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Arsenic Removal from Drinking Water by Adsorptive Media U.S. EPA Demonstration Project at Rollinsford, NH Final Performance Evaluation Report

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Sally Gutierrez, Director
National Risk Management Research Laboratory

ABSTRACT

This report documents the activities performed and the results obtained from the arsenic removal treatment technology demonstration project at Rollinsford, New Hampshire. The objectives of the project were to evaluate: 1) the effectiveness of AdEdge Technologies' AD -33™ media in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 µg/L; 2) the reliability of the treatment system; 3) the required system operation and maintenance (O&M) and operator skills; and 4) the capital and O&M costs of the technology. The project also characterized water in the distribution system and process residuals produced by the treatment system.

The Rollisford, NH demonstration project consisted of two study phases. The source water for both studies consisted of water from two wells having a flow capacity of 95 to 112 gal/min (gpm). Phase 1 of the study utilized an Arsenic Package Unit (APU)-100 system designed for a flowrate of 100 gpm. Because higher flowrates up to 112 gpm were experienced in Phase 1, a 120-gpm APU-RWS system was designed and installed for Phase 2 of the study. Both packages units contained the AdEdge AD-33™ media, which is an iron-based adsorptive media developed by Bayer AG under the brand name of Bayoxide 33.

The Phase 1 APU-100 system consisted of two 36-in-diameter, 72-in-tall pressure vessels in parallel configuration, each initially containing 27 ft^3 of AD-33™ media supported by a gravel underbed. Empty bed contact time (EBCT) for the system was approximately 4.0 min per vessel. Hydraulic loading to each vessel based on a design flowrate of 100 gpm was approximately 7 gpm/ft^2. The Phase 2 APU-RWS system consisted of two 48-in-diameter, 72-in-tall pressure vessels in parallel configuration, each initially containing 30 ft^3 of AD-33™ media also supported by a gravel underbed. EBCT for the APU-RWS system was approximately 3.7 min based on a media volume of 30 ft^3 per vessel. Hydraulic loading to each vessel based on a design flowrate of 120 gpm was about 4.8 gpm/ft^2.

The APU-100 system included a carbon dioxide (CO_2) injection module with manual controls for pH adjustment prior to arsenic adsorption. Contributing, in part, by mechanical problems, the CO_2 system failed to consistently adjust pH to the target value of 7.0. Attempts were made to upgrade the manual pH control system for automatic operation to provide for better control for Phase 2; however, the system automation was never completed because the CO_2 injection membrane was subject to fouling that could not be resolved. As a result, pH adjustment was not performed during the Phase 2 study.

Two system performance runs were conducted in the Phase 1 APU-100 treatment system. Run 1 operating from February 9, 2004, through October 27, 2004, and Run 2 from November 3, 2004, through January 15, 2005. The replacement system, APU-RWS, was evaluated under Phase 2 from June 13, 2005, through May 8, 2006. During Phase 1, the system was sometimes operated with only one supply well to reduce the flowrate to the system, thereby reducing the inlet pressure and differential pressure (Δp) in order to extend the time between backwash events. During Phase 2, the system also was operated with one supply well to reduce the flowrate to the system to try to improve arsenic removal performance.

Run 1 of the system treated approximately 11,926,000 gal of water based on totalizer readings from each vessel, operating 11.6 hr/day with an average flowrate of 95 (with both supply wells operating) or 60 gpm (with one supply well operating). Run 2 of the system treated approximately 3,921,000 gal of water operating 10.5 hr/day with an average flowrate of 112 gpm (with both supply wells operating). During Phase 2, the APU-RWS system treated approximately 12,881,000 gal of water, operating 9.7 hr/day with an average flowrate of 97 (with both supply wells operating) or 58 gpm (with one supply well operating). The EBCTs for Run 1 in each vessel ranged from 3.0 to 7.0 min with both wells running and from 4.3 to 9.5 min with only one well running. During Run 2, the EBCTs ranged from 2.5 to 3.9 min. The EBCTs

in Phase 2 ranged from 4.0 to 5.6 min with both wells running and from 4.0 to 10.0 min with only one well running.

During Phase 1, higher than normal system Δp and inlet pressures were experienced. Consequently, the operator conducted frequent backwashes and worked with the vendor to troubleshoot, modify, and replace several system components. The aggressive and frequent backwashing resulted in high media loss – up to 46 to 59% by the end of the study. The system design for Phase 2 successfully addressed the elevated pressure and eliminated the need for frequent backwashes.

Total arsenic concentrations in source water ranged from 28.7 to 52.4 µg/L with As(III) comprising a significant portion of the total soluble arsenic, with concentrations ranging from 7.6 to 28.8 µg/L. After one and one half months of Run 1 operation, the preexisting chlorine injection system was used to prechlorinate the source water and effectively oxidized the As(III) to As(V). The prechlorination step continued throughout the remainder of the study.

Breakthrough of total arsenic at concentrations above the 10 µg/L target MCL was first observed after the APU-100 system had processed between 12,500 and 17,000 bed volumes (BV) of water, representing about 17 to 23% of the estimated working capacity of 74,000 BV. The media performed similarly during the Phase 2 operation of the APU-RWS system. Although the re-design of the system helped alleviate both inlet pressure and Δp problems, it did not improve the media performance in terms of its run length.

Backwash wastewater contained soluble arsenic concentrations ranging from 9.5 to 33.8 µg/L. Soluble iron and soluble manganese concentrations ranged from <25 to 115 and 3.3 to 75.7 µg/L, respectively. As expected, total arsenic, iron, and manganese concentrations were considerably higher than the soluble concentrations, indicating the presence of particulate material in the backwash wastewater. Particulate arsenic might be associated with either iron particles filtered out by the media beds during the service cycle or the media fines. Based on the total suspended solids (TSS) values, approximately 8 lb of suspended solids would be produced in 1,890 gal of backwash wastewater from the vessels for Phase 1 and approximately 25 lb of solids would be produced in 4,200 gal of backwash wastewater for Phase 2.

The spent media passed the Resource Conservation and Recovery Act (RCRA) Toxicity Characteristic Leaching Procedure (TCLP) test for all metals, with only barium showing detectable concentrations ranging from 0.95 and 0.96 mg/L. The average arsenic loading on the spent media based on the inductively coupled plasma-mass spectrometry (ICP-MS) results was 1.88 mg/g or 0.188%. This 1.88 mg/g loading compared well (98%) with the average adsorptive capacity of 1.93 mg/g measured by dividing the area between the influent and effluent breakthrough curves by the amount of dry media in each tank.

Distribution system water samples were collected before and after the installation of the treatment system to determine any impact of arsenic treatment on the lead and copper level and water chemistry in the distribution system. However, because the distribution system in place was a looped system that included water from a third untreated well (General Sullivan Well), the impact of the treated water could not be exactly determined.

The capital investment cost for the re-designed APU-RWS system was $131,692, which included $105,805 for equipment, $4,672 for engineering, and $21,215 for installation. Using the system's rated capacity of 120 gpm (172,800 gal/day [gpd]), the capital cost was $1,097/gpm ($0.76/gpd). These calculations do not include the cost of a building to house the treatment system. The unit annualized capital cost is $0.20/1,000 gal, assuming the system operated 24 hours a day, 7 days a week, at the system design flowrate of 120 gpm. The system operated only 10 hr/day, producing 21,243,000 gal of water per year with both wells operating. At this reduced usage rate, the unit annualized capital cost increased to $0.59/1,000 gal.

The O&M cost for the APU-RWS system was estimated at $3.59/1,000 gal, which included media replacement and disposal, electricity consumption, and labor. Chlorination was not included in the O&M cost calculation because it was part of the existing treatment system.

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TABLES

ABBREVIATIONS AND ACRONYMS

Δp	differential pressure
AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media process
APU	arsenic package unit
As	arsenic
ASTI	Applied Technology System, Inc.
BET	Brunauer, Emmett and Teller
BV	bed volume
Ca	calcium
Cl	chloride
C/F	coagulation/filtration
CO_2	carbon dioxide
CRF	capital recovery factor
Cu	copper
DO	dissolved oxygen
EBCT	empty bed contact time
EPA	U.S. Environmental Protection Agency
Fe	iron
$FeCl_3$	ferric chloride
FRP	fiberglass reinforced plastic
gpd	gallons per day
gpm	gallons per minute
HCl	hydrochloric acid
HDPE	high-density polyethylene
H_2SO_4	sulfuric acid
HTA	Hoyle, Tanner & Associates, Inc.
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
ISFET	ion sensitive field effect transistor
IX	ion exchange
LCR	Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MDWCA	Mutual Domestic Water Consumers Association
Mg	magnesium
Mn	manganese

mV	millivolts
NA	not applicable
Na	sodium
NaOCl	sodium hypochlorite
NHDES	New Hampshire Department of Environmental Services
NRMRL	National Risk Management Research Laboratory
NS	not sampled
NSF	NSF International
O&M	operation and maintenance
ORD	Office of Research and Development
ORP	oxidation-reduction potential
Pb	lead
PID	Proportional Integral Derivative
PM	process modification
psi	pounds per square inch
PO_4	orthophosphate
PVC	polyvinyl chloride
QA	quality assurance
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RCRA	Resource conservation and Recovery Act
RPD	relative percent difference
Sb	antimony
SDWA	Safe Drinking Water Act
SiO_2	silica
SM	system modification
$SO4^{2-}$	sulfate
STMGID	South Truckee Meadows General Improvement District
STS	Severn Trend Services
TBD	to be determined
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
WRWC	White Rock Water Company

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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 (As) at 0.05 mg/L. Amended in 1996, the SDWA required that EPA develop an arsenic research strategy and publish a proposal to revise the arsenic MCL by January 2000. On January 18, 2001, EPA finalized the arsenic MCL at 0.01 mg/L (EPA, 2001). In order to clarify the implementation of the original rule, EPA revised the rule text on March 25, 2003, to express the MCL as 0.010 mg/L (10 µg/L) (EPA, 2003). The final rule 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 Round 1 of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 out of 115 sites to host the demonstration studies. The Rollinsford Water and Sewer District (the District) in New Hampshire 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 panel reviewed the proposals and provided its recommendations to EPA on the technologies that it determined were acceptable for demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration program. 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. AdEdge Technologies' (AdEdge) adsorptive media process was selected for the Rollinsford facility. Designated as AD-33™ by AdEdge, the process uses the Bayoxide E33 media developed by Bayer AG.

The Rollinsford, NH study was conducted in two phases. Phase 1 of the study utilized an Arsenic Package Unit (APU)-100 system designed for a maximum flowrate of 100 gal/min (gpm). Because higher flowrates up to 112 gpm (100 gpm average) were experienced in Phase 1, a 120-gpm APU-RWS system was designed and installed in Phase 2 to replace the APU-100. Following a series of predemonstration activities, including engineering design, permitting, and system installation, startup and shakedown, the Phase 1 performance evaluation began on February 9, 2004, and was completed on January 16, 2005. After state approval and installation of the APU-RWS system, the Phase 2 performance evaluation was conducted from June 13, 2005, to May 8, 2006. After the demonstration project, the District converted the adsorptive media system to a coagulation/filtration (C/F) system.

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 ion 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. An overview of the technology selection and system design for the 12 demonstration sites and the associated capital cost was provided in two EPA reports (Wang et al., 2004; Chen et al., 2004), which are posted on the EPA Website (http://www.epa.gov/ORD/NRMRL/wswrd/dw/arsenic/index.html). As of November 2008, all 12 systems have been operational and 11 performance evaluations have been completed.

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

Demonstration Site	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
				As (µg/L)	Fe (µg/L)	pH
WRWC (Bow), NH	AM (G2)	ADI	70[(a)]	39	<25	7.7
Rollinsford, NH	AM (E33)	AdEdge	100	36[(b)]	46	8.2
Queen Anne's County, MD	AM (E33)	STS	300	19[(b)]	270[(c)]	7.3
Brown City, MI	AM (E33)	STS	640	14[(b)]	127[(c)]	7.3
Climax, MN	C/F	Kinetico	140	39[(b)]	546[(c)]	7.4
Lidgerwood, ND	PM	Kinetico	250	146[(b)]	1,325[(c)]	7.2
Desert Sands MDWCA, NM	AM (E33)	STS	320	23[(b)]	39	7.7
Nambe Pueblo Tribe, NM	AM (E33)	AdEdge	145	33	<25	8.5
Rimrock, AZ	AM (E33)	AdEdge	90[(d)]	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; C/F = coagulation/filtration; IX = ion exchange; MDWCA = Mutual Domestic Water Consumer's Association; PM = process modification; STMGID = South Truckee Meadows General Improvement District; STS = Severn Trent Services; WRWC = White Rock Water Company

(a) System reconfigured from parallel to series operation due to a lower flowrate of 40 gpm at WRWC site

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

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

(d) System reconfigured from parallel to series operation due to a reduced flowrate of 30 gpm.

1.3 Project Objectives

The objective of the Round 1 arsenic demonstration program was to conduct full-scale arsenic removal technology demonstration studies on the removal of arsenic from drinking water supplies at 12 demonstration host sites. The specific objectives of the demonstration study in Rollinsford, NH were to:

- Evaluate the performance of AD-33™ arsenic removal technology for use on small systems.
- Determine the required system operation and maintenance (O&M) and operator skill levels.
- Characterize process residuals produced by the technology.
- Determine the capital and O&M cost of the technology.

This report summarizes the performance of AdEdge's APU-100 and APU-RWS systems at Rollinsford Water and Sewer District in New Hampshire from February 9, 2004, through January 16, 2005, and from June 13, 2005, through May 8, 2006, respectively. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), residuals characterization, and capital and O&M cost.

2.0 SUMMARY AND CONCLUSIONS

Based on the information collected during two years of system operation, the following observations were summarized and conclusions drawn relating to the overall objectives of the treatment technology demonstration study.

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

- The AD-33™ media was not effective at removing As(III). Breakthrough of arsenic at 7.7 μg/L occurred after only 2,700 bed volumes (BV) of throughput.
- Chlorine was effective at oxidizing As(III) to As(V), reducing As(III) concentrations from 17.6 μg/L (on average) in raw water to 1.1 μg/L (on average) after chlorination.
- Prechlorination significantly improved arsenic removal by the media. However, breakthrough of total arsenic at 10 μg/L occurred between 12,500 and 17,000 BV, representing only 17 to 23% of the vendor-projected media run length.
- The short run length observed was caused, in part, by the manganese (Mn) removed by the media. Manganese removal increased significantly with the presence of chlorine. For example, without chlorine, manganese reached about 100% "breakthrough" from the media beds after treating only about 3,700 BV of water. Following implementation of prechlorination, manganese, existing mostly in the soluble form, was removed almost entirely, presumably via precipitation on the media surface. Removal of manganese was supported by the chemical analysis of the spent media, which showed significantly higher manganese concentrations in the spent media than in the virgin media.
- Over 46 to 59% media loss was observed during the two media runs using the APU-100 system. The media loss was likely caused by frequent aggressive backwashing, which was used to address elevated differential pressure (Δp) and inlet pressure problems.

Required system O&M and operator skill levels:

- The operator typically spent only 20 min per day operating and maintaining the system. On days when the system was backwashed, the operator could spend as much as two hours completing the process.
- During Phase 1, the operator spent much more time troubleshooting operational issues, such as elevated Δp and inlet pressure, than would normally be expected. The operator also conducted frequent backwashes and worked with the vendor to troubleshoot, modify, and replace several system components.
- Changing the system design from controller valves to a valve tree prior to Phase 2 successfully addressed the Δp and elevated inlet pressure problems and eliminated the need for frequent backwashes.
- Due to mechanical problems associated with the carbon dioxide (CO_2) pH control system, the system failed to consistently reduce the pH to the target value of 7.0. Attempts were made to upgrade the manual pH control system for automatic operation to provide for better control in Phase 2; however, the system automation was never completed because the CO_2 injection membrane was subject to fouling.

Characteristics of residuals produced by the technology:

- During Phase 1, each backwash event produced 1,890 gal, on average, of wastewater. In Phase 2, each backwash event produced 4,200 gal, on average, of wastewater.
- Backwash wastewater contained less soluble arsenic than raw water, indicating removal of arsenic by the media during backwashing. High total suspended solids (TSS) concentrations (i.e., 308 to 788 mg/L) indicated removal of media fines during backwashing, which is

supported by the similar chemical composition of the backwash solids and spent media and by the observations of significant media loss in the vessels during operation.

- Approximately 1.88 mg of arsenic was loaded per gram of dry media, equivalent to about 0.19% arsenic loading. The spent media was non-hazardous and could be disposed of at a lined, permitted sanitary landfill per requirements by the State of New Hampshire.

Capital and O&M cost of the technology:

- The unit annualized capital cost is $0.20/1,000 gal if the system operates at a 100% utilization rate. The system's actual unit annualized capital cost is $0.59/1,000 gal, based on 10 hr/day of system operation and 21,243,000 gal of water production. The unit O&M cost is $3.59/1,000 gal, based on media replacement and disposal, electricity consumption, and labor.

3.0 MATERIALS AND METHODS

3.1 General Project Approach

Following the predemonstration activities summarized in Table 3-1, the performance evaluation study of AdEdge's APU-100 system began on February 9, 2004. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The study was intended initially to take place over a one-year period; however, because of several performance- and operational issues, the technology evaluation was extended for one additional year to evaluate a redesigned system, APU-RWS, which replaced the APU-100 system. Both systems are fixed-bed, down-flow adsorption systems using the AD-33™ media for the adsorption of dissolved arsenic. The APU-RWS system was designed to provide a higher treatment capacity and alleviate some of the operational problems experienced by the APU-100 system.

The overall performance of the systems was evaluated based on their ability to consistently remove arsenic to below the MCL of 10 μg/L through the collection of water samples across the treatment trains. The reliability of the systems 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. Predemonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	August 5, 2003
Request for Quotation Issued to Vendor	August 7, 2003
Draft Letter of Understanding Issued	August 13, 2003
Final Letter of Understanding Issued	September 9, 2003
Vendor Quotation Received	September 10, 2003
Purchase Order Completed and Signed	October 6, 2003
Letter Report Issued	October 17, 2003
Building Construction Began	November 3, 2003
Draft Study Plan Issued	November 26, 2003
Engineering Package Submitted to NHDES	December 19, 2003
Building Construction Completed	December 22, 2003
APU-100 Shipped by AdEdge	December 23, 2003
APU-100 Delivered to Site and System Installation Began	January 8, 2004
Permit for APU-100 Treatment System Issued by NHDES	January 12, 2004
Final Study Plan Issued	January 21, 2004
APU-100 System Installation Completed	January 23, 2004
APU-100 System Shakedown Completed	January 30, 2004
APU-100 Performance Evaluation Began	February 9, 2004

NHDES = New Hampshire Department of Environmental Services

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

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

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

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

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

3.2 System O&M and Cost Data Collection

The plant operator performed daily, weekly, and monthly system O&M and data collection 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, and hour meter readings on a Daily System Operation Log Sheet; checked sodium hypochlorite (NaOCl) drum levels; checked CO_2 consumption levels used for pH adjustment; and conducted visual inspections to ensure normal system operation. If any problem occurred, the plant operator contacted the Battelle Study Lead, who determined if the vendor and its subcontractors should be contacted for troubleshooting. Once a week, the plant operator measured water quality parameters, including temperature, pH, dissolved oxygen (DO)/oxidation-reduction potential (ORP), and residual chlorine, using field meters and recorded the data on a Weekly Water Quality Parameters Log Sheet. Backwash events also were recorded on a Backwash Log Sheet.

The capital cost for the arsenic removal system consisted of the cost for equipment, site engineering, and system installation. The O&M cost consisted of cost for media replacement and spent media disposal, chemical usage, electricity consumption, and labor. Consumption of NaOCl, CO_2, and electricity was tracked using the Daily System Operation Log Sheet. Labor for various activities, such as the routine system O&M, troubleshooting and repair, and demonstration-related work, was tracked using an Operator Labor Hour Log Sheet. The routine O&M included activities such as completing the daily field logs, replenishing the NaOCl solution, replacing CO_2 tanks, performing system inspection, and other miscellaneous routine requirements as recommended by the vendor. The demonstration-related labor, including activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead and vendor representatives, was recorded but not used for the cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate the system performance, samples were collected routinely from the wellhead, treatment plant, and distribution system. 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). The procedure for arsenic speciation is described in Appendix A of the QAPP.

3.3.1 Source Water. During the initial visit to the site on August 5, 2003, one set of source water samples was collected for detailed water quality analyses. The source water also was speciated for particulate and soluble As, iron (Fe), Mn, aluminum (Al), and As(III) and As(V) using an arsenic speciation kit described in Section 3.4.1. The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation.

3.3.2 Treatment Plant Water. Two media runs (i.e., Runs 1 and 2) were performed in Phase 1. Water samples were collected by the plant operator weekly, on a four-week cycle, for on- and off-site analyses. For the first week of each four-week cycle, water samples were collected at the wellhead (IN), after pH adjustment but before splitting to the two adsorption vessels (AP), and from the combined effluent of Vessels A and B (TT) and analyzed for the monthly treatment plant analyte list shown in Table 3-3. For the second, third, and fourth week of each cycle, water samples were collected at four locations across the treatment train, including IN, AP, after Vessel A (TA), and after Vessel B (TB) and analyzed for the weekly treatment plant analyte list shown in Table 3-3. After the APU-100 system was replaced with the redesigned, larger capacity APU-RWS system, the weekly sampling frequency was reduced to biweekly during the second year of system operation. After the system was converted into a coagulation/filtration (C/F) treatment system, several biweekly samples were collected for total As, Fe, and Mn to evaluate the effectiveness of the new treatment system at meeting the target MCL.

3.3.3 Backwash Wastewater. From April 26, 2004, through January 31, 2006, backwash wastewater was sampled and analyzed during nine backwash events. During the first eight events, grab samples were collected from the sample tap on the backwash wastewater discharge line from each vessel and filtered onsite with 0.45-μm disc filters. During the last event, composite samples were collected following a modified procedure to allow for more representative characterization of the wastewater. Tubing directed a portion of backwash water from the sample tap at approximately 1 gpm into a clean plastic container over the duration of the backwash for each vessel. After the content in the container was thoroughly mixed, composite samples were collected and/or filtered onsite with 0.45-μm disc filters. Analytes for the backwash samples are listed in Table 3-3. Unfiltered samples were analyzed for pH, turbidity, and TSS. Filtered samples were analyzed for soluble As, Fe, and Mn, and total dissolved solids (TDS). Arsenic speciation was not performed for the backwash wastewater samples.

3.3.4 Residual Solids. Residual solids included backwash solids and spent media. Backwash solid samples were collected twice on September 8 and 30, 2004. Backwash solids were taken from 1-gal plastic jars containing mixtures of backwash wastewater and solids. After solids in the jars were settled and the supernatant was carefully decanted, residual solids samples were air-dried, acid-digested, and analyzed for the analytes listed in Table 3-3.

Table 3-3. Sample Collection Schedule and Analyses

Sample Type	Sample Locations[(a)]	No. of Samples	Frequency	Analytes	Date(s) Samples Collected
Source Water	Wellhead (IN)	1	Once (during initial site visit)	Off-Site: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), Al (total and soluble), V (total and soluble), Mo (total and soluble), Sb (total and soluble), Na, Ca, Mg, Cl, F, SO_4, SiO_2, PO_4, TOC, alkalinity, turbidity, and pH	08/05/03
Treatment Plant Water	Wellhead (IN), after pH adjustment (AP), after Vessel A (TA), and after Vessel B (TB)	4	Weekly (second, third, and fourth weeks of every four-week cycle)	On-Site: pH, temperature, DO, ORP, and chlorine (free and total at AP, TA, and TB only) Off-Site: As (total), Fe (total), Mn (total), SiO_2, P, alkalinity, and turbidity	Phase 1 Run 1[(b)]: See Appendix B Phase 1 Run 2[(b)]: See Appendix B Phase 2[(c)]: See Appendix B Other[(d)(e)]: See Appendix B
	Wellhead (IN), after pH adjustment (AP), and combined effluent (TT)	3	Monthly (first week of every four-week cycle)	On-Site: pH, temperature, DO, ORP, and chlorine (free and total at AP and TT only) Off-Site: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), Ca, Mg, F, NO_3, SO_4, SiO_2, PO_4[(f)], P, alkalinity, and turbidity	Phase 1 Run 1[(b)]: See Appendix B Phase 1 Run 2[(b)]: See Appendix B Phase 2[(c)]: See Appendix B Other[(d)(e)]: See Appendix B
Distribution Water	One home (a non-LCR sampling location) and two non-residences within area served by Wells No. 3 and No. 4	3	Monthly	As, pH, alkalinity, Cu, Pb, Fe, and Mn	Baseline sampling[(g)]: See Table 4-15 Phase 1[(b)]: See Table 4-15 Phase 2[(c)]: See Table 4-15
Backwash Wastewater	From backwash discharge line	2	Monthly	As (soluble), Fe (soluble), Mn (soluble), TDS, TSS, turbidity, and pH	Phase 1[(b)]: See Table 4-11 Phase 2[(c)]: See Table 4-11 Other[(d)]: 05/08/06[(h)]

Table 3-3. Sample Collection Schedule and Analyses (Continued)

Sample Type	Sample Locations[(a)]	No. of Samples	Frequency	Analytes	Date(s) Samples Collected
Backwash Solids	From backwash discharge line	4	Twice	Total Al, As, Ca, Cd, Cu, Fe, Mg, Mn, Ni, P, Pb, Si, and Zn	09/08/04, 09/30/04
Spent Media	From spent media in vessel	2	Once during media changeout	TCLP metals Total Al, As, Ca, Cd, Cu, Fe, Mn, Mg, Ni, P, Pb, Si, and Zn	Phase 1[(b)]: 10/27/04

(a) Abbreviations in parentheses corresponding to sample locations shown in Figure 4-2.
(b) APU-100 system operating.
(c) APU-RWS system operating.
(d) System converted into a C/F system.
(e) Samples analyzed for total metals only.
(f) PO_4 replaced with P (total) analysis beginning January 10, 2006.
(g) Three baseline sampling events performed before system became operational.
(h) Modified sampling procedure to also include total metals on January 31, 2006.
LCR = Lead and Copper Rule; TCLP = toxicity characteristic leacing procedure

During the first media changeout on October 27, 2004, three spent media samples were collected from each adsorption vessel that contained approximately 12 to 15 ft^3 of AD-33™ media with a bed depth of 20.5 to 25 in. Spent media was removed from the top (0 to 4 in depth), middle (10 to 14 in depth), and bottom (19 to 25 in depth) of the bed in each vessel using a 5-gal wet/dry shop vacuum, which was thoroughly cleaned and disinfected. Using a garden spade, the media from each layer was well-mixed in a clean 5-gal pail prior to being filled in an unpreserved 1-gal wide-mouth high-density polyethylene (HDPE) bottle. One aliquot of each sample was sent to TCCI Laboratories in New Lexington, OH, for Toxicity Characteristic Leaching Procedure (TCLP) tests and another aliquot was air dried for metal analyses at Battelle's inductively coupled plasma-mass spectrometry (ICP-MS) laboratory.

3.3.5 Distribution System Water. 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, arsenic, lead (Pb) and copper (Cu) levels. In December 2003 and January 2004, prior to the startup of the treatment system, three baseline sampling events were conducted at three locations per sampling event within the distribution system. Following startup of the APU-100 and APU-RWS systems, distribution system sampling continued at the same three locations for eigh sampling events from March through December 2004 and for four sampling events from July 2005 through January 2006, respectively.

Baseline and monthly distribution system samples were collected by the plant operator and by one home-owner. Samples were collected at one home, not included as a Lead and Copper Rule (LCR) sampling residence, as well as two non-residences. The locations were selected to maximize the likelihood that the water supplied to these locations was produced by Wells No. 3 and No. 4, which were treated by the arsenic removal system. With a looped system being served by additional wells besides Wells No. 3 and No. 4, it was possible that water collected from the distribution system was from a source other than Wells No. 3 and No. 4 (see Section 4.1). Analytes for the baseline samples coincided with the monthly distribution water samples as described in Table 3-3. Arsenic speciation was not performed on the distribution water samples. The samples were collected following an instruction sheet developed according to the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). Sampling at the two non-residence locations was performed with the first sample taken at the first draw and the second sample taken after flushing the sample tap for several minutes. 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.

3.4 Sampling Logistics

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

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

3.4.2 Preparation of Sampling Coolers. For each sampling event, a cooler was prepared with the appropriate number and type of sample bottles, disc filters, and/or speciation kits. All sample bottles were new and contained appropriate preservatives. Each sample bottle was affixed with a pre-printed, colored-coded, waterproof label consisting of the sample identification (ID), date and time of sample collection, collector's name, site location, sample destination, analysis required, and preservative. The sample ID consisted of a two-letter code for the specific water facility, sampling date, a two-letter code for a specific sampling location, and a one-letter code for designating the arsenic speciation bottle (if necessary). The sampling locations at the treatment plant 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. The labeled bottles for each sampling location were placed in a ziplock bag (each corresponding to a specific sample location) and packed in the cooler. On a monthly basis, the sample cooler also included bottles for the distribution system sampling.

All sampling and shipping-related supplies, such as disposable gloves, sampling instructions, chain-of-custody forms, prepaid/pre-addressed FedEx air bills, and bubble wrap, were placed in each cooler. The chain-of-custody forms and air bills were completed except for the operator's signature and the sample date and time. After preparation, the sample cooler was sent to the site via FedEx for the following week's sampling event.

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

Samples for metal analyses were stored at Battelle's ICP-MS laboratory. Samples for other water quality analyses by Battelle's subcontract laboratories, including American Analytical Laboratories (AAL) in Columbus, OH, and TCCI Laboratories, were packed in coolers and picked up by couriers. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

3.5 Analytical Procedures

The analytical procedures described in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2004) were followed by Battelle ICP-MS, AAL, and TCCI Laboratories. Laboratory quality assurance/quality control (QA/QC) of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection limit (MDL), and completeness met the criteria established in the QAPP, i.e., 20% relative percent difference (RPD), 80 to 120% percent recovery, and 80% completeness. 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 upon completion of the Arsenic Demonstration Project.

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

4.0 RESULTS AND DISCUSSION

4.1 Existing Facility Description

The Rollinsford water system supplied water to approximately 450 connections. The water source was from three bedrock wells, two of which, Wells No. 3 and No. 4, were controlled through the Porter well house shown in Figure 4-1. The Porter well house was located in a wooded area approximately ¼ of a mile south of the town of Rollinsford. Water from these two wells were combined and chlorinated before being sent to the distribution system. The third supply well, the General Sullivan well, was located approximately 1.5 miles north of the Porter well house. Because the General Sullivan well was completely separated from the Porter well house, this well was not treated by either APU treatment system.

Figure 4-1. Preexisting Porter Well House – Prior to Building Construction and Treatment System Installation

4.1.1 Source Water Quality. Source water samples were collected at a sampling tap inside the Porter well house with water coming from both Wells No. 3 and No. 4 on August 5, 2003, and subsequently analyzed for the analytes presented 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 in source water ranged from 33.8 to 55.9 μg/L. Based on the August 5, 2003, sampling results, total arsenic concentration in source water was 36.2 μg/L, of which 33.9 μg/L was present in the soluble form and 2.3 μg/L in the particulate form. Of the soluble fraction, 20.1 μg/L (or 59%) existed as As(III) and 13.9 μg/L (or 41%) as As(V).

pH values of raw water ranged between 7.4 and 8.4. At pH values greater than 8.0, AdEdge recommended that the water pH be adjusted to increase media adsorptive capacity and prolong media run length. Therefore, the treatment process included a pH adjustment step prior to the arsenic adsorption system using a CO_2 injection module. The target pH value after adjustment was 7.0.

Table 4-1. Rollinsford, NH Water Quality Data

Parameter	Unit	Utility Raw Water Data[(a)]	EPA Raw Water Data[(b)]	EPA Raw Water Data[(c)]	Battelle Raw Water Data[(a)]	NHDES Raw Water Data[(a)]	NHDES Treated Water Data[(d)]
Sampling Date		NA	09/16/02	09/16/02	08/05/03	2000–2003	2000–2003
pH	–	8.4	NS	NA	7.4	8.4[(f)]	8.6[(g)]
Total Alkalinity (as $CaCO_3$)	mg/L	176	179	189	171	176[(f)]	110[(g)]
Hardness (as $CaCO_3$)	mg/L	50.0	46.6	40.9	50.9	49.7[(f)]	24.2–26.1
Turbidity	mg/L	NS	NS	NS	NS	NS	NS
Chloride	mg/L	42.0	42.3	47.7	48.0	42.0[(f)]	8.7[(g)]
Fluoride	mg/L	NS	NS	NS	0.8	0.57[(f)]	0.37–0.38
Sulfate	mg/L	38.0	40.5	29.0	36.0	38.0	21.0
Silica (as SiO_2)	mg/L	13.7	14.3	13.1	13.6	NS	NS
Orthophosphate (as P)	mg/L	0.07[(e)]	NS	NS	<0.10	NS	NS
TOC	mg/L	NS	NS	NS	<1.0	NS	NS
As(total)	μg/L	34.0–55.0	39.0	45.0	36.2	33.8–55.9	19.6–24.0
As (soluble)	μg/L	NS	NS	NS	33.9	NS	NS
As (particulate)	μg/L	NS	NS	NS	2.3	NS	NS
As(III)	μg/L	NS	NS	NS	20.1	NS	NS
As(V)	μg/L	NS	NS	NS	13.9	NS	NS
Fe (total)	μg/L	206	189	114	46.3	206[(f)]	<50[(g)]
Fe (soluble)	μg/L	NS	NS	NS	<30	NS	NS
Al (total)	μg/L	NS	<25	<25	<10	NS	NS
Al (soluble)	μg/L	NS	NS	NS	<10	NS	NS
Mn (total)	μg/L	88.0	100.5	56.7	70.8	88.2[(f)]	20.0–20.8
Mn (soluble)	μg/L	NS	NS	NS	68.6	NS	NS
V (total)	μg/L	NS	NS	NS	<0.1	NS	NS
V (soluble)	μg/L	NS	NS	NS	<0.1	NS	NS
Mo (total)	μg/L	NS	NS	NS	<0.1	NS	NS
Mo (soluble)	μg/L	NS	NS	NS	<0.1	NS	NS
Sb (total)	μg/L	NS	<25	<25	<0.1	<2[(f)]	<2[(g)]
Sb (soluble)	μg/L	NS	NS	NS	<0.1	NS	NS
Na (total)	mg/L	93.0	109	98.8	101.8	93.2[(f)]	50.8–52.0
Ca (total)	mg/L	10.0[(e)]	9.9	10.1	11.6	NS	NS
Mg (total)	mg/L	5.0[(e)]	5.3	3.8	5.3	NS	NS

(a) Collected from combined flow from Wells No. 3 and No. 4.
(b) Well No. 3.
(c) Well No. 4.
(d) Treated water data collected at residences.
(e) Data provided by EPA.
(f) Only one data point available for this time period for this parameter (Sample date – 11/19/01).
(g) Only one data point available for this time period for this parameter (Sample date – 04/12/00).
NS = not sampled

Iron levels in source water ranged from 46.3 to 206 μg/L; manganese levels ranged from 56.7 to 100.5 μg/L. At these levels, pretreatment for iron and manganese removal prior to adsorption was not considered necessary. Competing anions, such as orthophosphate and silica, were at levels sufficiently low (i.e., <0.1 mg/L and <14.3 mg/L, respectively) to not have any effect on arsenic adsorption. Other analytes also were at levels not expected to impact arsenic adsorption.

4.1.2 Predemonstration Treated Water Quality. During 2000 to 2003, the New Hampshire Department of Environmental Services (NHDES) collected and analyzed chlorinated water samples from the combined flow of Wells No. 3 and No. 4 for the constituents shown in Table 4-1. The concentrations were somewhat lower than those of the raw water samples analyzed by the utility, EPA, and Battelle, with the exception of pH, which was slightly higher at 8.6 (versus 8.4 in raw water). Arsenic concentrations remained high at 19.6 to 24 µg/L.

4.1.3 Distribution System. The town of Rollinsford received its water via a looped water distribution system, with water supplied from the three wells described in Section 4.1. Wells No. 3 and No. 4 were combined and sent to the distribution system from the Porter well house shown in Figure 4-1. Excess water generated by the supply wells was sent under pressure to an elevated storage tank. The water distribution mains were constructed of asbestos cement, cast iron, or ductile iron. The connections to the water system and piping within the residences themselves were primarily copper or polyvinyl chloride (PVC) pipe. The Rollinsford Water and Sewer District sampled water from the distribution system for various parameters. Each month, two locations within the distribution system were sampled for bacterial analyses including *E. coli* and total coliform. The Porter well water was sampled quarterly at the wellhead for total arsenic. Under the LCR, samples were collected from customer taps at 25 residences every three years.

4.2 Treatment Process Description

Two AdEdge APUs were installed at the Rollinsford demonstration site. Both systems used Bayoxide E33 media (labeled as AD-33™ by AdEdge), an iron-based adsorptive media developed by Bayer AG, for arsenic removal from drinking water supplies. The first treatment system, APU-100, was designed for a flow of 100 gpm. The redesigned system, APU-RWS, was intended for a maximum flow of 120 gpm. Both APUs were fixed-bed, down-flow adsorption systems. When the media reached its capacity, the spent media was removed and disposed of after being tested for EPA's TCLP. Table 4-2 presents the physical and chemical properties of the media. AD-33™ media was delivered in a dry crystalline form and listed by NSF International (NSF) under Standard 61 for use in drinking water applications. E33 media is available in both granular and pelletized forms, with the pelletized media being about 25% denser than its granular counterpart (i.e., 35 lb/ft^3 vs. 28 lb/ft^3). The media installed in the replacement system (i.e., APU-RWS) was the granular media, similar to that used for the original system (i.e., APU-100).

Table 4-3 presents the key system design parameters for the two systems. Figure 4-2 shows a simplified process flow diagram of the APU-100 and APU-RWS systems. Figure 4-3 is a generalized process flow diagram along with the sampling/analysis schedule. Both systems consisted of two pressure vessels operating in parallel. Key design changes for the replacement system included the use of larger diameter adsorption vessels (i.e., 48 vs. 36 in) with top/bottom openings and a valve tree design (vs. riser tubes and Fleck controller valves). The APU-RWS system also included larger diameter (3-in) piping and connections. Due to high pH values of the raw water (above 8), a CO_2 pH control system with manual controls was included as part of the original system. After the installation of the APU-RWS system, attempts were made to upgrade the manual pH control system for automatic operations. However, system automation was never completed, as discussed in Section 4.4.3, and not used during the operation of the APU-RWS operation. Key process components for each system include:

Table 4-2. Physical and Chemical Properties of AD-33™ Media[(a)]

Physical Properties	
Parameter	**Value**
Matrix	Iron oxide composite
Physical Form	Dry granular media
Color	Amber
Bulk Density (lb/ft^3)	28.1
BET Area (m^2/g)	142
Attrition (%)	0.3
Moisture Content (%)	<15% (by weight)
Particle Size Distribution	10 × 35 mesh
Crystal Size (Å)	70
Crystal Phase	α – FeOOH
Chemical Analysis	
Constituents	**Weight %**
FeOOH	90.1
CaO	0.27
MgO	1.00
MnO	0.11
SO_3	0.13
Na_2O	0.12
TiO_2	0.11
SiO_2	0.06
Al_2O_3	0.05
P_2O_5	0.02
Cl	0.01

(a) Provided by Bayer AG.
BET = Brunauer, Emmett, and Teller

- **Intake**. Raw water was pumped from Wells No. 3 and No. 4 and combined at the Porter well house before feeding the APU treatment system.

- **pH Adjustment Prior to Adsorption**. The pH of the feed water was adjusted to a target pH value of approximately 7.0 (±0.2 pH units) using CO_2. CO_2 was selected for pH adjustment because 1) it is less corrosive than mineral acids, such as sulfuric acid (H_2SO_4) and hydrochloric acid (HCl), and 2) when the treated water is depressurized, some CO_2 will degas, thereby raising the pH of the treated water and reducing its corrosivity.

  A manual CO_2 gas flow control system manufactured by Applied Technology Systems, Inc. (ATSI, Souderton, PA), was used for pH adjustment. Designed to introduce gaseous CO_2 into the water in a side-stream configuration, or a CO_2 loop (see a process diagram in Figure 4-4 and a composite of photographs in Figure 4-5), the system consisted of a liquid CO_2 supply assembly, a manual pH control panel, a CO_2 membrane assembly, and a pH probe:

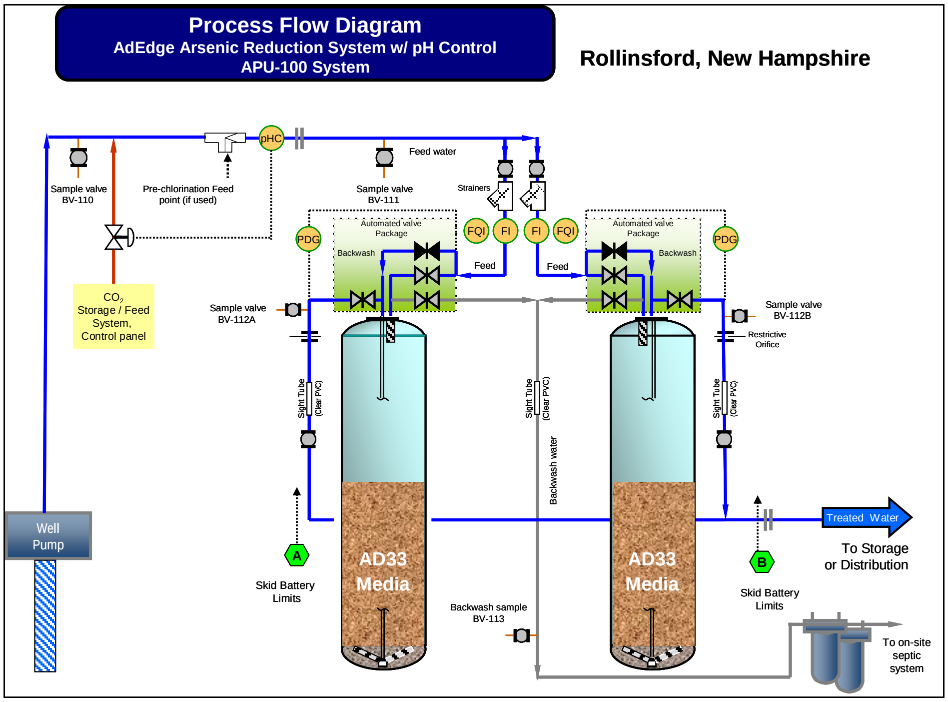
  - The liquid CO_2 supply assembly consisted of two 50-lb cylinders and a feed vaporizer, which allowed liquid CO_2 to vaporize into gaseous CO_2 prior to entering the pH control panel.

