

Arsenic Removal from Drinking Water by Adsorptive Media

EPA Demonstration Project at Rimrock, AZ Six-Month Evaluation Report

by

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Sally Gutierrez, Director
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ABSTRACT

This report documents the activities performed and the results obtained from the first six months of the arsenic removal treatment technology demonstration project in Rimrock, AZ. The objectives of the project are to evaluate: (1) the effectiveness of the AdEdge Arsenic Package Unit-100 (APU-100) AD-33™ media system 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 simplicity of required system operation, (4) the maintenance (O&M) and operator's skill levels, and (5) the cost-effectiveness of the technology. The project also is characterizing water in the distribution system and process residuals produced by the treatment process. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), process residuals, and capital and O&M costs.

The APU-100 treatment system consisted of two 36-inch-diameter, 72-inch-tall fiberglass-reinforced-plastic (FRP) vessels, each containing 22 ft³ of AD-33™ media. The media is Bayoxide E33 iron-based adsorption media developed by Bayer AG and branded under the name of AD-33™ by AdEdge. The system was originally designed to treat 90 gpm of water supplied by two production wells. Due to the loss of one well, the treatment flowrate was reduced by more than half, which prompted a change in system configuration from parallel to series (lead/lag). Following the conversion to series configuration in the field, the APU-100 system with a design capacity of 45 gpm began regular operation on June 24, 2004. The average flowrate through each vessel was 31.5 gpm, corresponding to an average empty bed contact time (EBCT) of 5.2 minutes per vessel and 10.4 minutes for both vessels.

Through the period June 24, 2004 through December 22, 2004, the APU-100 system operated for 12 hours a day on a timer for a total of 2,172 hours. The system treated approximately 4,109,000 gallons of water, or 25,000 bed volumes (BV), which was approximately 38% of the vendor-estimated working capacity for adsorptive media. Arsenic breakthrough from the lead and lag vessels was 3 µg/L and 1.3 µg/L, respectively. Total arsenic concentration in raw water ranged from 48.3 to 81.4 µg/L with As(V) being the predominating species, averaging 57.3 µg/L. Prechlorination, although not required for oxidation, was performed for disinfection. The residual chlorine measured before and after the treatment vessels was comparable, indicating little or no chlorine consumption by the AD-33™ media. Concentrations of iron, manganese, silica, orthophosphate, and other ions in raw water were not high enough to impact arsenic removal by the media.

Backwash was performed monthly since August 2004 with raw water at approximately 50 gpm, or 7 gpm/ft². Each vessel was backwashed for 15 minutes, producing between 631 to 910 gallons of water. Two sets of backwash water samples were collected during the first six months of system operation. Arsenic concentrations in the backwash water from the lead and lag vessels were approximately 48.0 µg/L and <3.0 µg/L, respectively, indicating that the lead vessel had less capacity to remove arsenic, and that the lag vessel was still very effective at removing arsenic during backwash. A backwash recycle loop enabled the system to reclaim nearly 100% of the wastewater produced by blending it with the chlorinated water at a rate of 0.5 gpm.

Comparison of the distribution system sampling results before and after operation of the APU-100 system began showed a decrease in the average arsenic concentration (from 44.6-55.2 µg/L to 18.8-21.8 µg/L) at each of the three sampling locations. However, the concentrations measured after system operation began were higher than those at the plant effluent. This was probably caused by the blending of treated water by the APU-100 system with untreated water from other wells in the distribution system. Neither lead nor copper concentrations appeared to have been affected by the operation of the system.

The capital investment cost of \$90,757 includes \$66,235 for equipment, \$11,372 for site engineering, and \$13,150 for installation. Using the system's rated capacity of 45 gpm (or 64,800 gpd), the capital cost was \$2,017/gpm (or \$1.40/gpd) and the equipment-only cost was \$1,472/gpm (or \$1.02/gpd). These calculations did not include the cost of the building construction.

O&M costs included only incremental costs associated with the APU-100 system, such as media replacement and disposal, chemical supply, electricity, and labor. Although not incurred during the first six months of operation, the media replacement cost would represent the majority of the O&M cost, and was estimated to be \$9,940 per vessel. This cost was used to estimate the media replacement cost per 1,000 gallons of water treated as a function of the projected media run length to the 10- μ g/L arsenic breakthrough. O&M costs will be refined once the actual throughput and cost at the time of the media replacement become available.

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ABBREVIATIONS AND ACRONYMS

Δp	differential pressure
AA	activated alumina
AAL	American Analytical Laboratories
ADEQ	Arizona Department of Environmental Quality
Al	aluminum
APU	arsenic package unit
As	arsenic
AWC	Arizona Water Company
bgs	below ground surface
BV	bed volume(s)
Ca	calcium
CCR	Consumer Confidence Report
Cl	chlorine
Cu	copper
DO	dissolved oxygen
EBCT	empty bed contact time
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
FRP	fiberglass-reinforced-plastic
GFH	granular ferric hydroxide
GFO	granular ferric oxide
gpd	gallons per day
gpm	gallons per minute
HDPE	high-density polyethylene
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IX	ion exchange
kwh	kilowatt-hour(s)
LCR	(EPA) Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MDWCA	Mutual Domestic Water Consumers Association
Mg	magnesium
mg/L	milligrams per liter

µg/L	micrograms per liter
µm	micrometer
Mn	manganese
mph	miles per hour
mV	millivolts
Na	sodium
NA	not applicable
NaOCl	sodium hypochlorite
ND	not detected
NS	not sampled
NSF	NSF International
NTU	nephelometric turbidity units
O&M	operation and maintenance
ORD	Office of Research and Development
ORP	oxidation-reduction potential
P&IDs	pipng and instrumentation diagrams
Pb	lead
PO ₄	orthophosphate
psi	pounds per square inch
PVC	polyvinyl chloride
QA	quality assurance
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RPD	relative percent difference
SDWA	Safe Drinking Water Act
SiO ₂	silica
SO ₄	sulfate
STMGID	South Truckee Meadows General Improvement District
STS	Severn Trent Services
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
TO	Task Order
TOC	total organic carbon

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1.0 INTRODUCTION

1.1 Background

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

In October 2001, EPA announced an initiative for additional research and development of cost-effective technologies to help small community water systems (<10,000 customers) meet the new arsenic standard, and to provide technical assistance to operators of small systems in order to reduce compliance costs. As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, on-site demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems. Shortly thereafter, an announcement was published in the *Federal Register* requesting water utilities interested in participating in the first round of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 sites from a list of 115 sites to be the host sites for the demonstration studies. The Arizona Water Company (AWC) water system in Rimrock, AZ 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 the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration project. Using the information provided by the review panel, EPA, in cooperation with the host sites and the drinking water programs of the respective states, selected one technical proposal for each site. AdEdge, using the Bayoxide E33 media developed by Bayer AG, was selected for Rimrock. AdEdge has given the E33 media the designation "AD-33™."

1.2 Treatment Technologies for Arsenic Removal

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

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

Demonstration Site	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
				As (µg/L)	Fe (µg/L)	pH
Bow, NH	AM (G2)	ADI	70 ^(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	SM	Kinetico	250	146 ^(b)	1,325 ^(c)	7.2
Desert Sands MDWCA, NM	AM (E33)	STS	320	23 ^(b)	39	7.7
Nambe Pueblo, NM	AM (E33)	AdEdge	145	33	<25	8.5
Rimrock, AZ	AM (E33)	AdEdge	90 ^(a)	50	170	7.2
Valley Vista, AZ	AM (AAFS50)	Kinetico	37	41	<25	7.8
Fruitland, ID	IX	Kinetico	250	44	<25	7.4
STMGID, NV	AM (GFH)	USFilter	350	39	<25	7.4

AM = adsorptive media process; C/F = coagulation/filtration process; IX = ion exchange process;

SM = system modification; MDWCA = Mutual Domestic Water Consumers Association;

STMGID = South Truckee Meadows General Improvement District; STS = Severn Trent Services.

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

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

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

1.3 Project Objectives

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

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

This report summarizes the results gathered during the first six months of the AdEdge system operation from June 24 through December 24, 2004. The types of data collected included system operational data, water quality data (both across the treatment train and in the distribution system), residuals characterization data, and capital and preliminary O&M cost data.

2.0 CONCLUSIONS

The AdEdge arsenic package unit (APU)-100 was installed and operated at Rimrock, AZ since June 24, 2004. Based on the information collected during the first six months of operation, the following preliminary conclusions were made relating to the overall project objectives.

Performance of the arsenic removal technology for use on small systems

- The APU-100 was effective at reducing As(V) in the raw water from 48.3-81.4 µg/L to less than 10 µg/L. After treating approximately 4.1 million gallons or 25,000 bed volumes of water, total arsenic concentrations in the effluent from the lead and lag vessels were measured at 3 µg/L and 1.3 µg/L, respectively.
- The presence of low concentrations of iron, manganese, silica, orthophosphate, and other ions in the water did not appear to impact arsenic removal by the AD-33™ media.
- Little or no chlorine was consumed by the AD-33™ media.

Simplicity of required system operation and maintenance and operator's skill levels

- The daily demand on the operator was typically 20 minutes to visually inspect the system and record operational parameters. The APU-100 was equipped with automated controls to initiate backwash by timer and/or differential pressure.
- Operation of the APU-100 did not require additional skills beyond those necessary to operate the existing water supply equipment.

Cost-effectiveness of the technology

- The capital investment for the APU-100 was \$90,757, including \$66,235 for equipment, \$11,372 for site engineering, and \$13,150 for installation.
- Based on a design capacity of 45 gpm, the capital cost was \$2,017/gpm (or \$1.40/gpd) and the equipment-only cost was \$1,472/gpm (or \$1.02/gpd), not including the cost for building construction.
- Media replacement cost, although not incurred during the first six months, represents the majority of the O&M cost. The media replacement for one vessel was estimated to be \$9,940.

Characteristics of process residuals produced by the technology

- The APU-100 was backwashed monthly, generating between 1,500 and 1,700 gallons of water. Nearly 100% of the wastewater was reclaimed via a backwash recycle system.
- Backwash effluent contained less arsenic than the backwash influent, indicating some arsenic removal by the media during backwashing.

3.0 MATERIALS AND METHODS

3.1 General Project Approach

Following the pre-demonstration activities summarized in Table 3-1, the performance evaluation study of the AdEdge treatment system began on June 24, 2004. Table 3-2 summarizes the types of data collected and/or considered as part of the technology evaluation process. The overall system performance was evaluated based on its ability to consistently remove arsenic to below the target MCL of 10 µg/L through the collection of weekly/biweekly water samples across the treatment train. The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

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

The cost-effectiveness of the system was evaluated based on the cost per 1,000 gallons (\$/1,000 gallons) of water treated. This task required the tracking of capital costs such as equipment, engineering, and installation costs, as well as O&M costs for media replacement and disposal, chemical supply, electrical power use, and labor hours. The capital costs have been detailed in an EPA report (Chen et al., 2004)

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

Activity	Date
Introductory Meeting Held	July 31, 2003
Request for Quotation Issued to Vendor	August 4, 2003
Draft Letter of Understanding Issued	August 13, 2003
Final Letter of Understanding Issued	September 9, 2003
Vendor Quotation Submitted to Battelle	September 9, 2003
Purchase Order Completed and Signed	October 6, 2003
Letter Report Issued	October 17, 2003
Draft Study Plan Issued	November 26, 2003
Engineering Package Submitted to ADEQ	December 11, 2003
Final Study Plan Issued	December 19, 2003
Approval to Construct Granted by ADEQ	February 18, 2004
Construction Permit Issued by County	March 15, 2004
APU-100 Unit Shipped	March 30, 2004
Initial System Installation and Shakedown Completed	April 22, 2004
Initial Approval of Construction Granted by ADEQ	April 29, 2004
Shed Construction Completed	May 21, 2004
System Re-Configuration Completed	May 27, 2004
Revised Engineering Package Submitted to ADEQ	June 1, 2004
Final Approval of Construction Granted by ADEQ	June 15, 2004
Performance Evaluation Begun	June 24, 2004

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

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

that is posted at the following EPA Web site: <http://www.epa.gov/ORD/NRMRL/arsenic/resource.htm>. Data on O&M costs were limited to chemicals, electricity, and labor hours because media replacement did not take place during the six months of operation.

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

3.2 System O&M and Cost Data Collection

The plant operator performed daily, weekly (changed to biweekly since November 3, 2004), and monthly system O&M and data collection following the instructions provided by Battelle. The plant operator recorded system operational data, such as pressure, flowrate, totalizer, and hour meter readings on a Daily System Operation Log Sheet; checked the sodium hypochlorite drum level; and conducted visual inspections to ensure normal system operations on a regular basis. If any problems occurred, the plant operator would contact the Battelle Study Lead, who then would determine if AdEdge should be contacted for troubleshooting. The plant operator recorded all relevant information on the Repair and Maintenance Log Sheet. Weekly or biweekly, the plant operator measured water quality parameters, including temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and residual chlorine and recorded the data on a Weekly On-Site Water Quality Parameters Log Sheet. Monthly backwash data also were recorded on a Backwash Log Sheet.

Capital costs for the APU-100 consisted of costs for equipment, site engineering, and system installation. The O&M costs consisted of costs for the media replacement and spent media disposal, chemical and electricity consumption, and labor. The sodium hypochlorite consumption was tracked on the Daily System Operation Log Sheet. Electrical consumption was estimated from an electric meter. Labor hours for various activities, such as the routine system O&M, system troubleshooting and repair, and demonstration-related work, were tracked using an Operator Labor Hour Log Sheet. The routine O&M included activities such as filling field logs, replenishing the sodium hypochlorite solution, ordering supplies, performing system inspection, and others as recommended by AdEdge. The demonstration-related work included activities such as performing field measurements, collecting and shipping samples,

and communicating with the Battelle Study Lead and AdEdge. The demonstration-related activities were recorded but not used for the cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate the system performance, samples were collected from the wellhead, treatment plant, distribution system, and adsorptive vessel backwash. Table 3-3 provides the sampling schedule and analytes measured during each sampling event. Specific sampling requirements for arsenic speciation, analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2003).

3.3.1 Source Water Sample Collection. The plant operator collected one set of source water samples from Montezuma Haven Well No. 2 for detailed water quality analyses (see Table 3-3) on October 22, 2003. The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. An arsenic speciation kit and sample bottles with appropriate preservatives were used for sample collection.

