

**Arsenic Removal from Drinking Water by Adsorptive Media
U.S. EPA Demonstration Project at
Covered Wells in Tohono O'odham Nation, AZ
Final Performance 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 arsenic removal treatment technology demonstration project at Covered Wells in Tohono O'odham Nation, AZ. The main objective of the project was to evaluate the effectiveness of AdEdge Technologies' (AdEdge) AD-33 media in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 µg/L. Additionally, this project evaluated 1) the reliability of the treatment system (Arsenic Package Unit [APU]), 2) the required system operation and maintenance (O&M) and operator skills, and 3) the capital and O&M cost of the technology. The project also characterized the water in the distribution system and 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 cost.

The treatment system consisted of two 36-in × 72-in composite vessels in parallel configuration, each containing approximately 19 ft³ of AD-33 pelletized media. AD-33 is an iron-based adsorptive media developed by Bayer AG and marketed under the name of AD-33 by AdEdge. The treatment system was designed for a flowrate of 63 gal/min (gpm) (31.5 gpm per vessel) and an empty bed contact time (EBCT) of 4.5 min. Over the performance evaluation period, the actual average flowrate was 29.5 gpm for Vessel A and 30.6 gpm for Vessel B, based on readings from the flow meter/totalizer installed on each adsorption vessel. The average EBCT was 4.8 min for Vessel A and 4.7 min for Vessel B.

Each of the two wells had its own chlorination system that consisted of a storage tank, a chemical feed pump, and an injector. The chemical feed pumps were tied to the well pumps, which operated on an alternating basis, and would start injecting sodium hypochlorite (NaOCl) solutions only when the well pumps turned on. The pre-existing chlorine addition systems were configured for prechlorination and could not be feasibly converted to post-chlorination as called for in the design since the predominate arsenic species was As(V) (>90%) and oxidation of As(III) (average concentration of 0.5 µg/L) was not needed. The prechlorination system was used to maintain a target free chlorine residual of 1.0 mg/L (as Cl₂) or less in the distribution system for disinfection.

As part of the water treatment system, a Destin North Bay carbon dioxide (CO₂) pH adjustment/control system was used to adjust pH values of raw water from as high as 8.4 to a target value of 7.0. Due to several operational issues, the Destin North Bay system was replaced with an AdEdge CO₂ pH adjustment/control system approximately five months into the study. The AdEdge system consisted of a control panel/cabinet and a "Venturi style" injector. The control panel/cabinet contained components such as an "Inlet" solenoid valve, a non-venting single stage pressure regulator, a manual loop controlled by a needle valve, an automatic loop controlled by a Burkert pH controller and solid-state SensorX in-line pH probe, a rotameter, an "Outlet" solenoid valve, and a check valve. CO₂ was injected downstream of the chlorination injection point.

The treatment system began regular operation on February 13, 2008. From February 13, 2008, through the end of the performance evaluation study on March 19, 2010, the treatment system operated for a total of 3,353 hr, treating approximately 11,686,000 gal (or 41,148 bed volume [BV]) of water. The average daily operation time was 4.38 hr/day and the average daily demand was 15,276 gal/day (gpd).

Total arsenic concentrations in raw water ranged from 29.0 to 38.6 µg/L and averaged 34.9 µg/L. Soluble As(V) was the predominating species, ranging from 33.3 to 36.4 µg/L and averaging 32.4 µg/L, based on the results from six speciation sampling events. At the end of the performance evaluation study on March 19, 2010, total arsenic levels in the treated water were 0.6 and 0.4 µg/L following Vessels A and B, respectively. (Note that treatment plant water sampling continued on June 15, September 29, and

November 3, 2010, with arsenic concentrations increasing from 1.2 to 4.2 and then to 3.3 $\mu\text{g/L}$ following Vessels A and from 0.7 to 3.2 and then 3.0 $\mu\text{g/L}$ following Vessel B. By November 3, 2010, the treatment system had treated approximately 60,000 BV of water.) Concentrations of silica and phosphorus, which could interfere with arsenic adsorption by competing for adsorption sites, averaged 26.2 mg/L (as SiO_2) and were less than the method detection limit (MDL) of 10.0 $\mu\text{g/L}$ (as P), respectively, in raw water. Concentrations of iron, manganese, and other ions in raw water were not high enough to impact arsenic removal by the media.

Comparison of the distribution system sampling results before and after operation of the system showed a significant decrease in arsenic concentration (from an average of 36.5 to an average of 0.9 $\mu\text{g/L}$). Arsenic concentrations in the distribution system were somewhat higher than those in the system effluent, probably caused by redissolution and resuspension of arsenic particles. Lead and copper concentrations appeared to have elevated somewhat after operation of the system; however, the elevated levels were significantly under their respective action levels.

The capital investment cost of \$115,306 included \$86,018 for equipment, \$12,897 for site engineering, and \$16,391 for installation. Using the system's rated capacity of 63 gpm (or 90,720 gpd), the capital cost was \$1,832/gpm (or \$1.27/gpd) of design capacity. The capital cost also was converted to an annualized cost of \$10,884/yr using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-year return period. At a 100% use rate, the unit capital cost would be \$0.33/1,000 gal. At the actual use rate, the unit capital cost increased to \$1.89/1,000 gal.

The O&M cost included only the cost associated with the media replacement and disposal, CO_2 and chlorine usage, electricity consumption, and labor. Although media replacement did not occur during the performance evaluation study, the media replacement cost would have represented the majority of the O&M cost. Media replacement and O&M cost per 1,000 gal of water treated was estimated and plotted as a function of the projected media run length to the 10 $\mu\text{g/L}$ arsenic breakthrough.

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ABBREVIATIONS AND ACRONYMS

Δp	differential pressure
AAL	American Analytical Laboratories
AM	adsorptive media
APU	arsenic package unit
As	arsenic
ATS	Aquatic Treatment Systems
BET	Brunauer, Emmett, and Teller
bgs	below ground surface
BV	bed volume
Ca	calcium
C/F	coagulation/filtration process
Cl	chlorine
CO ₂	carbon dioxide
CRF	capital recovery factor
Cu	copper
CWRWS	Covered Wells Regional Water System
DO	dissolved oxygen
EBCT	empty bed contact time
EPA	U.S. Environmental Protection Agency
F	fluorine
Fe	iron
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
HDPE	high-density polyethylene
HIX	hybrid ion exchanger
hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IHS	Indian Health Services
ISFET	Ion Sensitive Field Effect Transistor
IX	ion exchange
LCR	Lead and Copper Rule
lph	liter per hour
MCL	maximum contaminant level
MDL	method detection limit
MEI	Magnesium Elektron, Inc.

ABBREVIATIONS AND ACRONYMS (Continued)

Mg	magnesium
Mn	manganese
mV	millivolts
Na	sodium
NaOCl	sodium hypochlorite
NSF	NSF International
O&M	operation and maintenance
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
P	phosphorus
PID	Proportional Integral Derivative
PO ₄	phosphate
POU	point of use
psi	pounds per square inch
PVC	polyvinyl chloride
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RO	reverse osmosis
RPD	relative percent difference
scfh	standard cubic foot (feet) per hour
SDWA	Safe Drinking Water Act
SiO ₂	silica
SMCL	secondary maximum contaminant level
SO ₄ ²⁻	sulfate
SS	stainless steel
STS	Severn Trent Services
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids
TOC	total organic carbon
TOUA	Tohono O'odham Utility Authority
U	uranium
V	vanadium

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1.0 INTRODUCTION

1.1 Background

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

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

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 one to six proposals. In April 2003, an independent technical panel reviewed the proposals and recommended to EPA the technologies they determined to be acceptable for the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration project. Using the information provided by the review panel, EPA, in cooperation with the host sites and the drinking-water programs of the respective states, selected one technical proposal for each site.

In 2003, EPA initiated Round 2 arsenic technology demonstration projects that were partially funded with Congressional add-on funding to the EPA budget. In June 2003, EPA selected 32 potential demonstration sites, including the Covered Wells site in the Gu Achi District of the Tohono O'odham Nation in Arizona. The Covered Wells site is operated by the Tohono O'odham Utility Authority (TOUA), which is charged by the Nation to provide services, including water/wastewater, electric, telephone, cellular, propane, and internet to customers in the Nation.

In September 2003, EPA again solicited proposals from engineering firms and vendors for arsenic removal technologies. EPA received 148 technical proposals for the 32 host sites, with each site receiving from two to eight proposals. In April 2004, EPA convened another technical panel to review the proposals and provide recommendations to EPA; the number of proposals per site ranged from none (for two sites) to four. At the site receiving at least one proposal, the final selection of the treatment technology was made through a joint effort by EPA, the state regulators, and the host site. Since then, four sites have withdrawn from the demonstration program, reducing the number of sites to 28. AdEdge Technologies' (AdEdge) AD33 Arsenic Removal Technology was selected for demonstration at the TOUA site in April 2004.