Table 4-3. Design Specifications of APU-100 and RWS Systems

Parameter	APU-100	APU-RWS
Adsorption Vessels		
Vessel Size (in)	36 D × 72 H	48 D × 72 H
Cross-Sectional Area (ft^2/vessel)	7.1	12.6
No. of Vessels	2	2
Configuration	Parallel	Parallel
Adsorption Media Bed		
Media Weight (lbs)	1,517[(a)]/1,236[(b)]	1,680
Media Volume (ft^3)	54[(a)]/44[(b)]	60
Media Bed Depth (ft)	3.8[(a)]/3.1[(b)]	2.4
Service		
Design Flowrate (gpm)	100	120
Hydraulic Loading (gpm/ft^2)	7.0	4.8
EBCT (min/vessel)	4.0[(a)]/3.3[(b)]	3.7
Estimated Working Capacity (BV)[(c)]	74,000[(a)]	44,000
Throughput to Breakthrough (gal)[(c)]	29,890,000[(a)]	19,747,000
Average Use Rate (gal/day)	60,000[(a)]	60,000
Estimated Media Life (months)	16.8[(a)]	11
Pre-treatment pH adjustment	CO_2	CO_2 (never used)
Pre-treatment Prechlorination	NaClO	NaClO
Pressure Differential Set Point (psi)	10	10
Backwash		
Backwash Hydraulic Loading (gpm/ft^2)	6.0	9.9
Backwash Frequency (per month)	1 (or as needed)	As needed
Backwash Flowrate (gpm)	42	125
Backwash Duration (min/vessel)	20–25	20
Wastewater Production (gal/vessel)	840–1,050	1,500–2,700

(a) Phase 1 Run 1.
(b) Phase 1 Run 2.
(c) Bed volumes/throughput to 10-µg/L total arsenic breakthrough.

- The pH control panel housed a pH controller that provided gas flow control via a solenoid valve (to interlock with the well pump to allow gas flow only when the well pump was on) and a rotameter (for flowrate adjustment).
- After exiting the control panel, CO_2 was introduced into the water through a Celgard microporous hollow fiber membrane module contained within a stainless steel sanitary cross (see properties and specifications in Table 4-4). The sanitary cross was located in a side stream from the main water line to allow only a portion of water to flow through the membrane module to minimize the pressure drop. CO_2 gas entered into the top of the membrane module with water passing through the membrane module in a direction perpendicular to the gas flow. The membrane dispersed CO_2 gas into water, forming fine bubbles for rapid mixing to achieve a quick pH change.
- Located downstream from the sanitary cross was a Cole Palmer Model A-27011-01 glass pH probe, which read pH levels of the treated water. The pH controller monitored signals from the pH probe and set off alarms if the readings were ±0.5 pH units outside of the target set point. When the alarm was triggered, the solenoid valve in the panel shut off the flow of CO_2 gas.



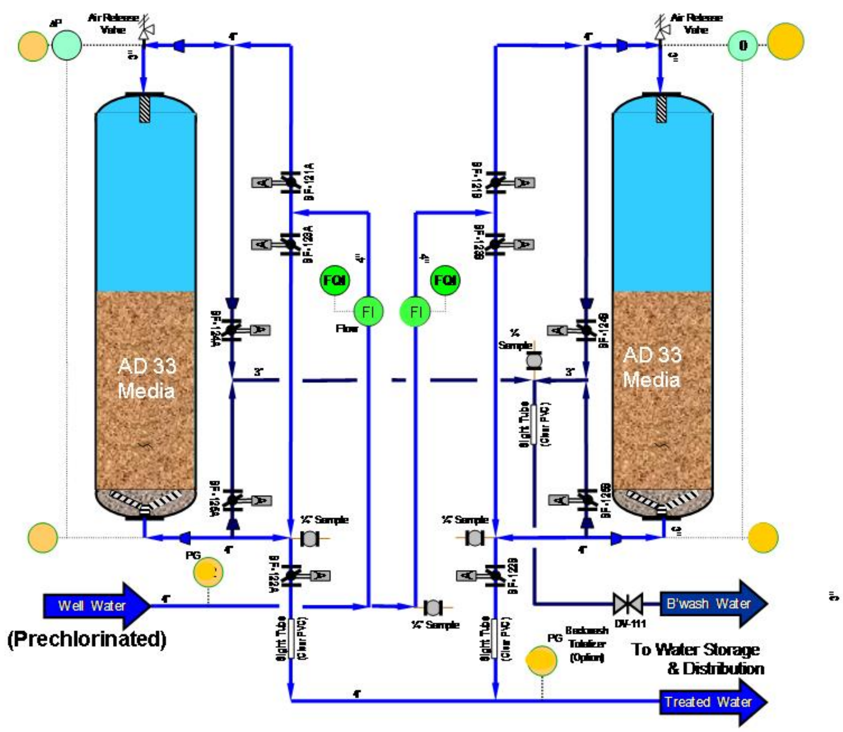


Figure 4-2. Schematic Diagrams for APU-100 (top) and APU-RWS Systems (bottom)

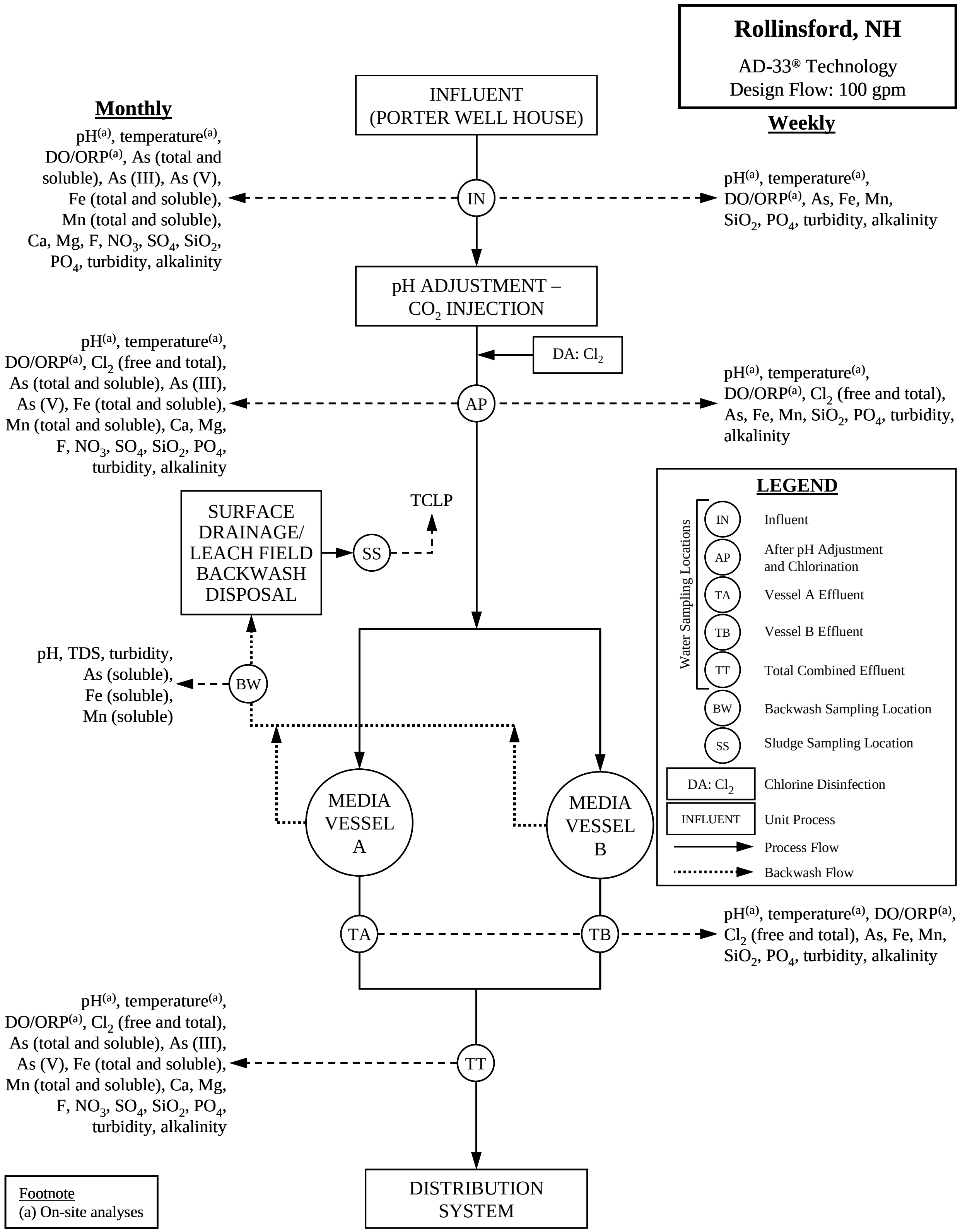
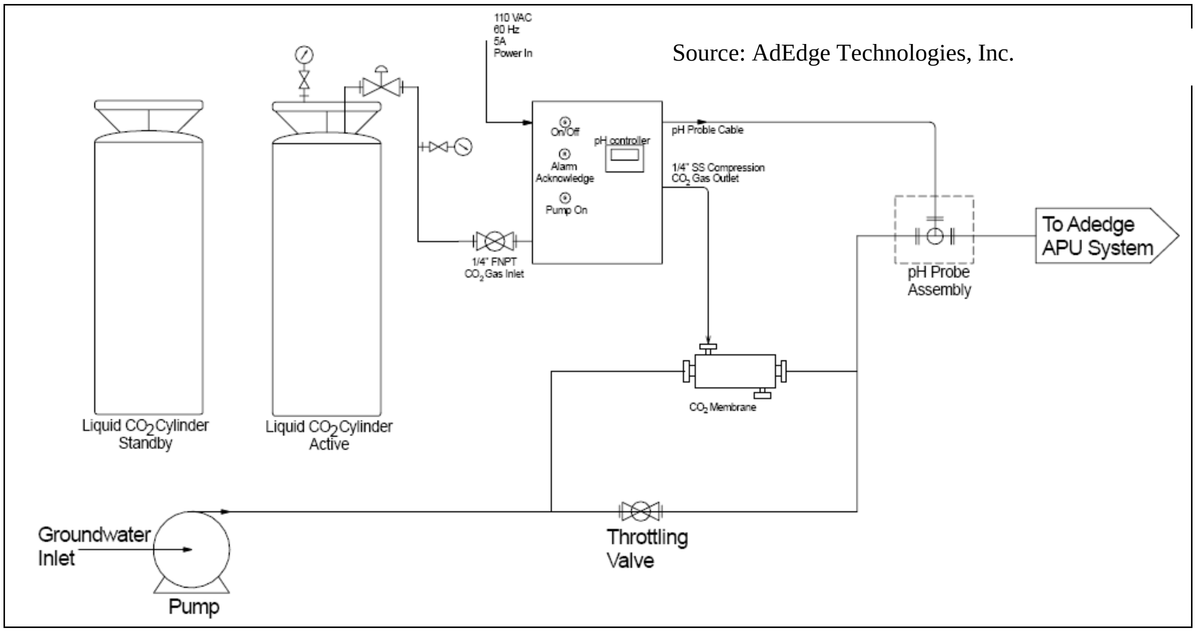


Figure 4-3. Process Flow Diagram and Sampling Locations and Schedules



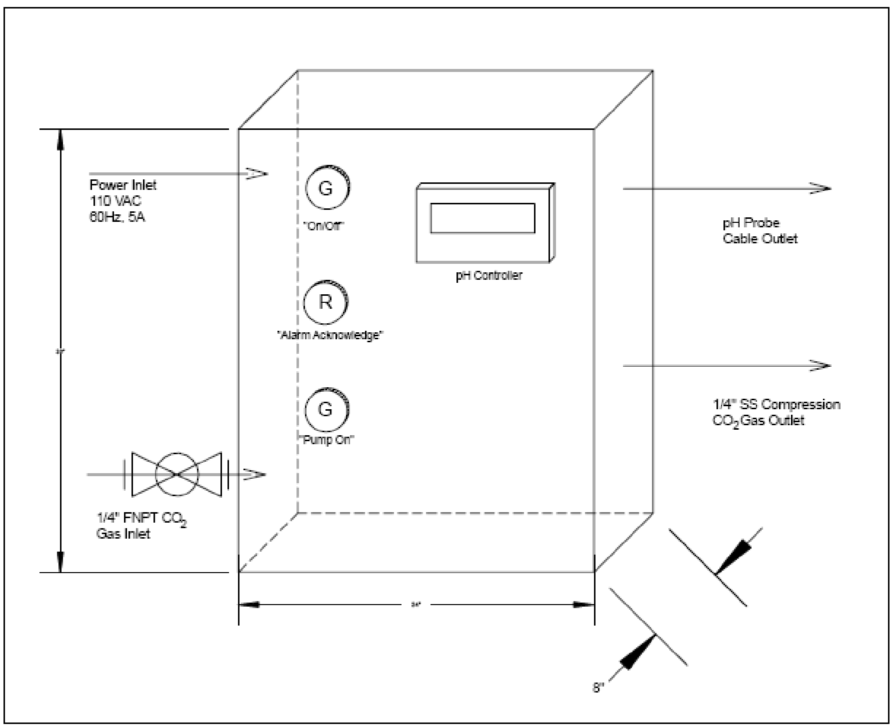


Figure 4-4. Diagram of CO_2 pH Adjustment System (top) and pH/PID Control Panel (bottom)

Figure 4-5. Carbon Dioxide Gas Flow Control System for pH Adjustment
(From Left to Right: Liquid CO_2 Supply Assembly; pH Control Panel; Sanitary Cross Containing CO_2 Membrane Module; Vault with CO_2 Injection Loop; Port for pH Probe)

Table 4-4. Properties of Celgard, Microporous Hollow Fiber Membrane

Parameter	Value
Porosity (%)	40
Pore Dimensions (µm)	0.04 × 0.10
Effective Pore Size (µm)	0.04
Minimum Burst Strength (psi)	400
Tensile Break Strength (g/filament)	≥ 300
Average Resistance to Air Flow (Gurley sec)	50
Axial Direction Shrinkage (%)	≤ 5
Fiber Internal Diameter, nominal (µm)	220
Fiber Wall Thickness, nominal (µm)	40
Fiber Outer Diameter, nominal (µm)	300
Module Dimensions (in)	4.0 ×9.0

Data Source: Celgard®

- The CO_2 pH control system supplied CO_2 at approximately 1 to 8 ft^3/hr, using about 1 to 9 lb/day (based on a gas density of 0.117 lb/ft^3 and an average operating time of 10 hr/day). The CO_2 gas supplied from two 50-lb cylinders provided CO_2 for about 4 to 30 days (average 19 days) before requiring change-out.

Prior to Phase 2 work, attempts were made to upgrade the CO_2 control system for automatic, feedback-based pH control in conjunction with the use of a more durable Sentron Ion Sensitive Field Effect Transistor (ISFET) type silicon chip sanitary pH probe as opposed to the original glass probe. Specific modifications to the CO_2 control system included retrofitting the pH control panel with a JUMO pH/Proportional Integral Derivative (PID) controller, an Alicat mass flow meter, a modulating valve, a control module, a ball valve, and stainless steel fittings to enable automatic pH control, and installing a Sentron pH probe, holder, and cable box assembly to allow for more accurate in-line pH monitoring.

As CO_2 gas flowed to the pH control panel, its flowrate was automatically controlled and adjusted by the PID controller and mass flow meter to reach a desired pH setpoint. The Sentron ISFET-type pH probe with automatic temperature compensation continuously monitored pH levels of the treated water and sent signals back to the pH/PID controller for pH control.

The retrofitted pH adjustment system was never fully functional during operation of the APU-RWS system due to fouling of two membrane modules and relocation of the underground wire for the pH probe control, which was originally installed too close to an electrical line (which, as indicated by the installer, could cause interference in pH readings). Because pH values of the inlet water to the system were lower than what were previously observed in Phase 1 (i.e., from 7.2 to 7.9 during Phase 2 versus 7.4 to 8.1 during Phase 1, Run 2), the operation continued without pH adjustment. Similar automatic pH control systems were used successfully at several arsenic demonstration sites in Taos, NM, Bruni, Texas, and Nambe Pueblo Tribe, NM. Details regarding their construction and performance are described in an EPA report (Williams et al., 2007).

- **Chlorination**. The existing chlorine injection system was used to chlorinate source water. During the first one and a half months of operation, chlorine was added to the treated water following the APU-100 adsorption system. In March 2004, total arsenic levels in the treated water measured as high as 7.7 μg/L, much earlier than projected, and the majority of arsenic was As(III). In late March 2004, the chlorine addition point was moved upstream of the adsorption vessels and after the CO_2 injection point. With this prechlorination step, As(III) was oxidized to As(V) and a target chlorine residual level of 0.1 to 0.5 mg/L (as Cl_2) was maintained in the treated water for disinfection purposes. The chlorine feed system included a 25 mL/min-rated chlorine metering pump and a 50-gal HDPE chemical feed tank to store a 4% NaOCl solution. NaOCl was injected into the raw water line following the CO_2 system for pH adjustment, and upstream of the pH probe and AP sampling location. Operation of the chlorine feed system was tied to the well pumps so that the chlorine was injected only when the wells were operating. Chlorine consumption was measured using volumetric markings on the outside of the feed tank. Prechlorination continued during operation of the APU-RWS system.

- **Arsenic Adsorption (APU-100 and APU-RWS)**. The APU-100 system consisted of two 36-in-diameter, 72-in-tall pressure vessels in parallel configuration, each initially containing 27 ft^3 of AD-33™ media supported by a gravel underbed. The delivery system components included inlet piping, two electrically actuated diaphragm valves (to control flow), two strainers, two programmable Fleck controller valves (to switch flow from a service to a backwash mode), two tanks (each with a top diffuser and a bottom lateral), two restrictive orifices, and outlet piping. The vessels were fiberglass-reinforced plastic (FRP) construction, rated for 150 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 was approximately 4.0 min based on a media volume of 27 ft^3 per vessel under Run 1 or 3.3 min on 22 ft^3 of media per vessel under Run 2. Hydraulic loading to each vessel based on a design flowrate of 100 gpm (50 gpm to each vessel) was about 7 gpm/ft^2. Figure 4-6 shows the installed APU-100 system.

  The APU-RWS system consisted of two 48-in-diameter, 72-in-tall pressure vessels in parallel configuration, each initially containing 30 ft^3 of AD-33™ media supported by a gravel underbed. The vessels also were FRP construction, rated for 150 psi working pressure, and piped to a valve rack mounted on a polyurethane-coated, steel frame. The APU-RWS system plumbing design eliminated the diaphragm valves, Fleck controller valves, and restrictive orifices, and replaced them with a nested system of fully ported actuated butterfly valves and a new control panel. The APU-RWS valve-tree design was based on a series of systematic hydraulic tests on similar, but larger-capacity systems at STS's Torrance, CA, fabrication shop and at the Brown City, MI, arsenic removal demonstration site in March and April 2004. The test results indicated that the fleck controller valves and restrictive orifices were the main sources of excessive pressure loss experienced at Desert Sands, NM, Brown City, MI, and Queen Anne's County, MD, arsenic removal demonstration sites. A summary of the hydraulic test results are provided in the Six Month Reports for the Desert Sands, Brown City, and Queen Anne's County sites (Coonfare et al., 2005; Condit et al., 2006; Oxenham et al., 2006).

  EBCT for the APU-RWS system was approximately 3.7 min based on a media volume of 30 ft^3 per vessel (compared to 4 min EBCT for the APU-100 system). The hydraulic loading to each vessel based on a design flowrate of 120 gpm (60 gpm to each vessel) was about 4.8 gpm/ft^2 (compared to 7 gpm/ft^2 for the APU-100 system). Figures 4-7 shows the installed APU-RWS system.

- **Backwash**. Based upon reaching a pressure differential of 10 psi across each vessel, the adsorption vessels were taken offline manually, one at a time, for backwashing using raw water from the source well supplemented with treated water from the distribution system. The purpose of the backwash was to remove particulates and media fines accumulating in the beds. Backwash wastewater produced was discharged to an on-site subsurface infiltration area for disposal.

Figure 4-6. APU-100 Treatment System Front and Side View (top) with a Close-up View of Fleck Controller Valve (bottom)

Figure 4-7. APU-RWS Treatment System (top left) with Valve Tree (bottom) and Backside of System Piping Including Backwash Sight Glass (top right)

4.3 System Installation

The installation of the APU-100 and APU-RWS systems was completed in January 2004 and May 2005, respectively. The system installation was completed by Waterline Services, a construction subcontractor to AdEdge. The building construction activities were carried out primarily by the local plant operator.

4.3.1 Permitting. Two permits were applied for and received from the NHDES. In late September 2003, a system permit application consisting of design drawings for the proposed APU-100 treatment system, new treatment building, and subsurface disposal area was submitted to the NHDES by Hoyle, Tanner, & Associates (HTA), the District's engineering consultant. An application for nondomestic wastewater discharge to groundwater also was submitted for backwash disposal into the subsurface infiltration area. NHDES granted the discharge permit on December 30, 2003, and the treatment system permit on January 12, 2004.

Prior to installing the APU-RWS system, AdEdge submitted a site layout and a letter of explanation of intensions to NHDES in order to obtain regulatory approval.

4.3.2 Building Construction. Building construction began on November 3, 2003, and was completed on December 22, 2003. The 33-ft × 13-ft building had a concrete foundation and floor and a wood frame with vinyl siding. It included two 10-ft roll-up doors on the front allowing access to the treatment equipment, and one walk-through door on the end of the building (Figure 4-8). Additionally, the Water and Sewer District installed a subsurface drainage structure in the parking area in front of the building to handle the disposal of backwash water generated by the treatment system.

Figure 4-8. Porter Well House Area after Building Construction and Treatment System Installation *(Large Treatment Building Addition in Background, Fenced Parking Area, and EPA Demonstration Project Sign to left of Gated Entrance)*

4.3.3 APU-100 Installation, Shakedown, and Startup. The APU-100 system was shipped on December 23, 2003, and arrived at the site on January 8, 2004. Waterline Services began system installation that same day. AdEdge and Waterline completed system installation on January 16, 2004, and system shakedown and startup on January 29 and 30, 2004. During the first day, the media in both vessels was backwashed and the flows to each vessel adjusted so that they were balanced. Meanwhile, Battelle provided operator training on data and sample collection and conducted an inspection of the system.

On January 30, 2004, the system was put into service mode for the first time. While operating, leaks were detected in the CO_2 injection system caused by cracks in plastic seals in the piping joints. Because of these leaks and required repairs, the system was not put into regular service until February 9, 2004.

4.3.4 APU-RWS Installation, Shakedown, and Startup. After the Phase 1 study, two options were considered to address the need for a larger capacity treatment system: 1) add a third vessel of similar design to the two existing vessels in the APU-100 treatment train and 2) remove the APU-100 and replace it with the higher-capacity APU-RWS system. A cost proposal was received from AdEdge on February 4, 2005, for these two options. For the second option, the new system would include larger vessels with top and bottom openings and a valve tree arrangement. Based on the costs of each option and consideration of the past operational difficulties with the existing system, the second option was selected.

Prior to installation, hydraulic testing was conducted on the APU-RWS system at the manufacturer's facility. Total pressure drop across the system was measured at 3 psi with a differential pressure across each vessel of 0.5 psi at a flow rate of 80 gpm through each vessel. The APU-RWS system was installed in May 2005 and operation commenced on June 13, 2005.

4.4 System Operation

Table 4-5 presents timelines of key activities/events that occurred during the system performance evaluation. These demonstration activities are described in more detail in the following sections.

Table 4-5. Demonstration Study Activities and Completion Dates

Activity/Event	Date
APU-100 Run 1 System Performance Evaluation Began (Start of Phase 1)	February 9, 2004
APU-100 System Retrofit Completed for Higher Flowrate during Backwash	August 4, 2004
APU-100 Run 1 Arsenic Breakthrough at 10 µg/L	August 17, 2004
Media Changeout	October 27–28, 2004
APU-100 Run 2 System Performance Evaluation Began	November 3, 2004
Pre-chlorination Temporarily Changed to Post-chlorination[(a)]	December 2, 2004
APU-100 System Shutdown (End of Phase 1)	January 16, 2005
APU-RWS System Proposed	February 4, 2005
APU RWS System Hydraulic Testing Completed Prior to Shipment	April 27, 2005
APU-100 System Removed	Week of May 16, 2005
APU-RWS System Installed	Week of May 23, 2005
APU-RWS System On-site Hydraulic Testing Completed	May 31, 2005
APU-RWS System Shakedown and Startup Completed [(b)] (Start of Phase 2)	June 13, 2005
CO_2 Injection System Permanently Taken Off-line[(c)]	July 25, 2005
APU-RWS Arsenic Breakthrough at 10 µg/L	November 30, 2005 December 14, 2005
Decision on Converting System to Coagulation/Filtration Made (End of Phase 2)	March 2006
APU-RWS System Converted to coagulation/Filtration	May 8, 2006
APU-RWS Property Transfer Completed	October 24, 2006

(a) Due to elevated pressure on inlet side of system.
(b) Shakedown and startup delayed due to previously scheduled well maintenance.
(c) pH adjustment system not functional during entire length of APU-RWS operation.

4.4.1 Operational Parameters. The operational parameters for the entire duration of system operation are tabulated and attached as Appendix A. Key parameters are summarized in Table 4-6. The APU-100 system as originally designed was evaluated under Phase 1 with Run 1 operating from February 9, 2004, through October 27, 2004, and Run 2 from November 3, 2004, through January 16, 2005. The replacement system, APU-RWS, was evaluated under Phase 2 from June 13, 2005, through May 8, 2006. Relevant system operational parameters are discussed in detail as follows:

Phase 1 Run 1. The APU-100 system with 27 ft^3 of media loaded in each vessel began its operation on February 9, 2004. In 2004, the system was shut down from March 13 through March 25 for CO_2 system repairs, from May 31 to June 1, June 5 to June 6, June 16 to June 18, and June 24 to July 8 for replacement of inlet diaphragm valves with true union ball valves, and on October 27 for media rebedding. The system operated 222 days for a total of 2,577 hr with an average daily operating time of 11.6 hr. The total run time was tracked by hour meter readings collected daily. The well pumps were controlled by separate timers that normally came on in the evenings at about 10:00 p.m. and went off in the mornings at about 8:00 a.m.

The system treated approximately 11,926,000 gal of water, with 47 and 53% flowing through Vessels A and B, respectively, based on totalizer readings from each vessel. This amount was 14% lower than that (i.e., 13,835,000 gal) recorded from the master flow meter at the Porter well house. These discrepancies were discussed with the vendor, but never properly addressed during the demonstration study. The 11,926,000 gal of water treated corresponded to 32,500 BV, based on 49 ft^3, instead of 54 ft^3, of media in both vessels. Per the vendor, close to 3 ft^3 of media in Vessel A, and possibly 2 ft^3 from Vessel B might have been washed away during the initial system backwash and follow-on media conditioning prior to system startup in February 2004. The original system design provided less than 15 in of freeboard in each vessel, which could accommodate no more than 30% bed expansion during media backwash. More detailed discussions about backwash and media loss can be found in Section 4.4.4.

As shown in Figure 4-9, the combined flowrates to the system, denoted by "×," as measured by individual flow meters installed on Vessels A and B (with respective flowrates denoted by "■" and "▲") varied widely from 47 to 112 gpm due mainly to operation of only one supply well during 28% of the system run time. (As discussed in Section 4.4.2, at times one supply well was operated to reduce the flowrate, thus reducing the inlet pressure and Δp levels in the system.) With both wells running, flowrates ranged from 72 to 112 and averaged 95 gpm. With either Well No. 3 or 4 running, flowrates ranged from 47 to 75 and averaged 60 gpm. Therefore, the EBCTs in each vessel ranged from 3.0 to 7.0 min with both wells running and from 4.3 to 9.5 min with only one well running (assuming that the amount of media in each vessel remained unchanged at 24.5 ft^3). As also shown in Figure 4-9, calculated flowrates based on the daily mass flow meter and pump hour meter readings, denoted as "♦," ranged from 83 to 115 gpm (and averaged 102 gpm) with both wells running and from 33 to 86 gpm (and averaged 59 gpm) with only one well running. These flowrates were somewhat higher than those recorded from the individual flow meters and the discrepancies again were never reconciled during the demonstration studies.

Phase 1 Run 2. After media changeout, Run 2 began on November 3, 2004, with a less amount of media in each vessel (i.e., 22 ft^3). The run was discontinued 73 days later on January 16, 2005. The system operated for 765 hr with an average daily operating time of 10.5 hr. The system was taken offline only one day, treating approximately 3,921,000 gal of water with flow equally split between Vessels A and B. The master flow meter again registered more flow (i.e., 13%) than the individual flow meters/totalizers on the vessels combined. The amount of water treated based on the combined total of the individual flow meters corresponded to 11,920 BV, which was based on 44 ft^3 of media in both vessels. During this run, both wells were on whenever the system was operating, resulting in a relatively tight flowrate range (i.e., from 97 to 118 gpm) based on the individual flow meters installed on Vessels A and B. Assuming that the media volume in each vessel remained unchanged at 22 ft^3, EBCTs would range from 2.5 to 3.9 min.

Table 4-6. Key Operational Parameters

Operational Parameter	Values/Conditions								
	APU-100 Run 1			APU-100 Run 2			APU-RWS		
Duration	02/09/04–10/27/04 (Weeks 1–38)			11/03/04 – 01/16/05 (Weeks 39–49)			06/13/05–05/08/06 (Weeks 1–47)		
Cumulative Operating Time (hr)	2,577			765			2,561		
Days of System Operations (day)	222[a]			73			263[b]		
Average Daily Operating Time (hr)[c]	11.6			10.5			9.7		
pH Adjustment [f]	Pre/Post	Range	Average	Pre/Post	Range	Average	Pre/Post	Range	Average
	Pre	7.0–8.3	7.8	Pre	7.4- 8.1	7.7	Pre	7.2–7.9	7.7
	Post	6.8–7.9	7.4	Post	7.2–8.1	7.6	Post	No pH Adjustment	
Throughput (kgal) [g]	Vessel A	Vessel B	Total	Vessel A	Vessel B	Total	Vessel A	Vessel B	Total
	5,580	6,346	11,926	1,952	1,969	3,921	6,360	6,521	12,881
Flowrate (gpm)[g]	Well(s)	Range	Average	Well(s)	Range	Average	Well(s)	Range	Average
	Two	72–112	95	Two	97–118	112	Two	80-106	97
	One	47–75	60	One	NA	NA	One	48–105	58
EBCT (min)[h]	Well(s)	Range	Average	Well(s)	Range	Average	Well(s)	Range	Average
	Two	3.0 – 7.0	3.9	Two	2.5–3.9	3.2	Two	4.0 – 5.6	4.7
	One	4.3 – 9.5	6.2	One	NA	NA	One	4.0–10.0	8.2
Pressure Loss across System (psi)	6–36+[d]			10–31			0–13		
Time Elapsed between Consecutive Backwash Events (day) [e]	1–22 (8)			1–28 (4)			7–109 (36)		

(a) Sixty-four out of 222 days with system operating with only one supply well.
(b) Sixty out of 263 days with system operating with only one supply well.
(c) Average daily operating times include only those days when treatment system was in operation.
(d) "+" denoting readings that passed highest values on gauges.
(e) Number in parentheses corresponding to average number of operating days between backwashes.
(f) Field probe readings
(g) Combined total of individual flow meters/totalizer readings.
(h) Calculated based on 49 and 60 ft^3 of media in APU-100 and APU-RWS systems, respectively.
NA = not applicable

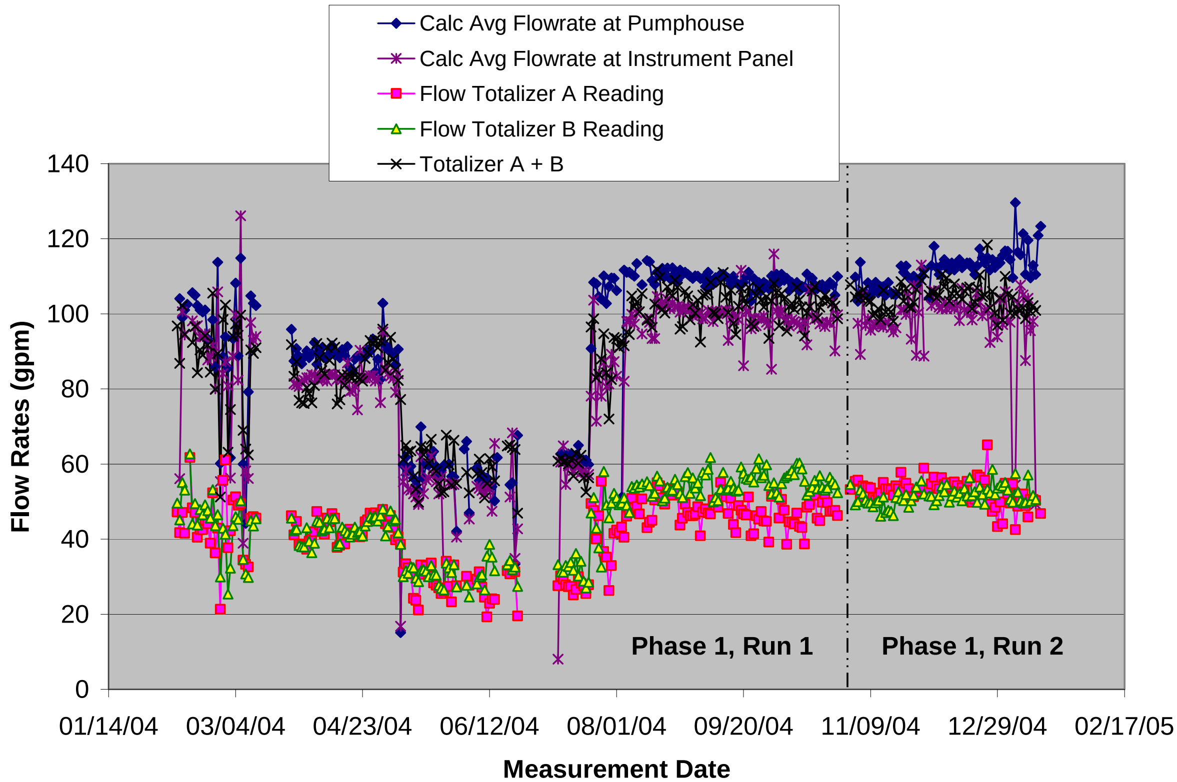


Figure 4-9. Flowrate Measurement Data for Phase 1, APU 100, Runs 1 and 2

Phase 2. The re-designed APU-RWS system became operational on June 13, 2005. The system operated 263 days for a total of 2,561 hr with an average daily operating time of 9.7 hr. The system was taken offline from August 5 through September 26, 2005, due to a ruptured pipe connection; from October 7 through 10 and, again, from October 17 through 20, 2005, while the operator attempted to find the source of entrained air in the distribution system (the APU-RWS system was not the cause); and from February 18 through 19, 2006, due to a power outage. On May 8, 2006, the demonstration project ended and the District began to add iron at the head of the treatment as part of its ongoing effort to improve arsenic removal.

Based on the individual flow meter on each vessel, the system treated approximately 12,881,000 gal of water with about even split (i.e., 49.4 and 50.6%) between the two vessels. This throughput value was 23% lower than the cumulative volume registered by the master flow meter, indicating even worse correlation between the master flow meter and the flow meters installed on the APU-RWS system. Assuming negligible media loss during the run, 12,881,000 gal corresponded to 28,700 BV, calculated based on 60 ft^3 of media in both vessels.

Similar to Run 1 under Phase 1, combined flowrates (denoted by "×" in Figure 4-10) to the system varied significantly from 48 to 106 gpm due, again, to operation of only one supply well during 23% of the system run time. Operation of only one well was done at the request of the NHDES as an attempt to improve system performance for arsenic removal. With both wells running, flowrates ranged from 80 to 106 and averaged 97 gpm. With either Well No. 3 or 4 running, flowrates ranged from 48 to 105 and averaged 58 gpm. With 30 ft^3 of media in each vessel, EBCTs ranged from 4.0 to 5.6 min with both wells running and from 4.0 to 10.0 min with only one well running.

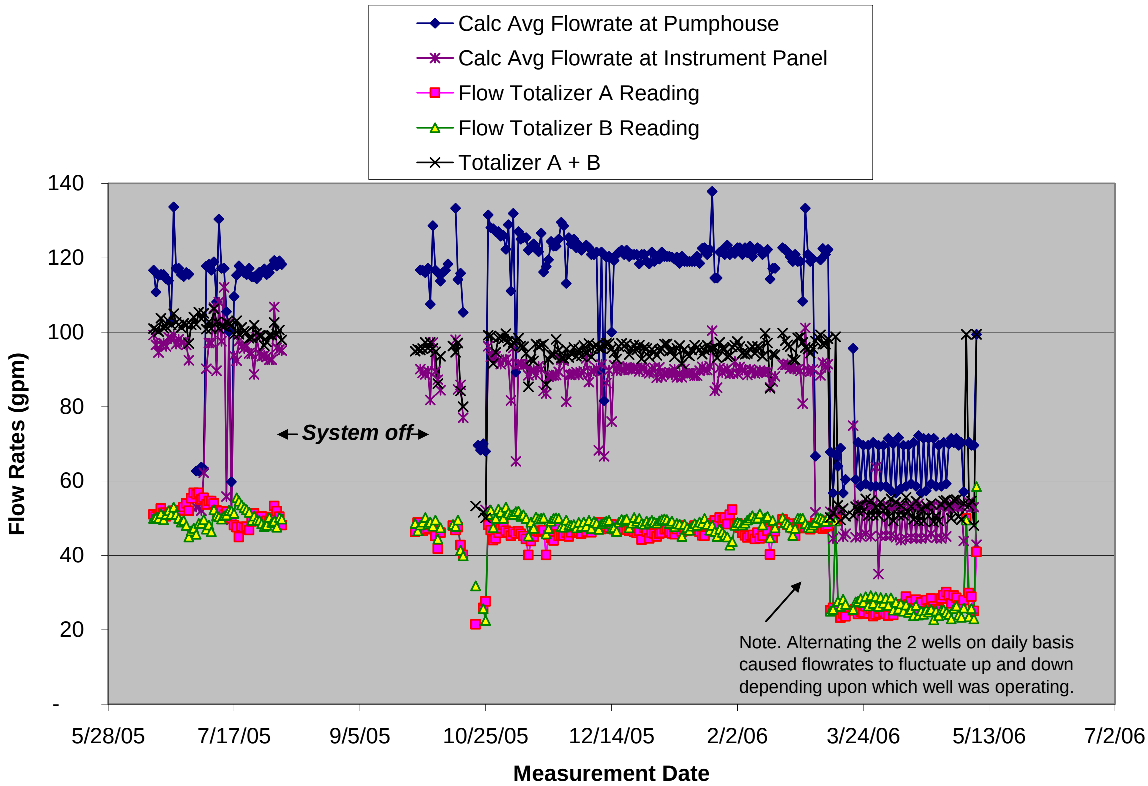


Figure 4-10. Flowrate Measurements for Phase 2, APU-RWS System

4.4.2 Differential Pressure. The APU-100 system experienced elevated inlet pressure and higher than expected differential pressure across each adsorption vessel. There were periods when the system was bypassed due to elevated pressure conditions at the system inlet. Extensive troubleshooting was performed and removal and/or replacement of several system components did not appear to be useful for solving the problems. Ultimately, the APU-100 system was replaced with the completely re-designed APU-RWS system. The following summarizes the differential pressure issues experienced:

Phase 1 Run 1. Figures 4-11 and 4-12 present histograms of Δp readings measured across Vessels A and B, respectively, and total well flowrates calculated based on master flow meter and well hour meter readings recorded at the wellheads. Based on the vendor, Δp across each vessel should be no more than 2 to 3 psi when operating the system at the design flowrate of 100 gpm and backwash should be performed when the Δp across each vessel had reached 10 psi. However, as shown in Figures 4-11 and 4-12, Δp consistently exceeded 10 psi for the majority of time the system operated.

During the first month of operation, the system was backwashed five times when Δp readings across each vessel reached approximately 15 psi, the upper limit of the pressure gauges originally installed on the system. Δp readings returned to 10 to 11.5 psi following each backwash. In order to extend the time between backwashes, the operator sometimes had to operate only one supply well to reduce the flowrate to the system, thereby reducing the inlet pressure and Δp levels in the system.