3.3.2 Treatment Plant Water Sample Collection. During the system performance study, the plant operator collected water samples across the treatment train in 250-mL plastic bottles containing nitric acid preservative for metal analyses and in additional plastic bottles containing appropriate preservatives for other water quality analyses. The plant operator also performed on-site arsenic speciation using arsenic speciation kits (see Section 3.4.1). For the first four months of the demonstration, samples were collected weekly on a four-week cycle at three locations (i.e. the wellhead [IN], after the lead vessel [TA], and after the lag vessel [TB]) for on- and off-site analyses. For the first week of each four-week cycle, samples were collected, speciated, and analyzed for the analytes listed under the monthly treatment plant analyte list (see Table 3-3). For the next three weeks, samples were collected and analyzed for the analytes listed under the weekly treatment plant analyte list. Since November 3, 2004, the weekly sampling frequency was reduced to biweekly and speciation sampling was reduced to bimonthly due to slow arsenic breakthrough in the treated water. Thus, the four-week sampling cycle became an eight-week cycle. On-site measurements also were taken after prechlorination (AC), in addition to IN, TA, and TB.

3.3.3 Backwash Water Sample Collection. Backwash water samples were collected on October 20, 2004 and December 15, 2004 from the sample taps located at the backwash water effluent line from each vessel. For each backwash sampling, an unfiltered sample from each vessel was collected in an unpreserved 1-gallon wide-mouth high-density polyethylene (HDPE) bottle for water quality analyses, and a 60-mL sample filtered on-site with 0.45- μ m filters was collected in a 125-mL HDPE bottle preserved with nitric acid for metal analyses. Analytes for the backwash samples are listed in Table 3-3.

3.3.4 Residual Solid Sample Collection. Residual solids including backwash sludge and spent media samples were not collected during the initial six months of this demonstration.

3.3.5 Distribution System Water Sample Collection. Samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically, the arsenic, lead, and copper levels. From December 2003 to February 2004, prior to the startup of the treatment system, four sets of baseline distribution water samples were collected from three locations within the distribution system. Following the startup of the arsenic adsorption system, distribution system sampling continued on a monthly basis at the same locations. Ideally, the sampling locations selected would have been the historical Lead and Copper Rule (LCR) locations served primarily by Well No. 2. However, because the distribution system of Rimrock is supplied by Well No. 2 and five other wells, such LCR locations do not exist (see Section 4.1.2).

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	As (total, soluble, and particulate), As(III), As(V), Fe (total and soluble), Mn (total and soluble), Al (total and soluble), Na, Ca, Mg, Cl, F, SO ₄ , SiO ₂ , PO ₄ , TOC, turbidity, pH, and alkalinity.	10/22/03
Treatment Plant Water	Wellhead (IN), after the lead vessel (TA), and after the lag vessel (TB)	3	Weekly ^(b)	On-site ^(c) : pH, temperature, DO, ORP, Cl ₂ (free and total). Off-site: As (total), Fe (total), Mn (total), SiO ₂ , PO ₄ , turbidity, and alkalinity.	07/07/04, 07/14/04, 07/21/04, 08/04/04, 08/11/04, 08/18/04, 09/01/04, 09/08/04, 09/15/04, 09/29/04, 10/06/04, 10/13/04, 10/27/04, 11/03/04, 11/17/04, 12/01/04
			Monthly	Same as weekly sampling (above) plus the following off-site: As (soluble and particulate), As(III), As(V), Fe (soluble), Mn (soluble), Ca, Mg, F, NO ₃ , and SO ₄ .	06/30/04, 07/28/04, 08/25/04, 09/22/04, 10/20/04, 12/15/04
Backwash Water	Backwash discharge line from each vessel	2	Monthly	pH, TDS, turbidity, As (soluble), Fe (soluble), and Mn (soluble).	10/20/04, 12/15/04
Residual Solid	Spent media from lead and lag vessels and backwash sludge from bag filter	2-3	Once	TCLP metals	To be determined
Distribution Water	Non-LCR residences served by Well No. 2 and other wells	3	Monthly ^(d)	pH, alkalinity, As, Fe, Mn, Cu, and Pb.	Baseline sampling: 12/17/03, 01/06/04, 01/21/04, 02/05/04, Monthly sampling: 07/28/04, 08/26/04, 09/22/04, 10/20/04, 11/17/04, 12/15/04

(a) The abbreviations in parentheses correspond to the sample locations shown in Figure 4-3.

(b) Began biweekly sampling on November 3, 2004.

(c) On-site measurements were performed on samples taken after prechlorination (AC), in addition to IN, TA, and TB. Chlorine measurements were not performed at IN.

(d) Four baseline sampling events were performed from December 2003 to February 2004 before the system became operational.

As such, three non-LCR residences that are served by Well No. 2 and other wells were used for the distribution system sampling.

For each location, samples were collected in one unpreserved 1-L HDPE wide-mouth bottle for metal analyses (preserved with nitric acid in the lab), and one unpreserved 250-mL plastic bottle for water quality analyses (see Table 3-3). The samples were collected following an instruction sheet developed according to the *Lead and Copper Rule Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The homeowners recorded the date and time of last water use before sampling and the date and time of sample collection to calculate the stagnation time. All samples were collected from a cold-water faucet that had not been used for at least six hours to ensure that stagnant water was sampled.

3.4 Sampling Logistics

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

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

3.4.2 Preparation of Sampling Coolers. For each sampling event, a cooler was prepared with an appropriate number and type of sample bottles, filters, and/or speciation kits needed. All sample bottles were new and contained appropriate preservatives. Each sample bottle was affixed with a pre-printed, colored-coded label consisting of the sample identification (ID), date and time of sample collection, collector's name, site location, where to send the sample, analysis required, and preservative. The sample ID consisted of a two-letter code for a specific water facility, the sampling date, a two-letter code for a specific sampling location, and a one-letter code designating the arsenic speciation bottle (if necessary). The sampling locations at the treatment plant were color-coded for easy identification. For example, red, orange, and yellow were used to designate sampling locations for IN, TA, and TB, respectively. The labeled bottles were then separated into ziplock bags by sampling locations and placed in the cooler.

In addition, all sampling- and shipping-related materials, such as disposable gloves, sampling instructions, chain-of-custody forms, prepaid and addressed Federal Express air bills, and bubble wrap, were packed into the coolers. Except for the operator's signature and the sample date and time, the chain-of-custody forms and prepaid Federal Express air bills were completed with the required information. After preparation, sample coolers were sent to the site via Federal Express 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, sample custodians verified that all samples indicated on the chain-of-custody forms were included and intact. Sample label identifications were checked against the chain-of-custody forms and the samples were logged into the laboratory sample receipt log. Discrepancies noted by the sample custodians were addressed with the plant operator by the Battelle Study Lead.

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

3.5 Analytical Procedures

The analytical procedures described in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2003) were followed by the Battelle ICP-MS Laboratory, AAL, and TCCI Laboratories. 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 by measuring the ORP of the 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 reached. The plant operator also performed free and total chlorine measurements using Hach chlorine test kits following the user's manual.

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

4.0 RESULTS AND DISCUSSION

4.1 Facility Description

The Montezuma Haven Wells No. 1 and No. 2 in Rimrock, AZ with a combined capacity of 90 gpm were selected for this demonstration study. These and five other wells serve a population of 2,556. From the summer of 2003 to October 2003, Wells No. 1 and No. 2 were taken off-line for repairs and redevelopment. Figure 4-1 shows the site condition in late July 2003. It was later discovered that Well No. 1 had become dry and that Well No. 2 produced no more than 35 gpm of water. This reduced flowrate prompted a change to the configuration of the adsorption vessels from parallel to series.

Well No. 2 is 6 inches in diameter and 165 ft deep with an open borehole extending from 80 to 165 ft below ground surface (bgs). During the first six months of the study, Well No. 2 operated 12 hours per day on a timer, i.e., from 8:00 am to 8:00 pm before November 22, 2004, and from 11:00 pm to 11:00 am afterwards (the operating time was adjusted to prevent the system components from being damaged under freezing conditions). The actual flowrate from Well No. 2 to the treatment system was approximately 31 gpm.

Well No. 3, a 1,000-ft-deep well located at the same site, was drilled in December 2002 and produced a flow of 315 gpm. This well became a main supply well and was controlled by level sensors in storage tanks. Before entering the distribution system, a 12% sodium hypochlorite solution was used to maintain a chlorine residual of about 0.3 mg/L (as Cl₂) in the distribution system.

4.1.1 Source Water Quality. Source water samples were collected for analysis from Well No. 2 on October 22, 2003. 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.



Figure 4-1. Pre-Demonstration Site Conditions

Table 4-1. Rimrock, AZ Source Water Quality Data

Parameter	Units	Facility Data ^(a)	Facility Data	EPA Data	Battelle Data
<i>Sampling Date</i>		Not specified	12/30/2002	10/03/2002	10/22/2003
<i>Well ID</i>		Wells No. 1&2	Well No. 3	Wells No. 1&2	Well No. 2
pH	–	7.2	7.6	NS	7.1
Total Alkalinity	mg/L ^(b)	334	444	374	378
Total Hardness	mg/L ^(b)	300	NS	330	335
Chloride	mg/L	25.0	NS	30.8	32.0
Fluoride	mg/L	NS	0.2	NS	0.5
Nitrate (as N)	mg/L	NS	0.1	NS	NS
Sulfate	mg/L	13.0	12.2	11.6	9.5
Silica (as SiO ₂)	mg/L	27.8	NS	26.3	24.8
Orthophosphate	mg/L	<0.065 ^(c)	NS	<0.065	<0.10
TOC	mg/L	NS	NS	NS	3.4 ^(d)
As (total)	µg/L	50.0	15.0	52.0	63.6
As (total soluble)	µg/L	NS	NS	NS	64.8
As (particulate)	µg/L	NS	NS	NS	<0.10
As(III)	µg/L	NS	NS	NS	<0.10
As(V)	µg/L	NS	NS	NS	64.8
Total Fe	µg/L	170 ^(c)	NS	170	36
Soluble Fe	µg/L	NS	NS	NS	<25
Total Al	µg/L	NS	NS	<25	13
Soluble Al	µg/L	NS	NS	NS	<10
Total Mn	µg/L	NS	NS	<0.4	7.5
Soluble Mn	µg/L	NS	NS	NS	8.1
Total Na	mg/L	35.0	93	41.6	40.3
Total Ca	mg/L	69.0	NS	80.2	82.8
Total Mg	mg/L	31.0	NS	31.6	31.0

(a) Provided by the facility to EPA for the demonstration site selection.

(b) As CaCO₃.

(c) Provided by EPA.

(d) Datum is questionable.

TOC = total organic carbon; NS = not sampled.

Based on the October 22, 2003 sampling results, the total arsenic concentration in Well No. 2 was 63.6 µg/L, with arsenic existing solely as As(V). Because the arsenic is As(V) and highly adsorbed with AD-33™ media, prechlorination upstream of the treatment process was not required. The AD-33™ media adsorbs arsenic more effectively at pH values ranging from 6.9 to 9.0, but less effectively at the upper end of the range. The source water pH value was 7.1; therefore, pH adjustment was not recommended.

The adsorption capacity of AD-33™ media can be impacted by high levels of competing ions such as silica, phosphate, and fluoride. Concentrations of these ions in the source water appeared to be low enough not to affect the media's adsorption of arsenic. The iron concentration (36 µg/L) in Well No. 2 water was sufficiently low that pretreatment for iron removal prior to adsorption was not required.

4.1.2 Distribution System. The distribution system is currently supplied by Montezuma Haven Wells No. 2, No. 3, and four other production wells. Well No. 1 is no longer in service. Water from Well No. 2 enters the distribution system via a 6-inch-diameter underground main. Chlorinated water from

Well No. 3 enters the distribution system at the fence line of the treatment plant. Well water blends within the distribution system and is stored in a 200,000-gallon tank. The distribution transmission main is constructed of 6-inch-diameter asbestos cement pipes.

Water from the distribution system is sampled periodically for state and federal compliance with safe drinking water standards. Every month, three samples are collected from the distribution system for bacteria analysis. Under the LCR, samples have been collected from customer taps at 14 locations every three years. The monitoring results for 2003 are summarized in Table 4-2.

Table 4-2. Rimrock, AZ Distribution System Water Quality Data^(a)

Parameter	Units	Detected Range
Alpha emitters	pCi/L	ND to 3.5
Arsenic (total)	µg/L	20 to 54
Barium	mg/L	0.3 to 0.4
Chromium	µg/L	11 to 15
Fluoride	mg/L	0.2 to 0.4
Nitrate (as N)	mg/L	ND to 0.9
Selenium	µg/L	3.2 to 4.2
Radium-226	pCi/L	ND to 0.2
Sodium	mg/L	38 to 45
Uranium	µg/L	1.3 to 4.5
Copper ^(b)	mg/L	0.43
Radon ^(c)	pCi/L	60

(a) All other constituents analyzed for AWC's Consumer Confidence Report (CCR) were under the respective detection limits (AWC, 2004).

(b) Parameter was sampled in 2002.

(c) Parameter was sampled in 1999.

ND = not detected.

4.2 Treatment Process Description

The APU-100 system is a fixed-bed, down-flow adsorption system used for small water systems with flows typically under 100 gpm. The treatment system uses Bayoxide[®] E33 granular ferric oxide (GFO) adsorptive media developed by Bayer AG for the removal of arsenic from drinking water supplies. This media is branded and referred to as AD-33[™] by AdEdge. Table 4-3 presents physical and chemical properties of the media. AD-33[™] is delivered in a dry crystalline form and has received NSF International (NSF) approval for use in drinking water under NSF Standard 61.

The original design of the APU-100 system consisted of two pressure vessels operating in parallel to treat an anticipated flowrate of 90 gpm. However, because Well No. 1 was no longer in service, the vessels were reconfigured to operate in series to treat half of that flow (i.e., 45 gpm).

For series operation, when the media in the lead vessel completely exhausts its capacity and/or the effluent from the lag vessel reaches 10 µg/L of arsenic, the spent media in the lead vessel is removed and disposed of as non-hazardous waste after passing the EPA's Toxicity Characteristic Leaching Procedure (TCLP) test. After new media is loaded into the "lead" vessel, it is switched to the lag position and the "lag" vessel is switched to the lead position. The series operation can better utilize the media capacity when compared to parallel operation.

Table 4-3. Physical and Chemical Properties of AD-33™ Media

<i>Physical Properties</i>	
Parameter	Value
Matrix	Iron oxide composite
Physical form	Dry granular media
Color	Amber
Bulk Density (g/cm ³)	0.45
Bulk Density (lb/ft ³)	28.1
BET Area (m ² /g)	142
Attrition (%)	0.3
Moisture Content (%)	<15% by weight
Particle size distribution	10 x 35 mesh
Crystal Size (Å)	70
Crystal Phase	α – FeOOH
<i>Chemical Analysis</i>	
Constituents	Weight %
FeOOH	90.1
CaO	0.27
MgO	1.00
MnO	0.11
SO ₃	0.13
Na ₂ O	0.12
TiO ₂	0.11
SiO ₂	0.06
Al ₂ O ₃	0.05
P ₂ O ₅	0.02
Cl	0.01

Source: Bayer AG.