As of July 2010, 39 of the 40 systems were operational, and the performance evaluation of all 39 systems was completed.

1.2 Treatment Technologies for Arsenic Removal

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

1.3 Project Objectives

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

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

This report summarizes the performance of the AdEdge AM system at the Covered Wells site in Tohono O'odham Nation, AZ, from February 13, 2008 to March 19, 2010. The data collected included system operation, water quality (both across the treatment train and in the distribution system), and capital and preliminary O&M cost.

**Table 1-1. Summary of Round 1 and Round 2 Arsenic Removal Demonstration
Locations, Technologies, and Source Water Quality**

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

**Table 1-1. Summary of Round 1 and Round 2 Arsenic Removal Demonstration
Locations, Technologies, and Source Water Quality (Continued)**

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

AM = adsorptive media process; C/F = coagulation/filtration; HIX = hybrid ion exchange; IX = ion exchange process; RO = reverse osmosis

ATS = Aquatic Treatment Systems; MEI = Magnesium Elektron, Inc.; STS = Severn Trent Services

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

(b) Design flowrate reduced by 50% due to system reconfiguration from parallel to series operation.

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

(d) Withdrew from program in 2007. Selected originally to replace Village of Lyman, NE site, which withdrew from program in June 2006.

(e) Facilities upgraded systems in Springfield, OH from 150 to 250 gal/min (gpm), Sandusky, MI from 210 to 340 gpm, and Arnaudville, LA from 385 to 770 gpm.

(f) Including nine residential units.

(g) Including eight under-the-sink units.

2.0 SUMMARY AND CONCLUSIONS

AdEdge's APU treatment system with AD-33 pelletized media was installed and has operated at the Covered Wells site in Tohono O'odham Nation, AZ since February 13, 2008. Based on the information collected during the system evaluation period, the following summary and conclusion statements are provided.

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

- AD-33 media effectively lowered arsenic concentrations to 0.6 and 0.4 µg/L following Vessels A and B, respectively, after treating 11,686,000 gal (or 41,148 bed volumes [BV]) of water, based on a total media volume of 38 ft³ (19 ft³ per vessel).
- The operation of the treatment system significantly lowered arsenic concentrations from 36.5 to 0.9 µg/L (on average) in the distribution system. Although lead and copper levels in the distribution system were slightly elevated after the system was put into service, the concentrations were significantly below their respective action levels.

Required system O&M and operator skill levels:

- The operator typically spent over an hour to visually inspect the system, record operational parameters, and change out carbon dioxide (CO₂) cylinders. Additional time and effort were required to troubleshoot the problems associated with the CO₂ system.
- Some operational issues were encountered during operation of the Destin North Bay and AdEdge CO₂ pH adjustment systems. Primary issues involved a leaking manifold, a malfunctioning pneumatic flow control valve, a faulty pH meter display, a faulty solenoid, and a faulty check valve.
- Operation of the system did not appear to require additional skills beyond those necessary to operate the existing water supply equipment, with the exception of the CO₂ and pH control portion of the system. The CO₂ system required additional operator training and safety awareness.

Process residuals produced by the technology:

- The pressure differential (Δp) measured across the media vessels remained low during system operation. Therefore, no backwash was required or performed throughout the performance evaluation study.

Cost-effectiveness of the technology:

- Based on the system's rated capacity of 63 gpm (or 90,720 gal/day [gpd]), the capital cost was \$1,830/gpm (or \$1.27/gpd) of design capacity.
- Media replacement and disposal did not occur during the performance evaluation study; however, the cost to change out both vessels (38 ft³ AD-33 media) was estimated to be \$18,405, which included the replacement media, spent media disposal, shipping, labor, and travel.

3.0 MATERIALS AND METHODS

3.1 General Project Approach

Following the predemonstration activities summarized in Table 3-1, the performance evaluation study of the AdEdge arsenic removal system began on February 13, 2008, and ended on March 19, 2010 (note that treatment samples continued to be collected and analyzed on a quarterly basis after the study had been ended). Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall performance of the system was determined based on its ability to consistently remove arsenic to below the arsenic MCL of 10 µg/L through the collection of water samples across the treatment plant, as described in the Study Plan (Battelle, 2006). The reliability of the system was evaluated by tracking the unscheduled system downtime and the frequency and extent of repair and replacement. Unscheduled downtime and repair information was recorded by the plant operator on a Repair and Maintenance Log Sheet.

Table 3-1. Predemonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	December 7, 2004
Project Planning Meeting Held	February 18, 2005
Draft Letter of Understanding Issued	February 25, 2005
Final Letter of Understanding Issued	March 11, 2005
Request for Quotation Issued to Vendor	March 11, 2005
Vendor Quotation Received by Battelle	September 7, 2005
Purchase Order Completed and Signed	October 5, 2005
Letter Report Issued	February 16, 2006
Final Study Plan Issued	May 5, 2006
Building Construction Completed	March 2007
Treatment System Shipped and Arrived	March 2007
System Installation Completed	January 7, 2008
System Shakedown Completed	January 7, 2008
Performance Evaluation Begun	February 13, 2008

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

The cost 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 gal of water treated. This task requires tracking the capital cost for equipment, site engineering, and installation, as well as the O&M cost for media replacement and disposal, CO₂ and chlorine consumption, electrical power usage, and labor. Data on O&M cost were limited to CO₂ consumption, electricity usage, and labor because media replacement did not take place during the performance evaluation study.

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

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

3.2 System O&M and Cost Data Collection

The plant operator performed daily, biweekly, and monthly system O&M and data collection according to instructions provided by the vendor and Battelle. On a regular basis, the plant operator recorded system operational data, such as pressure, flowrate, totalizer, and hour meter readings on a Daily System Operation Log Sheet, and conducted visual inspections to ensure normal system operations. If any problem occurred, the plant operator would contact the Battelle Study Lead, who determined if the vendor should be contacted for troubleshooting. The plant operator recorded all relevant information, including problem encountered, course of action taken, materials and supplies used, and cost and labor incurred on the Repair and Maintenance Log Sheet. Every other week, while collecting samples, the plant operator measured pH, temperature, dissolved oxygen (DO), and oxidation-reduction potential (ORP), and recorded the data on an Onsite Water Quality Parameters Log Sheet. Approximately three months after the start of the study, DO and ORP measurements were discontinued due to difficulties with the equipment encountered by the operator.

The capital cost for the arsenic removal system consisted of the cost for equipment, site engineering, and system installation. The O&M cost consisted of the cost for chemical usage, electricity consumption, and labor. CO₂ consumption was tracked by the number of CO₂ cylinder change-outs. Electricity consumption was tracked through an onsite electric meter. Labor for various activities, such as 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 completing field logs, replacing empty CO₂ cylinders, ordering supplies, performing system inspections, and others as recommended by the vendor. The demonstration-related work, including activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead and vendor, was recorded, but not used for the cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate the performance of the system, samples were collected from the wellheads, across the treatment plant, from the backwash discharge line, and from the distribution system. Table 3-3 provides the sampling schedule and analytes measured during each sampling event. Specific sampling

Table 3-3. Sampling Schedules and Analytes

Sample Type	Sampling Locations ^(a)	No. of Samples	Frequency	Analytes	Sampling Date
Source Water	Well No. 1 and Well No. 2	2	Once during initial site visit	Onsite: pH, temperature, DO, and ORP Offsite: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, Cl, F, NO ₃ , NO ₂ , NH ₃ , SO ₄ , SiO ₂ , PO ₄ , turbidity, alkalinity, TDS, and TOC	12/07/04
Treatment Plant Water (Speciation)	IN, AP, and TT	3	Before 05/28/08: once every 8 weeks; After 05/28/08: once every 3 to 4 months	Onsite: pH, temperature, DO ^(b) , ORP ^(b) , and total and free Cl ₂ ^(c) Offsite: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), U (total) ^(d) , V (total) ^(e) , Ca, Mg, F, NO ₃ , SO ₄ , SiO ₂ , P, turbidity, and alkalinity	04/01/08, 05/28/08, 10/07/08, 03/17/09, 07/14/09, 11/17/09
Treatment Plant Water (Regular)	IN, AP, TA, and TB	4	Before 05/28/08: 3 times in one 8-week cycle; After 05/28/08: monthly	Onsite: pH, temperature, DO ^(b) , ORP ^(b) , and total and free Cl ₂ ^(c) Offsite: As (total), Fe (total) ^(f) , Mn (total) ^(f) , U (total) ^(d,f) , V (total) ^(e) , SiO ₂ ^(f) , P ^(f) , turbidity ^(f) , and alkalinity ^(f)	02/13/08, 04/15/08, 04/29/08, 05/12/08, 07/08/08, 07/30/08, 09/02/08, 11/18/08, 12/16/08, 01/20/09, 02/17/09, 04/15/09, 05/20/09, 06/16/09, 08/18/09, 09/15/09, 10/20/09, 12/15/09, 01/19/10, 02/16/10, 03/16/10
Distribution System Water	Three LCR residences within distribution system	3	Monthly ^(g,h)	pH, alkalinity, As (total), Fe (total), Mn (total), Pb, and Cu	Baseline and monthly sampling: see Table 4-8

(a) Abbreviations in parentheses corresponding to sample locations shown in Figure 4-4.