The vendor speculated at the time that elevated Δp levels were caused by media fines present at the laterals that had not been removed during initial backwash. A series of aggressive backwashes were,

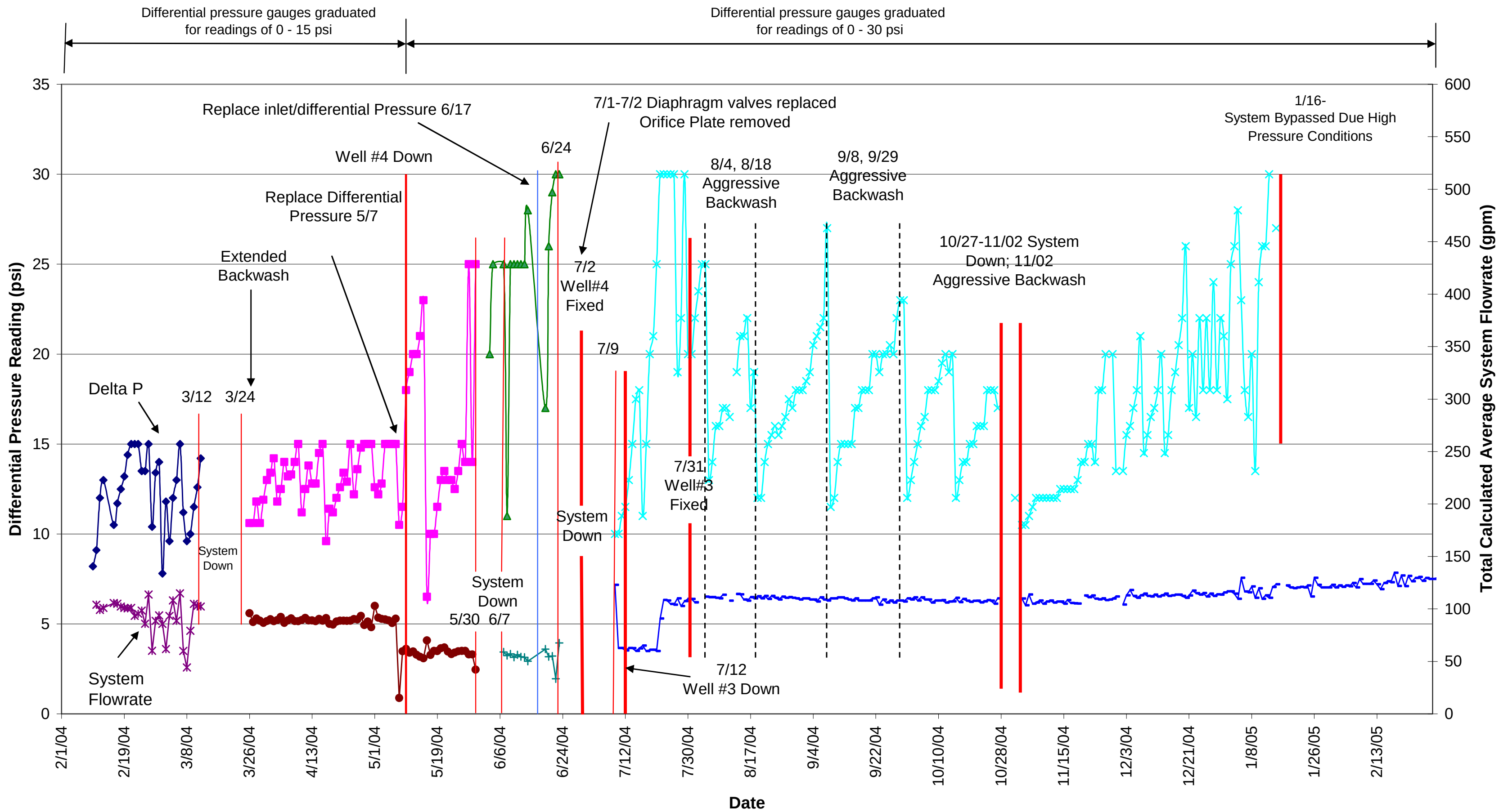


Figure 4-11. System Flowrate and Differential Pressure (Δp) across Vessel A of APU-100 System

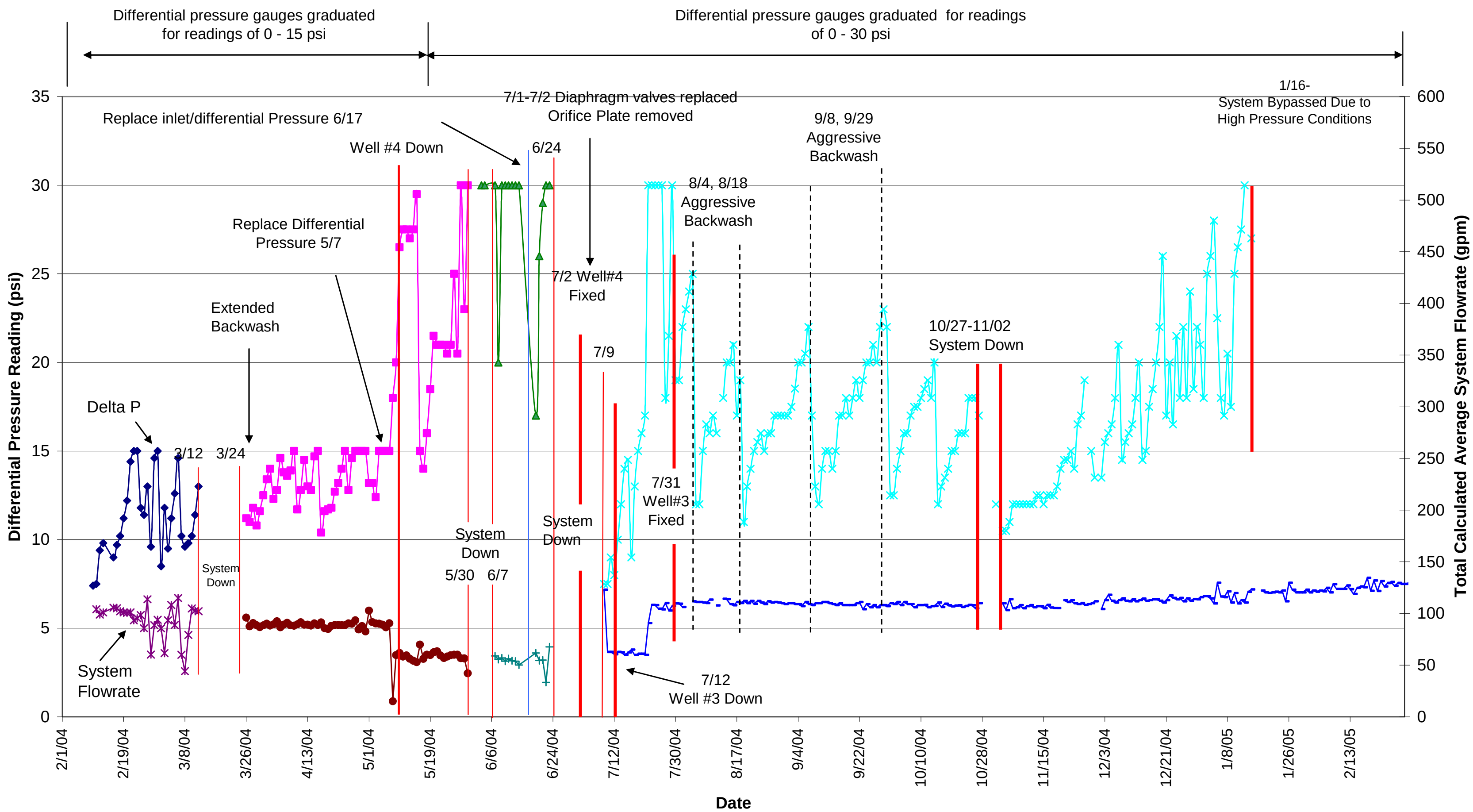


Figure 4-12. System Flowrate and Differential Pressure (Δp) across Vessel B of APU-100 System

therefore, performed at increased hydraulic loading rates of 8 to 9 gpm/ft^2. These backwashes, however, did not appear to be effective at reducing Δp across the vessels, restoring Δp to only 9 to 9.5 psi immediately following backwash. Furthermore, the Δp readings rose to approximately 14 psi within one week of operation. Six weeks following the aggressive backwashes, the system was backwashed once per week with Δp being reduced from 15 psi to about 10 to 12 psi after each backwash.

On May 7, 2004, the two differential pressure gauges installed on the vessels were replaced with those that read up to 30 psi. Meanwhile, Well No. 4 was shut down on May 9, 2004, and remained inoperable through July 2, 2004. With only Well No. 3 operating at flowrates typically <60 gpm, the system continued to experience elevated pressure conditions. On May 30, 2004, the system was shut down due to excessive pressure of over 100 psi at the inlet. During the next two weeks, backwash was performed five times, but failed to lower inlet pressure and Δp levels as shown in Figures 4-11 and 4-12.

On June 17, 2004, the vendor returned to the site to replace the inlet pressure and Δp gauges with new ones to ensure that the high readings observed were not the result of faulty gauges. The vendor also inspected two variable diaphragm valves installed upstream of each vessel for flow control. The diaphragm valves were determined to be in good working condition and re-installed back to the system. The system was put back into service and the inlet pressure was observed to be lower at 80 psi. Within five days, the inlet pressure levels again increased to over 90 psi and the Δp levels to above what the gauges were able to read at 30+ psi.

Due to the continuing high pressure conditions, the system was taken offline between June 24 and July 9, 2004, and the two diaphragm valves were replaced with simple non-actuated valves on July 1 and 2, 2004. In addition, the two orifice plates that controlled and balanced the flows to the two vessels were removed from the discharge side of the vessels to help reduce flow restriction. The system was put back online on July 9, 2004, and operated at lower pressure for a few days before the system pressure began to steadily rise to the same level of approximately 100 psi at the inlet and 30+ psi Δp across each vessel by July 22, 2004. During July 10 through 22, 2004, Well No. 3 was down, causing the system to operate at a reduced flowrate of approximately 60 gpm. After Well No. 3 was back in service on July 22, 2004, the inlet pressure and Δp for both vessels rose to 100+ and 30+ psi, respectively, exceeding the measurable levels on all three gauges.

The system was operating under these conditions for the next eight days before being bypassed again on August 2, 2004. On August 4, 2004, the vendor returned to the site to replace the 1-in diameter backwash flowmeter with a 2-in one in order to allow for an even higher loading rate (i.e., 10 to 11 gpm/ft^2) for backwash. Following the backwash, the inlet pressure fell to 76 psi and Δp to 12 to 13 psi across each vessel. Over the next 12 weeks, the system was backwashed five times using the elevated loading rate of approximately 11 gpm/ft^2. Each time, Δp was reduced from 20–23 psi to 12–13 psi, with the inlet pressure staying at about 90 to 100 psi. Meanwhile, the inlet pressure gauge was replaced again on September 1, 2004. Comparison of pressure readings indicated that the replaced gauge functioned normally; therefore, high pressure conditions were not the results of erroneously high readings from faulty gauges.

Phase 1 Run 2. After the media replacement (with only 22 ft^3 of media in each vessel) in late October 2004, the system operated very similarly to what was observed during Run 1. During the first month of system operation, Δp increased relatively slowly from the baseline level of 10.5 psi to about 19 to 20 psi across the vessels and the inlet pressure increased slightly from about 80 to 85 psi. Since then, Δp and inlet pressure continued to increase significantly (see Figures 4-11 and 4-12) even after repeated backwashes on November 30, 2004, December 7, 13, 20, 24, 26, 28, 30, and 31, 2004, and January 2, 3, and 4, 2005. On December 2, 2004, the chlorine injection point had to be relocated from the inlet side to the exit side of the system because the hose connected to the prechlorination injection point kept popping off due to elevated pressure on the inlet side of the system.

In early January 2005, the operator and the vendor's subcontractor, Waterline Services, conducted a series of system inspections to attempt to troubleshoot the elevated pressure conditions. Without any success, the system was bypassed on January 16, 2005.

Phase 2. Figures 4-13 and 4-14 present Δp readings measured across Vessels A and B, respectively, during operation of the re-designed system. As shown in the figures, the Δp readings ranged from 0 to 13 psi, significantly less than those measured during Phase 1. In addition, the system was first backwashed after 3½ weeks of operation on July 8, 2005, as the pressure drop across each vessel had exceeded 12 psi (that was 2+ psi over the target backwash trigger). Afterwards, the system operated for another 3½ weeks before reaching the 10-psi backwash trigger on August 1, 2005. The system was shut down for approximately seven weeks beginning August 5, 2005 due to a ruptured pipe connection on the inlet side of Vessel A (apparently caused by a factory defect in the union). In response to some media loss, approximately 1 ft^3 of media was added to each of the vessels, the system piping was reconnected, and a backflow preventor was installed. After being restarted on September 26, 2005, the system operated for 3.5 months without any backwash because the Δp across the vessels rose at an uncharacteristically slow rate to only <6 psi. During this period, the conditions of all pressure gauges were examined repeatedly by the operator and all readings were believed to be accurate. It is not known why the Δp behavior across the vessels changed so drastically.

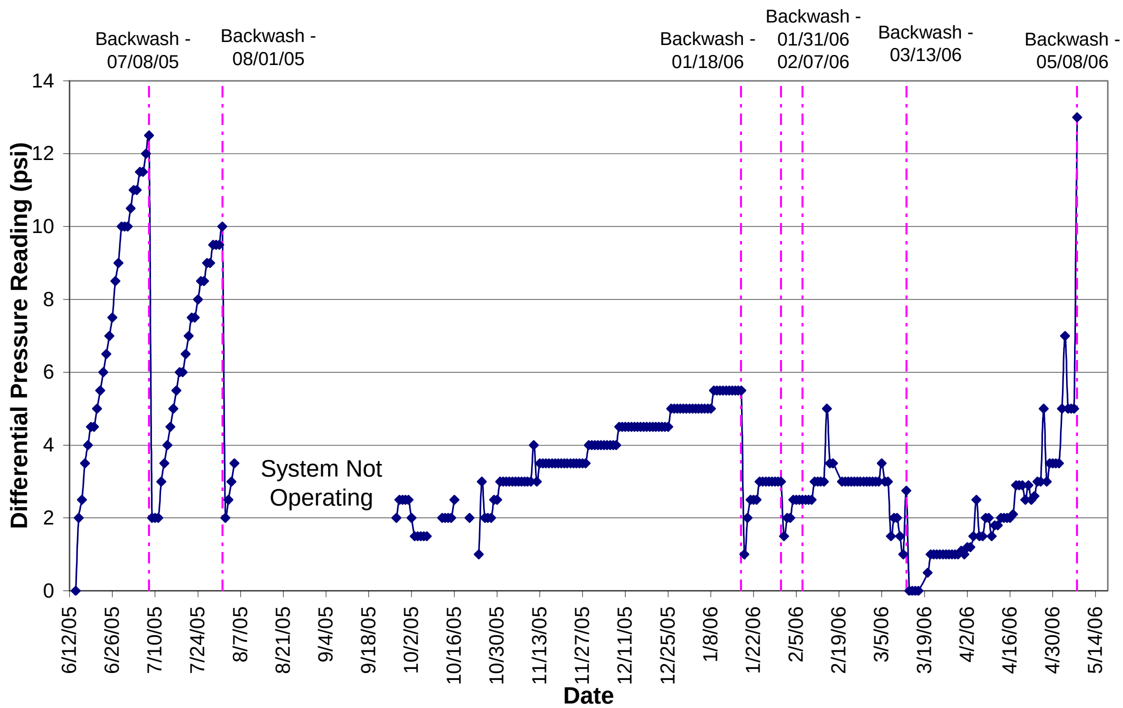
The system was backwashed on January 18, 2006, and the differential pressure across each vessel dropped from <6 to about 1 psi after backwash. The system was backwashed again on January 31, 2006, at a flowrate of 116 gpm for 22 min for each vessel. The operator reported that the backwash wastewater was clear by the end of backwash, indicating thorough removal of accumulated particulates and media fines. The system did not reach the target backwash trigger until the end of the study on May 8, 2005.

4.4.3 CO_2 Injection. The manual CO_2 gas flow control system used for pH adjustment experienced operational irregularities throughout Phase 1 of the demonstration study. Attempts were made to improve the system in preparation for the Phase 2 study; however, as discussed previously and below, the system experienced additional operational problems. Therefore, pH adjustment was not performed during operation of the APU-RWS system.

Phase 1. The CO_2 gas flow control system experienced several operational problems soon after system startup. Leaks were detected in the CO_2 system, resulting in frequent change-outs of the CO_2 gas cylinders during the first few weeks of system operation. A faulty gas regulator and a damaged O-ring at the CO_2 injection point also were identified, causing the system to function improperly. Following troubleshooting and repairs, the system appeared to function more consistently with the cylinder change-out frequency being extended to once every 2 to 3 weeks.

Contributed, in part, by the mechanical problems, the CO_2 system failed to consistently adjust pH to the target value of 7.0. pH values of the CO_2-treated water as measured by the inline pH probe varied widely between 4.7 and 9.1, although the average pH value was 6.9, just slightly below the target value of 7.0.

Significant differences were noted between pH readings measured by the inline pH probe and a laboratory pH probe (with samples taken from the AP [after pH adjustment] sampling location). As noted above and shown in Table 4-7, the readings by the inline probe varied from 4.7 to 9.1, while the readings by the laboratory pH probe varied only from 6.8 to 7.9. Therefore, the differences between the two set of readings ranged from -1.9 to 2.8 pH units. Some of the variation in the inline readings might have been caused by manual adjustments to the CO_2 gas flowrate, although a similar swing should have been



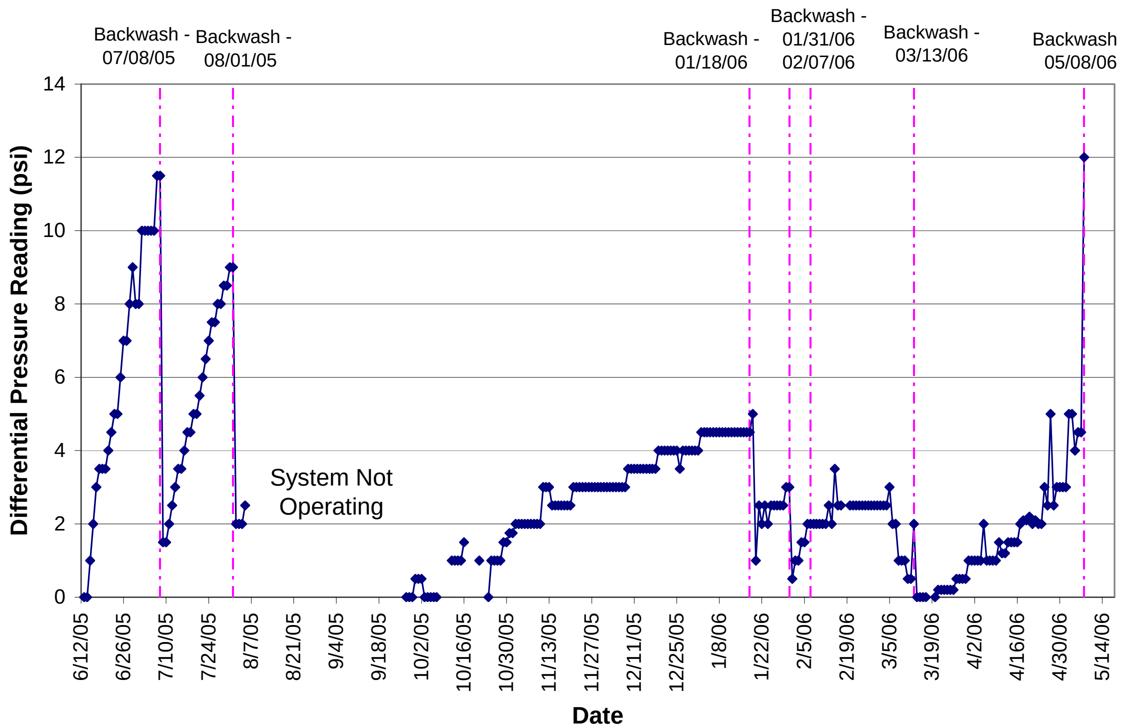


Figure 4-13. Differential Pressure (Δp) across Vessels A (top) and B (bottom) of APU-RWS System

observed in the AP readings. Another possible explanation for the variation was degassing of dissolved CO_2 from water during sampling and analysis because the laboratory measurements generally resulted in higher pH readings than the inline measurements. Further, buildup of a white film on the probe, first observed near the end of April 2004, also might have affected the inline probe performance, as elevated pH readings (see Table 4-7 for inline probe readings for April 19 and 29, 2004) were recorded during this period. Following cleaning, the inline readings returned to below 6.8 on May 7, 2004. Since then, the probe was removed every one to two weeks for cleaning. During the October 27 to 28, 2004, media changeout, it was noted by the vendor that the inline pH probe did not appear to be operating correctly. The inline pH probe was replaced then with a spare pH probe, which was kept on site.

Table 4-7. Summary of pH Readings after pH Adjustment

Date	pH Reading of Sample Taken at AP Sampling Location Using a Laboratory pH Probe	pH Reading by Inline pH Probe	Difference
01/30/04	7.3	–	–
02/16/04	6.8	7.3	-0.5
02/24/04	7.4	6.8	0.6
03/02/04	7.5	6.5	1.0
03/10/04	7.5	7.1	0.4
04/06/04	7.5	6.5	1.0
04/13/04	7.3	7.0	0.3
04/19/04	7.2	9.1	-1.9
04/29/04	7.1	8.1	-1.0
05/07/04	7.6	6.8	0.8
05/18/04	7.5	6.5	1.0
05/25/04	7.5	4.7	2.8
06/09/04	7.0	7.1	-0.1
07/13/04	NM	7.4	–
07/20/04	7.2	7.7	-0.5
08/04/04	7.6	6.2	1.4
08/10/04	7.4	7.4	0.0
08/17/04	7.8	6.6	1.2
08/24/04	7.0	7.1	-0.1
09/09/04	7.7	7.0	0.7
09/14/04	7.5	7.0	0.5
09/22/04	7.1	6.6	0.5
09/28/04	7.2	7.2	0.0
10/06/04	7.2	7.4	-0.2
10/12/04	7.8	6.6	1.2
10/21/04	7.9	6.6	1.3
11/04/04	7.7	7.0	0.7
11/10/04	8.1	7.1	1.0
12/08/04	7.8	7.1	0.7
12/13/04	7.2	7.0	0.2
01/05/05	7.4	7.0	0.4
Average	7.43	6.98	

Based on the operational issues experienced during Phase 1, it was decided to upgrade the CO_2 pH control system for Phase 2. Proposed upgrades included utilizing an active PID-based control instead of a manual control and a more durable ISFET-type pH probe as opposed to the conventional glass probe to reduce the need to clean and handle the glass probe.

Phase 2. After APU-RWS system installation in June 2005, the CO_2 system vendor, ATSI, was on site to upgrade the system for automatic operation during the week of July 25, 2005. The vendor discovered several problems with the original system, including 1) improper installation of an underground wire connecting the control panel and inline pH probe (i.e., the wire was too close to another electrical line, which could cause interference to the pH readings), 2) extensive biological growth in the CO_2 membrane module, and 3) damaged O-rings at the injection point on the CO_2 loop. The vendor indicated that some site re-work and additional parts would be required before the new CO_2 system installation could be completed and the pH adjustment put back online.

ATSI returned to the site on September 21, 2005 to complete CO_2 system modifications and parts replacement. Prior to its arrival, the underground line was relocated by a local subcontractor. ASTI replaced the CO_2 injection membrane, upgraded the control panel, installed a new pH probe, and left the CO_2 system online with the adsorption system. Upon checking the system, however, it was discovered that the CO_2 system was not operating correctly and the pH adjustment was discontinued. After being contacted, AdEdge made arrangements with ATSI to return to the site on October 4 through 5, 2005. While on site, ATSI and the facility operator observed the accumulation of a black silty material on the membrane module, indicating fouling. No further action was taken to resolve the operational problems because the cause of the membrane fouling had to be eliminated prior to installing another CO_2 membrane. With the raw water pH values ranging between 7.5 to 7.9 since startup of the new system, the need for pH adjustment diminished and pH adjustment was discontinued for the remainder of the Phase 2 study.

4.4.4 Backwash. AdEdge recommended that the APU system be backwashed, either manually or automatically, approximately once per month. Automatic backwash could be initiated by either a timer or a Δp setpoint. However, due to the ongoing problems with elevated Δp and inlet pressure (see Section 4.4.2), the APU-100 system was backwashed far more frequently than was originally anticipated. The need for frequent, aggressive backwashing was eliminated with the installation of the APU-RWS system. A brief description of the backwash events follows:

Phase 1. For Run 1, backwash events occurred 28 times during 33 weeks of system operation (not including the system downtime from March 13 to 25, 2004, and from June 24 to July 8, 2004), with the interval between two consecutive backwash events varying between 1 and 22 days (see Table 4-6). As discussed in Section 4.4.2, in an attempt to address the elevated pressure issues, the backwash flowrate was increased from 30 to 35 gpm (or approximately 4 to 5 gpm/ft^2) to 55 to 65 gpm (or 8 to 9 gpm/ft^2) in late March 2004, and then to 75 to 77 gpm (or 10 to 11 gpm/ft^2) following system retrofit with a larger diameter backwash flowmeter. Depending on the flowrate, a single 20-min backwash cycle for one vessel produced between 600 and 1,500 gal of water.

Following the media replacement in the APU-100 system in October 2004, the first backwash occurred after approximately 3½ weeks of system operation. However, after November 30, 2004, the system experienced elevated inlet pressure of near 100 psi or greater and elevated Δp (between 23 to 30 psi) requiring backwash on December 7, 13, and 20, 2004, and every other day during the period from December 22 through 30, 2004. Backwash frequency even increased to once a day in early January 2005. Δp readings did not return to the expected levels of 10 to 12 psi following the respective backwash cycles.

Phase 2. As discussed in Section 4.2, the APU-RWS system plumbing design eliminated the use of diaphragm valves, Fleck controller valves, and restrictive orifices; they were replaced with a nested system of fully ported actuated butterfly valves and a new control panel. The problems associated with the pressure losses were resolved with system retrofitting, resulting in far less frequent backwashing (i.e., seven times during 47 weeks of operation). The interval between two consecutive backwash events varied between 7 and 109 days (see Table 4-6). As discussed in Section 4.4.2 and shown in Figures 4-13 and 4-14, the system was manually backwashed on several occasions even though the Δp readings were less than the 10-psi backwash trigger. Depending on the flowrate, a single 20-min backwash cycle for one vessel produced between 1,500 and 2,700 gal of water.

4.4.5 Media Loading and Removal. The media was loaded on-site during the installation of each system (i.e., January 16, 2004, for the APU-100 system and June 13, 2005, for the APU-RWS system). In addition, one media changeout was performed during the APU-100 system operation between October 27 and 28, 2004. Before the removal of spent media, the heights of the freeboard were measured from the flange at the top of the vessels to the top of the media beds and summarized in Table 4-8. The spent media then was sampled and removed from each vessel as described in Section 3.3.4. As shown in Table 4-8, significant amounts (i.e., 39 to 53%) of the media were lost during Run 1 of the APU-100 system operation, based on the freeboard heights estimated/measured at media loading (i.e., <15 in) and before media changeout (i.e., 39 and 33 in for Vessels A and B, respectively). This loss of media apparently occurred during backwashing, especially after a more aggressive backwash procedure with approximately 11 gpm/ft^2 of hydraulic loading rate was implemented in August 2004. This observation was supported by much shorter freeboard heights (i.e., 25 and 20 in) measured in July 2004 during a vendor site visit than in October 2004 before the media changeout.

The APU-100 system was removed from the site during the week of May 16, 2005. During the decommissioning of the old system, freeboard heights were measured to be 42 and 38 in. Comparing to the freeboard heights recorded following the media replacement in October 2004 (i.e., 18.5 in), 13.9 and 11.5 ft^3 of the media (or 63 and 52%) were lost from Vessels A and B, respectively, over 2.5 months of system operations (i.e., from late October 2004 to mid January 2005). The aggressive backwash flowrates (75 to 77 gpm or 11 gpm/ft^2) again were thought to have caused the media to be washed away. Note that the system was backwashed at these flowrates 19 times during this adsorption run.

Table 4-8. APU-100 System Media Loading, Removal, and Freeboard Measurements

Media Run No.	Media Loading Date	Tank (A/B)	Media Volume (ft^3)	Freeboard Height at Media Loading (in)	Media Removal Date	Freeboard Height at Media Removal (in)	Difference of Freeboard Height (in)	Amount of Media Lost (ft^3)/%
1	01/16/04	A	27	<15[(a)]/25[(b)]	10/27/04	39	>24	14.2/53
	01/16/04	B	27	<15[(a)]/20[(b)]	10/27/04	33	>18	10.7/39
2	10/28/04	A	22	18.5	05/16/05	42	23.5	13.9/59
	10/28/04	B	22	18.5	05/16/05	38	19.5	11.5/46

(a) Estimated measurements (see Section 4.4.1 on page 28).
(b) Field measurements made in July 2004.

4.4.6 Residual Management. Residuals produced by the operation of the APU-100 and APU-RWS systems included backwash wastewater and spent media. Piping for discharging backwash wastewater from both vessels was combined aboveground inside the treatment building before exiting the building through the floor. Piping then traveled underground to a subsurface drainage structure located beneath a parking area in front of the treatment building. The backwash wastewater then infiltrated to the ground from this disposal structure. Particles or fines carried in backwash wastewater remained in the drainage structure.

4.4.7 System/Operation Reliability and Simplicity. The operational issues related to the elevated Δp and inlet pressure and the operation of the CO_2 gas flow control system were the primary factors affecting system reliability and operation simplicity.

Unscheduled downtime during the APU-100 system operation was caused by the need to address the elevated pressures and operational problems with the CO_2 injection system. As described in Section 4.4.1, the system was bypassed between March 13 to March 25, 2004, due to damaged parts in the CO_2 gas flow control system. Unscheduled downtime due to the elevated inlet pressure and Δp issues occurred from May 31 through June 1, June 5 and 6, June 16 through 18, June 24 through July 8, and August 2, 2004. During the first 261 days of operation, the system was down for a total of 36 days, representing 14% downtime. Following the media replacement in October 2004, the system ran almost on a daily basis. The replacement of the APU -100 system with the APU-RWS system eliminated downtime caused by elevated pressure.

The APU-RWS system ran on a daily basis except for an extended period from August 5 through September 26, 2005, when the system was shut down due to a ruptured pipe at the inlet side of Vessel A. On August 6, the operator discovered the pipe break and immediately shut down the well pumps. Due to backflow from the elevated storage tank through the system, a small amount of media was washed out of the adsorption vessels to the treatment building. AdEdge's local subcontractor, Waterline Services, was on site during the week of August 15 to fix the broken pipe connection and install a backflow preventer. Waterline Services opened the vessels and measured freeboard heights at 26 in for both vessels, which were very similar to those measured during system startup. This confirmed that only a small amount of media (estimated to be <1 ft^3) was lost during the pipe break.

In addition to the extended system shutdown from August 5 through September 26, 2005, the APU-RWS system was bypassed on October 7, 2005, due to air in the distribution system. Entrained air in the distribution system caused water to appear milky as it came from taps, resulting in some complaints from customers. Although the cause for this entrained air was not clear, the operator decided to temporarily bypass the APU unit. The unit was placed back online on October 10, 2005, because bypassing it did not appear to help solve the problem. The two supply wells at the Porter well house were turned off during the week of October 17, 2005, when the operator attempted to isolate the source of the entrained air in the system. The wells were back in operation by October 24, 2005, and it appeared that there was less air in the distribution system than previously observed. During the 328 days of operation, the system was down for a total of 59 days, equivalent to 18% downtime.

The requirements for system O&M and operator skills 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. Initially, the only pre-treatment performed was pH adjustment using CO_2. The raw water sample tap was relocated further upstream of the CO_2 injection point in late March 2004 to avoid possible influence by the CO_2 injection. During the first one and one half months of system operation, chlorine was added at the end of the treatment train to provide chlorine residuals as was performed prior to the arsenic demonstration study. In late March 2004, the chlorination point was moved upstream of the adsorption vessels and after the CO_2 injection point to oxidize As(III) to As(V) and improve arsenic removal efficiency. Post-chlorination was not required because as much as 0.6 mg/L (as Cl_2) of free chlorine residuals (on average) remained in the treated water before entering the distribution system.

System Automation. Both APU systems were fitted with automated controls that would allow for the backwash cycle to be controlled automatically; however, due to the pressure problems these automated controls were not used. Instead, the operator performed backwashes manually. The APU-100 CO_2 gas control flow was designed for manual operation in Phase 1. Attempts were made to upgrade the system for automatic flow control, which, however, was subject to CO_2 membrane fouling and other problems and pH adjustment was discontinued.

Operator Skill Requirements. Under normal operating conditions, the skill requirements to operate the APU systems were minimal. The daily demand on the operator was typically 15 to 20 min to perform daily checks of the system, visual inspections, and record the system operating parameters on the daily log sheets. Normal operation of the system did not appear to require additional skills beyond those necessary to operate the existing water supply equipment. On days when the systems were backwashed, the operator typically spent about two hours on site to complete this process.

Due to recurring problems with elevated Δp and inlet pressure and the CO_2 gas flow control system, the operator spent much more time troubleshooting the operation of the treatment system than would normally be expected. As requested by the vendor, the operator conducted backwash far more frequently than originally anticipated and worked with the vendor to troubleshoot, modify, and replace several system components. The majority of the labor to modify or replace system components was performed by the installation subcontractor hired by the vendor; however, all of the additional visits and coordination of additional work required the plant operator to be on site on several occasions for periods of two to four hours or more, depending on the type of work being conducted.

Preventive Maintenance Activities. Preventive maintenance tasks included such items as periodic checks of the flowmeters and pressure gauges and inspection of system piping and valves. As mentioned in Section 4.4.3, weekly cleaning of the inline pH probe was found to be necessary to remove the buildup of a film on the probe. The vendor suggested inspection of the vessel internals, including adsorber laterals and replacement of the underbedding gravel during media replacement. Due to the operational issues, the operator spent additional time troubleshooting and working with AdEdge technicians during their return visits to the site. Typically, the operator was onsite an additional 30 min to as much as two to three hours per week working to address these issues. Under normal operation, it is not expected that this additional time would be required.

Chemical/Media Handling and Inventory Requirements. The only chemicals required for the system operation included the NaOCl solution used for chlorination, which was already in use at the site, and the CO_2 gas cylinders used for pH adjustment. The CO_2 cylinders required change-out typically once every two to three weeks, and the 50-gal drums of 4% chlorine solution required refilling once every two to three weeks.

4.5 System Performance

The performance of the APU systems 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. Treatment plant water samples were collected at five locations through the treatment process, including IN, AP, TA, TB, and TT (see Table 3-3). During operation of the APU-100 system with prechlorination (excluding the six-week period when chlorine was added after the APU-100 system), water samples were collected on 37 occasions (including four sampling events with duplicate samples taken) with field speciation performed on eight occasions. Raw water from the IN location was sampled at each of the 37 occasions. AP was sampled 36 times, TA and TB 29 times, and TT eight times. During operation of the APU-RWS system, treatment plant water samples were collected on 11 occasions, with field speciation performed on six occasions. Water from the IN and AP locations were sampled at each of the 11 sampling occasions. TA and TB were sampled five times and TT six times.

Table 4-9 provides a summary of analytical results for arsenic, iron, and manganese after relocation of the chlorination point upstream of the adsorption vessels during APU-100 system operation from March 30, 2004, through January 5, 2005, and during APU-RWS system operation from June 13, 2005, through May 8, 2006. Table 4-10 summarizes the results of other water quality parameters during the same periods of time. Appendix B contains a complete set of analytical results during the operation of each system. The results of the water samples collected throughout the treatment plant are discussed below.

Arsenic. The key parameter for evaluating the effectiveness of APU systems was arsenic concentrations in the treated water. As shown by the comparison of the results, which are shown side by side in Tables 4-9 and 4-10, as well as in Figures 4-14 through 4-18, the behavior of the adsorptive media was very similar between the two systems.

Figure 4-14 contains three bar charts showing the concentrations of total arsenic, particulate arsenic, and soluble arsenic (including As[III] and As[V]) at the IN, AP, and TT sampling locations for each speciation event. Total arsenic concentrations in raw water ranged from 28.7 to 52.4 μg/L and averaged 37.0 μg/L during APU-100 system operation (excluding the six-week period when chlorine was added after the adsorption system) and ranged from 31.6 to 51.1 μg/L (average 37.7 μg/L) during APU-RWS system operation. Particulate arsenic concentrations averaged 6.2 and 3.4 μg/L during APU-100 and APU-RWS system operations, respectively. Typically, As (III) comprised a significant portion of total soluble arsenic with its concentrations averaging 18.3 and 16.8 μg/L, respectively. The remainder of soluble arsenic was As(V) with concentrations averaging 15.7 and 18.2 μg/L, respectively. The arsenic concentrations measured in raw water were consistent with those collected previously during the source water sampling (Table 4-1).

During the first six-weeks of APU-100 system operation, chlorine was added at the end of the treatment train. In March 2004, total arsenic levels in the treated water, existing primarily as As(III) as shown in Figure 4-14, increased to as high as 7.7 μg/L after only about 2,700 BV of throughput. This early arsenic breakthrough prompted relocation of the chlorine injection point to upstream of the adsorption vessels so that As(III) might be oxidized to As(V) before coming in contact with the adsorptive media. When prechlorination was performed, samples collected downstream of the chlorine injection/pH adjustment point (AP) had As(III) and As(V) concentrations ranging from 0.5 to 1.5 and 30.3 to 37.6 μg/L, respectively, indicating oxidation of As(III) by chlorine. Before the December 2, 2004, sampling event, the line that delivered chlorine to the chlorine injection point bursted due to high inlet pressure; therefore, prechlorination was not performed during sampling and a mix of As(III) and As(V) at 14.4 and 21.7 μg/L, respectively, was observed at the AP location.

The arsenic breakthrough curves for each media run are shown in Figure 4-15. As shown in the top graph, breakthrough of total arsenic at concentrations above the 10 μg/L target MCL was first observed at the TT location after the APU-100 system processed approximately 12,500 BV of water. Arsenic concentrations returned to below 10 μg/L at the TA/TB locations the following week at approximately 13,300 and 13,600 BV, respectively, but increased to over 10 μg/L again at the TA location at 14,300 BV. Samples of treated water collected at the TA location at 15,000 BV and at the TT location at 15,200 BV were again below 10 μg/L; however, the concentration was above 10 μg/L at the TB location at 17,400

Table 4-9. Analytical Results for Arsenic, Iron, and Manganese after Relocation of Chlorination Point Upstream of Adsorption Vessels for Phases 1 and 2 Studies

Parameter	Sampling Location[a]	Unit	Number of Samples Phase 1/ Phase 2	Minimum Concentration Phase 1/ Phase 2	Maximum Concentration Phase 1/ Phase 2	Average Concentration Phase 1/ Phase 2	Standard Deviation Phase 1/ Phase 2
As (total)	IN	μg/L	37/11	28.7/31.6	52.4/51.1	37.0/37.7	6.0/6.4
	AP	μg/L	36/11	23.3/28.5	75.2/48.6	38.1/37.5	8.6/5.6
	TA	μg/L	29/5	1.0/1.0	40.5/20.3	-[b]	-[b]
	TB	μg/L	29/5	1.4/1.0	30.0/19.5	-[b]	-[b]
	TT	μg/L	8/6	1.1/1.5	20.8/16.5	-[b]	-[b]
As (total soluble)	IN	μg/L	8/6	29.8/30.3	36.4/45.0	34.0/35.0	2.3/5.3
	AP	μg/L	7/6	30.7/30.8	39.1/37.2	35.5/33.5	2.8/2.2
	TT	μg/L	8/6	<0.1/1.2	19.1/16.3	-	-
As (particulate)	IN	μg/L	8/6	<0.1/<0.1	17.6/6.6	6.2/3.4	7.2/3.2
	AP	μg/L	7/6	<0.1/<0.1	7.1/10.5	2.7/3.1	2.6/4.1
	TT	μg/L	8/6	<0.1/<0.1	2.3/0.5	-	-
As (III) (soluble)	IN	μg/L	8/6	12.4/7.6	25.8/28.8	18.3/16.8	4.3/8.2
	AP	μg/L	6/6	0.5/0.4	1.5[c]/2.3	0.9/1.2	0.4/0.7
	TT	μg/L	7/6	0.3/0.5	0.8/1.3	-	-
As (V) (soluble)	IN	μg/L	8/6	4.1/11.1	19.1/25.3	15.7/18.2	5.0/5.0
	AP	μg/L	6/6	30.3[d]/29.6	37.6/35.9	34.9/32.3	2.9/2.1
	TT	μg/L	7/6	0.2/<0.1	18.3/15.6	-	-
Fe (total)	IN	μg/L	37/11	37/77	1,120[e]/799	208/297	209/213
	AP	μg/L	36/11	<25/56	898/555	185/239	176/163
	TA	μg/L	29/5	<25/<25	131/165	22.9/43	24/68
	TB	μg/L	29/5	<25/<25	280/64	33/23	50/23
	TT	μg/L	8/6	<25/<25	78/72	23/30	23/27
Fe (soluble)	IN	μg/L	8/6	<25/<25	183/158	42/72	58/49
	AP	μg/L	7/6	<25/<25	41/68	17/24	11/22
	TT	μg/L	8/6	<25/<25	<25/79	<25/24	0/27
Mn (total)	IN	μg/L	37/11	51.9/59.7	245.0/175.5	100.4/106.3	43.9/37.3
	AP	μg/L	36/11	53.1/55.6	240.7/192.0	100.2/109.3	37.9/44.7
	TA	μg/L	29/5	0.5/0.5	50.5/19.7	-[b]	-[b]
	TB	μg/L	29/5	0.8/0.5	69.6/11.2	-[b]	-[b]
	TT	μg/L	8/6	0.6/0.5	9.7/23.6	-[b]	-[b]
Mn (soluble)	IN	μg/L	8/6	48.9/57.6	235.3/181.6	97.9/128.2	58.9/47.7
	AP	μg/L	7/6	50.2/55.1	104.9/147.7	76.8/82.7	18.5/33.0
	TT	μg/L	8/6	0.6/0.5	2.7/15.3	-	-

(a) See Table 3-3 and Figure 4-2.
(b) Average concentration and standard deviation not calculated; see Figures 4-15 and 4-16 for total As and total Mn breakthrough curves.
(c) Omitted one outlying datum at 34.5 μg/L; also omitted 12/02/07 result at 14.4 μg/L due to a broken prechlorination line.
(d) Omitted one outlying datum at <0.1 μg/L; also omitted 12/02/07 result at 21.7 μg/L due to a broken prechlorination line.
(e) Omitted one outlying datum at 4,645 μg/L.
Phase 1 = APU-100 Run 1 from 03/30/04 through 10/27/04 and Run 2 from 11/03/04 through 01/05/05; Phase 2 = APU-RWS from 06/13/05 through 05/08/06
One-half of detection limit used for samples with concentrations less than the detection limit for calculations.
Duplicate samples were included in calculations.

