

**Arsenic Removal from Drinking Water by Adsorptive Media  
EPA Demonstration Project at Queen Anne's County, Maryland  
Six-Month Evaluation Report**

by

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**Contract No. 68-C-00-185  
Task Order No. 0019**

for

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## ABSTRACT

This report documents the activities performed and the results obtained from the first six months of the arsenic removal treatment technology demonstration project at the community of Prospect Bay at Grasonville in Queen Anne's County, MD. The objectives of the project were to evaluate the effectiveness of Severn Trent Services (STS) SORB 33™ media in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 µg/L. Additionally, this project evaluates the reliability of the treatment system (Arsenic Package Unit [APU]-300), the simplicity of required system operation and maintenance (O&M) and operator's skills, and the cost-effectiveness of the technology. The project also characterizes the water in the distribution system and process residuals produced by the treatment process.

The STS system consisted of two 63-inch-diameter, 86-inch-tall fiberglass reinforced plastic (FRP) vessels in parallel configuration, each containing approximately 80 ft<sup>3</sup> of SORB 33™ media. The media is an iron-based adsorptive media developed by Bayer AG and packaged under the name SORB 33™ by STS. The system was designed for a flowrate of 320 gallons per minute (gpm) (160 gpm to each vessel), corresponding to a design empty bed contact time (EBCT) of about 3.8 minutes per vessel and a hydraulic loading to each vessel of 7.4 gpm/ft<sup>2</sup>.

The treatment system began regular operation on June 30, 2004. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), process residuals, and capital and O&M costs. Through the period June 30 through December 30, 2004, the APU-300 system operated an average of 6.3 hours per day for a total operating time of 1,082 hours. The system treated approximately 14,856,000 gallons of water, or 12,400 bed volumes (BV), which was approximately 11% of the vendor-estimated working capacity for the SORB 33™ media. Total arsenic concentrations in raw water ranged from 18.3 to 25.8 µg/L with As(III) being the predominating species, averaging 18.7 µg/L. By the end of September 2004, the arsenic concentration in the treated water exceeded the target concentration of 10 µg/L after approximately 7,400 BVs of water treated. To improve arsenic removal by the media, prechlorination was implemented in early November. (Prior to this, chlorine was added at the end of the treatment train.) Arsenic in samples collected following prechlorination existed primarily as As(V) and particulate As, indicating the effectiveness of chlorination in oxidizing As(III) to As(V). In the week following the switch to prechlorination, arsenic in the treated water existed primarily as As(III) (i.e., 10.4 out of 12 µg/L). Within two weeks of switching to prechlorination, total arsenic concentrations in the treated water reduced to 0.9 µg/L.

Because there was no on-site disposal facility for the backwash water and because there was little change in the differential pressure during the first four months of operation, the system was backwashed only once during the first six months of operation. The backwash was initiated manually and the backwash water was discharged into a tanker truck and transported to the Stevensville Wastewater Treatment Plant (WWTP) for disposal. Each vessel was backwashed separately at a flowrate of 200 gpm for a period of 20 to 25 minutes, generating approximately 9,500 gallons of backwash water. Soluble arsenic concentrations in the backwash water were 5.4 and 3.4 µg/L from Vessels A and B, respectively, which was significantly lower than those in the raw water that was used for backwash, indicating some arsenic removal by the media during backwash.

Results of the distribution system sampling showed a distinct effect of the treatment system on the arsenic concentrations in the treated water. The results mirrored those seen from the treatment system sampling, as As concentrations dropped once the system was put into service, rose gradually during the first four months of operation as As(III) began to break through, and then went down again once the switch to

prechlorination was made. The APU-300 did not appear to have an effect on the Pb or Cu levels in the distribution.

The capital investment cost of \$211,000 included \$129,500 for equipment, \$4,907 for site engineering, and \$19,580 for installation. Using the system's rated capacity of 320 gpm (460,800 gallons per day [gpd]), the capital cost was \$659/gpm (\$0.46/gpd) and equipment-only cost was \$405/gpm (\$0.28/gpd). These calculations did not include the cost of the building construction.

O&M costs included only incremental costs associated with the adsorption system, such as media replacement and disposal, chemical supply, electricity, and labor. Although media replacement and disposal did not take place during the first six months of operation, the vendor estimated \$26,800 to change out both vessels. This cost was used to estimate the media replacement cost per 1,000 gallons of water treated as a function of the projected media run length to the 10 µg/L arsenic breakthrough.

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## ABBREVIATIONS AND ACRONYMS

AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
APU	arsenic package unit
As	arsenic
BV	bed volume(s)
Ca	calcium
C/F	coagulation/filtration
Cl <sub>2</sub>	chlorine
CRF	capital recovery factor
Cu	copper
DO	dissolved oxygen
EBCT	empty bed contact time
EPA	United States Environmental Protection Agency
Fe	iron
FRP	fiberglass reinforced plastic
GFH	granular ferric hydroxide
gpd	gallons per day
gpm	gallons per minute
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IX	ion exchange
LCR	(EPA) Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MDE	Maryland Department of the Environment
MDWCA	Mutual Domestic Water Consumers Association
Mg	magnesium
Mn	manganese
Mo	molybdenum
mV	millivolts
Na	sodium
NS	not sampled
NSF	NSF International
NTU	nephelometric turbidity units
O&M	operation and maintenance
ORD	Office of Research and Development



ORP	oxidation-reduction potential
P&ID	pipng and instrumentation diagram
psi	pounds per square inch
PVC	polyvinyl chloride
QAC	Queen Anne's County
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
QA	quality assurance
RPD	relative percent difference
Sb	antimony
SDWA	Safe Drinking Water Act
SM	system modification
STMGID	South Truckee Meadows General Improvement District
STS	Severn Trent Services
TBD	to be determined
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
TOC	total organic carbon
V	vanadium
VOC	volatile organic compounds
WWTP	wastewater treatment plant

## **ACKNOWLEDGMENTS**

The authors wish to extend their sincere appreciation to the staff of the Queen Annes's County (QAC) Department of Public Works in Stevensville, Maryland. The QAC staff monitored the treatment system daily and collected samples from the treatment system and distribution system on a regular schedule throughout this reporting period. This performance evaluation would not have been possible without their efforts.

## **1.0 INTRODUCTION**

### **1.1 Background**

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

In October 2001, EPA announced an initiative for additional research and development of cost-effective technologies to help small community water systems (<10,000 customers) meet the new arsenic standard, and to provide technical assistance to operators of small systems in order to reduce compliance costs. As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, on-site demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems. Shortly thereafter, an announcement was published in the *Federal Register* requesting water utilities interested in participating in the first round of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 sites from a list of 115 sites to be the host sites for the demonstration studies. The community of Prospect Bay at Grasonville in Queen Anne's County (QAC), MD 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), using the Bayoxide E33 media developed by Bayer AG, was selected for the Prospect Bay facility. STS has given the E33 media the designation "SORB 33<sup>TM</sup>."

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

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

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

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

AM = adsorptive media process; C/F = coagulation/filtration process; GFH = granular ferric hydroxide

IX = ion exchange process; SM = system modification;

MDWCA = Mutual Domestic Water Consumer's Association

STMGID = South Truckee Meadows General Improvement District.

(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 June 30 through December 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:*

- The SORB 33™ media was not effective at removing As(III), as demonstrated by total arsenic breakthrough at 10 µg/L after approximately 7,400 bed volumes (BVs) of water treated.
- After switching to prechlorination on November 9, 2004, arsenic removal improved with total arsenic concentrations decreasing to 0.9 µg/L within two weeks of modifying the chlorination point.
- Iron in the source water varied from 193 to 315 µg/L, with most of the iron present in the soluble form ranging from 156 to 222 µg/L. Iron was removed by the SORB 33™ media to less than the detection limit of 25 µg/L. Iron removal does not appear to be related to iron precipitation based on the constant  $\Delta p$  readings observed across the adsorption vessels prior to the switch to prechlorination.
- The treatment system had a distinct effect on the arsenic concentrations of the water in the distribution system. Results from samples collected from within the distribution system followed the same pattern as those from the treatment system, as As concentrations dropped once the system was put into service, rose gradually during the first four months of operation as As(III) began to break through, and then went down again once the switch to prechlorination was made.
- The treatment did not appear to have an effect on the Pb or Cu levels in the distribution system.

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

- The treatment system operated as expected during the first six months of the demonstration study and did not experience any issues related to flow restriction or pressure drop.
- The skill requirements to operate the treatment system were minimal with a typical daily demand on the operator of 15-20 minutes. Normal operation of the system did not appear to require additional skills beyond those necessary to operate the existing water supply equipment. A Class I state-certified operator was required for operation of the water system at Prospect Bay.

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

- Residuals produced by the operation of the treatment system included backwash water and spent media. Because the media was not replaced during the first six months of system operation, the only residual produced was backwash water.

- Soluble arsenic concentrations in the backwash water were 5.4 and 3.4 µg/L from Vessels A and B, respectively, significantly lower than the arsenic concentration in the raw water used for backwash, indicating some arsenic removal by the media during backwash.

*Cost-effectiveness of the technology:*

- Using the system's rated capacity of 320 gallons per minute (gpm) (460,800 gallons per day [gpd]), the capital cost was \$659/gpm (\$0.46/gpd) and equipment-only cost was \$405/gpm (\$0.28/gpd). These calculations did not include the cost of the building construction.
- Although media replacement and disposal did not take place during the first six months of operation, the media replacement cost represented the majority of the O&M cost for the system and the vendor estimated \$26,800 to change out both vessels.

### 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 June 30, 2004. Table 3-2 summarizes the types of data collected and/or considered as part of the technology evaluation process. The overall performance of the system was determined based on its ability to consistently remove arsenic to the target MCL of 10 µg/L; this was monitored through the collection of weekly and monthly water samples across the treatment train. The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

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

Activity	Date
Introductory Meeting Held	August 7, 2003
Request for Quotation Issued to Vendor	August 11, 2003
Draft Letter of Understanding Issued	August 13, 2003
Final Letter of Understanding Issued	September 5, 2003
Vendor Quotation Submitted to Battelle	September 8, 2003
Purchase Order Completed and Signed	October 3, 2003
Letter Report Issued	October 17, 2003
Draft Study Plan Issued	February 6, 2004
Final Study Plan Issued	February 23, 2004
Engineering Package Submitted to MDE	March 12, 2004
Building Construction Begun	May 17, 2004
APU-300 Shipped by STS	May 26, 2004
APU-300 Delivered to Site and System Installation Begun	June 1, 2004
Permit for Treatment System Issued by MDE	June 15, 2004
System Installation Completed	June 17, 2004
Building Construction Completed	June 24, 2004
System Shakedown Completed	June 29, 2004
Performance Evaluation Begun	June 30, 2004

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 pretreatment 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 is evaluated based on the cost per 1,000 gallons (\$/1,000 gallons) of water treated. This requires the tracking of capital costs such as equipment, engineering, and installation

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

<b>Evaluation Objectives</b>	<b>Data Collection</b>
Performance	-Ability to consistently meet 10 µg/L of arsenic in 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 preventive 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

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 hours because media replacement did not take place during the six months of operation.

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 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 the vendor and Battelle. On a daily basis, the plant operator recorded system operational data, such as pressure, flowrate, totalizer readings, and hour meter readings on a Battelle-provided Daily Field Log Sheet; and conducted visual inspections to ensure normal system operations. In the event of problems, the plant operator would contact the Battelle Study Lead, who then would determine if STS should be contacted for troubleshooting. The plant operator recorded all relevant information on the Repair and Maintenance Log Sheet. On a weekly basis, the plant operator measured temperature, pH, dissolved oxygen (DO), and oxidation-reduction potential (ORP), and recorded the data on a Weekly Water Quality Parameters Log Sheet. During the six-month study period, the system was manually backwashed on only one occasion.

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, chemical and electricity consumption, and labor. Chlorine gas application and electricity consumption were tracked using the Daily Field Log Sheet. 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 completing the daily field logs and performing regular system inspections. The demonstration-related work included activities such as performing field measurements, collecting and shipping samples, and communicating with the



Battelle Study Lead. The demonstration-related activities were recorded but not included in 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. Table 3-3 provides the sampling schedules and analytes measured during each sampling event. Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2003).

**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, iron (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 four locations (i.e., at the wellhead [IN], after chlorination [AC], after Tank A [TA], and after Tank B [TB]), and analyzed for the analytes listed in Table 3-3. For the second biweekly event, treatment plant samples were collected for arsenic speciation at three locations (i.e., at the wellhead [IN], after chlorination [AC], and after the combined effluent [TT]) and also analyzed for the analytes listed in Table 3-3. The sampling frequency was reduced from weekly to biweekly following the first month of system operation due to low water demand and resulting low volume throughput. The AC sampling location was added after switching to prechlorination on November 9, 2004 after approximately four months of system operation. Weekly sampling was resumed after switching to prechlorination in order to monitor for the conversion and breakthrough of As(III) and to better observe the effects of this change in operation on the treatment system performance.

**3.3.3 Backwash Water Sample Collection.** Two backwash water samples were collected on November 17, 2004 from the sample taps located at the backwash water discharge line from each vessel. Unfiltered samples were sent to American Analytical Laboratories (AAL) for pH, total dissolved solids (TDS) and turbidity measurements. Filtered samples using 0.45- $\mu$ m disc filters were sent to Battelle's inductively coupled plasma-mass spectrometry (ICP-MS) laboratory for soluble As, Fe, and Mn analyses. Arsenic speciation was not performed for the backwash water samples.

**3.3.4 Backwash Solid Sample Collection.** Backwash solid samples were not collected in the initial six months of this demonstration. Backwash solid samples will be collected during the second half of the demonstration. 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, the lead and copper level. Beginning in December 2003 through March 2004, four sets of baseline distribution system samples were collected monthly by the plant operator at each of three homes which had been included in the Prospect Bay Lead and Copper Rule (LCR) sampling in the past. Following the installation of the arsenic adsorption system, distribution system sampling continued on a monthly basis at the same three locations.

**Table 3-3. Sampling Schedule for Prospect Bay, Queen Anne's County, MD**

<b>Sample Type</b>	<b>Sample Locations<sup>(a)</sup></b>	<b>No. of Samples</b>	<b>Frequency</b>	<b>Analytes</b>	<b>Date(s) Samples Collected</b>
Source Water	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 <sub>4</sub> , SiO <sub>2</sub> , PO <sub>4</sub> , TOC, and alkalinity.	08/07/03
Treatment Plant Water	At the wellhead (IN), after prechlorination (AC) <sup>(b)</sup> , after Tank A (TA), after Tank B (TB)	4	Monthly (once every four weeks) <sup>(c)</sup>	On-site: pH, temperature, DO/ORP. Off-site: As (total), Fe (total), Mn (total), SiO <sub>2</sub> , PO <sub>4</sub> , turbidity, and alkalinity.	<b>07/07/04</b> , 07/13/04, 07/20/04, <b>07/27/04</b> , 08/03/04, <b>08/18/04</b> , 08/31/04, <b>09/22/04</b> , 10/07/04, <b>10/19/04</b> , <b>10/26/04</b> , 11/03/04, <b>11/09/04</b> , <b>11/16/04</b> , <b>11/23/04</b> , 12/01/04, <b>12/07/04</b> , <b>12/15/04</b>
	At the wellhead (IN), after prechlorination (AC) <sup>(b)</sup> , and after the combined effluent (TT)	2	Monthly (once every four weeks)	On-site: pH, temperature, DO/ORP, and Cl <sub>2</sub> (free and total, sampled at locations AC and TT) Off-site: As(total), particulate and soluble As, As(III), As(V), Fe (total and soluble), Mn (total and soluble), Ca, Mg, F, NO <sub>3</sub> , SO <sub>4</sub> , SiO <sub>2</sub> , PO <sub>4</sub> , turbidity, and alkalinity	
Distribution Water	Three homes	3	Monthly	pH, alkalinity, As, Fe, Mn, Pb, Cu, and PO <sub>4</sub> .	Baseline sampling <sup>(d)</sup> : 12/17/03, 01/14/04, 02/11/04, 03/19/04  Monthly sampling: 07/20/04, 08/31/04, 09/23/04, 10/26/04, 11/16/04, 12/08/04
Backwash Water	From backwash discharge line	2	As needed	TDS, turbidity, pH, As (soluble), Fe (soluble), and Mn (soluble)	11/17/04
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 4-3.

(b) Prechlorination started on November 9, 2004.

(c) Reduced from weekly to once every four weeks after one month of system operation.

(d) Four baseline sampling events were performed before the system became operational.

TBD = to be determined.

Bold font indicates speciation was performed on-site.

The samples collected at the LCR locations were taken following an instruction sheet developed according to the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The first draw sample was collected from a cold-water faucet that had not been used for at least six 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. Analytes for the baseline samples coincided with the monthly distribution system water samples as described in Table 3-3. Arsenic speciation was not performed for the distribution water samples.