(b) Measurement discontinued after 05/28/08.

(c) Except IN location.

(d) Measurement discontinued after 09/02/08.

(e) Measurement added on 09/02/08.

(f) Measurements discontinued after 11/17/09.

(g) Four baseline sampling events performed from October 2005 to January 2006 before system startup.

(h) Sampling frequency reduced to quarterly after system startup in February 2008.

DO = dissolved oxygen; LCR = Lead and Copper Rule; NA = not applicable; ORP = oxidation-reduction potential; TDS = total dissolved solids; TOC = total organic carbon

requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2004).

3.3.1 Source Water. During the initial site visit on December 7, 2004, one set of source water samples was collected from each of the two supply wells (i.e., Wells No. 1 and No. 2) and speciated using an arsenic speciation kit (see Section 3.4.1). Sample taps were flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Analytes for the source water samples are listed in Table 3-3.

3.3.2 Treatment Plant Water. During the performance evaluation study, the plant operator collected water samples across the treatment train for onsite and offsite analyses. Battelle's Study Plan (Battelle, 2006) called for biweekly sampling at the wellhead (IN), after chlorination and pH adjustment (AP), after Vessels A and B (TA/TB), and/or after effluent from Vessels A and B combined (TT). Speciation was performed once every 8 weeks, with samples taken at IN, AP, and TT and analyzed for the analytes listed under "speciation" in Table 3-3. The other three sampling events collected samples at IN, AP, TA, and TB and analyzed for analytes listed under "regular" in Table 3-3. This sampling schedule was followed only briefly from April 1 through May 28, 2008. Since then, treatment plant water samples were collected monthly for a total of 21 times, including four speciation events collected once every 3 to 4 months.

Over the course of the performance evaluation study, the sampling schedule was changed several times as presented below:

- After May 28, 2008, onsite measurements were modified to include only pH, temperature, and total and free chlorine; DO and ORP measurement were discontinued.
- On September 2, 2008, uranium (total) was deleted from the list of analytes due to low levels present in raw water. Meanwhile, vanadium (total) was added to the list of analytes.
- After the November 17, 2009, sampling event, speciation sampling was discontinued and regular, non-speciation sampling was modified to include only arsenic (total), vanadium (total), and the aforementioned water quality measurements.

3.3.3 Backwash Wastewater/Solids and Spent Media. Because the system did not require backwashing during the performance evaluation study, no backwash residuals were produced. Further, because media replacement did not take place, media samples were not collected.

3.3.4 Distribution System Water. Samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically the arsenic, lead, and copper levels. From October 2005 to January 2006, prior to the startup of the treatment system, four monthly baseline distribution sampling events were conducted at three residences located within the distribution system. Following the startup of the arsenic adsorption system, distribution system sampling continued on a quarterly basis at the same three residences until October 20, 2009, when it was discontinued.

The three residences selected were included in the Lead and Copper Rule (LCR) sampling in the past. The baseline and quarterly distribution system samples were collected following an instruction sheet developed according to the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The date and time of the last water use before sampling and the date and time of sample collection were recorded for calculation of the stagnation time. All samples were collected from a cold water faucet that had not been used for at least 6 hr to ensure that stagnant water was sampled.

Analytes for the baseline samples coincided with the quarterly distribution system water samples as described in Table 3-3. Arsenic speciation was not performed for the distribution system water samples.

3.4 Sampling Logistics

All sampling logistics including preparation of arsenic speciation kits and sample coolers, and sample shipping and handling are discussed as follows.

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

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

When appropriate, the sample cooler was packed with bottles for the three distribution system sampling locations. In addition, all sampling- and shipping-related materials, such as latex gloves, sampling instructions, chain-of-custody forms, prepaid UPS air bills, and bubble wrap, were included. Except for the operator's signature, the chain-of-custody forms and prepaid UPS air bills had already been completed with the required information. The sample coolers were shipped via FedEx to the facility approximately 1 week prior to the scheduled sampling date.

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

Samples for metal analyses were stored at Battelle's inductively coupled plasma-mass spectrometry (ICP-MS) laboratory. Samples for other water quality analyses were packed in separate coolers and picked up by couriers from American Analytical Laboratories (AAL) in Columbus, OH and Belmont Labs in Englewood, OH, both of which were under contract with Battelle for this demonstration study. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

3.5 Analytical Procedures

The analytical procedures described in detail in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2004) were followed by Battelle ICP-MS, AAL, and Belmont Labs. Laboratory quality assurance/quality

control (QA/QC) of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection limits (MDLs), and completeness met the criteria established in the QAPP (i.e., relative percent difference [RPD] of 20%, percent recovery of 80% to 120%, and completeness of 80%). The QA data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project.

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

4.0 RESULTS AND DISCUSSION

4.1 Facility Description and Pre-existing Treatment System Infrastructure

The Tohono O'odham Nation's Covered Wells Regional Water System (CWRWS) serves the communities of Lower Covered Wells and Upper Covered Wells (Covered Wells), located approximately 20 miles northwest of Sells, Arizona in the Gu Achi District of the Tohono O'odham Reservation. The CWRWS has a total 64 of connections, serving a population of 310. The facility operates approximately 10 hr/day with an estimated daily demand of 36,000 gpd. The water system is supplied by two 8-in diameter wells (Wells No. 1 and No. 2), which operate on an alternating basis at approximately 60 gpm. Wells No. 1 and No. 2 are installed to a depth of 755 ft below ground surface (bgs) and screened from 605 to 745 ft bgs. The static water level is approximately 610 ft bgs. The pump is set at 692 ft bgs in each well. Figures 4-1 and 4-2 are photographs of the fenced-in area surrounding Wells No. 1 and No. 2, respectively.

The existing water facility was comprised of the following: two 8-in diameter wells each equipped with a 30-horsepower (hp) submersible pump and a pressure reducing valve in a vault, one 88,000-gal above groundwater storage tank located approximately 9 miles from the well site, and 45,589 ft of 6-in water line. Chlorination with a sodium hypochlorite (NaOCl) solution was the only pre-existing treatment, which was accomplished by injecting the solution at the point of entry using a chemical metering pump for a target free chlorine residual level of 1 mg/L (as Cl_2) or less. The metering pump was set based on the system flowrate. The proposed arsenic removal system was placed in between Wells No.1 and No.2 (Figure 4-2).



Figure 4-1. Fenced-In Area Around Well No. 1 and Pressure Reducing Valve Vault



**Figure 4-2. Future Location of Arsenic Treatment System
(Well No. 2 in a Fenced-in Area in the Background)**

4.1.1 Source Water Quality. Source water samples from Wells No. 1 and No. 2 were collected and speciated on December 7, 2004. The results are presented in Table 4-1 and compared to those taken by the facility and Indian Health Services (IHS) for the EPA demonstration site selection.

Arsenic. Total arsenic concentrations in source water ranged from 26.0 to 37.0 µg/L. Based on the December 7, 2004 sampling results, of the 31.8 to 33.1 µg/L of total arsenic, 30.1 to 32.7 µg/L existed as As(V) and up to 0.7 and 1.2 µg/L existed as particulate arsenic and As(III), respectively. Therefore, As(V) was the predominating arsenic species in source water.