The APU-100 system consists of a bag filter assembly, two pressure vessels arranged in series with hub and lateral underdrains, a backwash recycle system, piping with an automated valve assembly, and instrumentation and controls such as a flow meters and totalizers, pressure and differential pressure gauges, and ball valve sample ports. Figure 4-2 is a simplified instrumentation diagram of the APU-100 system with series configuration. The design features of the APU-100 system are summarized in Table 4-4, and a flow diagram along with the sampling/analysis schedule are presented in Figure 4-3. The major components of the treatment process are discussed as follows.

- **Intake.** Raw water is pumped from Montezuma Haven Well No. 2 at a flowrate of approximately 31 gpm.
- **Prechlorination.** Although prechlorination was not needed to oxidize the water, a sodium hypochlorite feed port was installed on the inlet piping to the treatment system for disinfection. A 12% sodium hypochlorite (NaOCl) solution is fed with a metering pump via polyvinyl chloride (PVC) tubing. The target residual chlorine in the treated water is 0.3 mg/L (as Cl₂). The metering pump is interlocked with the well pump so that both pumps can be on or off at the same time.
- **Bag Filter Filtration.** After prechlorination, a 25-µm bag filter with replaceable polypropylene felt bags is used to remove any sediment from the intake to protect the treatment equipment.
- **Adsorption.** The APU-100 system consists of two 36-inch-diameter, 72-inch-tall pressure vessels in series configuration, each containing 22 ft³ of AD-33™ media supported by a gravel

underbed. Although originally proposed to contain 27 ft³ of media in each vessel, less media was loaded to provide additional freeboard for backwash. The vessels are of fiberglass-reinforced-plastic (FRP) construction, rated for 150 psi working pressure, skid mounted, and piped to a valve rack mounted on a polyurethane coated, welded steel frame. Based on the actual flowrate of 31 gpm, the empty bed contact time (EBCT) and hydraulic loading for each vessel are approximately 5.3 minutes and 4.4 gpm/ft², respectively. Figure 4-4 is a photograph of the APU-100 system.

- **Backwash.** Based upon a set time or a set pressure differential (Δp), the adsorption vessels are taken off line for backwash one at a time using raw water from the well. The purpose of the backwash is to remove particulates and/or media fines accumulating in the beds. Backwash may be initiated either manually or automatically. Each backwash event produces 8 to 10 BV of wastewater.
- **Backwash Water Recycling.** Due to the lack of sewer or other wastewater discharge facilities on site, a backwash recycle loop was added to the system to reclaim the wastewater. The recycle system consists of a 25- μm bag filter, a 3,000-gallon polyethylene tank, and a reclaim pump. Wastewater from the storage tank is metered into the system intake between the NaOCl injection point and the bag filter at a rate of 0.5 gpm. Figure 4-5 is a photograph of the recycle system.

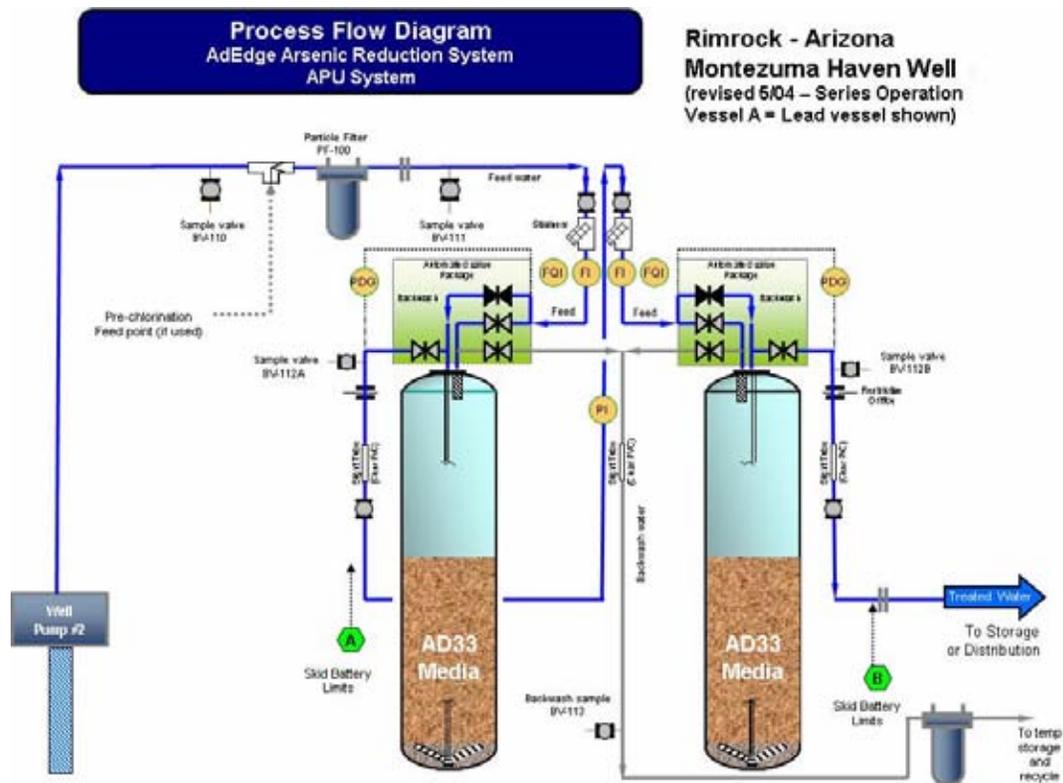


Figure 4-2. Schematic of AdEdge APU-100 System with Series Operation

Table 4-4. Design Features of the APU-100 System

Parameter	Parallel Operation ^(a)	Series Operation ^(b)
Pretreatment	NaOCl	NaOCl
No. of adsorbers	2	2
Vessel size (inch)	36 D × 72 H	36 D × 72 H
Type of media	AD-33 TM	AD-33 TM
Quantity of media (ft ³ /vessel)	27	22
Backwash flowrate (gpm)	56	50
Backwashing hydraulic loading (gpm/ft ²)	8	7
Backwash frequency, per month	1	1
Total backwash duration (min)	50-75	30
Design flowrate (gpm)	90	45
Actual flowrate (gpm)	-	31
EBCT (min/vessel)	4.5	5.3
Average use rate (gpd)	50,000	22,320
Hydraulic utilization (%)	38.6	50.0
Estimated working capacity (BV)	66,000 ^(c)	66,000 ^(d)
Bed volumes/day (BV/day)	124 (per vessel)	136 (per vessel)
Estimated gallons to breakthrough (gal)	26,700,000 ^(c)	10,900,000 ^(d)
Estimated media life (months)	17.8	16.2
Estimated media life (yrs)	1.5	1.3

(a) Proposed by AdEdge.

(b) Values were modified due to the system reconfiguration.

(c) Based on 10-µg/L arsenic breakthrough from both vessels.

(d) Based on 10-µg/L arsenic breakthrough from lead vessel.

4.3 System Installation

Installation of the AdEdge APU-100 system was completed in mid-April 2004. The system was reconfigured from parallel to series operation in mid-May. The system installation activities were carried out by Fann Environmental (Prescott, AZ) as a subcontractor to AdEdge.

4.3.1 Permitting. Engineering plans for the system permit application were prepared by AdEdge and its subcontractor and submitted to Arizona Department of Environmental Quality (ADEQ) for approval on December 11, 2003. The plans included piping and instrumentation diagrams (P&IDs) and specifications of the APU-100 system, control panel schematics, equipment cut sheets, and drawings of a site plan, treatment plan, and piping plan. After the Approval to Construct was granted on February 18, 2004, a construction permit was applied for and approved by Yavapai County in mid-March 2004. Upon completion of system installation, as-built drawings were submitted to ADEQ and Approval of Construction was granted on April 29, 2004. Following the system reconfiguration, updated information was submitted to ADEQ and a second approval was granted on June 15, 2004.

4.3.2 System Installation, Shakedown, and Startup. The APU-100 system was delivered to the site on March 30, 2004. AdEdge's subcontractor performed the off-loading and installation of the system, including piping connections to the existing intake and distribution system. The mechanical installation, hydraulic testing of the unit (with no media), and media loading were completed on April 20, 2004. Due to the loss of Well No. 1, a water line from Well No. 3 was installed to allow additional flow for media backwash. During startup, however, some lubricating oil (used to lubricate the pump shaft of Well No. 3)

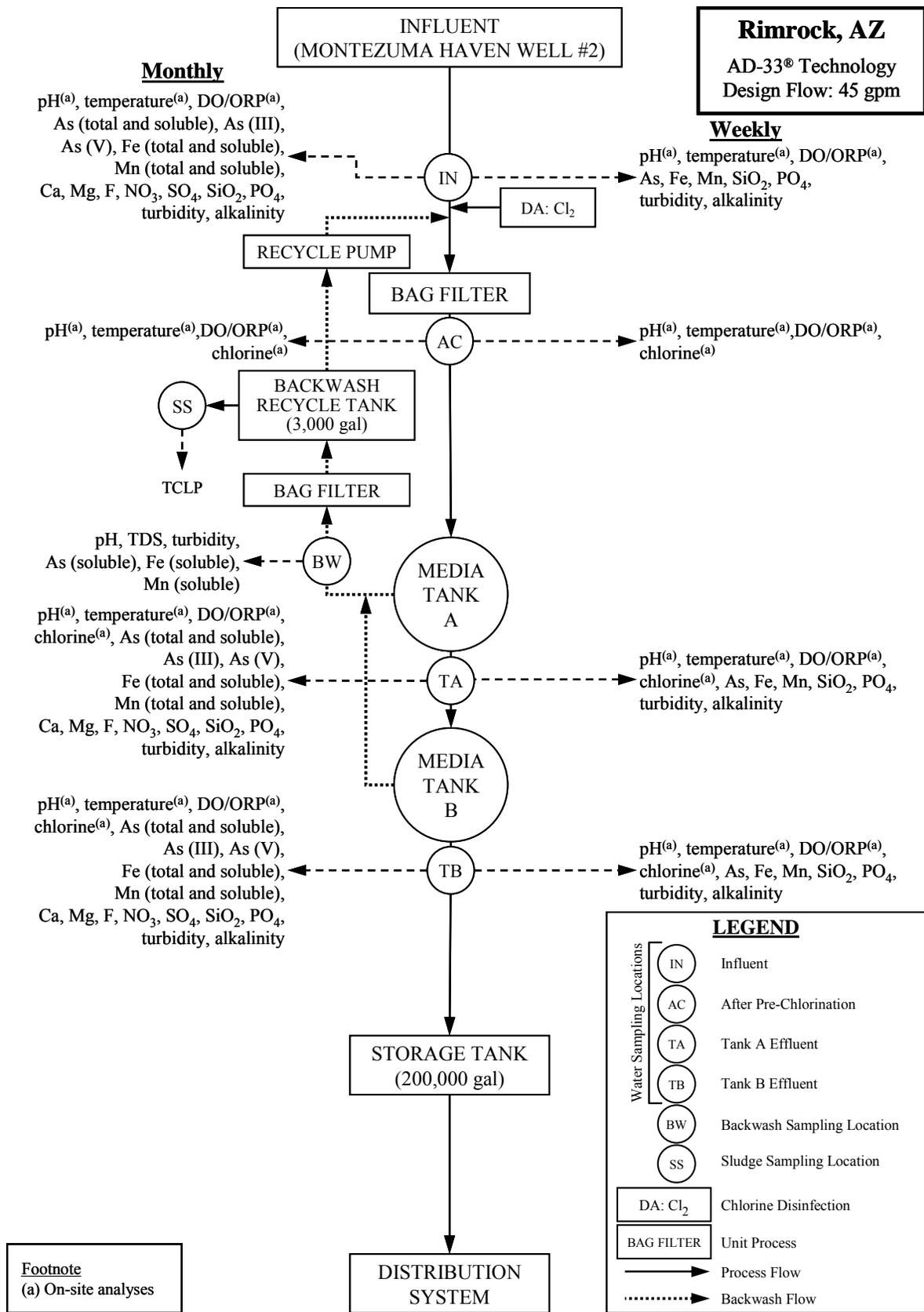


Figure 4-3. Process Flow Diagram and Sampling Locations



Figure 4-4. Photograph of the APU-100 System



Figure 4-5. Photograph of the Backwash Recycle System

was found in Well No. 3 water, and a decision was made not to use Well No. 3 water for media backwash.

Because of the reduced flowrate (from 90 to 31 gpm), the corresponding EBCT across each vessel would have been more than doubled (from 4.5 minutes to 10.6 minutes) if the system configuration remained in parallel. To evaluate the system performance close to the originally designed EBCT and to fully utilize the media capacity, the vessel configuration was changed to series. The required modifications were made in mid-May 2004, and shakedown and startup completed in early June 2004. After the system was sanitized and passed bacteria tests, the performance evaluation of the APU-100 system began on June 24, 2004.

4.3.3 Shed Construction. After the APU-100 system was installed, a sun shed structure was built by AWC over the treatment system in mid-May (Figure 4-6). The dimensions of the shed structure, manufactured by Versa-Tube, were 12 ft × 15 ft with a height of 9.5 ft. The shed was constructed with a galvanized steel frame anchored to the concrete pad and sheeted with 29-gauge steel that had a specially coated surface. The shed was pre-engineered with a 90-mph wind load and a 30-lb/ft² snow loading capacity. From late-November to mid-December 2004, the sides and ends of the shed structure were enclosed with metal covering for the winter.



Figure 4-6. Sun Shed Structure over the Treatment System

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters for the first six months of the system operation are tabulated and attached as Appendix A. Key parameters are summarized in Table 4-5. From June 24 through December 22, 2004, the APU-100 system operated for 2,172 hours based on 12-hour daily operation of Well No. 2. This value represents a utilization rate of 50% over the 27-week period. An hour meter was installed on November 4, 2004 to accurately monitor any system downtime due to repairs and maintenance.

Table 4-5. Summary of APU-100 System Operations

Operational Parameter	Value
Period	06/24/04-12/22/04
Daily Operating Time (hr)	12
Total Operating Time (hr)	2,172
Throughput (kgal)	4,109
Bed Volumes (BV) ^(a)	25,000
Average Flowrate (gpm)	31.5
Range of Flowrate (gpm)	26-34
Average EBCT (min) ^(b)	10.4 (5.2 per vessel)
Range of EBCT (min) ^(b)	9.8-12.6 (4.9-6.3 per vessel)
Range of Δp (psi/vessel)	3.5-6.5

(a) 1 BV = 22 ft³ = 165 gallons.

(b) Calculated based on 22 ft³ of media per vessel.

The average system throughput during this 27-week period was approximately 4,109,000 gallons (or 25,000 BV), which was 3.2% higher than that measured from the wellhead master totalizer (i.e., 3,982,000 gallons). The flowrate readings ranged from 26 to 34 gpm and averaged 31.5 gpm. The average EBCT was 5.2 minutes per vessel and 10.4 minutes for both vessels.