### **3.4 Sampling Logistics**

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

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

**3.4.2 Preparation of Sampling Coolers.** All sample bottles were new and contained appropriate preservatives. Each sample bottle was taped with a pre-printed, color-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. For example, red, orange, yellow, and green were used to designate sampling locations for IN, TA, TB, and TT, respectively. Pre-labeled bottles were placed in one of the plastic bags (each corresponding to a specific sampling location) in a sample cooler. When arsenic speciation samples were to be collected, an appropriate number of arsenic speciation kits also were included in the cooler. When appropriate, the sample cooler was packed with bottles for the three distribution system sampling locations and/or the two backwash sampling locations (one for each vessel).

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

**3.4.3 Sample Shipping and Handling.** After sample collection, samples for off-site analyses were packed carefully in the original coolers with wet ice and shipped to Battelle. Upon receipt, sample custodians verified that all samples indicated on the chain-of-custody forms were included and intact. Sample label 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 respective duration of the required hold time and disposed of properly thereafter.

### **3.5 Analytical Procedures**

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

Laboratory quality assurance/quality control (QA/QC) of all methods followed the guidelines provided in the QAPP (Battelle, 2003). Data quality in terms of precision, accuracy, method detection limit (MDL), and completeness met the criteria established in the QAPP, i.e., relative percent difference (RPD) of 20%, percent recovery of 80-120%, and completeness of 80%. The quality assurance (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 treatment system supplies drinking water to approximately 300 connections in the community of Prospect Bay at Grasonville in Queen Anne's County, MD. The water source for this system is supplied by two wells, which alternate operation on a daily basis, such that each well operates every other day, and each well supplies roughly half of the total production to the community. Well No. 1, located off Prospect Bay Road near the Prospect Bay Golf Course and Country Club, was chosen for treatment with the arsenic adsorption system as part of this demonstration study. Figure 4-1 shows Well House No. 1.

Well No. 1 was drilled to a depth of approximately 360 ft and estimated, prior to the beginning of the demonstration study, to operate for about 3 to 4 hours per day, every other day, at a rate of about 300 gpm. Prior to entering the distribution system, water was chlorinated for disinfection using chlorine gas (Figure 4-2) and treated for corrosion inhibition with a polyphosphate. Historical operational data from QAC indicated that the chlorine residual in the treated water typically was about 0.5 mg/L or less. The target concentration for polyphosphate was 0.8 mg/L.



**Figure 4-1. Existing Well House No. 1**

**4.1.1 Source Water Quality.** Source water samples were collected at a sampling tap located outside Well House No. 1 on August 7, 2003 and analyzed as 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.

Total arsenic concentrations of the source water ranged from 17.0 to 19.0  $\mu\text{g/L}$ . Based on the August 7, 2003 sampling results, arsenic existed primarily as As(III) (i.e., 98% of 18.8  $\mu\text{g/L}$ ). Only a small amount of arsenic was present as particulate As (0.1  $\mu\text{g/L}$ ) and As(V) (0.3  $\mu\text{g/L}$ ).



**Figure 4-2. Chlorine Gas System at Well No. 1**

The pH values of the raw water samples varied between 6.0 and 8.3, which was within the range recommended by STS. Therefore, pH adjustment was not recommended.

The source water iron levels ranged from less than 50 to 1,660  $\mu\text{g/L}$ ; however, more recent data indicated that iron levels were around 300  $\mu\text{g/L}$  or less and that iron existed primarily in the soluble form. Manganese concentrations ranged from 0.4 to 8  $\mu\text{g/L}$ . Because iron and manganese concentrations were sufficiently low, pretreatment prior to the adsorption process was not required. The concentrations of orthophosphate ranged from <0.10 to 0.4 mg/L and silica from 13.4 to 14.5 mg/L (as  $\text{SiO}_2$ ). SORB 33<sup>™</sup> media is reported to be affected by silica at levels greater than 40 mg/L and phosphate at levels greater than 1 mg/L. Neither of these compounds is expected to affect the adsorption of arsenic onto the media at this site.

**4.1.2 Pre-Demonstration Treated Water Quality.** Treated water samples after post-chlorination were collected by the county and the EPA prior to the demonstration study and analyzed for certain constituents as shown in Table 4-1. As expected, because the treatment process prior to distribution included only chlorination and the addition of polyphosphate, concentrations of these constituents in the treated water were very similar to those of the raw water. Total arsenic concentrations in the treated water ranged from 17 to 18  $\mu\text{g/L}$ . Iron concentration ranged from less than 50 to 1,100  $\mu\text{g/L}$  and manganese from 0.8 to 9  $\mu\text{g/L}$ . The pH values of the treated water ranged from 6.7 to 8.2 based on historical data from the years 2000 to 2003.

**Table 4-1. Prospect Bay Water Quality Data**

Parameter	Units	Utility Raw Water Data	EPA Raw Water Data	EPA Treated Water Data	Battelle Raw Water Data	County Raw Water Data	County Treated Water Data
<i>Sampling Date</i>		NA	10/04/02	10/04/02	08/07/03	00 – 03	00 – 03
pH		8.3	NS	NS	7.3	6.0 – 8.2	6.7 – 8.2
Total Alkalinity	mg/L	150.0	136.7	NA	168.0	NS	150
Hardness (as CaCO <sub>3</sub> )	mg/L	91.0	98.0	NA	101.5	NS	91
Turbidity	mg/L	NS	NS	NS	NS	NS	NS
Chloride	mg/L	1.5	16.7	NA	1.4	NS	1.6
Fluoride	mg/L	NS	NS	NS	1.0	NS	NS
Sulfate	mg/L	5.8	4.3	4.2	4.3	NS	5.3
Silica (as SiO <sub>2</sub> )	mg/L	14.5	13.4	13.3	14.1	NS	NS
Orthophosphate	mg/L	0.4	NS	NS	<0.10	NS	0.038
TOC	mg/L	<0.5	NS	NS	NA	NS	<0.50
As(total)	µg/L	17.0	19.0	18.0	18.8	NS	17 – 18
As (total soluble)	µg/L	NS	NS	NS	18.7	NS	NS
As (particulate)	µg/L	NS	NS	NS	0.1	NS	NS
As(III)	µg/L	NS	NS	NS	18.4	NS	NS
As(V)	µg/L	NS	NS	NS	0.3	NS	NS
Total Fe	µg/L	300.0	95.0	91.0	269.9	<50 – 1,660	<50 – 1,100
Soluble Fe	µg/L	NS	NS	NS	253.6	NS	NS
Total Al	µg/L	NS	<25	<25	<10	NS	NS
Soluble Al	µg/L	NS	NS	NS	<10	NS	NS
Total Mn	µg/L	8.0	0.4	0.8	1.5	NS	<5 – 9
Soluble Mn	µg/L	NS	NS	NS	1.4	NS	NS
Total V	µg/L	NS	NS	NS	<0.1	NS	NS
Soluble V	µg/L	NS	NS	NS	<0.1	NS	NS
Total Mo	µg/L	NS	NS	NS	<0.1	NS	NS
Soluble Mo	µg/L	NS	NS	NS	<0.1	NS	NS
Total Sb	µg/L	NS	<25	<25	<0.1	NS	NS
Soluble Sb	µg/L	NS	NS	NS	<0.1	NS	NS
Total Na	mg/L	27.0	24.1	23.6	26.2	NS	24
Total Ca	mg/L	20.0	23.3	23.0	23.5	NS	21
Total Mg	mg/L	9.7	9.7	9.5	10.4	NS	9.4

NA = Not Available

NS = Not Sampled

**4.1.3 Distribution System.** The Prospect Bay distribution system consists of a looped drinking water distribution line supplied by two production wells (Well No. 1 and Well No. 2). Prior to the demonstration study, the two wells alternated operation on a daily basis, such that each well supplied roughly half of the total production to the community. The water is sent to a 300,000-gallon storage tank, which serves to supply the distribution system constructed primarily of polyvinyl chloride (PVC) pipe. The connections to the distribution system and piping within the residences themselves are primarily PVC and some copper pipe. It is estimated that a few homes may have pipe with lead solder and that no homes have lead pipe.

The QAC Department of Public Works samples water from the distribution system for various parameters. Each month, five locations within the distribution system are sampled for bacterial analysis. The finish water also is sampled for volatile organic compounds (VOCs) on a regular basis. Under the EPA LCR, samples are collected from customer taps at five residences every three years.

## 4.2 Treatment Process Description

The STS arsenic package unit (APU) is designed for arsenic removal for small systems with flowrates greater than 100 gpm. It uses Bayoxide® E33 (branded as SORB 33™ by STS), an iron-based adsorptive media developed by Bayer AG, for the removal of arsenic from drinking water supplies. 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 International (NSF) 61 approval for use in drinking water.

**Table 4-2. Physical and Chemical Properties of SORB 33™ Media<sup>(a)</sup>**

<i>Physical Properties</i>	
<b>Parameter</b>	<b>Value</b>
Matrix	Iron oxide composite
Physical form	Dry granules
Color	Amber
Bulk Density (lb/ft <sup>3</sup> )	28.1
BET Area (m <sup>2</sup> /g)	142
Attrition (%)	0.3
Moisture Content (%)	<15% (by weight)
Particle size distribution	10 × 35 mesh
Crystal Size (Å)	70
Crystal Phase	$\alpha$ – FeOOH
<i>Chemical Analysis</i>	
<b>Constituents</b>	<b>Weight %</b>
FeOOH	90.1
CaO	0.27
MgO	1.00
MnO	0.11
SO <sub>3</sub>	0.13
Na <sub>2</sub> O	0.12
TiO <sub>2</sub>	0.11
SiO <sub>2</sub>	0.06
Al <sub>2</sub> O <sub>3</sub>	0.05
P <sub>2</sub> O <sub>5</sub>	0.02
Cl	0.01

(a) Provided by STS.

BET = Brunauer, Emmett, and Teller

The STS APU system is a fixed-bed downflow adsorption system. When the media reaches breakthrough at 10 µg/L of arsenic, the spent media is removed and disposed of after being subjected to the EPA TCLP. The APU-300 adsorption system at Prospect Bay consists of two pressure vessels operating in parallel. The design features of the APU-300 system are summarized in Table 4-3, and a flow diagram along with the sampling/analysis schedule are presented in Figure 4-3. Key process components are discussed as follows:

- **Intake.** Raw water pumped from Well No.1 was sent to the APU-300 treatment system.



**Table 4-3. Design Specifications of the APU-300 System**

Parameter	Value	Remarks
Pre-treatment/post-treatment	Chlorination <sup>(a)</sup>	—
Number of adsorber vessels	2	2 vessels per unit
Vessel configuration	Parallel	2 units in parallel; each with 2 vessels in parallel
Vessel size (in)	63 × 86	—
Type of media	SORB 33 <sup>TM</sup>	—
Media volume (ft <sup>3</sup> /vessel)	80	160 ft <sup>3</sup> total
Media bed depth (in)	44	—
Free board depth (in)	22	—
Design flowrate (gpm/vessel)	160	320 gpm total
Hydraulic loading rate (gpm/ft <sup>2</sup> )	7.4	Based on vessel cross sectional area of 21.6 ft <sup>2</sup> given an inner diameter of 63 in
EBCT (min)	3.8	Based on the design flow per vessel
Backwash frequency (per 45 days)	1	—
Backwash flowrate (gpm)	200	—
Backwash hydraulic loading rate (gpm/ft <sup>2</sup> )	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)	72,000	Based on 4 hours of daily operation at 300 gpm
Estimated working capacity (bed volume [BV])	114,000 <sup>(b)</sup>	Bed volumes to 10 µg/L total As breakthrough based on an influent As concentration of 19 µg/L and a bed volume of 160 ft <sup>3</sup>
Throughput (BV/day)	60	Based on 4 hours of daily operation at 300 gpm
Estimated throughput to 10 µg/L As breakthrough	136,400,000	Based on a bed volume of 160 ft <sup>3</sup>
Estimated media life (months)	63	Estimated frequency of changeout at 17% utilization

(a) Switched from post-chlorination to prechlorination on November 9, 2005.

(b) Based on STS provided estimate with an influent As concentration of 19 µg/L.

- Chlorination.** During the first four months of operation, chlorine was added at the end of the treatment train following the APU-300 adsorption system. In late September 2004, total arsenic levels in the treated water rose to above 10 µg/L, much earlier than projected, and the analytical results from speciation samples showed the majority of arsenic passing through the SORB 33<sup>TM</sup> media was As(III). On November 9, 2004, the treatment system was modified with a new chlorine addition point upstream of the adsorption vessels. With this prechlorination step in place, As(III) was oxidized to As(V) to improve the adsorption capacity of the media.
- Adsorption System.** The APU-300 system consists of two 63-inch-diameter, 86-inch-tall vessels configured in parallel, each containing approximately 80 ft<sup>3</sup> of SORB 33<sup>TM</sup> media supported by a gravel underbed. The vessels are constructed of fiberglass reinforced plastic (FRP), rated for 75 pounds per square inch (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 3.8 minutes in each vessel. Hydraulic loading to each vessel based on a design flowrate of 320 gpm is approximately 7.4



gpm/ft<sup>2</sup>. Figure 4-4 shows the APU-300 system at the manufacturing facility prior to shipment to the site.



**Figure 4-4. APU-300 Treatment System Prior to Shipment**

- **Backwash.** STS recommends that the SORB 33<sup>TM</sup> 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. Backwash of the system was initiated manually by the system operator because there was no on-site disposal facility to receive the backwash water. The backwash water was discharged into a tanker truck and transported to a local wastewater treatment plant.

### **4.3 System Installation**

The construction of the treatment building and the installation of the STS APU-300 system were completed on June 24, 2004 by Stearns and Wheler, LLC, a local engineering subcontractor hired by QAC and STS.

**4.3.1 Permitting.** Engineering plans for the system permit application were prepared by Stearns and Wheler. The plans included a site plan, construction drawings and details of the new treatment building to be constructed, and process and mechanical drawings of the APU-300 treatment system. The plans, along with a construction permit application, were submitted to the MDE for review on March 12, 2004. The MDE replied with comments on the engineering package on April 23, 2004 and issued a letter of approval for operation of the treatment system on June 15, 2004.

**4.3.2 Building Construction.** QAC constructed an addition to its existing pump house (Well House No. 1) to contain the APU-300 treatment system. The addition included a 16-ft × 23-ft treatment

area onto the existing 8-ft × 16-ft well house. The building was constructed using concrete block with brick siding and included a 10-ft-wide rollup door on the end of the building and access hatches in the roof to facilitate future media replacement. A photograph of the building housing the equipment is shown in Figure 4-5. Building construction began on May 17, 2004 and was completed on June 24, 2004 including placement and setting of the vessels within the building, which were put into place before the roof was installed.



**Figure 4-5. New Treatment Building Addition with Two Access Hatches in the Roof**

**4.3.3 System Installation, Shakedown, and Startup.** The APU-300 system was shipped by the vendor on May 26, 2004 and arrived at the site on June 1, 2004. Stearns and Wheler, LLC performed the off-loading and installation of the system, including all plumbing, mechanical, and electrical work and connections of the treatment system to the existing entry and distribution piping. A photograph of the system being unloaded and set in place with a crane is shown in Figure 4-6. The system mechanical equipment installation was completed by June 11, 2004. Gravel underbedding was placed in the vessels on June 15, 2004 and the adsorption media was loaded in both vessels on June 16, 2004. A bacteria test sample, required by the state, was collected on June 16, 2004 from the system, which had previously been treated with chlorine for disinfection. Once the media was loaded, Stearns and Wheler conducted a pressure test of the system piping. The system was backwashed for media conditioning prior to service on June 17, 2004. The results from the bacteria test, received on June 17, were negative.

Battelle, STS, Stearns and Wheler, and representatives from QAC were on site to complete system shakedown and startup procedures on June 29, 2004. All backwashing and system shakedown procedures were completed prior to this date, so that the system was ready to go into regular service operation.





**Figure 4-6. Unloading of the APU Skid into the Partially Completed Treatment Building Addition**

Battelle provided operator training on data and sample collection and conducted a review of the piping and instrumentation diagram (P&ID) and system checklist with the vendor. The system was put into regular service mode on June 30, 2004.

#### **4.4 System Operation**

**4.4.1 Operational Parameters.** The operational parameters for the first six months of system operation are tabulated and included as Appendix A. Key parameters are summarized in Table 4-4 including operational time, throughput, flowrate, EBCT, and pressure information. Plant operations were initiated on June 30, 2004 and continued through December 30, 2004 with few operational problems for the first six months of the demonstration period.

