.7	4.4	2.8	66	60	6
	05/15/04	NA	NA	NA	NA	NR	183.837	NA	216.7	NR	201.828	NA	213.0	NR	NR	NR	NR	NA
	05/16/04	NA	NA	NA	NA	NR	228.270	NA	295.0	NR	246.131	NA	291.1	NR	NR	NR	NR	NA
2	05/17/04	NA	NA	NA	NA	160	272.865	NA	373.7	162	290.377	NA	369.1	3.2	2.9	65	58	7
	05/18/04	NA	NA	NA	NA	151	313.825	NA	445.9	161	331.255	NA	441.2	3.2	2.9	65	59	6
	05/19/04	NA	NA	NA	NA	173	318.571	NA	454.2	160	335.899	NA	449.3	3.2	2.9	60	54	6
	05/20/04	NA	NA	NA	NA	161	372.478	NA	549.3	153	389.394	NA	543.7	3.6	3.1	64	58	6
	05/21/04	NA	NA	NA	NA	160	414.647	NA	623.6	154	431.453	NA	617.8	3.6	3.1	65	60	5
	05/22/04	NA	NA	NA	NA	171	416.054	NA	626.1	170	432.858	NA	620.3	3.6	3.1	60	55	5
	05/23/04	NA	NA	NA	NA	NR	465.207	NA	712.8	NR	481.841	NA	706.7	NR	NR	NR	NR	NA
3	05/24/04	NA	NA	NA	NA	160	495.832	NA	766.8	148	512.374	NA	760.5	3.2	2.9	62	58	4
	05/25/04	NA	NA	NA	NA	167	542.984	NA	849.9	156	559.458	NA	843.5	3.1	3	62	58	4
	05/26/04	NA	NA	NA	NA	166	551.846	NA	865.6	157	568.312	NA	859.1	3.6	3	62	57	5
	05/27/04	NA	NA	NA	NA	168	598.829	NA	948.4	158	615.068	NA	941.6	3.8	3.2	62	56	6
	05/28/04	NA	NA	NA	NA	NR	646.928	NA	1033.2	NR	662.993	NA	1026.1	NR	NR	NR	NR	NA
	05/29/04	NA	NA	NA	NA	169	689.973	NA	1109.1	152	705.651	NA	1101.3	3.7	3.2	66	60	6
	05/30/04	NA	NA	NA	NA	160	704.951	NA	1135.5	151	720.591	NA	1127.6	3.2	2.8	62	57	5
4	05/31/04	NA	NA	NA	NA	166	739.799	NA	1196.9	162	755.361	NA	1188.9	3.5	3.0	63	57	6
	06/01/04	NA	NA	NA	NA	157	785.052	NA	1276.7	161	800.464	NA	1268.4	3.2	3.0	58	56	2
	06/02/04	NA	NA	NA	NA	158	830.267	NA	1356.5	161	845.019	NA	1347.0	3.5	3.0	58	57	1
	06/03/04	NA	NA	NA	NA	166	887.743	NA	1457.8	162	902.285	NA	1448.0	3.5	3.0	59	56	3
	06/04/04	NA	NA	NA	NA	157	932.469	NA	1536.6	160	946.932	NA	1526.7	3.5	3.0	58	57	1
	06/05/04	NA	NA	NA	NA	NR	978.901	NA	1618.5	NR	993.219	NA	1608.3	NR	NR	NR	NR	NA
	06/06/04	NA	NA	NA	NA	NR	1029.094	NA	1707.0	NR	1043.325	NA	1696.6	NR	NR	NR	NR	NA
5	06/07/04	NR	5.1	NA	191600	165	1076.384	NA	1790.4	169	1090.546	NA	1779.9	3.8	3.0	62	56	6
	06/08/04	NR	5.8	NA	217900	163	1129.432	152.4	1883.9	162	1143.459	152.0	1873.2	3.6	3.0	63	57	6
	06/09/04	NR	5.5	NA	208900	168	1180.313	154.2	1973.6	170	1194.214	153.8	1962.7	3.0	3.0	64	60	4
	06/10/04	NR	3.1	NA	119800	150	1209.263	155.6	2024.7	156	1223.006	154.8	2013.5	3.0	2.8	64	58	6
	06/11/04	NR	4.9	NA	63900	169	1259.343	170.3	2113.0	169	1273.014	170.1	2101.6	4.6	2.8	64	58	6
	06/12/04	NR	NA	NA	NA	NR	1273.504	NA	2137.9	NR	1287.035	NA	2126.3	NR	NR	NR	NR	NA
	06/13/04	NR	NA	NA	NA	NR	1323.025	NA	2225.3	NR	1336.439	NA	2213.5	NR	NR	NR	NR	NA
6	06/14/04	NR	5.6	NA	204400	168	1373.086	149.0	2313.5	161	1386.065	147.7	2301.0	3.3	3	64	59	5
	06/15/04	NR	4.5	NA	170700	175	1414.744	154.3	2387.0	163	1427.542	153.6	2374.1	3.4	3	65	60	5
	06/16/04	NR	2.6	NA	97100	172	1438.503	152.3	2428.9	165	1451.468	153.4	2416.3	3.6	3.4	62	56	6
	06/17/04	NR	5.5	NA	209200	170	1491.156	159.6	2521.7	164	1504.426	160.5	2509.6	4.6	3	64	56	8
	06/18/04	NR	5.4	NA	181900	162	1537.023	141.6	2602.6	168	1550.457	142.1	2590.8	4.8	3	65	58	7
	06/19/04	NR	3.7	NA	143200	159	1571.981	157.5	2664.2	162	1585.942	159.8	2653.4	4.1	3	64	59	5
	06/20/04	NR	6.1	NA	231500	163	1631.160	161.7	2768.6	188	1645.949	164.0	2759.2	4.8	3.5	65	59	6

Table A-1. U.S. EPA Arsenic Demonstration Project at Brown City, MI – Daily System Operation Log Sheet (page 2 of 12)

Week No.	Date	Pump Hour		Well Totalizer		Flow Totalizer TA				Flow Totalizer TB				Head Loss		Pressure A/B		
		Meter	Op Hours	Meter	GAL	GPM	KGAL	Avg GPM	Cumulative Bed Volume	GPM	KGAL	Avg GPM	Cumulative Bed Volume	Tank A psi	Tank B psi	Influent psig	Effluent psig	ΔP
7	06/21/04	NR	2.2	NA	85000	167	1652.422	161.1	2806.0	156	1667.722	164.9	2797.6	4	3.2	64	58	6
	06/22/04	157.8	2.8	63005400	108800	170	1679.876	163.4	2854.4	170	1695.329	164.3	2846.2	5.4	3	63	56	7
	06/23/04	163.4	5.6	63250100	244700	170	1740.701	181.0	2961.7	179	1756.855	183.1	2954.7	3.6	3.6	64	58	6
	06/24/04	168.1	4.7	63426100	176000	167	1784.262	154.5	3038.5	175	1800.935	156.3	3032.4	5	3.2	66	60	6
	06/25/04	168.4	0.3	63437900	11800	170	1787.186	162.4	3043.6	172	1803.885	163.9	3037.6	3.6	3.1	68	62	6
	06/26/04	NR	NA	63640100	202200	NR	1837.227	NA	3131.9	NR	1854.253	NA	3126.4	NR	NR	NR	NR	NA
	06/27/04	NR	NA	63835800	195700	NR	1885.586	NA	3217.1	NR	1903.133	NA	3212.6	NR	NR	NR	NR	NA
8	06/28/04	184.5	NA	64039500	203700	153	1936.024	NA	3306.1	169	1954.016	NA	3302.3	3.4	3	64	58	6
	06/29/04	189.0	4.5	64209400	169900	158	1978.058	155.7	3380.2	156	1996.398	157.0	3377.1	3.4	3	66	60	6
	06/30/04	189.2	0.2	64219700	10300	157	1980.588	210.8	3384.6	162	1998.944	212.2	3381.6	3.4	3	66	60	6
	07/01/04	193.7	4.5	64421300	201600	156	2030.435	184.6	3472.5	161	2049.123	185.8	3470.0	3.4	3	64	58	6
	07/02/04	199.7	6	64634600	213300	164	2083.219	146.6	3565.6	156	2102.226	147.5	3563.7	3.4	3	62	56	6
	07/03/04	205.3	5.6	64847800	213200	NR	2135.890	156.8	3658.5	NR	2155.313	158.0	3657.3	NR	NR	NR	NR	NA
	07/04/04	210.5	5.2	65042600	194800	NR	2184.052	154.4	3743.4	NR	2203.936	155.8	3743.0	NR	NR	NR	NR	NA
9	07/05/04	213.1	2.6	65109500	66900	163	2199.704	100.3	3771.0	161	2219.753	101.4	3770.9	3.8	2.8	62	56	6
	07/06/04	216.7	3.6	65243800	134300	164	2233.734	157.5	3831.0	154	2254.023	158.7	3831.3	3.8	3	62	56	6
	07/07/04	222.3	5.6	65450500	206700	150	2284.732	151.8	3920.9	156	2305.502	153.2	3922.1	3.8	3	62	56	6
	07/08/04	226.8	4.5	65625100	174600	157	2327.858	159.7	3996.9	178	2349.120	161.5	3999.0	3.8	3	64	59	5
	07/09/04	226.8	0	65625100	0	162	2338.512	NA	4015.7	161	2359.932	NA	4018.0	3.6	3	62	58	4
	07/10/04	232.1	5.3	65825900	200800	NR	2377.569	122.8	4084.6	NR	2399.256	123.7	4087.4	NR	NR	NR	NR	NA
	07/11/04	237.6	5.5	66032000	206100	NR	2428.535	154.4	4174.4	NR	2450.728	156.0	4178.1	NR	NR	NR	NR	NA
10	07/12/04	243.1	5.5	66234900	202900	162	2478.721	152.1	4262.9	167	2501.298	153.2	4267.3	3.7	3.6	64	58	6
	07/13/04	247.8	4.7	66416400	181500	159	2522.278	154.5	4339.7	165	2545.293	156.0	4344.9	3.7	3	64	59	5
	07/14/04	251.3	3.5	66544400	128000	153	2555.110	156.3	4397.6	164	2578.485	158.1	4403.4	3.6	2.8	64	58	6
	07/15/04	253.2	1.9	66614900	70500	154	2572.546	152.9	4428.4	166	2596.063	154.2	4434.4	3.6	3	62	57	5
	07/16/04	258.5	5.3	66811300	196400	155	2621.027	152.5	4513.8	172	2645.117	154.3	4520.9	3.6	3	61	56	5
	07/17/04	264.0	5.5	NR	NA	NR	2671.860	154.0	4603.5	NR	2696.327	155.2	4611.2	NR	NR	NR	NR	NA
	07/18/04	268.8	4.8	NR	NA	NR	2716.725	155.8	4682.6	NR	2741.592	157.2	4691.0	NR	NR	NR	NR	NA
11	07/19/04	273.0	4.2	67352300	NA	133.4	NA	NA	NA	157.8	2778.792	147.6	4756.6	3.7	3	64	60	4
	07/20/04	273.7	0.7	67380100	27800	169	2761.547	NA	4761.6	174	2786.859	192.1	4770.8	3.7	3.6	60	54	6
	07/21/04	274.3	0.6	67403600	23500	160.9	2767.358	161.4	4771.8	171	2792.739	163.3	4781.1	3.7	3	63	59	4
	07/22/04	281.7	7.4	67475800	72200	162	2785.192	40.2	4803.3	162	2810.777	40.6	4812.9	2.8	3.2	63	56	7
	07/23/04	287.1	5.4	67679100	203300	160	2835.338	154.8	4891.7	161	2861.406	156.3	4902.2	2.8	3	62	58	4
	07/24/04	292.8	5.7	67893400	214300	NR	2888.310	154.9	4985.1	NR	2915.004	156.7	4996.7	NR	NR	NR	NR	NA
	07/25/04	293.2	0.4	68107000	213600	NR	2940.996	2195.3	5078.0	NR	2968.242	2218.3	5090.6	NR	NR	NR	NR	NA