The Δp across each vessel ranged from 3.5 to 6.5 psi. During the startup, the hydraulic testing performed with no media in the vessels measured a pressure loss of 4.3 psi across each vessel at a flowrate of 33 gpm. Therefore, the media did not cause significant pressure losses. Results of hydraulic testing performed for another APU-100 system with similar design for the Rollinsford, NH host site indicated that the controller valves were the source of elevated pressure losses (Oxenham et al., 2005). Further, the pressure loss across each vessel between two consecutive backwash events did not increase significantly, indicating that no or little particulates or media fines were accumulating in the media bed.

4.4.2 Backwash. The APU-100 system experienced unscheduled backwashes during the first several months of operation when the system was set for automatic backwash at 15 psi of Δp or 27 or 28 days of system operation (Table 4-6). It was suspected that the operation of the nearby well, Well No. 3, might have caused the system pressure to spike thereby initiating unscheduled backwashes. Because the backwashes occurred when the operator was absent, relevant operational parameters were not recorded. In order to monitor the backwash process and facilitate backwash water sampling, the Δp relays were disengaged on August 12, 2004 so that the backwash would be controlled solely by a timer. The first set of backwash samples was collected on October 20, 2004 when the vessels were manually backwashed. After another backwash was missed on November 15, 2004, the timer setting was changed from 27 or 28 days to 30 days. The second set of backwash samples was collected on December 15, 2004. Backwash was performed with raw water at 48-52 gpm, or approximately 7 gpm/ft². Each vessel was backwashed for 15 minutes, generating between 631 and 910 gallons of water per vessel.

4.4.3 Residual Management. The backwash recycle loop enabled the system to reclaim nearly 100% of the wastewater produced by blending it with the chlorinated water at a rate of 0.5 gpm before the bag filter assembly. Thus, no liquid residual was generated by the APU-100. The solid residuals produced included backwash solids and spent media. The backwash solids were filtered by bag filters, which have been replaced and disposed of after each backwash event. The media was not exhausted during the first six months of system operation.

Table 4-6. Backwash Event Summary

Date	Vessel	Backwash Flowrate	Backwash Duration	Wastewater Generated ^(a)	Recycle Volume ^(a)	Estimated Time between Backwashes
	A/B	gpm	min	gal	gal	days
06/26/04	Data not available due to unscheduled backwashes.			NA	511	NA
07/15/04				800	779	NA
07/26/04				869	770	NA
08/10/04				631	780	NA
08/23/04				700	530	NA
09/26/04				800	1,479	NA
09/27/04 ^(b)	B	48	15	709		NA
10/20/04 ^(b)	A	49	15	700	1,481	24
10/20/04 ^(b)	B	49	15	800		23
11/15/04	Data not available due to unscheduled backwashes.			764	1,578	26
11/16/04				786		27
12/15/04 ^(b)	A	52	15	800	1,610	30
12/15/04 ^(b)	B	52	15	910		29
Total				9,269	9,518	

(a) Based on respective flow meter/totalizer readings.

(b) Manual backwash.

NA = not available.

4.4.4 System/Operation Reliability and Simplicity. The operational issues related to backwash were the primary source of concerns during system operations in this six-month reporting period. Because the bag filter was installed upstream of the backwash recycle tank (see Figure 4-3), the filter had to be replaced after each backwash event. Operations could be simplified if the bag filter was installed downstream of the recycle tank, allowing solids to settle prior to the bag filter, and thereby reducing the replacement frequency.

The O&M issues encountered were problems with the chlorine injector, backwash recycle pump, and broken inlet and outlet pressure gauges, recycle meter, and backwash totalizer due to unusually cold weather in late November. A minimal amount of unscheduled downtime was necessary to repair system components. The actual downtime was not calculated due to the lack of an hour meter until November 4, 2004, but estimated to be no more than 1-2%.

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

Pre- and Post-Treatment Requirements. Although not required for treatment, NaOCl was injected upstream of the system for disinfection. The prechlorination system was used to provide chlorine residuals in water through the adsorption vessels and the distribution system. As such, post-treatment was not required at the site.

System Automation. The APU-100 system is equipped with an automatic backwash control to initiate backwash automatically by timer and/or Δp . However, the system experienced several unscheduled backwashes from June through September, 2004 as discussed above. Due to the needs for the study such

as filling up logs and collecting backwash samples, the automated backwash control was disabled to allow manual backwashes. The system also can recycle the backwash water automatically.

Operator Skill Requirements. Under normal operating conditions, the skill requirements to operate the APU-100 system were minimal. The daily demand on the operator was typically 20 minutes for visual inspection of the system and recording of operational parameters on the log sheets. On days when the system was backwashed, the operator typically spent approximately two hours on site to complete this process. However, if the system was set on automatic backwash, it would not require the operator to be present. The operation of the system did not appear to require additional skills beyond those necessary to operate the existing water supply equipment. One operator had a Level 4 Distribution Grade and a Level 4 Treatment Grade, and the other had a Level 4 Distribution Grade and a Level 3 Treatment Grade.

Preventative Maintenance Activities. Preventative maintenance tasks recommended by AdEdge included daily system inspection and weekly monitoring of the pressure, Δp , and backwash recycle tank level (if applicable). Also recommended were the checking of the flowrate, throughput, visual clarity of the treated water, bag filters, and performance (i.e. via sample analysis) monthly and the Y-strainers (for sediment capture) quarterly. The bag filter before the backwash recycle tank needed replacement after every backwash event. All system components were maintained according to the O&M Manual.

Chemical/Media Handling and Inventory Requirements. Chemical use was not required beyond the chlorination system for disinfection. NaOCl consumption varied, but was typically dosed to achieve a chlorine residual of 0.3-0.4 mg/L. The chlorine tank was refilled on an as-needed basis.

4.5 System Performance

The performance of the APU-100 system was evaluated based on analyses of water samples collected from the treatment plant, media backwashing, and distribution system.

4.5.1 Treatment Plant Sampling. Water samples were collected at three locations throughout the treatment train: the inlet (IN), the effluent of the lead vessel (TA), and the effluent of the lag vessel (TB). The treatment plant water was sampled on 22 occasions (including two events with duplicate samples taken) during the first six months of system operation, with field speciation performed on six of the 22 occasions. Table 4-7 summarizes the analytical results of critical constituents including arsenic, iron, and manganese. On-site water quality measurements including pH, temperature, DO, and ORP were performed at IN, after prechlorination (AC), TA, and TB locations. Chlorine residuals also were measured at AC, TA, and TB locations. Table 4-8 summarizes the results of the other water quality parameters. Appendix B contains a complete set of analytical results through the first six months of system operation. The results of the water samples collected throughout the treatment plant are discussed below.

Arsenic. Total As concentrations in the raw water ranged from 48.3 to 81.4 $\mu\text{g/L}$ and averaged 61.0 $\mu\text{g/L}$ (Table 4-7). As(V) was the predominating species, ranging from 48.0 to 63.2 $\mu\text{g/L}$ and averaging 57.3 $\mu\text{g/L}$. Only trace amounts of particulate As and As(III) existed, with average concentrations of 0.9 and 1.5 $\mu\text{g/L}$, respectively. Figure 4-7 contains bar charts presenting the concentrations of total As, particulate As, As(III), and As(V) at the IN, TA, and TB locations for each speciation sampling event. The arsenic concentrations measured during this six-month period were consistent with those in the raw water sample collected on October 22, 2003 (Table 4-1).

The key parameter for evaluating the effectiveness of the APU-100 system was the arsenic concentration in the treated water. The arsenic breakthrough curve in Figure 4-8 indicates that the lead vessel (TA) removed the majority of arsenic (existing predominantly as As[V]) in the influent water, leaving only 0.7

to 3.0 µg/L to be further polished by the lag vessel. The treated water from the lag vessel contained only 0.2 to 1.3 µg/L of total arsenic. By the end of the first six months of system operation, the APU-100 system treated approximately 25,000 BV of water (equivalent to 4,109,000 gallons of water), which was about 38% of the vendor-estimated working capacity (66,000 BV as shown in Table 4-4). It must be noted, however, that the treatment system was operating with a reduced flowrate and a longer EBCT than was originally designed, which might increase the removal capacity of the media.

As shown in Figure 4-7 and Table 4-7, the particulate As concentrations at the TA and TB locations were less than 0.3 µg/L. The average As(III) concentrations were 1.5, 1.4, and 0.7 µg/L at IN, TA, and TB, respectively, indicating little or no As(III) removal by the AD-33™ media. It is not clear why up to 2.7 and 1.3 µg/L of As(III) were measured at TA and TB even in the presence of at least 0.2 mg/L (as Cl₂) of free chlorine.

Iron and Manganese. Average concentrations of Fe and Mn were near and/or below the respective detection limits throughout the treatment system. Total Fe concentrations were <25 µg/L for all samples (Table 4-7) except for five exceedances, including one on July 21 (i.e., 47.3 µg/L in TB), three on September 22 (i.e., 127, 27, and 56 µg/L in IN, TA, and TB, respectively), and one on October 27 (27 µg/L in TA). Dissolved Fe concentrations were <25 µg/L for all samples. Total Mn levels ranged from <0.1 to 1.6 µg/L (Table 4-7), with the majority being dissolved Mn. The average total Mn concentrations were 0.5, 0.2, and 0.2 µg/L at IN, TA, and TB, respectively. The reduction of total Mn between IN and TA and TB indicates some removal of Mn within the adsorption vessels.

Other Water Quality Parameters. In addition As, Fe, and Mn, other water quality parameters were analyzed to provide insight into the chemical processes occurring within the treatment system. The inlet pH values ranged from 6.9 to 7.1, which were the lowest among the 12 Round 1 demonstration sites (Table 1-1). This near neutral pH condition is desirable for adsorptive media which, in general, have a greater arsenic removal capacity when treating lower-pH water.

The residual chlorine levels measured at the TA and TB locations were comparable to those measured at the AC location, indicating little or no chlorine consumption through the AD-33™ vessels. ORP readings at the IN location ranged from 148 to 510 mV. Due to the presence of residual chlorine at the AC, TA, and TB locations, the respective ORP readings increased to the range of 491 to 710 mV. With DO concentrations ranging from 3.3 to 4.7 mg/L, the inlet water was oxidizing, thus explaining why little or no As(III) was present in the raw water.

The results for alkalinity, fluoride, sulfate, silica, and nitrate remained fairly constant throughout the treatment train. Orthophosphate (as PO₄) was always below the detection limit for all samples. The total hardness results ranged from 287 to 397 mg/L as CaCO₃, consisting approximately 60% of calcium hardness and 40% of magnesium hardness. Hardness did not appear to be affected by the treatment process.

4.5.2 Backwash Water Sampling. The analytical results of the two backwash water sampling events are summarized in Table 4-9. Both sampling events showed similar results for soluble As, Fe, and Mn. The arsenic concentrations in the backwash water from both vessels were lower than those in the raw water used for backwash, indicating some arsenic removal by the media during backwash. The backwash water from Vessel A contained much higher arsenic levels (e.g., 48 µg/L) than those from Vessel B (e.g., <3 µg/L) most likely due to the fact that the media in Vessel A had a more reduced adsorptive capacity than Vessel B. The pH of the backwash water was similar to that of the raw water. Turbidity readings from Vessel A were higher than those from Vessel B, most likely because the lead tank had removed the majority of particulates from the raw water.

Table 4-7. Summary of Arsenic, Iron, and Manganese Analytical Results

Parameter	Sampling Location	Unit	Count	Minimum	Maximum	Average	Standard Deviation
As (total)	IN	µg/L	24	48.3	81.4	61.0	10.2
	TA	µg/L	24	0.7	3.0	1.4	0.6
	TB	µg/L	24	0.2	1.3	0.5	0.3
As (soluble)	IN	µg/L	6	50.2	65.0	58.8	4.9
	TA	µg/L	6	0.9	3.0	1.9	1.0
	TB	µg/L	6	0.3	1.2	0.6	0.3
As (particulate)	IN	µg/L	6	0.1	3.5	0.9	1.3
	TA	µg/L	6	0.1	0.3	0.1	0.1
	TB	µg/L	6	0.1	0.3	0.2	0.1
As(III)	IN	µg/L	6	0.8	2.2	1.5	0.6
	TA	µg/L	6	0.6	2.7	1.4	0.8
	TB	µg/L	6	0.2	1.3	0.7	0.4
As(V)	IN	µg/L	6	48.0	63.2	57.3	5.0
	TA	µg/L	6	0.1	1.7	0.5	0.6
	TB	µg/L	6	0.1	0.5	0.1	0.2
Total Fe	IN	µg/L	24	<25	127	<25	23.4
	TA	µg/L	24	<25	31.1	<25	4.7
	TB	µg/L	24	<25	56.0	<25	11.1
Dissolved Fe	IN	µg/L	6	<25	<25	<25	0.0
	TA	µg/L	6	<25	<25	<25	0.0
	TB	µg/L	6	<25	<25	<25	0.0
Total Mn	IN	µg/L	24	<0.1	1.6	0.5	0.4
	TA	µg/L	24	<0.1	1.2	0.2	0.3
	TB	µg/L	24	<0.1	0.9	0.2	0.3
Dissolved Mn	IN	µg/L	6	0.1	1.1	0.6	0.4
	TA	µg/L	6	<0.1	0.7	0.2	0.3
	TB	µg/L	6	<0.1	0.6	0.2	0.2

One-half of the detection limit was used for nondetect samples for calculations.
Duplicate samples were included in the calculations.