During the first six months of operation, Well No. 1 operated for approximately 1,083 total hours based on the well pump hour meter readings with an average daily operating time of 6.3 hrs per day. This operating time represented a utilization rate of approximately 25% over that time period. The well operated more during the first three months of operation (July through September 2004) than the second three-month period (October through December 2004) with an average daily operating time from July through September of 8.0 hrs/day compared to just 4.5 hrs/day from October through December.

The total system throughput from June 30 to December 30, 2004 was approximately 14,856,000 gallons based on the flow totalizer readings from the APU-300 system. This corresponds to approximately 12,400 BVs of water processed through the entire system. The throughput to each vessel was 7,526 and 7,406 kilogallons through Vessels A and B, respectively.

**Table 4-4. Summary of APU-300 System Operation**

Operational Parameter	Value / Condition		
Duration	06/30/04 – 12/30/04 (Week 1 – Week 27)		
Cumulative Operating Time (hr)	1083		
Average Daily Operating Time (hr)	8.0 hrs/day July thru Sept; 4.5 hrs/day Oct thru Dec		
	Vessel A	Vessel B	Total
Throughput (kgal)	7,526	7,406	14,856
Average Flowrate (gpm)	115	114	229
Range of Flowrate (gpm)	105 - 121	93 - 121	198 - 242
Average EBCT (min) <sup>(a)</sup>	5.2	5.3	NA
Range of EBCT (min) <sup>(a)</sup>	4.9 – 5.7	4.9 – 6.5	NA
Differential Pressure across Bed (psi)	2.0 – 7.5	1.8 – 7.5	NA
System Pressure Loss (psi)	NA	NA	1 - 16

(a) Calculated based on 80 ft<sup>3</sup> of media in each vessel.

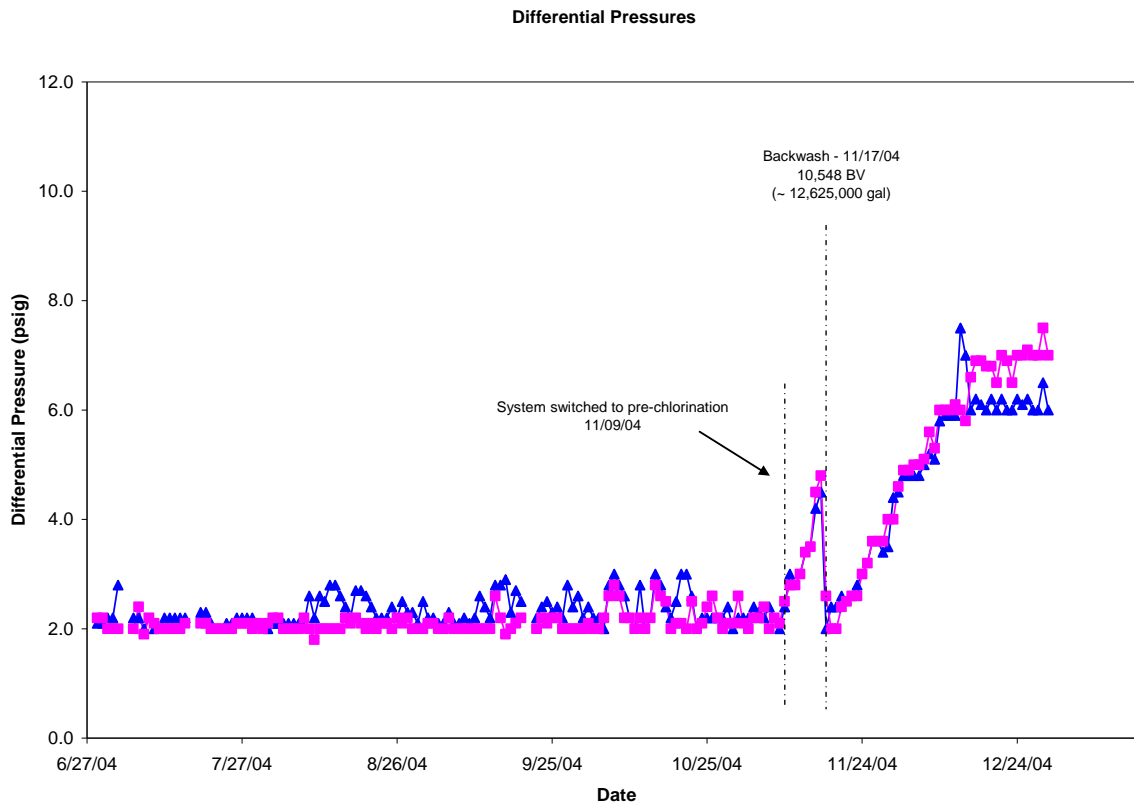
NA = not applicable.

The average flowrates were 115 gpm through Vessel A and 114 gpm through Vessel B, indicating that the flow to each vessel was well balanced for the majority of the first six months of operation. As a result, the average EBCT for both the vessels was about 5.2 to 5.3 minutes. This EBCT is greater than the design EBCT of 3.7 minutes shown in Table 4-3 because the average total flowrate to the system was about 229 gpm, which is lower than the design peak flowrate of 320 gpm.

Figure 4-7 shows the differential pressures measured across the media bed in both vessels during the first six months of system operation. The differential pressure ( $\Delta P$ ) readings across the adsorption vessels were low (approximately 2 to 3 psi) and constant prior to the switch to prechlorination. Following the switch to prechlorination on November 9, 2004, the  $\Delta P$  readings across the vessels began to rise from about 2.0 to 4.5 psi with 425 BVs of water treated. A backwash was performed on November 17, 2004 and the  $\Delta P$  readings returned to the original level around 2 psi. Prior to this, no backwash had been performed. Soon after the backwash, the  $\Delta P$  readings began to rise steadily and reached 6 to 7 psi across both vessels by the end of December 2004. It was postulated at the time that this  $\Delta P$  rise was caused by the accumulation of iron solids in the media bed due to the addition of chlorine before the adsorption vessels.

No significant pressure-related problems or operational difficulties were encountered with the system with the exception of malfunction of the Vessel B flowmeter on November 18-20. During this period, the flowmeter read 0.0 gpm even though the system was operating and there was clearly flow going through the vessel. The meter was removed for cleaning and inspection and returned to the system. Following this maintenance, the meter functioned properly.

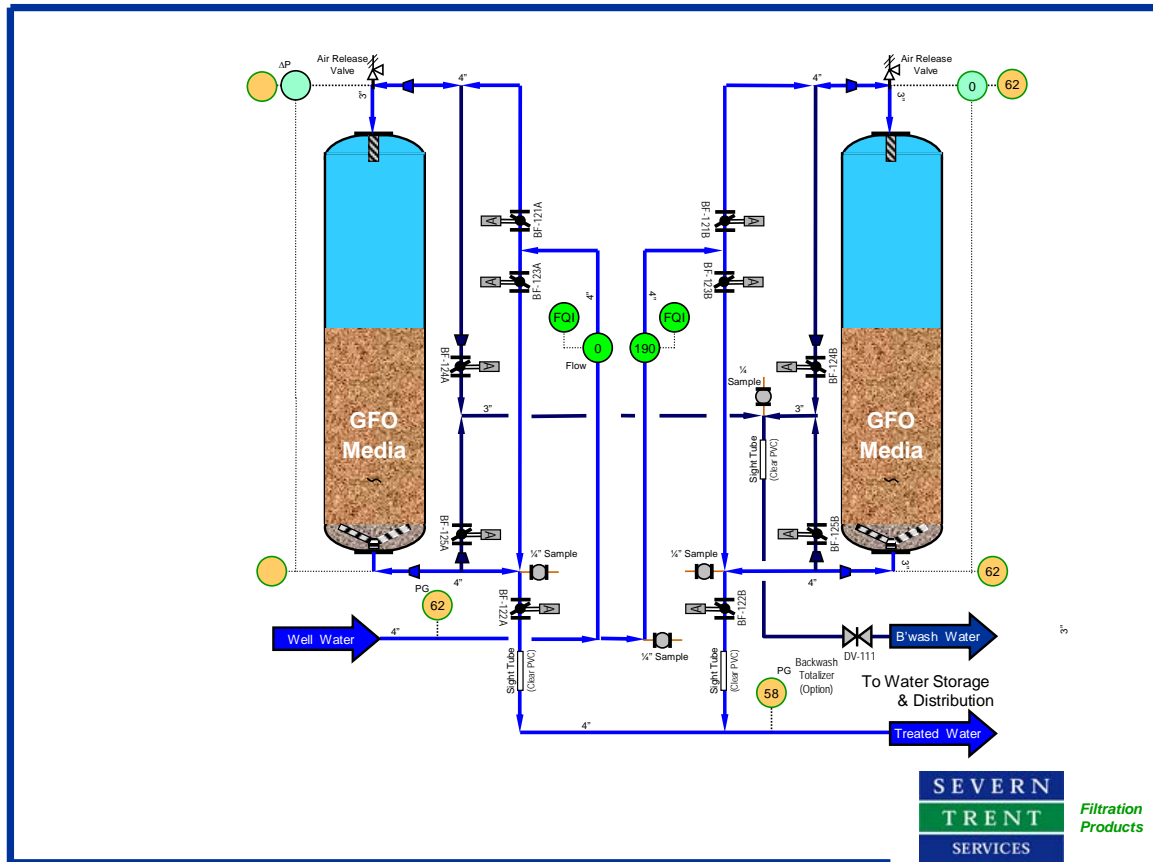
**4.4.2 Previous System Design Changes.** Prior to shipment of the APU-300 system to Prospect Bay, the system was modified from its original design with revised plumbing that included replacement of the 3-inch-diameter system piping with 4-inch-diameter pipe; removal of the diaphragm valves, restrictive orifices, and valve controllers; and installation of a nested system of fully ported actuated butterfly valves, and a new control panel. A diagram of the APU-300 system as installed at Prospect Bay



**Figure 4-7. Differential Pressure Loss across Adsorption Vessels**

is shown in Figure 4-8. These modifications were made due to operational problems experienced by APU-300 systems previously installed at two other sites as part of the arsenic demonstration study – one at the Desert Sands Mutual Domestic Water Consumers Association (MDWCA) in Anthony, New Mexico and a second system in Brown City, Michigan. Both of these systems experienced operational issues related to flow restriction, flow imbalance, and excessive pressure losses as described in the Desert Sands MDWCA Six-Month Report and the Brown City, Michigan Six-Month Report (Battelle, 2005a and 2005b). To troubleshoot the operational problems discovered with these two systems, STS performed a series of systematic hydraulic testing at its Torrance, California fabrication shop and at the Brown City, Michigan site. The results of this testing indicated that the flow restrictions and elevated pressure drop issues were most likely caused by the programmable Fleck valve controller and the restrictive orifices included in the original system. After considering several options, STS retrofitted the systems as described above with larger diameter pipe and removed certain system components determined to have caused excessive flow restrictions and pressure loss.

All such system modifications were completed on the APU-300 system for Prospect Bay prior to being shipped from the manufacturing facility in Torrance to the site in Maryland. With these modifications already in place, the Prospect Bay system operated as expected during the first six months of the demonstration study and did not experience the issues related to flow restriction and pressure drop as seen initially at the other two locations.



**Figure 4-8. Diagram of STS APU-300 System as Installed at Prospect Bay**

**4.4.3 Backwash.** The APU-300 system was not backwashed during the first four months of operation because  $\Delta P$  readings across both adsorption vessels remained low and because the backwash water produced would require off-site disposal. Following the switch to prechlorination, the  $\Delta P$  readings across the vessels began to rise from about 2.0 to 4.5 psi. A backwash was performed on November 17, 2004, with each vessel backwashed separately at a flowrate of 200 gpm for a period of 20 to 25 minutes. A total volume of approximately 9,500 gallons of backwash water was generated during the backwash event.

**4.4.4 Residual Management.** Residuals produced by the operation of the APU-300 system include 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. Because there was no on-site disposal facility, the backwash water was discharged into a tanker truck and transported to the Stevensville Wastewater Treatment Plant (WWTP) for disposal. The Stevensville WWTP also is owned and operated by QAC.

**4.4.5 System/Operation Reliability and Simplicity.** Because all relevant system modifications related to operational issues were completed prior to the APU-300 being shipped to Prospect Bay, no major operational problems were encountered. The only O&M issue was related to the Vessel B flowmeter which was not operating on November 18-20, 2004. Following some simple cleaning and maintenance, the meter functioned properly. The APU-300 system did not experience any unscheduled downtime during the first six months of operation.



The simplicity of system operation and operator skill requirements are discussed below in relation to pre- and post-treatment requirements, levels of system automation, operator skill requirements, preventive maintenance activities, and frequency of chemical/media handling and inventory requirements.

***Pre- and Post-Treatment Requirements.*** During the first four months of operation, no pretreatment was implemented at the site. In early November 2004, the treatment system was modified to include a new chlorine addition point upstream of the adsorption vessels to oxidize As(III) to As(V) and improve the adsorption capacity of the media. Post-treatment consisted only of the addition of polyphosphate as a corrosion inhibitor using the preexisting polyphosphate feed system.

***System Automation.*** All major functions of the APU-300 system can be automated and require 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 requirements to operate the APU-300 system were basic and limited to observation of the process equipment integrity and operating parameters such as pressure, flow, and system alarms. The operational setup was intuitive and all major system operations were automated as described above. A Class I state-certified operator was required for operation of the water system at Prospect Bay. The daily demand on the operator was typically only 10-15 minutes to allow the operator to visually inspect the system and record the operating parameters on the daily log sheets. The time requirement does not include travel time to and from the site.

***Preventive Maintenance Activities.*** Preventive maintenance tasks recommended by STS included monthly inspection of the control panel, quarterly checking and calibration of the flowmeters, biannual inspection of the actuator housings, fuses, relays, and pressure gauges, and annual inspection of the butterfly valves. Further, inspection of the adsorber laterals and replacement of the underbedding gravel were recommended to be performed concurrently with the media replacement. During this reporting period, maintenance activities performed by the operator included cleaning and repair of the flowmeter paddle wheels on the flowmeter for Vessel B.

***Chemical/Media Handling and Inventory Requirements.*** The chemicals required for system operation included the chlorine gas injection system and the polyphosphate addition system which were both already in use at the site. Media change-out was not required during the first six months of operation; thus, no additional media handling was required after the initial installation.

## **4.5 System Performance**

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

**4.5.1 Treatment Plant Sampling.** Water samples were collected at four locations throughout the treatment train: at the inlet (IN), after Vessels A and B (TA and TB), and after the combined effluent (TT). Following switching to prechlorination on November 9, 2004, a fifth sampling location was added after the prechlorination injection point (AC). Overall, during the first six months of system operation, water samples were collected on 18 occasions with field speciation performed on 8 occasions. Table 4-5 summarizes the As, Fe, and Mn analytical results collected prior to switching to prechlorination, and Table 4-6 summarizes these results after switching to prechlorination on November 9, 2004. Table 4-7 summarizes the results of the other water quality parameters collected during the first six months of system operation. Appendix B contains a complete set of analytical results collected during this period. 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 prior to Switching to Prechlorination (July 7 to November 3, 2004)**

Parameter	Sampling Location	Units	Number of Samples	Minimum Concentration	Maximum Concentration	Average Concentration	Standard Deviation
As (total)	IN	µg/L	12	18.4	25.8	21.0	2.2
	TA	µg/L	7	0.7	14.8	7.6	6.0
	TB	µg/L	7	0.3	12.9	6.1	5.4
	TT	µg/L	6	0.3	13.3	7.3	5.9
As (total soluble)	IN	µg/L	5	19.0	22.0	20.6	1.3
	TT	µg/L	4	0.2	13.1	4.8	5.8
As (particulate)	IN	µg/L	5	<0.1	0.8	0.3	0.3
	TT	µg/L	4	<0.1	0.2	0.1	0.1
As(III)	IN	µg/L	6	12.8	22.4	18.7	4.0
	TT	µg/L	6	0.2	13.2	7.1	5.8
As(V)	IN	µg/L	5	0.1	8.1	1.7	3.6
	TT	µg/L	4	<0.1	0.3	0.1	0.1
Total Fe	IN	µg/L	12	193	315	241	36
	TA	µg/L	7	<25	77	30	29
	TB	µg/L	7	<25	38	16	10
	TT	µg/L	6	<25	116	30	42
Dissolved Fe	IN	µg/L	5	161	222	195	24
	TT	µg/L	4	<25	80	29	34
Total Mn	IN	µg/L	12	1.4	6.0	2.4	1.4
	TA	µg/L	7	1.2	17.9	6.3	5.4
	TB	µg/L	7	0.8	9.6	4.9	2.9
	TT	µg/L	6	1.5	6.7	4.4	2.0
Dissolved Mn	IN	µg/L	5	1.5	3.1	2.0	0.7
	TT	µg/L	4	1.5	5.9	3.5	1.9

Note:

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

Duplicate samples were included in the calculations.