Table A-1. U.S. EPA Arsenic Demonstration Project at Brown City, MI – Daily System Operation Log Sheet (page 3 of 12)

		Pump Hour		Well Totalizer		Flow Totalizer TA				Flow Totalizer TB				Head Loss		Pressure A/B		
Week No.	Date	Meter	Op Hours	Meter	GAL	GPM	KGAL	Avg GPM	Cumulative Bed Volume	GPM	KGAL	Avg GPM	Cumulative Bed Volume	Tank A psi	Tank B psi	Influent psig	Effluent psig	ΔP
12	07/26/04	299.2	6	68332700	225700	173	2996.551	154.3	5176.0	167	3024.475	156.2	5189.7	3	3.6	64	58	6
	07/27/04	304.2	5	68516400	183700	151	3041.739	150.6	5255.6	169	3069.980	151.7	5270.0	3	3.6	64	58	6
	07/28/04	305.2	1	68525600	9200	152	3044.011	37.9	5259.6	166	3072.286	38.4	5274.0	2.8	3.6	62	56	6
	07/29/04	310.4	5.2	68747400	221800	175	3098.278	173.9	5355.3	179	3127.310	176.4	5371.0	3.2	3.4	62	58	4
	07/30/04	315.5	5.1	68942600	195200	181	3146.499	157.6	5440.3	164	3175.843	158.6	5456.6	3.2	3.4	62	58	4
	07/31/04	320.3	4.8	69121100	178500	181	3190.561	153.0	5518.0	163	3220.191	154.0	5534.8	3.2	3.4	62	58	4
	08/01/04	324.4	4.1	69275700	154600	162	3228.229	153.1	5584.4	161	3258.260	154.8	5601.9	2.4	3.2	64	58	6
13	08/02/04	325.8	1.4	69327700	52000	164	3241.637	159.6	5608.1	154	3271.628	159.1	5625.5	2.8	3.6	60	56	4
	08/03/04	331.6	5.8	69545300	217600	177	3295.618	155.1	5703.3	171	3325.930	156.0	5721.2	3	3.6	64	57	7
	08/04/04	337.9	6.3	69779600	234300	164	3353.549	153.3	5805.4	163	3384.293	154.4	5824.1	3	3.6	66	60	6
	08/05/04	342.7	4.8	69959000	179400	167	3397.916	154.1	5883.6	170	3428.890	154.9	5902.8	3	3.4	68	62	6
	08/06/04	342.8	0.1	69961400	2400	186	3398.509	98.8	5884.7	169	3429.493	100.5	5903.8	3	3.6	62	58	4
	08/07/04	348.3	5.5	70164600	203200	164	3448.819	152.5	5973.4	171	3480.127	153.4	5993.1	3	3.2	62	58	4
	08/08/04	353.6	5.3	70365100	200500	179	3498.296	155.6	6060.6	182	3530.098	157.1	6081.2	3	3.2	64	60	4
14	08/09/04	358.8	5.2	70560900	195800	177	3546.467	154.4	6145.5	174	3578.485	155.1	6166.5	3	4	63	58	5
	08/10/04	363.8	5	70745700	184800	170	3592.056	152.0	6225.9	163	3624.430	153.1	6247.5	3	3.2	64	58	6
	08/11/04	365.0	1.2	70794000	48300	160	3604.023	166.2	6247.0	166	3636.553	168.4	6268.9	2.9	3.4	61	56	5
	08/12/04	369.1	4.1	70952300	158300	NR	3643.034	158.6	6315.8	NR	3675.998	160.3	6338.5	NR	NR	NR	NR	NA
	08/13/04	374.3	5.2	71143500	191200	NR	3690.203	151.2	6399.0	NR	3723.375	151.8	6422.0	NR	NR	NR	NR	NA
	08/14/04	379.3	5	71332200	188700	NR	3736.696	155.0	6480.9	NR	3770.260	156.3	6504.7	NR	NR	NR	NR	NA
	08/15/04	384.1	4.8	71513000	180800	171	3781.307	154.9	6559.6	160	3815.255	156.2	6584.0	3	3.6	65	58	7
15	08/16/04	388.8	4.7	71690100	177100	175	3825.047	155.1	6636.7	170	3859.337	156.3	6661.7	3	3.6	62	57	5
	08/17/04	394.0	5.2	71877100	187000	161	3871.220	148.0	6718.1	172	3905.800	148.9	6743.6	3	3.6	66	59	7
	08/18/04	395.0	1	71913300	36200	166	3880.057	147.3	6733.7	167	3914.767	149.4	6759.5	3	3.6	60	56	4
	08/19/04	401.3	6.3	72113900	200600	168	3929.629	131.1	6821.1	170	3964.661	132.0	6847.4	3	3.6	62	57	5
	08/20/04	407.1	5.8	72331600	217700	162	3983.447	154.6	6916.0	160	4018.874	155.8	6943.0	3	3.8	65	59	6
	08/21/04	412.5	5.4	72533900	202300	170	4033.436	154.3	7004.1	169	4069.234	155.4	7031.8	3	3.8	62	57	5
	08/22/04	418.1	5.6	72743700	209800	161	4085.240	154.2	7095.5	172	4121.514	155.6	7124.0	3	3.8	60	56	4
16	08/23/04	423.9	5.8	72961300	217600	NR	4138.999	154.5	7190.3	NR	4175.703	155.7	7219.5	NR	NR	NR	NR	NA
	08/24/04	428.5	4.6	73163600	202300	170	4189.020	181.2	7278.5	164	4226.111	182.6	7308.4	3	3.8	65	59	6
	08/25/04	434.3	5.8	73383000	219400	NR	4243.217	155.7	7374.0	NR	4280.706	156.9	7404.7	NR	NR	NR	NR	NA
	08/26/04	449.3	15	73938800	555800	NR	4381.027	153.1	7617.0	NR	4419.407	154.1	7649.2	NR	NR	NR	NR	NA
	08/27/04	455.3	6	74163100	224300	NR	4436.595	154.4	7715.0	NR	4475.420	155.6	7748.0	NR	NR	NR	NR	NA
	08/28/04	458.4	3.1	74280300	117200	150	4464.967	152.5	7765.0	157	4504.061	154.0	7798.5	2.8	3	64	59	5
	08/29/04	460.2	1.8	74348000	67700	NR	4482.336	160.8	7795.6	NR	4521.507	161.5	7829.2	NR	NR	NR	NR	NA

Table A-1. U.S. EPA Arsenic Demonstration Project at Brown City, MI – Daily System Operation Log Sheet (page 4 of 12)