Iron. Iron concentrations in source water ranged from less than its detection limit of 25 µg/L to 240 µg/L. In general, adsorptive media technologies are best suited to sites with relatively low iron levels (e.g., less than 300 µg/L of iron, which is the secondary maximum contaminant level [SMCL] for iron). With concentrations greater than 300 µg/L, taste, odor, and color problems can occur in the treated water, along with an increased potential for fouling of the adsorption system components with iron particulates.

pH. The source water pH was relatively high, with values ranging from 7.7 to 8.4. The pH of the water was adjusted to a target value of 7.0 using CO₂ prior to adsorptive media to increase its adsorptive capacity and prolong its run length. CO₂ was also less corrosive than mineral acids, such as H₂SO₄,

Table 4-1. Water Quality Data for Covered Wells Site in Tohono O'odham Nation, AZ

Parameter	Unit	Facility Data ^(a)	IHS Data ^(b)	Battelle Data	
<i>Date</i>	--	NA	12/08/03	12/07/04	
<i>Well</i>	--	NA	NA	Well No. 1	Well No. 2
pH	--	7.7	8.4	8.2	8.2
Temperature	°C	NA	NA	21.5	21.5
DO	mg/L	NA	NA	4.3	4.3
Total Alkalinity (as CaCO ₃)	mg/L	150, 140*	150	150	150
Hardness (as CaCO ₃)	mg/L	27	32.0	39.1	39.6
Turbidity	NTU	NA	NA	0.2	0.5
TDS	mg/L	NA	NA	214	248
TOC	mg/L	NA	0.5	<0.7	1.0
Nitrate (as N)	mg/L	NA	NA	1.1	1.2
Nitrite (as N)	mg/L	NA	NA	<0.01	<0.01
Ammonia (as N)	mg/L	NA	NA	<0.05	<0.05
Chloride	mg/L	17, 21*	6.9	20.0	21.0
Fluoride	mg/L	NA	NA	0.6	0.6
Sulfate	mg/L	23, 23*	33.0	23.0	23.0
Silica (as SiO ₂)	mg/L	24*	22.7	25.7	27.1
Orthophosphate (as PO ₄)	mg/L	<0.065*	ND	<0.06	<0.06
As (total)	µg/L	26, 34*	37.0	31.8	33.1
As (soluble)	µg/L	NA	NA	31.1	33.9
As (particulate)	µg/L	NA	NA	0.7	<0.1
As(III)	µg/L	NA	ND	1.0	1.2
As(V)	µg/L	NA	37.0	30.1	32.7
Fe (total)	µg/L	228*, 29*	240	<25	<25
Fe (soluble)	µg/L	NA	NA	<25	<25
Mn (total)	µg/L	4*	ND	0.6	1.1
Mn (soluble)	µg/L	NA	NA	0.3	0.5
U (total)	µg/L	NA	NA	8.0	7.4
U (soluble)	µg/L	NA	NA	8.1	7.6
V (total)	µg/L	NA	NA	32.2	30.7
V (soluble)	µg/L	NA	NA	34.2	31.2
Na (total)	mg/L	76, 72*	78.9	77.5	75.0
Ca (total)	mg/L	11, 10*	9.1	11.7	11.4
Mg (total)	mg/L	2*	2.2	2.4	2.7

(a) Data provided by Facility unless otherwise noted.

(b) After Farley, 2004.

*EPA analytical results

DO = dissolved oxygen; NA = not available; ND = not detected; TDS = total dissolved solids; TOC = total organic carbon

and when the treated water depressurized after exiting the adsorption vessels, some CO₂ may degas, thereby raising pH values of the treated water and reducing its corrosivity to the distribution piping.

Competing Anions. Arsenic adsorption can be influenced by the presence of competing anions such as silica and phosphate. Analysis of source water indicated that silica levels ranged from 22.7 to 27.1 mg/L and that orthophosphate levels were less than the detection limit (i.e., <0.06 mg/L). The effect of silica on arsenic adsorption was monitored closely during the demonstration study.

Other Water Quality Parameters. Nitrate levels in source water ranged from 1.1 to 1.2 mg/L (as N), which were far below the MCL of 10 mg/L (as N). Nitrite levels were below the MDL of 0.01 mg/L (as N). Chloride, fluoride, sulfate, manganese, and TDS were below their respective SMCLs. TOC levels were <0.7 mg/L for Well No. 1 and 1.0 mg/L for Well No. 2.

4.1.2 Distribution System. The distribution system at Covered Wells is supplied by two wells (Wells No. 1 and No. 2) that operate on an alternating basis. Water from each well is stored in a 88,000-gallon aboveground storage tank, which is located approximately 9 miles from the well site. The mains for the water distribution system are constructed primarily of 6-in C900 polyvinyl chloride (PVC). Copper piping is used in some of the connections to the distribution system. Three locations, which are part of the historic LCR sampling network, were selected to provide a good representation of the distribution system for both baseline sampling and quarterly sampling after the system startup.

4.2 Treatment Process Description

The AdEdge arsenic package unit (APU) is a fixed-bed, down-flow adsorption system used for small water systems with flowrates up to 75 gpm. The system uses Bayoxide[®] E33 media, an iron-based adsorptive media developed by Bayer AG, for the removal of arsenic from drinking water supplies. Table 4-2 presents physical and chemical properties of the media. The Bayoxide[®] E33 media is delivered in a dry granular form and is listed by NSF under Standard 61 for use in drinking water application. For this site, Bayoxide[®] E33 was supplied in pelletized form, which has a density of 35 lb/ft³.

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

Physical Properties	
Parameter	Value
Matrix	Iron oxide composite
Physical form	Dry pellets
Color	Amber
Bulk Density (lb/ft ³)	35
BET Area (m ² /g)	142
Attrition (%)	0.3
Moisture Content (%)	<15 (by weight)
Particle size distribution (U.S. Standard mesh)	10 × 35
Crystal Size (Å)	70
Crystal Phase	α – FeOOH
Chemical Analysis	
Constituents	Weight (%)
FeOOH	90.1
CaO	0.27
MgO	1.00
MnO	0.11
SO ₃	0.13
Na 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

(a) Provided by AdEdge.

BET = Brunauer, Emmett, and Teller

As groundwater is pumped through fixed-bed pressure vessels, dissolved arsenic is adsorbed onto the media, reducing its concentration to below the 10 µg/L MCL. When the effluent arsenic concentration reaches 10 µg/L, the spent media is removed and can be disposed of as non-hazardous waste if it successfully passes the EPA's toxicity characteristic leaching procedure (TCLP) test. The media capacity is dependent upon arsenic species and its concentration in influent water, empty bed contact time (EBCT), influent pH, and concentrations of interfering ions in the water. During the performance evaluation study, the need for media replacement was never required. At the end of the study, arsenic concentrations in Vessels A and B effluent were 0.6 and 0.4 µg/L, respectively.

The APU system at TOUA consisted of two pressure vessels (i.e., Vessels A and B) operating in parallel. Figure 4-3 shows a simplified process flow diagram of the treatment system. The system sat on a covered concrete pad, which provided sufficient space for the modular treatment system and booster system consisting of one 5,000-gal intermediate storage tank and three booster pumps. Figure 4-4 is a generalized process flow sampling diagram of the system that illustrates sampling locations and parameters analyzed during the demonstration study. Table 4-3 presents key system design parameters.

The key process steps and major components of the water treatment system include:

- (a) **Intake.** Raw water was pumped from Wells No. 1 and No. 2 to the APU treatment system via 6-in PVC pipe.
- (b) **Prechlorination.** The original design called for post-chlorination since As(V) was the predominant species. Due to the location of the chlorine injection point (i.e., at each wellhead) and the associated cost required to relocate the injection point to the end of the treatment train, a decision was made to keep the pre-existing chlorination setup. The chlorine addition system was used to oxidize any As(III) in source water to As(V), while providing the needed chlorine residuals for disinfection. Each well had its own NaOCl addition system (see Figure 4-5), which consisted of a ProMinent Concept Plus Model 704 pump with a maximum capacity of 1.03 gal/hr (gph) or 3.9 L/hr (lph), a chlorine injection tap, a 30-gal chemical feed tank (containing a 2% NaOCl solution, which was diluted down from 12.5%), and a control relay box for chlorine pump control. Chlorine addition was synchronized with the well pumps and consumption was monitored by measuring the solution level in each feed tank. The metering pumps were set for a target free chlorine residual level of 1 mg/L (as Cl₂) or less.
- (c) **pH Adjustment.** The raw water had high pH values (i.e., 8.4) that had to be lowered to a target value of 7.0 to enhance arsenic adsorption. A CO₂ automatic pH adjustment/control system manufactured by Destin North Bay in Niceville, FL was initially used for pH adjustment, but was later replaced with a system produced by AdEdge. Figure 4-6 presents a schematic diagram of the original system, which was designed to introduce gaseous CO₂ into water using an in-line CO₂ injector. The four major components of the system, as shown in Figure 4-7, included a non-glass pH probe, a pH controller, a gas flow control panel, and a CO₂ injector, all of which are further explained below:
 - The non-glass pH probe was a Honeywell Durafet III Electrode mounted inline with an integral 50-ft cable, which was connected to a Honeywell pH controller. This probe was more durable than its glass counterpart and utilized an ion sensitive field effect transistor (ISFET), a miniaturized semiconductor chemical sensor, for a fast response.
 - The pH controller was a Honeywell controller with dual 4 to 20 milliamp outputs, two alarm relays, NEMA-4X enclosure, panel-mounting hardware, and an infrared communications port. The pH controller required 110 V power.