Table 4-10. Analytical Results of Other Water Quality Parameters after Relocation of Chlorination Point Upstream of Adsorption Vessels for Phases 1 and 2 Studies

Parameter	Sampling Location[a]	Unit	Number of Samples Phase 1/ Phase 2	Minimum Concentration Phase 1/ Phase 2	Maximum Concentration Phase 1/ Phase 2	Average Concentration Phase 1/ Phase 2	Standard Deviation Phase 1/ Phase 2
Alkalinity (as $CaCO_3$)	IN	mg/L	37/11	162/158	259/198	184.7/179.9	18.2/12.5
	AP	mg/L	36/11	162/172	236/198	182.4/184.0	14.9/9.8
	TA	mg/L	29/5	160/172	219/189	182.0/179.6	11.7/7.1
	TB	mg/L	29/5	163/172	207/185	181.3/177.0	9.2/4.8
	TT	mg/L	8/6	160/172	196/198	179.3/187.0	12.8/10.9
Fluoride	IN	mg/L	8/6	0.5/0.3	1.5/0.6	0.7/0.5	0.3/0.1
	AP	mg/L	7/6	0.5/0.4	1.7/0.6	0.8/0.5	0.4/0.0
	TT	mg/L	8/6	0.5/0.4	1.6/0.6	0.7/0.5	0.4/0.1
Sulfate	IN	mg/L	8/6	35.0/27.7	72.0/59.0	44.8/40.5	11.6/12.8
	AP	mg/L	7/6	33.0/28.6	46.0/56.0	41.3/39.9	4.2/9.6
	TT	mg/L	8/6	33.0/30.8	80.0/76.0	44.8/44.5	14.6/17.3
Orthophosphate (as P)[b]	IN	mg/L	34/4	<0.06/<0.05	2.3/0.1	0.1/0.00	0.4/0.00
	AP	mg/L	33/4	< 0.06/<0.05	0.1/0.1	0.00/0.00	0.00/0.00
	TA	mg/L	26/1	<0.06/<0.05	0.1/<0.05	0.1/<0.05	0.00/0.00
	TB	mg/L	26/1	<0.06/<0.05	0.2/<0.05	0.1/<0.05	0.00/0.00
	TT	mg/L	8/3	<0.06/<0.05	0.1/0.1	0.00/0.1	0.00/0.1
Total P (as P)	IN	μg/L	0/6	NS/72.8	NS/100.6	NS/81.5	NS/10.4
	AP	μg/L	0/6	NS/71.4	NS/94.2	NS/82.9	NS/7.8
	TA	μg/L	0/3	NS/5.0	NS/86.2	-[c]	-[c]
	TB	μg/L	0/3	NS/5.0	NS/72.9	-[c]	-[c]
	TT	μg/L	0/3	NS/15.3	NS/50.3	-[c]	-[c]
Silica (as SiO_2)	IN	mg/L	37/11	13.6/13.9	16.7/17.0	15.0/15.3	0.7/0.9
	AP	mg/L	36/11	13.7/14.0	16.5/16.4	14.9/15.0	0.6/0.8
	TA	mg/L	29/5	13.8/13.5	15.9/15.6	15.0/14.7	0.5/0.9
	TB	mg/L	29/5	13.5/13.1	16.1/15.4	15.0/14.6	0.6/0.9
	TT	mg/L	8/6	9.9/1.6	15.3/15.5	14.1/12.6	1.8/5.4
Nitrate (as N)	IN	mg/L	8/6	<0.04/<0.05	0.1/0.1	0.00/<0.05	0.00/0.00
	AP	mg/L	7/6	<0.04/<0.05	0.1/0.5	0.00/0.10	0.00/0.2
	TT	mg/L	8/6	<0.04/<0.05	0.1/0.4	0.00/0.10	0.00/0.1
Turbidity	IN	NTU	37/11	0.3/0.5	36.0/5.1	3.8/2.0	7.7/1.6
	AP	NTU	36/11	0.2/0.2	14.0/5.0	1.2/1.7	2.2/1.6
	TA	NTU	29/5	0.2/0.2	7.4/2.7	0.8/1.1	1.4/1.0
	TB	NTU	29/5	0.3/0.2	2.1/1.3	0.6/0.5	0.4/0.5
	TT	NTU	8/6	0.2/0.2	1.3/1.4	0.6/0.6	0.3/0.5
pH	IN	S.U.	35/8	7.4/7.2	8.2/7.9	7.9/7.7	0.2/0.2
	AP	S.U.	34/8	7.0/7.6	8.1/8.1	7.5/7.8	0.3/0.2
	TA	S.U.	27/5	7.1/7.8	8.0/8.1	7.5/7.9	0.3/0.1
	TB	S.U.	26/5	7.1/7.8	8.0/8.1	7.5/7.9	0.3/0.1
	TT	S.U.	8/4	7.0/7.8	8.0/8.3	7.5/8.1	0.3/0.2
Temperature	IN	°C	24/8	8.3/5.6	19.5/19.7	13.6/11.7	2.6/3.9
	AP	°C	23/8	7.6/6.5	17.7/18.7	13.1/11.6	2.4/3.4
	TA	°C	17/5	9.0/5.9	16.4/12.2	13.2/10.0	1.9/2.4
	TB	°C	16/5	9.1/7.0	17.5/11.6	13.4/10.1	2.1/1.8
	TT	°C	7/4	7.8/7.0	16.0/18.3	12.5/12.2	2.7/4.6

Table 4-10. Analytical Results of Other Water Quality Parameters after Relocation of Chlorination Point Upstream of Adsorption Vessels for Phase 1 and Phase 2 Studies (Continued)

Parameter	Sampling Location[(a)]	Unit	Number of Samples Phase 1/ Phase 2	Minimum Concentration Phase 1/ Phase 2	Maximum Concentration Phase 1/ Phase 2	Average Concentration Phase 1/ Phase 2	Standard Deviation Phase 1/ Phase 2
DO	IN	mg/L	24/7	3.2/3.5	5.5/7.8	4.2/5.3	0.7/1.4
	AP	mg/L	23/7	2.0/4.1	4.2/9.4	3.3/6.3	0.6/1.9
	TA	mg/L	17/4	1.9/6.4	4.4/9.6	3.3/7.6	0.6/1.4
	TB	mg/L	16/4	2.2/6.2	5.4/9.5	3.4/7.1	0.8/1.6
	TT	mg/L	7/4	2.0/3.3	3.5/5.9	2.7/4.0	0.6/1.1
ORP	IN	mV	24/8	-70.0/164	234/224	46/198	133/20
	AP	mV	23/8	-47.0/158	434/436	71/213	136/91
	TA	mV	17/5	-54.0/159	437/336	77/201	144/76
	TB	mV	16/5	-54.0/157	466/314	86/196	151/67
	TT	mV	7/4	-50.0/151	262/201	39/172	125/24
Free Chlorine (as Cl_2)	AP	mg/L	20/6	0.0/0.0	1.8/0.4	0.2/0.1	0.4/0.1
	TT	mg/L	6/3	0.0/0.0	3.2/0.1	0.6/0.0	1.3/0.1
Total Chlorine (as Cl_2)	AP	mg/L	19/6	0.0/0.1	3.8/0.6	0.7/0.3	1.1/0.2
	TT	mg/L	5/3	0.1/0.0	3.2/0.3	0.8/0.2	1.4/0.1
Total Hardness (as $CaCO_3$)	IN	mg/L	8/6	47.8/53.4	101.0/87.7	67.7/66.9	17.6/13.1
	AP	mg/L	7/6	48.9/46.4	81.4/83.0	61.5/62.6	10.9/13.7
	TT	mg/L	8/6	54.7/48.7	103.1/92.0	70.1/68.5	16.1/18.0
Ca Hardness (as $CaCO_3$)	IN	mg/L	8/6	28.2/29.5	52.8/47.6	39.8/38.4	9.2/7.0
	AP	mg/L	7/6	28.5/25.1	51.0/46.6	37.0/35.4	7.6/8.6
	TT	mg/L	8/6	31.1/27.8	53.4/52.2	39.8/39.0	7.8/11.3
Mg Hardness (as $CaCO_3$)	IN	mg/L	8/6	19.6/22.3	48.2/29.2	29.2/27.1	9.0/6.7
	AP	mg/L	7/6	20.4/21.2	30.4/26.1	26.1/25.6	3.9/5.8
	TT	mg/L	8/6	22.1/19.6	49.7/31.1	31.1/28.7	9.0/7.1

(a) See Table 3-3 and Figure 4-2.
(b) Orthophosphate (as P) data generated between 1/1/05 to 10/3/05 was considered unusable and was removed from data set.
(c) See Figure 4-19 for total P breakthrough curve.
Phase 1 = APU-100 Run 1 from 03/30/04 through 10/27/04 and Run 2 from 11/03/04 through 01/05/05; Phase 2 = APU-RWS from 06/13/05 through 05/08/06
One-half of detection limit used for samples with concentrations less than detection limit for calculations.
Duplicate samples included in calculations.
Only samples collected after switched to prechlorination, beginning with samples collected on 03/30/04.

BV. Total arsenic concentrations measured at the AP location at about 13,500 BV and at the TT location at about 12,500 BV were unusually high at 75.2 and 20.3 µg/L, respectively. It was not clear why these concentrations were higher than the other relevant data points. Based on these data, breakthrough of arsenic at 10 µg/L occurred somewhere between 12,500 and 17,000 BV, representing about 17 to 23% of the vendor-estimated working capacity of 74,000 BV.

After the media was changed out, the APU-100 system processed approximately 10,000 BV before it was bypassed due to unacceptably high inlet pressure. Breakthrough of arsenic at this time was at about 4 µg/L (middle graph in Figure 4-15), which comprised primarily As(III) (see Figure 4-14) following the switch back of the chlorine injection point to after the adsorption vessels on December 2, 2004, due to elevated inlet pressure problems as discussed in Section 4.4.2.

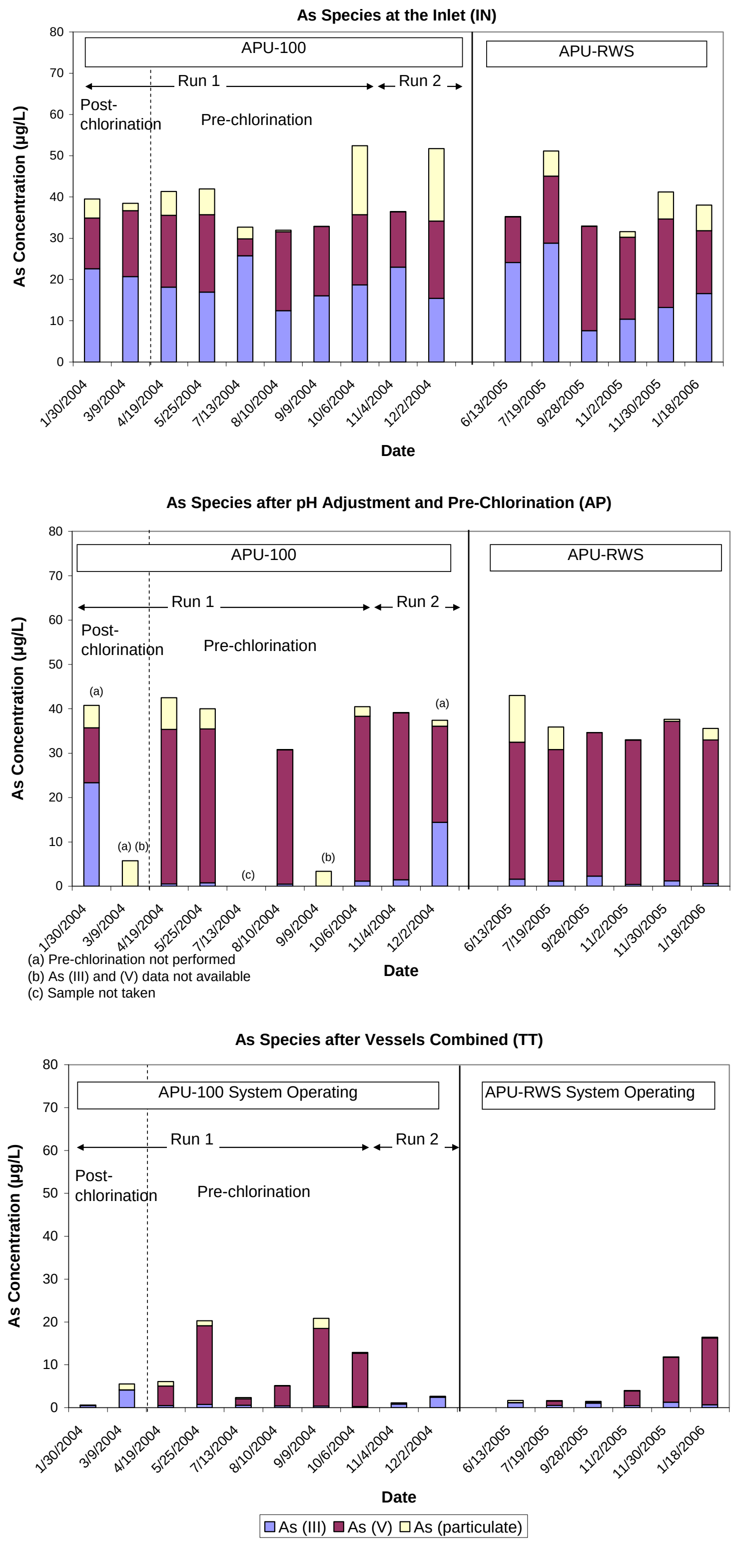
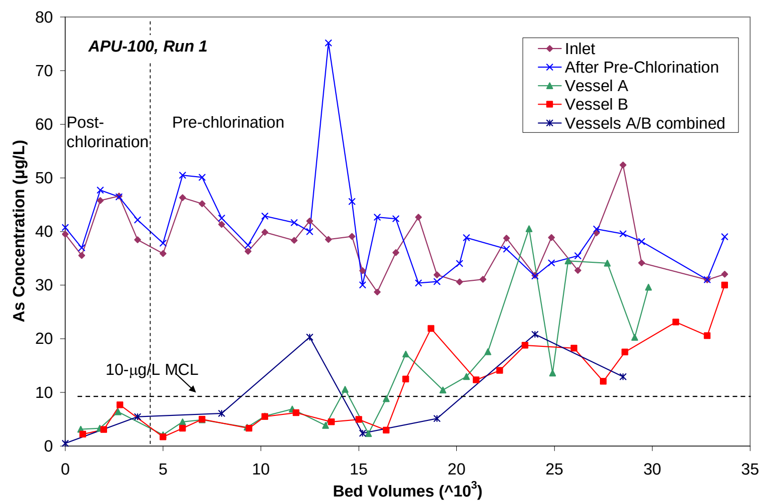
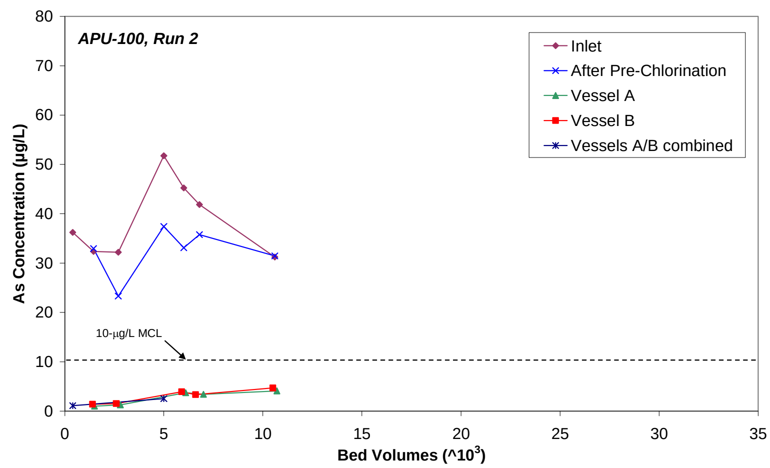


Figure 4-14. Concentrations of Arsenic Species at IN, AP, and TT Sampling Locations





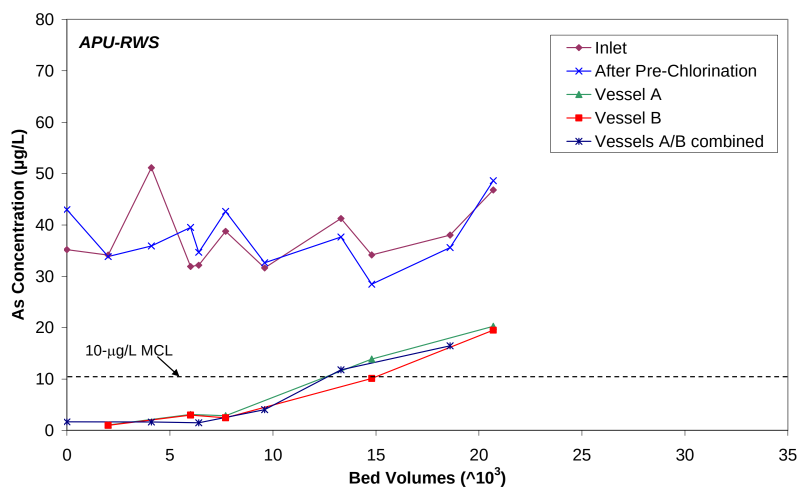


Figure 4-15. Total Arsenic Breakthrough Curves

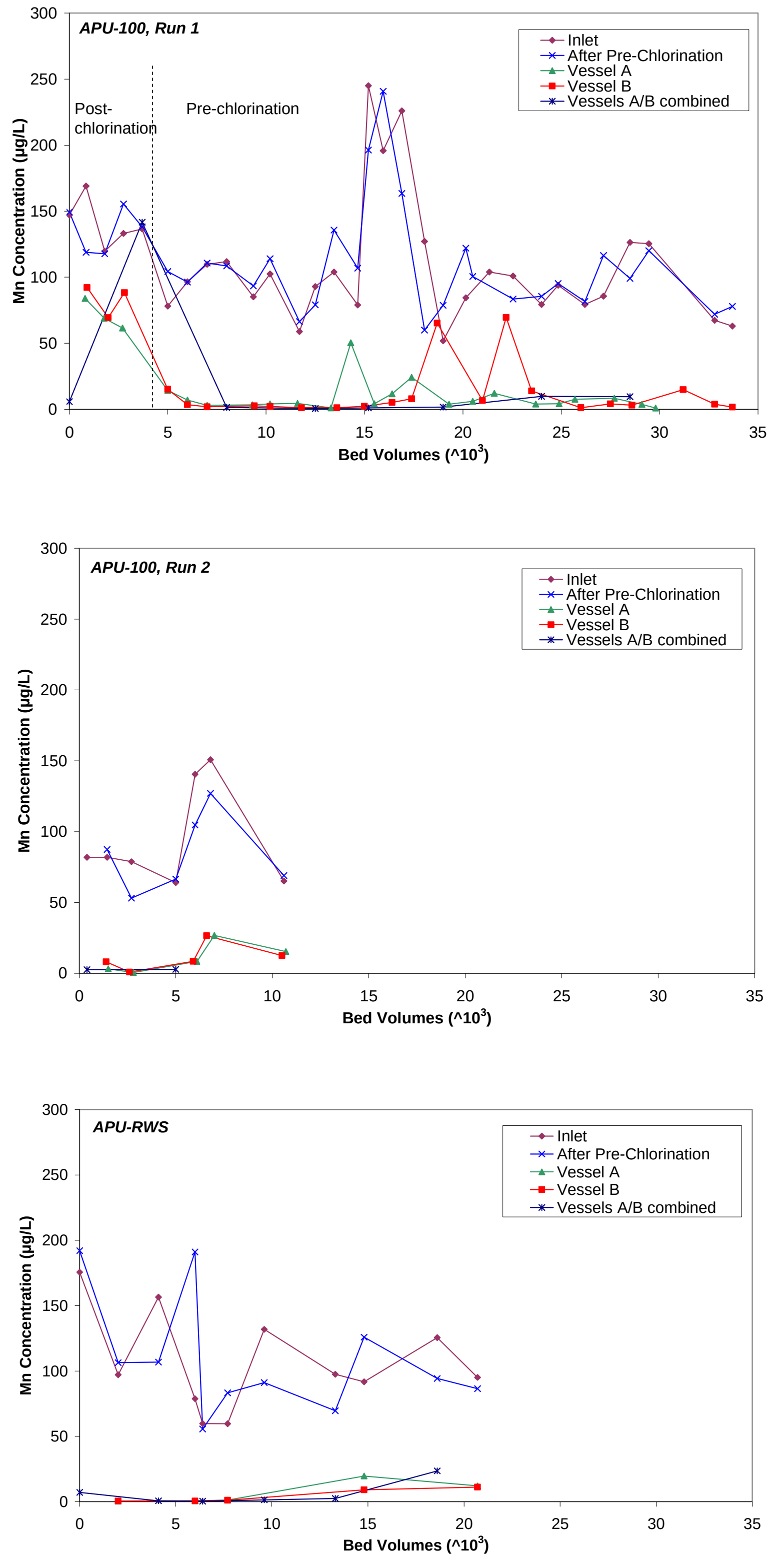


Figure 4-16. Total Manganese Concentrations Measured during Phases 1 and 2 Studies

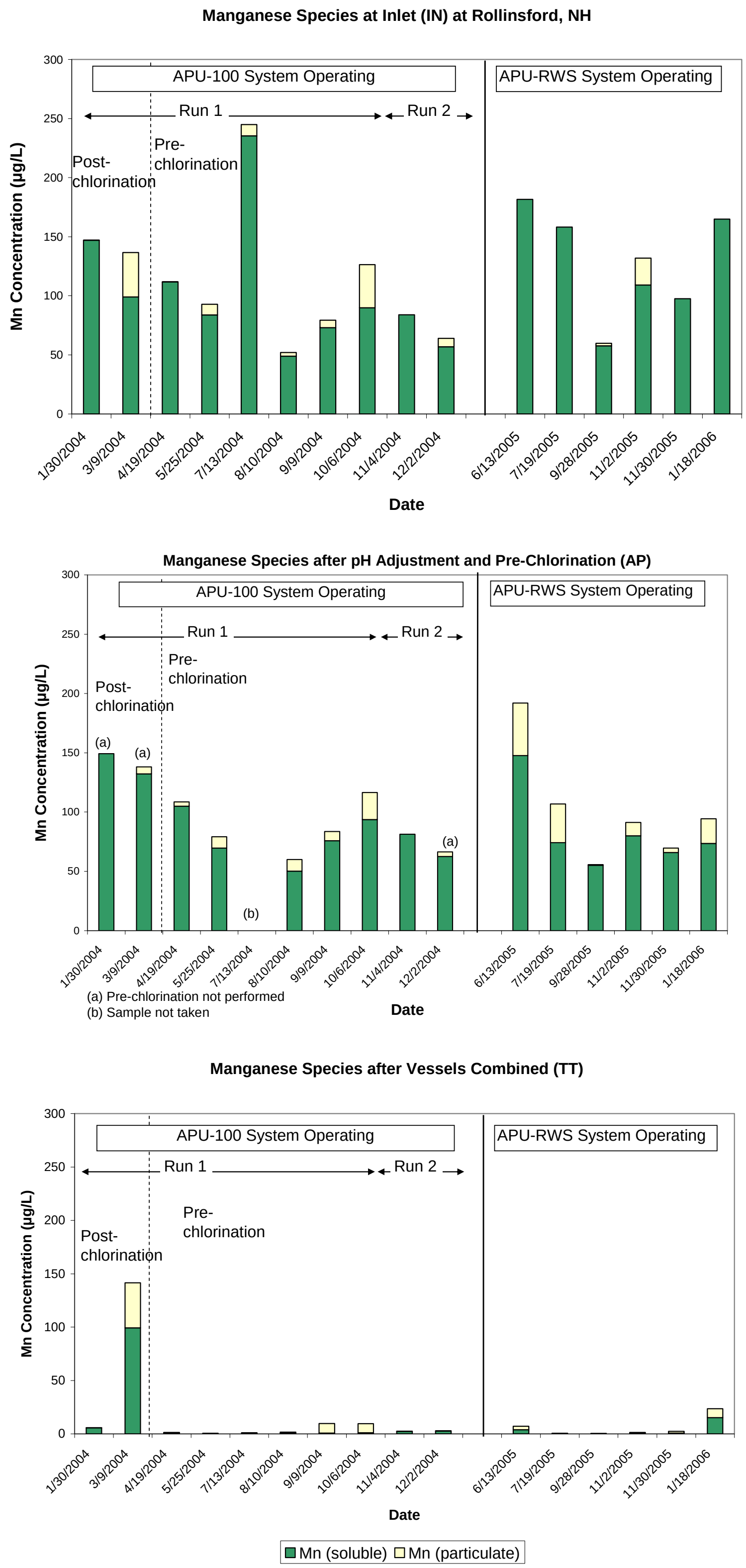


Figure 4-17. Concentrations of Manganese Species at IN, AP, and TT Sampling Locations

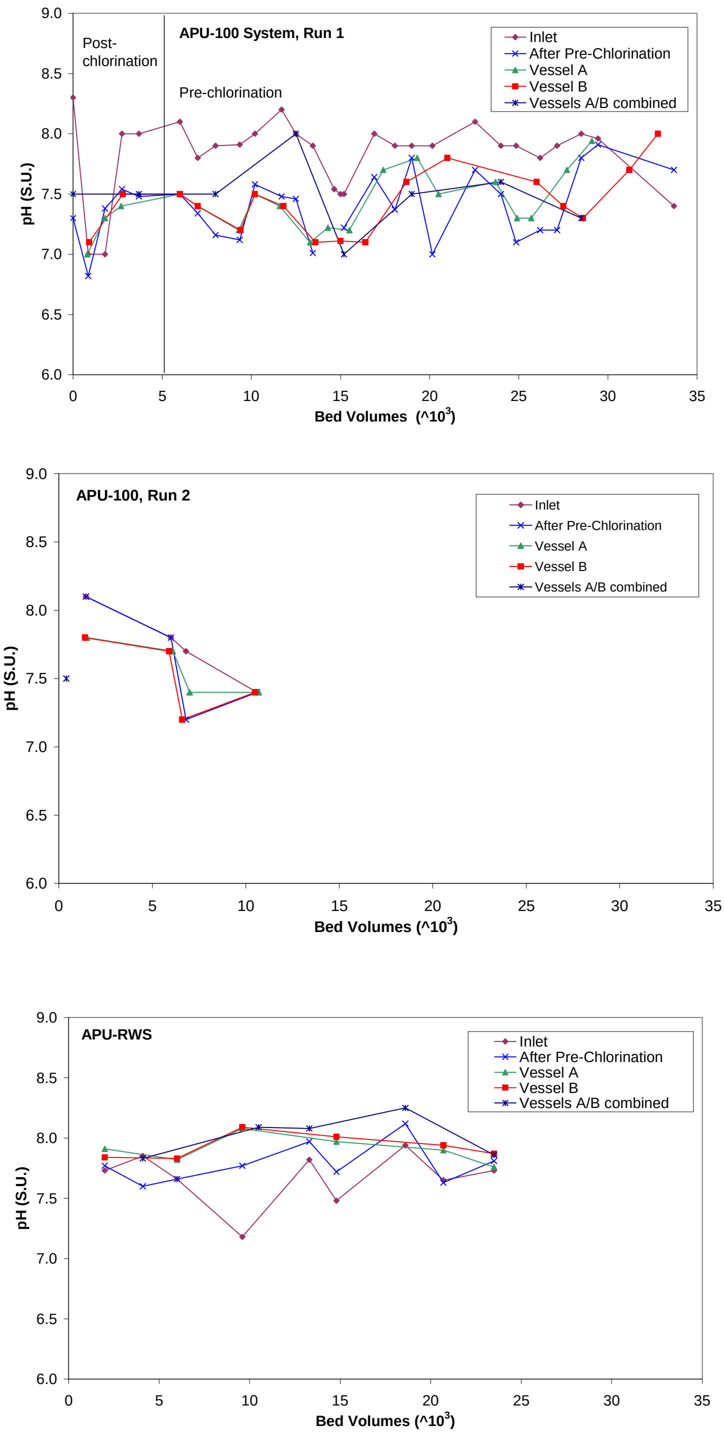


Figure 4-18. pH Values Measured During Phases 1 and 2 Studies

The media performed similarly with prechlorination as the only pretreatment step during the operation of the APU-RWS system. Breakthrough of arsenic above the 10 μg/L MCL occurred at approximately 12,500 BV (bottom graph of Figure 4-15), similar to that observed for the APU-100 system. Although it helped alleviate both inlet pressure and Δp problems, re-design of the system did not improve the media performance in terms of its run length.

Iron. Total iron concentrations in raw water ranged from 37.1 to 1,120 μg/L and averaged 208 μg/L during the operation of the APU-100 system and ranged from 77 to 799 μg/L and averaged 297 μg/L during the operation of the APU-RWS system. Iron concentrations following pH adjustment and prechlorination at the AP location ranged from <25 to 898 μg/L and averaged 185 μg/L during APU-100 system operation and ranged from 56 to 555 μg/L and averaged 239 μg/L during APU-RWS system operation. Total iron concentrations following the adsorption vessels at the TA and TB locations ranged from <25 μg/L to 280 μg/L and averaged 23 and 33 μg/L, respectively, for the APU-100 system, and ranged from <25 to 165 with an average of 43 and 23 μg/L, respectively, for the APU-RWS system. Out of 34 sampling occasions (including duplicates) after relocating the chlorination point upstream of adsorption vessels, only 14 had concentrations higher than the method detection limit of 25 μg/L in the treated water. Soluble iron levels ranged from <25 to 183 μg/L at the inlet (IN), and were almost always <25 μg/L at the AP and TT locations. These data indicate that the majority of iron entering the adsorption vessels existed in the particulate form, and that iron particles were mostly captured by the media beds.

Manganese. The treatment plant water samples were analyzed for total manganese at each sampling event and soluble manganese during speciation sampling. Total manganese concentrations at the various sampling locations are plotted over time in Figure 4-16. Total and soluble manganese concentrations are shown in Figure 4-17. Total manganese levels in raw water ranged from 51.9 to 245.0 μg/L and averaged 100.4 μg/L during the operation of the APU-100 system, and ranged from 59.7 to 175.5 and averaged 106.3 μg/L during the operation of the APU-RWS system (Table 4-9). As shown in Figure 4-17, manganese existed almost entirely in the soluble form. In contrast to complete iron precipitation, chlorination precipitated less than 20% of soluble manganese before water entered the adsorption vessels. This observation was consistent with previous findings that free chlorine was relatively ineffective at oxidizing Mn(II) at pH values less than 8.5 (Knocke et al., 1987 and 1990).

Prior to switching to prechlorination, manganese, existing primarily as soluble manganese based on the use of 0.45-μm disc filters, quickly broke through the AD-33™ adsorbers and reached about 100% breakthrough after only about 3,700 BV of throughput. However, after prechlorination was implemented, total manganese concentrations at the TA, TB, and TT locations were typically reduced to <10 μg/L, indicating removal of manganese within the adsorption vessels. Knocke et al. (1990) reported that the presence of free chlorine promoted Mn(II) removal on MnO_x-coated media, and that in the absence of free chlorine, Mn(II) removal was by adsorption only. In the absence of free chlorine, AD-33™ media apparently had a limited adsorptive capacity for Mn(II). The presence of 0.1 to 0.2 mg/L (as Cl_2) of free chlorine (Table 4-10) apparently was enough to promote the removal of manganese by the AD-33™ media presumably via a mechanism similar to that proposed by Knocke et al.

The removal of manganese was supported by the observation of a black coating on the spent media retrieved from the top several inches of the media bed during media changeout in October 2004. Furthermore, the ICP-MS result of the spent media (see Table 4-14) showed samples collected from the top layer contained notably more manganese than the samples collected from deeper depths.

Other Water Quality Parameters. In addition to arsenic analyses, other water quality parameters were analyzed to provide insight into the chemical processes occurring within the treatment system.

Table 4-10 provides a summary of analytical results during APU-100 system operation from March 30, 2004, through January 5, 2005, and during APU-RWS system operation from June 13, 2005, through May 8, 2006. Appendix B contains a complete set of analytical results during the operation of each system.

pH values of raw water measured at the IN location throughout the study varied from 7.2 to 8.2 and averaged 7.8. As noted in Section 4.4.3, pH values of the pH-adjusted water taken at the AP location and measured with a laboratory probe were generally higher than those measured with the inline probe. Possible explanations for the differences were provided in Section 4.4.3. pH values of the treated water taken from TA, TB, and TT locations ranged from 7.0 to 8.3 and averaged 7.6. Considering degassing of CO_2 during sampling and analysis, the actual pH values of the treated water might have been lower than what were measured in the laboratory. Figure 4-18 plotted pH values at the various sampling locations throughout the treatment train over time.

Chlorine residuals were monitored at the AP and TT sampling locations to ensure that the target residual levels were properly maintained. Chlorine residuals measured at the AP location throughout the study ranged from 0.0 to 1.8 mg/L (as Cl_2) and averaged 0.2 mg/L (as Cl_2) for free chlorine and from 0.0 to 3.8 mg/L (as Cl_2) and averaged 0.7 mg/L (as Cl_2) for total chlorine. The free and total chlorine levels measured at the TT location were similar to those measured at the AP location, indicating little or no chlorine consumption through the AD-33™ media beds.

Sulfate concentrations at the IN location ranged from 27.7 to 72 mg/L, and remained unchanged across the treatment train throughout the study with concentrations at the AP and TT locations ranging from 28.6 to 80.0 mg/L. Alkalinity, measured as $CaCO_3$, ranged from 158 to 259 mg/L. The results indicated that alkalinity was not affected by prechlorination, pH adjustment, or the media, with concentrations at the AP and TT locations ranging from 160 to 236 mg/L. Again, degassing of CO_2 during sampling and analysis might have played a role. The treatment plant samples were analyzed for hardness only during speciation events. Total hardness at the IN sampling location ranged from 47.8 to 101.0 mg/L (as $CaCO_3$) and remained constant throughout the treatment train.

Fluoride levels ranged from 0.3 to 1.7 mg/L in all samples throughout the study. Fluoride was measured only during speciation events and did not appear to be affected by the AD-33™ media. Orthophosphate was below or very near the method detection limit of 0.10 mg/L for all samples. Total phosphorus (as P), which was measured during operation of the APU-RWS system, ranged between 71.4 and 94.2 μg/L prior to the adsorption vessels (AP location) and was initially removed by the media and reached complete breakthrough at approximately 15,000 BV (Figure 4-19). Silica concentrations in the AP location ranged from 13.7 to 16.5 mg/L (as SiO_2), and quickly reached breakthrough, as indicated by the low concentrations at the TT location measured once at the beginning of the Phase 2 performance evaluation.

DO levels measured at the IN sampling location ranged from 3.2 to 7.8 mg/L, which were uncharacteristically high for water containing significant amounts of As(III) and Fe(II). Errors associated with sampling and the handheld meter might have been the contributing factors. ORP readings were consistently lower in the raw water sample collected at the IN sample location than those from AP or the treated water samples. There did not appear to be a significant difference in the ORP readings between the AP samples and the treated water samples (TA, TB, TT), indicating that the AD-33™ media did not have an effect on ORP values.

4.5.2 Backwash Wastewater Sampling. Backwash wastewater samples were collected periodically from the sample ports located in the backwash effluent discharge lines from each vessel. Backwash was performed using raw water (non-chlorinated). The unfiltered samples were analyzed for pH, turbidity, and TDS/TSS. Filtered samples using 0.45-μm disc filters were analyzed for soluble

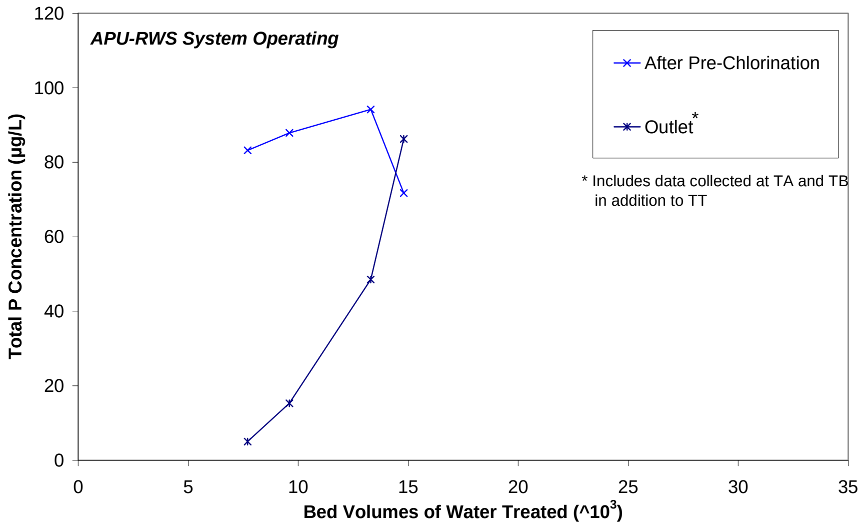


Figure 4-19. Total Phosphorus (as P) Breakthrough Curve

arsenic, iron, and manganese. For the last backwash wastewater sampling event taking place during the APU-RWS system operation in Phase 2, total As, Fe, and Mn concentrations also were measured. The analytical results are summarized in Table 4-11. As shown in the table, most results for the September 8, 2004, sample were uncharacteristically higher than the rest of the data and, therefore, are not included in the following discussion.

pH values of backwash wastewater ranged from 7.2 to 8.4, similar to those of raw water. Soluble arsenic concentrations ranged from 9.5 to 33.8 µg/L, which were somewhat lower than those in raw water. Some soluble arsenic might have been removed by the media during backwash. Soluble iron and soluble manganese concentrations ranged from <25 to 115 and from 3.7 to 118 µg/L (omitting data for July 22, 2004, Vessel A sample and data for September 8, 2004, Vessel B sample), respectively. As expected, total arsenic, iron, and manganese concentrations were considerably higher than the soluble concentrations, indicating the presence of particulate metals in the backwash wastewater. Particulate arsenic might be associated with either iron particles filtered out by the media beds during the service cycle or the media fines. Assuming that 521 mg/L of TSS (average of TSS values measured during Phase 1 APU-100 system operation) was produced in 1,890 gal of backwash wastewater from the vessels, approximately 8.2 lb of solids would be discharged during each backwash event in Phase 1. Assuming that 724 mg/L of TSS (average of TSS values measured during Phase 2 APU-RWS system operation) was produced in 4,200 gal of backwash wastewater from the vessels, approximately 25.4 lb of solids would be discharged during each backwash event in Phase 2. Based on the total metal (or, more correctly, digested metal) data collected during the last backwash event, the solids discharged would be composed of 0.05, 0.38, and 0.05 lb of arsenic, iron, and manganese, respectively, assuming 132 µg/L of particulate arsenic, 10,869 µg/L of particulate iron, and 1,535 µg/L of particulate manganese in the backwash wastewater. These amounts, even after being converted to the weights of corresponding metal oxides, apparently were much lower than those estimated based on TSS. Challenges associated with sampling and sample digestion were believed to have contributed to the discrepancies observed.

Table 4-12 presents the total metal results of two backwash solid samples (one each from Vessels A and B backwash) collected on September 8 and 30, 2004 and analyzed in triplicate. Iron levels in the solids

Table 4-11. Backwash Wastewater Sampling Results

Sampling Event		Vessel A									
		pH	Turbidity	TDS	TSS	As (total)	As (soluble)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)
No	Date	S.U.	NTU	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
APU-100 Phase 1 Run 1											
1	04/26/04	7.4	470	NS	734	NS	18.9	NS	<25	NS	20.9
2	06/08/04	7.2	110	320	NS	NS	21.3	NS	<25	NS	22.9
3	07/22/04	7.3	23(a)	402	NS	NS	33.4 **33.8**	NS	47 **34**	NS	240(b) **246**(b)
4	09/08/04	8.8(b)	120	1,040(b)	NS	NS	70.9(b)	NS	28	NS	3.7
5	09/30/04	7.5	620	406	NS	NS	26.3	NS	85	NS	11.7
APU-100 Phase 1 Run 2											
6	11/30/04	7.7	390	278	NS	NS	9.5	NS	27	NS	24.4
7	12/13/04	7.7	140	348	NS	NS	13.5	NS	<25	NS	55.6
APU-RWS Phase 2											
1	08/01/05	8.2	620	398	NS	NS	10.8	NS	<25	NS	3.3
2	01/31/06(d)	8.2	NS	300	788	166	19.8	3,008	53	401	33.5

Sampling Event		Vessel B									
		pH	Turbidity	TDS	TSS	As (total)	As (soluble)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)
No	Date	S.U.	NTU	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
APU-100 Phase 1 Run 1											
1	04/26/04	7.4	360	NS	308	NS	21.8	NS	<25	NS	27.7
2	06/08/04	7.2	260	352	NS	NS	17.5	NS	<25	NS	12.5
3	07/22/04	7.2	820	450	NS	NS	11.1	NS	83	NS	32.3
4	09/08/04	8.4	1,400(b)	386	NS	NS	191(b) **193**(b)	NS	11,130(b) **11,130**(b)	NS	744(b) **744**(b)
5	09/30/04	7.4	1,100(b)	342	NS	NS	22.8	NS	113	NS	118
APU-100 Phase 1 Run 2											
6	11/30/04	7.6	220	310	NS	NS	10.8	NS	67	NS	14.9
7	12/13/04	7.7	190	374	NS	NS	11.8	NS	<25	NS	75.7
APU-RWS Phase 2											
1	08/01/05	8.4	180	392	NS	NS	14.2	NS	<25	NS	3.9
2	01/31/06(d)	8.2	NS	304	660	136	18.2	18,897	115	2,776	74.1

(a) Sample analyzed outside of hold time.
(b) Data questionable.
(c) Data in boldface indicating re-run results.
(d) Modified backwash procedures used (see Section 3.3.3).
NS = not sampled

ranged from 556 to 641 mg/g (of dry media) and averaged 590 mg/g (or 59%). Arsenic levels ranged from 2.1 to 3.7 mg/g and averaged 2.7 mg/g (or 0.27%). This yields an Fe:As ratio of 152:1 to 290:1, which, as expected, is much higher than the rule-of-thumb ratio of 20:1 for the removal of natural iron (EPA, 2001; Sorg, 2002). These solids likely contained some media fines accounting for the higher ratios.