Week No.	Date	Pump Hour		Well Totalizer		Flow Totalizer TA				Flow Totalizer TB				Head Loss		Pressure A/B		
		Meter	Op Hours	Meter	GAL	GPM	KGAL	Avg GPM	Cumulative Bed Volume	GPM	KGAL	Avg GPM	Cumulative Bed Volume	Tank A psi	Tank B psi	Influent psig	Effluent psig	ΔP
17	08/30/04	465.5	5.3	74545800	197800	NR	4531.284	153.9	7881.9	NR	4570.822	155.1	7916.2	NR	NR	NR	NR	NA
	08/31/04	470.8	5.3	74739700	193900	184	4579.144	150.5	7966.3	179	4619.151	152.0	8001.4	3.2	4	64	60	4
	09/01/04	471.5	0.7	74761500	21800	174	4584.525	128.1	7975.8	169	4624.574	129.1	8011.0	3	3.4	62	54	8
	09/02/04	476.7	5.2	74955600	194100	NR	4632.531	153.9	8060.4	NR	4672.952	155.1	8096.3	NR	NR	NR	NR	NA
	09/03/04	482.1	5.4	75159600	204000	NR	4682.929	155.5	8149.3	NR	4723.924	157.3	8186.1	NR	NR	NR	NR	NA
	09/04/04	486.9	4.8	75339700	180100	NR	4727.469	154.7	8227.8	NR	4768.626	155.2	8264.9	NR	NR	NR	NR	NA
	09/05/04	491.6	4.7	75518500	178800	NR	4771.724	156.9	8305.9	NR	4813.205	158.1	8343.5	NR	NR	NR	NR	NA
18	09/06/04	492.3	0.7	75548500	30000	162	4779.803	192.4	8320.1	169	4821.392	194.9	8358.0	3	4	60	56	4
	09/07/04	497.8	5.5	75755200	206700	NR	4830.332	153.1	8409.2	NR	4872.174	153.9	8447.5	NR	NR	NR	NR	NA
	09/08/04	502.3	4.5	75914600	159400	163	4869.733	145.9	8478.7	161	4911.832	146.9	8517.4	3	3.2	62	56	6
	09/09/04	507.9	5.6	76123800	209200	170	4921.357	153.6	8569.7	162	4963.877	154.9	8609.2	3	3.8	65	60	5
	09/10/04	509.8	1.9	76194300	70500	NR	4938.969	154.5	8600.7	NR	4980.815	148.6	8639.1	NR	NR	NR	NR	NA
	09/11/04	515.2	5.4	76396100	201800	NR	4989.458	155.8	8689.8	NR	5030.742	154.1	8727.1	NR	NR	NR	NR	NA
	09/12/04	520.3	5.1	76586900	190800	NR	5037.255	156.2	8774.0	NR	5077.936	154.2	8810.3	NR	NR	NR	NR	NA
19	09/13/04	525.2	4.9	76771600	184700	NR	5083.534	157.4	8855.6	NR	5123.582	155.3	8890.8	NR	NR	NR	NR	NA
	09/14/04	528.3	3.1	76890900	119300	158	5113.468	160.9	8908.4	156	5153.076	158.6	8942.8	2.6	3	64	58	6
	09/15/04	530.7	2.4	76980700	89800	NR	5136.039	156.7	8948.2	NR	5175.191	153.6	8981.8	NR	NR	NR	NR	NA
	09/16/04	538.8	8.1	77193700	213000	NR	5189.433	109.9	9042.3	NR	5227.659	108.0	9074.3	NR	NR	NR	NR	NA
	09/17/04	542.5	3.7	77415500	221800	167	5245.048	250.5	9140.4	172	5282.371	246.5	9170.8	3	3.8	63	57	6
	09/18/04	547.4	4.9	77599000	183500	NR	5291.023	156.4	9221.5	NR	5327.558	153.7	9250.4	NR	NR	NR	NR	NA
	09/19/04	552.0	4.6	77771300	172300	NR	5334.175	156.3	9297.6	NR	5369.943	153.6	9325.2	NR	NR	NR	NR	NA
20	09/20/04	557.0	5	77955300	184000	NR	5380.325	153.8	9378.9	NR	5415.248	151.0	9405.0	NR	NR	NR	NR	NA
	09/21/04	560.7	3.7	78046300	91000	167	5416.220	161.7	9442.2	148	5450.568	159.1	9467.3	2.4	4	65	60	5
	09/22/04	564.4	3.7	78235900	189600	NR	5451.256	157.8	9504.0	NR	5484.917	154.7	9527.9	NR	NR	NR	NR	NA
	09/23/04	570.2	5.8	78456400	220500	166	5506.044	157.4	9600.6	170	5538.703	154.6	9622.7	2.6	3.6	64	58	6
	09/24/04	576.2	6	78680100	223700	161	5562.250	156.1	9699.7	172	5593.930	153.4	9720.1	2.6	4.8	64	58	6
	09/25/04	583.6	7.4	78955300	275200	NR	5631.430	155.8	9821.7	NR	5662.127	153.6	9840.3	NR	NR	NR	NR	NA
	09/26/04	588.3	4.7	79130800	175500	NR	5675.510	156.3	9899.4	NR	5705.434	153.6	9916.7	NR	NR	NR	NR	NA
21	09/27/04	593.2	4.9	79315200	184400	NR	5721.823	157.5	9981.0	NR	5750.926	154.7	9996.9	NR	NR	NR	NR	NA
	09/28/04	599.0	5.8	79521400	206200	171	5773.682	149.0	10072.5	177	5801.817	146.2	10086.6	3	3.8	64	58	6
	09/29/04	599.5	0.5	79558200	36800	NR	5782.936	308.5	10088.8	NR	5810.924	303.6	10102.7	NR	NR	NR	NR	NA
	09/30/04	605.7	6.2	79755100	196900	NR	5832.344	132.8	10175.9	NR	5859.629	130.9	10188.6	NR	NR	NR	NR	NA
	10/01/04	610.7	5	79958900	203800	164	5883.586	170.8	10266.2	169	5910.058	168.1	10277.5	3	3.4	62	57	5
	10/02/04	616.1	5.4	80161900	203000	NR	5934.522	157.2	10356.1	NR	5960.125	154.5	10365.7	NR	NR	NR	NR	NA
	10/03/04	621.5	5.4	80332000	170100	NR	5977.235	131.8	10431.4	NR	6002.108	129.6	10439.8	NR	NR	NR	NR	NA

Table A-1. U.S. EPA Arsenic Demonstration Project at Brown City, MI – Daily System Operation Log Sheet (page 5 of 12)

Week No.	Date	Pump Hour		Well Totalizer		Flow Totalizer TA				Flow Totalizer TB				Head Loss		Pressure A/B		
		Meter	Op Hours	Meter	GAL	GPM	KGAL	Avg GPM	Cumulative Bed Volume	GPM	KGAL	Avg GPM	Cumulative Bed Volume	Tank A psi	Tank B psi	Influent psig	Effluent psig	ΔP
22	10/04/04	621.5	0	80332000	0	NR	5977.235	NA	10431.4	NR	6002.108	NA	10439.8	NR	NR	NR	NR	NA
	10/05/04	626.7	5.2	80526700	194700	172	6026.088	156.6	10517.5	158	6050.130	153.9	10524.4	3.2	4	60	56	4
	10/06/04	632.0	5.3	80725200	198500	NR	6075.869	156.5	10605.3	NR	6099.067	153.9	10610.7	NR	NR	NR	NR	NA
	10/07/04	636.3	4.3	80911300	186100	173	6122.481	180.7	10687.5	166	6145.029	178.1	10691.8	3	4	64	58	6
	10/08/04	641.1	4.8	81093000	181700	NR	6168.076	158.3	10767.9	NR	6189.880	155.7	10770.8	NR	NR	NR	NR	NA
	10/09/04	645.6	4.5	81264000	171000	NR	6210.960	158.8	10843.5	NR	6232.058	156.2	10845.2	NR	NR	NR	NR	NA
	10/10/04	645.6	0	81264000	0	NR	6210.960	NA	10843.5	NR	6232.058	NA	10845.2	NR	NR	NR	NR	NA
23	10/11/04	650.9	5.3	81463600	199600	165	6261.015	157.4	10931.7	162	6281.302	154.9	10932.0	2.6	2.8	60	56	4
	10/12/04	658.9	8	81763200	299600	163	6336.357	157.0	11064.6	164	6355.360	154.3	11062.6	2.8	3	64	59	5
	10/13/04	663.1	4.2	81919800	156600	NR	6373.468	147.3	11130.0	NR	6391.866	144.9	11127.0	NR	NR	NR	NR	NA
	10/14/04	672.6	9.5	82271900	352100	166	6461.988	155.3	11286.1	158	6479.542	153.8	11281.6	2.8	3.6	68	62	6
	10/15/04	677.1	4.5	82448800	176900	NR	6506.433	164.6	11364.4	NR	6523.402	162.4	11358.9	NR	NR	NR	NR	NA
	10/16/04	677.1	0	82448800	0	NR	6506.433	NA	11364.4	NR	6523.402	NA	11358.9	NR	NR	NR	NR	NA
	10/17/04	682.4	5.3	82647300	198500	NR	6556.288	156.8	11452.3	NR	6572.713	155.1	11445.8	NR	NR	NR	NR	NA
24	10/18/04	687.5	5.1	82840100	192800	NR	6604.728	158.3	11537.7	NR	6620.624	156.6	11530.3	NR	NR	NR	NR	NA
	10/19/04	692.8	5.3	83010200	170100	166	6647.529	134.6	11613.2	165	6662.841	132.8	11604.7	2.8	4	66	59	7
	10/20/04	693.1	0.3	83023800	13600	NR	6650.931	189.0	11619.2	NR	6666.199	186.6	11610.7	NR	NR	NR	NR	NA
	10/21/04	698.1	5	83211700	187900	NR	6698.260	157.8	11702.6	NR	6712.851	155.5	11692.9	NR	NR	NR	NR	NA
	10/22/04	703.2	5.1	83399200	187500	164	6745.434	154.2	11785.8	170	6759.491	152.4	11775.2	2.9	5	64	58	6
	10/23/04	705.3	2.1	83480200	81000	NR	6765.973	163.0	11822.0	NR	6777.897	146.1	11807.6	NR	NR	NR	NR	NA
	10/24/04	712.6	7.3	83674400	194200	NR	6814.714	111.3	11908.0	NR	6826.266	110.4	11892.9	NR	NR	NR	NR	NA
25	10/25/04	717.6	5	83862200	187800	NR	6861.857	157.1	11991.1	NR	6872.979	155.7	11975.3	NR	NR	NR	NR	NA
	10/26/04	722.0	4.4	84026900	164700	NR	6903.227	156.7	12064.0	NR	6913.946	155.2	12047.5	NR	NR	NR	NR	NA
	10/27/04	722.0	0	84026900	0	169	6903.227	NA	12064.0	171	6913.946	NA	12047.5	2.8	3	64	60	4
	10/28/04	727.0	5	84213400	186500	NR	6949.989	155.9	12146.5	NR	6960.326	154.6	12129.3	NR	NR	NR	NR	NA
	10/29/04	732.1	5.1	84406700	193300	NR	6998.465	158.4	12232.0	NR	7008.371	157.0	12214.0	NR	NR	NR	NR	NA
	10/30/04	736.5	4.4	84572400	165700	NR	7039.997	157.3	12305.2	NR	7049.552	156.0	12286.6	NR	NR	NR	NR	NA
	10/31/04	736.5	0	84572400	0	NR	7039.997	NA	12305.2	NR	7049.552	NA	12286.6	NR	NR	NR	NR	NA
26	11/01/04	740.1	3.6	84959000	NA	NR	7089.632	229.8	12392.7	NR	7098.683	227.5	12373.2	NR	NR	NR	NR	NA
	11/02/04	745.1	5	84770000	NA	163	7137.105	158.2	12476.4	151	7145.650	156.6	12456.0	3	3.2	64	60	4
	11/03/04	746.3	1.2	85004400	NA	NR	7148.444	157.5	12496.4	NR	7156.908	156.4	12475.9	NR	NR	NR	NR	NA
	11/04/04	751.3	5	85189200	184800	170	7194.811	154.6	12578.1	167	7202.886	153.3	12556.9	3	3.2	64	58	6
	11/05/04	756.2	4.9	85374400	185200	NR	7241.365	158.3	12660.2	NR	7249.096	157.2	12638.4	NR	NR	NR	NR	NA
	11/06/04	756.4	0.2	85388500	14100	173	7246.114	395.8	12668.6	159	7253.858	396.8	12646.8	3	3	62	52	10
	11/07/04	761.1	4.7	85564300	175800	NR	7289.078	152.4	12744.4	NR	7296.407	150.9	12721.8	NR	NR	NR	NR	NA