**Arsenic.** Total As concentrations in the raw water ranged from 18.3 to 25.8 µg/L and averaged 21.0 µg/L (Tables 4-5 and 4-6). As(III) was the predominating species, ranging from 12.8 to 22.4 µg/L and averaging 18.7 µg/L. Only trace amounts of particulate As were detected in the raw water with all concentrations less than 1 µg/L. As(V) concentrations were typically below the detection limit of 0.1 µg/L. Figure 4-9 contains three bar charts showing the concentrations of total As, particulate As, As(III), and As(V) at the IN, AC, and TT locations for each speciation sampling event. The arsenic concentrations measured during this six-month period were consistent with those in the raw water sample collected on August 7, 2003 (Table 4-1).

The key parameter for evaluating the effectiveness of the SORB 33<sup>TM</sup> media was the concentration of arsenic in the treated water. As shown in the arsenic breakthrough curve in Figure 4-10, total arsenic levels in the treated water, existing primarily as As(III) (see Figure 4-9), exceeded the target concentration of 10 µg/L after less than 7,400 BVs of throughput in late September 2004. To improve

**Table 4-6. Summary of Arsenic, Iron, and Manganese Analytical Results after Switching to Prechlorination (November 9, 2004 to December 30, 2004)**

Parameter	Sampling Location	Units	Number of Samples	Minimum Concentration	Maximum Concentration	Average Concentration	Standard Deviation
As (total)	IN	µg/L	4	18.3	20.0	19.0	0.7
	AC	µg/L	3	18.8	22.1	20.3	1.7
	TA	µg/L	2	0.4	0.4	0.4	0.0
	TB	µg/L	2	0.3	0.3	0.3	0.0
	TT	µg/L	5	0.3	14.7	5.7	7.1
As (total soluble)	IN	µg/L	2	19.0	20.0	19.5	0.7
	AC	µg/L	3	12.2	19.0	15.5	3.4
	TT	µg/L	5	0.2	14.6	5.7	7.0
As (particulate)	IN	µg/L	2	<0.10	<0.10	<0.10	0.0
	AC	µg/L	3	<0.10	7.7	4.9	4.2
	TT	µg/L	5	<0.10	<0.10	0.1	0.0
As(III)	IN	µg/L	2	18.4	20.3	19.4	1.3
	AC	µg/L	3	<0.10	1.6	0.6	0.9
	TT	µg/L	5	0.4	14.8	5.5	6.7
As(V)	IN	µg/L	2	<0.10	0.6	0.3	0.4
	AC	µg/L	3	12.0	18.9	14.8	3.6
	TT	µg/L	5	<0.10	1.5	0.4	0.6
Total Fe	IN	µg/L	3	229	264	251	19
	AC	µg/L	3	212	268	236	29
	TA	µg/L	2	<25	<25	<25	0.0
	TB	µg/L	2	<25	<25	<25	0.0
	TT	µg/L	5	<25	108	32	43
Dissolved Fe	IN	µg/L	1	156	156	156	0.0
	AC	µg/L	3	<25	173	66	93
	TT	µg/L	5	<25	61	22	22
Total Mn	IN	µg/L	4	2.5	9.8	4.4	3.6
	AC	µg/L	5	1.5	2.5	2.0	0.5
	TA	µg/L	2	2.0	2.1	2.1	0.1
	TB	µg/L	2	3.0	3.0	3.0	0.0
	TT	µg/L	5	2.0	11.5	6.0	4.5
Dissolved Mn	IN	µg/L	2	2.1	14.3	8.2	8.6
	AC	µg/L	3	0.2	1.7	0.7	0.8
	TT	µg/L	5	1.5	11.2	5.8	4.7

Note: One-half of the detection limit was used for samples with concentrations less than the detection limit for calculations.

Duplicate samples were included in the calculations.

arsenic removal by the media, prechlorination was implemented on November 9, 2004. Chlorine gas was applied at a rate of 12 lb/day, which is equivalent to a dosage of 3.6 mg/L (as Cl<sub>2</sub>) assuming complete dissolution of the chlorine gas into the water. The chlorine residual measured at the plant tap just prior to distribution increased from 0.1 to 0.5 mg/L (as Cl<sub>2</sub>) over a twelve hour period immediately following the modification of the chlorine addition point. Measurements collected over the next two days showed the chlorine residual remained at 0.5 mg/L to 0.9 mg/L following the treatment system.

**Table 4-7. Summary of Water Quality Parameter Results**

Parameter	Sampling Location	Units	Number of Samples	Minimum Concentration	Maximum Concentration	Average Concentration	Standard Deviation
Alkalinity	IN	mg/L	16	158	176	164.8	4.4
	AC	mg/L	5	154	176	165.0	8.0
	TA	mg/L	9	154	172	164.1	5.9
	TB	mg/L	9	154	180	165.9	7.5
	TT	mg/L	11	152	171	162.5	4.9
Fluoride	IN	mg/L	16	0.5	0.9	0.7	0.13
	AC	mg/L	5	0.7	1.1	0.9	0.14
	TA	mg/L	9	0.2	1.0	0.7	0.25
	TB	mg/L	9	0.5	1.0	0.8	0.14
	TT	mg/L	11	0.6	0.9	0.7	0.10
Sulfate	IN	mg/L	11	1.5	5.3	3.5	1.2
	AC	mg/L	3	2.7	6.0	4.1	1.7
	TA	mg/L	4	2.5	5.3	3.2	1.4
	TB	mg/L	4	2.5	2.5	2.5	0.0
	TT	mg/L	11	2.5	6.0	3.8	1.0
Orthophosphate (as PO <sub>4</sub> )	IN	mg/L	16	<0.06	<0.10	0.04	0.01
	AC	mg/L	5	<0.06	1.6	0.60	0.78
	TA	mg/L	8	<0.06	<0.10	0.04	0.01
	TB	mg/L	8	<0.06	<0.10	0.04	0.01
	TT	mg/L	11	<0.06	<0.10	0.04	0.01
Silica	IN	mg/L	16	8.5	15.9	14.3	1.6
	AC	mg/L	5	14.3	15.0	14.6	0.3
	TA	mg/L	9	13.2	14.6	14.3	0.4
	TB	mg/L	9	13.2	14.8	14.1	0.5
	TT	mg/L	11	13.7	15.4	14.6	0.5
Nitrate (as N)	IN	mg/L	11	<0.04	0.1	0.03	0.02
	AC	mg/L	3	<0.04	<0.04	<0.04	0.00
	TA	mg/L	4	<0.04	<0.04	<0.04	0.00
	TB	mg/L	4	<0.04	0.09	0.04	0.04
	TT	mg/L	11	<0.04	0.1	0.03	0.02
Turbidity	IN	NTU	16	0.5	3.0	1.0	0.61
	AC	NTU	5	0.1	0.6	0.3	0.21
	TA	NTU	9	0.1	0.6	0.3	0.15
	TB	NTU	9	0.1	0.7	0.4	0.20
	TT	NTU	11	0.1	1.1	0.3	0.30
pH	IN	S.U.	14	7.4	8.2	7.9	0.24
	AC	S.U.	1	7.8	7.8	7.8	NA
	TA	S.U.	7	7.4	8.2	7.9	0.27
	TB	S.U.	7	7.2	8.3	7.9	0.34
	TT	S.U.	9	7.3	8.1	7.8	0.25
Temperature	IN	°C	14	14.9	21.7	17.4	2.27
	AC	°C	1	14.9	14.9	14.9	NA
	TA	°C	7	15.4	18.4	16.6	1.15

**Table 4-7. Summary of Water Quality Parameter Results**

Parameter	Sampling Location	Units	Number of Samples	Minimum Concentration	Maximum Concentration	Average Concentration	Standard Deviation
Temperature (Continued)	TB	°C	7	15.4	18.6	16.5	1.19
	TT	°C	9	14.7	18.4	16.5	1.31
Dissolved Oxygen	IN	mg/L	12	0.9	5.5	2.6	1.46
	TA	mg/L	6	0.8	2.6	1.7	0.67
	TB	mg/L	5	0.7	2.2	1.2	0.59
	TT	mg/L	8	2.1	5.8	4.7	1.25
ORP	IN	mV	14	-148	160	-76	94.8
	TA	mV	7	-112	114	-29	70.3
	TB	mV	7	-83	120	-1	69.5
	TT	mV	9	-76	286	19	124.0
Free Chlorine	AC	mg/L	1	0.4	0.4	0.4	NA
	PT	mg/L	14	0.1	0.5	0.3	0.11
Total Chlorine	AC	mg/L	1	0.1	0.1	0.1	NA
	PT	mg/L	14	0.3	1.7	0.9	0.42
Total Hardness (as CaCO <sub>3</sub> )	IN	mg/L	8	97.7	116.7	108	7.2
	AC	mg/L	3	95.5	113.3	102	10.0
	TT	mg/L	11	92.5	129.1	109	9.3

Note: One-half of the detection limit was used for samples with concentrations less than the detection limit for calculations.

NTU = nephelometric turbidity units

Duplicate samples were included in the calculations.

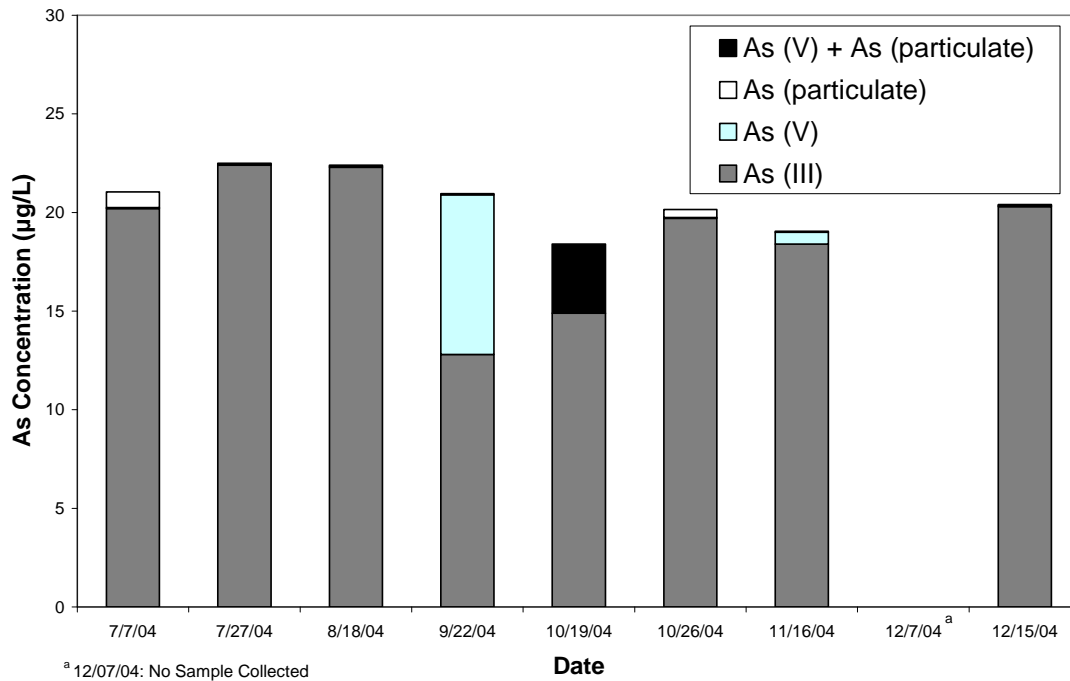
The day after switching to prechlorination, a treated water sample was collected from the TT location and speciated for arsenic. This sample had a total As concentration of 14.7 µg/L with all arsenic present as As(III). On November 16 (after about 220 BVs of water treated since November 10, 2004), samples were collected from the IN, AC, and TT locations and speciated for arsenic. As shown in Figure 4-9, As(III) in the raw water was converted almost completely to As(V) and particulate As (i.e., 12 and 7.7 µg/L, respectively) after chlorination; however, about 87% of the 12.0 µg/L total As in the combined treated water remained as As(III). It was likely that chlorine added to the water was consumed by the As(III) and ferrous ions previously removed by the media and some As(III) in the media bed was displaced into the treated water during this early stage of prechlorination.

On November 23, 2004 (after an additional 220 BVs of water treated since November 16, 2004), As concentration in the treated water decreased sharply to 0.9 µg/L, of which only 0.4 µg/L existed as As(III). Subsequent treated water samples collected through December 15, 2004 continued to show decreasing arsenic concentrations to 0.3 µg/L, indicating that prechlorination was effective at increasing media adsorptive capacity and sustaining media life.

By December 30, 2004, the APU-300 system treated approximately 12,400 BVs of water (equivalent to 14,856,000 gallons of water), which is about 11% of the vendor-estimated working capacity (114,000 BVs to 10 µg/L total As breakthrough as shown in Table 4-3).

**Iron.** Figure 4-11 shows the total iron concentrations versus BVs of water treated during the first six months at the various sampling locations throughout the treatment train. Total iron concentrations in the

### Arsenic Species at the Inlet (IN) at Prospect Bay



### Arsenic Species after Pre-Chlorination (AC) at Prospect Bay

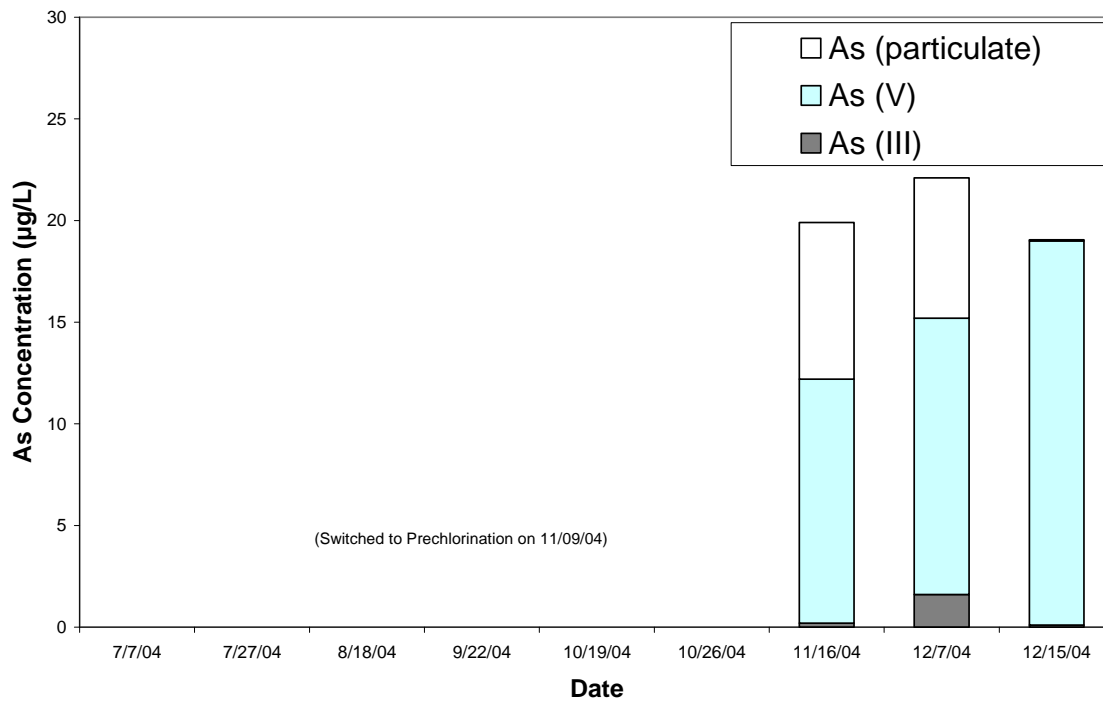
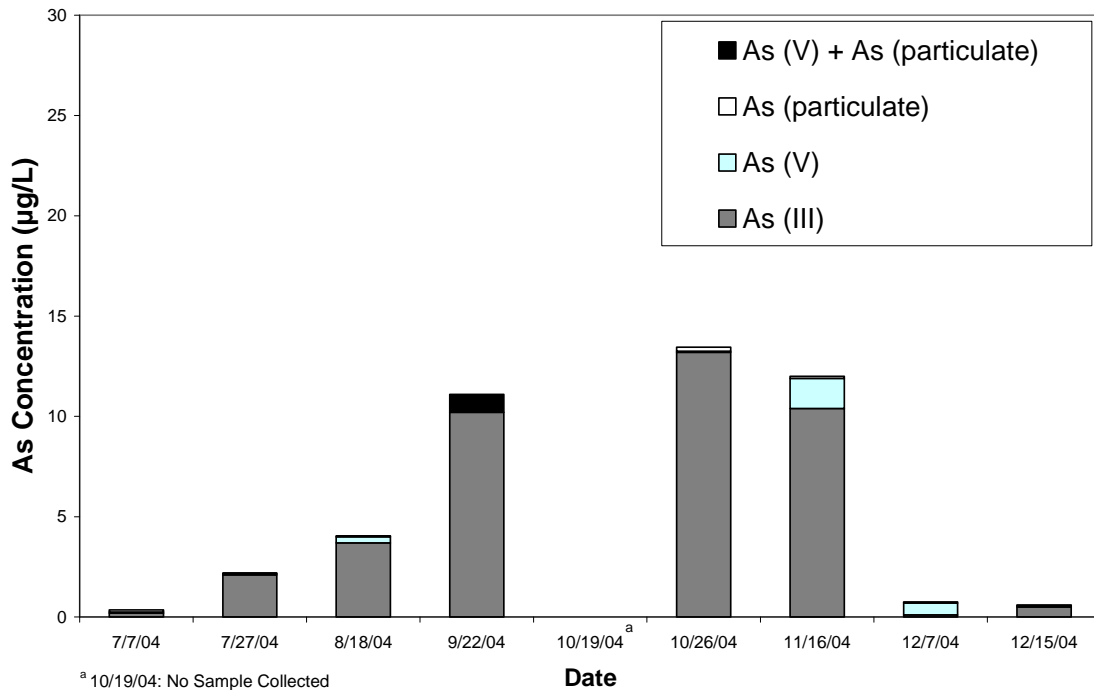
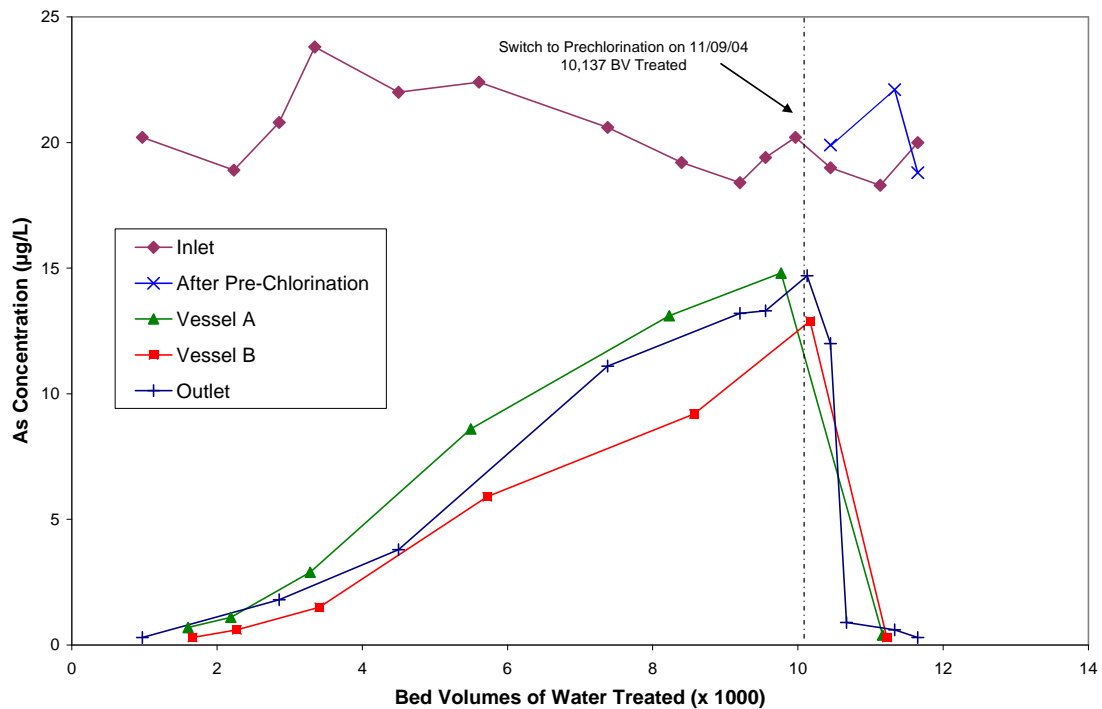