Table 4-12. Backwash Solid Total Metal Results under Phase 1 Run 1

Sample ID	Unit	Mg	Al	Si	P	Ca	Fe	Mn	Ni	Cu	Zn	As	Cd	Pb	Fe/As Ratio[(a)]
RF-09-08-04-BW1a	µg/g	2,271	397	89.8	5,703	6,742	587,491	12,409	156	24.0	904	2,356	0.08	3.45	249
RF-09-08-04-BW1b	µg/g	2,472	431	109	6,262	7,415	641,332	13,414	173	25.0	930	2,676	0.07	4.07	240
RF-09-08-04-BW1c	µg/g	2,363	410	84.0	5,942	7,065	616,609	13,084	164	23.7	918	2,434	0.07	3.29	253
Vessel 1 Average	µg/g	2,369	413	94.1	5,969	7,074	615,144	12,969	164	24.2	917	2,489	0.07	3.60	247
RF-09-08-04-BW2a	µg/g	1,639	403	136	4,588	4,778	587,864	10,053	165	25.0	837	2,080	0.07	1.66	283
RF-09-08-04-BW2b	µg/g	1,633	406	97.8	4,568	4,711	597,157	10,256	163	22.6	848	2,058	0.08	1.69	290
RF-09-08-04-BW2c	µg/g	1,626	401	199	4,552	4,570	579,148	10,129	163	21.4	846	2,063	0.09	1.61	281
Vessel 2 Average	µg/g	1,633	403	144	4,570	4,686	588,057	10,146	164	23.0	844	2,067	0.08	1.65	284
RF-09-30-04-BW1a	µg/g	1,922	441	72.3	6,291	6,264	597,885	14,345	161	21.7	910	2,747	0.07	3.53	218
RF-09-30-04-BW1b	µg/g	1,967	448	72.3	6,251	6,217	587,580	14,251	166	21.5	906	2,740	0.06	3.48	214
RF-09-30-04-BW1c	µg/g	1,932	437	70.3	5,936	5,975	574,195	13,992	165	21.1	897	2,687	0.07	3.46	214
Vessel 1 Average	µg/g	1,940	442	71.6	6,159	6,152	586,553	14,196	164	21.4	904	2,725	0.06	3.49	215
RF-09-30-04-BW2a	µg/g	2,216	668	81.5	9,494	9,943	569,533	23,940	150	25.5	1134	3,538	0.06	7.29	161
RF-09-30-04-BW2b	µg/g	2,224	668	85.2	9,143	9,601	556,097	22,829	153	25.7	1141	3,648	0.06	7.39	152
RF-09-30-04-BW2c	µg/g	2,261	669	87.2	9,219	9,809	584,040	23,597	157	24.3	1080	3,709	0.06	7.31	157
Vessel 2 Average	µg/g	2,234	668	84.6	9,285	9,784	569,890	23,456	153	25.2	1,118	3,632	0.06	7.3	157

(a) No unit.

4.5.3 Spent Media Sampling. On October 27, 2004, spent media samples were collected for metals and TCLP analysis (Section 3.3.4). The results from TCLP analysis (Table 4-13) indicated that the media was non-hazardous and could be disposed of in a lined, permitted sanitary landfill. Only barium was detected at 0.96 and 0.95 mg/L for the spent media taken from Vessels A and B, respectively; the other Resource Conservation and Recovery Act (RCRA) metals were at concentrations less than the respective method detection limits.

Table 4-13. TCLP Results for Spent Media under Phase 1 Run 1

Parameter	Unit	Method	Concentration	
			Tank A	Tank B
Arsenic	mg/L	EPA 200. 7	<0.05	<0.05
Barium	mg/L	EPA 200. 7	0.96	0.95
Cadmium	mg/L	EPA 200. 7	<0.05	<0.05
Chrome	mg/L	EPA 200. 7	<0.05	<0.05
Lead	mg/L	EPA 200. 7	<0.1	<0.1
Mercury	mg/L	EPA 245.1	<0.003	<0.003
Selenium	mg/L	EPA 200.7	<0.3	<0.3
Silver	mg/L	EPA 200. 7	<0.05	<0.05

The ICP-MS results of the spent media were compared to ICP-MS results of the virgin media. The virgin media contained mostly iron at 570 mg/g (as Fe) or 907 mg/g (as FeOOH), which compares closely to the 90.1% (by weight) specified by Bayer AG (Table 4-2). The spent media also contained mostly iron at a higher concentration, i.e., 675 mg/g (as Fe). The metals results indicate that, when compared with the virgin media, the spent media contained higher concentrations of nearly every metal analyzed, including even cations, such as Al, Ca, Cd, Cu, Mg, Mn, Ni, Pb, and Zn. These cationic and anionic metals apparently were removed by the AD-33™ media, as evident by the decreasing concentrations from top to bottom of the media beds. The mechanisms that govern the removal of the cations by this positively charged media is unknown.

The arsenic loading on the spent media based on the ICP-MS results was 1.88 mg/g or 0.188% (average across bed from Table 4-14). The adsorptive capacity also was calculated by dividing the arsenic mass represented by the area between the influent (AP) and effluent (TT) breakthrough curves, as shown in Figure 4-15, by the amount of dry media in each tank. Assuming no media loss, the calculated dry weight of the media, i.e., 1,170 lb, was based on a wet weight of 1,380 lb (i.e., 49 ft^3 of media at 28.1 lb/ft^3) and a maximum moisture content of 15% (Table 4-2). Using this approach, the arsenic loading for the spent media was 1.93 mg/g.

Table 4-14. Total Metals Analysis Results for Virgin and Spent Media*

Analyte	Mg	Al	Si	P	Ca	Fe	Mn	Ni	Cu	Zn	As	Cd	Pb
Unit	µg/g	µg/g	µg/g	µg/g	µg/g	mg/g	mg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
Virgin Media	766	166	96.3	<25.4	1,678	570	1.4	89.5	5.4	9.9	0.9	<0.13	0.52
Top of Tank A	2,088	414	8.9	3,779	5,687	643	27.3	213	14.7	2,550	2,515	0.09	2.9
Middle of Tank A	2,134	314	8.1	3,761	4,335	663	11.1	163	13.5	906	1,831	0.05	1.0
Bottom of Tank A	2,044	309	13.2	3,495	3,680	642	4.8	138	10.4	321	1,392	0.06	0.5
Top of Tank B	2,138	407	11.2	3,706	5,750	654	26.7	217	11.0	2,424	2,475	0.16	2.6
Middle of Tank B	2,245	446	8.0	3,840	3,399	689	7.8	154	9.7	626	1,644	0.17	2.0
Bottom of Tank B	2,186	276	7.9	3,529	2,867	759	5.1	140	8.7	326	1,421	0.07	0.7

*Average compositions calculated from triplicate analyses.

The ICP-MS result of the spent media (see Table 4-14) showed samples collected from the top layer contained notably more manganese than the samples collected from deeper depths. As discussed in Section 4.5.1, it appears that the presence of free chlorine prompted Mn(II) removal on the AD-33™ media. This phenomenon was observed on MnO_x-coated media in a report by Knocke et al. (1990), and likely a similar mechanism resulting from prechlorination occurred in this study.

The chemical composition of the spent media is similar to that of the backwash solids (see Table 4-12), indicating that the backwash solids is comprised mostly of spent media.

4.5.4 Distribution System Water Sampling. Distribution system water samples were collected to determine if the arenic treatment would impact the lead and copper level and water chemistry in the distribution system. Prior to the installation/operation of the treatment system, baseline distribution water samples were collected on December 10, 2003, and January 6, and 21, 2004. Following the installation of the treatment system, distribution water sampling continued on a monthly basis (except during Phase 2) at the same three locations.

The samples were analyzed for pH, alkalinity, arsenic, iron, manganese, lead, and copper. First draw samples were collected at the three sampling locations according to the procedure noted in Section 3.3.5. In addition, flushed samples also were collected at the DS2 and DS3 locations, which were non-residences.

Results of the distribution samples from all three locations following installation of the treatment system were similar to the results from the baseline sampling (Table 4-15). Copper levels did seem to fluctuate slightly more than the other metals analyzed, especially at the DS3 location; however, there was no discernable trend in any of the distribution sampling results collected. It was not possible to determine the effect of the treatment system on the water quality in the distribution system. The distribution system in place was a looped system, combining water from Wells No. 3 and No. 4 at the Porter well house, which typically operated at 100 gpm for about 10 hr/day with the APU-100 system online, and water from the General Sullivan Well, which typically operates at 80 to 100 gpm for about 12 hr/day (see Section 4.1). The blending of the treated water with the untreated water from General Sullivan might have masked any detectable effects of the APU systems on the water quality in the distribution system.

4.6 System Conversion to Coagulation/Filtration

As the longevity of the media did not meet expectations, the NHDES and District made a decision to convert the adsorption system into a C/F system. The conversion was achieved by adding ferric chloride ($FeCl_3$) to raw water to remove soluble As(V) and filtering particles, including arsenic-laden iron solids, using the existing AD-33™ media beds. Specific steps included 1) adding a static in-line mixer where the CO_2 was previously introduced into water at the stainless steel sanitary cross; 2) adding two new chemical feed taps upstream of the static mixer, with one for NaOCl followed by another one for $FeCl_3$; and 3) using existing adsorptive vessels as filters pending evaluation of alternatives. NaOCl was added at a rate similar to that during the adsorption study. $FeCl_3$ was added at a target dose rate of 1 mg/L (as Fe). Contact time prior to entering the media beds was estimated at 1 to 2 min based on a flowrate of 100 gpm and the freeboard height. Treatment plant water samples were collected across the treatment train during four sampling events in May and June 2006, and analyzed for total and/or soluble arsenic, iron, and manganese (including two speciation events). The results, as shown in Appendix B and summarized in Table 4-16, were sporadic and did not show satisfactory treatment results. Backwash sampling results, as presented in Table 4-17, were similar to those for APU-RWS operation except that total metal concentrations were consistently higher as would be expected.

Table 4-15. Distribution System Sampling Results

No. of Sampling Events		DS1								DS2																DS3															
	Address	50 Water Street								Silver St. (Town Garage)																679 Main Street															
	Sample Type	Non-LCR								Non-Residence																Non-Residence															
	Flushed / 1st Draw	1st Draw								1st Draw								Flushed								1st Draw								Flushed							
	Sampling Date	Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time (hrs)	pH	Alkalinity	As	Fe	Mn	Pb	Cu
BL1	12/10/03	6.2	8.6	35	3.3	53	7.1	0.3	7.2	20.2	7.6	27	1.0	<25	4.8	6.2	70.7	NS	NS	NS	NS	NS	NS	NS	NS	20.2	7.6	27	3.5	108	13.0	0.9	290	NS	NS	NS	NS	NS	NS	NS	NS
BL2	01/06/04	6	7.7	41	3.9	100	8.5	1.4	200.0	14.3	6.9	29	0.6	<25	8.6	8.8	103	NA	7.6	31	0.5	<25	8.9	3.1	44.5	9.75	7.3	66	7.1	<25	6.5	2.2	326	NA	7.6	70	6.9	<25	6.3	0.5	328
BL3	01/21/04	18	8.1	49	4.4	149	13.0	2.1	187.7	288	7.8	35	0.6	<25	8.0	1.2	95.6	NA	7.9	29	0.5	<25	7.9	0.6	41.5	14.5	7.8	31	2.7	<25	5.8	3.5	869	NA	7.8	146	24.9	93	62.8	1.5	110
APU-100 Operating																																									
1	03/03/04	6.5	7.2	110	6.6	46	10.3	1.9	192.0	144	6.9	25	0.4	<25	6.3	3.6	77.2	NA	6.8	23	0.3	<25	6.5	0.5	12.4	14.5	7.0	88	5.6	<25	5.6	4.3	531	NA	7.5	157	9.9	<25	22.2	1.8	515
2	04/09/04	7.0	7.8	98	6.7	<25	12.1	0.7	130.5	571	7.8	16	0.5	<25	9.2	1.5	148	NA	7.7	26	0.6	<25	8.1	0.3	22.8	14.8	7.6	90	8.8	<25	4.4	3.1	528	NA	7.6	115	8.3	<25	4.4	2.1	314
3	5/26/2004[a]	6.0	NA	NA	3.0	74	8.9	1.2	192.0	9.5	NA	NA	0.5	<25	4.1	2.7	377[e]	NA	NA	NA	0.4	<25	7.4	0.9	79.1	12.8	NA	NA	2.8	<25	4.1	9.4	830	NA	NA	NA	7.2	<25	2.8	2.3	463
3	5/26/2004[a] rerun																439.1																								
4	7/27/2004[b]	7.0	7.2	77	3.9	108	6.8	2.3	186.0	77	6.8	32	0.8	<25	7.2	7.4	61.5	NA	6.9	20	0.6	<25	8.8	0.9	31.2	13.8	NA	NA	6.0	<25	5.3	9.5	709	NA	7.0	99	13.2	<25	15.4	3.5	195
5	8/25/04[c]	18.1	7.5	120	6.6	<25	3.5	1.6	165.0	552	6.9	32	1.0	<25	6.4	9.9	102	NA	7.3	30	0.8	<25	13.0	2.7	35.1	12.5	7.5	116	6.0	<25	3.3	7.0	771	NA	7.6	130	10.8	<25	9.5	2.6	302
6	09/29/04	7.0	7.8	123	8.3	130	10.9	2.5	118.0	13.9	7.4	41	1.0	<25	4.9	3.5	322	NA	7.6	31	2.5	31	12.1	2.5	32.0	13.8	7.7	123	6.9	<25	3.4	5.8	641	NA	7.5	152	18.9	36	6.6	5.1	804
7	10/28/04	NA	NA	NA	NA	NA	NA	NA	NA	14.0	7.1	36	2.4	<25	8.0	3.4	42.1	NA	8.0	164	1.6	<25	6.9	0.9	128	13.7	7.8	115	9.7	<25	1.8	2.4	234	NA	7.9	115	10.4	<25	1.7	1.2	178
8	12/9/2004[d]	6.0	7.0	106	8.5	99	4.4	1.6	93.2	10.7	7.1	40	1.0	<25	9.0	22.1	110	NA	7.2	37	0.5	<25	9.1	1.0	19.7	15.3	7.1	106	5.4	<25	3.7	4.6	698	NA	7.3	175	4.5	<25	5.0	1.4	111
APU-RWS Operating																																									
1	7/27/2005	7.5	8.2	106	13.0	60	2.5	0.8	28.0	NA	7.5	33	0.5	<25	6.3	4.0	23.8	NA	7.5	136	0.5	<25	12.4	1.9	25.1	NA	8.2	106	8.5	<25	3.1	3.7	67.9	NA	7.5	106	9.8	<25	3.9	1.6	77.4
2	11/3/2005	8.5	7.8	110	9.0	<25	1.9	0.2	8.6	9.5	6.6	44	2.2	<25	4.8	3.8	38.7	NA	6.5	32	0.5	<25	5.4	1.0	66.0	15.0	7.6	110	5.8	<25	3.4	3.9	67.8	NA	7.6	101	5.5	<25	2.7	2.7	80.9
3	12/14/2005	6.1	8.5	114	9.1	<25	2.2	0.2	4.0	13.0	7.7	43	0.7	<25	5.9	2.7	6.8	NA	7.7	42	0.4	<25	6.8	1.0	8.0	14.0	8.2	114	6.3	<25	3.3	1.6	42.1	NA	8.2	114	6.0	<25	3.5	0.6	6.3
4	1/26/2006	12.8	8.3	180	19.1	<25	2.7	0.5	8.7	8.0	7.9	40	1.1	<25	9.2	3.0	9.0	NA	7.9	40	0.7	<25	12.1	0.7	8.2	NA	8.3	104	9.1	<25	5.1	2.5	20.7	NA	8.3	171	18.5	<25	2.9	1.0	21.9

(a) DS1 sampled on May 27, 2004.
(b) DS1 and DS4 sampled on July 26, 2004.
(c) DS2 sampled on August 26, 2004.
(d) DS3 sampled on December 8, 2004.
(e) Data questionable.
BL = baseline sampling; NA = not analyzed; NS = not sampled
Lead action level = 15 µg/L; copper action level = 1.3 mg/L
µg/L as units for all analytical parameters except for alkalinity, which is mg/L (as $CaCO_3$).

Table 4-16. Treatment Train Sampling Results after Conversion to Coagulation/Filtration

Sampling Date		05/08/06			05/17/06			06/07/06			06/22/06		
Parameter	**Unit**	**IN**	**AP**	**TT**	**IN**	**AP**	**TT**	**IN**	**AP**	**TT**	**IN**	**AP**	**TT**
pH	S.U.	7.7	7.4	7.3	7.8	7.8	7.1	7.8	7.9	7.8	7.5	6.9	7.4
Temperature	^{0}C	12.4	12.6	12.2	12.7	12.5	12.5	12.1	12.9	12.9	20.4	16.0	15.6
Free Chlorine	mg/L	-	0.3	0.0	-	0.1	0.1	-	0.0	0.0	-	0.3	0.1
Total Chlorine	mg/L	-	0.6	0.1	-	0.4	0.1	-	0.4	0.0	-	0.6	0.1
As (total)	µg/L	43.0	9.9	12.4	31.8	6.1	7.2	33.0	34.7	15.7	30.9	24.6	11.3
As (soluble)	µg/L	-	-	-	27.3	3.7	4.5	-	-	-	27.4	0.6	10.6
As (particulate)	µg/L	-	-	-	4.4	2.3	2.7	-	-	-	3.5	24.0	0.7
As (III)	µg/L	-	-	-	13.6	0.4	0.4	-	-	-	14.7	0.4	10.4
As (V)	µg/L	-	-	-	13.8	3.3	4.1	-	-	-	12.7	0.2	0.2
Fe (total)	µg/L	556	349	722	399	231	217	273	181	<25	185	10,915	<25
Fe (soluble)	µg/L	-	-	-	512	<25	<25	-	-	-	72	<25	<25
Mn (total)	µg/L	115	41.0	51.4	280	4.0	9.3	98.4	121	8.5	160	209	1.1
Mn (soluble)	µg/L	-	-	-	281	1.3	1.3	-	-	-	148	153	1.3

Table 4-17. Backwash Wastewater Sampling Results after Conversion to Coagulation/Filtration

Date	Vessel A					Vessel B				
	pH	**TDS[(a)]**	**Soluble As[(b)]**	**Soluble Fe[(b)]**	**Soluble Mn[(b)]**	**pH**	**TDS**	**Soluble As[(b)]**	**Soluble Fe[(b)]**	**Soluble Mn[(b)]**
	S.U.	**mg/L**	**µg/L**	**µg/L**	**µg/L**	**S.U.**	**mg/L**	**µg/L**	**µg/L**	**µg/L**
05/08/06	7.5	288 [142]	4.8 (233)	93.3 (19,762)	4.3 (1,416)	7.6	308 [182]	5.9 (171)	86.1 (20,298)	6.3 (1,286)

(a) Values in brackets are TSS results.
(b) Values in parentheses are total metals results.

4.7 System Cost

The cost of the Phase 2 APU-RWS system was evaluated based on the capital cost per gpm (or gpd) of the design capacity and the O&M cost per 1,000 gal of water treated. The capital and O&M cost for the APU-100 system was evaluated previously and reported in the six-month report (Battelle, 2005).

4.7.1 Capital Cost. The capital cost for equipment, site engineering, and installation was $131,692 (see Table 4-18). The equipment cost was $105,805 (or 80% of the total capital investment), which included $30,970 for the skid-mounted APU-RWS unit, $25,100 for the CO_2 gas flow control system and field upgrade, $14,700 for the AD-33™ media ($245/$ft^3$ to fill both vessels), and $35,035 for miscellaneous materials and labor for system fabrication.

The engineering cost included the cost for the preparation of the engineering plans, system layout and footprint, drawings of site and piping plans, and equipment cut sheets for the permit application submittal (see Section 4.3.1). The engineering cost was $4,672, which was 4% of the total capital investment.

The installation cost included the equipment and labor to unload and install the skid-mounted unit, perform the piping tie-ins and electrical work, and load and backwash the media (see Section 4.3.3). The installation was performed by AdEdge and Waterline Services, a local contractor subcontracted by AdEdge to perform the installation. The installation cost was $21,215, or 16% of the total capital investment.

Table 4-18. Capital Investment Cost for APU-RWS System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Cost			
APU Skid-Mounted System	1 unit	$30.970	–
AD-33™ Media	60 ft^3	$14,700	–
pH Adjustment Module	1	$25,100	–
Miscellaneous Materials and Labor	–	$35,035	–
Equipment Total	–	**$105,805**	**80%**
Engineering Cost			
Material	–	$98	–
Vendor Labor	–	$2,935	–
Vendor Travel	–	$1,640	–
Engineering Total	–	**$4,672**	**4%**
Installation Cost			
Material	–	$240	–
Subcontractor	–	$17,215	–
Vendor Labor	–	$2,160	–
Vendor Travel	–	$1,600	–
Installation Total	–	**$21,215**	**16%**
Total Capital Investment	–	**$131,692**	**100%**

The Rollinsford Water and Sewer District constructed a new treatment building next to the existing Porter well house. The wood frame structure measures 33 ft × 13 ft and has a concrete foundation and floor. The building cost was approximately $57,000, including design and construction of the subsurface leach field directly adjacent to the building, used for disposing of the backwash water from the system.

The capital cost of $131,692 was normalized to $1,097/gpm ($0.76/gpd) of design capacity using the system's design flowrate of 120 gpm (or 172,800 gpd). The capital cost also was converted to an annualized cost of $12,431/yr using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-year return period. If the system had operated 24 hr/day, 7 day/week at the 120-gpm design flowrate to produce 63,072,000 gal/yr, the unit capital cost would have been $0.20/1000 gal. Because the system operated only about 10 hr/day (see Table 4-6), producing approximately 21,243,000 gal of water in one year, the unit annualized capital cost increased to $0.59/1,000 gal at this reduced rate of usage.

4.7.2 Operation and Maintenance Cost. The O&M cost included media replacement and disposal, chemical supply, electricity consumption, and labor (Table 4-19). The media replacement cost represented the majority of the O&M cost and was estimated to be $19,520 to change out both vessels. This media change-out cost included costs for media, freight, labor, travel expenses, and media profiling and disposal fee. This cost was used to estimate the media replacement cost per 1,000 gal of water treated as a function of the projected media run length to the 10 μg/L arsenic breakthrough (Figure 4-20). Based on a breakthrough of 12,500 BV, the media replacement and disposal cost was $3.48/1,000 gal of water treated. As shown in Figure 4-20, the unit O&M cost can be significantly lower if the media run length is longer.

The chemical cost associated with the operation of the treatment system included the use of NaOCl for prechlorination, which had already been used prior to this demonstration study. The APU-RWS system did not affect the use rate of the NaOCl solution, therefore, the incremental chemical cost for chlorine was negligible. As discussed in Section 4.4.3, the CO_2 gas flow control system was not used during operation of the APU-RWS system.

Comparison of electrical bills supplied by the District prior to system installation and since system startup did not indicate a noticeable increase in power consumption. Therefore, electrical cost associated with APU system operation was assumed to be negligible.

Under normal operating conditions, routine labor activities to operate and maintain the system required only 15 to 20 min/day, as noted in Section 4.4.7. Therefore, the estimated labor cost was $0.11/1,000 gal of water treated, based on operating 10 hours per day, 7 days per week, at 97 gpm. Thus, the total O&M cost, including media replacement, is $3.59/1,000 gal of water treated.

Table 4-19. O&M Cost for the APU-RWS System

Cost Category	Value	Assumptions
Volume processed (kgal)	5,613	12,500 BV treatment capacity
Media Replacement and Disposal		
Media cost ($/ft^3)	$245	Vendor quote
Total media volume (ft^3)	60	Both vessels
Media replacement cost	$14,700	Vendor quote
Under-bedding replacement cost	$350	Vendor quote
Freight	$450	Vendor quote
Labor cost	$3,120	Vendor quote
Waste analysis	$450	Vendor quote
Media disposal fee	$450	Vendor quote
Subtotal	$19,520	Vendor quote
Media replacement and disposal cost ($/1,000 gal)	3.48	Based upon media run length at 10-μg/L arsenic breakthrough
Chemical Usage		
Chemical cost ($/1,000 gal)	$0	No additional costs for chlorination
Electricity		
Electricity cost ($/1,000 gal)	$0.001	Electrical costs assumed negligible
Labor		
Average weekly labor (hr)	2.3	20 min/day, 7 day/week
Labor cost ($/1,000 gal)	$0.11	Labor rate $20/hr, 407,400 gal/wk
Total O&M Cost/1,000 gal	3.59	Based upon media run length at 10-μg/L arsenic breakthrough

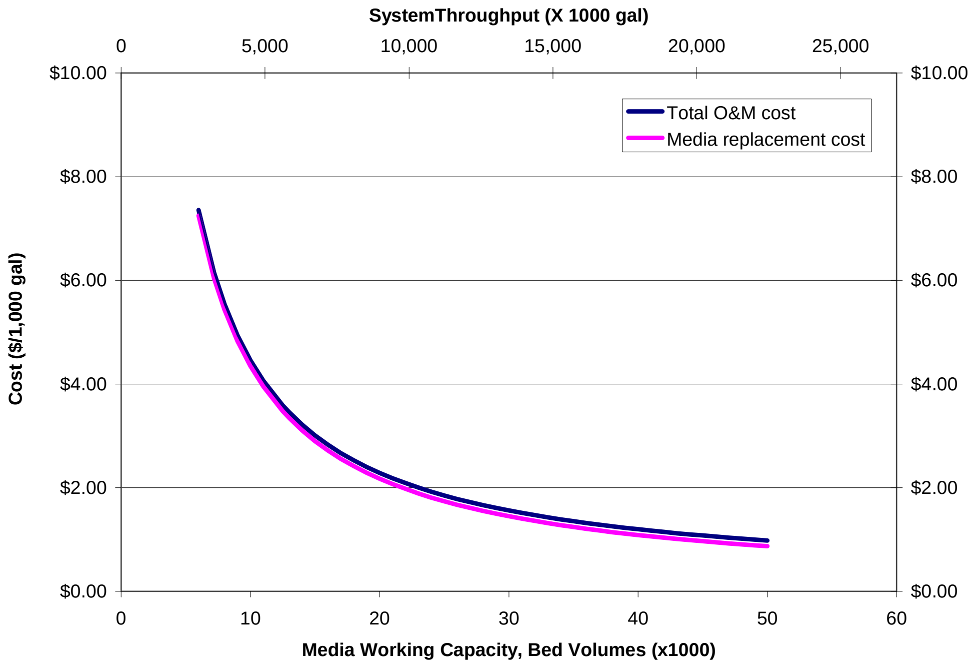


Figure 4-20. Media Replacement and Operation and Maintenance Cost

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APPENDIX A

OPERATIONAL DATA

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation

Week No.	Date	Pump House: Avg Operation Hours (hr)	Pump House: Cumulative Operation Hours (hr)	Pump House: Master Flow Meter (gal)	Instrument Panel: Flow Totalizer Vessel A (Kgal)	Flow Totalizer Vessel B (kgal)	Cumulative Flow Totalizer (kgal)	Avg Flowrate (gpm)	Cumulative Bed Volumes Treated (a)(b) (No.)	Head Loss: Tank A (psi)	Head Loss: Tank B (psi)	System Pressure: Influent (psi)	System Pressure: Effluent (psi)	System Pressure: ΔP (psi)
1	2/9/2004	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2/10/2004	0.0	0.0	36,690	NA	NA	NA	NA	NA	8.2	7.4	79	64	15
	2/11/2004	16.5	16.5	36,793	27	29	56	56	151	9.1	7.5	80	64	16
	2/12/2004	10.1	26.6	36,853	55	61	116	101	317	12.0	9.4	82	65	17
	2/13/2004	9.9	36.5	36,913	80	92	172	94	470	13.0	9.8	82	64	18
	2/14/2004	0.6	37.1	36,917	83	95	178	NA	485	0.0	0.0	0	0	0
	2/15/2004	0.1	37.2	36,917	83	96	179	NA	487	12.5	11.2	84	64	20
2	2/16/2004	10.1	47.3	36,981	112	126	238	98	649	10.5	9.0	80	64	16
	2/17/2004	10.0	57.3	37,044	139	157	296	97	807	11.7	9.7	81	64	17
	2/18/2004	10.0	67.3	37,105	167	187	354	97	964	12.5	10.2	81	64	17
	2/19/2004	9.9	77.1	37,165	193	216	410	94	1,116	13.2	11.2	82	64	18
	2/20/2004	9.9	87.1	37,225	220	246	466	94	1,269	14.4	12.2	83	64	19
	2/21/2004	9.9	97.0	37,285	246	276	522	95	1,422	15+	14.4	84	64	20
	2/22/2004	10.3	107.3	37,343	272	304	577	88	1,571	15+	15+	88	65	23
3	2/23/2004	10.0	117.3	37,400	297	332	629	89	1,715	15+	15+	90	66	24
	2/24/2004	10.5	127.8	37,462	325	362	687	92	1,873	13.5	11.8	85	68	17
	2/25/2004	11.8	139.7	37,523	352	392	744	80	2,028	13.5	11.4	84	67	17
	2/26/2004	8.3	148.0	37,580	378	420	797	106	2,172	15.0	13.0	85	67	18
	2/27/2004	9.7	157.7	37,615	392	437	829	55	2,260	10.4	9.6	77	64	13
	2/28/2004	11.9	169.5	37,678	428	461	889	84	2,423	13.4	14.6	86	67	19
	2/29/2004	10.7	180.2	37,738	460	485	945	87	2,575	14.0	15+	88	68	20

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel									
		Avg Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Amount Treated[(a)(b)]	Head Loss		System Pressure		
										Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	kgal	kgal	kgal	gpm	BV	psi	psi	psi	psi	psi
4	03/01/04	7.2	187.4	37,775	481	499	980	81	2,670	7.8	8.5	76	65	11
	03/02/04	10.0	197.4	37,812	501	513	1014	56	2,762	11.8	11.8	80	66	14
	03/03/04	11.6	209.0	37,877	533	542	1075	89	2,930	9.6	9.5	82	66	16
	03/04/04	9.4	218.4	37,938	563	569	1132	100	3,083	12.0	11.2	82	66	16
	03/05/04	11.4	229.9	37,999	593	596	1188	82	3,238	13.0	12.6	83	66	17
	03/06/04	8.9	238.7	38,060	632	623	1255	126	3,420	15+	14.6	86	66	20
	03/07/04	10.0	248.7	38,096	639	640	1278	39	3,484	11.2	10.2	78	66	12
5	03/08/04	9.8	258.5	38,122	657	656	1313	58	3,577	9.6	9.6	77	65	12
	03/09/04	10.1	268.6	38,170	674	672	1347	56	3,670	10.0	9.8	79	67	12
	03/10/04	11.4	280.0	38,242	708	705	1414	98	3,852	11.5	10.2	82	67	15
	03/11/04	10.1	290.1	38,304	736	734	1470	93	4,005	12.6	11.4	83	66	17
	03/12/04	9.9	300.0	38,365	764	762	1526	94	4,158	14.2	13.0	84	66	18
6	System Not Operating													

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel									
		Avg Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Bed Volumes Treated (a)(b)	Head Loss Tank A	Head Loss Tank B	System Pressure Influent	System Pressure Effluent	System Pressure ΔP
		hr	hr	gal	kgal	kgal	kgal	gpm	No.	psi	psi	psi	psi	psi
7				39,302										
	3/26/2004	11.3	311.4	39,367	827	827	1654	NA	4,508	10.6	11.2	83	67	16
	3/27/2004	10.1	321.4	39,420	852	851	1704	81	4,642	10.6	11.0	82	67	15
	3/28/2004	10.1	331.6	39,475	877	876	1753	81	4,776	11.8	11.8	84	67	17
8	3/29/2004	10.1	341.7	39,529	901	901	1802	81	4,910	10.6	10.8	83	67	16
	3/30/2004	10.0	351.7	39,581	925	926	1851	82	5,044	11.9	11.6	83	67	16
	3/31/2004	10.5	362.3	39,637	951	952	1903	82	5,186	13.0	12.5	83	66	17
	4/1/2004	9.8	372.1	39,690	975	977	1952	83	5,319	13.4	13.4	83	66	17
	4/2/2004	10.0	382.1	39,743	999	1,003	2002	83	5,455	14.2	14.0	84	66	18
	4/3/2004	11.0	393.1	39,802	1,027	1,030	2057	84	5,606	11.8	12.3	83	66	17
	4/4/2004	10.1	403.2	39,858	1,053	1,055	2108	84	5,744	12.5	12.8	84	67	17
9	4/5/2004	10.2	413.4	39,911	1,078	1,080	2159	83	5,882	14.0	14.6	86	66	20
	4/6/2004	10.1	423.4	39,965	1,103	1,106	2209	83	6,018	13.2	13.8	86	67	19
	4/7/2004	11.0	434.4	40,025	1,130	1,133	2263	82	6,167	13.3	13.6	84	67	17
	4/8/2004	9.8	444.3	40,077	1,154	1,158	2312	83	6,300	14.0	13.9	84	66	18
	4/9/2004	10.2	454.4	40,131	1,179	1,183	2362	82	6,437	15+	15+	90	66	24
	4/10/2004	11.0	465.4	40,190	1,207	1,210	2418	84	6,588	11.2	11.7	82	66	16
	4/11/2004	10.2	475.7	40,246	1,233	1,236	2469	84	6,728	12.5	12.8	84	67	17

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

		Pump House			Instrument Panel									
										Head Loss		System Pressure		
Week No.	Date	Avg Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Bed Volumes Treated (a)(b)	Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	k gal	k gal	k gal	gpm	No.	psi	psi	psi	psi	psi
10	4/12/2004	10.1	485.8	40,300	1,259	1,261	2520	84	6,866	13.8	14.5	86	65	21
	4/13/2004	10.1	495.9	40,354	1,283	1,286	2570	83	7,002	12.8	13.0	84	65	19
	4/14/2004	10.0	505.9	40,407	1,308	1,312	2620	83	7,138	12.8	12.8	84	66	18
	4/15/2004	9.9	515.8	40,461	1,333	1,336	2669	82	7,272	14.5	14.7	84	66	18
	4/16/2004	10.0	525.8	40,514	1,357	1,361	2719	83	7,407	15.0	15+	84	66	18
	4/17/2004	12.6	538.4	40,583	1,391	1,394	2784	87	7,586	9.6	10.4	82	66	16
	4/18/2004	18.9	557.2	40,680	1,436	1,438	2874	79	7,831	11.4	11.6	84	68	16
11	4/19/2004	10.0	567.2	40,731	1,460	1,462	2922	80	7,961	11.2	11.7	84	68	16
	4/20/2004	10.8	578.0	40,788	1,486	1,488	2974	81	8,103	12.0	11.8	83	67	16
	4/21/2004	9.9	587.9	40,841	1,510	1,508	3018	74	8,225	12.6	12.7	83	67	16
	4/22/2004	10.0	597.9	40,894	1,534	1,538	3072	90	8,371	13.4	13.2	84	66	18
	4/23/2004	11.1	609.0	40,953	1,562	1,566	3128	83	8,522	12.9	14.0	84	66	18
	4/24/2004	10.1	619.2	41,007	1,586	1,592	3178	83	8,660	15+	15+	86	66	20
	4/25/2004	11.3	630.4	41,068	1,615	1,619	3234	83	8,812	12.2	12.8	85	67	18
12	4/26/2004	10.0	640.4	41,122	1,640	1,644	3284	84	8,949	13.6	14.6	84	67	17
	4/27/2004	10.0	650.4	41,178	1,666	1,669	3334	84	9,085	14.8	15+	87	67	20
	4/28/2004	10.0	660.4	41,229	1,690	1,694	3384	82	9,220	15.0	15+	87	66	21
	4/29/2004	10.1	670.5	41,282	1,715	1,719	3434	83	9,356	15+	15+	86	65	21
	4/30/2004	11.3	681.8	41,338	1,740	1,745	3486	76	9,497	15+	15+	87	64	23
	5/1/2004	10.1	691.9	41,400	1,770	1,773	3543	95	9,654	12.6	13.2	82	65	17
	5/2/2004	10.0	701.9	41,455	1,796	1,798	3594	85	9,793	12.2	13.2	81	65	16

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel									
		Avg Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Bed Volumes Treated (a)(b)	Head Loss Tank A	Head Loss Tank B	System Pressure Influent	System Pressure Effluent	System Pressure ΔP
		hr	hr	gal	kgal	kgal	kgal	gpm	No.	psi	psi	psi	psi	psi
13	5/3/2004	9.9	711.8	41,509	1,821	1,823	3644	84	9,930	12.8	12.4	82	65	17
	5/4/2004	10.0	721.8	41,563	1,846	1,848	3694	83	10,067	15.0	15+	85	64	21
	5/5/2004	10.1	731.9	41,617	1,871	1,873	3745	83	10,203	15.0	15.0	85	66	19
	5/6/2004	10.4	742.3	41,671	1,896	1,898	3794	79	10,338	15+	15+	85	66	19
	5/7/2004	9.8	752.1	41,724	1,919	1,924	3843	84	10,472	15+	15+	86	66	20
	5/8/2004	12.1	764.2	41,735	1,926	1,930	3855	NA	10,505	10.5	18.0	80	66	14
	5/9/2004	10.1	774.3	41,771	1,941	1,948	3889	55	10,596	11.5	20.0	76	64	12
14	5/10/2004	9.7	783.9	41,807	1,957	1,966	3923	58	10,688	18.0	26.5	78	62	16
	5/11/2004	10.3	794.3	41,843	1,973	1,983	3956	53	10,778	19.0	27.5	78	62	16
	5/12/2004	10.1	804.3	41,879	1,988	2,000	3988	53	10,866	20.0	27.5	79	62	17
	5/13/2004	24.9	829.3	41,963	2,023	2,043	4065	52	11,077	20.0	27.0	80	64	16
	5/14/2004	23.6	852.8	42,040	2,055	2,083	4138	51	11,275	21.0	27.5	82	65	17
	5/15/2004	25.5	878.3	42,121	2,089	2,124	4213	49	11,480	23.0	29.5	82	64	18
	5/16/2004	6.2	884.5	42,147	2,101	2,135	4236	62	11,543	6.5	15.0	76	64	12
15	5/17/2004	10.7	895.3	42,183	2,118	2,152	4270	52	11,634	10.0	14.0	72	64	8
	5/18/2004	10.0	905.3	42,219	2,135	2,168	4303	56	11,725	10.0	16.0	75	64	11
	5/19/2004	10.6	915.8	42,257	2,153	2,186	4339	56	11,823	11.5	18.5	75	64	11
	5/20/2004	0.8	916.6	42,260	2,155	2,187	4342	NA	11,831	13.0	21.5	76	63	13
	5/21/2004	10.0	926.6	42,298	2,172	2,205	4376	57	11,924	13.5	21.0	74	62	12
	5/22/2004	25.0	951.6	42,387	2,213	2,246	4459	55	12,150	13.0	21.0	76	62	14
	5/23/2004	24.6	976.3	42,471	2,251	2,285	4536	52	12,360	13.0	21.0	77	64	13

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

		Pump House			Instrument Panel									
		Avg Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Bed Volumes Treated (a)(b)	Head Loss		System Pressure		
Week No.	Date									Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	kgal	kgal	kgal	gpm	No.	psi	psi	psi	psi	psi
16	5/24/2004	10.0	986.3	42,506	2,268	2,302	4570	57	12,452	12.5	20.5	79	64	15
	5/25/2004	20.4	1,006.7	42,579	2,284	2,319	4603	27	12,542	13.5	21.0	78	65	13
	5/26/2004	NA	NA	NA	2,302	2,336	4638	NA	12,636	15.0	25.0	78	62	16
	5/27/2004	10.0	1,016.7	42,615	2,317	2,353	4671	55	12,726	14.0	20.5	76	64	12
	5/28/2004	10.0	1,026.7	42,649	2,332	2,372	4703	55	12,816	25.0	30.0	82	63	19
	5/29/2004	11.2	1,037.9	42,687	2,350	2,390	4740	55	12,915	14.0	23.0	84	63	21
	5/30/2004	10.3	1,048.2	42,713	2,360	2,405	4765	41	12,984	25.0	30.0	100	64	36
17	5/31/2004	0.0	1,048.2	42,714	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	6/1/2004	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	6/2/2004	9.9	1,058.1	42,752	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	6/3/2004	10.1	1,068.2	42,792	2,363	2,407	4770	NA	12,996	20.0	30.0	100	64	36
	6/4/2004	11.0	1,079.2	42,823	2,378	2,421	4799	45	13,078	25.0	30.0	96	64	32
	6/5/2004	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	6/6/2004	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
18	6/7/2004	32.5	1,111.7	42,938	2,431	2,474	4905	NA	13,365	25.0	30+	96	64	32
	6/8/2004	9.9	1,121.6	42,971	2,447	2,490	4937	54	13,452	11.0	20.0	75	62	13
	6/9/2004	11.1	1,132.7	43,009	2,462	2,510	4972	53	13,548	25.0	30+	87	63	24
	6/10/2004	23.8	1,156.5	43,086	2,497	2,550	5046	52	13,750	25.0	30+	88	62	26
	6/11/2004	24.0	1,180.5	43,167	2,524	2,599	5123	53	13,959	25.0	30+	80	60	20
	6/12/2004	18.4	1,198.9	43,227	2,545	2,637	5182	54	14,121	25.0	30+	92	62	30
	6/13/2004	10.2	1,209.1	43,260	2,554	2,657	5211	47	14,200	25.0	30+	96	62	34