Table A-1. U.S. EPA Arsenic Demonstration Project at Brown City, MI – Daily System Operation Log Sheet (page 6 of 12)

Week No.	Date	Pump Hour		Well Totalizer		Flow Totalizer TA				Flow Totalizer TB				Head Loss		Pressure A/B		
		Meter	Op Hours	Meter	GAL	GPM	KGAL	Avg GPM	Cumulative Bed Volume	GPM	KGAL	Avg GPM	Cumulative Bed Volume	Tank A psi	Tank B psi	Influent psig	Effluent psig	ΔP
27	11/08/04	766.2	5.1	85755800	191500	169	7337.275	157.5	12829.3	172	7344.173	156.1	12806.0	3	3	62	56	6
	11/09/04	771.2	5	85931700	175900	162	7381.504	147.4	12907.3	161	7388.015	146.1	12883.3	3	3	66	60	6
	11/10/04	771.8	0.6	85958700	27000	164	7388.376	190.9	12919.4	163	7394.869	190.4	12895.4	3	4	66	62	4
	11/11/04	776.5	4.7	86128100	169400	NR	7430.962	151.0	12994.5	NR	7436.970	149.3	12969.7	NR	NR	NR	NR	NA
	11/12/04	781.4	4.9	86312100	184000	NR	7477.247	157.4	13076.1	NR	7482.808	155.9	13050.5	NR	NR	NR	NR	NA
	11/13/04	785.9	4.5	86481600	169500	NR	7519.882	157.9	13151.3	NR	7525.004	156.3	13124.9	NR	NR	NR	NR	NA
	11/14/04	787.5	1.6	86542300	60700	141.7	7535.594	163.7	13179.0	144.4	7540.687	163.4	13152.5	3	4	62	59	3
28	11/15/04	791.1	3.6	86672300	130000	NR	7567.866	149.4	13235.9	NR	7572.517	147.4	13208.6	NR	NR	NR	NR	NA
	11/16/04	796.0	4.9	86855300	183000	171	7613.893	156.6	13317.1	175	7618.088	155.0	13289.0	3	3	64	58	6
	11/17/04	800.5	4.5	87026700	171400	166	7657.378	161.1	13393.7	155	7661.282	160.0	13365.2	3	3	62	60	2
	11/18/04	801.4	0.9	87058800	32100	NR	7665.106	143.1	13407.4	NR	7668.862	140.4	13378.5	NR	NR	NR	NR	NA
	11/19/04	806.4	5	87246400	187600	NR	7712.296	157.3	13490.6	NR	7715.604	155.8	13460.9	NR	NR	NR	NR	NA
	11/20/04	811.3	4.9	87428700	182300	NR	7758.117	155.9	13571.3	NR	7761.055	154.6	13541.1	NR	NR	NR	NR	NA
	11/21/04	815.9	4.6	87600700	172000	NR	7801.389	156.8	13647.6	NR	7803.942	155.4	13616.7	NR	NR	NR	NR	NA
29	11/22/04	815.9	0	87600700	0	NR	7801.389	NA	13647.6	NR	7803.942	NA	13616.7	NR	NR	NR	NR	NA
	11/23/04	815.9	0	87730000	129300	163	7826.418	NA	13691.8	165	7836.342	NA	13673.8	2.8	2.8	62	56	6
	11/24/04	817.7	1.8	87799700	69700	NR	7851.447	231.7	13735.9	NR	7836.652	2.9	13674.4	NR	NR	NR	NR	NA
	11/25/04	822.9	5.2	87996100	196400	NR	7900.857	158.4	13823.0	NR	7836.652	NA	13674.4	NR	NR	NR	NR	NA
	11/26/04	822.9	0	87996100	0	NR	7900.857	NA	13823.0	NR	7836.652	NA	13674.4	NR	NR	NR	NR	NA
	11/27/04	829.7	6.8	88252800	256700	NR	7965.340	158.0	13936.7	NR	NR	NA	NA	NR	NR	NR	NR	NA
	11/28/04	834.5	4.8	88433600	180800	NR	8010.916	158.3	14017.1	NR	NR	NA	NA	NR	NR	NR	NR	NA
30	11/29/04	834.5	0	88433600	0	176	8021.543	NA	14035.8	NR	7836.652	NA	13674.4	2.8	3	62	56	6
	11/30/04	843.7	9.2	88633600	200000	166	8061.260	72.0	14105.8	NR	7836.652	NA	13674.4	2.8	3	64	58	6

Table A-1. U.S. EPA Arsenic Demonstration Project at Brown City, MI – Daily System Operation Log Sheet (page 7 of 12)

Week No.	Date	Flow Totalizer TC				Flow Totalizer TD				Head Loss		Pressure C/D		
		GPM	KGAL	Avg GPM	Cumulative Bed Volume	GPM	KGAL	Avg GPM	Cumulative Bed Volume	Tank C psi	Tank D psi	Influent psig	Effluent psig	ΔP
1	05/12/04	NR	109.790	NA	70.8	NR	114.571	NA	77.3	NR	NR	NR	NR	NA
	05/13/04	147	119.673	NA	88.2	148	125.300	NA	96.2	2.6	1.7	52	56	-4
	05/14/04	126	175.054	NA	185.9	150	184.938	NA	201.4	2.3	1.5	64	62	2
	05/15/04	NR	179.684	NA	194.0	NR	189.859	NA	210.1	NR	NR	NR	NR	NA
	05/16/04	NR	220.452	NA	265.9	NR	233.650	NA	287.3	NR	NR	NR	NR	NA
2	05/17/04	161	262.550	NA	340.1	161	277.445	NA	364.5	2.2	1.2	64	60	4
	05/18/04	151	300.841	NA	407.6	159	317.329	NA	434.8	2.2	1.2	64	60	4
	05/19/04	153	305.065	NA	415.1	133	321.661	NA	442.4	2.2	1.2	60	54	6
	05/20/04	163	355.552	NA	504.1	165	373.048	NA	533.0	2.6	1.2	62	58	4
	05/21/04	160	395.179	NA	574.0	157	414.685	NA	606.5	2.6	1.2	66	60	6
	05/22/04	141	396.406	NA	576.1	146	416.038	NA	608.8	2.6	1.2	63	58	5
	05/23/04	NR	442.715	NA	657.8	NR	463.226	NA	692.0	NR	NR	NR	NR	NA
3	05/24/04	150	491.501	NA	743.8	153	492.931	NA	744.4	2.4	1.2	64	59	5
	05/25/04	156	515.886	NA	786.8	160	538.692	NA	825.1	NR	1.2	64	59	5
	05/26/04	160	524.235	NA	801.5	161	547.306	NA	840.3	2.5	1.4	62	57	5
	05/27/04	161	568.329	NA	879.3	166	593.048	NA	920.9	2.7	1.6	62	56	6
	05/28/04	NR	613.441	NA	958.8	NR	639.870	NA	1003.5	NR	NR	NR	NR	NA
	05/29/04	160	654.642	NA	1031.4	151	681.960	NA	1077.7	2.7	1.4	66	62	4
	05/30/04	155	668.179	NA	1055.3	153	696.401	NA	1103.2	2.7	1.5	62	58	4
4	05/31/04	154	701.103	NA	1113.4	162	730.179	NA	1162.7	2.7	2	63	58	5
	06/01/04	151	743.762	NA	1188.6	166	773.887	NA	1239.8	2.6	2.3	60	56	4
	06/02/04	151	786.476	NA	1263.9	163	817.877	NA	1317.4	2.6	2.3	60	56	4
	06/03/04	153	840.696	NA	1359.5	162	873.881	NA	1416.1	2.6	2.3	60	56	4
	06/04/04	151	882.967	NA	1434.0	163	917.388	NA	1492.8	2.7	2.3	63	58	5
	06/05/04	NR	926.814	NA	1511.3	NR	962.458	NA	1572.3	NR	NR	NR	NR	NA
	06/06/04	NR	974.219	NA	1594.9	NR	1011.296	NA	1658.4	NR	NR	NR	NR	NA
5	06/07/04	148	1019.011	NA	1673.9	156	1057.645	NA	1740.1	2.6	1.4	62	56	6
	06/08/04	151	1069.078	143.9	1762.2	155	1109.166	148.0	1830.9	2.6	1.4	63	58	5
	06/09/04	157	1117.091	145.5	1846.8	160	1158.868	150.6	1918.6	2.2	1	64	60	4
	06/10/04	149	1144.636	148.1	1895.4	144	1187.023	151.4	1968.2	2.8	1.2	64	60	4
	06/11/04	152	1191.852	160.6	1978.6	165	1235.582	165.2	2053.8	2.4	1.2	65	60	5
	06/12/04	NR	1204.935	NA	2001.7	NR	1249.005	NA	2077.5	NR	NR	NR	NR	NA
	06/13/04	NR	1251.707	NA	2084.2	NR	1297.311	NA	2162.7	NR	NR	NR	NR	NA
6	06/14/04	161	1298.811	140.2	2167.2	160	1345.953	144.8	2248.4	2.6	1.4	64	60	4
	06/15/04	156	1338.089	145.5	2236.5	168	1386.452	150.0	2319.8	2.6	1.4	66	61	5
	06/16/04	147	1361.052	147.2	2277.0	158	1408.409	140.8	2358.6	3.4	2.4	61	56	5
	06/17/04	158	1407.619	141.1	2359.1	158	1454.439	139.5	2439.7	3	2.2	62	57	5
	06/18/04	160	1448.061	124.8	2430.4	156	1494.498	123.6	2510.3	3	2.2	64	59	5
	06/19/04	150	1479.695	142.5	2486.1	155	1525.727	140.7	2565.4	3	2.8	64	60	4
	06/20/04	151	1531.712	142.1	2577.9	150	1577.346	141.0	2656.4	3.2	2.2	65	59	6