Table 4-8. Summary of Water Quality Parameter Measurements

Parameter	Sampling Location	Unit	Count	Minimum	Maximum	Average	Standard Deviation
Alkalinity	IN	mg/L	24	330	390	370	12.8
	TA	mg/L	24	345	386	372	8.3
	TB	mg/L	24	351	395	373	10.6
Fluoride	IN	mg/L	6	0.3	0.4	0.35	0.05
	TA	mg/L	6	0.3	0.5	0.35	0.08
	TB	mg/L	6	0.3	0.4	0.32	0.04
Sulfate	IN	mg/L	6	8.9	10	9.6	0.4
	TA	mg/L	6	8.8	10	9.4	0.4
	TB	mg/L	6	8.7	10	9.4	0.6

Table 4-8. Summary of Water Quality Parameter Measurements (Continued)

Parameter	Sampling Location	Unit	Count	Minimum	Maximum	Average	Standard Deviation
Orthophosphate (as PO ₄)	IN	mg/L	24	<0.06	0.05	0.04	0.01
	TA	mg/L	24	<0.06	0.05	0.04	0.01
	TB	mg/L	24	<0.06	0.05	0.04	0.01
Silica	IN	mg/L	24	24.0	26.7	25.5	0.6
	TA	mg/L	24	24.3	27.2	25.4	0.6
	TB	mg/L	24	23.9	26.9	25.2	0.7
Nitrate (as N)	IN	mg/L	6	0.2	0.3	0.22	0.04
	TA	mg/L	6	0.2	0.3	0.22	0.04
	TB	mg/L	6	0.2	0.3	0.22	0.04
Turbidity	IN	NTU	24	<0.1	0.6	0.2	0.2
	TA	NTU	24	<0.1	0.5	0.2	0.1
	TB	NTU	24	<0.1	0.9	0.3	0.2
pH	IN	S.U.	21	6.9	7.1	7.0	0.1
	AC	S.U.	21	6.9	7.6	7.1	0.2
	TA	S.U.	21	6.9	7.1	7.0	0.1
	TB	S.U.	21	6.8	7.1	7.0	0.1
Temperature	IN	°C	21	19.5	26.1	21.6	1.6
	AC	°C	21	19.8	24.5	21.4	1.2
	TA	°C	21	19.7	26.7	21.5	1.5
	TB	°C	21	19.7	24.0	21.5	1.2
Dissolved Oxygen	IN	mg/L	21	3.3	4.7	4.0	0.3
	AC	mg/L	21	3.2	6.8	4.8	1.1
	TA	mg/L	21	3.5	6.6	4.1	0.8
	TB	mg/L	21	3.4	6.9	4.1	0.8
ORP	IN	mV	21	148	510	304	132
	AC	mV	21	491	642	594	36
	TA	mV	21	565	681	623	30
	TB	mV	21	590	710	637	31
Free Chlorine	AC	mg/L	21	0.2	0.5	0.4	0.1
	TA	mg/L	21	0.2	0.5	0.4	0.1
	TB	mg/L	21	0.2	0.4	0.3	0.1
Total Chlorine	AC	mg/L	21	0.2	0.7	0.4	0.1
	TA	mg/L	21	0.2	0.6	0.4	0.1
	TB	mg/L	21	0.2	0.6	0.4	0.1
Total Hardness (as CaCO ₃)	IN	mg/L	6	287	384	337	37
	TA	mg/L	6	298	397	349	37
	TB	mg/L	6	299	377	341	28
Ca Hardness (as CaCO ₃)	IN	mg/L	6	171	241	201	25
	TA	mg/L	6	175	236	206	26
	TB	mg/L	6	174	235	202	22
Mg Hardness (as CaCO ₃)	IN	mg/L	6	116	152	136	14
	TA	mg/L	6	123	161	142	13
	TB	mg/L	6	124	149	139	10

One-half of the detection limit was used for nondetect samples for calculations.

Duplicate samples were included in the calculations.

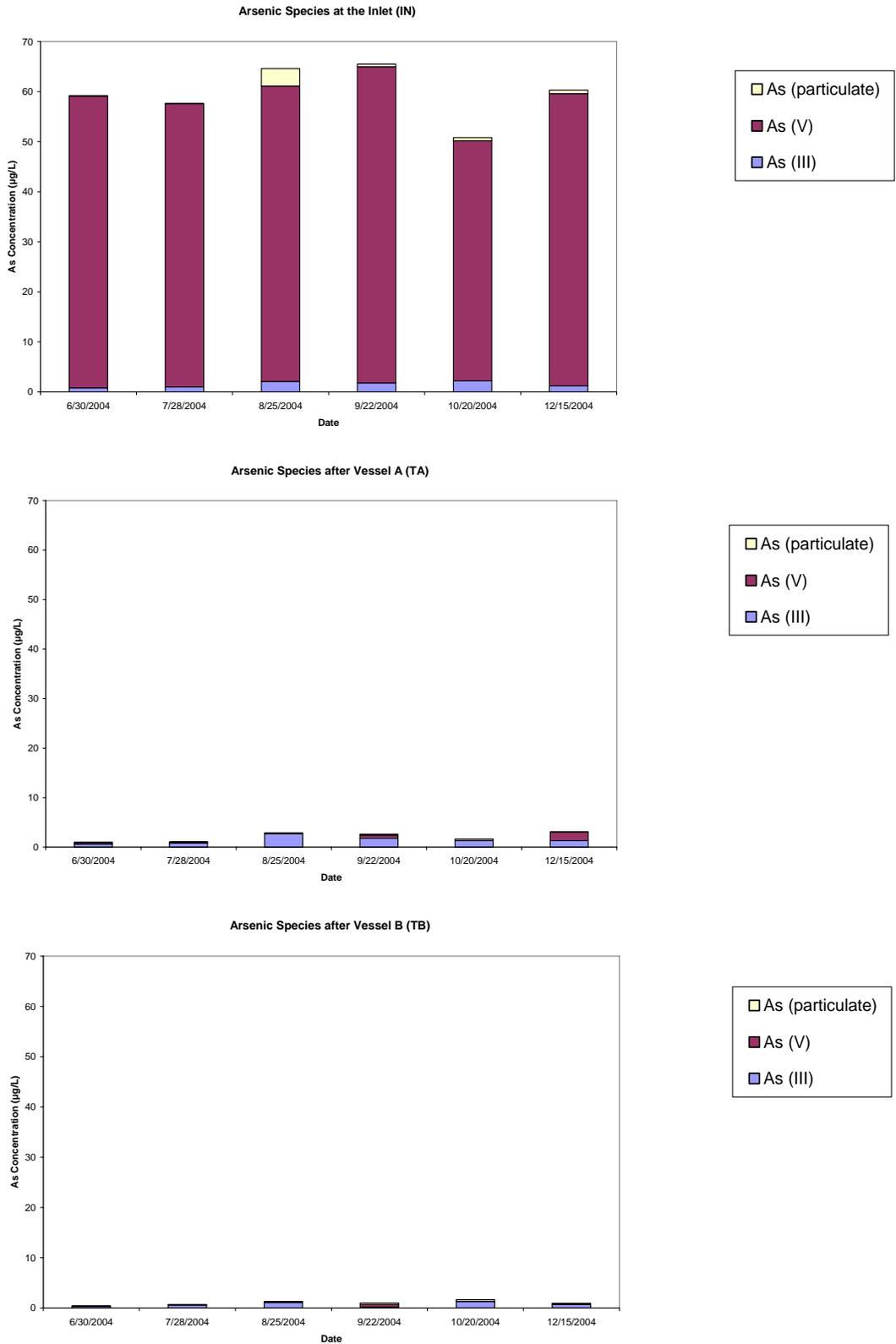


Figure 4-7. Concentration of Arsenic Species at the Inlet, after Vessel A, and after Vessel B

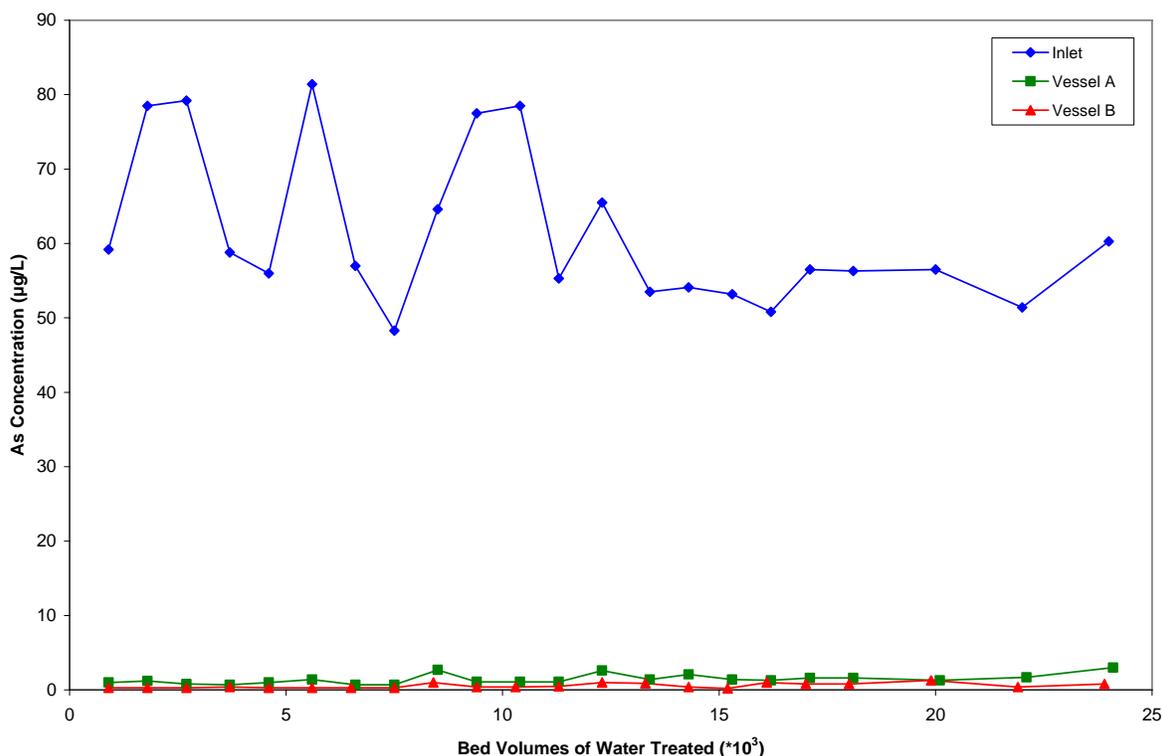


Figure 4-8. Total Arsenic Breakthrough Curve

Table 4-9. Backwash Water Sampling Results

Sampling Event		Vessel A						Vessel B					
		pH	Turbidity	TDS	Soluble As	Soluble Fe	Soluble Mn	pH	Turbidity	TDS	Soluble As	Soluble Fe	Soluble Mn
No.	Date	S.U.	NTU	mg/L	µg/L	µg/L	µg/L	S.U.	NTU	mg/L	µg/L	µg/L	µg/L
1	10/20/2004	7.3	22	486	48.2	<25	0.1	7.3	6.5	442	2.7	<25	0.1
2	12/15/2004	7.1	45	358	48.0	<25	0.4	7.1	25	306	1.6	<25	<0.1

4.5.3 Distribution System Water Sampling. The results of the distribution system sampling are summarized in Table 4-10. The most noticeable change in the distribution samples since the system began operation was a decrease in arsenic concentrations, with an exception for the August 26, 2004 DS3 sample. Average baseline arsenic concentrations were 55.2, 44.6, and 46.6 µg/L at DS1, DS2, and DS3, respectively, and ranged from 20.8 to 80.1 µg/L. After the performance evaluation began, average concentrations at DS1, DS2, and DS3 were 18.8, 20.1, and 21.8 µg/L, respectively, and ranged from 9.3 to 28.5 µg/L (with an exception for the August 26, 2004 DS3 sample). The arsenic concentrations in the distribution system were higher than those in the system effluent, presumably due to the blending of the

Table 4-10. Distribution System Sampling Results

Sampling Event		DS1									DS2							DS3							
		4125 E. Shade Road									4095 E. Goldmine ^(a)							4075 Goldmine							
		Non-LCR									Non-LCR							Non-LCR							
		1st Draw									1st Draw							1st Draw							
		Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu
No.	Date	hrs	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hrs	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	hrs	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	
BL1	12/17/03	12.0	7.1	387	38.5	<25	1.2	2.3	119	7.0	7.2	405	20.8	182	68.4	1.6	106	8.5	7.2	407	37.1	<25	0.3	1.3	89.7
BL2	01/06/04	14.0	8.9	411	49.3	<25	0.8	0.5	24.2	11.3	8.5	407	48.4	<25	0.6	2.4	64.0	6.0	8.2	419	49.5	<25	0.6	1.0	64.2
BL3	01/21/04	34.0	7.2	367	80.1	<25	0.2	1.2	24.0	11.0	7.2	371	57.0	<25	0.3	3.8	128	7.8	7.1	336	47.0	<25	0.3	2.1	142
BL4	02/05/04	23.0	7.1	394	52.8	46.1	0.5	0.5	31.3	9.8	7.1	406	52.2	40.2	0.2	0.8	34.4	7.0	7.1	406	52.7	47.9	0.3	1.1	121
1	07/28/04 ^(b)	11.0	7.2	373	11.7	<25	<0.1	4.4	147	Homeowner was unavailable							5.3	7.2	413	22.7	<25	0.1	2.1	107	
2	08/26/04 ^(b)	20.5	6.9	379	15.4	<25	0.3	4.8	112	10.0	6.9	395	28.5	<25	0.3	4.3	66.7	7.5	6.9	395	45.6	<25	0.3	1.4	46.7
3	09/22/04 ^(c)	12.0	7.2	402	18.0	<25	1.3	4.4	194	10.5	6.9	373	9.3	<25	0.3	2.9	33.8	7.3	7.0	381	23.3	<25	1.8	2.4	116
4	10/20/04	19.0	6.7	406	22.9	<25	0.4	2.9	99.6	9.0	6.9	410	19.8	<25	3.0	7.0	129	6.5	7.0	394	21.3	<25	0.7	1.3	43.3
5	11/17/04	7.5	7.0	418	21.2	<25	0.4	1.4	79.5	Homeowner was unavailable							6.3	7.1	418	15.6	<25	0.5	1.8	68.2	
6	12/15/04 ^(b)	9.0	7.1	370	15.0	<25	0.7	4.1	52.5	9.0	7.2	403	21.8	<25	1.1	6.6	139	9.0	7.2	394	14.4	<25	0.8	2.7	124

(a) Sample DS2 was taken from 4055 E. Goldmine Rd on December 17, 2003.

(b) Sample DS1 was collected on the previous day.

(c) Sample DS1 was taken on September 30, 2004 when homeowner returned from vacation; pH was analyzed out of hold time.

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

BL = Baseline Sampling.

treated water (supplied by Well No. 2) with untreated water from Well No. 3 and other wells, which also contained arsenic (Table 4-1).

Lead concentrations ranged from 0.5 to 7.0 µg/L, with none of the samples exceeding the action level of 15 µg/L. Copper concentrations ranged from 24.0 to 194 µg/L, with no samples exceeding the 1,300 µg/L action level. Due to the blending of water from untreated wells, it was inconclusive whether the Pb or Cu concentrations in the distribution system had been affected by the arsenic treatment system.

Measured pH values ranged from 6.7 to 7.2, except for the baseline pH analyses performed on January 6, 2004. Alkalinity levels ranged from 336 to 419 mg/L (as CaCO₃). Iron concentrations ranged from <25 to 182 µg/L, with concentrations in the majority of the samples at <25 µg/L. Since the system became operational, iron concentrations in the distribution system samples were consistently below the detection limit. The concentrations of Mn in the distribution system samples were ≤ 3.0 µg/L, except for the first baseline sample at DS2. Mn levels do not appear to have been affected since the system began to operate.

4.6 System Costs

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

4.6.1 Capital Costs. The capital investment costs for equipment, site engineering, and installation were \$90,757 (see Table 4-11) as provided by the AdEdge in a cost proposal to Battelle dated September 9, 2003. The equipment costs were \$66,235 (or 73% of the total capital investment), which included costs for two FRP treatment vessels, 54 ft³ of AD-33™ media (\$245/ft³ or \$8.73/lb), piping and valves, instrumentation and controls, field services (including operator training, technical support, and system shakedown), miscellaneous materials and supplies, and a change order for system reconfiguration from parallel to series operation.