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

Week No.	Date	Pump House: Avg Operation Hours (hr)	Pump House: Cumulative Operation Hours (hr)	Pump House: Master Flow Meter (gal)	Instrument Panel: Flow Totalizer Vessel A (kgal)	Flow Totalizer Vessel B (kgal)	Cumulative Flow Totalizer (kgal)	Avg Flowrate (gpm)	Cumulative Bed Volumes Treated (a)(b) (No.)	Head Loss: Tank A (psi)	Head Loss: Tank B (psi)	System Pressure: Influent (psi)	System Pressure: Effluent (psi)	System Pressure: ΔP (psi)
	6/14/2004	10.3	1,219.40	43,291	2,567	2,685	5252	66	14,310	28	30+	100+	64	36+
	6/15/2004	21.6	1,241.00	43,371										
	6/16/2004					System Not Operating								
	6/17/2004													
	6/18/2004													
	6/19/2004	75.3	1,316.30	43,636	2,586	2,699	5285	NA	14,402	17	17	80	63	17
19	6/20/2004	10.1	1,326.40	43,669	2,599	2,718	5316	51	14,486	26	26	86	62	24
	6/21/2004	10	1,336.40	43,702	2,620	2,737	5357	68	14,598	29	29	90	61	29
	6/22/2004	10	1,346.40	43,722	2,623	2,755	5378	35	14,655	30+	30+	93	60	33
	6/23/2004	10.1	1,356.50	43,763	2,635	2,769	5404	43	14,725	30+	30+	93	60	33
	6/24/2004													
	6/25/2004													
	6/26/2004													
20	6/27/2004													
	6/28/2004					System Not Operating								
	6/29/2004													
	6/30/2004													
	7/1/2004													
	7/2/2004													
	7/3/2004													
21	7/4/2004													

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel									
		Avg Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Bed Volumes Treated (a)(b)	Head Loss Tank A	Head Loss Tank B	System Pressure Influent	System Pressure Effluent	System Pressure ΔP
		hr	hr	gal	kgal	kgal	kgal	gpm	No.	psi	psi	psi	psi	psi
22	7/5/2004													
	7/6/2004					System Not Operating								
	7/7/2004													
	7/8/2004													
	7/9/2004	96.4	1,452.8	44,474	2,657	2,793	5450	NA	14,851	10.0	7.5	72	63	9
	7/10/2004	10.1	1,462.9	44,512	2,673	2,814	5487	60	14,951	10.0	7.5	71	63	8
	7/11/2004	10.1	1,473.0	44,550	2,693	2,834	5526	65	15,058	11.0	9.0	74	63	11
23	7/12/2004	10.2	1,483.2	44,587	2,706	2,854	5560	55	15,149	11.5	8.0	73	62	11
	7/13/2004	10.1	1,493.3	44,625	2,722	2,874	5596	60	15,248	13.0	10.0	74	62	12
	7/14/2004	10.4	1,503.7	44,664	2,739	2,894	5633	60	15,349	15.0	12.0	75	62	13
	7/15/2004	10.0	1,513.7	44,700	2,754	2,914	5668	58	15,444	17.5	14.0	78	62	16
	7/16/2004	9.9	1,523.6	44,737	2,770	2,934	5703	60	15,541	18.0	14.5	79	63	16
	7/17/2004	10.0	1,533.6	44,776	2,786	2,954	5740	61	15,640	11.0	9.0	72	64	8
	7/18/2004	10.3	1,543.9	44,813	2,802	2,974	5775	58	15,737	15.0	13.0	78	63	15
24	7/19/2004	10.1	1,554.0	44,850	2,817	2,993	5811	58	15833	20.0	15.0	82	62	20
	7/20/2004	10.1	1,564.1	44,887	2,835	3,010	5846	58	15,928	21.0	16.0	82	62	20
	7/21/2004	10.3	1,574.4	44,924	2,853	3,028	5881	57	16,024	25.0	17.0	85	62	23
	7/22/2004	12.3	1,586.7	44,991	2,883	3,055	5939	78	16,181	30+	30+	100+	64	36+
	7/23/2004	10.3	1,597.0	45,058	2,916	3,086	6003	104	16,356	30+	30+	100+	64	36+
	7/24/2004	10.8	1,607.8	45,128	2,940	3,109	6049	71	16,482	30+	30+	98	64	34
	7/25/2004	10.2	1,618.0	45,192	2,963	3,137	6100	84	16,622	30+	30+	100	66	34

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel									
		Avg Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Bed Volumes Treated (a)(b)	Head Loss		System Pressure		
										Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	kgal	kgal	kgal	gpm	No.	psi	psi	psi	psi	psi
25	7/26/2004	10.1	1,628.1	45,255	2,991	3,156	6148	78	16,751	30+	30+	100	66	34
	7/27/2004	10.9	1,639.0	45,327	3,015	3,190	6204	87	16,906	19.0	18.0	84	66	18
	7/28/2004	10.7	1,649.7	45,393	3,036	3,221	6256	81	17,047	22.0	21.5	88	66	22
	7/29/2004	16.0	1,665.7	45,496	3,066	3,268	6334	81	17,260	30+	30+	100	65	35
	7/30/2004	10.8	1,676.5	45,567	3,094	3,298	6392	89	17,417	20.0	19.0	84	64	20
	7/31/2004	10.0	1,686.6	45,633	3,116	3,329	6445	87	17,561	20.0	19.0	82	63	19
	8/1/2004	14.8	1,701.3	45,727	3,147	3,372	6519	83	17,762	22.0	22.0	87	64	23
26	8/2/2004	0.0	1,701.3	45,792	3,167	3,402	6569	NA	17,899	23.5	23.0	90	64	26
	8/3/2004	20.2	1,721.5	45,854	3,188	3,431	6619	41	18,035	25.0	24.0	92	64	28
	8/4/2004	10.0	1,731.5	45,921	3,207	3,461	6668	82	18,169	25.0	25.0	90	64	26
	8/5/2004	12.0	1,743.5	46,001	3,242	3,497	6739	98	18,362	13.0	12.0	76	64	12
	8/6/2004	9.9	1,753.4	46,067	3,270	3,527	6797	98	18,520	14.0	12.0	74	64	10
	8/7/2004	10.1	1,763.5	46,134	3,300	3,558	6857	100	18,685	16.0	15.0	78	64	14
	8/8/2004	10.2	1,773.7	46,201	3,329	3,588	6917	97	18,847	16.0	16.5	80	65	15
27	8/9/2004	9.7	1,783.4	46,267	3,356	3,619	6975	100	19,006	17.0	16.0	82	65	17
	8/10/2004	0.0	1,783.4	46,267	3,356	3,619	6975	NA	19,006	17.0	17.0	80	64	16
	8/11/2004	11.6	1,795.0	46,342	3,387	3,654	7041	95	19,185	16.5	16.0	80	64	16
	8/12/2004	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	8/13/2004	19.7	1,814.7	46,477	3,439	3,718	7158	99	19,503	19.0	18.0	82	64	18
	8/14/2004	10.1	1,824.8	46,546	3,465	3,752	7217	98	19,664	21.0	20.0	84	64	20
	8/15/2004	10.3	1,835.0	46,613	3,489	3,785	7274	93	19,821	21.0	20.0	86	65	21

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel									
		Avg Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Bed Volumes Treated (a)(b)	Head Loss Tank A	Head Loss Tank B	System Pressure Influent	System Pressure Effluent	System Pressure ΔP
		hr	hr	gal	kgal	kgal	kgal	gpm	No.	psi	psi	psi	psi	psi
28	8/16/2004	10.2	1,845.2	46,679	3,514	3,818	7331	93	19,977	22.0	21.0	100	67	33
	8/17/2004	10.3	1,855.6	46,748	3,543	3,853	7396	105	20,154	17.0	17.0	94	66	28
	8/18/2004	10.5	1,866.0	46,817	3,574	3,886	7460	102	20,328	19.0	19.0	99	68	31
	8/19/2004	10.7	1,876.7	46,889	3,608	3,919	7526	103	20,508	12.0	11.0	90	68	22
	8/20/2004	10.0	1,886.7	46,955	3,639	3,949	7588	102	20,675	12.0	13.0	90	68	22
	8/21/2004	10.1	1,896.8	47,023	3,670	3,981	7651	104	20,847	14.0	14.0	92	68	24
	8/22/2004	10.2	1,907.0	47,090	3,700	4,012	7713	101	21,016	15.0	15.0	94	68	26
29	8/23/2004	10.0	1,917.0	47,157	3,730	4,044	7774	103	21,183	15.5	15.5	94	68	26
	8/24/2004	10.1	1,927.1	47,224	3,760	4,076	7836	102	21,351	16.0	16.0	96	68	28
	8/25/2004	10.3	1,937.3	47,291	3,789	4,110	7899	102	21,522	15.5	15.0	96	68	28
	8/26/2004	10.0	1,947.3	47,358	3,817	4,141	7959	100	21,687	16.0	16.0	94	68	26
	8/27/2004	10.0	1,957.3	47,424	3,846	4,173	8020	101	21,852	16.5	16.0	95	68	27
	8/28/2004	10.2	1,967.5	47,492	3,875	4,206	8081	101	22,020	17.5	17.0	96	68	28
	8/29/2004	10.1	1,977.6	47,559	3,904	4,239	8143	102	22,188	17.0	17.0	96	68	28
30	8/30/2004	10.0	1,987.6	47,625	3,932	4,272	8204	101	22,354	18.0	17.0	96	68	28
	8/31/2004	10.1	1,997.6	47,691	3,959	4,305	8264	100	22,517	18.0	17.0	98	68	30
	9/1/2004	10.8	2,008.4	47,762	3,988	4,340	8328	100	22,693	18.0	17.0	98	68	30
	9/2/2004	10.3	2,018.7	47,830	4,016	4,374	8390	100	22,862	18.5	17.5	84	68	16
	9/3/2004	9.9	2,028.6	47,895	4,043	4,407	8450	100	23,023	19.0	18.5	83	68	15
	9/4/2004	10.2	2,038.8	47,962	4,069	4,441	8510	99	23,188	20.5	20.0	84	68	16
	9/5/2004	10.3	2,049.0	48,028	4,095	4,476	8571	99	23,354	21.0	20.0	86	68	18

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

Week No.	Date	Pump House: Avg Operation Hours (hr)	Pump House: Cumulative Operation Hours (hr)	Pump House: Master Flow Meter (gal)	Instrument Panel: Flow Totalizer Vessel A (kgal)	Flow Totalizer Vessel B (kgal)	Cumulative Flow Totalizer (kgal)	Avg Flowrate (gpm)	Cumulative Bed Volumes Treated (a)(b) (No.)	Head Loss: Tank A (psi)	Head Loss: Tank B (psi)	System Pressure: Influent (psi)	System Pressure: Effluent (psi)	System Pressure: ΔP (psi)
	9/6/2004	9.9	2,058.9	48,094	4,120	4,511	8631	101	23,517	21.5	20.5	86	68	18
	9/7/2004	9.9	2,068.9	48,159	4,145	4,546	8691	100	23,680	22.0	22.0	86	66	20
	9/8/2004	10.2	2,079.1	48,225	4,175	4,576	8751	98	23,844	27.0	17.0	92	68	24
31	9/9/2004	11.1	2,090.2	48,298	4,208	4,609	8818	101	24,026	11.5	13.0	76	68	8
	9/10/2004	10.8	2,101.0	48,369	4,240	4,642	8882	100	24,203	12.0	12.0	78	68	10
	9/11/2004	10.1	2,111.1	48,436	4,270	4,673	8943	101	24,369	14.0	14.0	80	68	12
	9/12/2004	10.1	2,121.2	48,503	4,300	4,705	9004	101	24,535	15.0	15.0	80	68	12
	9/13/2004	10.0	2,131.2	48,569	4,328	4,737	9065	101	24,700	15.0	15.0	80	68	12
	9/14/2004	10.2	2,141.4	48,636	4,355	4,767	9122	93	24,855	15.0	14.0	82	68	14
	9/15/2004	11.0	2,152.3	48,707	4,384	4,802	9187	99	25,032	15.0	15.0	82	68	14
32	9/16/2004	9.9	2,162.2	48,772	4,411	4,835	9246	101	25,194	17.0	17.0	82	68	14
	9/17/2004	10.0	2,172.2	48,837	4,437	4,869	9306	99	25,356	17.0	17.0	82	68	14
	9/18/2004	10.2	2,182.4	48,903	4,463	4,903	9366	98	25,520	18.0	18.0	84	68	16
	9/19/2004	10.0	2,192.4	48,968	4,488	4,945	9433	112	25,703	18.0	17.0	84	68	16
	9/20/2004	10.0	2,202.4	49,033	4,514	4,971	9485	86	25,844	18.0	18.0	84	68	16
	9/21/2004	10.0	2,212.4	49,099	4,539	5,006	9545	101	26,009	20.0	19.0	86	68	18
	9/22/2004	9.9	2,222.3	49,165	4,567	5,038	9605	101	26,172	20.0	18.0	86	68	18
33	9/23/2004	11.0	2,233.3	49,233	4,593	5,075	9668	96	26,344	19.0	19.0	84	68	16
	9/24/2004	9.9	2,243.2	49,298	4,618	5,109	9727	99	26,503	20.0	20.0	86	68	18
	9/25/2004	10.3	2,253.4	49,363	4,642	5,144	9786	97	26,665	20.0	20.0	86	68	18
	9/26/2004	10.1	2,263.6	49,429	4,667	5,180	9846	99	26,829	20.5	21.0	86	68	18

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel										
		Avg Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Bed Volumes Treated (a)(b)	Head Loss		System Pressure		
										Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	kgal	kgal	kgal	gpm	No.	psi	psi	psi	psi	psi
34	9/27/2004	10.1	2,273.6	49,493	4,691	5,215	9906	99	26,992	20.0	20.0	86	68	18
	9/28/2004	10.0	2,283.6	49,558	4,715	5,250	9966	99	27,154	22.0	22.0	86	68	18
	9/29/2004	10.2	2,293.8	49,624	4,740	5,286	10025	98	27,317	23.0	23.0	88	68	20
	9/30/2004	10.0	2,303.8	49,688	4,763	5,321	10084	97	27,476	23.0	22.0	88	68	20
	10/1/2004	10.7	2,314.6	49,759	4,786	5,353	10139	85	27,626	12.0	12.5	76	68	8
	10/2/2004	10.1	2,324.7	49,825	4,826	5,383	10209	116	27,818	13.0	12.5	80	68	12
	10/3/2004	10.1	2,334.8	49,892	4,856	5,414	10270	101	27,984	14.0	14.0	80	68	12
35	10/4/2004	10.0	2,344.8	49,957	4,885	5,445	10330	100	28,147	15.0	15.0	74	68	6
	10/5/2004	9.8	2,354.6	50,022	4,912	5,478	10389	101	28,309	16.0	16.0	82	68	14
	10/6/2004	10.1	2,364.7	50,088	4,938	5,511	10449	98	28,471	16.5	16.0	83	68	15
	10/7/2004	10.1	2,374.7	50,154	4,964	5,544	10508	99	28,633	18.0	17.0	83	68	15
	10/8/2004	10.2	2,384.9	50,219	4,988	5,579	10568	97	28,795	18.0	17.5	82	68	14
	10/9/2004	10.0	2,394.9	50,284	5,012	5,614	10627	98	28,956	18.0	17.5	84	68	16
	10/10/2004	10.1	2,405.0	50,349	5,036	5,650	10686	98	29,116	18.5	18.0	84	68	16
36	10/11/2004	10.0	2,415.0	50,414	5,059	5,685	10744	98	29,276	19.5	18.5	85	68	17
	10/12/2004	10.0	2,425.0	50,478	5,083	5,720	10803	97	29,436	20.0	19.0	85	68	17
	10/13/2004	10.4	2,435.4	50,545	5,107	5,756	10863	96	29,599	19.0	18.0	84	68	16
	10/14/2004	10.0	2,445.4	50,609	5,130	5,791	10921	98	29,758	20.0	20.0	85	69	16
	10/15/2004	10.7	2,456.1	50,680	5,162	5,818	10980	92	29,918	12.0	12.0	76	68	8
	10/16/2004	10.5	2,466.6	50,747	5,193	5,854	11047	106	30,101	13.0	13.0	78	68	10
	10/17/2004	10.1	2,476.6	50,813	5,222	5,885	11107	100	30,265	14.0	13.5	80	69	11

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

		Pump House			Instrument Panel									
										Head Loss		System Pressure		
Week No.	Date	Avg Operation Hours	Avg Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Bed Volumes Treated (a)(b)	Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	kgal	kgal	kgal	gpm	No.	psi	psi	psi	psi	psi
37	10/18/2004	10.1	2,486.7	50,878	5,250	5,916	11167	99	30,427	14.0	14.0	80	68	12
	10/19/2004	8.9	2,495.6	50,935	5,275	5,944	11219	99	30,571	15.0	15.0	80	68	12
	10/20/2004	11.2	2,506.7	51,007	5,305	5,980	11285	97	30,748	15.0	15.0	81	68	13
	10/21/2004	10.0	2,516.8	51,072	5,331	6,012	11344	98	30,909	16.0	16.0	82	68	14
	10/22/2004	10.4	2,527.1	51,138	5,358	6,046	11404	97	31,072	16.0	16.0	82	68	14
	10/23/2004	10.1	2,537.2	51,203	5,384	6,079	11463	98	31,234	16.0	16.0	82	68	14
	10/24/2004	10.0	2,547.2	51,268	5,410	6,112	11521	98	31,393	18.0	18.0	83	68	15
38	10/25/2004	10.0	2,557.3	51,333	5,439	6,144	11584	103	31,563	18.0	18.0	83	68	15
	10/26/2004	10.0	2,567.3	51,396	5,460	6,178	11638	90	31,710	18.0	18.0	83	68	15
	10/27/2004	10.0	2,577.3	51,462	5,485	6,212	11697	100	31,873	17.0	17.0	82	68	14
	10/28/2004	System Not Operating												
	10/29/2004													
	10/30/2004													
	10/31/2004													
39	11/1/2004													
	11/2/2004													
	11/3/2004	72.9	2,650.1	51,942	37	36	73	NA	223	10.5	10.5	80	70	10
	11/4/2004	10.0	2,660.1	52,004	67	64	132	98	401	10.5	10.5	80	70	10
	11/5/2004	10.4	2,670.5	52,075	94	94	188	89	570	11.0	11.0	80	70	10
	11/6/2004	10.3	2,680.8	52,140	130	122	252	105	767	11.5	12.0	81	70	11
	11/7/2004	10.1	2,690.9	52,204	161	150	311	97	946	12.0	12.0	81	69	12

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

		Pump House			Instrument Panel									
									Cumulative Bed Volumes Treated (a)(b)	Head Loss		System Pressure		
Week No.	Date	Avg Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate		Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	kgal	kgal	kgal	gpm	No.	psi	psi	psi	psi	psi
40	11/8/2004	9.9	2,700.8	52,268	191	179	369	99	1,123	12.0	12.0	82	70	12
	11/9/2004	10.1	2,710.9	52,332	221	207	428	96	1,300	12.0	12.0	81	69	12
	11/10/2004	10.1	2,721.0	52,397	251	235	486	97	1,478	12.0	12.0	82	68	14
	11/11/2004	10.3	2,731.3	52,464	282	265	546	97	1,660	12.0	12.0	82	70	12
	11/12/2004	10.1	2,741.4	52,528	312	293	605	97	1,839	12.0	12.0	81	70	11
	11/13/2004	10.1	2,751.5	52,593	342	322	664	97	2,018	12.0	12.5	81	70	11
	11/14/2004	10.1	2,761.6	52,658	372	350	722	96	2,196	12.5	12.5	82	70	12
41	11/15/2004	10.0	2,771.6	52,721	402	379	781	98	2,374	12.5	12.0	82	70	12
	11/16/2004	10.0	2,781.6	52,786	432	407	840	98	2,552	12.5	12.5	82	70	12
	11/17/2004	10.1	2,791.7	52,850	462	436	898	96	2,730	12.5	12.5	82	70	12
	11/18/2004(c)	10.5	2,802.2	52,916	493	465	958	95	2,911	12.5	12.5	82	70	12
	11/19/2004	10.3	2,812.5	52,981	523	494	1017	96	3,092	13.0	13.0	82	70	12
	11/20/2004	10.1	2,822.6	52,982	524	494	1018	NA	3,095	14.0	14.0	84	70	14
	11/21/2004	10.2	2,832.8	53,051	555	525	1080	101	3,283	14.0	14.5	84	70	14
42	11/22/2004	10.0	2,842.8	53,118	586	555	1141	101	3,468	15.0	14.5	85	70	15
	11/23/2004	10.2	2,853.0	53,187	617	585	1202	100	3,654	15.0	15.0	86	70	16
	11/24/2004	12.3	2,865.3	53,268	658	621	1279	105	3,888	14.0	14.0	84	70	14
	11/25/2004	10.7	2,876.0	53,338	685	654	1339	93	4,070	18.0	16.5	86	70	16
	11/26/2004	10.2	2,886.2	53,405	720	685	1405	108	4,269	18.0	17.0	88	70	18
	11/27/2004	10.1	2,896.3	53,471	743	715	1459	89	4,434	20.0	19.0	90	70	20
	11/28/2004	10.1	2,906.4	53,537	773	746	1520	51	4,619	NA	NA	NA	NA	NA

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel									
		Avg Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Bed Volumes Treated (a)(b)	Head Loss		System Pressure		
										Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	kgal	kgal	kgal	gpm	No.	psi	psi	psi	psi	psi
43	11/29/2004	8.9	2,915.4	53,596	799	781	1580	NA	4,803	20.0	15.0	100	69	31
	11/30/2004	9.1	2,924.5	53,657	826	802	1629	89	4,950	13.5	13.5	94	70	24
	12/1/2004	System Not Operating												
	12/2/2004	1.6	2,926.1	53,667	831	807	1638	NA	4,979	13.5	13.5	90	67	23
	12/3/2004	9.6	2,935.7	53,732	862	835	1697	102	5,158	15.5	15.5	94	68	26
	12/4/2004	8.9	2,944.6	53,795	891	863	1754	106	5,331	16.0	16.0	95	69	26
	12/5/2004	9.1	2,953.6	53,856	920	890	1810	103	5,501	17.0	16.5	98	70	28
44	12/6/2004	9.0	2,962.7	53,916	949	916	1865	102	5,669	18.0	18.0	100	70	30
	12/7/2004	9.0	2,971.7	53,977	977	943	1920	101	5,835	21.0	21.0	100	70	30
	12/8/2004	9.9	2,981.6	54,045	1,008	973	1981	103	6,022	14.5	14.5	96	70	26
	12/9/2004	9.3	2,990.9	54,108	1,038	1,000	2038	101	6,194	15.5	15.5	96	70	26
	12/10/2004	9.1	3,000.0	54,169	1,067	1,000	2067	102	6,282	16.5	16.0	98	70	28
	12/11/2004	9.1	3,009.1	54,231	1,096	1,027	2122	102	6,451	17.0	16.5	98	70	28
	12/12/2004	9.1	3,018.2	54,292	1,124	1,054	2178	101	6,620	18.0	18.0	100	70	30
45	12/13/2004	9.0	3,027.2	54,353	1,152	1,081	2233	102	6,788	20.0	20.0	100	70	30
	12/14/2004	10.1	3,037.3	54,422	1,185	1,108	2292	98	6,968	14.5	14.5	95	70	25
	12/15/2004	9.2	3,046.5	54,484	1,214	1,138	2351	107	7,147	15.5	15.0	96	70	26
	12/16/2004	9.1	3,055.6	54,546	1,242	1,165	2407	101	7,316	18.0	17.5	98	70	28
	12/17/2004	9.1	3,064.7	54,608	1,268	1,193	2462	100	7,482	19.0	18.5	100	70	30
	12/18/2004	9.1	3,073.8	54,670	1,296	1,221	2517	102	7,651	20.5	20.0	100	70	30
	12/19/2004	9.2	3,083.0	54,732	1,321	1,250	2572	98	7,816	22.0	22.0	100	70	30

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

		Pump House			Instrument Panel									
										Head Loss		System Pressure		
Week No.	Date	Avg Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Bed Volumes Treated (a)(b)	Tank A	Tan k B	Influent	Effluent	ΔP
		hr	hr	gal	kgal	kgal	kgal	gpm	No.	psi	psi	psi	psi	psi
46	12/20/2004	9.0	3,092.1	54,792	1,347	1,279	2626	101	7,983	26.0	26.0	100	70	30
	12/21/2004	9.9	3,102.0	54,859	1,381	1,309	2689	106	8,174	17.0	17.0	98	70	28
	12/22/2004	8.9	3,110.9	54,922	1,409	1,336	2745	103	8,342	20.0	20.0	100	70	30
	12/23/2004	10.0	3,120.9	54,991	1,442	1,362	2804	99	8,524	16.5	16.5	98	70	28
	12/24/2004	9.1	3,130.0	55,053	1,470	1,390	2859	101	8,691	22.0	21.5	100	70	30
	12/25/2004	9.9	3,139.9	55,121	1,502	1,417	2919	101	8,873	18.0	18.0	100	70	30
	12/26/2004	9.1	3,149.0	55,182	1,524	1,446	2970	92	9,026	22.0	22.0	100	70	30
47	12/27/2004	9.9	3,158.9	55,250	1,552	1,477	3029	100	9206	18.0	18.0	100	70	30
	12/28/2004	9.0	3,167.9	55,311	1,572	1,510	3082	98	9,367	24.0	24.0	100	70	30
	12/29/2004	10.1	3,178.0	55,380	1,598	1,541	3139	94	9,540	18.0	18.5	100	70	30
	12/30/2004	9.1	3,187.1	55,442	1,621	1,575	3195	104	9,712	22.0	22.0	100	70	30
	12/31/2004	9.9	3,197.1	55,511	1,648	1,606	3253	97	9,889	21.0	21.0	100	70	30
	1/1/2005	9.9	3,206.9	55,580	1,677	1,638	3316	106	10,079	17.5	18.0	100	70	30
	1/2/2005	9.0	3,215.9	55,643	1,701	1,668	3369	98	10,240	25.0	25.0	100	70	30
48	1/3/2005	9.9	3,225.8	55,711	1,730	1,697	3427	98	10,417	26.0	26.0	100+	70	30
	1/4/2005	11.1	3,236.9	55,784	1,733	1,727	3460	50	10,518	28.0	28.0	100+	70	30
	1/5/2005	9.9	3,246.8	55,861	1,763	1,730	3493	54	10,616	23.0	22.5	100+	70	30
	1/6/2005	10.3	3,257.1	55,933	1,791	1,765	3556	103	10,809	18.0	18.0	100	70	30
	1/7/2005	9.6	3,266.8	56,000	1,820	1,798	3619	108	10,999	16.5	17.0	96	70	26
	1/8/2005	8.6	3,275.4	56,063	1,847	1,827	3673	105	11,164	20.0	20.5	100+	70	30
	1/9/2005	10.4	3,285.8	56,132	1,874	1,853	3728	88	11,330	13.5	17.5	98	70	28

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-100 System Operation (Continued)

		Pump House			Instrument Panel									
										Head Loss		System Pressure		
Week No.	Date	Avg Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Bed Volumes Treated (a)(b)	Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	kgal	kgal	kgal	gpm	No.	psi	psi	psi	psi	Psi
49	1/10/2005	8.5	3,294.3	56,193	1,896	1,884	3781	104	11,492	24.0	25.0	100	70	30
	1/11/2005	10.6	3,305.0	56,263	1,927	1,914	3842	96	11,677	26.0	26.5	100	70	30
	1/12/2005	9.0	3,314.0	56,324	1,952	1,943	3895	98	11,838	26.0	27.5	100	70	30
	1/13/2005	9.0	3,323.0	56,384	1,952	1,969	3922	49	11,920	30.0	30.0	100	70	30
	1/14/2005	9.1	3,332.1	56,450	NA	NA	NA	NA	NA	Off	Off	Off	Off	Off
	1/15/2005	10.0	3,342.1	56,524	1,979	NA	NA	NA	NA	27.0	27.0	100	70	30
	1/16/2005	NA	NA	Off	NA	NA	NA	NA	NA	Off	Off	Off	Off	Off

NA = Not Applicable

(a) Initial Bed Volume = 49 cu.ft. or 367 gal total for both vessels

(b) Media change on 10/27/04. New bed volume = 44 cu. ft. (22 cu. ft. for each vessel) or 329 gal total for both vessels

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation

		Pump House			Instrument Panel									
										Head Loss		System Pressure		
Week No.	Date	Average Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Total Bed Volumes Treated[(a)]	Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	gal	gal	gal	gpm	No.	psi	psi	psi	Psi	psi
1	6/13/2005	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	6/14/2005	NA	NA	65,033	33	37	NA	NA	NA	0.0	0.0	59.0	58.0	1.0
	6/15/2005	10.0	10.0	65,103	62	67	60	99	133	2.0	1.0	67.0	64.0	3.0
	6/16/2005	18.0	28.0	65,223	113	121	164	97	366	2.5	2.0	67.0	62.0	5.0
	6/17/2005	17.4	45.4	65,343	163	169	263	95	585	3.5	3.0	67.0	62.0	5.0
	6/18/2005	10.1	55.5	65,413	193	198	321	97	715	4.0	3.5	69.0	63.0	6.0
	6/19/2005	10.1	65.6	65,483	223	227	340	97	846	4.5	3.5	68.0	64.0	4.0
2	6/20/2005	10.2	75.8	65,553	253	256	439	96	977	4.5	3.5	68.0	68.0	0.0
	6/21/2005	10.0	85.8	65,621	283	285	498	99	1,109	5.0	4.0	70.0	62.0	8.0
	6/22/2005	10.0	95.8	65,683	312	315	557	98	1,240	5.5	4.5	70.0	62.0	8.0
	6/23/2005	10.1	105.9	65,764	341	346	617	99	1,375	6.0	5.0	69.0	63.0	6.0
	6/24/2005	10.1	116.0	65,835	371	375	676	97	1,505	6.5	5.0	70.0	62.0	8.0
	6/25/2005	10.1	126.1	65,906	401	404	735	98	1,638	7.0	6.0	70.0	62.0	8.0
	6/26/2005	10.1	136.2	65,976	432	433	794	97	1,769	7.5	7.0	70.0	63.0	7.0
3	6/27/2005	10.0	146.2	66,045	462	461	853	97	1,899	8.5	7.0	71.0	61.0	10.0
	6/28/2005	10.2	156.4	66,116	493	489	911	97	2,031	9.0	8.0	72.0	62.0	10.0
	6/29/2005	13.7	170.1	66,211	531	526	988	92	2,200	10.0	9.0	74.0	62.0	12.0
	6/30/2005	NA	NA	66,233	544	534	1001	NA	2,246	10.0	8.0	70.0	62.0	8.0
	7/1/2005	15.6	185.7	66,268	562	548	1040	33	2,316	10.0	8.0	70.0	60.0	10.0
	7/2/2005	10.1	195.8	66,306	580	562	1071	53	2,387	10.5	10.0	72.0	62.0	10.0
	7/3/2005	10.1	205.9	66,344	599	575	1104	53	2,459	11.0	10.0	74.0	62.0	12.0

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel									
		Average Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Total Bed Volumes Treated[(a)]	Head Loss: Tank A	Head Loss: Tank B	System Pressure: Influent	System Pressure: Effluent	System Pressure: ΔP
		hr	hr	gal	gal	gal	gal	gpm	No.	psi	psi	psi	psi	psi
4	7/4/2005	10.2	216.1	66,383	616	590	1136	52	2,530	11.0	10.0	76.0	64.0	12.0
	7/5/2005	10.0	226.1	66,421	639	604	1173	62	2,613	11.5	10.0	74.0	61.0	13.0
	7/6/2005	10.1	236.2	66,492	667	631	1228	90	2,734	11.5	10.0	74.0	62.0	12.0
	7/7/2005	10.1	246.3	66,564	700	657	1286	97	2,866	12.0	11.5	75.0	63.0	12.0
	7/8/2005	10.0	256.3	66,634	731	684	1345	97	2,996	12.5	11.5	76.0	63.0	13.0
	7/9/2005	10.6	266.9	66,710	765	718	1413	107	3,147	2.0	1.5	67.0	63.0	4.0
	7/10/2005	11.1	278.0	66,782	795	748	1473	90	3,280	2.0	1.5	67.0	63.0	4.0
5	7/11/2005	9.2	287.2	66,854	826	777	1533	108	3,413	2.0	2.0	68.0	62.0	6.0
	7/12/2005	10.1	297.3	66,925	856	806	1592	98	3,545	3.0	2.5	68.0	63.0	5.0
	7/13/2005	10.1	307.4	66,996	886	843	1660	112	3,696	3.5	3.0	69.0	63.0	6.0
	7/14/2005	10.9	318.3	67,065	910	856	1696	56	3,778	4.0	3.5	68.0	62.0	6.0
	7/15/2005	9.6	328.0	67,123	940	885	1756	102	3,910	4.5	3.5	68.0	62.0	6.0
	7/16/2005	13.1	341.1	67,170	959	905	1794	50	3,997	5.0	4.0	69.0	62.0	7.0
	7/17/2005	7.1	348.2	67,217	978	926	1835	94	4,086	5.5	4.5	69.0	62.0	7.0
6	7/18/2005	10.6	358.8	67,290	1006	958	1893	92	4,216	6.0	4.5	70.0	62.0	8.0
	7/19/2005	9.9	368.7	67,360	1032	989	1951	98	4,345	6.0	5.0	69.0	61.0	8.0
	7/20/2005	10.4	379.1	67,433	1060	1021	2011	96	4,479	6.5	5.0	70.0	62.0	8.0
	7/21/2005	10.2	389.3	67,504	1087	1053	2070	96	4,609	7.0	5.5	70.0	62.0	8.0
	7/22/2005	10.1	399.4	67,574	1114	1084	2128	96	4,740	7.5	6.0	70.0	61.0	9.0
	7/23/2005	10.1	409.5	67,645	1142	1114	2185	94	4,867	7.5	6.5	71.0	62.0	9.0
	7/24/2005	10.2	419.7	67,715	1169	1144	2243	94	4,995	8.0	7.0	72.0	63.0	9.0

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel									
		Average Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Total Bed Volumes Treated[a]	Head Loss: Tank A	Head Loss: Tank B	System Pressure: Influent	System Pressure: Effluent	System Pressure: ΔP
		hr	hr	gal	gal	gal	gal	gpm	No.	psi	psi	psi	psi	psi
7	7/25/2005	10.1	429.8	67,785	1194	1173	2297	89	5,115	8.5	7.5	68.0	62.0	6.0
	7/26/2005	10.1	439.8	67,854	1225	1201	2356	99	5,247	8.5	7.5	69.0	62.0	7.0
	7/27/2005	10.1	449.9	67,924	1255	1229	2413	94	5,374	9.0	8.0	72.0	62.0	10.0
	7/28/2005	10.2	460.1	67,995	1284	1256	2470	94	5,502	9.0	8.0	73.0	62.0	11.0
	7/29/2005	10.4	470.5	68,068	1315	1284	2529	94	5,632	9.5	8.5	73.0	62.0	11.0
	7/30/2005	10.1	480.6	68,138	1344	1312	2585	93	5,758	9.5	8.5	73.0	62.0	11.0
	7/31/2005	10.2	490.8	68,209	1372	1340	2642	93	5,884	9.5	9.0	74.0	62.0	12.0
8	8/1/2005	10.1	500.8	68,280	1400	1367	2698	93	6,008	10.0	9.0	74.5	63.0	11.5
	8/2/2005	5.4	506.3	68,319	1418	1384	2733	107	6,086	2.0	2.0	66.0	62.0	4.0
	8/3/2005	10.1	516.3	68,390	1450	1411	2791	96	6,215	2.5	2.0	66.0	62.0	4.0
	8/4/2005	10.4	526.7	68,464	1480	1439	2850	95	6,347	3.0	2.0	67.0	62.0	5.0
	8/5/2005[b]	10.1	536.8	68,536	1509	1468	2908	95	6,476	3.5	2.5	67.0	62.0	5.0
	8/6/2005													
	8/7/2005													
9	8/8/2005													
	8/9/2005													
	8/10/2005													
	8/11/2005													
	8/12/2005													
	8/13/2005													
	8/14/2005													

System Offline Between August 5, 2005 and September 26, 2005.