Table A-1. U.S. EPA Arsenic Demonstration Project at Brown City, MI – Daily System Operation Log Sheet (page 8 of 12)

Week No.	Date	Flow Totalizer TC				Flow Totalizer TD				Head Loss		Pressure C/D		
		GPM	KGAL	Avg GPM	Cumulative Bed Volume	GPM	KGAL	Avg GPM	Cumulative Bed Volume	Tank C psi	Tank D psi	Influent psig	Effluent psig	ΔP
7	06/21/04	147	1550.962	145.8	2611.8	150	1596.585	145.8	2690.3	3.2	2.2	64	58	6
	06/22/04	135	1575.022	143.2	2654.2	147	1620.202	140.6	2732.0	3.2	2	62	58	4
	06/23/04	154	1628.973	160.6	2749.3	148	1673.389	158.3	2825.8	3.3	2.2	64	58	6
	06/24/04	149	1667.542	136.8	2817.3	147	1711.392	134.8	2892.8	3.4	2	66	60	6
	06/25/04	152	1670.122	143.3	2821.9	148	1713.949	142.1	2897.3	3	2	68	62	6
	06/26/04	NR	1714.283	NA	2899.8	NR	1757.673	NA	2974.4	NR	NR	NR	NR	NA
	06/27/04	NR	1757.023	NA	2975.1	NR	1799.960	NA	3048.9	NR	NR	NR	NR	NA
8	06/28/04	143	1801.423	NA	3053.4	148	1844.034	NA	3126.6	3	2.2	66	59	7
	06/29/04	144	1838.395	136.9	3118.6	147	1880.729	135.9	3191.3	3	2	66	60	6
	06/30/04	149	1840.622	185.6	3122.5	146	1882.934	183.8	3195.2	3	2	66	60	6
	07/01/04	139	1884.502	162.5	3199.9	141	1926.365	160.9	3271.8	3	2	64	58	6
	07/02/04	144	1930.917	128.9	3281.7	147	1972.479	128.1	3353.1	3	2	62	56	6
	07/03/04	NR	1977.272	138.0	3363.4	NR	2018.462	136.9	3434.2	NR	NR	NR	NR	NA
	07/04/04	NR	2019.592	135.6	3438.1	NR	2060.456	134.6	3508.2	NR	NR	NR	NR	NA
9	07/05/04	134	2033.632	90.0	3462.8	135	2074.436	89.6	3532.9	2.8	1.8	64	58	6
	07/06/04	146	2068.245	160.2	3523.8	139	2103.766	135.8	3584.6	3	2	62	58	4
	07/07/04	145	2108.073	118.5	3594.1	140	2148.215	132.3	3662.9	3	2	62	58	4
	07/08/04	147	2145.983	140.4	3660.9	152	2185.787	139.2	3729.2	3	2	64	59	5
	07/09/04	140	2155.540	NA	3677.8	133	2195.326	NA	3746.0	3	2	62	58	4
	07/10/04	NR	2189.552	107.0	3737.7	NR	2229.099	106.2	3805.6	NR	NR	NR	NR	NA
	07/11/04	NR	2234.232	135.4	3816.5	NR	2273.498	134.5	3883.8	NR	NR	NR	NR	NA
10	07/12/04	149	2278.147	133.1	3893.9	146	2317.292	132.7	3961.1	3.2	2	64	58	6
	07/13/04	154	2316.276	135.2	3961.2	147	2355.290	134.7	4028.1	3.2	2	64	59	5
	07/14/04	148	2345.305	138.2	4012.3	141	2384.199	137.7	4079.0	3	2	64	60	4
	07/15/04	144	2360.291	131.5	4038.8	148	2399.060	130.4	4105.2	3	2	62	57	5
	07/16/04	142	2402.747	133.5	4113.6	156	2441.387	133.1	4179.9	3	2	62	57	5
	07/17/04	NR	2447.251	134.9	4192.1	NR	2485.806	134.6	4258.2	NR	NR	NR	NR	NA
	07/18/04	NR	2486.541	136.4	4261.4	NR	2524.969	136.0	4327.2	NR	NR	NR	NR	NA
11	07/19/04	140.9	2518.928	128.5	4318.5	142.9	2557.272	128.2	4384.2	3	2	66	62	4
	07/20/04	149	2525.844	164.7	4330.7	146	2564.104	162.7	4396.2	3	2.2	60	55	5
	07/21/04	139	2530.954	141.9	4339.7	139	2569.184	141.1	4405.2	3	2.2	62	60	2
	07/22/04	150	2546.569	35.2	4367.2	151	2584.818	35.2	4432.7	3.2	2.2	60	56	4
	07/23/04	143	2590.503	135.6	4444.7	135	2628.701	135.4	4510.1	3	2	64	58	6
	07/24/04	NR	2636.838	135.5	4526.4	NR	2675.008	135.4	4591.8	NR	NR	NR	NR	NA
	07/25/04	NR	2683.016	1924.1	4607.8	NR	2721.097	1920.4	4673.0	NR	NR	NR	NR	NA

Table A-1. U.S. EPA Arsenic Demonstration Project at Brown City, MI – Daily System Operation Log Sheet (page 9 of 12)

		Flow Totalizer TC				Flow Totalizer TD				Head Loss		Pressure C/D		
Week No.	Date	GPM	KGAL	Avg GPM	Cumulative Bed Volume	GPM	KGAL	Avg GPM	Cumulative Bed Volume	Tank C psi	Tank D psi	Influent psig	Effluent psig	ΔP
12	07/26/04	131	2731.768	135.4	4693.7	151	2769.864	135.5	4759.0	3.2	2.2	64	58	6
	07/27/04	150	2771.298	131.8	4763.4	148	2809.497	132.1	4828.9	3	2	64	58	6
	07/28/04	131	2773.293	33.3	4767.0	141	2811.501	33.4	4832.4	3	2	62	56	6
	07/29/04	149	2821.301	153.9	4851.6	135	2859.811	154.8	4917.6	3	2	62	58	4
	07/30/04	151	2863.298	137.2	4925.7	145	2901.906	137.6	4991.8	3.2	2	62	58	4
	07/31/04	150	2901.722	133.4	4993.4	135	2940.348	133.5	5059.6	3	2	62	58	4
	08/01/04	148	2934.860	134.7	5051.8	136	2973.537	134.9	5118.1	2.8	2	64	60	4
13	08/02/04	142	2946.287	136.0	5072.0	147	2984.870	134.9	5138.1	3	2.6	60	56	4
	08/03/04	150	2993.284	135.0	5154.8	157	3031.829	134.9	5220.9	3	2.2	63	58	5
	08/04/04	154.7	3044.037	134.3	5244.3	144	3082.475	134.0	5310.2	3	2	66	60	6
	08/05/04	151.7	3082.787	134.5	5312.6	147	3120.938	133.6	5378.0	3	2	68	62	6
	08/06/04	146	3083.211	70.7	5313.4	152	3121.447	84.8	5378.9	3	2	62	56	6
	08/07/04	153	3127.336	133.7	5391.2	142	3165.239	132.7	5456.1	3	2.2	64	58	6
	08/08/04	146	3170.709	136.4	5467.7	142	3208.196	135.1	5531.9	3	2	66	60	6
14	08/09/04	165	3212.662	134.5	5541.6	150	3249.779	133.3	5605.2	3	2	64	58	6
	08/10/04	150	3252.673	133.4	5612.2	149	3289.447	132.2	5675.1	3	2	64	58	6
	08/11/04	145	3263.457	149.8	5631.2	140	3300.282	150.5	5694.2	3	2	62	56	6
	08/12/04	NR	3297.430	138.1	5691.1	NR	3333.858	136.5	5753.4	NR	NR	NR	NR	NA
	08/13/04	NR	3338.839	132.7	5764.1	NR	3374.953	131.7	5825.9	NR	NR	NR	NR	NA
	08/14/04	NR	3379.776	136.5	5836.3	NR	3415.491	135.1	5897.4	NR	NR	NR	NR	NA
	08/15/04	151	3419.003	136.2	5905.4	148	3454.295	134.7	5965.8	3	2	65	58	7
15	08/16/04	148	3457.362	136.0	5973.1	143	3492.315	134.8	6032.8	3	2	62	57	5
	08/17/04	146	3497.878	129.9	6044.5	148	3532.431	128.6	6103.5	3	2	66	59	7
	08/18/04	150.7	3505.859	133.0	6058.6	134	3540.358	132.1	6117.5	3	2	60	56	4
	08/19/04	161	3549.140	114.5	6134.9	150	3583.137	113.2	6192.9	3	2	62	57	5
	08/20/04	147	3596.454	136.0	6218.3	145	3629.658	133.7	6275.0	3	2	65	59	6
	08/21/04	140	3640.357	135.5	6295.7	150	3673.056	133.9	6351.5	3	2	62	57	5
	08/22/04	150	3865.934	NA	6693.5	148	3717.985	133.7	6430.7	3	2.4	60	56	4
16	08/23/04	NR	3733.177	NA	6459.4	NR	3764.599	133.9	6512.9	NR	NR	NR	NR	NA
	08/24/04	154	3777.147	159.3	6536.9	146	3807.769	156.4	6589.0	3	2.4	66	60	6
	08/25/04	NR	3824.736	136.8	6620.8	NR	3854.657	134.7	6671.7	NR	NR	NR	NR	NA
	08/26/04	NR	3945.532	134.2	6833.8	NR	3973.532	132.1	6881.3	NR	NR	NR	NR	NA
	08/27/04	NR	3994.336	135.6	6919.9	NR	4021.487	133.2	6965.8	NR	NR	NR	NR	NA
	08/28/04	149	4019.491	135.2	6964.2	139	4046.256	133.2	7009.5	3	2.4	64	60	4
	08/29/04	NR	4034.531	139.3	6990.7	NR	4060.927	135.8	7035.4	NR	NR	NR	NR	NA