The engineering costs included the costs for preparation of the engineering plans, system layout and footprint, drawings of site and piping plans, and equipment cut sheets for the permit application submittal (Section 4.3.1). The costs also included resubmission of the redesigned system layout and piping plans to ADEQ for approval. The engineering costs were \$11,372, which was 13% of the total capital investment.

The installation costs included the costs for the equipment and labor to unload and install the APU-100 system, perform the piping tie-ins and electrical work, load and backwash the media, and reconfigure the system (Section 4.3.2). The installation was performed by AdEdge and its subcontractor, Fann Environmental. The installation costs were \$13,150, or 14% of the total capital investment.

The costs associated with the backwash recycle system were not reflected in the capital investment shown in Table 4-11. AWC contracted AdEdge to design and install the backwash recycle system for handling the backwash water. The total cost for the backwash recycle system was \$11,546, including material, engineering, and installation costs.

AWC installed a sun shed structure with a galvanized steel frame over the APU-100 system (Section 4.3.3). The 12 ft × 15 ft structure has a height of 9.5 ft and is mounted on a 12 ft × 15 ft concrete pad. The structure was pre-engineered to sustain a 90-mph wind load and a 30-lb/ft² snow load. The total cost for the building was \$13,677 which included \$3,500 for materials and labor to assemble the structure.

Table 4-11. Summary of Capital Investment Costs

Description	Quantity	Cost	% of Capital Investment Cost
<i>Equipment Costs</i>			
Adsorptive Media Vessels	2	\$21,800	–
AD-33™ Media	54 ft ³	\$13,230	–
Piping and Valves	1	\$7,520	–
Instrumentation and Controls	1	\$4,575	–
O&M Manual, Operator Training, Technical Support	1	\$3,800	–
Procurement, Assembly, Labor, Shakedown	1	\$12,575	–
Freight Costs	1	\$1,855	–
Change Order for System Reconfiguration	1	\$880	–
Equipment Total	–	\$66,235	73%
<i>Engineering Costs</i>			
Materials, Submittals, FedEx, Postage, Supplies	1	\$75	–
AdEdge PM Oversight, Specification Preparation	1	\$3,420	–
Design, Drawings, Coordination	1	\$4,970	–
Review Meeting, Airfare, Lodging and Meals	1	\$1,017	–
Change Order for System Reconfiguration	–	\$1,890	–
Engineering Total	–	\$11,372	13%
<i>Installation Costs</i>			
Subcontractor	1	\$6,750	–
Vendor Labor	4 days	\$3,040	–
Vendor Travel	4 days	\$1,290	–
Change order for System Reconfiguration	–	\$2,070	–
Installation Total	–	\$13,150	14%
Total Capital Investment^(a)	–	\$90,757	100%

(a) Estimated costs of \$11,546 for a backwash recycle system not included.

The total capital cost of \$90,757 and equipment cost of \$66,235 were converted to a unit cost of \$0.13/1,000 gallon and \$0.09/1,000 gallon, respectively, using a capital recovery factor of 0.06722 based on a 3% interest rate and a 20-year return period (Chen et al., 2004). These calculations assumed that the system operated 24 hours a day, 7 days a week at the system design flowrate of 90 gpm. The system operated only 12 hours a day at approximately 31.5 gpm (see Table 4-5), producing 4,109,000 gallons of water during the six-month period, so the total unit cost and equipment-only unit cost were increased to \$0.74/1,000 gallon and \$0.54/1,000 gallon, respectively, at this reduced usage rate. Using the system's rated capacity of 45 gpm (or 64,800 gpd), the capital cost was \$2,017/gpm (or \$1.40/gpd) and the equipment-only cost was \$1,472/gpm (or \$1.02/gpd). These calculations did not include the cost of the building construction.

4.6.2 Operation and Maintenance Costs. O&M costs included only incremental costs associated with the APU-100 system, such as media replacement and disposal, chemical supply, electricity, and labor (Table 4-12). Because media replacement and disposal did not take place during the first six months of operation, its cost per 1,000 gallons of water treated was calculated as a function of the projected media run length using the vendor-estimated \$9,940 for one vessel's media changeout. The cost included new media for one vessel, freight, labor, travel expenses, and spent media testing and disposal. At the vendor estimated media capacity of 66,000 BV (see Table 4-4) or a throughput of 10,861 kgal, the unit O&M cost is projected to be \$1.27/1,000 gallons of water treated including the estimated

Table 4-12. Summary of O&M Costs

Cost Category	Value	Assumptions
Volume processed (kgal)	4,109	From 06/24/04 to 12/22/04
<i>Media Replacement and Disposal</i>		
Media cost (\$/ft ³)	\$245	Vendor quote
Total media volume (ft ³)	22	One vessel
Media replacement cost (\$)	\$5,390	Vendor quote
Freight (\$)	\$465	Vendor quote for delivery
Labor cost (\$)	\$3,840	Vendor quote includes disposal
Waste Analysis (\$)	\$245	Vendor quote for one TCLP test
Subtotal	\$9,940	Vendor quote
Media replacement and disposal cost (\$/1,000 gal)	See Figure 4-9	Based upon media run length at 10-μg/L arsenic breakthrough
<i>Chemical Usage</i>		
Chemical cost (\$)	\$0.000	No additional chemicals required
<i>Electricity</i>		
Electric utility charge (\$/kWh)	\$0.089	Rate provided by AWC
Usage (kWh)	377	–
Total electricity cost (\$)	\$33.52	–
Electricity cost (\$/1,000 gal)	\$0.008	–
<i>Labor</i>		
Average weekly labor (hrs)	2.6	20-30 minutes/day
Labor cost (\$/1,000 gal)	\$0.35	Labor rate = \$21/hr
Total O&M cost (\$/1,000 gal)	See Figure 4-9	Based upon media run length at 10-μg/L arsenic breakthrough

media replacement and disposal cost (\$0.92/1,000 gallons) and chemical supply, electricity, and labor costs (\$0.36/1,000 gallons) (Figure 4-9). The projected media replacement and disposal cost will be refined once the actual throughput and cost at the time of the media replacement become available.

The only chemical cost was the use of NaOCl for disinfection. Because the APU-100 system did not appear to consume any chlorine, the incremental chemical cost was negligible.

Incremental electrical power consumption was calculated based on the electric meter readings for one day (12 hours) of system operation. This usage rate was approximately 2.07 kWh per day and included electrical consumption by the recycle pump. Therefore, the electricity cost was \$0.008/1,000 gallons of water treated.

The routine, non-demonstration related labor activities (Section 4.4.4) in addition to preventative maintenance activities and repairs consumed 20-30 minutes per day. Based on this time commitment and a labor rate of \$21/hr, the labor cost was \$0.35/1,000 gallons of water treated.

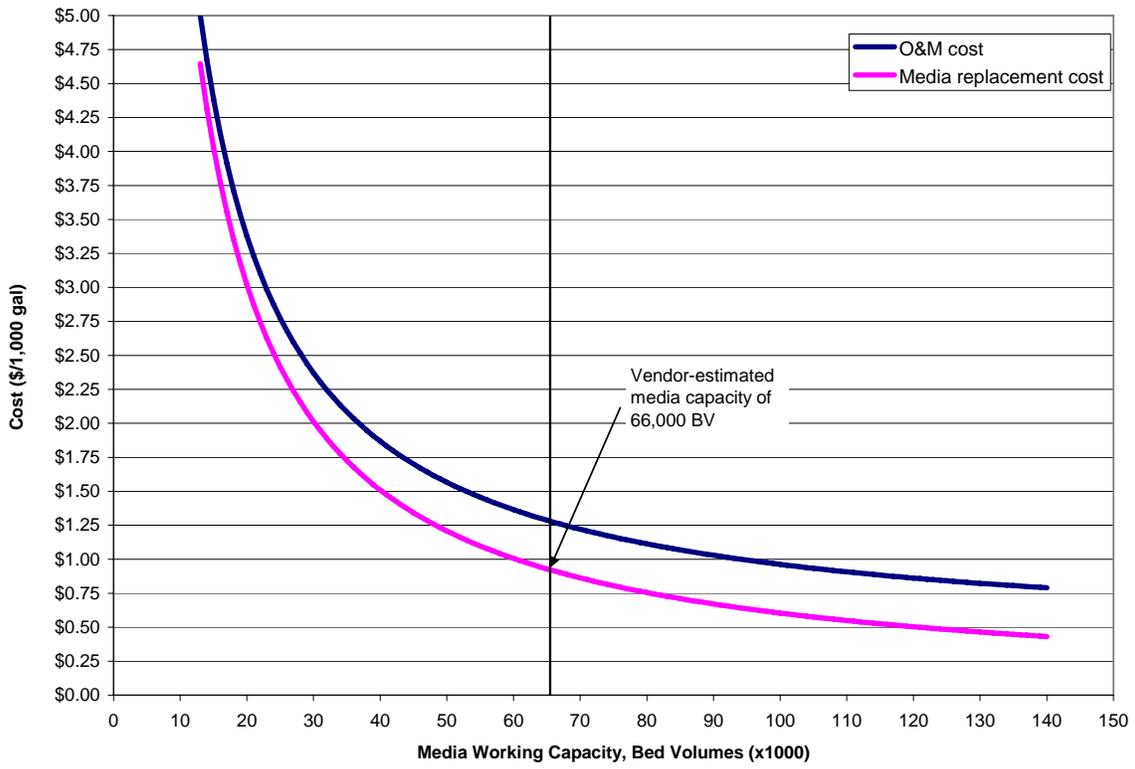


Figure 4-9. Media Replacement and O&M Costs for the Rimrock Treatment System

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APPENDIX A
OPERATIONAL DATA

EPA Arsenic Demonstration Project at Rimrock, AZ - Daily System Operation Log Sheet

Daily System Operation

Week No.	Date & Time	Run Time hr	Tank Position		Vessel A Flow Meter				Vessel B Flow Meter				ΔP		Pressure			Master Totalizer gal	Backwash Water Recycle		
			Lead	Lag	Flow rate	Totalizer	Flow rate	Bed Volume	Flow rate	Totalizer	Flow rate	Bed Volume	Vessel A	Vessel B	Inlet	Between Tanks	Outlet		Flow rate	Totalizer	Recycle Volume
			A/B	A/B	gpm	gal	gpm	Volume	gpm	gal	gpm	Volume	psi	psi	psig	psig	psig		gpm	gal	gal
1	6/24/04 12:32	NA	A	B	28	23971	NA	NA	27	23294	NA	NA	4	3.5	105	104	100+	7866300	0	0	NA
	6/25/04 11:30	11.0	A	B	33	44991	31.9	128	31	44375	32.0	128	5.5	5	98	95	92	7886600	0	0	NA
2	6/28/04 9:17	33.8	A	B	32	108441	31.3	513	32	108075	31.4	515	5.5	5	100	96	93	7947740	0	0	NA
	6/29/04 9:19	12.0	A	B	29	131386	31.8	653	28	130974	31.7	654	4.5	4	105	103	100+	7969880	1.5	287	NA
	6/30/04 16:01	18.7	A	B	30	166117	31.0	864	30	165692	30.9	865	5	5	101	100	90	8003315	0	510.7	511
	7/1/04 13:59	10.0	A	B	31	185223	31.9	980	30	184858	32.1	982	5.5	5	100	96	93	8021980	0	510.7	NA
	7/2/04 14:56	12.9	A	B	32	209871	31.7	1130	31	209636	31.9	1132	5.5	5	100	96	94	8045860	0	510.7	NA
3	7/6/04 13:30	46.6	A	B	29	297899	31.5	1665	28	297866	31.6	1669	4	4	105	109	100+	8131200	0	510.7	NA
	7/7/04 9:00	7.5	A	B	32	312011	31.4	1750	33	311809	31.0	1753	5.5	4.5	100	95	94	8144500	0	510.7	NA
	7/8/04 16:32	19.5	A	B	32	348968	31.5	1975	32	349009	31.7	1979	5	5	100	97	93	8180600	0	510.7	NA
	7/9/04 13:35	9.0	A	B	31	365938	31.3	2078	31	366086	31.4	2083	5	5	100	97	94	8197165	0	510.7	NA
4	7/12/04 13:30	35.9	A	B	32	433271	31.2	2487	31	433584	31.3	2493	5	5	100	96	92	8262820	0	510.7	NA
	7/13/04 10:00	8.5	A	B	32	449425	31.7	2585	32	449865	31.9	2592	5	5	100	95	93	8278285	0	510.7	NA
	7/14/04 9:30	11.5	A	B	32	470700	30.8	2715	32	471247	31.0	2722	5.5	5	100	93	92	8298930	0	510.7	NA
	7/15/04 13:30	16.0	A	B	30	500630	31.2	2897	31	500527	30.5	2900	4.5	4.5	101	100	87	8327300	0.5	850.8	NA
	7/16/04 14:25	12.9	A	B	27	525019	31.5	3045	27	524715	31.2	3047	3.5	3.5	110	110	100+	8350800	0.5	1220	NA
5	7/19/04 9:30	31.1	A	B	32	584077	31.7	3404	33	583614	31.6	3405	5.5	5	99	95	92	8407800	0	1290	779
	7/20/04 8:57	11.4	A	B	28	605379	31.0	3533	27	604867	30.9	3534	4	3.5	102	104	104	8428555	0	1290	NA
	7/21/04 14:02	17.1	A	B	31	637557	31.4	3729	30	637111	31.5	3730	5	4.9	100	97	94	8459790	0	1290	NA
	7/22/04 16:12	14.2	A	B	32	664233	31.4	3891	32	663800	31.4	3892	5	5	99	95	93	8485780	0	1290	NA
	7/23/04 14:48	10.6	A	B	32	683833	30.8	4010	31	683350	30.7	4011	5	4.5	100	96	94	NR	0	1290	NA
6	7/26/04 9:16	30.5	A	B	28	740859	31.2	4356	28	740026	31.0	4355	4	4	102	102	101	8558975	1	1420	NA
	7/27/04 14:12	16.9	A	B	32	772923	31.6	4551	32	772091	31.6	4550	5.9	5	100	95	93	8590090	1	1910	NA
	7/28/04 9:46	7.6	A	B	33	787316	31.7	4639	32	786508	31.8	4638	5.5	5	100	95	92	8603940	0	2060	770
	7/29/04 9:01	11.3	A	B	30	808295	31.1	4766	30	807403	31.0	4765	5	5	100	96	94	8624215	0	2060	NA
	7/30/04 16:18	19.3	A	B	31	844137	31.0	4984	31	843320	31.0	4983	5	5	100	96	94	8659035	0	2060	NA
7	8/2/04 10:29	30.2	A	B	32	899068	30.3	5318	31	898410	30.4	5318	5	5	100	96	90	8712530	0	2060	NA
	8/3/04 9:27	11.0	A	B	32	919909	31.7	5444	31	919248	31.7	5445	5	4.5	100	96	90	8732720	0	2060	NA
	8/4/04 9:47	12.3	A	B	27	943057	31.3	5585	26	942185	31.0	5584	4	3.6	105	103	96	8755000	0	2060	NA
	8/5/04 8:58	11.2	A	B	32	963804	30.9	5711	30	962970	31.0	5710	5	5	100	96	90	8775200	0	2060	NA
	8/6/04 14:25	17.4	A	B	30	996229	31.0	5908	30	995478	31.0	5908	5	5	100	98	90	8806800	0	2060	NA
8	8/9/04 9:45	31.3	A	B	26	1055151	31.3	6266	26	1054232	31.3	6265	3.6	3.6	103	104	99	8863945	0	2060	NA
	8/10/04 16:09	18.4	A	B	31	1089574	31.2	6475	30	1087899	30.5	6469	5	5	100	98	90	8897000	0.5	2130	NA
	8/11/04 11:09	7.0	A	B	32	1102913	31.8	6557	31	1100798	30.7	6548	5	5	100	97	90	8909815	0.5	2330	NA
	8/12/04 9:19	10.2	A	B	32	1122569	32.2	6676	31	1120172	31.8	6666	5	5	100	97	90	8928325	0.5	2630	NA
	8/13/04 17:18	20.0	A	B	30	1160528	31.7	6907	30	1157685	31.3	6893	5	5	100	97	90	8964840	0	2840	780
9	8/16/04 9:00	27.7	A	B	28	1214460	32.5	7234	26	1210860	32.0	7217	3.8	3.8	105	103	98	9016630	0	2840	NA
	8/17/04 12:00	15.0	A	B	31	1240824	29.3	7395	30	1236957	29.0	7375	5	4.8	100	98	90	9042150	0	2840	NA
	8/18/04 9:00	9.0	A	B	28	1259075	33.8	7505	26	1255175	33.7	7486	3.9	3.5	105	103	97	9059840	0	2840	NA
	8/19/04 11:30	14.5	A	B	29	1284888	29.7	7662	29	1280719	29.4	7641	4	3.9	101	101	96	9084760	0	2840	NA
	8/20/04 15:34	16.1	A	B	30	1315490	31.7	7848	31	1310625	31.0	7823	5	5	100	98	90	9113900	0	2840	NA
10	8/23/04 10:18	30.7	A	B	32	1375391	32.5	8212	31	1369612	32.0	8181	5	4.5	100	96	90	9170640	NA	NA	NA
	8/24/04 12:31	14.2	A	B	31	1401393	30.5	8370	30	1395087	29.9	8336	5	4.5	100	96	90	9195500	0	2840	NA
	8/25/04 9:12	8.7	A	B	31	1418118	32.1	8472	30	1411570	31.6	8436	5	4.5	100	97	90	9211500	0	2840	NA
	8/26/04 13:54	16.7	A	B	31	1449870	31.7	8665	30	1442950	31.3	8627	5	4.5	100	97	89	9242000	0	2840	NA
	8/27/04 15:31	13.6	A	B	31	1475337	31.2	8820	31	1468239	31.0	8781	5	4.6	100	97	90	9266635	0	2840	NA
11	8/30/04 16:13	36.7	A	B	27	1544210	31.3	9238	27	1536384	30.9	9195	4	4	104	101	106	9333305	0	2840	NA
	8/31/04 11:17	7.1	A	B	31	1557388	31.1	9318	30	1549642	31.3	9275	5	4.7	100	97	90	9345950	0	2840	NA
	9/1/04 11:00	11.7	A	B	32	1578093	29.5	9444	31	1570127	29.1	9400	5.5	4.8	100	97	90	9365910	0.5	3100	NA
	9/2/04 13:54	14.9	A	B	32	1605790	31.0	9612	32	1597517	30.6	9566	5	5	100	96	89	9392690	0	3370	530
	9/3/04 12:42	10.8	A	B	30	1625872	31.0	9734	30	1617330	30.6	9687	5	5	100	97	90	9412000	0	3370	NA