Figure 4-9. Concentration of Arsenic Species at the IN, AC, and TT Sample Locations

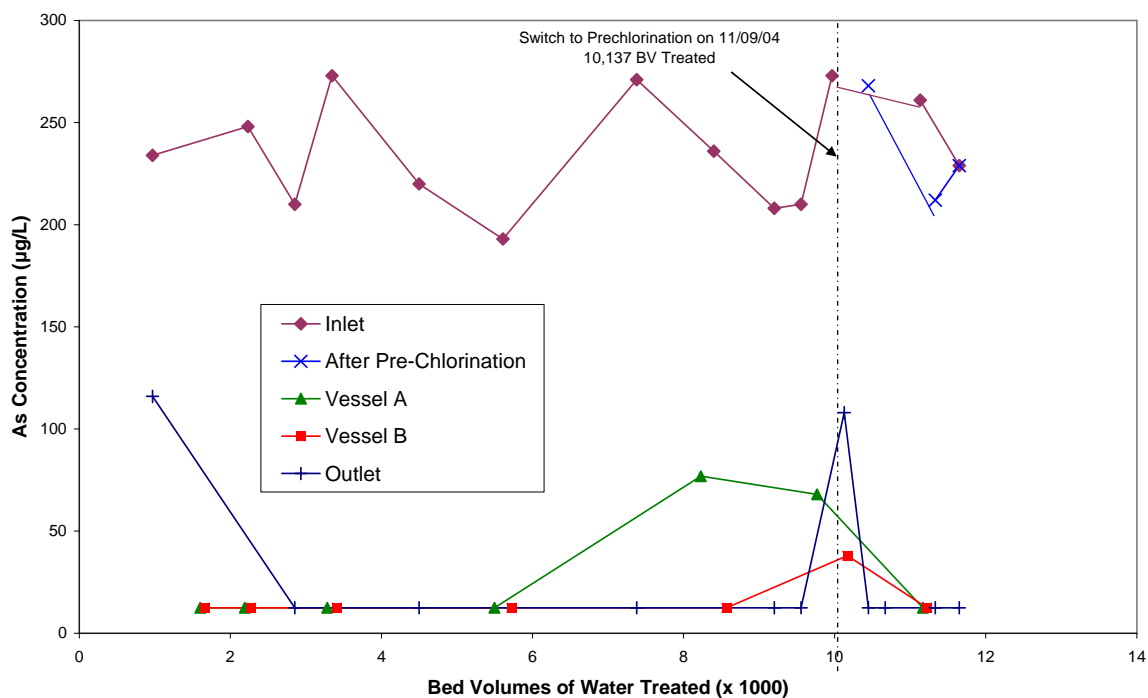
### Arsenic Species After Treatment (TT) at Prospect Bay



**Figure 4-9. Concentration of Arsenic Species at the IN, AC, and TT Sample Locations (Continued)**



**Figure 4-10. Total Arsenic Breakthrough Curve**



Note: One-half of the detection limit (12.5 µg/L) was used for plotting data below the detection limit for iron (<25 µg/L).

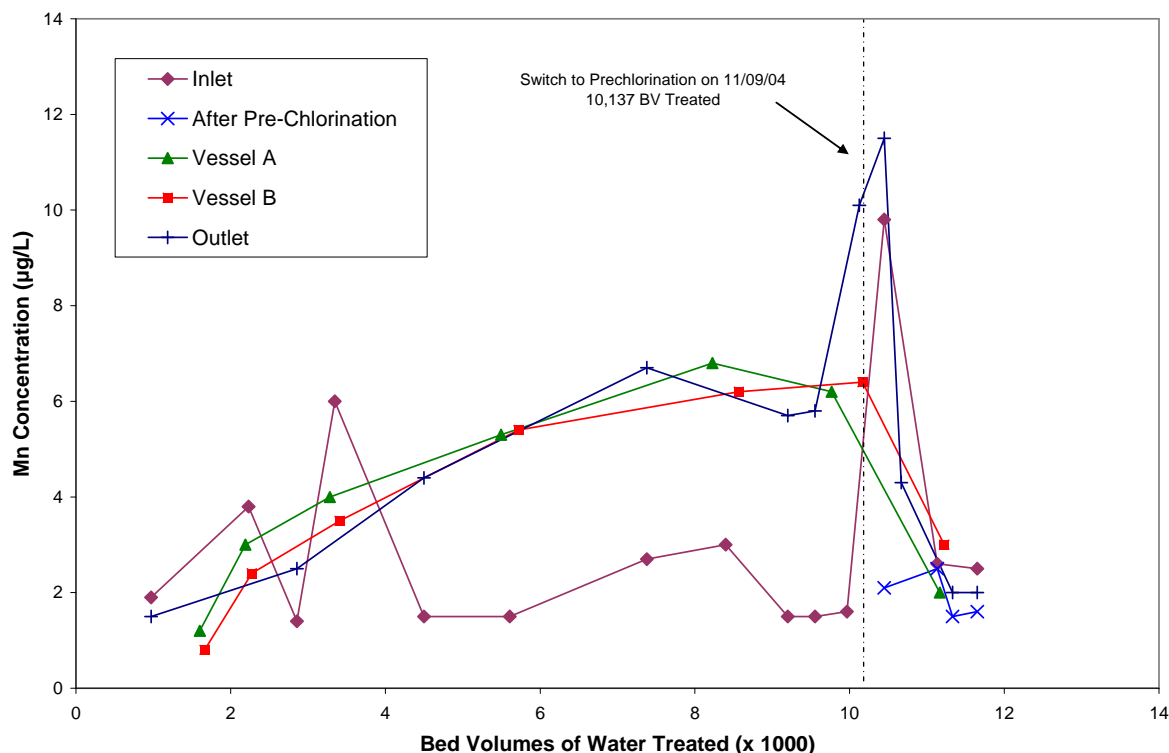
**Figure 4-11. Total Iron Concentrations Versus Bed Volumes**

raw water varied from 193 to 315 µg/L, with most of the iron present in the soluble form ranging from 156 to 222 µg/L at the influent (Tables 4-5 and 4-6). After the SORB 33<sup>TM</sup> adsorption vessels, the iron concentrations were much lower, in most cases below the detection limit of 25 µg/L. These results indicated the removal of soluble iron by the SORB 33<sup>TM</sup> media bed. Although it was not clear how the soluble iron was removed, its removal did not appear to be related to iron precipitation based on the constant ΔP readings observed across the adsorption vessels as shown in Figure 4-7.

After treating about 8,200 BVs, iron concentrations ranging from 38 to 77 µg/L were detected in the treated water indicating that iron was beginning to break through the SORB 33<sup>TM</sup> media. After switching to prechlorination, Fe(II) in the raw water was oxidized to Fe(III) and iron solids were filtered by the media bed to less than the detection limit.

**Manganese.** Figure 4-12 shows the total Mn concentrations versus BVs of water treated during the first six months at the various sampling locations throughout the treatment train. Total Mn concentrations in the raw water were low and ranged from 1.4 to 9.8 µg/L (Tables 4-5 and 4-6) and existed almost entirely in the soluble form. Through approximately 4,000 BVs of water treated, the total Mn concentrations in the raw and treated water were similar with most values less than 4 µg/L. After 4,000 BVs and prior to the switch to prechlorination (at about 10,000 BVs), the Mn concentration in the treated water began to increase, and was higher than that in the raw water. It is not clear why the concentrations of manganese increased in the treated water, but the increase may indicate that the media contributed a small amount of manganese to the water. After switching to prechlorination in November 2004 through the end of December 2004, there was little discernable difference between the manganese concentrations in the water prior to and after the treatment system.





**Figure 4-12. Total Manganese Concentrations Versus Bed Volumes**

**Other Water Quality Parameters.** In addition to the critical parameter analyses for 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 4-7.

The inlet pH values ranged from 7.4 to 8.2, with an average concentration of 7.9. The pH values were consistent and similar at all sampling locations across the treatment train. Free and total chlorine were monitored at the AC location and at a tap just prior to the distribution system (referred to as the Plant Tap, PT, as listed in Table 4-7). Free chlorine measurements at the AC and PT locations ranged from 0.1 to 0.5 mg/L and total chlorine levels ranged from 0.1 to 1.7 mg/L (Table 4-7).

ORP measurements across the treatment train were erratic with a wide range of values collected at the inlet, ranging from -148 to 160 mV, and at the treated water locations, ranging from -112 to 286 mV. DO measurements were also highly variable. Several attempts were made to verify and improve the readings, including replacing the field meter and probe and working closely with the operator to ensure the meter was used properly. Due to the spread in these measurements, no discernable trend could be identified from these data.

The results for alkalinity, fluoride, sulfate, silica, and nitrate remained fairly consistent throughout the treatment train, appearing unaffected by the media and prechlorination. Orthophosphate (as  $\text{PO}_4$ ) was less than the detection limit for all samples, except for one sample collected at the AC location in December

which had a concentration of 1.3 mg/L. Total hardness ranged from 93 to 129 mg/L as CaCO<sub>3</sub> and remained constant across the treatment train.

**4.5.2 Backwash Water Sampling.** The analytical results of the backwash water sampling are summarized in Table 4-8. Soluble arsenic and iron concentrations in the backwash water from both vessels were significantly lower than those in the raw water, which was used for backwash, indicating some removal by the media during backwash. The pH of the backwash water also was similar to that of the raw water. The results of all parameters measured from the Vessel A backwash were consistent with the results from Vessel B. As the system was only backwashed once during the first six months of operation, a backwash solids sample was not collected. Backwash solid samples will be collected during the second half of the demonstration.

**Table 4-8. Backwash Water Sampling Results**

	Vessel A						Vessel B					
	pH	Turbidity	TDS	Soluble As	Soluble Fe	Soluble Mn	pH	Turbidity	TDS	Soluble As	Soluble Fe	Soluble Mn
Date	S.U.	mg/L	NTU	µg/L	µg/L	µg/L	S.U.	NTU	mg/L	µg/L	µg/L	µg/L
11/17/2004	7.3	600	234	5.4	<25	1.6	7.2	520	222	3.4	<25	2.1

**4.5.3 Distribution System Water Sampling.** The results of the distribution system sampling are summarized in Table 4-9. The most apparent change in the distribution samples was a decrease in total arsenic concentrations once the treatment system began operation. Average baseline arsenic concentrations were 19.2, 19.3, and 18.5 µg/L at DS1, DS2, and DS3, respectively, and ranged from 16.0 to 21.5 µg/L. After the performance evaluation began, average concentrations at DS1, DS2, and DS3 were 7.5, 8.0, and 9.4 µg/L, respectively, and ranged from 1.5 to 16.7 µg/L. Note that the arsenic results from the distribution sampling mirrored the results seen from the treatment system sampling in that the As concentrations dropped once the system was put into service, rose gradually during the first four months of operation as As(III) began to break through, and then went down again once the switch to prechlorination was made.

Pb concentrations ranged from 0.1 to 1.7 µg/L and Cu concentrations ranged from 53 to 494 µg/L. None of the Pb or Cu samples exceeded the respective action levels for these two metals (15 µg/L and 1,300 µg/L for Pb and Cu, respectively). Because there was no trend or major difference observed in the Pb or Cu values collected from the baseline sampling versus the samples collected following treatment, it appeared that the APU-300 treatment system did not have an effect on the Pb or Cu levels in the water.

pH values ranged from 6.8 to 7.8, with exception to the pH values collected on December 8, 2004, which were higher at 8.2 to 8.9. Alkalinity levels ranged from 155 to 182 mg/L as CaCO<sub>3</sub>. Total Fe concentrations were typically less than 25 µg/L. Since the system became operational, all of the Fe concentrations in the distribution system samples were less than the detection limit with the exception of two instances at DS3 which were measured at 26 and 27 µg/L. Total Mn concentrations in the distribution system samples were typically low, ranging from 0.5 to 22.9 µg/L, with the majority of Mn concentrations at less than 5 µg/L.