Table A-1. U.S. EPA Arsenic Demonstration Project at Brown City, MI – Daily System Operation Log Sheet (page 10 of 12)

Week No.	Date	Flow Totalizer TC				Flow Totalizer TD				Head Loss		Pressure C/D		
		GPM	KGAL	Avg GPM	Cumulative Bed Volume	GPM	KGAL	Avg GPM	Cumulative Bed Volume	Tank C psi	Tank D psi	Influent psig	Effluent psig	ΔP
17	08/30/04	NR	4077.545	135.3	7066.6	NR	4102.983	132.3	7109.5	NR	NR	NR	NR	NA
	08/31/04	145	4119.722	132.6	7140.9	141	4144.285	129.9	7182.3	4	2.4	66	62	4
	09/01/04	144	4124.468	113.0	7149.3	149	4148.936	110.7	7190.5	3	2.4	62	54	8
	09/02/04	NR	4166.658	135.2	7223.7	NR	4190.162	132.1	7263.2	NR	NR	NR	NR	NA
	09/03/04	NR	4210.961	136.7	7301.8	NR	4233.471	133.7	7339.6	NR	NR	NR	NR	NA
	09/04/04	NR	4250.125	136.0	7370.8	NR	4271.783	133.0	7407.1	NR	NR	NR	NR	NA
	09/05/04	NR	4288.982	137.8	7439.4	NR	4309.724	134.5	7474.0	NR	NR	NR	NR	NA
18	09/06/04	149	4296.299	174.2	7452.3	149	4316.920	171.3	7486.7	2.8	2.8	62	56	6
	09/07/04	NR	4340.479	133.9	7530.2	NR	4360.036	130.7	7562.7	NR	NR	NR	NR	NA
	09/08/04	142	4375.129	128.3	7591.2	152	4393.808	125.1	7622.3	3.4	2.6	62	56	6
	09/09/04	144	4420.622	135.4	7671.5	143	4438.204	132.1	7700.6	3	2.6	65	60	5
	09/10/04	NR	4436.103	135.8	7698.8	NR	4453.543	134.6	7727.6	NR	NR	NR	NR	NA
	09/11/04	NR	4479.699	134.6	7775.6	NR	4496.667	133.1	7803.6	NR	NR	NR	NR	NA
	09/12/04	NR	4521.038	135.1	7848.5	NR	4537.540	133.6	7875.7	NR	NR	NR	NR	NA
19	09/13/04	NR	4560.992	135.9	7919.0	NR	4577.018	134.3	7945.3	NR	NR	NR	NR	NA
	09/14/04	136	4586.943	139.5	7964.7	140	4602.683	138.0	7990.6	2.8	2	64	60	4
	09/15/04	NR	4606.198	133.7	7998.7	NR	4621.603	131.4	8023.9	NR	NR	NR	NR	NA
	09/16/04	NR	4652.188	94.6	8079.7	NR	4666.941	93.3	8103.9	NR	NR	NR	NR	NA
	09/17/04	146	4700.133	216.0	8164.3	143	4714.237	213.0	8187.2	3	2	64	58	6
	09/18/04	NR	4739.762	134.8	8234.2	NR	4753.419	133.3	8256.3	NR	NR	NR	NR	NA
	09/19/04	NR	4776.941	134.7	8299.7	NR	4790.161	133.1	8321.1	NR	NR	NR	NR	NA
20	09/20/04	NR	4816.589	132.2	8369.6	NR	4829.483	131.1	8390.4	NR	NR	NR	NR	NA
	09/21/04	140	4847.701	140.1	8424.5	131	4860.336	139.0	8444.8	2.8	2	65	60	5
	09/22/04	NR	4877.839	135.8	8477.6	NR	4890.151	134.3	8497.4	NR	NR	NR	NR	NA
	09/23/04	134	4924.836	135.0	8560.5	141	4936.737	133.9	8579.6	2.8	2.8	64	59	5
	09/24/04	139	4973.144	134.2	8645.6	140	4984.586	132.9	8663.9	2.8	2.6	64	59	5
	09/25/04	NR	5032.222	133.1	8749.8	NR	5043.251	132.1	8767.4	NR	NR	NR	NR	NA
	09/26/04	NR	5070.088	134.3	8816.6	NR	5080.753	133.0	8833.5	NR	NR	NR	NR	NA
21	09/27/04	NR	5109.803	135.1	8886.6	NR	5120.154	134.0	8902.9	NR	NR	NR	NR	NA
	09/28/04	149	5154.303	127.9	8965.1	157	5164.104	126.3	8980.4	3	2	64	58	6
	09/29/04	NR	5162.268	265.5	8979.1	NR	5171.954	261.7	8994.3	NR	NR	NR	NR	NA
	09/30/04	NR	5204.704	114.1	9053.9	NR	5213.948	112.9	9068.3	NR	NR	NR	NR	NA
	10/01/04	158	5248.719	146.7	9131.5	146	5257.398	144.8	9144.9	3	2	62	57	5
	10/02/04	NR	5292.486	135.1	9208.7	NR	5300.683	133.6	9221.2	NR	NR	NR	NR	NA
	10/03/04	NR	5329.143	113.1	9273.3	NR	5337.010	112.1	9285.3	NR	NR	NR	NR	NA

Table A-1. U.S. EPA Arsenic Demonstration Project at Brown City, MI – Daily System Operation Log Sheet (page 11 of 12)

		Flow Totalizer TC				Flow Totalizer TD				Head Loss		Pressure C/D		
Week No.	Date	GPM	KGAL	Avg GPM	Cumulative Bed Volume	GPM	KGAL	Avg GPM	Cumulative Bed Volume	Tank C psi	Tank D psi	Influent psig	Effluent psig	ΔP
22	10/04/04	NR	5329.143	NA	9273.3	NR	5337.010	NA	9285.3	NR	NR	NR	NR	NA
	10/05/04	141	5371.084	134.4	9347.3	149	5378.646	133.4	9358.7	2.8	2.6	60	56	4
	10/06/04	NR	5413.814	134.4	9422.6	NR	5420.918	132.9	9433.2	NR	NR	NR	NR	NA
	10/07/04	152	5453.892	155.3	9493.3	148	5460.528	153.5	9503.1	2.8	2	64	58	6
	10/08/04	NR	5492.938	135.6	9562.1	NR	5499.203	134.3	9571.3	NR	NR	NR	NR	NA
	10/09/04	NR	5529.687	136.1	9626.9	NR	5535.516	134.5	9635.3	NR	NR	NR	NR	NA
	10/10/04	NR	5529.687	NA	9626.9	NR	5535.516	NA	9635.3	NR	NR	NR	NR	NA
23	10/11/04	147	5572.569	134.8	9702.5	145	5577.978	133.5	9710.2	3.2	2	60	56	4
	10/12/04	152	5637.080	134.4	9816.3	145	5641.777	132.9	9822.6	3	2.2	64	59	5
	10/13/04	NR	5668.856	126.1	9872.3	NR	5673.190	124.7	9878.0	NR	NR	NR	NR	NA
	10/14/04	144	5745.047	133.7	10006.6	133	5748.336	131.8	10010.5	2.8	2	68	64	4
	10/15/04	NR	5783.000	140.6	10073.5	NR	5785.583	138.0	10076.2	NR	NR	NR	NR	NA
	10/16/04	NR	5783.000	NA	10073.5	NR	5785.583	NA	10076.2	NR	NR	NR	NR	NA
	10/17/04	NR	5825.824	134.7	10149.1	NR	5827.575	132.1	10150.2	NR	NR	NR	NR	NA
24	10/18/04	NR	5867.410	135.9	10222.4	NR	5868.414	133.5	10222.2	NR	NR	NR	NR	NA
	10/19/04	156	5904.081	115.3	10287.0	149	5904.385	113.1	10285.7	3	2	66	59	7
	10/20/04	NR	5907.003	162.3	10292.2	NR	5907.250	159.2	10290.7	NR	NR	NR	NR	NA
	10/21/04	NR	5947.517	135.0	10363.6	NR	5946.919	132.2	10360.7	NR	NR	NR	NR	NA
	10/22/04	148	5987.913	132.0	10434.8	143	5986.486	129.3	10430.4	3	2	64	58	6
	10/23/04	NR	6006.032	143.8	10466.8	NR	6004.418	142.3	10462.0	NR	NR	NR	NR	NA
	10/24/04	NR	6047.648	95.0	10540.2	NR	6045.656	94.2	10534.8	NR	NR	NR	NR	NA
25	10/25/04	NR	6087.794	133.8	10610.9	NR	6085.656	133.3	10605.3	NR	NR	NR	NR	NA
	10/26/04	NR	6122.979	133.3	10673.0	NR	6120.678	132.7	10667.0	NR	NR	NR	NR	NA
	10/27/04	145	6122.979	NA	10673.0	141	6120.678	NA	10667.0	2.6	2	64	60	4
	10/28/04	NR	6162.830	132.8	10743.2	NR	6160.377	132.3	10737.0	NR	NR	NR	NR	NA
	10/29/04	NR	6204.150	135.0	10816.1	NR	6201.478	134.3	10809.5	NR	NR	NR	NR	NA
	10/30/04	NR	6239.645	134.5	10878.7	NR	6236.714	133.5	10871.6	NR	NR	NR	NR	NA
	10/31/04	NR	6239.645	NA	10878.7	NR	6236.714	NA	10871.6	NR	NR	NR	NR	NA
26	11/01/04	NR	6281.918	195.7	10953.2	NR	7098.683	NA	NA	NR	NR	NR	NR	NA
	11/02/04	144	6322.362	134.8	11024.5	143	6318.872	NA	11016.5	2.8	2	64	60	4
	11/03/04	NR	6332.059	134.7	11041.6	NR	6328.497	133.7	11033.4	NR	NR	NR	NR	NA
	11/04/04	146	6391.641	198.6	11146.7	141	6367.823	131.1	11102.8	2.8	2.6	64	58	6
	11/05/04	NR	6411.334	67.0	11181.4	NR	6407.247	134.1	11172.3	NR	NR	NR	NR	NA
	11/06/04	151	6415.579	353.8	11188.9	140	6411.543	358.0	11179.9	3	2.8	62	56	6
	11/07/04	NR	6452.052	129.3	11253.2	NR	6447.715	128.3	11243.6	NR	NR	NR	NR	NA