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel									
										Head Loss		System Pressure		
		Average Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Total Bed Volumes Treated[(a)]	Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	gal	gal	gal	gpm	No.	psi	psi	psi	psi	psi
16	9/26/2005[(d)]													
	9/27/2005				1647	1603	NA		NA	2.0	0.0	66.0	62.0	4.0
	9/28/2005	NA	536.8	72,285	1675	1630	2962		6,596	2.5	0.0	67.0	62.0	5.0
	9/29/2005	10.8	547.7	72,361	1704	1659	3020	90	6,727	2.5	0.0	67.0	63.0	4.0
	9/30/2005	10.2	557.8	72,432	1731	1687	3075	89	6,848	2.5	0.5	68.0	62.0	6.0
	10/1/2005	10.2	568.0	72,503	1757	1715	3129	89	6,969	2.5	0.5	67.0	62.0	5.0
	10/2/2005	10.1	578.1	72,574	1784	1742	3183	90	7,090	2.0	0.5	68.0	63.0	5.0
17	10/3/2005	11.0	589.1	72,645	1810	1770	3237	82	7,210	1.5	0.0	69.0	62.0	7.0
	10/4/2005	9.2	598.3	72,716	1837	1797	3291	97	7,329	1.5	0.0	70.0	63.0	7.0
	10/5/2005	10.0	608.3	72,786	1863	1824	3344	89	7,449	1.5	0.0	68.0	63.0	5.0
	10/6/2005	13.8	622.1	72,882	1899	1861	3417	87	7,610	1.5	0.0	66.0	62.0	4.0
	10/7/2005	12.6	634.7	72,968	1930	1893	3481	84	7,752	1.5	0.0	67.0	62.0	5.0
	10/8/2005	10.2	644.9	73,039										
	10/9/2005	10.0	654.9	73,109		System Not Operating								
18	10/10/2005	10.0	664.9	73,180										
	10/11/2005	0.0	664.9	73,180										
	10/12/2005	0.0	664.9	73,180	1931	1894	3481	NA	7,753	2.0	1.0	65.0	60.0	5.0
	10/13/2005	9.5	674.4	73,256	1959	1922	3537	98	7,877	2.0	1.0	66.0	61.0	5.0
	10/14/2005	10.9	685.4	73,331	1986	1950	3592	85	8,001	2.0	1.0	67.0	62.0	5.0
	10/15/2005	22.3	707.7	73,486	2043	2008	3707	86	8,257	2.0	1.0	67.0	62.0	5.0
	10/16/2005	24.2	731.9	73,639	2099	2064	3819	77	8,506	2.5	1.5	67.0	62.0	5.0

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation (Continued)

Week No.	Date	Pump House: Average Operation Hours (hr)	Pump House: Cumulative Operation Hours (hr)	Pump House: Master Flow Meter (gal)	Instrument Panel: Flow Totalizer Vessel A (gal)	Flow Totalizer Vessel B (gal)	Cumulative Flow Totalizer (gal)	Avg Flowrate (gpm)	Cumulative Total Bed Volumes Treated[(a)] (No.)	Head Loss: Tank A (psi)	Head Loss: Tank B (psi)	System Pressure: Influent (psi)	System Pressure: Effluent (psi)	System Pressure: ΔP (psi)
19	10/17/2005	System Not Operating												
	10/18/2005	System Not Operating												
	10/19/2005	System Not Operating												
	10/20/2005	System Not Operating												
	10/21/2005	NA	731.9	73,786	2153	2118	NA	NA	NA	2.0	1.0	70.0	64.0	6.0
	10/22/2005	15.8	747.7	73,852	System Not Operating									
	10/23/2005	10.0	757.7	73,893	System Not Operating									
20	10/24/2005	10.0	767.7	73,935	2153	2119	NA	NA	NA	1.0	0.0	70.0	69.0	1.0
	10/25/2005	10.3	778.0	73,977	2169	2135	3851	52	8,578	3.0	1.0			
	10/26/2005	13.0	791.0	74,080	2205	2174	3927	96	8,745	2.0	1.0	76.0	70.0	6.0
	10/27/2005	10.1	801.2	74,158	2232	2204	3984	93	8,872	2.0	1.0	76.0	71.0	5.0
	10/28/2005	10.3	811.5	74,237	2260	2235	4041	94	9,001	2.0	1.0	76.0	71.0	5.0
	10/29/2005	10.1	821.6	74,314	2286	2265	4098	94	9,127	2.5	1.5	76.0	71.0	5.0
	10/30/2005	10.1	831.7	74,391	2313	2294	4154	93	9,252	2.5	1.5	76.0	71.0	5.0
21	10/31/2005	10.2	841.9	74,468	2339	2324	4210	91	9,377	3.0	1.8	76.0	70.0	6.0
	11/1/2005	10.1	851.9	74,544	2365	2353	4266	93	9,501	3.0	1.8	76.0	70.0	6.0
	11/2/2005	9.9	861.9	74,617	2392	2383	4321	93	9,624	3.0	2.0	76.0	70.0	6.0
	11/3/2005	10.6	872.5	74,699	2419	2413	4380	92	9,754	3.0	2.0	76.0	69.0	7.0
	11/4/2005	11.3	883.7	74,774	2445	2442	4435	82	9,877	3.0	2.0	76.0	69.0	7.0
	11/5/2005	9.6	893.3	74,850	2471	2471	4490	96	10,000	3.0	2.0	76.0	69.0	7.0
	11/6/2005	14.0	907.3	74,925	2498	2500	4545	65	10,122	3.0	2.0	77.0	69.0	8.0

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation (Continued)

Week No.	Date	Pump House: Average Operation Hours	Pump House: Cumulative Operation Hours	Pump House: Master Flow Meter	Instrument Panel: Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Total Bed Volumes Treated[a]	Head Loss: Tank A	Head Loss: Tank B	System Pressure: Influent	System Pressure: Effluent	ΔP
		hr	hr	gal	gal	gal	gal	gpm	No.	psi	psi	psi	psi	psi
22	11/7/2005	10.1	917.4	75,002	2524	2529	4600	91	10,245	3.0	2.0	76.0	70.0	6.0
	11/8/2005	10.0	927.4	75,077	2550	2557	4655	91	10,368	3.0	2.0	76.0	70.0	6.0
	11/9/2005	10.1	937.5	75,153	2577	2586	4710	91	10,491	3.0	2.0	77.0	71.0	6.0
	11/10/2005	10.1	947.6	75,229	2604	2615	4766	91	10,614	3.0	2.0	76.0	70.0	6.0
	11/11/2005	17.8	965.4	75,359	2649	2662	4860	88	10,824	4.0	3.0	76.0	70.0	6.0
	11/12/2005	10.0	975.4	75,433	2675	2692	4914	90	10,944	3.0	3.0	77.0	71.0	6.0
	11/13/2005	10.1	985.5	75,508	2701	2720	4968	90	11,065	3.5	3.0	77.0	71.0	6.0
23	11/14/2005	10.2	995.7	75,583	2727	2748	5023	89	11,186	3.5	2.5	76.0	70.0	6.0
	11/15/2005	10.0	1,005.8	75,656	2753	2777	5077	91	11,308	3.5	2.5	76.0	71.0	5.0
	11/16/2005	10.0	1,015.8	75,732	2779	2804	5131	90	11,428	3.5	2.5	77.0	71.0	6.0
	11/17/2005	24.1	1,039.9	75,900	2839	2867	5253	84	11,699	3.5	2.5	77.0	71.0	6.0
	11/18/2005	11.9	1,051.8	75,984	2868	2898	5313	84	11,832	3.5	2.5	77.0	71.0	6.0
	11/19/2005	10.6	1,062.4	76,060	2895	2926	5368	88	11,957	3.5	2.5	77.0	71.0	6.0
	11/20/2005	10.0	1,072.4	76,135	2920	2954	5422	88	12,075	3.5	2.5	77.0	71.0	6.0
24	11/21/2005	10.1	1,082.6	76,210	2946	2982	5476	88	12,195	3.5	3.0	77.0	70.0	7.0
	11/22/2005	10.2	1,092.7	76,285	2972	3010	5529	89	12,315	3.5	3.0	77.0	70.0	7.0
	11/23/2005	10.0	1,102.7	76,360	2998	3038	5583	89	12,434	3.5	3.0	77.0	70.0	7.0
	11/24/2005	9.6	1,112.4	76,435	3024	3066	5637	93	12,554	3.5	3.0	77.0	70.0	7.0
	11/25/2005	12.1	1,124.4	76,528	3056	3100	5703	92	12,703	3.5	3.0	77.0	70.0	7.0
	11/26/2005	11.0	1,135.5	76,603	3082	3128	5757	81	12,823	3.5	3.0	77.0	70.0	7.0
	11/27/2005	10.1	1,145.6	76,679	3108	3156	5811	89	12,942	3.5	3.0	77.0	71.0	6.0

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel									
		Average Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Total Bed Volumes Treated[(a)]	Head Loss Tank A	Head Loss Tank B	System Pressure Influent	System Pressure Effluent	System Pressure ΔP
		hr	hr	gal	gal	gal	gal	gpm	No.	psi	psi	psi	psi	psi
25	11/28/2005	10.1	1,155.7	76,754	3134	3183	5865	89	13,062	3.5	3.0	77.0	71.0	6.0
	11/29/2005	10.0	1,165.7	76,829	3160	3211	5918	89	13,181	4.0	3.0	78.0	70.0	8.0
	11/30/2005	10.1	1,175.7	76,903	3186	3239	5972	89	13,301	4.0	3.0	78.0	71.0	7.0
	12/1/2005	12.1	1,187.9	76,993	3217	3272	6037	89	13,444	4.0	3.0	78.0	71.0	7.0
	12/2/2005	9.1	1,197.0	77,060	3241	3297	6085	89	13,553	4.0	3.0	78.0	71.0	7.0
	12/3/2005	9.1	1,206.1	77,127	3265	3322	6134	89	13,662	4.0	3.0	78.0	71.0	7.0
	12/4/2005	9.1	1,215.2	77,194	3289	3349	6185	93	13,774	4.0	3.0	78.0	71.0	7.0
26	12/5/2005	9.1	1,224.3	77,261	3313	3372	6232	87	13,880	4.0	3.0	77.0	70.0	7.0
	12/6/2005	9.1	1,233.4	77,327	3337	3396	6281	89	13,989	4.0	3.0	78.0	71.0	7.0
	12/7/2005	9.1	1,242.5	77,393	3361	3421	6330	90	14,098	4.0	3.0	78.0	71.0	7.0
	12/8/2005	9.6	1,252.1	77,463	3387	3447	6382	90	14,213	4.0	3.0	78.0	71.0	7.0
	12/9/2005	9.1	1,261.2	77,512	3406	3466	6419	68	14,296	4.5	3.5	78.0	70.0	8.0
	12/10/2005	9.0	1,270.2	77,578	3430	3491	6469	91	14,407	4.5	3.5	78.0	70.0	8.0
	12/11/2005	9.2	1,279.4	77,623	3450	3508	6504	67	14,489	4.5	3.5	78.0	71.0	7.0
27	12/12/2005	9.1	1,288.6	77,689	3472	3533	6553	86	14,594	4.5	3.5	78.0	70.0	8.0
	12/13/2005	9.0	1,297.6	77,754	3497	3557	6601	90	14,702	4.5	3.5	78.0	70.0	8.0
	12/14/2005	9.0	1,306.6	77,808	3517	3578	6642	76	14,794	4.5	3.5	78.0	71.0	7.0
	12/15/2005	9.5	1,316.1	77,876	3543	3604	6694	91	14,909	4.5	3.5	78.0	72.0	6.0
	12/16/2005	9.1	1,325.2	77,942	3567	3629	6743	90	15,018	4.5	3.5	78.0	72.0	6.0
	12/17/2005	9.1	1,334.2	78,008	3591	3654	6793	91	15,128	4.5	3.5	78.0	71.0	7.0
	12/18/2005	9.1	1,343.4	78,075	3616	3679	6842	90	15,238	4.5	3.5	78.0	71.0	7.0

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel									
		Average Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Total Bed Volumes Treated[a]	Head Loss		System Pressure		
										Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	gal	gal	gal	gpm	No.	psi	psi	psi	psi	psi
28	12/19/2005	9.1	1,352.5	78,141	3640	3704	6891	90	15,348	4.5	4.0	77.0	71.0	6.0
	12/20/2005	9.1	1,361.6	78,208	3665	3729	6941	91	15,458	4.5	4.0	77.0	71.0	6.0
	12/21/2005	9.0	1,370.6	78,273	3688	3754	6990	90	15,567	4.5	4.0	78.0	71.0	7.0
	12/22/2005	9.1	1,379.7	78,339	3713	3779	7039	90	15,676	4.5	4.0	78.0	71.0	7.0
	12/23/2005	9.1	1,388.8	78,405	3737	3804	7088	90	15,786	4.5	4.0	78.0	71.0	7.0
	12/24/2005	9.1	1,397.9	78,471	3761	3829	7137	90	15,896	4.5	4.0	78.0	71.0	7.0
	12/25/2005	9.1	1,407.1	78,536	3785	3854	7186	89	16,005	4.5	4.0	79.0	71.0	8.0
29	12/26/2005	9.1	1,416.2	78,602	3809	3879	7236	90	16,115	5.0	3.5	78.0	71.0	7.0
	12/27/2005	9.1	1,425.3	78,668	3833	3905	7285	90	16,225	5.0	4.0	78.0	71.0	7.0
	12/28/2005	9.1	1,434.4	78,733	3857	3930	7334	89	16,334	5.0	4.0	78.0	71.0	7.0
	12/29/2005	9.1	1,443.5	78,798	3880	3955	7383	89	16,442	5.0	4.0	79.0	71.0	8.0
	12/30/2005	9.1	1,452.6	78,864	3904	3980	7432	90	16,551	5.0	4.0	78.0	71.0	7.0
	12/31/2005	9.1	1,461.7	78,929	3928	4006	7481	90	16,661	5.0	4.0	78.0	71.0	7.0
	1/1/2006	9.2	1,470.8	78,995	3951	4030	7529	88	16,769	5.0	4.0	78.0	71.0	7.0
30	1/2/2006	9.0	1,479.9	79,060	3976	4055	7578	91	16,878	5.0	4.5	78.0	71.0	7.0
	1/3/2006	9.0	1,488.9	79,126	3999	4080	7626	88	16,985	5.0	4.5	78.0	71.0	7.0
	1/4/2006	9.0	1,497.9	79,191	4022	4105	7674	89	17,092	5.0	4.5	78.0	71.0	7.0
	1/5/2006	9.0	1,506.9	79,256	4045	4130	7722	89	17,199	5.0	4.5	79.0	71.0	8.0
	1/6/2006	9.0	1,515.9	79,321	4069	4154	7770	89	17,306	5.5	4.5	79.0	71.0	8.0
	1/7/2006	9.1	1,525.1	79,387	4093	4179	7819	89	17,415	5.5	4.5	79.0	71.0	8.0
	1/8/2006	9.0	1,534.1	79,452	4117	4204	7868	90	17,523	5.5	4.5	79.0	71.0	8.0

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation (Continued)

Week No.	Date	Pump House: Average Operation Hours (hr)	Pump House: Cumulative Operation Hours (hr)	Pump House: Master Flow Meter (gal)	Instrument Panel: Flow Totalizer Vessel A (gal)	Instrument Panel: Flow Totalizer Vessel B (gal)	Instrument Panel: Cumulative Flow Totalizer (gal)	Instrument Panel: Avg Flowrate (gpm)	Instrument Panel: Cumulative Total Bed Volumes Treated[(a)] (No.)	Head Loss: Tank A (psi)	Head Loss: Tank B (psi)	System Pressure: Influent (psi)	System Pressure: Effluent (psi)	System Pressure: ΔP (psi)
31	1/9/2006	9.2	1,543.3	79,518	4140	4229	7916	88	17,631	5.5	4.5	78.0	71.0	7.0
	1/10/2006	9.0	1,552.3	79,582	4164	4253	7964	89	17,738	5.5	4.5	79.0	72.0	7.0
	1/11/2006	9.0	1,561.3	79,647	4187	4277	8012	88	17,844	5.5	4.5	79.0	71.0	8.0
	1/12/2006	9.1	1,570.4	79,712	4211	4303	8061	90	17,953	5.5	4.5	79.0	71.0	8.0
	1/13/2006	9.1	1,579.5	79,777	4235	4327	8110	89	18,061	5.5	4.5	79.0	71.0	8.0
	1/14/2006	9.1	1,588.6	79,842	4259	4352	8158	89	18,170	5.5	4.5	79.0	71.0	8.0
	1/15/2006	9.1	1,597.7	79,907	4283	4377	8207	89	18,278	5.5	4.5	79.0	71.0	8.0
32	1/16/2006	9.1	1,606.8	79,972	4306	4401	8255	88	18,385	5.5	4.5	79.0	71.0	8.0
	1/17/2006	9.0	1,615.8	80,037	4329	4426	8303	88	18,491	5.5	4.5	79.0	71.0	8.0
	1/18/2006	9.0	1,624.8	80,101	4353	4451	8351	90	18,599	5.5	4.5	79.0	71.0	8.0
	1/19/2006	10.2	1,635.0	80,176	4382	4477	8407	91	18,723	1.0	5.0	78.0	71.0	7.0
	1/20/2006	9.1	1,644.1	80,243	4405	4504	8456	90	18,832	2.0	1.0	78.0	71.0	7.0
	1/21/2006	9.1	1,653.2	80,309	4428	4530	8505	90	18,941	2.5	2.5	77.0	71.0	6.0
	1/22/2006	9.0	1,662.2	80,375	4451	4555	8554	91	19,051	2.5	2.0	77.0	70.0	7.0
33	1/23/2006	8.1	1,670.3	80,442	4475	4580	8603	100	19,160	2.5	2.5	77.0	70.0	7.0
	1/24/2006	9.6	1,679.9	80,508	4500	4604	8651	84	19,268	3.0	2.0	76.0	68.0	8.0
	1/25/2006	9.6	1,689.5	80,574	4524	4629	8700	85	19,377	3.0	2.5	76.0	70.0	6.0
	1/26/2006	9.0	1,698.5	80,640	4549	4653	8749	90	19,486	3.0	2.5	77.0	71.0	6.0
	1/27/2006	9.2	1,707.7	80,707	4573	4678	8798	89	19,595	3.0	2.5	77.0	71.0	6.0
	1/28/2006	9.1	1,716.8	80,773	4598	4701	8847	90	19,704	3.0	2.5	77.0	71.0	6.0
	1/29/2006	9.0	1,725.8	80,840	4623	4725	8896	90	19,813	3.0	2.5	77.0	71.0	6.0

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation (Continued)

Week No.	Date	Pump House: Average Operation Hours (hr)	Pump House: Cumulative Operation Hours (hr)	Pump House: Master Flow Meter (gal)	Instrument Panel: Flow Totalizer Vessel A (gal)	Instrument Panel: Flow Totalizer Vessel B (gal)	Instrument Panel: Cumulative Flow Totalizer (gal)	Instrument Panel: Avg Flowrate (gpm)	Instrument Panel: Cumulative Total Bed Volumes Treated[(a)] (No.)	Head Loss: Tank A (psi)	Head Loss: Tank B (psi)	System Pressure: Influent (psi)	System Pressure: Effluent (psi)	System Pressure: ΔP (psi)
34	1/30/2006	9.1	1,734.9	80,906	4649	4749	8945	89	19,921	3.0	3.0	77.0	72.0	5.0
	1/31/2006	9.0	1,744.0	80,972	4674	4771	8993	89	20,029	3.0	3.0	76.0	70.0	6.0
	2/1/2006	9.9	1,753.9	81,044	4700	4800	9048	92	20,151	1.5	0.5	76.0	71.0	5.0
	2/2/2006	9.1	1,763.0	81,111	4725	4824	9096	89	20,259	2.0	1.0	76.0	71.0	5.0
	2/3/2006	9.1	1,772.1	81,178	4749	4849	9146	91	20,369	2.0	1.0	76.0	72.0	4.0
	2/4/2006	9.1	1,781.2	81,244	4773	4874	9195	90	20,478	2.5	1.5	77.0	71.0	6.0
	2/5/2006	9.1	1,790.3	81,311	4797	4900	9244	90	20,587	2.5	1.5	77.0	71.0	6.0
35	2/6/2006	9.2	1,799.5	81,378	4820	4926	9293	88	20,696	2.5	2.0	76.0	71.0	5.0
	2/7/2006	9.2	1,808.7	81,446	4843	4952	9343	90	20,807	2.5	2.0	76.0	71.0	5.0
	2/8/2006	9.0	1,817.7	81,511	4866	4977	9391	90	20,915	2.5	2.0	76.0	71.0	5.0
	2/9/2006	9.1	1,826.8	81,578	4889	5003	9440	89	21,023	2.5	2.0	77.0	71.0	6.0
	2/10/2006	9.1	1,835.9	81,645	4913	5028	9488	89	21,132	2.5	2.0	77.0	71.0	6.0
	2/11/2006	9.0	1,844.9	81,711	4935	5054	9537	90	21,240	3.0	2.0	76.0	71.0	5.0
	2/12/2006	9.1	1,854.0	81,777	4959	5080	9585	89	21,348	3.0	2.0	73.0	71.0	2.0
36	2/13/2006	9.0	1,863.1	81,843	4981	5105	9634	89	21,456	3.0	2.5	77.0	71.0	6.0
	2/14/2006	9.0	1,872.1	81,909	5004	5131	9682	89	21,564	3.0	2.0	76.0	71.0	5.0
	2/15/2006	22.8	1,894.8	82,065	5059	5192	9798	85	21,823	5.0	3.5	78.0	71.0	7.0
	2/16/2006	9.1	1,903.9	82,129	5081	5218	9846	87	21,928	3.5	2.5	78.0	72.0	6.0
	2/17/2006	9.1	1,913.0	82,193	5104	5243	9894	88	22,035	3.5	2.5	78.0	71.0	7.0
	2/18/2006[(e)]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2/19/2006	0.1	1,913.1	82,194	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation (Continued)

Week No.	Date	Pump House			Instrument Panel									
		Average Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Total Bed Volumes Treated[(a)]	Head Loss		System Pressure		
										Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	gal	gal	gal	gpm	No.	psi	psi	psi	psi	psi
37	2/20/2006	9.1	1,922.2	82,261	5128	5268	9944	91	22,146	3.0	2.5	76.0	70.0	6.0
	2/21/2006	9.0	1,931.2	82,327	5150	5296	9993	91	22,256	3.0	2.5	76.0	70.0	6.0
	2/22/2006	9.0	1,940.3	82,393	5173	5323	10043	92	22,367	3.0	2.5	77.0	71.0	6.0
	2/23/2006	9.1	1,949.4	82,459	5197	5348	10092	90	22,477	3.0	2.5	77.0	71.0	6.0
	2/24/2006	9.1	1,958.5	82,524	5222	5372	10142	91	22,587	3.0	2.5	77.0	71.0	6.0
	2/25/2006	9.1	1,967.6	82,590	5247	5397	10191	90	22,697	3.0	2.5	77.0	71.0	6.0
	2/26/2006	9.1	1,976.7	82,655	5271	5421	10240	90	22,806	3.0	2.5	77.0	71.0	6.0
38	2/27/2006	9.1	1,985.8	82,720	5295	5446	10289	90	22,915	3.0	2.5	77.0	71.0	6.0
	2/28/2006	10.0	1,995.8	82,785	5319	5471	10337	81	23,023	3.0	2.5	77.0	71.5	5.5
	3/1/2006	8.0	2,003.8	82,849	5343	5496	10386	101	23,131	3.0	2.5	77.0	71.0	6.0
	3/2/2006	9.1	2,012.9	82,915	5367	5521	10435	90	23,241	3.0	2.5	77.0	71.0	6.0
	3/3/2006	9.1	2,022.0	82,980	5390	5546	10484	89	23,349	3.0	2.5	77.0	71.0	6.0
	3/4/2006	9.0	2,031.1	83,045	5414	5572	10533	90	23,458	3.0	2.5	77.0	71.0	6.0
	3/5/2006	9.0	2,040.1	83,081	5427	5586	10561	52	23,520	3.5	3.0	77.0	71.0	6.0
39	3/6/2006	-0.4	2,039.7	83,082	5428	5586	10561	NA	23,521	3.0	2.0	75.0	70.0	5.0
	3/7/2006	9.3	2,049.0	83,149	5452	5612	10611	88	23,632	3.0	2.0	75.0	69.0	6.0
	3/8/2006	9.8	2,058.8	83,221	5478	5639	10665	92	23,752	1.5	1.0	74.0	68.0	6.0
	3/9/2006	9.1	2,067.9	83,287	5502	5664	10714	91	23,862	2.0	1.0	74.0	70.0	4.0
	3/10/2006	9.0	2,076.9	83,353	5526	5690	10763	91	23,972	2.0	1.0	75.0	71.0	4.0
	3/11/2006	9.1	2,086.0	83,390	5540	5704	10792	52	24,035	1.5	0.5	70.0	67.0	3.0
	3/12/2006	9.1	2,095.1	83,421	5552	5717	10816	45	24,089	1.0	0.5	71.0	68.0	3.0

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation (Continued)

Week No.	Date	Pump House: Average Operation Hours (hr)	Pump House: Cumulative Operation Hours (hr)	Pump House: Master Flow Meter (gal)	Instrument Panel: Flow Totalizer Vessel A (gal)	Instrument Panel: Flow Totalizer Vessel B (gal)	Instrument Panel: Cumulative Flow Totalizer (gal)	Instrument Panel: Avg Flowrate (gpm)	Instrument Panel: Cumulative Total Bed Volumes Treated[a] (No.)	Head Loss: Tank A (psi)	Head Loss: Tank B (psi)	System Pressure: Influent (psi)	System Pressure: Effluent (psi)	System Pressure: ΔP (psi)
40	3/13/2006	9.2	2,104.3	83,458	5566	5730	10844	51	24,152	2.8	2.0	76.0	71.0	5.0
	3/14/2006	9.9	2,114.2	83,496	5581	5746	10874	51	24,219	0.0	0.0	60.0	58.0	2.0
	3/15/2006	9.2	2,123.4	83,534	5594	5762	10903	52	24,283	0.0	0.0	60.0	58.0	2.0
	3/16/2006	9.1	2,132.5	83,565	5605	5775	10928	45	24,338	0.0	0.0	60.0	58.0	2.0
	3/17/2006	9.1	2,141.6	83,598	5616	5789	10953	46	24,393	0.0	0.0	60.0	58.0	2.0
	3/18/2006	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	3/19/2006	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
41	3/20/2006	18.3	2,159.9	83,703	5655	5832	11035	75	24,576	0.5	0.0	62.0	60.0	2.0
	3/21/2006	9.1	2,169.0	83,736	5667	5845	11059	45	24,631	1.0	0.2	62.0	59.0	3.0
	3/22/2006	9.0	2,178.0	83,774	5681	5860	11088	54	24,695	1.0	0.2	62.0	59.0	3.0
	3/23/2006	9.1	2,187.1	83,806	5693	5873	11113	45	24,750	1.0	0.2	62.0	58.0	4.0
	3/24/2006	9.1	2,196.2	83,844	5707	5888	11142	53	24,815	1.0	0.2	62.0	58.0	4.0
	3/25/2006	9.0	2,205.2	83,876	5718	5901	11167	46	24,870	1.0	0.2	62.0	58.0	4.0
	3/26/2006	9.1	2,214.3	83,914	5732	5916	11196	53	24,935	1.0	0.2	62.0	60.0	2.0
42	3/27/2006	9.1	2,223.4	83,946	5744	5929	11220	45	24,990	1.0	0.5	62.0	59.0	3.0
	3/28/2006	9.0	2,232.4	83,984	5757	5945	11249	54	25,054	1.0	0.5	63.0	59.0	4.0
	3/29/2006	9.1	2,241.5	84,016	5779	5958	11284	64	25,132	1.0	0.5	62.0	59.0	3.0
	3/30/2006	9.1	2,250.6	84,054	5782	5974	11303	35	25,174	1.0	0.5	62.0	59.0	3.0
	3/31/2006	9.1	2,259.7	84,086	5794	5987	11328	45	25,229	1.1	1.0	61.0	58.0	3.0
	4/1/2006	9.1	2,268.8	84,124	5807	6002	11357	53	25,294	1.0	1.0	61.0	58.0	3.0
	4/2/2006	9.1	2,277.9	84,156	5819	6016	11382	45	25,349	1.2	1.0	62.0	59.0	3.0

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation (Continued)

Week No.	Date	Pump House: Average Operation Hours	Pump House: Cumulative Operation Hours	Pump House: Master Flow Meter	Instrument Panel: Flow Totalizer Vessel A	Instrument Panel: Flow Totalizer Vessel B	Instrument Panel: Cumulative Flow Totalizer	Instrument Panel: Avg Flowrate	Instrument Panel: Cumulative Total Bed Volumes Treated[(a)]	Head Loss: Tank A	Head Loss: Tank B	System Pressure: Influent	System Pressure: Effluent	System Pressure: ΔP
		hr	hr	gal	gal	gal	gal	gpm	No.	psi	psi	psi	psi	psi
43	4/3/2006	9.1	2,287.0	84,195	5832	6031	11411	53	25,414	1.2	1.0	62.0	59.0	3.0
	4/4/2006	9.0	2,296.0	84,226	5843	6045	11435	45	25,469	1.5	1.0	62.0	59.0	3.0
	4/5/2006	21.9	2,317.9	84,318	5877	6081	11505	53	25,624	2.5	2.0	63.0	60.0	3.0
	4/6/2006	9.1	2,327.0	84,349	5888	6094	11530	45	25,679	1.5	1.0	62.0	60.0	2.0
	4/7/2006	9.3	2,336.3	84,389	5903	6109	11560	54	25,745	1.5	1.0	62.0	59.0	3.0
	4/8/2006	9.2	2,345.5	84,421	5915	6121	11584	44	25,799	2.0	1.0	62.0	59.0	3.0
	4/9/2006	9.1	2,354.6	84,459	5930	6135	11612	53	25,864	2.0	1.0	62.0	59.0	3.0
44	4/10/2006	9.1	2,363.7	84,491	5942	6147	11637	45	25,918	1.5	1.5	63.0	59.0	4.0
	4/11/2006	9.1	2,372.8	84,529	5957	6161	11666	53	25,983	1.8	1.2	62.0	58.0	4.0
	4/12/2006	9.0	2,381.8	84,561	5970	6173	11690	45	26,037	1.8	1.2	62.0	58.0	4.0
	4/13/2006	9.0	2,390.8	84,599	5985	6187	11719	53	26,101	2.0	1.5	62.0	59.0	3.0
	4/14/2006	9.1	2,399.9	84,631	5997	6199	11744	45	26,155	2.0	1.5	62.0	59.0	3.0
	4/15/2006	9.0	2,408.9	84,670	6012	6213	11773	54	26,220	2.0	1.5	62.0	58.0	4.0
	4/16/2006	9.1	2,418.0	84,701	6025	6225	11797	45	26,274	2.0	1.5	62.0	59.0	3.0
45	4/17/2006	9.1	2,427.1	84,740	6041	6238	11826	53	26,339	2.1	2.0	62.0	58.0	4.0
	4/18/2006	9.0	2,436.1	84,771	6053	6250	11850	45	26,393	2.9	2.1	63.0	58.0	5.0
	4/19/2006	9.1	2,445.2	84,810	6068	6263	11879	53	26,457	2.9	2.1	63.0	59.0	4.0
	4/20/2006	9.0	2,454.2	84,842	6082	6275	11904	46	26,512	2.9	2.2	62.0	58.0	4.0
	4/21/2006	9.1	2,463.3	84,881	6097	6288	11933	54	26,577	2.5	2.0	62.0	58.0	4.0
	4/22/2006	9.1	2,472.4	84,913	6110	6300	11957	45	26,631	2.9	2.1	62.0	58.0	4.0
	4/23/2006	9.1	2,481.5	84,951	6126	6313	11987	53	26,696	2.5	2.0	62.0	58.0	4.0

EPA Arsenic Demonstration Project at Rollinsford, NH – Daily System Operation Log Sheet
APU-RWS System Operation (Continued)

		Pump House			Instrument Panel									
										Head Loss		System Pressure		
Week No.	Date	Average Operation Hours	Cumulative Operation Hours	Master Flow Meter	Flow Totalizer Vessel A	Flow Totalizer Vessel B	Cumulative Flow Totalizer	Avg Flowrate	Cumulative Total Bed Volumes Treated[a]	Tank A	Tank B	Influent	Effluent	ΔP
		hr	hr	gal	gal	gal	gal	gpm	No.	psi	psi	psi	psi	psi
46	4/24/2006	9.1	2,490.6	84,983	6139	6325	12011	45	26,750	2.6	2.0	62.0	59.0	3.0
	4/25/2006	9.0	2,499.6	85,021	6154	6338	12040	53	26,814	3.0	3.0	63.0	58.0	5.0
	4/26/2006	9.0	2,508.6	85,053	6167	6349	12064	45	26,869	3.0	2.5	63.0	59.0	4.0
	4/27/2006	19.3	2,527.9	85,134	6201	6377	12125	53	27,005	5.0	5.0	64.0	58.0	6.0
	4/28/2006	9.1	2,537.0	85,173	6217	6390	12154	53	27,070	3.0	2.5	62.0	57.0	5.0
	4/29/2006	9.0	2,546.0	85,211	6232	6404	12183	54	27,134	3.5	3.0	63.0	58.0	5.0
	4/30/2006	9.1	2,555.1	85,250	6247	6418	12212	53	27,199	3.5	3.0	64.0	59.0	5.0
47	5/1/2006	9.1	2,564.2	85,288	6262	6432	12241	53	27,264	3.5	3.0	62.0	59.0	3.0
	5/2/2006	9.0	2,573.2	85,326	6277	6446	12270	53	27,328	3.5	3.0	62.0	59.0	3.0
	5/3/2006	18.1	2,591.3	85,388	6302	6469	12318	44	27,434	5.0	5.0	64.0	59.0	5.0
	5/4/2006	0.0	2,591.3	85,389	6301	6469	12318	NA	27,434	7.0	5.0	70.0	64.0	6.0
	5/5/2006	9.0	2,600.3	85,427	6317	6483	12347	54	27,499	5.0	4.0	63.0	58.0	5.0
	5/6/2006	9.1	2,609.4	85,465	6332	6497	12376	53	27,564	5.0	4.5	64.0	59.0	5.0
	5/7/2006	9.1	2,618.5	85,503	6347	6510	12405	53	27,628	5.0	4.5	65.0	59.0	6.0

NA = Not Applicable
(a) Bed volume = 60 cu.ft. or 449 gallons total for both vessels
(b) System down since August 5, 2005.
(c) CO_2 shut off because it was adding air bubbles to the system.
(d) Unit bypassed on September 26, 2005.
(e) Power outage between February 18-19, 2006.
(f) Week of 6/12/2006 through 6/18/2006 used 6% chlorine solution.
(g) Operational data from pump house was not collected from 7/3/2006 to 7/9/2006.
(h) Operational data was not collected from 7/10/2006 to 7/23/2006.
(i) Operational data was not collected from 8/7/2006 to 8/13/2006.

APPENDIX B

ANALYTICAL DATA

Table 1. Analytical Results from Long-Term Sampling, Rollinsford, NH (APU-100)

Sampling Date		02/10/04[c]			02/17/04[d]				02/24/04				03/02/04			
Sampling Location Parameter	**Unit**	**IN**	**AP**	**TT**	**IN**	**AP**	**TA**	**TB**	**IN**	**AP**	**TA**	**TB**	**IN**	**AP**	**TA**	**TB**
Bed Volume		–	–	0	–	–	759	855	–	–	1,773	1,972	–	–	2,728	2,796
Alkalinity	mg/L[a]	165	165	161	149	174	170	170	176	176	185	189	164	180	164	164
Fluoride	mg/L	0.6	0.6	0.6	–	–	–	–	–	–	–	–	–	–	–	–
Sulfate	mg/L	40	40	45	–	–	–	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L[b]	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Silica (as SiO_2)	mg/L	13.9	13.7	6.6	15.0	15.2	15.2	15.1	15.5	15.4	14.4	14.6	14.1	13.9	14.9	14.0
NO_3-N	mg/L	–	–	<0.08	–	–	–	–	–	–	–	–	–	–	–	–
Turbidity	NTU	0.8	0.8	0.3	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.3	1.8	0.3	1.0	0.7
pH	S.U.	8.3	7.3	7.5	7.0	6.8	7.0	7.1	7.0	7.4	7.3	7.4	8.0	7.6	7.4	7.5
Temperature	ºC	10.6	11.3	11.1	10.0	10.2	10.6	11.5	9.8	11.6	11.8	11.8	12.8	13.0	13.1	13.3
DO	mg/L	2.2	1.0	2.0	4.7	3.1	2.8	2.8	4.5	3.6	3.6	4.2	4.4	3.2	3.2	3.8
ORP	mV	-86	-28	-25	0	7	-2	-4	4	24	18	18	-60	-33	-23	-27
Free Chlorine	mg/L	–	–	–	–	–	–		–	–	–	–	–	–	–	–
Total Chlorine	mV	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total Hardness	mg/L[a]	73.0	78.4	93.5	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L[a]	40.5	42.4	51.8	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L[a]	32.5	36.0	41.7	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	39.5	40.8	0.5	35.5	37.0	3.1	2.2	45.8	47.7	3.3	3.1	46.6	46.5	6.4	7.7
As (total soluble)	µg/L	34.9	35.7	0.4	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	4.6	5.1	0.1	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	22.6	23.3	0.5	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	12.3	12.4	<0.1	–	–	–	–	–	–	–	–	–	–	–	–
Total Fe	µg/L	170	166	45	236	148	105	51	100	120	<25	<25	166	276	31	106
Dissolved Fe	µg/L	74	81	<25	–	–	–	–	–	–	–	–	–	–	–	–
Total Mn	µg/L	147	149	5.8	169	119	83.9	92.3	120	118	68.9	69.5	133	155	61.5	88.3
Dissolved Mn	µg/L	147	149	5.7	–	–	–	–	–	–	–	–	–	–	–	–

(a) Measured as $CaCO_3$. (b) As P. (c) Water quality parameters and metals were sampled on January 30, 2004. (d) On-site water quality measurements sampled on February 16, 2004.
IN = inlet; AP = after pH adjustment; TA = after tank A; TB = after the tank B; TT = after tanks combined.
NA = data not available.

Table 1. Analytical Results from Long-Term Sampling, Rollinsford, NH(APU-100) (Continued)

Sampling Date		03/09/04[c]			03/30/04[h]				04/06/04[h]				04/14/04[e]			
Sampling Location Parameter	Unit	IN	AP	TT	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB
Bed Volume		–	–	3,670	–	–	5,043	5,045	–	–	6,012	6,025	–	–	6,994	7,011
Alkalinity	mg/L[a]	164	156	160	175	167	165	163	176	180	180	176	182	176	172	174
Fluoride	mg/L	0.6	0.6	0.6	–	–	–	–	–	–	–	–	–	–	–	–
Sulfate	mg/L	37	35	38	–	–	–	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L[b]	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Silica (as SiO_2)	mg/L	13.3	13.4	13.2	14.1	14.1	13.8	13.5	16.0	16.5	15.1	15.7	15.2	14.8	15.4	15.0
NO_3-N	mg/L	<0.04	<0.04	<0.04	–	–	–	–	–	–	–	–	–	–	–	–
Turbidity	NTU	1.0	1.6	0.4	1.0	2.0[f]	0.8	0.5	0.9	1.1	1.1	0.7	0.4	2.1[f]	0.3	0.7
pH	–	8.0	7.5	7.5	NA[g]	NA[g]	NA[g]	NA[g]	8.1	7.5	7.5	7.5	7.8	7.3	7.4	7.4
Temperature	°C	10.4	10.5	10.3	NA[g]	NA[g]	NA[g]	NA[g]	12.5	12.4	12.4	12.4	10.1	8.9	9.0	9.1
DO	mg/L	4.7	3.5	2.0	NA[g]	NA[g]	NA[g]	NA[g]	4.2	3.2	2.9	3.4	4.5	3.9	2.8	2.8
ORP	mV	-59	-29	-27	NA[g]	NA[g]	NA[g]	NA[g]	-64	-31	-32	-33	-51	-27	-30	-31
Free Chlorine	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total Chlorine	mV	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total Hardness	mg/L[a]	80.1	83.3	82.4	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L[a]	51.4	52.8	53.4	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L[a]	28.7	30.5	29.0	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	38.5	42.1	5.5	35.9	37.8	2.1	1.7	46.3	50.5	4.5	3.3	45.2	50.1	4.9	5.0
As (total soluble)	µg/L	36.7	36.4	4.1	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	1.8	5.7	1.4	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	20.7	NA[d]	4.1	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	16.0	NA[d]	<0.1	–	–	–	–	–	–	–	–	–	–	–	–
Total Fe	µg/L	127	485[f]	<25	130	359[f]	<25	<25	97	133	<25	<25	75	276[f]	<25	<25
Dissolved Fe	µg/L	22	51	<25	–	–	–	–	–	–	–	–	–	–	–	–
Total Mn	µg/L	137	138	142	78.1	104.3	14.2	15.2	96.5	96.3	6.9	3.5	109.7	110.8	3.0	1.8
Dissolved Mn	µg/L	99.1	132	99.2	–	–	–	–	–	–	–	–	–	–	–	–

(a) Measured as $CaCO_3$. (b) As P. (c) On-site water quality parameters were sampled on March 10, 2004. (d) Re-run was done for AP sample but the As sample value exceeded the calibration range (likely due to contamination of ion exchange resin). (e) On-site water quality measurements were sampled on April 13, 2004. (f) Data is questionable. (g) Operator did not take on-site water quality measurements. (h) Pre-chlorination started on March 30, 2004.

IN = inlet; AP = after pH adjustment and after pre-chlorination; TA = after tank A; TB = after the tank B; TT = after tanks combined.

NA = data not available.

Table 1. Analytical Results from Long-Term Sampling, Rollinsford, NH (APU-100) (Continued)

Sampling Date		04/19/04			04/29/04				05/05/04				05/18/04[c]			
Sampling Location **Parameter**	**Unit**	**IN**	**AP**	**TT**	**IN**	**AP**	**TA**	**TB**	**IN**	**AP**	**TA**	**TB**	**IN**	**AP**	**TA**	**TB**
Bed Volume	10^3	–	–	8.0	–	–	9.3	9.4	–	–	10.2	10.2	–	–	11.6	11.8
Alkalinity	mg/L[a]	188	188	196	195	191	187	171	259	231	219	207	176 197	181 185	189 185	193 185
Fluoride	mg/L	0.6	0.6	0.6	–	–	–	–	–	–	–	–	–	–	–	–
Sulfate	mg/L	46	46	40	–	–	–	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L[b]	<0.10	<0.10	<0.10	NA[e]	NA[e]	NA[e]	NA[e]	0.11	<0.10	<0.10	<0.10	<0.10 0.12	0.12 <0.10	<0.10 <0.10	<0.10 <0.10
Silica (as SiO_2)	mg/L	15.3	15.6	15.3	14.0	14.2	15.1	15.2	15.6	15.4	15.3	15.7	14.2 14.7	14.4 14.7	14.8 14.7	14.7 14.7
NO_3-N	mg/L	<0.05	<0.05	<0.05	–	–	–	–	–	–	–	–	–	–	–	–
Turbidity	NTU	0.4	0.3	0.6	1.0	1.4	0.7	0.7	1.3	0.9	0.4	0.5	0.7 2.4	0.7 0.9	0.5 0.6	0.5 0.4
pH	–	7.9	7.2	7.5	7.8	7.1	7.2	7.2	8.0	7.6	7.5	7.5	8.2	7.5	7.4	7.4
Temperature	ºC	12.4	12.5	13.5	13.6	12.8	12.6	12.5	14.8	14.2	14.3	13.9	14.8	14.1	14.0	13.9
DO	mg/L	5.4	3.3	2.0	4.3	2.0	1.9	2.3	4.3	3.6	3.4	4.1	3.9	4.1	3.9	4.0
ORP	mV	-64	-16	-33	-50	-7	-10	-11	-56	-30	-27	-26	-66	-24	-18	-19
Free Chlorine	mg/L	–	–	–	–	0.40	–	–	–	0.06	–	–	–	0.14	–	–
Total Chlorine	mV	–	–	–	–	0.60	–	–	–	0.30	–	–	–	0.30	–	–
Total Hardness	mg/L[a]	54.9	54.3	64.6	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L[a]	30.2	29.7	35.4	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L[a]	24.7	24.6	29.2	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	41.3	42.5	6.1	36.3	37.4	3.5	3.3	39.9	42.9	5.6	5.5	38.3 37.0	41.7/38.1 40.1/35.6	6.9 6.5	6.2 5.9
As (total soluble)	µg/L	35.5	35.4	5.1	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	5.8	7.1	1.0	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	18.1	0.5	0.5	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	17.4	34.9	4.6	–	–	–	–	–	–	–	–	–	–	–	–
Total Fe	µg/L	68	53	<25	115	214[d]	<25	<25	211	144	<25	<25	83 89	350/426[d] 46/44	<25 <25	<25 <25
Dissolved Fe	µg/L	29	<25	<25	–	–	–	–	–	–	–	–	–	–	–	–
Total Mn	µg/L	112	109	1.5	85.1	93.4	3.3	2.7	102	114	4.1	2.2	58.9 58.1	66.3/66.5 59.5/59.8	4.5 0.6	1.2 1.1
Dissolved Mn	µg/L	112	105	1.0	–	–	–	–	–	–	–	–	–	–	–	–

(a) Measured as $CaCO_3$. (b) As P. (c) (/) indicates re-run data with original result/re-run result. (d) Data is questionable. (e) Laboratory did not analyze sample because it was out of hold time.
IN = inlet; AP = after pH adjustment and after pre-chlorination; TA = after tank A; TB = after the tank B; TT = after tanks combined.
NA = data not available.