Table 4-9. Distribution System Sampling Results

No. of Sampling Events	Sample ID	DS1									DS2									DS3								
	Sampling Date	Stagnation Time (hrs)	pH	Alkalinity	Total As	Total Fe	Total Mn	Total Pb	Total Cu	(ortho) PO <sub>4</sub>	Stagnation Time (hrs)	pH	Alkalinity	Total As	Total Fe	Total Mn	Total Pb	Total Cu	(ortho) PO <sub>4</sub>	Stagnation Time (hrs)	pH	Alkalinity	Total As	Total Fe	Total Mn	Total Pb	Total Cu	(ortho) PO <sub>4</sub>
BL1	12/17/03	8.3	7.2	166	18.5	88	0.8	1.3	255	0.5	NS	NS	NS	NS	NS	NS	NS	NS	NS	6.0	7.6	164	16.0	<25	0.7	0.5	288	0.5
BL2	01/14/04	8.5	7.8	159	17.5	<25	0.5	0.6	429	0.4	8.5	7.6	163	21.5	<25	1.0	<0.1	210	1.0	6.0	7.6	159	19.5	<25	16.6	0.4	299	0.6
BL3	02/11/04	7.8	7.4	174	21.2	107	1.1	0.9	180	0.4	10.0	7.3	182	18.1	47	3.9	0.1	207	0.5	6.0	7.2	161	19.5	69	9.9	0.5	279	0.4
BL4	03/19/04	7.1	7.2	156	19.5	<25	0.7	0.6	248	0.4	7.5	7.2	160	18.4	<25	1.5	0.2	120	0.5	6.0	7.7	168	19.2	<25	1.3	0.4	322	0.4
1	07/20/04	10.3	6.8	156	3.0	<25	1.3	0.9	360	2.2	10.8	6.9	156	3.5	<25	1.1	0.3	171	0.5	6.0	6.8	160	4.6	<25	1.2	1.1	297	0.5
2	08/31/04	8.3	7.6	167	7.7	<25	4.1	1.0	384	0.5	Homeowner on vacation									6.0	7.5	155	7.0	<25	3.6	0.8	279	0.6
3	09/23/04	8.2	7.1	162	8.4	<25	5.5	1.7	462	1.6	9.5	7.3	162	8.8	<25	3.0	0.6	65	2.2	8.3	7.4	162	16.7	26.9	8.7	1.6	494	2.3
4	10/26/04	7.5	7.7	164	11.9	<25	4.6	0.9	407	1.9	9.0	7.6	164	10.7	<25	2.6	0.3	146	1.8	9.0	7.7	164	11.2	<25	2.4	0.5	200	1.9
5	11/16/04	9.0	7.6	164	12.3	<25	22.9/ 20.6	0.8	174	1.7	7.5	7.7	164	13.2	<25	2.7	0.2	126	1.8	9.0	7.7	164	12.4	<25	11.8	0.3	53	1.6
6	12/8/2004 <sup>(a)</sup>	8.5	8.9	162	1.5	<25	2.2	0.5	231	0.5	8.0	8.4	162	3.6	<25	2.3	0.1	84	0.6	7.0	8.2	162	4.3	26	1.9	0.3	416	0.6

BL = baseline sampling

NS = not sampled

NA = not analyzed

(/) indicates rerun data with original result/rerun result.

(a) DS2 was sampled on December 7, 2004

The unit for analytical parameters is µg/L except for pH (s.u.), alkalinity (mg/L as CaCO<sub>3</sub>), and orthophosphate (mg/L).

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

## 4.6 System Costs

The cost-effectiveness of the system is evaluated based on the capital cost per gpm (or gpd) of the design capacity and the O&M cost per 1,000 gallons of water treated. The capital costs included equipment, engineering, and installation costs and O&M costs included 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 \$211,000 (see Table 4-10). The equipment costs were \$129,500 (or 62% of the total capital investment), which included costs for two FRP treatment vessels, 160 ft<sup>3</sup> of SORB 33™ media (\$150/ft<sup>3</sup> or \$5.34/lb), piping and valves, instrumentation and controls, field services (including operator training, technical support, and system shakedown), and miscellaneous materials and supplies.

**Table 4-10. Capital Investment for the Prospect Bay Treatment System**

Description	Quantity	Cost	% of Capital Investment Cost
<i>Equipment Costs</i>			
APU Skid-Mounted System	1 unit	\$72,200	—
E33 Media	160 ft <sup>3</sup>	\$24,000	—
Misc. Equipment and Materials	1	\$19,800	—
Vendor Labor	—	\$10,000	—
Vendor Travel	—	\$3,500	—
<b>Equipment Total</b>	—	<b>\$129,500</b>	<b>62%</b>
<i>Engineering Costs</i>			
Subcontractor	—	28,940	—
Vendor Labor	—	\$6,680	—
Vendor Travel	—	\$1,080	—
<b>Engineering Total</b>	—	<b>\$36,700</b>	<b>17%</b>
<i>Installation Costs</i>			
Subcontractor	—	\$35,800	—
Vendor Labor	—	\$5,600	—
Vendor Travel	—	\$3,400	—
<b>Installation Total</b>	—	<b>\$44,800</b>	<b>21%</b>
<b>Total Capital Investment</b>		<b>\$211,000</b>	<b>100%</b>

The engineering costs included the costs for preparation of the system layout and footprint, treatment system process flow diagram, and mechanical drawings of the treatment system equipment submitted as part of the permit application submittal (Section 4.3.1). The final set of engineering plans were prepared by Stearns and Wheler and included detailed construction drawings of the new treatment building, a floor plan, and tie-ins and connections for the treatment system. The engineering costs were \$36,700, which was 17% of the total capital investment.

The installation costs include the labor, equipment, and materials to unload and install the skid-mounted unit, perform the piping tie-ins and electrical work, and load and backwash the media. The installation was performed by the vendor and the installation subcontractor, Stearns and Wheler. Installation costs were \$44,800 or 21% of the total capital investment.

The Queen Anne's County Department of Public Works subcontracted Stearns and Wheler to construct the addition to the treatment building. Total construction cost for the addition was \$92,630, including

about \$18,000 for the building design and \$75,000 for construction. The 16-ft × 23-ft treatment area was an addition to the original 8-ft × 16-ft well house. The building was constructed using concrete block and brick siding. Construction took approximately one month to complete including placement and setting of the vessels within the building, which were put into place before the roof was installed.

The total capital cost of \$211,000 and equipment cost of \$129,500 were converted to a unit cost of \$0.09/1,000 gallons and \$0.06/1,000 gallons, respectively, using a capital recovery factor (CRF) of 0.06722 based on a 3% interest rate and a 20-year return period (Chen, et al. 2004). These calculations assumed that the system operated 24 hours a day, 7 days a week at the system design flowrate of 300 gpm. The system operated only 6.3 hours per day on average during the first six months of operation (Section 4.4.1), producing 14,856,000 gallons of water during this period, so the total unit cost and equipment-only unit cost is \$0.48/1,000 gallons and \$0.29/1,000 gallons, respectively, at this reduced rate of usage. Using the system's rated capacity of 320 gpm (460,800 gpd), the capital cost was \$659/gpm (\$0.46/gpd) and equipment-only cost was \$405/gpm (\$0.28/gpd). These calculations did not include the cost of the building construction.

**4.6.2 Operation and Maintenance Costs.** O&M costs include only incremental costs associated with the APU-300 treatment system, such as media replacement and disposal, chemical supply, electricity, and labor. These costs are summarized in Table 4-11. Although media replacement and disposal did not take place during the first six months of operation, the vendor estimated \$26,800 to change out both vessels, which included media, freight, labor, travel expenses, and media profiling and disposal fee. This cost was used to estimate the media replacement cost per 1,000 gallons of water treated as a function of the projected media run length to the 10 µg/L arsenic breakthrough (Figure 4-13).

Disposal costs for backwash water were minimal during the first six months of system operation since the system was only backwashed one time. The cost for disposal includes trucking costs, but no additional disposal fees because the backwash water was disposed of at the Stevensville WWTP, also owned and operated by QAC. The O&M costs for the second half of the demonstration will be revised accordingly should backwash frequency increase and disposal costs become more significant.

The chemical cost associated with the operation of the treatment system included chlorine addition prior to the adsorption vessels and injection of a polyphosphate after the APU-300 system. Both of these treatment steps were in use at the site prior to installation of the APU-300 treatment system, which did not have a significant effect on the chlorine gas usage based on the data collected during the first six months of operation. Therefore, the incremental chemical cost due to the APU-300 system was negligible.

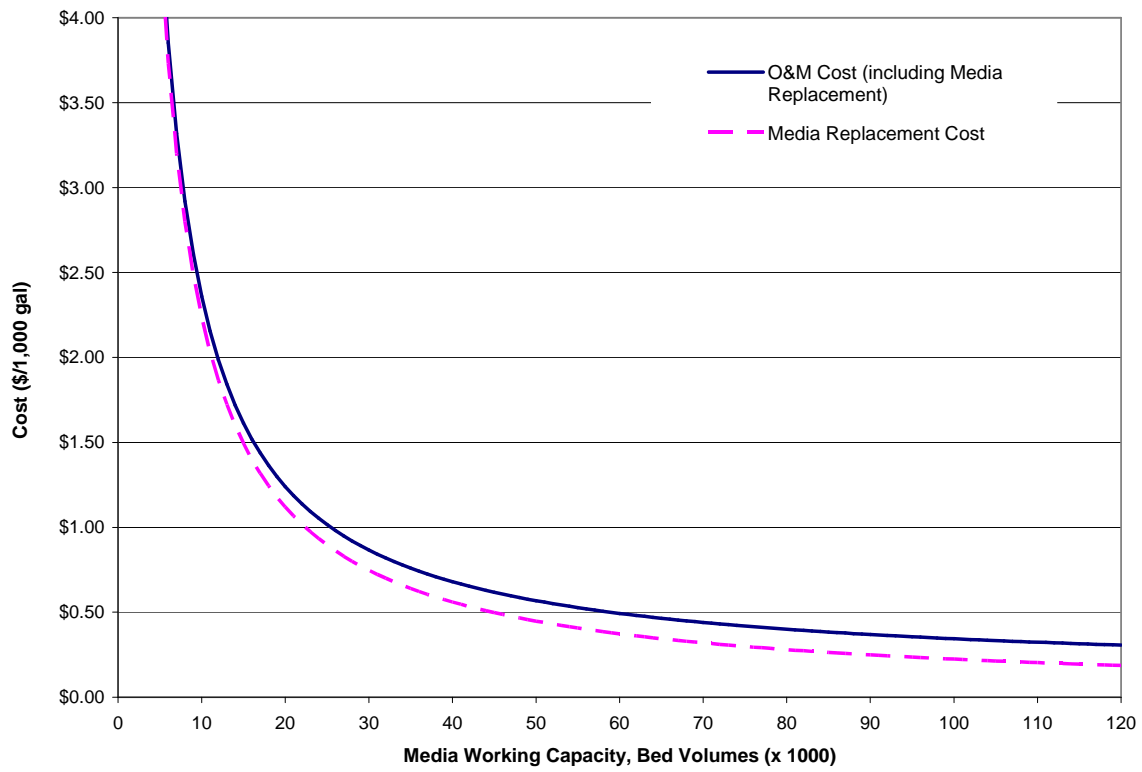
The incremental electrical power consumption was reviewed. Electrical usage during the months August and September 2003 were compared to usage for the same period in 2004 following installation of the APU system. Additionally, the 2003 usage estimate was determined by adding the usage at both Well No. 1 and Well No. 2 because operation of these wells was alternated during this time. The estimated average monthly usage for Wells No.1 and No. 2 for August and September 2003 was about 4,160 kWh. For August and September 2004, the average monthly usage for Well No.1 was 5,360 kWh. Note that once the APU-300 treatment system was installed at Well House No. 1, Well No. 2 was only rarely operated, if at all. The incremental electrical usage was thus determined to be approximately 1,200 kWh per month during the summer months when peak water demand was expected. At a rate of about \$0.10/kWh (including delivery and supply charges), an additional utility cost of approximately \$120 per month to operate the APU-300 system was calculated. Over the six-month operating period, the incremental utility cost to operate the treatment system was \$0.05/1,000 gallons. Although there are few electrical parts on the APU-300 system that would require additional electrical consumption, the

**Table 4-11. O&M Costs for the Prospect Bay Treatment System**

<b>Cost Category</b>	<b>Value</b>	<b>Assumptions</b>
Volume processed (Kgal)	14,856	From 06/30/04 through 12/30/04
<b><i>Media Replacement and Disposal</i></b>		
Media cost (\$/ft <sup>3</sup> )	\$150	Vendor quote
Total media volume (ft <sup>3</sup> )	160	Both vessels
Media replacement cost (\$)	\$24,000	Vendor quote
Labor cost (\$)	\$2,120	Vendor quote
Media disposal fee (\$)	\$680	Vendor quote
Subtotal	\$26,800	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
<b><i>Chemical Usage</i></b>		
Chemical cost (\$)	\$0.00	No additional chemical usage required.
<b><i>Electricity</i></b>		
Electric utility charge (\$/kWh)	\$0.10	Includes delivery and supply charges
Incremental monthly usage (kWh)	1200	Average monthly incremental usage for August and September 2004
Estimated incremental electricity cost (\$)	\$720	From July to December 2004
Incremental cost (\$/1,000 gal)	\$0.05	–
<b><i>Labor</i></b>		
Average weekly labor (hrs)	1.75	15 minutes/day, 7 days/week
Labor cost (\$/1,000 gal)	\$0.07	Average Labor rate = \$21.75/hr
<b>Total O&amp;M Cost/1,000 gallons</b>	See Figure 4-13	Based upon media run length at 10-µg/L arsenic breakthrough

increased usage may be due to increased total dynamic head on the well pump and electrical consumption within the treatment building addition (i.e., lights, heating, etc.).

The routine, nondemonstration-related labor activities consumed only about 15 minutes per day, as noted in Section 4.4.5. Based on this time requirement and a labor rate of \$21.75/hr, the labor cost was \$0.07/1,000 gallons of water treated.



**Figure 4-13. Media Replacement and Operation and Maintenance Costs**

## 5.0 REFERENCES

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## **APPENDIX A**

### **OPERATIONAL DATA**

**EPA Arsenic Demonstration Project at Queen Anne's County, MD - Daily System Operation Log Sheet**

Week No.	Date	Well House			Instrument Panel								
		Avg Operation Hours	Cumulative Operation Hours	Avg Flowrate	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Cumulative Bed Volumes Treated <sup>(a)</sup>	Head Loss		System Pressure		
									Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gpm	kgal	kgal	gal	BV	psi	psi	psi	psi	psi
1	06/28/04												
	06/29/04												
	06/30/04	NM	NM		NM	NM	NM	NM	2.1	2.2	62	59	3
	07/01/04	NM	NM	248	75	78	152,598	127	2.2	2.0	65	60	5
	07/02/04	NM	NM	247	116	121	236,605	198	2.2	2.0	60	58	2
	07/03/04	NM	NM	248	247	258	504,686	422	2.8	2.0	60	55	5
	07/04/04	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
2	07/05/04	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	07/06/04	35.1	35.1	247	480	500	979,901	819	2.2	2.0	60	56	4
	07/07/04	13.6	48.7	246	570	593	1,162,503	971	2.2	2.4	62	54	8
	07/08/04	9.1	57.8	247	631	656	1,286,364	1,075	2.0	1.9	62	59	3
	07/09/04	6.0	63.8	242	670	697	1,366,714	1,142	2.2	2.2	60	55	5
	07/10/04	16.6	80.4	247	781	812	1,592,923	1,331	2.0	2.1	60	58	2
	07/11/04	12.4	92.8	243	863	897	1,760,194	1,471	2.0	2.0	60	59	1
3	07/12/04	13.2	106.0	242	951	988	1,939,200	1,620	2.2	2.0	62	58	4
	07/13/04	1.1	107.1	258	959	995	1,954,132	1,633	2.2	2.0	60	56	4
	07/14/04	8.8	115.9	244	1,017	1,056	2,072,652	1,732	2.2	2.0	62	57	5
	07/15/04	12.3	128.2	248	1,100	1,142	2,241,912	1,873	2.2	2.0	63	58	5
	07/16/04	3.4	131.6	235	1,120	1,164	2,283,833	1,908	2.2	2.1	61	56	5
	07/17/04	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
	07/18/04	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
4	07/19/04	19.7	151.3	244	1,253	1,300	2,553,002	2,133	2.3	2.1	59	55	4
	07/20/04	8.8	160.1	246	1,311	1,361	2,671,977	2,232	2.3	2.1	60	56	4
	07/21/04	8.4	168.5	238	1,398	1,451	2,848,763	2,380	2.1	2.0	60	58	2
	07/22/04	8.0	176.5	252	1,421	1,475	2,895,500	2,419	2.0	2.0	60	56	4
	07/23/04	8.3	184.8	241	1,475	1,532	3,006,940	2,512	2.0	2.0	60	56	4
	07/24/04	8.7	193.5	278	1,537	1,598	3,134,400	2,619	2.1	2.0	60	58	2
	07/25/04	11.5	205.0	220	1,610	1,672	3,282,729	2,743	2.1	2.0	62	60	2
5	07/26/04	0.2	205.2	NA	1,611	1,673	3,284,354	2,744	2.2	2.1	54	54	0
	07/27/04	9.7	214.9	246	1,676	1,741	3,417,200	2,855	2.2	2.1	62	58	4
	07/28/04	2.0	216.9	250	1,690	1,755	3,444,847	2,878	2.2	2.1	60	56	4
	07/29/04	9.3	226.2	242	1,752	1,819	3,570,824	2,983	2.2	2.0	62	58	4
	07/30/04	2.1	228.3	246	1,766	1,834	3,600,062	3,008	2.0	2.1	60	56	4
	07/31/04	9.7	238.0	258	1,834	1,905	3,739,253	3,124	2.1	2.0	60	56	4
	08/01/04	10.2	248.2	227	1,898	1,971	3,868,787	3,232	2.0	2.1	60	58	2