EPA Arsenic Demonstration Project at Rimrock, AZ - Daily System Operation Log Sheet
Daily System Operation (Continued)

Week No.	Date & Time	Run Time hr	Tank Position		Vessel A Flow Meter				Vessel B Flow Meter				ΔP		Pressure			Backwash Water Recycle			
			Lead A/B	Lag A/B	Flow rate gpm	Totalizer gal	Flow rate gpm	Bed Volume	Flow rate gpm	Totalizer gal	Flow rate gpm	Bed Volume	Vessel A psi	Vessel B psi	Inlet psig	Between Tanks psig	Outlet psig	Master Totalizer gal	Flow rate gpm	Totalizer gal	Recycle Volume gal
22	11/15/04 18:03	37.1	A	B	30	3296170	31.9	19885	33	3272583	31.4	19745	5	5	101	99	100	11026175	0.5	6451	NA
	11/16/04 10:12	4.5	A	B	32	3304356	30.3	19934	31	3280723	30.1	19795	5.9	5.1	100	97	97	11034090	0.5	6565	NA
	11/17/04 9:46	11.0	A	B	32	3326877	34.1	20071	28	3303126	33.9	19931	5.5	5	101	98	99	11055250	0.5	6913	NA
	11/18/04 14:49	17.4	A	B	32	3359732	31.5	20271	33	3335681	31.2	20129	5.9	5	101	97	97	11087000	0.5	7406	NA
	11/19/04 15:40	12.7	A	B	31	3384711	32.8	20423	32	3360410	32.5	20279	5.5	5	101	99	99	11111180	0.5	7784	NA
23	11/22/04 9:38	30.5	A	B	32	3443037	31.9	20777	30	3418182	31.6	20630	5.6	5.1	100	97	99	11167700	0	7905	1575
	11/23/04 10:00	12.5	A	B	33	3466574	31.4	20920	33	3441496	31.1	20772	5.5	5	101	98	98	11190480	0	7905	NA
	11/24/04 14:11	13.0	A	B	31	3492632	33.4	21078	31	3467298	33.1	20929	5.5	5	101	97	98	11215740	0	7905	NA
	11/25/04 0:00																				
	11/26/04 0:00																				
24	11/29/04 10:14	58.4	A	B	30	3605433	32.2	21764	30	3579122	31.9	21608	6	5	122*	97	115	11325230	0	7908	3
	11/30/04 10:47	11.0	A	B	31	3629181	36.0	21908	32	3602681	35.7	21751	5.5	5	NA	98	NA	11348235	0	7908	NA
	12/1/04 10:58	NA	A	B	32	3652572	NA	22050	33	3625889	NA	21892	5.4	5	NA	97	NA	11370865	0	7908	NA
	12/2/04 0:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	12/3/04 0:00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
25	12/6/04 9:35	NA	A	B	33	3766441	NA	22742	33	3738862	NA	22579	5.5	5.5	NA	96	NA	11481663	0	7908	NA
	12/7/04 9:15	11.9	A	B	33	3788938	31.5	22879	31	3761091	31.1	22714	5.5	5	NA	97	NA	11503262	0	7908	NA
	12/8/04 10:04	12.3	A	B	31	3813731	33.6	23030	32	3785617	33.2	22863	5.5	5	NA	97	NA	11527300	0	7908	NA
	12/9/04 9:32	11.6	A	B	33	3835866	31.8	23164	33	3807480	31.4	22996	5.5	5.3	NA	97	NA	11548800	0	7908	NA
	12/10/04 14:00	13.8	A	B	33	3863117	32.9	23330	31	3834341	32.4	23159	6.5	5.5	NA	97	NA	11575040	0	7908	NA
26	12/13/04 8:15	NA	A	B	33	3927415	NA	23720	34	3897613	NA	23544	5.5	5	NA	98	NA	11636970	0	7908	NA
	12/14/04 14:00	NA	A	B	33	3957724	NA	23905	33	3927319	NA	23724	5.5	5.1	NA	98	NA	11666085	0	7908	NA
	12/15/04 17:00	NA	A	B	NA	3982673	NA	24056	NA	3950999	NA	23868	NA	NA	NA	85	NA	11688387	0	23	NA
	12/16/04 15:13	13.0	A	B	33	4008571	33.2	24214	31	3976384	32.5	24022	6	5.5	NA	97	NA	11713150	0.5	403	NA
	12/17/04 16:39	11.9	A	B	NA	4032260	33.2	24358	NA	3999641	32.6	24164	NA	NA	NA	NA	NA	11735780	NA	751	NA
27	12/20/04 17:14	35.7	A	B	NA	4103115	33.1	24788	NA	4068989	32.4	24585	NA	NA	NA	NA	NA	11803505	0	1610	1610
	12/21/04 9:24	NA	A	B	32	4122253	NA	24904	33	4087888	NA	24700	5.5	5	NA	97	NA	11822050	0	1610	NA
	12/22/04 15:02	NA	A	B	NA	4149825	NA	25072	NA	4114985	NA	24864	NA	NA	NA	NA	NA	11848442	0	1610	NA
	12/23/04 0:00																				
	12/24/04 0:00																				

Highlighted rows indicate vessel backwash.

NA = data not available.

APPENDIX B
ANALYTICAL DATA TABLES

Analytical Results from Long-Term Sampling, Rimrock, AZ

B-1

Sampling Date		6/30/04				7/07/04				7/14/04				7/21/04			
Sampling Location	Parameter Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10 ³	–	–	0.9	0.9	–	–	1.8	1.8	–	–	2.7	2.7	–	–	3.7	3.7
Alkalinity	mg/L ^(a)	355	–	367	351	330	–	382	365	383	–	371	367	379	–	375	383
Fluoride	mg/L	0.3	–	0.3	0.3	–	–	–	–	–	–	–	–	–	–	–	–
Sulfate	mg/L	9.4	–	9.4	9.4	–	–	–	–	–	–	–	–	–	–	–	–
NO ₃ -N	mg/L	0.3	–	0.3	0.3	–	–	–	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L ^(b)	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	<0.1
Silica (as SiO ₂)	mg/L	26.0	–	25.4	23.9	25.7	–	24.4	24.1	24.0	–	24.3	23.9	26.1	–	25.9	25.1
Turbidity	NTU	0.5	–	0.3	0.4	0.3	–	0.2	0.6	<0.1	–	0.2	0.9	0.3	–	0.3	0.4
pH	–	7.0	7.4	7.0	7.0	7.0	7.2	7.0	7.0	7.0	7.2	7.1	7.1	6.9	7.2	7.0	7.0
Temperature	°C	21.5	21.2	22.9	23.7	24.1	22.3	21.9	22.1	22.4	22.4	22.7	23.1	24.1	23.5	23.1	23.2
DO	mg/L	3.8	4.9	3.6	3.8	4.1	5.0	4.1	3.7	3.5	4.7	3.7	3.6	4.7	6.8	6.6	6.9
ORP	mV	475	637	637	649	476	596	596	611	488	607	619	628	510	608	621	624
Free Chlorine	mg/L	–	0.4	0.4	0.4	–	0.4	0.4	0.4	–	0.4	0.4	0.4	–	0.5	0.5	0.4
Total Chlorine	mg/L	–	0.6	0.6	0.6	–	0.7	0.6	0.5	–	0.6	0.6	0.6	–	0.5	0.5	0.5
Total Hardness	mg/L ^(a)	287.0	–	297.7	298.5	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L ^(a)	171.3	–	174.8	174.3	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L ^(a)	115.7	–	122.9	124.2	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	59.2	–	1.0	0.3	78.5	–	1.2	0.3	79.2	–	0.8	0.3	58.8	–	0.7	0.4
As (total soluble)	µg/L	59.1	–	0.9	0.3	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	0.1	–	0.1	<0.1	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	0.8	–	0.6	0.3	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	58.3	–	0.3	<0.1	–	–	–	–	–	–	–	–	–	–	–	–
Total Fe	µg/L	<25	–	<25	<25	<25	–	<25	<25	<25	–	<25	<25	<25	–	<25	47.3
Dissolved Fe	µg/L	<25	–	<25	<25	–	–	–	–	–	–	–	–	–	–	–	–
Total Mn	µg/L	1.0	–	0.4	0.4	0.7	–	<0.1	<0.1	0.4	–	<0.1	<0.1	1.6	–	0.4	0.4
Dissolved Mn	µg/L	1.1	–	0.7	0.6	–	–	–	–	–	–	–	–	–	–	–	–

(a) As CaCO₃. (b) As PO₄.

IN = inlet; AC = after prechlorination (field parameters only); TA = after tank A; TB = after tank B.

Analytical Results from Long-Term Sampling, Rimrock, AZ

B-2

Sampling Date		7/28/04				8/04/04				8/11/04				8/18/04			
Sampling Location	Parameter Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10 ³	–	–	4.6	4.6	–	–	5.6	5.6	–	–	6.6	6.5	–	–	7.5	7.5
Alkalinity	mg/L ^(a)	369	–	381	377	379	–	367	395	376	–	376	381	363	–	375	367
Fluoride	mg/L	0.3	–	0.3	0.3	–	–	–	–	–	–	–	–	–	–	–	–
Sulfate	mg/L	10.0	–	10.0	10.0	–	–	–	–	–	–	–	–	–	–	–	–
NO ₃ -N	mg/L	0.2	–	0.2	0.2	–	–	–	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L ^(b)	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	<0.1
Silica (as SiO ₂)	mg/L	24.6	–	24.5	24.3	25.3	–	25.6	25.0	25.3	–	25.2	25.0	25.6	–	25.6	25.3
Turbidity	NTU	0.2	–	0.3	0.2	0.3	–	0.3	0.5	0.1	–	0.2	0.1	0.3	–	0.4	0.7
pH	–	7.0	7.2	7.1	7.1	7.0	7.0	7.0	7.0	7.0	7.2	7.1	7.0	7.0	7.4	7.1	7.0
Temperature	°C	26.1	24.5	26.7	24.0	22.0	21.7	21.0	21.1	21.9	21.0	21.2	21.1	22.0	21.7	21.3	22.2
DO	mg/L	4.4	5.5	4.2	4.1	4.2	4.1	4.0	3.8	4.2	5.8	4.1	4.1	4.1	4.5	3.9	5.1
ORP	mV	484	590	599	613	203	609	634	647	247	587	627	641	239	552	614	622
Free Chlorine	mg/L	–	0.5	0.5	0.4	–	0.5	0.4	0.4	–	0.4	0.4	0.4	–	0.4	0.4	0.4
Total Chlorine	mg/L	–	0.6	0.6	0.5	–	0.5	0.5	0.5	–	0.4	0.4	0.4	–	0.4	0.4	0.4
Total Hardness	mg/L ^(a)	351.3	–	397.2	351.7	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L ^(a)	208.0	–	236.1	207.0	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L ^(a)	143.3	–	161.1	144.7	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	56.0	–	1.0	0.3	81.4	–	1.4	0.3	57.0	–	0.7	0.3	48.3	–	0.7	0.3
As (total soluble)	µg/L	57.6	–	1.0	0.3	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	<0.1	–	<0.1	<0.1	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	1.0	–	0.8	0.6	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	56.6	–	0.2	<0.1	–	–	–	–	–	–	–	–	–	–	–	–
Total Fe	µg/L	<25	–	<25	<25	<25	–	<25	<25	<25	–	<25	<25	<25	–	<25	<25
Dissolved Fe	µg/L	<25	–	<25	<25	–	–	–	–	–	–	–	–	–	–	–	–
Total Mn	µg/L	0.3	–	<0.1	<0.1	0.5	–	<0.1	<0.1	0.8	–	0.2	<0.1	0.4	–	<0.1	0.1
Dissolved Mn	µg/L	0.4	–	<0.1	<0.1	–	–	–	–	–	–	–	–	–	–	–	–

(a) As CaCO₃. (b) As PO₄.