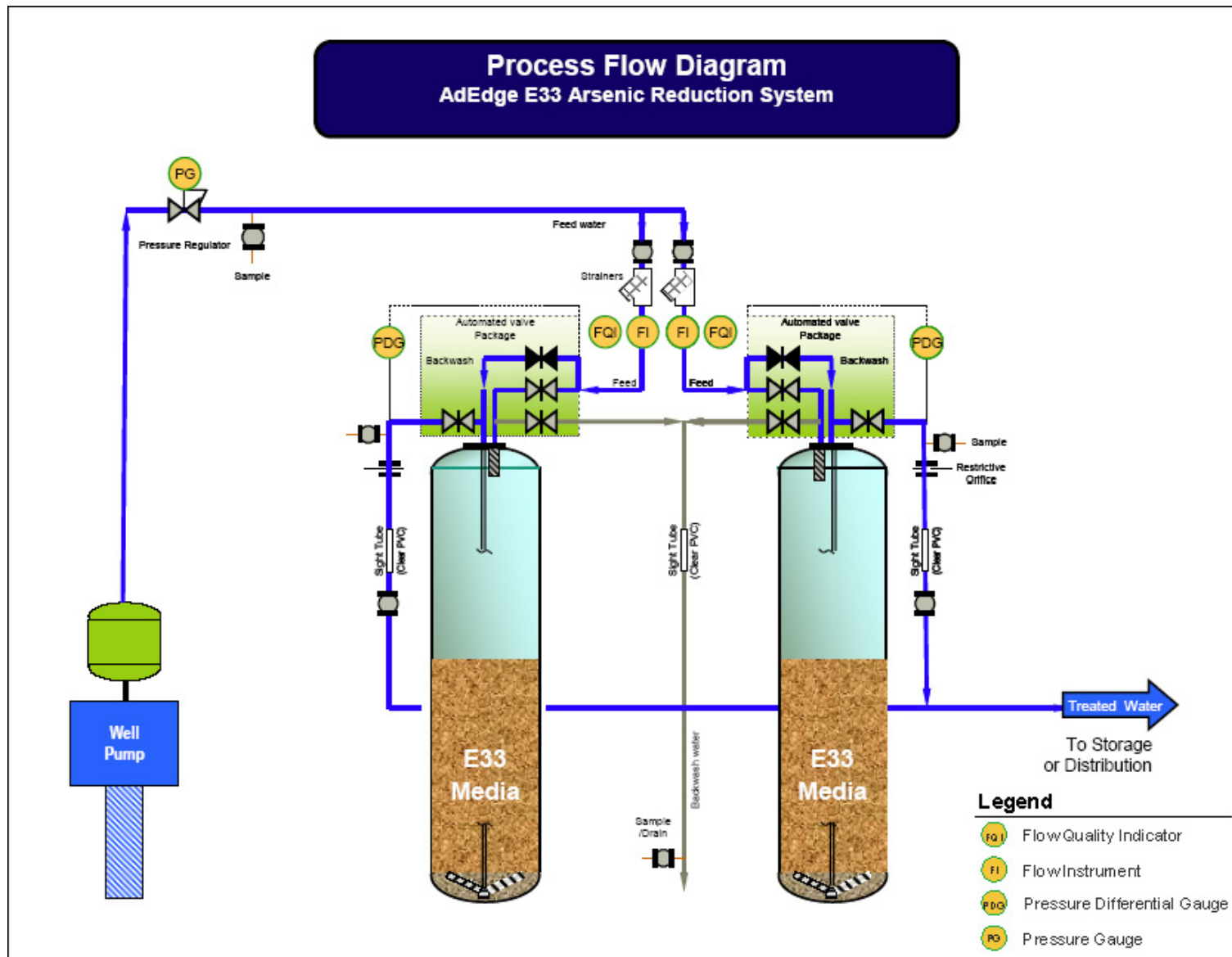


Figure 4-3. Process Flow Diagram for APU System at TOUA

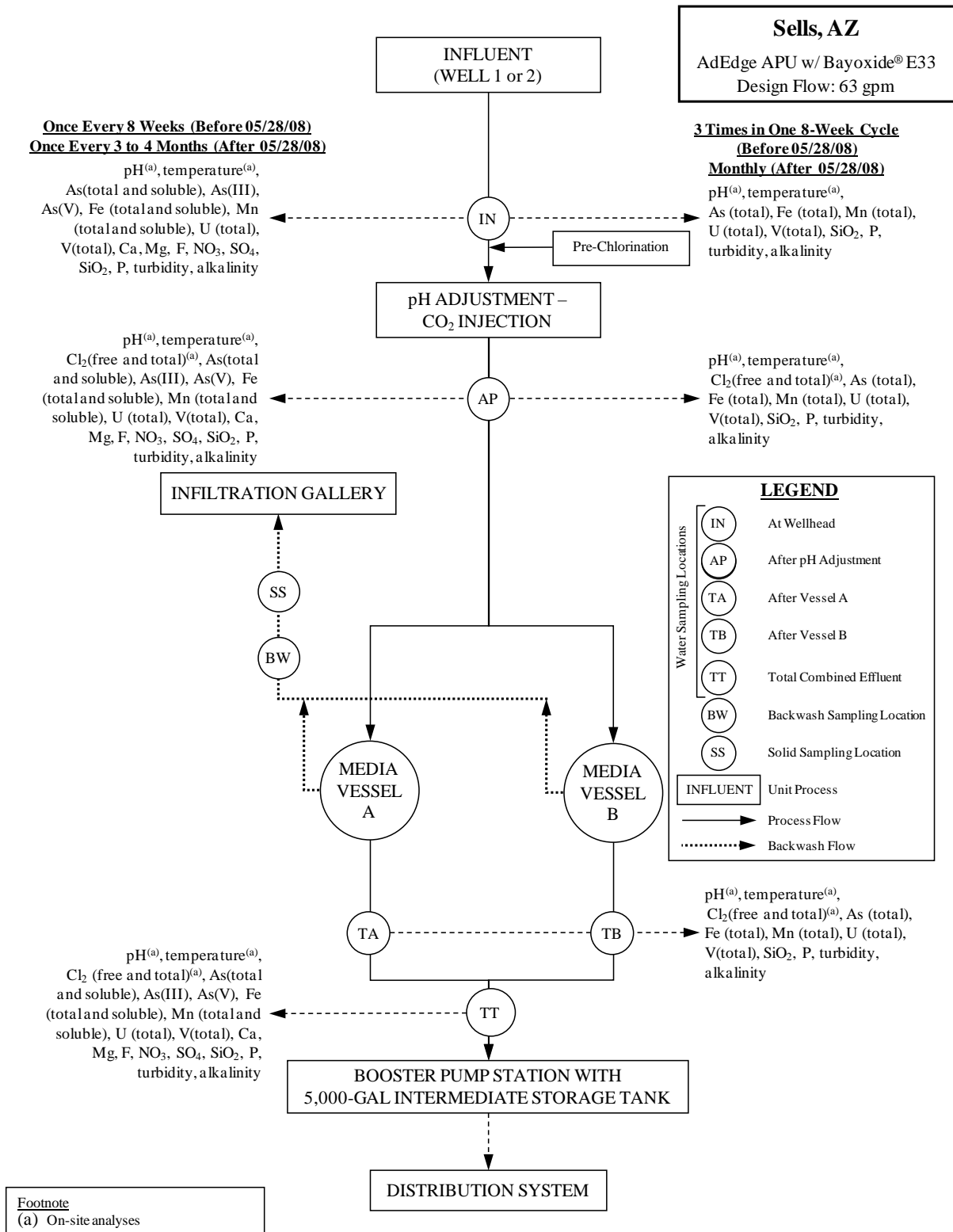


Figure 4-4. Process Flow Diagram with Sampling Schedules and Locations

Table 4-3. Design Specifications of AdEdge APU System

Parameter	Value	Remarks
<i>Prechlorination (Pre-existing)</i>		
Target Free Chlorine Residual Level (mg/L [as Cl ₂])	<1.0	Using NaOCl solution
<i>CO₂ pH Adjustment</i>		
Total Usage (lb CO ₂ /day)	5.6	Reducing pH from 8.2 to 7.0
Injection Rate (scfh)	6.1	–
No. of 50 lb Cylinders Used per Month	3 to 4	–
<i>Adsorption Vessels</i>		
Vessel Size (in)	36 D × 72 H	–
Cross-Sectional Area (ft ² /vessel)	7.1	–
No. of Vessels	2	–
Configuration	Parallel	–
Underlying Gravel Bulk Density (lb/ft ³)	100	Gravel composed of ¼-in × 1/8-in quartz
Underlying Gravel Quantity (lb/vessel)	450	900 lb in both vessels
Media Quantity (lb)	1,330	Media bulk density 35 lb/ft ³
Media Volume (ft ³ /vessel)	19	38 ft ³ in both vessels
Media Bed Depth (in)	32	–
Pressure Drop (psi)	4	Across a clean bed
<i>Service</i>		
Design Flowrate (gpm)	63	System maximum flowrate 75 gpm
Hydraulic Loading (gpm/ft ²)	4.4	–
EBCT (min)	4.5	Based on design flowrate
Estimated Working Capacity (BV)	51,000	–
Throughput To Breakthrough at 10 µg/L (gal)	14,484,000	1 BV = 284 gal
Average Use Rate (gal/day)	22,500	Based on 7 to 8 hr of daily operation at 50 gpm
Estimated Media Life (months)	21	–
<i>Backwash</i>		
Pressure Differential Setpoint (psi)	10–15	–
Backwash Flowrate (gpm)	64	–
Backwash Hydraulic Loading (gpm/ft ²)	9.0	–
Backwash Frequency (per month)	1	On as needed basis
Backwash Duration (min/vessel)	15	–
Filter-to-Waste Flowrate (gpm)	64	–
Filter-to-Waste Duration (min/vessel)	5	–
Wastewater Production (gal/event)	2,560	Both vessels combined