**EPA Arsenic Demonstration Project at Queen Anne's County, MD - Daily System Operation Log Sheet (Continued)**

Week No.	Date	Well House			Instrument Panel								
		Avg Operation Hours	Cumulative Operation Hours	Avg Flowrate	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Cumulative Bed Volumes Treated <sup>(a)</sup>	Head Loss		System Pressure		
									Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gpm	kgal	kgal	gal	BV	psi	psi	psi	psi	psi
6	08/02/04	4.1	252.3	248	1,925	2,000	3,925,158	3,279	2.1	2.2	60	54	6
	08/03/04	5.9	258.2	240	1,964	2,040	4,004,375	3,346	2.1	2.2	61	56	5
	08/04/04	4.2	262.4	246	1,992	2,070	4,062,367	3,394	2.1	2.0	61	56	5
	08/05/04	7.1	269.5	242	2,039	2,119	4,157,642	3,474	2.1	2.0	61	56	5
	08/06/04	9.5	279.0	244	2,103	2,185	4,287,806	3,582	2.1	2.0	63	60	3
	08/07/04	10.1	289.1	244	2,170	2,256	4,425,258	3,697	2.1	2.0	63	58	5
	08/08/04	1.3	290.4	218	2,178	2,264	4,441,636	3,711	2.1	2.2	60	56	4
7	08/09/04	11.2	301.6	244	2,253	2,342	4,594,680	3,839	2.6	2.0	62	58	4
	08/10/04	10.9	312.5	243	2,325	2,418	4,742,388	3,962	2.2	1.8	64	59	5
	08/11/04	1.4	313.9	238	2,334	2,427	4,761,653	3,978	2.6	2.0	60	55	5
	08/12/04	10.2	324.1	243	2,402	2,499	4,901,258	4,095	2.5	2.0	62	58	4
	08/13/04	2.3	326.4	239	2,419	2,514	4,933,288	4,122	2.8	2.0	60	58	2
	08/14/04	8.8	335.2	242	2,476	2,575	5,051,076	4,220	2.8	2.0	60	56	4
	08/15/04	8.7	343.9	247	2,534	2,636	5,169,934	4,320	2.6	2.0	61	56	5
8	08/16/04	0.3	344.2	NA	2,536	2,638	5,174,090	4,323	2.4	2.2	60	56	4
	08/17/04	9.9	354.1	242	2,602	2,707	5,308,785	4,436	2.2	2.1	61	58	3
	08/18/04	5.6	359.7	238	2,639	2,746	5,384,655	4,499	2.7	2.2	61	57	4
	08/19/04	5.3	365.0	245	2,674	2,782	5,456,174	4,559	2.7	2.1	61	58	3
	08/20/04	10.4	375.4	242	2,743	2,854	5,597,437	4,677	2.6	2.0	62	58	4
	08/21/04	11.2	386.6	243	2,817	2,894	5,711,414	4,772	2.4	2.1	62	59	3
	08/22/04	0.4	387.0	208	2,822	2,936	5,758,071	4,811	2.2	2.0	60	55	5
9	08/23/04	9.2	396.2	243	2,881	2,998	5,879,465	4,912	2.2	2.1	62	60	2
	08/24/04	6.3	402.5	246	2,923	3,048	5,971,793	4,989	2.2	2.1	61	58	3
	08/25/04	4.5	407.0	237	2,953	3,073	6,026,249	5,035	2.4	2.0	60	55	5
	08/26/04	10.4	417.4	242	3,022	3,146	6,168,051	5,153	2.2	2.2	62	58	4
	08/27/04	11.0	428.4	242	3,095	3,222	6,317,193	5,278	2.5	2.1	63	59	4
	08/28/04	8.8	437.2	241	3,154	3,283	6,436,567	5,378	2.3	2.2	62	58	4
	08/29/04	4.8	442.0	240	3,185	3,316	6,501,426	5,432	2.3	2.0	60	54	6
10	08/30/04	12.5	454.5	240	3,268	3,402	6,669,901	5,573	2.1	2.0	62	58	4
	08/31/04	3.0	457.5	250	3,288	3,423	6,711,558	5,608	2.5	2.0	60	56	4
	09/01/04	7.1	464.6	239	3,335	3,472	6,806,750	5,687	2.2	2.1	60	56	4
	09/02/04	9.9	474.5	241	3,400	3,541	6,941,297	5,799	2.2	2.1	62	58	4
	09/03/04	10.2	484.7	240	3,468	3,612	7,079,957	5,915	2.1	2.0	62	58	4
	09/04/04	6.0	490.7	244	3,508	3,654	7,161,660	5,984	2.1	2.0	61	56	5
	09/05/04	7.2	497.9	241	3,555	3,703	7,258,093	6,064	2.3	2.2	60	56	4

**EPA Arsenic Demonstration Project at Queen Anne's County, MD - Daily System Operation Log Sheet (Continued)**

Week No.	Date	Well House			Instrument Panel								
		Avg Operation Hours	Cumulative Operation Hours	Avg Flowrate	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Cumulative Bed Volumes Treated <sup>(a)</sup>	Head Loss		System Pressure		
									Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gpm	kgal	kgal	gal	BV	psi	psi	psi	psi	psi
11	09/06/04	10.2	508.1	240	3,623	3,773	7,396,028	6,179	2.1	2.0	60	56	4
	09/07/04	6.7	514.8	241	3,667	3,820	7,486,955	6,255	2.1	2.0	62	58	4
	09/08/04	4.4	519.2	239	3,696	3,850	7,546,306	6,305	2.2	2.0	61	56	5
	09/09/04	9.2	528.4	241	3,757	3,914	7,671,429	6,410	2.1	2.0	62	58	4
	09/10/04	4.1	532.5	248	3,785	3,943	7,728,304	6,457	2.2	2.0	60	56	4
	09/11/04	9.4	541.9	239	3,847	4,008	7,855,463	6,563	2.6	2.0	60	55	5
	09/12/04	8.9	550.8	240	3,906	4,069	7,974,335	6,663	2.4	2.0	58	56	2
12	09/13/04	11.3	562.1	242	3,981	4,147	8,128,226	6,791	2.2	2.0	62	58	4
	09/14/04	10.4	572.5	242	4,050	4,220	8,269,655	6,909	2.8	2.6	62	58	4
	09/15/04	3.0	575.5	233	4,069	4,240	8,309,314	6,942	2.8	2.2	60	56	4
	09/16/04	8.5	584.0	241	4,127	4,300	8,426,676	7,041	2.9	1.9	63	59	4
	09/17/04	0.2	584.2	250	4,127	4,300	8,427,426	7,041	2.3	2.0	60	55	5
	09/18/04	9.2	593.4	241	4,188	4,364	8,552,144	7,145	2.7	2.1	61	56	5
	09/19/04	0.0	593.4	NA	4,189	4,364	8,552,990	7,146	2.5	2.2	58	54	4
13	09/20/04	0.1	593.5	NA	4,189	4,364	8,552,990	7,146	NM	NM	50	50	0
	09/21/04	0.0	593.5	NA	4,189	4,364	8,552,990	7,146	NM	NM	46	46	0
	09/22/04	20.7	614.2	238	4,325	4,507	8,831,527	7,379	2.2	2.0	58	54	4
	09/23/04	11.8	626.0	260	4,410	4,594	9,004,147	7,523	2.4	2.2	62	57	5
	09/24/04	5.3	631.3	242	4,446	4,631	9,076,803	7,584	2.5	2.1	61	58	3
	09/25/04	7.5	638.8	242	4,496	4,683	9,179,029	7,669	2.3	2.2	60	55	5
	09/26/04	8.8	647.6	239	4,554	4,744	9,297,353	7,768	2.4	2.2	58	56	2
14	09/27/04	10.1	657.7	241	4,621	4,814	9,435,258	7,883	2.2	2.0	63	58	5
	09/28/04	0.8	658.5	250	4,628	4,820	9,447,892	7,894	2.8	2.0	60	55	5
	09/29/04	2.1	660.6	238	4,641	4,834	9,474,929	7,916	2.4	2.0	58	54	4
	09/30/04	10.3	670.9	241	4,710	4,906	9,615,224	8,034	2.6	2.0	62	58	4
	10/01/04	2.3	673.2	254	4,726	4,922	9,648,223	8,061	2.2	2.0	60	56	4
	10/02/04	8.2	681.4	240	4,780	4,978	9,758,364	8,153	2.4	2.1	62	58	4
	10/03/04	9.9	691.3	239	4,846	5,047	9,892,282	8,265	2.2	2.0	64	59	5
15	10/04/04	0.3	691.6	222	4,853	5,055	9,908,416	8,279	2.2	2.0	62	57	5
	10/05/04	0.9	692.5	259	4,854	5,056	9,909,824	8,280	2.0	2.2	60	56	4
	10/06/04	9.3	701.8	238	4,916	5,089	10,005,086	8,359	2.8	2.6	62	58	4
	10/07/04	1.2	703.0	250	4,924	5,128	10,052,151	8,399	3.0	2.8	60	56	4
	10/08/04	2.2	705.2	242	4,938	5,143	10,081,573	8,423	2.8	2.6	60	56	4
	10/09/04	8.4	713.6	240	4,995	5,201	10,195,976	8,519	2.6	2.2	60	55	5
	10/10/04	13.0	726.6	242	5,082	5,292	10,374,158	8,668	2.2	2.2	62	57	5

**EPA Arsenic Demonstration Project at Queen Anne's County, MD - Daily System Operation Log Sheet (Continued)**

Week No.	Date	Well House			Instrument Panel								
		Avg Operation Hours	Cumulative Operation Hours	Avg Flowrate	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Cumulative Bed Volumes Treated <sup>(a)</sup>	Head Loss		System Pressure		
									Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gpm	kgal	kgal	gal	BV	psi	psi	psi	psi	psi
16	10/11/04	7.3	733.9	242	5,131	5,344	10,474,948	8,752	2.0	2.0	62	58	4
	10/12/04	2.9	736.8	236	5,150	5,363	10,512,904	8,784	2.8	2.2	62	57	5
	10/13/04	7.7	744.5	242	5,202	5,417	10,618,567	8,872	2.0	2.0	62	58	4
	10/14/04	1.2	745.7	292	5,211	5,427	10,637,839	8,888	2.2	2.2	58	58	0
	10/15/04	0.3	746.0	NA	5,211	5,427	10,638,051	8,888	3.0	2.8	60	58	2
	10/16/04	10.9	756.9	242	5,284	5,502	10,786,815	9,012	2.8	2.6	60	56	4
17	10/17/04	6.5	763.4	238	5,327	5,547	10,874,105	9,085	2.4	2.5	62	58	4
	10/18/04	0.0	763.4	NA	5,328	5,548	10,876,688	9,088	2.2	2.0	60	56	4
	10/19/04	10.0	773.4	240	5,396	5,618	11,013,602	9,202	2.5	2.1	63	58	5
	10/20/04	2.6	776.0	237	5,412	5,635	11,046,056	9,229	3.0	2.1	63	58	5
	10/21/04	8.8	784.8	241	5,470	5,696	11,165,770	9,329	3.0	2.0	64	59	5
	10/22/04	0.1	784.9	NA	5,471	5,696	11,167,215	9,330	2.6	2.5	62	58	4
18	10/23/04	10.1	795.0	243	5,541	5,769	11,310,344	9,450	2.0	2.0	64	59	5
	10/24/04	0.5	795.5	200	5,542	5,769	11,311,071	9,450	2.2	2.1	65	58	7
	10/25/04	0.1	795.6	NA	5,542	5,770	11,312,591	9,452	2.2	2.4	56	58	2
	10/26/04	9.0	804.6	241	5,603	5,833	11,435,462	9,554	2.2	2.6	62	58	4
	10/27/04	1.0	805.6	233	5,609	5,839	11,448,526	9,565	2.2	2.2	62	56	6
	10/28/04	8.6	814.2	242	5,667	5,899	11,565,886	9,663	2.2	2.0	64	58	6
19	10/29/04	0.5	814.7	233	5,670	5,903	11,572,713	9,669	2.4	2.1	61	56	5
	10/30/04	8.1	822.8	241	5,726	5,960	11,686,048	9,764	2.0	2.1	62	58	4
	10/31/04	0.7	823.5	262	5,779	5,964	11,742,781	9,811	2.2	2.6	60	56	4
	11/01/04	8.3	831.8	241	5,784	6,021	11,805,435	9,864	2.2	2.1	64	58	6
	11/02/04	0.5	832.3	233	5,788	6,025	11,812,783	9,870	2.2	2.0	60	56	4
	11/03/04	8.7	841.0	239	5,845	6,084	11,929,896	9,967	2.4	2.2	60	58	2
20	11/04/04	1.0	842.0	250	5,852	6,092	11,943,662	9,979	2.3	2.2	62	56	6
	11/05/04	6.7	848.7	239	5,897	6,138	12,034,305	10,055	2.2	2.4	64	58	6
	11/06/04	3.4	852.1	240	5,903	6,161	12,064,076	10,080	2.4	2.0	62	56	6
	11/07/04	5.3	857.4	245	NA	6,198	NA	NA	2.2	2.2	62	58	4
	11/08/04	4.5	861.9	233	5,966	6,229	12,118,669	10,125	2.0	2.1	64	59	5
	11/9/2004 <sup>(b)</sup>	0.0	861.9	NA	5,967	6,230	12,120,184	10,126	2.4	2.5	58	60	2
20	11/10/04	8.9	870.8	242	6,026	6,290	12,239,986	10,227	3.0	2.8	64	59	5
	11/11/04	0.5	871.3	NA	6,030	6,294	12,246,468	10,232	2.8	2.8	58	59	1
	11/12/04	1.5	872.8	NA	6,040	6,304	12,266,703	10,249	3.0	3.0	60	56	4
	11/13/04	7.8	880.6	237	6,092	6,355	12,370,563	10,336	3.4	3.4	63	58	5
	11/14/04	4.1	884.7	240	6,120	6,381	12,424,882	10,381	3.5	3.5	64	58	6

**EPA Arsenic Demonstration Project at Queen Anne's County, MD - Daily System Operation Log Sheet (Continued)**

Week No.	Date	Well House			Instrument Panel								
		Avg Operation Hours	Cumulative Operation Hours	Avg Flowrate	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Cumulative Bed Volumes Treated <sup>(a)</sup>	Head Loss		System Pressure		
									Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gpm	kgal	kgal	gal	BV	psi	psi	psi	psi	psi
21	11/15/04	5.6	890.3	235	6,158	6,417	12,498,204	10,442	4.2	4.5	66	58	8
	11/16/04	0.4	890.7	292	6,162	6,420	12,504,435	10,448	4.5	4.8	64	58	6
	11/17/04	9.3	900.0	233	6,225	6,476	12,624,832	10,548	2.0	2.6	70	58	12
	11/18/04	0.3	900.3	NA	6,228	6,478	12,629,651	10,552	2.4	2.0	68	58	10
	11/19/04	1.6	901.9	281	6,238	6,484	12,645,584	10,565	2.4	2.0	66	56	10
	11/20/04	8.3	910.2	241	6,294	6,484	12,701,438	10,612	2.6	2.4	68	58	10
22	11/21/04	7.2	917.4	245	6,343	6,484	12,750,270	10,653	2.5	2.5	69	58	11
	11/22/04	2.2	919.6	227	6,358	6,485	12,765,960	10,666	2.6	2.6	69	58	11
	11/23/04	0.1	919.7	NA	6,358	6,485	12,766,977	10,667	2.8	2.6	68	56	12
	11/24/04	7.9	927.6	241	6,410	6,536	12,869,014	10,752	3.0	3.0	70	60	10
	11/25/04	0.1	927.7	NA	6,413	6,536	12,871,965	10,755	3.2	3.2	70	55	15
	11/26/04	8.8	936.5	239	6,473	6,589	12,985,890	10,850	3.6	3.6	70	58	12
23	11/27/04	0.1	936.6	NA	6,474	6,590	12,987,109	10,851	3.6	3.6	68	58	10
	11/28/04	8.8	945.4	242	6,540	6,647	13,110,082	10,954	3.4	3.6	69	57	12
	11/29/04	0.7	946.1	238	6,540	6,648	13,111,222	10,955	3.5	4.0	70	58	12
	11/30/04	8.7	954.8	239	6,602	6,700	13,224,902	11,049	4.4	4.0	70	60	10
	12/01/04	3.1	957.9	226	6,683	6,717	13,323,149	11,132	4.5	4.6	70	58	12
	12/02/04	0.5	958.4	267	6,687	6,720	13,330,245	11,137	4.8	4.9	68	56	12
24	12/03/04	9.4	967.8	234	6,693	6,774	13,390,318	11,188	4.8	4.9	72	59	13
	12/04/04	2.0	969.8	242	6,707	6,786	13,416,288	11,209	4.8	5.0	70	58	12
	12/05/04	5.2	975.0	244	6,746	6,816	13,485,306	11,267	4.8	5.0	70	58	12
	12/06/04	3.9	978.9	235	6,773	6,839	13,535,284	11,309	5.0	5.1	72	58	14
	12/07/04	2.0	980.9	233	6,787	6,850	13,560,562	11,330	5.2	5.6	71	57	14
	12/08/04	1.5	982.4	233	6,799	6,860	13,581,776	11,348	5.1	5.3	70	56	14
25	12/09/04	8.7	991.1	236	6,861	6,906	13,690,265	11,438	5.8	6.0	75	60	15
	12/10/04	0.1	991.2	NA	6,862	6,907	13,692,504	11,440	5.9	6.0	70	56	14
	12/11/04	7.2	998.4	264	6,920	6,952	13,795,098	11,526	5.9	6.0	72	58	14
	12/12/04	0.9	999.3	NA	6,921	6,952	13,796,335	11,527	5.9	6.1	70	57	13
	12/13/04	8.4	1007.7	238	6,983	6,998	13,904,079	11,617	7.5	6.0	59	61	2
	12/14/04	0.1	1007.8	NA	6,984	6,999	13,906,120	11,619	7.0	5.8	59	60	1
25	12/15/04	3.0	1010.8	261	7,005	7,015	13,943,899	11,650	6.0	6.6	71	56	15
	12/16/04	6.7	1017.5	221	7,094	7,051	14,068,253	11,754	6.2	6.9	70	58	12
	12/17/04	0.7	1018.2	214	7,100	7,055	14,077,898	11,762	6.1	6.9	70	56	14
	12/18/04	9.7	1027.9	241	7,131	7,108	14,161,948	11,832	6.0	6.8	71	56	15
	12/19/04	5.9	1033.8	229	7,174	7,140	14,237,138	11,895	6.2	6.8	72	58	14