Table A-1. U.S. EPA Arsenic Demonstration Project at Brown City, MI – Daily System Operation Log Sheet (page 12 of 12)

Week No.	Date	Flow Totalizer TC				Flow Totalizer TD				Head Loss		Pressure C/D		
		GPM	KGAL	Avg GPM	Cumulative Bed Volume	GPM	KGAL	Avg GPM	Cumulative Bed Volume	Tank C psi	Tank D psi	Influent psig	Effluent psig	ΔP
27	11/08/04	141	6493.121	134.2	11325.6	143	6483.547	117.1	11306.8	3	2.8	62	56	6
	11/09/04	144	6530.875	125.8	11392.2	150	6526.007	141.5	11381.7	3	2.8	66	60	6
	11/10/04	140	6536.912	167.7	11402.8	143	6532.062	168.2	11392.4	3	2.8	62	56	6
	11/11/04	NR	6573.001	128.0	11466.4	NR	6567.877	127.0	11455.5	NR	NR	NR	NR	NA
	11/12/04	NR	6612.485	134.3	11536.1	NR	6607.015	133.1	11524.5	NR	NR	NR	NR	NA
	11/13/04	NR	6648.888	134.8	11600.2	NR	6643.101	133.7	11588.1	NR	NR	NR	NR	NA
	11/14/04	132.6	6662.613	143.0	11624.4	137.1	6656.767	142.4	11612.2	3	3	61	58	3
28	11/15/04	NR	6689.849	126.1	11672.5	NR	6683.665	124.5	11659.7	NR	NR	NR	NR	NA
	11/16/04	145	6729.132	133.6	11741.7	153	6722.580	132.4	11728.3	3	2.4	64	58	6
	11/17/04	131	6766.423	138.1	11807.5	134	6759.578	137.0	11793.5	3	2.5	63	60	3
	11/18/04	NR	6772.783	117.8	11818.7	NR	6765.839	115.9	11804.5	NR	NR	NR	NR	NA
	11/19/04	NR	6813.090	134.4	11889.8	NR	6805.788	133.2	11875.0	NR	NR	NR	NR	NA
	11/20/04	NR	6815.830	NA	11894.6	NR	6844.607	132.0	11943.4	NR	NR	NR	NR	NA
	11/21/04	NR	6815.830	NA	11894.6	NR	6881.211	132.6	12008.0	NR	NR	NR	NR	NA
29	11/22/04	NR	6815.830	NA	11894.6	NR	6881.211	NA	12008.0	NR	NR	NR	NR	NA
	11/23/04	NR	6815.831	NA	11894.6	146	6909.036	NA	12057.0	2.8	1.8	62	56	6
	11/24/04	NR	NR	NA	NA	NR	6923.572	134.6	12082.7	NR	NR	NR	NR	NA
	11/25/04	NR	6857.973	NA	11968.9	NR	6965.326	133.8	12156.3	NR	NR	NR	NR	NA
	11/26/04	NR	6857.973	NA	11968.9	NR	6965.326	NA	12156.3	NR	NR	NR	NR	NA
	11/27/04	NR	6913.039	135.0	12066.0	NR	7019.942	133.9	12252.6	NR	NR	NR	NR	NA
	11/28/04	NR	6951.789	134.5	12134.3	NR	7058.368	133.4	12320.3	NR	NR	NR	NR	NA
30	11/29/04	145	6961.023	NA	12150.6	140	7067.549	NA	12336.5	2.8	3	62	58	4
	11/30/04	142	6994.733	61.1	12210.0	136	7100.799	60.2	12395.1	2.8	2.6	64	58	6

NA = not applicable.
NR = no reading.

APPENDIX B

ANALYTICAL DATA

Table B-1. Analytical Results from Long-Term Sampling, Brown City, MI

Sampling Date		05/18/04					05/25/04		06/08/04					06/24/04[e]	
Sampling Location Parameter	Unit	IN	TA	TB	TC	TD	IN	TT	IN	TA	TB	TC	TD	IN	TT
Bed Volume ($\times 10^3$)	No.	–	0.4	0.4	0.4	0.4	–	0.8	–	1.9	1.9	1.8	1.8	–	2.9
Alkalinity	mg/L[a]	238	234	217	234	234	246	246	228	236	236	240	236	227	240
Fluoride	mg/L	–	–	–	–	–	1.5	1.5	–	–	–	–	–	1.4	1.5
Sulfate	mg/L	–	–	–	–	–	95	73	–	–	–	–	–	65	80
Orthophosphate	mg/L[b]	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Silica (as SiO_2)	mg/L	10.2	17.4	2.3	2.7	3.1	7.9	5.0	8.6	7.2	7.0	7.1	7.0	8.5	7.4
NO_3-N	mg/L	–	–	–	–	–	<0.04	<0.04	–	–	–	–	–	<0.04	<0.04
Turbidity	NTU	1.5	0.5	0.4	0.5	0.9	1.4	0.4	1.1	0.3	0.3	0.8	0.8	1.0	0.8
pH	–	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	8.2	7.9	8.5	8.0	7.9	7.9	7.9	8.0	7.9
Temperature	°C	14.3	13.8	12.8	12.3	12.3	12.4	11.0	11.7	11.7	11.7	11.3	11.2	11.9	11.4
DO	mg/L	4.2[d]	4.4[d]	4.7[d]	1.8	1.7	1.7	0.7	1.0	1.6	1.2	0.7	1.3	1.8	1.9
ORP	mV	4	3	2	3	2	3	7	10	7	7	8	7	5	2
Total Hardness	mg/L[a]	–	–	–	–	–	109.8	93.1	–	–	–	–	–	65.0	92.1
Ca Hardness	mg/L[a]	–	–	–	–	–	77.7	63.5	–	–	–	–	–	39.4	62.9
Mg Hardness	mg/L[a]	–	–	–	–	–	32.1	29.6	–	–	–	–	–	25.6	29.2
As (total)	µg/L	28.7	1.1	0.5	2.3	2.5	15.6	2.1	15.1	0.6	1.0	3.2	2.9	14.3	0.8
As (total soluble)	µg/L	–	–	–	–	–	13.4	1.8	–	–	–	–	–	12.5	0.6
As (particulate)	µg/L	–	–	–	–	–	2.2	0.3	–	–	–	–	–	1.8	0.2
As (III)	µg/L	–	–	–	–	–	13.1	1.9	–	–	–	–	–	11.7	0.7
As (V)	µg/L	–	–	–	–	–	0.3	<0.1	–	–	–	–	–	0.8	<0.1
Fe (total)	µg/L	168	<25	<25	<25	<25	149	<25	101	<25	<25	<25	<25	113	<25
Fe (soluble)	µg/L	–	–	–	–	–	139	<25	–	–	–	–	–	99	<25
Mn (total)	µg/L	14.3	<0.5	<0.5	1.5	2.1	15.5	1.3	17	0.7	0.7	2.9	2.7	13.5	2.2
Mn (soluble)	µg/L	–	–	–	–	–	15.8	1.6	–	–	–	–	–	13.2	2.5

(a) as $CaCO_3$.
(b) as PO_4.
(c) pH probe was not operational.
(d) Samples might have been aerated during sampling.
(e) Field data (temp, pH, DO, ORP) measured on 6/29/04 for this date.
IN = inlet; TA = after tank A; TB = after tank B; TC = after tank C; TD = after tank D; TT = after tanks combined.
NA = data not available.

Table B-1. Analytical Results from Long-Term Sampling, Brown City, MI (page 2 of 4)