- The CO₂ gas flow control panel adjusted the CO₂ gas injection rate in response to the pH controller signal to maintain the setpoint of 7.0. The pressure regulator inside the panel was set at 100 psig and the instrument regulator was set at 20 psig. The CO₂ pH control system was designed to feed 6.1 standard ft³/hr (scfh). The average CO₂ use rate was estimated to be 5.6 lb/day based on a 63 gpm flowrate and the source water quality. The gas supply included up to four 50-lb cylinders to provide a one-month supply of CO₂.
- The in-line CO₂ injector used the “Venturi effect” to provide CO₂ gas mixing with the water stream. The assembly included the injector, a check valve, a metering valve, and a 5-ft long stainless steel (SS) flexible hose. The CO₂ injector was installed on the well pump discharge piping where the piping comes onto the treatment system slab.



Figure 4-5. Chlorine Addition System at TOUA

Several issues, such as malfunctioning components and leaks in the manifold, were encountered immediately after installation of the Destin North Bay system in January 2008. By early July 2008, AdEdge replaced the original system, at no additional cost, with one that was designed and built by AdEdge. The problems associated with the Destin North Bay System are further discussed in Section 4.4.3. Figure 4-8 shows a process and instrument diagram of the AdEdge pH adjustment system and photographs of the control panel are presented in Figure 4-9. Details concerning operation and components of the replacement AdEdge CO₂ pH adjustment system are described below:

- Gas supplied by the two 50-lb CO₂ cylinders entered the control panel through an inlet solenoid valve, which was controlled by a logic circuit that allowed CO₂ gas to enter the panel only if a signal was received by the control panel when the well pump was on.
- From the inlet solenoid valve, CO₂ gas flowed to a non-venting single stage pressure regulator mounted inside the control panel, by which gas pressure supplied to the remainder of the panel components and ultimately to the injector was further reduced and controlled. An “Inlet Pressure” gauge mounted on the control panel indicated the gas pressure supplied to the upstream side of the pressure regulator.
- After the panel-mounted pressure regulator, the CO₂ gas flow path was split into a manual adjustment loop and an automatic adjustment loop depending on which mode, automatic or manual, was selected. When the manual valve was opened, CO₂ gas flowed through the valve to a needle valve, by which the operator could control the gas flow delivered to the injector. When the automatic valve was opened, CO₂ gas proceeded

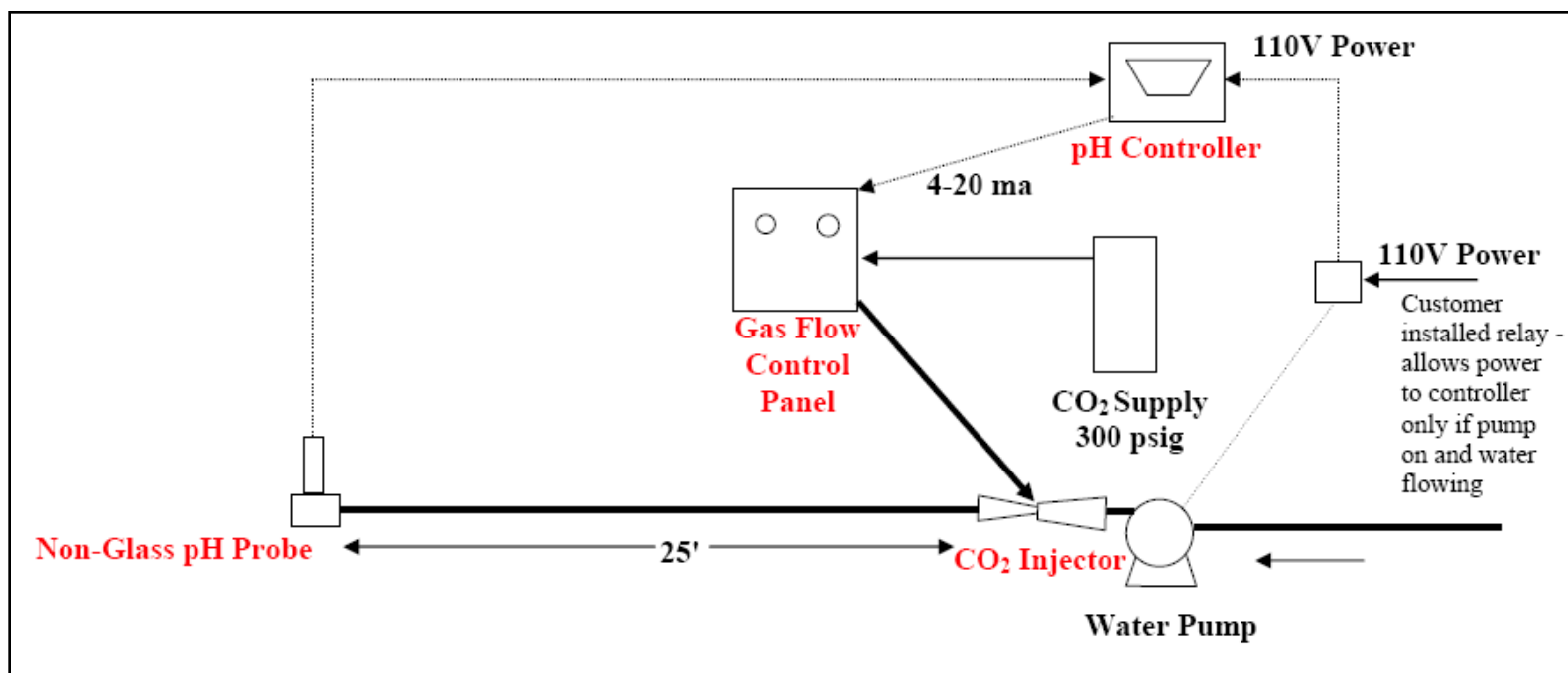


Figure 4-6. Overview of Destin North Bay CO₂ pH Adjustment System



Figure 4-7. Destin North Bay CO₂ Gas Flow Control System for pH Adjustment

*(Clockwise from top left: non-glass inline pH probe;
Honeywell pH controller; gas flow control panel; Venturi injector)*

through the valve to a proportional solenoid valve. The valve was automatically controlled via the proportional integral derivative (PID) functionality of the Burkert 8205 pH controller, which was connected to a solid state SensorX in-line pH probe mounted approximately 25 ft downstream of the injection point. The manual and automatic flow paths were brought back together and CO₂ gas flow proceeded through a panel mounted rotameter, by which the operator could gauge and record relative gas flow to the injector. The rotameter reading was a relative reading only, since the meter was calibrated for air and not CO₂.

- An “Outlet Pressure” gauge mounted on the control panel measured the delivery pressure of CO₂ gas at the outlet of the panel. CO₂ gas flowed to an outlet solenoid valve, which was controlled by the same logic circuit as the inlet solenoid valve, allowing CO₂ gas to flow only when the well pump was on. CO₂ gas then flowed from the outlet solenoid away from the panel through a check valve and a submicron filter to the injector. The injector from the original system, which employs the “Venturi effect”, was used with the new pH adjustment system. Failure of the outlet solenoid valve and check valve occurred during the performance evaluation period leading to problems with the pH adjustment system. The problems experienced and the corrective actions taken are explained in further detail in Section 4.4.3.