Table 1. Analytical Results from Long-Term Sampling, Rollinsford, NH (APU-100) (Continued)

Sampling Date		05/25/04[c]			06/08/04[c][d]				06/22/04[c]				07/13/04[f]	
Sampling Location Parameter	Unit	IN	AP	TT	IN	AP	TA	TB	IN	AP	TA	TB	IN	TT
Bed Volume	10^3	–	–	12.5	–	–	13.3	13.6	–	–	14.3	15.0	–	15.2
Alkalinity	mg/L[a]	182	186	190	240	236	203	199	179	162	162	171	184	176
Fluoride	mg/L	0.6	0.6	0.6	–	–	–	–	–	–	–	–	0.5	0.5
Sulfate	mg/L	37	40	40	–	–	–	–	–	–	–	–	72	80
Orthophosphate	mg/L[b]	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Silica (as SiO_2)	mg/L	15.0	14.9	13.9	15.0	14.8	15.1	15.0	16.1	15.2	14.9	15.6	14.7	14.5
NO_3-N	mg/L	<0.04	<0.04	<0.04	–	–	–	–	–	–	–	–	<0.04	<0.04
Turbidity	NTU	3.3	1.0	1.3	0.5	1.3	3.1	0.7	2.6	14[e]	0.7	1.6	0.5	0.2
pH	–	8.0	7.5	8.0	7.9	7.0	7.1	7.1	NA[g]	NA[g]	NA[g]	NA[g]	7.5	7.0
Temperature	ºC	10.9	11.0	10.7	17.2	16.0	15.9	16.0	NA[g]	NA[g]	NA[g]	NA[g]	14.1	12.1
DO	mg/L	4.6	4.1	2.2	4.4	2.8	2.6	3.1	NA[g]	NA[g]	NA[g]	NA[g]	3.4	3.0
ORP	mV	-58	-25	-50	-48	1	-2	-3	NA[g]	NA[g]	NA[g]	NA[g]	-30	-3
Free Chlorine	mg/L	–	1.75	3.20	–	0.28	–	–	–	NA[g]	–	–	–	0.05
Total Chlorine	mV	–	2.52	3.24	–	0.58	–	–	–	NA[g]	–	–	–	0.23
Total Hardness	mg/L[a]	54.1	53.9	54.7	–	–	–	–	–	–	–	–	101.0	103.1
Ca Hardness	mg/L[a]	31.9	32.1	32.6	–	–	–	–	–	–	–	–	52.8	53.4
Mg Hardness	mg/L[a]	22.2	21.8	22.1	–	–	–	–	–	–	–	–	48.2	49.7
As (total)	µg/L	41.9	40.0	20.3/ 17.8[e]	38.5	75.2/ 67.6[e]	3.9	4.5	39.1	45.6	10.6/ 19.4	5.0	32.7	2.4
As (total soluble)	µg/L	35.7	35.5	19.1[e]	–	–	–	–	–	–	–	–	29.8	2.1
As (particulate)	µg/L	6.2	4.5	1.2	–	–	–	–	–	–	–	–	2.9	0.3
As (III)	µg/L	16.9	0.8	0.8	–	–	–	–	–	–	–	–	25.8	0.6
As (V)	µg/L	18.8	34.7	18.3	–	–	–	–	–	–	–	–	4.0	1.5
Total Fe	µg/L	489/ 484[e]	36	<25/ <25	37	898/ 911[e]	<25	<25	175	624	<25	29	307[e]	<25
Dissolved Fe	µg/L	<25	<25	<25	–	–	–	–	–	–	–	–	183	<25
Total Mn	µg/L	95.1/ 92.9	79.1	0.6/ 0.6	104.0	135.7/ 134.1	1.0	1.1	79.1	106.8	8.5	2.3	245.0[e]	1.0
Dissolved Mn	µg/L	83.7	69.6	0.6	–	–	–	–	–	–	–	–	235.0	0.9

(a) Measured as $CaCO_3$. (b) As P. (c) (/) indicates re-run data with original result/re-run result. (d) On-site water quality parameters were sampled on June 9, 2004.
(e) Data is questionable. (f) AP sample tap removed during system maintenance on July 1-2 and later re-installed. (g) Operator did not take on-site water quality measurements.
IN = inlet; AP = after pH adjustment and after pre-chlorination; TA = after tank A; TB = after the tank B; TT = after tanks combined.
NA = data not available.

Table 1. Analytical Results from Long-Term Sampling, Rollinsford, NH (APU-100) (Continued)

Sampling Date		07/20/04				07/29/04[c]				08/04/04[c]				08/10/04		
Sampling Location Parameter	Unit	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TT
Bed Volume	10^3	–	–	15.5	16.4	–	–	16.4	17.4	–	–	17.4	18.7	–	–	19.0
Alkalinity	mg/L[a]	164	164	160	172	177	177	177	181	192	188	184	180	176	168	160
Fluoride	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	0.6	0.6	0.5
Sulfate	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	35	33	33
Orthophosphate	mg/L[b]	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Silica (as SiO_2)	mg/L	13.9	13.9	14.3	14.2	15.2	14.9	14.7	15.0	14.7	15.3	15.0	14.7	13.6	13.7	14.4
NO_3-N	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	<0.04	<0.04	<0.04
Turbidity	NTU	0.8	0.6	0.7	0.7	36[d]	2.3	7.4	2.1	0.7	0.3	0.3	13[d]	29[d]	0.8	0.4
pH	–	7.5	7.2	7.2	7.1	NA[e]	NA[e]	NA[e]	NA[e]	8.0	7.6	7.7	7.6	7.9	7.4	7.5
Temperature	ºC	14.1	13.6	13.6	14.1	NA[e]	NA[e]	NA[e]	NA[e]	19.5	17.7	16.4	17.5	15.1	15.3	15.0
DO	mg/L	3.4	2.7	3.8	2.2	NA[e]	NA[e]	NA[e]	NA[e]	3.2	2.8	2.6	3.2	3.2	2.4	2.0
ORP	mV	-30	-17	-13	-11	NA[e]	NA[e]	NA[e]	NA[e]	-61	-44	-41	-43	-60	-27	-34
Free Chlorine	mg/L	–	0.07	–	–	–	NA[e]	–	–	–	0.21	–	–	–	0.05	0.04
Total Chlorine	mV	–	0.71	–	–	–	NA[e]	–	–	–	0.44	–	–	–	0.20	0.26
Total Hardness	mg/L[a]	–	–	–	–	–	–	–	–	–	–	–	–	62.7	68.1	79.6
Ca Hardness	mg/L[a]	–	–	–	–	–	–	–	–	–	–	–	–	34.2	38.2	41.6
Mg Hardness	mg/L[a]	–	–	–	–	–	–	–	–	–	–	–	–	28.5	29.9	38.0
As (total)	µg/L	28.7	30.0	2.3	2.9	36.1	42.7	8.8/ 7.9	12.5/ 11.9	42.7	42.4	17.2/ 17.2	21.9/ 16.6	31.9	30.4	5.1
As (total soluble)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	31.6	30.7	5.1
As (particulate)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	0.3	<0.1	<0.1
As (III)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	12.4	0.5	0.4
As (V)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	19.2	30.2	4.7
Total Fe	µg/L	178	171	<25	<25	260	373	32/ 37.5	<25/ <25	99	146	131/ 125	280/ 186	89	<25	<25
Dissolved Fe	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	<25	<25	<25
Total Mn	µg/L	196	196	4.3	5.2	226	241.0	11.8/ 12.3	8.0/ 7.4	127	163	24.2/ 27.7	65.3/ 69.6	51.9	60.0	1.6
Dissolved Mn	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	48.9	50.2	0.9

(a) Measured as $CaCO_3$. (b) As P. (c) (/) indicates re-run data with original result/re-run result. (d) Data is questionable. (e) Operator did not take on-site water quality measurements.
IN = inlet; AP = after pH adjustment and after pre-chlorination; TA = after tank A; TB = after the tank B; TT = after tanks combined
NA = data not available.

Table 1. Analytical Results from Long-Term Sampling, Rollinsford, NH (APU-100) (Continued)

Sampling Date		08/17/04[c]				08/24/04[d]				8/31/04				09/09/04[e][f]		
Sampling Location Parameter	Unit	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TT
Bed Volume	10^3	–	–	19.3	21.0	–	–	20.5	22.2	–	–	21.6	23.5	–	–	24.0
Alkalinity	mg/L[a]	172 168	180 180	172 176	180 172	186	186	186	186	188	188	188	184	182	186	182
Fluoride	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	1.5	1.7	1.6
Sulfate	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	42	43	42
Orthophosphate	mg/L[b]	<0.10 <0.10	<0.10 <0.10	<0.10 <0.10	<0.10 <0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Silica (as SiO_2)	mg/L	14.9 14.8	14.8 14.8	14.6 14.8	15.0 14.7	15.0	15.6	15.5	15.2	15.1	15.1	15.9	15.4	15.0	14.9	15.2
NO_3-N	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	0.14	0.07	0.09
Turbidity	NTU	2.4 1.9	0.8 0.9	0.8 0.6	0.6 0.5	1.8	0.8	0.2	0.4	1.4	0.8	0.7	0.5	0.8	0.4	0.4
pH	–	7.9	7.8	7.8	7.8	7.9	7.0	7.5	7.5	NA[h]	NA[h]	NA[h]	NA[h]	8.1	7.7	7.6
Temperature	ºC	18.1	16.0	16.2	16.2	11.7	11.6	11.9	12.2	NA[h]	NA[h]	NA[h]	NA[h]	14.7	15.8	16.0
DO	mg/L	4.0	3.0	4.0	3.4	5.0	3.9	4.4	4.5	NA[h]	NA[h]	NA[h]	NA[h]	3.6	2.7	3.2
ORP	mV	-66	-40	-54	-54	-61	-10	-34	-34	NA[h]	NA[h]	NA[h]	NA[h]	-70	-47	-42
Free Chlorine	mg/L	–	0.00	–	–	–	0.00	–	–	–	NA[h]	–	–	–	0.79	0.28
Total Chlorine	mV	–	0.20	–	–	–	0.00	–	–	–	NA[h]	–	–	–	–	0.34
Total Hardness	mg/L[a]	–	–	–	–	–	–	–	–	–	–	–	–	47.8	48.9	56.4
Ca Hardness	mg/L[a]	–	–	–	–	–	–	–	–	–	–	–	–	28.2	28.4	33.5
Mg Hardness	mg/L[a]	–	–	–	–	–	–	–	–	–	–	–	–	19.6	20.4	22.8
As (total)	µg/L	30.6 30.9	30.7 30.3	10.4 10.6	12.3 12.6	31.1	34.1	12.9	14.1	38.8	38.9	17.6	18.8	31.8	36.7	20.8
As (total soluble)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	32.8	0.5/ 33.4[g]	18.5
As (particulate)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	<0.1	2.2	2.3
As (III)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	16.0	34.5[e][g]	0.4
As (V)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	16.8	<0.1[g]	18.1
Total Fe	µg/L	285 225	142 130	40 40	57 58	89	122	46	67	65	42	<25	<25	185	68	78
Dissolved Fe	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	<25	<25/ <25	<25
Total Mn	µg/L	84.4 84.3	78.7 78.3	3.8 3.5	6.7 4.0	104	122	6.0	14.5	101	101	12.1	14.0	79.3	83.5	9.7
Dissolved Mn	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	73.0	71.7/ 75.8	0.7

(a) Measured as $CaCO_3$. (b) As P. (c) On-site water quality measurements were sampled on August 18, 2004. (d) On-site water quality measurements were sampled on August 26, 2004.
(e) Not enough sample for re-analysis. (f) (/) indicates re-run data w/original result/re-run result. (g) Data is questionable. (h) Operator did not take on-site water quality measurements.
IN = inlet; AP = after pH adjustment and after pre-chlorination; TA = after tank A; TB = after the tank B; TT = after tanks combined.

Table 1. Analytical Results from Long-Term Sampling, Rollinsford, NH (APU-100) (Continued)

Sampling Date		09/14/04[c]				09/22/04				09/28/04[e]				10/06/04		
Sampling Location Parameter	Unit	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TT
Bed Volume	10^3	–	–	23.7	26.0	–	–	24.9	27.5	–	–	25.7	28.6	–	–	28.5
Alkalinity	mg/L[a]	182	186	182	186	166	166	170	174	176	172	185	172	183	183	187
Fluoride	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	0.6	0.6	0.6
Sulfate	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	44	44	44
Orthophosphate	mg/L[b]	0.06	<0.06	0.10	0.08	<0.06	<0.06	<0.06	<0.06	0.09	0.10	<0.06	0.08	<0.06	<0.06	<0.06
Silica (as SiO_2)	mg/L	15.5	15.1	15.5	14.9	15.2	14.9	15.1	15.1	14.3	14.3	15.2	14.9	15.0	15.1	15.2
NO_3-N	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	<0.04	<0.04	<0.04
Turbidity	NTU	0.3	0.2	0.2	0.6	0.8	0.4	0.2	0.3	0.7	0.8	0.7	0.3	0.6	0.7	0.4
pH	–	7.9	7.5	7.6	7.6	7.9	7.1	7.3	7.4	7.8	7.2	7.3	7.3	7.9	7.2	7.3
Temperature	ºC	11.9	10.7	11.1	10.9	15.3	15.0	13.3	13.5	15.8	13.3	13.3	13.3	8.3	7.6	7.8
DO	mg/L	4.6	3.6	3.0	3.0	5.5	4.0	3.4	5.4	4.0	3.4	3.4	3.0	4.2	3.6	3.5
ORP	mV	201	212	210	209	233	247	251	254	197	210	207	214	220	232	262
Free Chlorine	mg/L	–	0.05	–	–	–	0.16	–	–	–	0.10	–	–	–	0.23	0.06
Total Chlorine	mV	–	2.70	–	–	–	3.80	–	–	–	0.18	–	–	–	0.44	NA[f]
Total Hardness	mg/L[a]	–	–	–	–	–	–	–	–	–	–	–	–	83.3	62.1	66.2
Ca Hardness	mg/L[a]	–	–	–	–	–	–	–	–	–	–	–	–	47.8	34.2	37.2
Mg Hardness	mg/L[a]	–	–	–	–	–	–	–	–	–	–	–	–	35.5	27.9	29.0
As (total)	µg/L	38.9/ 36.7	31.7	40.5	18.2	32.7	34.1	13.6	12.0	39.7	35.5	34.5	17.5	52.4	40.5	12.9
As (total soluble)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	35.7	38.3	12.7
As (particulate)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	16.7	2.2	0.2
As (III)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	18.7	1.2	0.3
As (V)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	17.0	37.1	12.4
Total Fe	µg/L	1120/ 1225[d]	47	<25	32	54	92	<25	<25	217	128	52	27	671	174	27
Dissolved Fe	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	35	41	<25
Total Mn	µg/L	93.9/ 89.3	85.5	3.9	1.3	79.3	95.3	4.3	4.0	85.6	81.6	7.6	3.2	126	117	9.6
Dissolved Mn	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	89.8	93.6	1.2

(a) Measured as $CaCO_3$. (b) As P. (c) (/) indicates re-run data with original result/re-run result. (d) Data is questionable.
(e) On-site water quality measurements were sampled on September 29, 2004. (f) Operator did not take measurement.
IN = inlet; AP = after pH adjustment and after pre-chlorination; TA = after tank A; TB = after the tank B; TT = after tanks combined.
NA = data not available.

Table 1. Analytical Results from Long-Term Sampling, Rollinsford, NH (APU-100) (Continued)

Sampling Date		10/12/04				10/21/04				10/26/04				11/04/04(c)(e)		
Sampling Location Parameter	**Unit**	**IN**	**AP**	**TA**	**TB**	**IN**	**AP**	**TA**	**TB**	**IN**	**AP**	**TA**	**TB**	**IN**	**AP**	**TT**
Bed Volume	10^3	–	–	27.7	31.2	–	–	29.1	32.8	–	–	29.8	33.7	–	–	0.4
Alkalinity	mg/L(a)	191	183	183	183	185 185	185 181	185 185	181 181	172	172	172	172	181	181	181
Fluoride	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	0.5	0.5	0.5
Sulfate	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	41	41	41
Orthophosphate	mg/L(b)	<0.06	<0.06	<0.06	<0.06	2.30 <0.06	<0.06 <0.06	<0.06 0.10	<0.06 0.08	<0.06	<0.06	0.12	0.23	0.08	0.08	0.07
Silica (as SiO_2)	mg/L	16.7	15.3	14.7	15.2	7.5(f) 7.4	7.8(f) 7.3	7.6(f) 7.6	7.7(f) 7.8	14.5	14.5	14.4	14.2	15.0	15.1	9.9
NO_3-N	mg/L	–	–	–	–	–	–	–	–	–	–	–	–	<0.04	<0.04	<0.04
Turbidity	NTU	1.1	0.8	0.3	0.3	6.4 1.8	0.4 0.5	0.2 0.2	0.5 0.5	0.7	0.5	0.2	0.3	1.6	0.5	0.6
pH	–	8.0	7.8	7.7	7.7	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	7.4(f)	7.7(f)	7.5
Temperature	ºC	13.2	12.5	12.5	12.6	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	12.1	12.0	12.2
DO	mg/L	4.4	2.8	3.3	2.9	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	3.2	3.0	2.8
ORP	mV	220	434	437	466	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	NA(d)	182	172	171
Free Chlorine	mg/L	–	0.40	–	–	–	NA(d)	–	–	–	NA(d)	–	–	–	0.04	0.05
Total Chlorine	mV	–	0.50	–	–	–	NA(d)	–	–	–	NA(d)	–	–	–	0.03	0.07
Total Hardness	mg/L(a)	–	–	–	–	–	–	–	–	–	–	–	–	63.5	62.0	59.6
Ca Hardness	mg/L(a)	–	–	–	–	–	–	–	–	–	–	–	–	36.4	34.1	31.1
Mg Hardness	mg/L(a)	–	–	–	–	–	–	–	–	–	–	–	–	27.1	27.9	28.5
As (total)	µg/L	34.2	39.6	34.1	23.1	31.0 32.0	38.0 35.0	20.0 19.0	21.0 23.0	32.0	31.0	29.6	30.0	36.2	39.0	1.1
As (total soluble)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	36.4	39.1	1.0
As (particulate)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	<0.1	<0.1	0.1
As (III)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	23.0	1.5	0.8
As (V)	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	13.4	37.6	0.2
Total Fe	µg/L	133	142	25	<25	204(f) 133	327(f) 222	<25 <25	25(f) 39	119	95	<25	28	120	73	<25
Dissolved Fe	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	38	<25	<25
Total Mn	µg/L	125.0	99.1	8.3	14.9	67.0 67.0	120.0(f) 81.0	3.8(f) 1.4	3.8(f) 6.9	63.0	72.0	0.9	1.7	81.8	77.9	2.6
Dissolved Mn	µg/L	–	–	–	–	–	–	–	–	–	–	–	–	83.9	81.3	2.4

(a) Measured as $CaCO_3$. (b) As P. (c) On-site water quality measurements were sampled on November 5, 2004. (d) Operator did not take weekly on-site water quality measurement.
(e) Media change on October 27, 2004. Bed volume = 44 cu. ft. (22 cu. ft. for each vessel) or 329 gallons for both vessels. (f) Data is questionable.
IN = inlet; AP = after pH adjustment and after pre-chlorination; TA = after tank A; TB = after the tank B; TT = after tanks combined.
NA = data not available.

Table 1. Analytical Results from Long-Term Sampling, Rollinsford, NH (APU-100) (Continued)

Sampling Date		11/10/04				11/17/04[d]				12/02/04[d]			12/08/04			
Sampling Location Parameter	Unit	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TT	IN	AP	TA	TB
Bed Volume	10^3	–	–	1.5	1.4	–	–	2.8	2.6	–	–	5.0	–	–	6.1	5.9
Alkalinity	mg/L[a]	185	184	181	185	185	185	185	185	162	166	162	191	183	183	183
Fluoride	mg/L	–	–	–	–	–	–	–	–	0.7	0.6	0.6	–	–	–	–
Sulfate	mg/L	–	–	–	–	–	–	–	–	41.0	42.0	38.0	–	–	–	–
Orthophosphate	mg/L[b]	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Silica (as SiO_2)	mg/L	15.3	15.1	14.4	14.4	14.9	15.0	15.4	15.4	13.9	13.8	14.8	16.0	15.4	15.3	15.5
NO_3-N	mg/L	–	–	–	–	–	–	–	–	<0.04	<0.04	<0.04	–	–	–	–
Turbidity	NTU	0.8	0.9	0.6	0.7	18[c]	0.7	0.3	0.5	1.0	0.7	0.5	2.8	1.1	0.6	0.4
pH	–	8.1	8.1[c]	7.8	7.8	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	7.8	7.8	7.7	7.7
Temperature	ºC	13.6	13.8	13.9	14.3	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	10.9	12.9	12.9	12.7
DO	mg/L	3.6	3.6	3.4	4.6	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	4.9	3.7	3.2	3.4
ORP	mV	234	238[c]	227	220	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	223	159	155	149
Free Chlorine	mg/L	–	0.20	–	–	–	NA[d]	–	–	–	NA[d]	NA[d]	–	0.02	0.10	–
Total Chlorine	mV	–	0.40	–	–	–	NA[d]	–	–	–	NA[d]	NA[d]	–	0.02	0.16	–
Total Hardness	mg/L[a]	–	–	–	–	–	–	–	–	73.9	81.3	76.4	–	–	–	–
Ca Hardness	mg/L[a]	–	–	–	–	–	–	–	–	45.9	51.0	46.8	–	–	–	–
Mg Hardness	mg/L[a]	–	–	–	–	–	–	–	–	28.0	30.3	29.6	–	–	–	–
As (total)	µg/L	32.3	32.9	1.0	1.4	32.2	23.3	1.3	1.6	51.7	37.4	2.5	45.3	33.1	3.7	3.9
As (total soluble)	µg/L	–	–	–	–	–	–	–	–	34.2	36.1	2.4	–	–	–	–
As (particulate)	µg/L	–	–	–	–	–	–	–	–	17.5	1.3	0.1	–	–	–	–
As (III)	µg/L	–	–	–	–	–	–	–	–	15.4	14.4	2.5	–	–	–	–
As (V)	µg/L	–	–	–	–	–	–	–	–	18.8	21.7	<0.1	–	–	–	–
Total Fe	µg/L	164	176	<25	51	190	92	<25	<25	4645[c]	144	<25	372	141	<25	<25
Dissolved Fe	µg/L	–	–	–	–	–	–	–	–	<25	<25	<25	–	–	–	–
Total Mn	µg/L	81.8	87.5	3.1	8.1	78.8	53.1	0.5	0.9	64.0	66.4	2.8	141	105	8.5	8.4
Dissolved Mn	µg/L	–	–	–	–	–	–	–	–	56.7	62.5	2.7	–	–	–	–

(a) Measured as $CaCO_3$. (b) As P. (c) Data is questionable. (d) Operator did not take weekly on-site water quality measurements.
IN = inlet; AP = after pH adjustment and after pre-chlorination; TA = after tank A; TB = after the tank B; TT = after tanks combined.
NA = data not available.

Table 1. Analytical Results from Long-Term Sampling, Rollinsford, NH (APU-100) (Continued)

Sampling Date		12/13/04				01/05/05[d]			
Sampling Location / Parameter	Unit	IN	AP	TA	TB	IN	AP	TA	TB
Bed Volume	10^3	–	–	7.0	6.6	–	–	10.7	10.5
Alkalinity	mg/L[a]	203	191	195	191	174 174	174 174	182 186	186 186
Fluoride	mg/L	–	–	–	–	–	–	–	–
Sulfate	mg/L	–	–	–	–	–	–	–	–
Orthophosphate	mg/L[b]	<0.06	<0.06	<0.06	<0.06	<0.06 <0.06	<0.06 <0.06	<0.06 <0.06	<0.06 <0.06
Silica (as SiO_2)	mg/L	16.1	15.9	15.3	16.1	15.1 14.8	14.4 14.5	15.9 15.8	15.8 15.8
NO_3-N	mg/L	–	–	–	–	–	–	–	–
Turbidity	NTU	3.7	2.0	0.9	0.7	2.4 8.0	0.6 0.6	0.4 0.4	0.4 0.4
pH	–	7.7	7.2	7.4	7.2	7.4 7.6	7.4 7.6	7.4 7.5	7.4 7.6
Temperature	ºC	11.3	11.2	11.0	11.8	NA[d]	NA[d]	NA[d]	NA[d]
DO	mg/L	4.8	4.2	3.7	3.4	NA[d]	NA[d]	NA[d]	NA[d]
ORP	mV	210	81	86	88	NA[d]	NA[d]	NA[d]	NA[d]
Free Chlorine	mg/L	–	0.01	–	–	NA[d]	NA[d]	NA[d]	NA[d]
Total Chlorine	mV	–	0.03	–	–	NA[d]	NA[d]	NA[d]	NA[d]
Total Hardness	mg/L[a]	–	–	–	–	–	–	–	–
Ca Hardness	mg/L[a]	–	–	–	–	–	–	–	–
Mg Hardness	mg/L[a]	–	–	–	–	–	–	–	–
As (total)	µg/L	41.9	35.7	3.4	3.4	31.2 31.6	31.5 31.8	4.1 3.5	4.7 4.7
As (total soluble)	µg/L	–	–	–	–	–	–	–	–
As (particulate)	µg/L	–	–	–	–	–	–	–	–
As (III)	µg/L	–	–	–	–	–	–	–	–
As (V)	µg/L	–	–	–	–	–	–	–	–
Total Fe	µg/L	492	333	36	37	96 60	47 70	<25 <25	<25 <25
Dissolved Fe	µg/L	–	–	–	–	–	–	–	–
Total Mn	µg/L	151	127	26.7	26.5	65.1 69.1	69.0 71.1	15.4 12.9	12.5 12.5
Dissolved Mn	µg/L	–	–	–	–	–	–	–	–

(a) Measured as $CaCO_3$. (b) As P. (c) On-site water quality measurements taken on December 14, 2004. (d) On-site water quality measurements not taken. (d) The pH was measured at the laboratory and not on-site. (e) System bypassed due to high pressure conditions.

IN = inlet; AP = after pH adjustment and after pre-chlorination; TA = after tank A; TB = after the tank B; TT = after tanks combined. NA = data not available.

Table 2. Analytical Results from Long-Term Sampling, Rollinsford, NH (APU-RWS)

Sampling Date		6/13/2005[(c)]			6/28/2005[(c)]					7/19/2005[(c)]				8/3/2005[(c)(d)]				
Sampling Location		IN	AP	TT	IN	AP	TA	TB	PT	IN	AP	TT	PT	IN	AP	TA	TB	CA
Parameter	Unit																	
Bed Volume	10^3	-	-	NA	-	-	2.0		-	-	-	4.1	-	-	-	6.0		-
Alkalinity	mg/L[(a)]	198	198	198	176	176	176	176	-	180	176	176	-	167	180	172	172	-
Fluoride	mg/L	0.5	0.5	0.5	-	-	-	-	-	0.6	0.5	0.5	-	-	-	-	-	-
Sulfate	mg/L	54	56	76	-	-	-	-	-	59	46	53	-	-	-	-	-	-
Orthophosphate	mg/L[(b)]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	<0.05	<0.05	-	<0.05	<0.05	<0.05	<0.05	-
Total P (as PO_4)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO_2)	mg/L	17.0	16.4	1.6	15.6	15.0	15.4	15.4	-	15.4	14.0	14.8	-	14.6	14.5	13.9	14.7	-
Nitrate (as N)	mg/L	0.1	<0.05	<0.05	-	-	-	-	-	0.1	0.5	0.4	-	-	-	-	-	-
Turbidity	NTU	0.5	0.5	0.3	5.1	5.0	2.7	0.3	-	1.7	1.0	1.0	-	0.6	0.2	1.3	0.2	-
pH	S.U.	7.6	7.6	7.3	7.7	7.8	7.9	7.8	7.4	7.9	7.6	7.8	7.4	7.7	7.8	7.7	7.8	8.7
Temperature	^0C	NA	NA	NA	12.7	12.9	12.2	11.6	13.0	19.7	18.7	18.3	13.0	10.6	10.1	10.5	10.0	12.1
DO	mg/L	NA	NA	NA	7.8	9.4	9.6	9.5	-	4.3	4.4	3.3	-	5.6	6.4	6.6	6.2	-
ORP	mV	NA	NA	NA	196	180	159	168	-	164	158	151	-	199	161	175	160	-
Free Chlorine	mg/L	-	-	-	-	-	-	-	0.20	-	-	-	0.20	-	-	0.05	-	0.02
Total Chlorine	mg/L	-	-	-	-	-	-	-	0.30	-	-	-	0.30	-	-	0.25	-	0.11
Total Hardness	mg/L[(a)]	87.7	83.0	92.0	-	-	-	-	-	74.6	72.5	84.6	-	-	-	-	-	-
Ca Hardness	mg/L[(a)]	47.6	46.6	52.2	-	-	-	-	-	46.2	45.3	51.7	-	-	-	-	-	-
Mg Hardness	mg/L[(a)]	40.1	36.4	39.8	-	-	-	-	-	28.3	27.1	32.9	-	-	-	-	-	-
As (total)	µg/L	35.2	43.0	1.7	34.1	33.8	1.0	1.0	-	51.1	35.9	1.6	-	31.9	39.5	3.1	3.0	-
As (soluble)	µg/L	35.2	32.5	1.2	-	-	-	-	-	45.0	30.8	1.5	-	-	-	-	-	-
As (particulate)	µg/L	<0.1	10.5	0.5	-	-	-	-	-	6.1	5.1	0.1	-	-	-	-	-	-
As (III)	µg/L	24.1	1.6	1.1	-	-	-	-	-	28.8	1.1	0.5	-	-	-	-	-	-
As (V)	µg/L	11.1	30.9	<0.1	-	-	-	-	-	16.3	29.6	1.0	-	-	-	-	-	-
Total Fe	µg/L	203	470	72	77	121	<25	<25	-	798	211	<25	-	140	555	<25	<25	-
Soluble Fe	µg/L	158	68	79	-	-	-	-	-	50	<25	<25	-	-	-	-	-	-
Total Mn	µg/L	176	192	7.2	97.2	106	0.5	0.5	-	157	107	0.7	-	78.8	191	0.7	0.6	-
Soluble Mn	µg/L	182	148	4.0	-	-	-	-	-	158	74.3	0.6	-	-	-	-	-	-

(a) Measured as $CaCO_3$. (b) as P. (c) pH adjustment not yet working since system start-up. (d) On-site water quality measurements were taken on August 2, 2005.
IN = inlet; AP = after pH adjustment and after pre-chlorination; TA = after tank A; TB = after the tank B; TT = after tanks combined; PT = plant tap; CA = after caustic addition.
NA = data not available.

Table 2. Analytical Results from Long-Term Sampling, Rollinsford, NH (APU-RWS) (Continued)

Sampling Date		9/28/2005[e][f]				10/13/2005					11/2/2005			
Sampling Location		IN	AC	TT	CA	IN	AP	TA	TB	CA	IN	AP	TT	CA
Parameter	Unit													
Bed Volume	10^3	-	-	6.4	-	-	-	7.7		-	-	-	9.6	-
Alkalinity	mg/L[a]	194	194	198	-	198	189	189	185	-	158	176	172	-
Fluoride	mg/L	0.6	0.6	0.6	-	-	-	-	-	-	0.4	0.5	0.4	-
Sulfate	mg/L	28	29	31	-	-	-	-	-	-	33	37	37	-
Orthophosphate	mg/L[b]	<0.05	<0.05	<0.05	-	0.1	<0.06	<0.06	<0.06	-	<0.05	<0.05	<0.05	-
Total P (as PO_4)	μg/L	-	-	-	-	83.2	83.2	<10	<10	-	72.8	87.9	15.3	-
Silica (as SiO_2)	mg/L	16.4	16.3	13.8	-	13.9	14.1	13.5	13.1	-	14.4	15.0	14.9	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	0.1	<0.05	<0.05	-
Turbidity	NTU	0.6	0.4	0.6	-	1.0	2.3	0.2	0.2	-	2.2	1.0	0.2	-
pH	S.U.	7.8	7.9	7.7	NA[f]	6.8	7.4	7.7	7.7	NA[g]	7.6	7.9	8.0	NA[g]
Temperature	^{0}C	14.6	14.5	14.7	NA[f]	12.9	12.4	13.2	13.3	NA[g]	10.0	9.0	10.1	NA[g]
DO	mg/L	4.3	4.2	4.4	-	3.9	4.5	4.7	4.1	-	4.0	4.1	3.1	-
ORP	mV	144	168	192	-	-19	132	135	144	-	187	192	192	-
Free Chlorine	mg/L	-	0.02	0.05	-	-	0.05	-	-	-	-	0.28	0.07	-
Total Chlorine	mg/L	-	0.20	0.25	-	-	0.27	-	-	-	-	0.46	0.43	-
Total Hardness	mg/L[a]	55.5	52.4	48.7	-	-	-	-	-	-	70.0	65.8	75.1	-
Ca Hardness	mg/L[a]	33.3	31.0	29.1	-	-	-	-	-	-	46.0	40.6	45.3	-
Mg Hardness	mg/L[a]	22.3	21.4	19.6	-	-	-	-	-	`	24.0	25.1	29.8	-
As (total)	μg/L	32.1	34.7	1.5	-	38.7	42.7	2.9	2.4	-	31.6	32.6	4.0	-
As (soluble)	μg/L	32.9	34.6	1.3	-	-	-	-	-	-	30.3	32.9	3.9	-
As (particulate)	μg/L	<0.1	<0.1	0.2	-	-	-	-	-	-	1.4	<0.1	0.1	-
As (III)	μg/L	7.6	2.3	1.1	-	-	-	-	-	-	10.4	0.4	0.5	-
As (V)	μg/L	25.3	32.3	0.2	-	-	-	-	-	-	19.9	32.5	3.4	-
Total Fe	μg/L	167	56	<25	-	167	344	<25	<25	-	347	169	<25	-
Soluble Fe	μg/L	<25	<25	<25	-	-	-	-	-	-	86	28	<25	-
Total Mn	μg/L	59.8	55.6	0.5	-	59.7	83.3	1.2	1.2	-	132	91.2	1.4	-
Soluble Mn	μg/L	57.6	55.1	0.5	-	-	-	-	-	-	109	80.0	1.1	-

(a) Measured as $CaCO_3$. (b) As P. (c) pH adjustment not yet working since system start-up. (d) On-site water quality measurements were taken on August 2, 2005. (e) System was back online starting September 26, 2005. (f) CO2 system was down therefore caustic addition was not needed to raise the pH of the treated water. (g) CO2 system is down therefore caustic addition is not needed to raise the pH of the treated water.
IN = inlet; AP = after pH adjustment and after pre-chlorination; TA = after tank A; TB = after the tank B; TT = after tanks combined; CA = after caustic addition. NA = data not available.

Table 2. Analytical Results from Long-Term Sampling, Rollinsford, NH (APU-RWS) (Continued)

Sampling Date		11/30/2005				12/14/2005					1/18/2006				2/6/2006				
Sampling Location		IN	AP	TT	CA	IN	AP	TA	TB	CA	IN	AP	TT	CA	IN	AP	TA	TB	CA
Parameter	Unit																		
Bed Volume	10^3	-	-	13.3	-	-	-	14.8		-	-	-	18.6	-	-	-	20.7		-
Alkalinity	mg/L[a]	176	198	189	-	176	172	185	176	-	180	189	189	-	176	176	176	176	-
Fluoride	mg/L	0.4	0.5	0.4	-	-	-	-	-	-	0.3	0.4	0.4	-	-	-	-	-	-
Sulfate	mg/L	35	36	34	-	-	-	-	-	-	35	36	36	-	-	-	-	-	-
Orthophosphate	mg/L[b]	0.1	0.1	0.1	-	<0.05	<0.05	<0.05	<0.05	-	<0.05	<0.05	<0.05	-	-	-	-	-	-
Total P (as PO_4)	μg/L	82.3	94.2	48.5	-	101	71.7	86.2	72.9	-	77.3	77.4	50.3	-	72.8	83.0	66.2	62.8	-
Silica (as SiO_2)	mg/L	15.0	14.4	15.1	-	14.2	14.4	15.1	14.6	-	15.7	15.3	15.5	-	15.6	15.6	15.6	15.3	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-
Turbidity	NTU	1.3	0.8	0.2	-	4.2	4.4	1.0	1.3	-	3.4	1.5	1.4	-	1.5	1.8	0.3	0.3	-
pH	S.U.	7.8	8.0	8.1	NA[c]	7.5	7.7	8.0	8.0	NA[c]	7.9	8.1	8.3	NA[c]	7.7	7.6	7.9	7.9	NA[c]
Temperature	°C	10.3	11.3	11.5	NA[c]	11.5	11.1	11.4	11.2	NA[c]	12.1	11.8	12.1	NA[c]	11.3	10.1	10.6	10.7	NA[c]
DO	mg/L	3.9	4.1	3.5	-	4.8	6.2	5.2	6.3	-	3.5	5.5	3.6	-	NA[d]	NA[d]	NA[d]	NA[d]	-
ORP	mV	178	179	180	-	195	436	176	314	-	224	192	201	-	210	200	186	183	-
Free Chlorine	mg/L	-	0.15	0.03	-	-	0.41	-	-	-	-	0.1	0.1	-	-	0.1	-	-	-
Total Chlorine	mg/L	-	0.28	0.24	-	-	0.63	-	-	-	-	0.2	0.3	-	-	0.2	-	-	-
Total Hardness	mg/L[a]	53.4	46.4	52.1	-	-	-	-	-	-	60.1	55.3	58.3	-	-	-	-	-	-
Ca Hardness	mg/L[a]	29.5	25.1	27.8	-	-	-	-	-	-	36.3	33.2	32.6	-	-	-	-	-	-
Mg Hardness	mg/L[a]	23.9	21.2	24.3	-	-	-	-	-	-	23.9	22.2	25.7	-	-	-	-	-	-
As (total)	μg/L	41.2	37.6	11.8[d]	-	34.2	28.5	13.9	10.1	-	38.0	35.6	16.5	-	46.8	48.6	20.3	19.5	-
As (soluble)	μg/L	34.7	37.2	11.8[d]	-	-	-	-	-	-	31.8	33.0	16.3	-	-	-	-	-	-
As (particulate)	μg/L	6.6	0.5	<0.1	-	-	-	-	-	-	6.2	2.6	0.2	-	-	-	-	-	-
As (III)	μg/L	13.2	1.2	1.3	-	-	-	-	-	-	16.6	0.6	0.7	-	-	-	-	-	-
As (V)	μg/L	21.4	35.9	10.5	-	-	-	-	-	-	15.2	32.4	15.6	-	-	-	-	-	-
Total Fe	μg/L	322	62	<25	-	201	120	165	64	-	570	278	55	-	271	247	<25	<25	-
Soluble Fe	μg/L	48	<25	<25	-	-	-	-	-	-	79	<25	<25	-	-	-	-	-	-
Total Mn	μg/L	97.5	69.7	2.5	-	91.8	126	19.7	9.1	-	126	94.3	23.6	-	95.1	86.5	12.1	11.2	-
Soluble Mn	μg/L	97.5	65.8	0.8	-	-	-	-	-	-	165	73.5	15.3	-	-	-	-	-	-

(a)Measured as $CaCO_3$. (b) As P. (c) CO2 system is down therefore caustic addition is not needed to raise the pH of the treated water. (d) DO probe not working.
IN = inlet; AP = after pH adjustment and after pre-chlorination; TA = after tank A; TB = after the tank B; TT = after tanks combined; CA = after caustic addition. NA = data not available.

Table 3. Analytical Results from Long-Term Sampling, Rollinsford, NH (After Conversion to Coagulation/Filtration)

Sampling Date		5/8/2006						5/17/2006[e]				6/7/2006				6/22/2006			
Sampling Location		IN	AP	TA	TB	TT	CA	IN	AP	TT	CA	IN	AP	TT	CA	IN	AP	TT	CA
Parameter	Unit																		
Bed Volume	10^3	-	-	26.9		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alkalinity	mg/L[a]	-	-	-	-	-	-	186	165	-	-	-	-	-	-	180	142	172	-
Fluoride	mg/L	-	-	-	-	-	-	0.3	0.4	-	-	-	-	-	-	0.5	0.5	0.5	-
Sulfate	mg/L	-	-	-	-	-	-	85	59	-	-	-	-	-	-	59	48	49	-
Orthophosphate	mg/L[b]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as PO_4)	µg/L	-	-	-	-	-	-	49.6	<10	13.7	-	-	-	-	-	55.1	37.3	24.8	-
Silica (as SiO_2)	mg/L	-	-	-	-	-	-	16.3	15.6	15.6	-	-	-	-	-	15.3	14.7	15.5	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	<0.05	<0.05	-
Turbidity	NTU	-	-	-	-	-	-	1.3	0.6	0.9	-	-	-	-	-	0.7	5.7	0.3	-
pH	S.U.	7.7	7.4	7.2	7.3	7.3	NA[c]	7.8	7.8	7.1	NA[c]	7.8	7.9	7.8	NA[c]	7.5	6.9	7.4	NA[c]
Temperature	^0C	12.4	12.6	12.0	12.0	12.2	NA[c]	12.7	12.5	12.5	NA[c]	12.1	12.9	12.9	NA[c]	20.4	16.0	15.6	NA[c]
DO	mg/L	3.5	4.5	3.7	6.0	4.3	-	NA[f]	NA[f]	NA[f]	-	NA[f]	NA[f]	NA[f]	-	NA[f]	NA[f]	NA[f]	-
ORP	mV	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	-	NA[d]	NA[d]	NA[d]	-	NA[d]	NA[d]	NA[d]	-	NA[d]	NA[d]	NA[d]	-
Free Chlorine	mg/L	-	0.3	-	-	0.0	-	-	0.1	0.1	-	-	0.0	0.0	-	-	0.3	0.1	-
Total Chlorine	mg/L	-	0.6	-	-	0.1	-	-	0.4	0.1	-	-	0.4	0.0	-	-	0.6	0.1	-
Total Hardness	mg/L[a]	-	-	-	-	-	-	120	108	97.0	-	-	-	-	-	-	-	-	-
Ca Hardness	mg/L[a]	-	-	-	-	-	-	64.6	58.3	54.8	-	-	-	-	-	-	-	-	-
Mg Hardness	mg/L[a]	-	-	-	-	-	-	55.7	50.1	42.3	-	-	-	-	-	-	-	-	-
As (total)	µg/L	43.0	9.9	-	-	12.4	-	31.8	6.1	7.2	-	33.0	34.7	15.7	-	30.9	24.6	11.3	-
As (soluble)	µg/L	-	-	-	-	-	-	27.3	3.7	4.5	-	-	-	-	-	27.4	0.6	10.6	-
As (particulate)	µg/L	-	-	-	-	-	-	4.4	2.3	2.7	-	-	-	-	-	3.5	24.0	0.7	-
As (III)	µg/L	-	-	-	-	-	-	13.6	0.4	0.4	-	-	-	-	-	14.7	0.4	10.4	-
As (V)	µg/L	-	-	-	-	-	-	13.8	3.3	4.1	-	-	-	-	-	12.7	0.2	0.2	-
Total Fe	µg/L	556	349	-	-	722	-	399	231	217	-	273	181	<25	-	185	10,915	<25	-
Soluble Fe	µg/L	-	-	-	-	-	-	512	<25	<25	-	-	-	-	-	72	<25	<25	-
Total Mn	µg/L	115	41.0	-	-	51.4	-	280	4.0	9.3	-	98.4	121	8.5	-	160.4	209	1.1	-
Soluble Mn	µg/L	-	-	-	-	-	-	281	1.3	1.3	-	-	-	-	-	148	153	1.3	-

(a) Measured as $CaCO_3$. (b) As P. (c) CO2 system is down therefore caustic addition is not needed to raise the pH of the treated water. (d) ORP measurements will no longer be taken. (e) On-site water quality measurements were taken on May 19, 2006. (f) DO measurements will no longer be taken.
IN = inlet; AP = after pH adjustment and after pre-chlorination; TA = after tank A; TB = after the tank B; TT = after tanks combined; CA = after caustic addition. NA = data not available.