Sampling Date		07/06/04					07/20/04		08/03/04					08/17/04	
Sampling Location Parameter	Unit	IN	TA	TB	TC	TD	IN	TT	IN	TA	TB	TC	TD	IN	TT
Bed Volume ($\times10^3$)	No.	–	3.8	3.8	3.5	3.6	–	4.6	–	5.7	5.7	5.2	5.2	–	6.4
Alkalinity	mg/L[a]	218	214	214	202	214	277	223	236 236	217 236	225 236	236 236	256 240	233	164
Fluoride	mg/L	–	–	–	–	–	1.3	1.4	–	–	–	–	–	1.4	1.8
Sulfate	mg/L	–	–	–	–	–	56	79	–	–	–	–	–	59	82
Orthophosphate	mg/L[b]	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10 <0.10	<0.10 <0.10	<0.10 <0.10	<0.10 <0.10	<0.10 <0.10	<0.10	<0.10
Silica (as SiO_2)	mg/L	9.5	7.5	8.1	7.5	7.8	14.3	7.2	8.3 8.7	8.0 7.8	8.1 7.8	7.7 7.7	7.6 7.6	8.7	7.9
NO_3-N	mg/L	–	–	–	–	–	NA[c]	NA[c]	–	–	–	–	–	<0.04	<0.04
Turbidity	NTU	2.3	0.4	0.6	0.6	0.4	0.8	0.6	0.2 1.2	0.3 0.2	0.3 0.5	0.3 0.2	0.1 0.2	0.5	0.1
pH	–	8.0	7.9	7.9	7.9	7.9	8.0	7.9	7.6	7.6	7.6	7.6	7.6	8.0	7.9
Temperature	°C	11.9	11.7	11.6	11.6	11.7	11.7	13.4	11.6	11.7	11.7	11.8	11.7	11.8	11.6
DO	mg/L	2.5	1.4	1.6	2.7	2.2	2.4	1.5	2.3	2.0	1.9	1.4	2.3	1.7	1.4
ORP	mV	7	5	5	4	4	9	13	12	13	13	14	16	18	31
Total Hardness	mg/L[a]	–	–	–	–	–	111.2	131.1	–	–	–	–	–	82.9	99.2
Ca Hardness	mg/L[a]	–	–	–	–	–	66.4	91.1	–	–	–	–	–	55.0	71.4
Mg Hardness	mg/L[a]	–	–	–	–	–	44.8	40.0	–	–	–	–	–	27.9	27.8
As (total)	µg/L	21.5	0.7	0.7	0.8	0.4	15.6	0.7	14.5 14.3	1.2 1.6	2.0 2.1	0.8 1.2	1.6 1.8	13.1	2.8
As (total soluble)	µg/L	–	–	–	–	–	14.9	0.6	–	–	–	–	–	12.9	2.2
As (particulate)	µg/L	–	–	–	–	–	0.7	0.1	–	–	–	–	–	0.2	0.6
As (III)	µg/L	–	–	–	–	–	14.2	0.9	–	–	–	–	–	12.9	2.0
As (V)	µg/L	–	–	–	–	–	0.7	<0.1	–	–	–	–	–	<0.1	0.2
Fe (total)	µg/L	228	<25	<25	<25	<25	157	<25	164 167	<25 <25	<25 <25	<25 <25	<25 <25	108	<25
Fe (soluble)	µg/L	–	–	–	–	–	135	<25	–	–	–	–	–	105	<25
Mn (total)	µg/L	17.0	2.2	3.8	4.7	2.4	12.3	2.9	18.3 18.5	11.4 9.6	14.2 12.5	12.5 12.3	13.4 13.4	12.6	13.0
Mn (soluble)	µg/L	–	–	–	–	–	13.4	2.7	–	–	–	–	–	12.7	14.0

(a) as $CaCO_3$.
(b) as PO_4.
(c) Sample out of holding time for laboratory analysis.
IN = inlet; TA = after tank A; TB = after tank B; TC = after tank C; TD = after tank D; TT = after tanks combined.
NA = data not available.

Table B-1. Analytical Results from Long-Term Sampling, Brown City, MI (page 3 of 4)

Sampling Date		08/31/04					09/14/04		09/28/04					10/12/04	
Sampling Location / Parameter	**Unit**	**IN**	**TA**	**TB**	**TC**	**TD**	**IN**	**TT**	**IN**	**TA**	**TB**	**TC**	**TD**	**IN**	**TT**
Bed Volume ($\times 10^3$)	No.	–	8.0	8.0	7.1	7.2	–	8.5	–	10.1	10.1	9.0	9.0	–	10.4
Alkalinity	mg/L[(a)]	241	241	241	241	245	242	242	234	230	234	238	234	231	236
Fluoride	mg/L	–	–	–	–	–	1.8	1.8	–	–	–	–	–	3.3	1.6
Sulfate	mg/L	–	–	–	–	–	120	120	–	–	–	–	–	54	74
Orthophosphate	mg/L[(b)]	<0.10	<0.10	<0.10	<0.10	<0.10	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Silica (as SiO_2)	mg/L	8.3	8.0	7.5	7.6	7.5	7.7	7.6	8.4	7.8	7.8	7.5	7.4	9.2	7.3
NO_3-N	mg/L	–	–	–	–	–	<0.04	<0.04	–	–	–	–	–	<0.04	<0.04
Turbidity	NTU	0.9	0.2	0.3	0.3	0.1	0.6	0.2	0.8	0.2	0.3	0.2	0.3	2.1	0.6
pH	–	8.0	7.9	7.9	7.9	7.9	7.9	7.9	8.0	7.9	7.8	7.9	7.8	7.9	7.9
Temperature	°C	11.2	11.0	11.1	11.2	11.2	11.2	11.2	11.2	11.1	11.5	11.6	12.0	10.3	10.2
DO	mg/L	5.6[(c)]	2.0	2.0	1.7	2.3	2.2	1.6	1.9	1.6	1.6	1.9	1.6	1.4	1.8
ORP	mV	24	29	30	29	28	47	33	58	45	38	36	34	24	18
Total Hardness	mg/L[(a)]	–	–	–	–	–	98.4	100.3	–	–	–	–	–	104.1	87.5
Ca Hardness	mg/L[(a)]	–	–	–	–	–	75.9	77.0	–	–	–	–	–	62.9	61.4
Mg Hardness	mg/L[(a)]	–	–	–	–	–	22.5	23.3	–	–	–	–	–	41.2	26.1
As (total)	µg/L	14.9	1.4	2.1	1.8	2.2	9.5	3.6	12.6	2.4	2.8	2.2	3.0	15.6	2.6
As (total soluble)	µg/L	–	–	–	–	–	9.6	3.5	–	–	–	–	–	15.8	2.4
As (particulate)	µg/L	–	–	–	–	–	<0.1	0.1	–	–	–	–	–	<0.1	0.2
As (III)	µg/L	–	–	–	–	–	9.0	3.3	–	–	–	–	–	14.2	<1.0[(d)]
As (V)	µg/L	–	–	–	–	–	0.6	0.2	–	–	–	–	–	1.6	2.4
Fe (total)	µg/L	115	<25	<25	<25	<25	159	35	160	<25	<25	<25	<25	203	<25
Fe (soluble)	µg/L	–	–	–	–	–	127	<25	–	–	–	–	–	135	<25
Mn (total)	µg/L	13.7	13.2	15.5	15.6	17.1	17.0	19.7	15.0	20.5	21.8	19.2	22.0	16.6	22.4
Mn (soluble)	µg/L	–	–	–	–	–	16.5	19.1	–	–	–	–	–	14.8	19.3

(a) as $CaCO_3$.
(b) as PO_4.
(c) Samples might have been aerated during sampling.
(d) Rerun sample was diluted 10 times due to insufficient quantity for analysis.
IN = inlet; TA = after tank A; TB = after tank B; TC = after tank C; TD = after tank D; TT = after tanks combined.
NA = data not available.

Table B-1. Analytical Results from Long-Term Sampling, Brown City, MI (page 4 of 4)

Sampling Date		11/02/04[c]					11/16/04		11/30/04				
Sampling Location Parameter	Unit	IN	TA	TB	TC	TD	IN	TT	IN	TA	TB	TC	TD
Bed Volume ($\times 10^3$)	No.	–	12.5	12.5	11.0	11.0	–	12.5	–	14.1	13.7	12.2	12.4
Alkalinity	mg/L[a]	246 242	246 246	246 246	250 250	250 250	246	250	234	236	236	240	240
Fluoride	mg/L	–	–	–	–	–	1.4	1.5	–	–	–	–	–
Sulfate	mg/L	–	–	–	–	–	62	85	–	–	–	–	–
Orthophosphate	mg/L[b]	<0.06 <0.06	<0.06 <0.06	<0.06 <0.06	<0.06 <0.06	<0.06 <0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Silica (as SiO_2)	mg/L	7.9 8.1	7.5 7.6	7.6 7.7	7.5 7.5	7.6 7.6	8.3	7.6	8.5	7.7	7.5	7.5	7.6
NO_3-N	mg/L	–	–	–	–	–	<0.04	<0.04	–	–	–	–	–
Turbidity	NTU	0.7 0.7	0.6 0.6	0.7 0.5	0.3 0.3	0.3 0.3	0.9	0.4	0.5	0.2	0.1	0.3	0.3
pH	–	8.0	7.9	7.8	7.8	7.8	7.9	7.7	7.9	7.8	7.8	7.7	7.7
Temperature	°C	10.9	10.8	10.9	10.9	10.9	11.0	11.4	11.0	10.9	10.9	10.8	10.7
DO	mg/L	2.1	1.3	1.4	1.4	1.2	1.7	1.5	2.1	1.5	1.8	1.4	1.9
ORP	mV	69	62	57	54	53	88	77	106	99	102	104	104
Total Hardness	mg/L[a]	–	–	–	–	–	71.2	92.1	–	–	–	–	–
Ca Hardness	mg/L[a]	–	–	–	–	–	41.8	60.1	–	–	–	–	–
Mg Hardness	mg/L[a]	–	–	–	–	–	29.4	32.0	–	–	–	–	–
As (total)	µg/L	12.4 12.9	4.3 5.2	7.8 8.7	7.8 7.6	8.0 7.9	12.1	7.1	11.6	2.4	3.6	3.8	4.1
As (total soluble)	µg/L	–	–	–	–	–	11.7	6.2	–	–	–	–	–
As (particulate)	µg/L	–	–	–	–	–	0.4	0.9	–	–	–	–	–
As (III)	µg/L	–	–	–	–	–	12.0	5.3	–	–	–	–	–
As (V)	µg/L	–	–	–	–	–	<0.1	0.9	–	–	–	–	–
Fe (total)	µg/L	165 152	<25 <25	<25 <25	<25 <25	<25 <25	142	<25	144	<25	<25	<25	<25
Fe (soluble)	µg/L	–	–	–	–	–	108	<25	–	–	–	–	–
Mn (total)	µg/L	13.8 13.3	16.5 17.3	17.3 17.2	21.7 22.8	23.7 25.0	13.7	20.5	13.1	18.1	16.1	19.5	20.5
Mn (soluble)	µg/L	–	–	–	–	–	13.0	19.9	–	–	–	–	–

(a) as $CaCO_3$.
(b) as PO_4.
(c) Vessel B did not fast rinse properly during 10/22/04 backwash, possibly affecting TB sample.
IN = inlet; TA = after tank A; TB = after tank B; TC = after tank C; TD = after tank D; TT = after tanks combined.
NA = data not available.