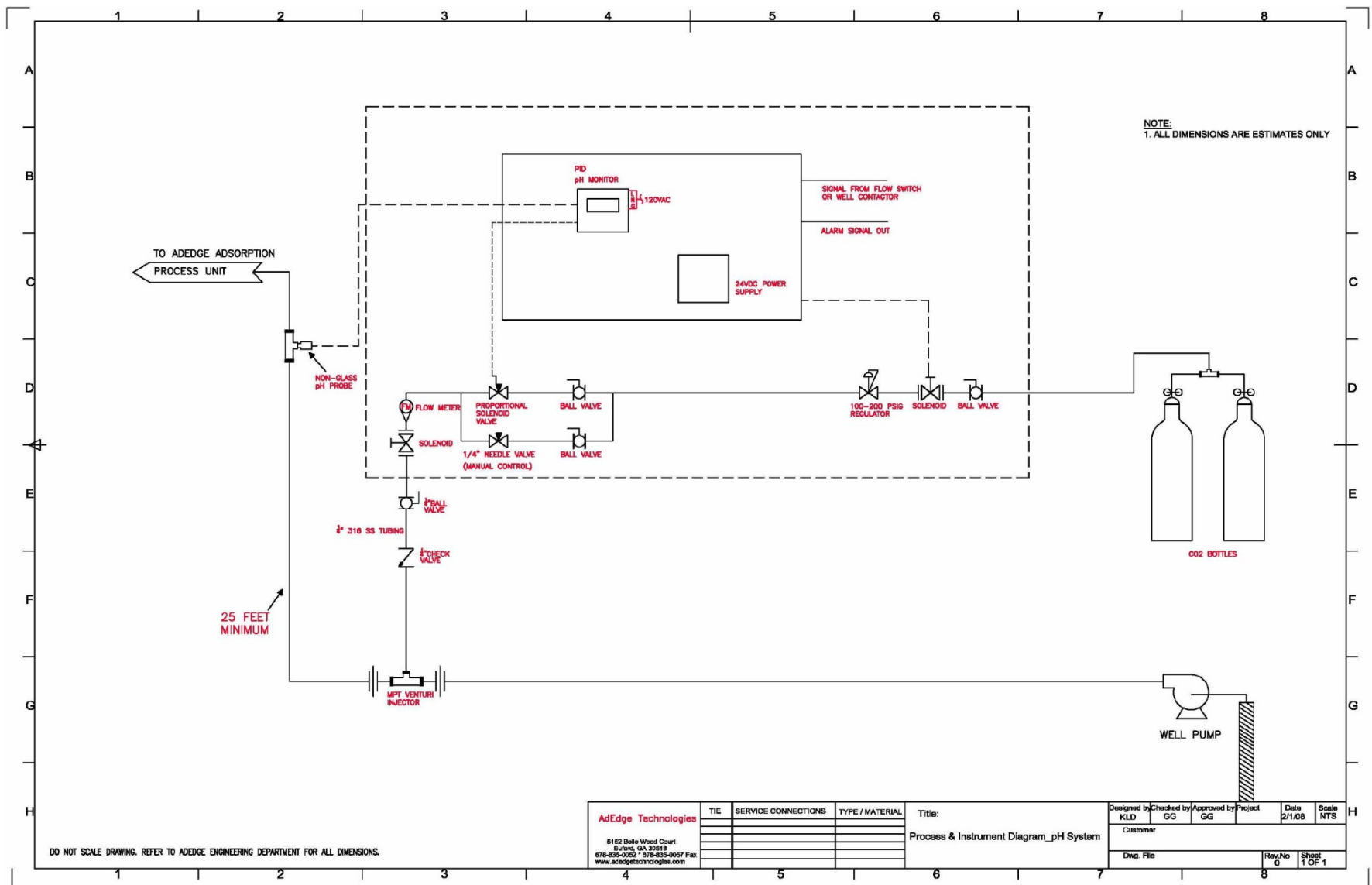
Figure 4-8. Process and Instrument Diagram of AdEdge CO₂ pH Adjustment System



Figure 4-9. AdEdge CO₂ pH Adjustment System Control Panel

- (d) **Adsorption.** The APU system consisted of two 36-in × 72-in composite vessels configured in parallel, each containing 18.5 ft³ of pelletized E33 media supported by a gravel underbed. The vessels had a 6-in flange opening on the top of the vessel for loading media and assessing vessel contents. A 2-in Fleck control valve (Fleck Model 3150) was used on each vessel to allow the vessel to operate independently. Each valve had a 3200NT timer for electronic programming, which allowed for setting custom parameters such as backwashing frequency, external notifications for alarm conditions, and accommodating other inputs and outputs. Water entered the system through 2-in piping and flowed in parallel through the vessels. Water in each vessel flowed from the upper distributor downward through the media where treated water was collected at the bottom through a slotted hub and lateral assembly. The treated water then traveled up through the riser piping in the vessel before it exited at the outlet of the Fleck control valve.

All piping on the APU system was Schedule 80 PVC. The inlet line to each control valve contained a diaphragm valve for isolation followed by a Y-strainer to prevent particulates

from entering the controller. Ball valves were located on each outlet line from the controllers also for isolation. Based on a design flowrate of 63 gpm, the EBCT for each vessel was 4.5 min and the hydraulic loading to each vessel was 4.4 gpm/ft². Figure 4-10 shows the APU system along with the booster station (left) and CO₂ pH adjustment system (center background).



Figure 4-10. AdEdge APU Arsenic Adsorption System

- **Backwash.** Backwashing was performed with raw water and initiated in one of three ways: (1) automatically based on the number of days since the last backwash (once every 30 to 45 days as recommended by the vendor); (2) automatically based on reaching a high pressure differential (typical setpoint of 10 to 15 psi); and (3) manually by depressing the backwashing selector switch. The system was designed to backwash one vessel at a time while the second vessel remained in service. During a backwash, each vessel underwent 15 min of an upflow wash followed by 5 min of a downflow rapid rinse, both at a flowrate of 64 gpm. Each backwash event (both vessels combined) would produce 2,560 gal of wastewater, which was directed to a modified evaporation/transpiration bed consisting of four infiltration chambers covered with gravel.

The differential pressure and timer triggers were disabled during the entire performance evaluation period allowing backwash to only occur manually. Due to minimal pressure drop across the vessels and low levels of arsenic in the treated effluent, routine system backwashing was not performed. Pressure drop and arsenic concentrations across the vessels were monitored regularly.

On August 18, 2009, during sample collection by the operator, Vessel A went into backwash. The operator noticed an unfamiliar value on the display screen of the control valve during the backwash and made note of it. Battelle contacted the vendor the following day to determine what triggered the vessel to automatically engage into a backwash. The vendor informed Battelle that the value the operator recorded indicated the valve programming had been reset, possibly by a power surge. The vendor walked the operator through the valve re-programming steps on September 2, 2009, making certain to disable the timer and differential pressure triggers for backwash. To engage a backwash, the operator would have to do it manually by depressing the selector switch on the control valve.

- **Media Replacement.** Based on the analytical results from the final sampling event on March 16, 2010, total arsenic concentrations in the treated water were 0.6 and 0.4 µg/L for Vessels A and B, respectively. The total arsenic concentration in the combined effluent did not exceed the MCL of 10 µg/L; therefore, the media was not replaced during the study period. Based on the estimate provided by the vendor, breakthrough of arsenic at 10 µg/L was expected to occur after treating approximately 14,484,000 gal (51,000 BV) or 21 months of system operation assuming an estimated daily throughput of 22,500 gal.

4.3 System Installation

The installation of the APU system was completed by AdEdge on January 7, 2008. The following briefly summarizes some of the predemonstration activities, including permitting, building preparation, and, installation, shakedown, and startup.

4.3.1 Permitting. Because the Tohono O’odham Nation is governed by Tribal Sovereignty and IHS performed the work related to site engineering and system/building tie-ins, the issuing of permits was not required. Instead, the vendor provided IHS and TOUA with the system layout, footprint, and electrical requirement for all system components to facilitate the facility’s building design and construction.

4.3.2 Building Preparation. A new structure was designed and funded by IHS and constructed by TOUA to house the treatment system and other necessary components (i.e., pH adjustment system and booster system). The new structure consisted of a 10 ft × 12 ft concrete slab covered by a 20 ft × 20 ft ramada shelter enclosed on the sides with corrugated metal panels. A fence was constructed around the building and 5,000 gal storage tank for the booster system for additional security. Figure 4-11 shows the new building and storage tank.

4.3.3 Installation, Shakedown, and Startup. The treatment system arrived onsite in March 2007, but installation was delayed due to construction upgrades being made to the well site, which were not completed until December 2007. The vendor was onsite for the system installation and shakedown during the week of January 7, 2008. Onsite activities included hydraulic testing, media loading, freeboard measurements, and media backwash along with the installation and shakedown of the CO₂ pH adjustment system. The vendor returned to the site the week of February 4, 2008 to train the operator and put the system online. Battelle was onsite on March 31 and April 1, 2008, to inspect the system and provide training to the operator for sampling and data collection. As a result of the system inspection, a punch-list of items was identified. Table 4-4 summarizes the items identified and corrective actions taken. In addition, these problems are discussed in detail in Section 4.4.3.