IN = inlet; AC = after prechlorination (field parameters only); TA = after tank A; TB = after tank B.

Analytical Results from Long-Term Sampling, Rimrock, AZ

B-3

Sampling Date		8/25/04				9/01/04				9/08/04				9/15/04			
Sampling Location	Parameter Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10 ³	–	–	8.5	8.4	–	–	9.4	9.4	–	–	10.4	10.3	–	–	11.3	11.3
Alkalinity	mg/L ^(a)	359	–	363	367	371	–	375	371	383	–	375	375	372 376	–	376 372	372 384
Fluoride	mg/L	0.3	–	0.3	0.3	–	–	–	–	–	–	–	–	–	–	–	–
Sulfate	mg/L	10.0	–	9.8	10.0	–	–	–	–	–	–	–	–	–	–	–	–
NO ₃ -N	mg/L	0.2	–	0.2	0.2	–	–	–	–	–	–	–	–	–	–	–	–
Orthophosphate	mg/L ^(b)	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	<0.1	<0.1	–	<0.1	<0.1	<0.06 <0.06	–	<0.06 <0.06	<0.06 <0.06
Silica (as SiO ₂)	mg/L	26.7	–	27.2	26.9	25.3	–	25.2	25.1	25.6	–	25.2	25.6	25.9 25.6	–	25.6 25.0	25.9 25.5
Turbidity	NTU	0.1	–	0.1	<0.1	0.1	–	0.3	0.2	0.1	–	0.1	0.2	0.6 0.5	–	0.5 0.5	0.6 0.5
pH	–	7.0	7.0	7.0	6.9	7.1	7.6	7.1	7.1	6.9	7.1	6.9	6.9	7.1	7.4	7.1	7.1
Temperature	°C	21.9	21.2	21.2	21.4	21.2	21.6	21.2	21.2	22.6	22.3	21.5	22.0	21.5	21.9	21.2	21.3
DO	mg/L	3.3	4.7	3.6	3.4	4.6	4.5	4.4	4.6	3.5	3.4	3.6	3.5	3.8	6.1	4.9	4.7
ORP	mV	210	610	649	658	213	608	637	637	431	642	668	685	226	578	619	633
Free Chlorine	mg/L	–	0.5	0.3	0.3	–	0.4	0.3	0.3	–	0.4	0.4	0.4	–	0.4	0.4	0.4
Total Chlorine	mg/L	–	0.5	0.4	0.4	–	0.4	0.4	0.4	–	0.5	0.5	0.5	–	0.4	0.4	0.4
Total Hardness	mg/L ^(a)	304.8	–	319.3	327.6	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L ^(a)	183.0	–	182.3	182.3	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L ^(a)	121.8	–	137.0	145.3	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	64.6	–	2.7	1.0	77.5	–	1.1	0.4	78.5	–	1.1	0.4	55.3 60.2	–	1.1 1.1	0.5 0.3
As (total soluble)	µg/L	61.1	–	2.8	1.2	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	3.5	–	<0.1	<0.1	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	2.1	–	2.7	1.1	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	59.0	–	0.1	0.1	–	–	–	–	–	–	–	–	–	–	–	–
Total Fe	µg/L	<25	–	<25	<25	<25	–	<25	<25	<25	–	<25	<25	<25 <25	–	<25 <25	<25 <25
Dissolved Fe	µg/L	<25	–	<25	<25	–	–	–	–	–	–	–	–	–	–	–	–
Total Mn	µg/L	1.4	–	1.2	0.9	0.4	–	<0.1	<0.1	0.3	–	<0.1	0.1	0.4 0.3	–	0.2 0.2	0.1 <0.1
Dissolved Mn	µg/L	0.5	–	0.3	0.1	–	–	–	–	–	–	–	–	–	–	–	–

(a) As CaCO₃. (b) As PO₄.

IN = inlet; AC = after prechlorination (field parameters only); TA = after tank A; TB = after tank B.

Analytical Results from Long-Term Sampling, Rimrock, AZ

B-4

Sampling Date		9/22/04				9/29/04				10/06/04				10/13/04 ^(c)			
Sampling Location	Parameter Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10 ³	–	–	12.3	12.3	–	–	13.4	13.3	–	–	14.3	14.3	–	–	15.3	15.2
Alkalinity	mg/L ^(a)	369	–	373	373	369	–	369	369	370	–	370	370	353	–	345	353
Fluoride	mg/L	0.4	–	0.5	0.3	–	–	–	–	–	–	–	–	–	–	–	–
Sulfate	mg/L	8.9	–	8.8	8.7	–	–	–	–	–	–	–	–	–	–	–	–
NO ₃ -N	mg/L	0.2	–	0.2	0.2	–	–	–	–	–	–	–	–	–	–	–	–
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	25.9	–	25.7	25.6	25.6	–	25.8	25.8	25.7	–	25.6	25.0	24.9	–	25.2	24.9
Turbidity	NTU	0.1	–	<0.1	0.1	<0.1	–	<0.1	0.1	0.3	–	0.5	0.2	0.2	–	0.2	0.2
pH	–	7.0	7.4	7.0	7.0	7.0	7.0	7.0	7.1	7.0	7.0	7.0	7.0	NA	NA	NA	NA
Temperature	°C	20.1	20.0	20.2	20.3	20.9	21.0	21.0	21.0	20.8	20.6	20.7	20.6	NA	NA	NA	NA
DO	mg/L	4.1	6.4	5.7	4.2	4.1	5.2	4.4	4.2	3.9	6.3	3.5	4.0	NA	NA	NA	NA
ORP	mV	214	584	605	622	224	568	605	617	148	552	590	593	NA	NA	NA	NA
Free Chlorine	mg/L	–	0.4	0.4	0.4	–	0.3	0.3	0.3	–	0.2	0.2	0.2	–	NA	NA	NA
Total Chlorine	mg/L	–	0.5	0.4	0.4	–	0.4	0.4	0.4	–	0.2	0.2	0.2	–	NA	NA	NA
Total Hardness	mg/L ^(a)	331.8	–	339.7	331.8	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L ^(a)	190.8	–	196.4	200.7	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L ^(a)	141.0	–	143.3	131.1	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	65.5	–	2.6	1.0	53.5	–	1.4	0.9	54.1	–	2.1	0.4	53.2	–	1.4	0.2
As (total soluble)	µg/L	65.0	–	2.4	0.7	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	0.5	–	0.2	0.3	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	1.8	–	1.8	0.2	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	63.2	–	0.6	0.5	–	–	–	–	–	–	–	–	–	–	–	–
Total Fe	µg/L	127	–	27	56	<25	–	<25	<25	<25	–	<25	<25	<25	–	<25	<25
Dissolved Fe	µg/L	<25	–	<25	<25	–	–	–	–	–	–	–	–	–	–	–	–
Total Mn	µg/L	0.8	–	0.3	0.5	0.3	–	0.4	0.2	0.1	–	0.2	<0.1	0.4	–	<0.1	<0.1
Dissolved Mn	µg/L	0.4	–	0.1	0.1	–	–	–	–	–	–	–	–	–	–	–	–

(a) As CaCO₃. (b) As PO₄. (c) Operator was not available to take water quality measurements.
 IN = inlet; AC = after prechlorination (field parameters only); TA = after tank A; TB = after tank B.
 NA = data not available.

Analytical Results from Long-Term Sampling, Rimrock, AZ

B-5

Sampling Date		10/20/04				10/27/04				11/03/04				11/17/04			
Sampling Location	Parameter Unit	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10 ³	–	–	16.2	16.1	–	–	17.1	17.0	–	–	18.1	18.0	–	–	20.1	19.9
Alkalinity	mg/L ^(a)	377	–	377	373	386	–	382	390	369	–	377	369	390	–	386	390
Fluoride	mg/L	0.4	–	0.3	0.4	–	–	–	–	–	–	–	–	–	–	–	–
Sulfate	mg/L	9.8	–	9.4	9.6	–	–	–	–	–	–	–	–	–	–	–	–
NO ₃ -N	mg/L	0.2	–	0.2	0.2	–	–	–	–	–	–	–	–	–	–	–	–
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	24.9	–	25.0	24.6	25.2	–	25.5	25.3	24.7	–	25.0	25.0	25.6	–	25.1	25.1
Turbidity	NTU	0.1	–	0.1	0.2	0.1	–	0.1	0.3	0.2	–	0.2	0.2	0.3	–	0.3	0.3
pH	–	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	6.9	6.9	6.9	6.9	6.9 ^(d)	6.9	6.9	6.8
Temperature	°C	20.1	20.1	20.3	20.3	19.5	19.8	19.7	19.7	20.4	20.6	20.6	20.6	20.7 ^(d)	20.7	21.2	20.8
DO	mg/L	4.0	4.5	4.1	4.1	4.2	3.6	3.7	3.6	4.0	3.8	4.1	3.9	3.8 ^(d)	4.0	3.5	4.1
ORP	mV	190	637	681	710	216	552	577	590	180	491	565	591	504 ^(d)	619	640	651
Free Chlorine	mg/L	–	0.2	0.2	0.2	–	0.3	0.3	0.3	–	0.3	0.3	0.3	–	0.3	0.3	0.3
Total Chlorine	mg/L	–	0.2	0.2	0.2	–	0.4	0.4	0.4	–	0.4	0.4	0.4	–	0.3	0.3	0.3
Total Hardness	mg/L ^(a)	365.9	–	364.5	361.1	–	–	–	–	–	–	–	–	–	–	–	–
Ca Hardness	mg/L ^(a)	214.4	–	214.3	212.1	–	–	–	–	–	–	–	–	–	–	–	–
Mg Hardness	mg/L ^(a)	151.5	–	150.2	149.0	–	–	–	–	–	–	–	–	–	–	–	–
As (total)	µg/L	50.8	–	1.3	1.0	56.5	–	1.6	0.8	56.3	–	1.6	0.8	56.5	–	1.3	1.3
As (total soluble)	µg/L	50.2	–	1.1	0.7	–	–	–	–	–	–	–	–	–	–	–	–
As (particulate)	µg/L	0.6	–	0.3	0.3	–	–	–	–	–	–	–	–	–	–	–	–
As (III)	µg/L	2.2	–	1.3 ^(c)	1.3 ^(c)	–	–	–	–	–	–	–	–	–	–	–	–
As (V)	µg/L	48.0	–	<0.1	<0.1	–	–	–	–	–	–	–	–	–	–	–	–
Total Fe	µg/L	<25	–	<25	<25	<25	–	27.0	<25	<25	–	31.1	<25	<25	–	<25	<25
Dissolved Fe	µg/L	<25	–	<25	<25	–	–	–	–	–	–	–	–	–	–	–	–
Total Mn	µg/L	0.6	–	<0.1	0.3	0.2	–	0.2	<0.1	0.3	–	0.4	0.2	<0.1	–	<0.1	0.9
Dissolved Mn	µg/L	1.0	–	<0.1	<0.1	–	–	–	–	–	–	–	–	–	–	–	–

(a) As CaCO₃. (b) As PO₄. (c) Data has been rerun. (d) Water quality measurement may have been taken from the wrong location.
 IN = inlet; AC = after prechlorination (field parameters only); TA = after tank A; TB = after tank B.

Analytical Results from Long-Term Sampling, Rimrock, AZ

Sampling Date		12/01/04				12/15/04 ^(c)			
Sampling Location	Parameter	IN	AC	TA	TB	IN	AC	TA	TB
Bed Volume	10 ³	–	–	22.1	21.9	–	–	24.1	23.9
Alkalinity	mg/L ^(a)	365 365	–	365 365	365 370	383	–	370	366
Fluoride	mg/L	–	–	–	–	0.4	–	0.4	0.3
Sulfate	mg/L	–	–	–	–	9.7	–	9.1	8.8
NO ₃ -N	mg/L	–	–	–	–	0.2	–	0.2	0.2
Orthophosphate	mg/L ^(b)	<0.06 <0.06	–	<0.06 <0.06	<0.06 <0.06	<0.06	–	<0.06	<0.06
Silica (as SiO ₂)	mg/L	25.5 25.3	–	25.2 25.4	25.3 25.3	25.9	–	26.4	26.3
Turbidity	NTU	0.1 0.1	–	0.1 0.2	0.1 0.3	0.2	–	0.2	0.1
pH	–	7.0	6.9	6.9	6.9	6.9	6.9	6.9	6.9
Temperature	°C	20.1	21.2	20.6	21.1	20.6	20.1	20.4	20.0
DO	mg/L	4.3	3.4	3.9	3.5	4.0	3.2	3.5	3.4
ORP	mV	267	626	646	673	230	618	660	672
Free Chlorine	mg/L	–	0.4	0.4	0.4	–	0.3	0.3	0.3
Total Chlorine	mg/L	–	0.5	0.5	0.5	–	0.4	0.3	0.3
Total Hardness	mg/L ^(a)	–	–	–	–	383.7	–	374.2	376.7
Ca Hardness	mg/L ^(a)	–	–	–	–	241.0	–	233.8	235.2
Mg Hardness	mg/L ^(a)	–	–	–	–	142.7	–	140.4	141.5
As (total)	µg/L	51.4 52.3	–	1.7 1.7	0.4 0.4	60.3	–	3.0	0.8
As (total soluble)	µg/L	–	–	–	–	59.6	–	3.0	0.6
As (particulate)	µg/L	–	–	–	–	0.7	–	<0.1	0.2
As (III)	µg/L	–	–	–	–	1.2	–	1.3	0.7
As (V)	µg/L	–	–	–	–	58.4	–	1.7	<0.1
Total Fe	µg/L	<25 <25	–	<25 <25	<25 <25	<25	–	<25	<25
Dissolved Fe	µg/L	–	–	–	–	<25	–	<25	<25
Total Mn	µg/L	0.1 0.1	–	<0.1 0.4	<0.1 <0.1	0.3	–	<0.1	0.2
Dissolved Mn	µg/L	–	–	–	–	0.1	–	<0.1	<0.1

(a) As CaCO₃. (b) As PO₄. (c) Water quality measurements were taken on 12/16/04.
 IN = inlet; AC = after prechlorination (field parameters only); TA = after tank A; TB = after tank B.