**EPA Arsenic Demonstration Project at Queen Anne's County, MD - Daily System Operation Log Sheet (Continued)**

Week No.	Date	Well House			Instrument Panel								
		Avg Operation Hours	Cumulative Operation Hours	Avg Flowrate	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Cumulative Bed Volumes Treated <sup>(a)</sup>	Head Loss		System Pressure		
									Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gpm	kgal	kgal	gal	BV	psi	psi	psi	psi	psi
26	12/20/04	4.6	1038.4	250	7,207	7,165	14,294,755	11,943	6.0	6.5	75	60	15
	12/21/04	0.1	1038.5	NA	7,207	7,165	14,296,174	11,945	6.2	7.0	70	56	14
	12/22/04	9.2	1047.7	226	7,275	7,216	14,414,075	12,043	6.0	6.9	74	60	14
	12/23/04	2.2	1049.9	227	7,290	7,228	14,441,944	12,066	6.0	6.5	72	58	14
	12/24/04	10.6	1060.5	NA	7,324	7,254	14,501,500	12,116	6.2	7.0	72	56	16
	12/25/04	2.7	1063.2	NA	7,367	7,286	14,576,528	12,179	6.1	7.0	72	58	14
	12/26/04	1.6	1064.8	NA	7,399	7,310	14,632,491	12,226	6.2	7.1	72	58	14
27	12/27/04	5.7	1070.5	231	7,440	7,341	14,703,635	12,285	6.0	7.0	70	59	11
	12/28/04	0.4	1070.9	292	7,443	7,343	14,709,268	12,290	6.0	7.0	70	56	14
	12/29/04	2.3	1073.2	239	7,460	7,356	14,738,907	12,314	6.5	7.5	70	56	14
	12/30/04	9.3	1082.5	235	7,526	7,406	14,855,963	12,412	6.0	7.0	73	59	14

(a) Bed volume = 160 cu.ft. or 1,197 gallons total for both vessels

(b) Pre-chlorination started November 9, 2004

NM = Not Measured

NA = Not Available

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



### Analytical Results from Long-Term Sampling, Queen Anne's County, MD

Sampling Date		07/07/04 <sup>(c)</sup>		07/13/04			07/20/04			07/27/04		08/03/04			08/18/04	
Sampling Location	Parameter Unit	IN	TT	IN	TA	TB	IN	TA	TB	IN	TT	IN	TA	TB	IN	TT
Bed Volume		–	971	–	1,602	1,663	–	2,190	2,274	–	2,855	–	3,282	3,410	–	4,499
Alkalinity	mg/L <sup>(a)</sup>	166	158	NA	172	172	164	168	180	167	171	158	158	162	164	160
Fluoride	mg/L	0.8	0.8	NA	0.9	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.8	0.8
Sulfate	mg/L	5.3	5.3	NA	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	3.7	3.7
Orthophosphate	mg/L <sup>(b)</sup>	<0.10	<0.10	NA	<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 <sub>2</sub> )	mg/L	14.6	14.4	NA	13.2	13.2	8.5	14.4	13.6	14.2	13.7	14.6	14.4	13.9	14.5	14.5
NO <sub>3</sub> -(N)	mg/L	<0.20	<0.20	NA	<0.04	0.09	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Turbidity	NTU	1.1	1.1	NA	0.3	0.7	0.6	0.4	0.4	0.5	0.3	1.0	0.6	0.2	1.3	0.7
pH	–	8.0	8.0	NA	7.9	7.9	8.1	8.0	8.0	8.2	8.0	8.1	7.9	7.9	7.7	7.8
Temperature	°C	17.0	16.1	NA	16.8	16.5	21.6	16.1	16.0	21.7	16.2	18.0	16.4	16.1	18.4	18.4
DO	mg/L	2.9	4.3	NA	1.8	0.9	0.9	1.0	0.7	1.11	4.8	2.5	2.1	NA	NA	NA
ORP	mV	-64	-63	NA	-50	-50	-112	-42	12	-119	-43	-122	-43	-18	-134	-7
Total Hardness	mg/L <sup>(a)</sup>	97.7	129.1	–	–	–	–	–	–	103.1	104.1	–	–	–	109.4	109.7
Ca Hardness	mg/L <sup>(a)</sup>	52.5	53.9	–	–	–	–	–	–	61.9	61.5	–	–	–	65.8	66.0
Mg Hardness	mg/L <sup>(a)</sup>	45.2	75.2	–	–	–	–	–	–	41.2	42.6	–	–	–	43.6	43.7
As (total)	µg/L	20.2	0.3	NA	0.7	0.3	18.9	1.1	0.6	20.8	1.8	23.8	2.9	1.5	22.0	3.8
As (total soluble)	µg/L	19.4	0.2	–	–	–	–	–	–	21.7	1.8	–	–	–	22.0	4.0
As (particulate)	µg/L	0.8	0.1	–	–	–	–	–	–	<0.1	<0.1	–	–	–	<0.1	<0.1
As (III)	µg/L	20.2	0.2	–	–	–	–	–	–	22.4	2.1	–	–	–	22.3	3.7
As (V)	µg/L	<0.1	<0.1	–	–	–	–	–	–	<0.1	<0.1	–	–	–	<0.1	0.3
Total Fe	µg/L	234	116	NA	<25	<25	248	<25	<25	210	<25	273	<25	<2.5	220	<25
Dissolved Fe	µg/L	210	80	–	–	–	–	–	–	201	<25	–	–	–	222	<25
Total Mn	µg/L	1.9	1.5	NA	1.2	0.8	3.8	3.0	2.4	1.4	2.5	6.0	4.0	3.5	1.5	4.4
Dissolved Mn	µg/L	2.3	1.5	–	–	–	–	–	–	1.5	2.6	–	–	–	1.6	4.1

(a) as CaCO<sub>3</sub>. (b) as PO<sub>4</sub>. (c) Water quality parameters sampled on July 9, 2004.

IN = at the inlet; AC = after prechlorination; TA = after tank A; TB = after tank B; TT = after tanks combined.

NA = data not available.

### Analytical Results from Long-Term Sampling, Queen Anne's County, MD

B-2

Sampling Date		08/31/04			09/22/04		10/07/04			10/19/04		10/26/04		11/03/04		
Sampling Location	Parameter Unit	IN	TA	TB	IN	TT	IN	TA	TB	IN	TT	IN	TT	IN	TA	TB
Bed Volume		–	5,495	5,721	–	7,379	–	8,228	8,569	–	9,202	–	9,554	–	9,768	10,167
Alkalinity	mg/L <sup>(a)</sup>	171	171	171	166	166	166 166	166 162	166 162	162	162	164	164	164	164	164
Fluoride	mg/L	0.6	0.6	0.7	0.5	0.6	0.7 0.9	0.8 0.9	0.8 0.8	0.7	0.8	0.5	0.6	0.6	0.5	0.5
Sulfate	mg/L	5.3	5.3	<5.0	3.3	3.4	–	–	–	4.0	4.0	4.0	4.0	–	–	–
Orthophosphate	mg/L <sup>(b)</sup>	<0.10	<0.10	<0.10	<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 <sub>2</sub> )	mg/L	14.6	14.5	14.4	14.7	14.2	14.5 14.2	14.3 14.2	14.3 13.9	14.4	14.3	14.6	14.4	14.1	14.2	14.1
NO <sub>3</sub> -(N)	mg/L	<0.04	<0.04	<0.04	<0.04	<0.04	–	–	–	<0.04	<0.04	<0.04	<0.04	–	–	–
Turbidity	NTU	0.9	0.3	0.5	0.6	0.1	0.8 0.7	0.3 0.5	0.6 0.5	0.9	0.3	0.5	0.1	0.7	0.4	0.4
pH	–	8.0	8.0	8.0	8.0	8.1	8.0	8.2	8.3	8.0	8.1	7.7	7.8	7.6	7.6	7.7
Temperature	°C	18.0	17.9	17.7	15.4	15.5	15.4	15.4	15.4	15.7	15.8	14.9	14.7	18.5	18.4	18.6
DO	mg/L	NA	NA	NA	2.2	3.8	2.2	0.8	1.0	1.8	5.4	1.6	5.5	1.6	2.6	2.2
ORP	mV	-99	-10	53	-14	-62	-140	-63	-44	-126	-76	-132	-74	-148	-112	-83
Total Hardness	mg/L <sup>(a)</sup>	–	–	–	112.4	109.3	–	–	–	110.3	114.8	116.7	111.0	–	–	–
Ca Hardness	mg/L <sup>(a)</sup>	–	–	–	66.6	65.2	–	–	–	55.8	62.3	63.6	57.9	–	–	–
Mg Hardness	mg/L <sup>(a)</sup>	–	–	–	45.8	44.1	–	–	–	54.5	52.5	53.1	53.1	–	–	–
As (total)	µg/L	22.4	8.6	5.9	20.6	11.1	19.2 25.8	13.1 11.9	9.2 12.1	18.4	13.2	19.4	13.3	20.2	14.8	12.9
As (total soluble)	µg/L	–	–	–	20.9	NA	–	–	–	–	–	19.0	13.1	–	–	–
As (particulate)	µg/L	–	–	–	<0.1	–	–	–	–	–	–	0.4	0.2	–	–	–
As (III)	µg/L	–	–	–	12.8/ 12.3	10.2	–	–	–	14.9	13.1	19.7	13.2	–	–	–
As (V)	µg/L	–	–	–	8.1/ 7.1	–	–	–	–	–	–	<0.1	<0.1	–	–	–
Total Fe	µg/L	193	<25	<25	271	<25	236 315	76.9 <25	<25 <25	208	<25	210	<25	273	68	38
Dissolved Fe	µg/L	–	–	–	161/ 150	–	–	–	–	–	–	180	<25	–	–	–
Total Mn	µg/L	1.5	5.3	5.4	2.7	6.7	3.0 2.7	17.9 6.8	6.2 9.6	1.5	5.7	1.5	5.8	1.6	6.2	6.4
Dissolved Mn	µg/L	–	–	–	3.1	–	–	–	–	–	–	1.6	5.9	–	–	–

(a) as CaCO<sub>3</sub>. (b) as PO<sub>4</sub>. (/) indicates re-run data with original result/re-run result.

IN = at the inlet; AC = after prechlorination; TA = after tank A; TB = after tank B; TT = after tanks combined.

NA = data not available.

### Analytical Results from Long-Term Sampling, Queen Anne's County, MD

Sampling Date		11/10/04 <sup>(c)</sup>	11/16/04			11/23/04	12/01/04 <sup>(f)</sup>			12/07/04		12/15/04		
Sampling Location	Parameter Unit	TT	IN	AC	TT	TT	IN	TA	TB	AC	TT	IN	AC	TT
Bed Volume		10,137	–	–	10,190	10,731	–	11,167	11,224	–	11,330	–	–	11,650
Alkalinity	mg/L <sup>(a)</sup>	152	176	176	164	162	158 162	154 162	154 162	166	166	163	167	163
Fluoride	mg/L	0.6	0.7	0.7	0.7	0.8	0.8 0.9	1.0 0.2	0.8 0.9	0.9	0.8	0.8	0.9	0.9
Sulfate	mg/L	3.1	1.5	2.7	3.1	3.5	–	–	–	6.0	6.0	3.7	3.7	3.7
Orthophosphate	mg/L <sup>(b)</sup>	<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 <sub>2</sub> )	mg/L	14.9	15.9	14.6	15.4	15.4	14.6 14.3	14.6 14.5	14.6 14.8	15.0	14.8	15.8	14.9	14.7
NO <sub>3</sub> -(N)	mg/L	<0.04	<0.04	<0.04	<0.04	<0.04	–	–	–	<0.04	<0.04	<0.04	<0.04	<0.04
Turbidity	NTU	0.3	3.0	0.5	0.4	0.1	1.5 1.1	0.1 0.2	0.2 0.1	0.3	0.2	0.5	0.6	0.2
pH	–	7.8	7.7	NA	7.7	NA	7.4	7.4	7.2	NA	NA	8.1	7.8	7.3
Temperature	°C	18.0	18.4	NA	17.9	NA	15.2	15.5	15.5	NA	NA	15.2	14.9	15.5
DO	mg/L	5.8	4.7	NA	2.1	NA	4.2	1.7	1.4	NA	NA	5.5	NA	5.6
ORP	mV	286	160	NA	126	NA	101	114	120	NA	NA	-119	NA	88
Free Chlorine	mg/L	0.5	–	0.68 <sup>(d)</sup>	0.13 <sup>(d)</sup>	0.12 <sup>(e)</sup>	–	–	–	–	–	–	0.4	–
Total Chlorine	mg/L	–	–	–	–	–	–	–	–	–	–	–	0.1	–
Total Hardness	mg/L <sup>(a)</sup>	98.8	98.6	95.5	92.5	111.9	–	–	–	96.4	112.1	114.4	113.3	107.8
Ca Hardness	mg/L <sup>(a)</sup>	56.6	50.2	48.4	47.7	66.1	–	–	–	54.8	67.5	67.3	66.7	63.9
Mg Hardness	mg/L <sup>(a)</sup>	42.2	48.4	47.1	44.8	45.8	–	–	–	41.6	44.6	47.1	46.6	43.9
As (total)	µg/L	14.7	19.0	19.9	12.0	0.9	18.3 18.8	0.4 0.4	0.3 0.3	22.1	0.6	20.0	18.8	0.3
As (total soluble)	µg/L	14.6	19.0	12.2	11.9	0.9	–	–	–	15.2	0.7	20.0	19.0	0.2
As (particulate)	µg/L	0.1	<0.1	7.7	0.1	<0.1	–	–	–	6.9	<0.1	<0.1	<0.1	<0.1
As (III)	µg/L	14.8	18.4	0.2	10.4	0.4	–	–	–	1.6	<0.1	20.3	<0.1	0.5
As (V)	µg/L	<0.1	0.6	12.0	1.5	0.5	–	–	–	13.6	<0.1	<0.1	18.9	<0.1
Total Fe	µg/L	108	802	268	<25	<25	261 264	<25 <25	<25 <25	212	<25	229	229	<25
Dissolved Fe	µg/L	61	777	<25	<25	<25	–	–	–	<25	<25	156	173	<25
Total Mn	µg/L	10.1	9.8	2.1	11.5 <sup>(f)</sup>	4.3	2.6 2.6	2.0 2.1	3.0 3.0	1.5	2.0	2.5	1.6	2.0
Dissolved Mn	µg/L	10.4	14.3	0.3	11.2	4.1	–	–	–	0.2	1.9	2.1	1.7	1.5

(a) as CaCO<sub>3</sub>. (b) as PO<sub>4</sub>. (c) Prechlorination started November 9, 2004. (d) Chlorine residual measured on November 17, 2004. (e) Chlorine residual measured on November 21, 2004.

(f) Weekly on-site water quality parameters measured on December 2, 2004. ORP measured on December 3, 2004.

IN = at the inlet; AC = after prechlorination; TA = after tank A; TB = after tank B; TT = after tanks combined. NA = data not available.