Figure 4-11. New Treatment Building with 5,000 gal Storage Tank (left)

Table 4-4. System Punch-List/Operational Issues

Item No.	Punch-List/ Operational Issues	Corrective Action(s) Taken	Resolution Date
1	Well pump hour meter not provided for each well	Not in request for quotation (RFQ) to vendor; two hours meters purchased from AdEdge and installed by TOUA	07/07/08
2	CO ₂ regulators not functioning properly	Two new CO ₂ regulators sent to site by AdEdge	05/15/08
3	Sample tap not installed at combined effluent location (TT)	Sample tap supplied by AdEdge and installed by TOUA	06/08
4	pH controller display not working	Destin North Bay CO ₂ pH adjustment unit replaced with new unit designed and installed by AdEdge.	07/10/08
5	Pneumatic flow control valve malfunctioning		
6	CO ₂ manifold leaking		

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters for the system performance evaluation were tabulated and are attached as Appendix A. Key parameters are summarized in Table 4-5. From February 13, 2008, through March 19, 2010, the system operated for a total of 3,353 hr. Due to a

Table 4-5. Summary of APU System Operation

Operational Parameter	Value
Performance Evaluation Study Duration	02/13/08 to 03/19/10
Number of Days System Operating (day)	765
Cumulative Operating Time (hr)	3,353
Average Daily Operating Time (hr)	4.38
Throughput (gal)	11,686,000
Throughput (BV) ^(a)	41,148
Average (Range) of Instantaneous Flowrate (gpm)	Vessel A
	29.5 (9.4-52.8) ^(b,c)
	Vessel B
	30.6 (20.1-54.2)
Average (Range) of EBCT per Vessel (min) ^(d)	Vessel A
	4.8 (2.7-15.1) ^(b,c)
	Vessel B
	4.7 (2.6-7.1)
Average (Range) of System Inlet Pressure (psi)	9.0 (5.0-18.0)
Average (Range) of System Outlet Pressure (psi)	5.1 (2.0-10.0)
Average (Range) of Δp Across System (psi)	4.0 (0.0-14.0)
Average (Range) of Δp Across Vessel A (psi)	2.4 (0.0-10.0)
Average (Range) of Δp Across Vessel B (psi)	2.7 (0.0-9.0)

(a) Calculated based on 38 ft³ of media; 1 BV = 284 gal.

(b) Not including two outliers on November 23, 2009.

(c) Not including values from April 30 to May 20, 2009; flowmeter not functioning.

lack of hour meters on the well pumps since system startup until July 8, 2008, the system operating time during this period was estimated based on the average daily operating time of 4.38 hr/day from July 8, 2008, through the end of the performance evaluation study.

Figure 4-12 compares calculated flowrates at each wellhead with instantaneous and calculated flowrates through each vessel. Calculated flowrates were obtained by dividing incremental volumes recorded by a totalizer by respective incremental operating times recorded from the well pump hour meter. Instantaneous flowrates were recorded by the operator from a flow meter. Because the wellheads did not have flowmeters, no instantaneous flowrates were recorded. Calculated flowrates for Wells No. 1 and No. 2 averaged 59.9 and 60.3 gpm, respectively. The flowrate through each vessel was consistent at approximately 30 gpm with slight fluctuations being observed periodically. The exceptions occurred during the period when the vessel totalizers were not operating correctly, such as from April 30, 2009, through May 20, 2009, for Vessel A. Excluding the data collected during this period and an outlier recorded on November 23, 2009, also for Vessel A, an average instantaneous flowrate of 29.5 gpm was calculated for Vessel A and 30.6 gpm for Vessel B. Since the vessels were configured in parallel, the flow through each vessel should have been one-half (i.e., 30 gpm) of the total flow from the wellhead.

At the end of the study, the system had treated 11,686,000 gal of water based on the totalizers installed on the vessels. This amount is comparable to the 11,627,700 gal recorded from the well head totalizers. The amount of water treated was equivalent to 41,148 BV based on the 38 ft³ of media in both vessels (19 ft³ per vessel). Based on the instantaneous flowrates to the vessels, the average EBCT was 4.8 min for Vessel A and 4.7 min for Vessel B, which were very close to the design value of 4.5 min as presented in Table 4-3.

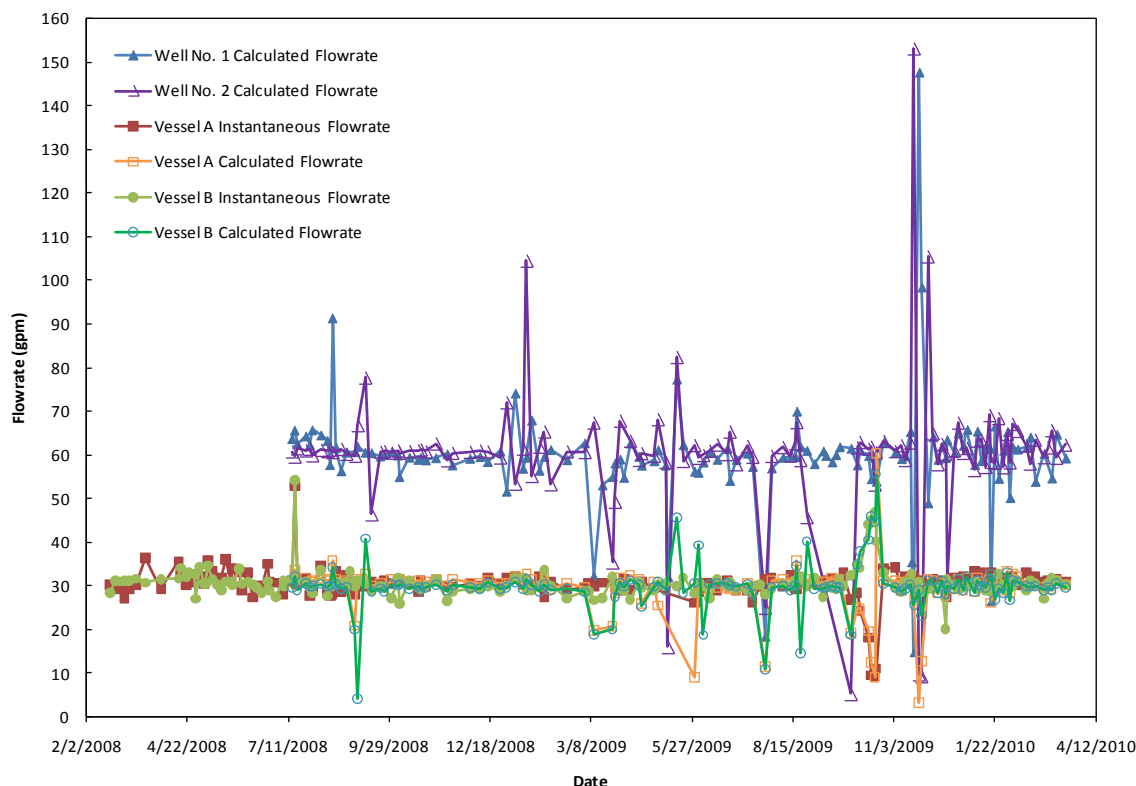


Figure 4-12. System Instantaneous and Calculated Flowrates

Pressure readings of the APU system were monitored at the system inlet and outlet, while only differential pressures (Δp) were monitored across the vessels. Throughout the duration of the performance evaluation period, system inlet and outlet pressure readings averaged 9.0 and 5.1 psi, respectively. The average Δp across the system was 4.0 psi. Δp readings ranged from 0 to 10 psi and averaged 2.4 psi across Vessel A and from 0 to 9 psi and averaged 2.7 psi across Vessel B. Due to low differential pressures across the system and vessels, no media backwash was performed during the performance evaluation study. Figure 4-13 presents system pressure readings at the inlet and outlet along with calculated differential pressures. Figure 4-14 presents differential pressures across Vessels A and B.

4.4.2 Residual Management. No residuals were produced because neither backwash nor media replacement was required during the evaluation period.

4.4.3 CO₂ pH Adjustment System. As described in Section 4.2, pH adjustment using a CO₂ gas flow control system was a process component. During system startup in early February 2008, problems with regulators on the CO₂ gas cylinders were observed. Leaks were detected in the SS hoses that connected the regulators on the CO₂ cylinders to the pH adjustment system. In addition, the low pressure side (delivery pressure) of one of the regulators continually read 150 psi. The problems with the regulators persisted until the vendor sent a new set of regulators to the site on May 15, 2008. Since then, TOUA had to have one of the regulators rebuilt twice and the other once. Rebuilding the regulators has kept them functioning properly throughout the evaluation period.

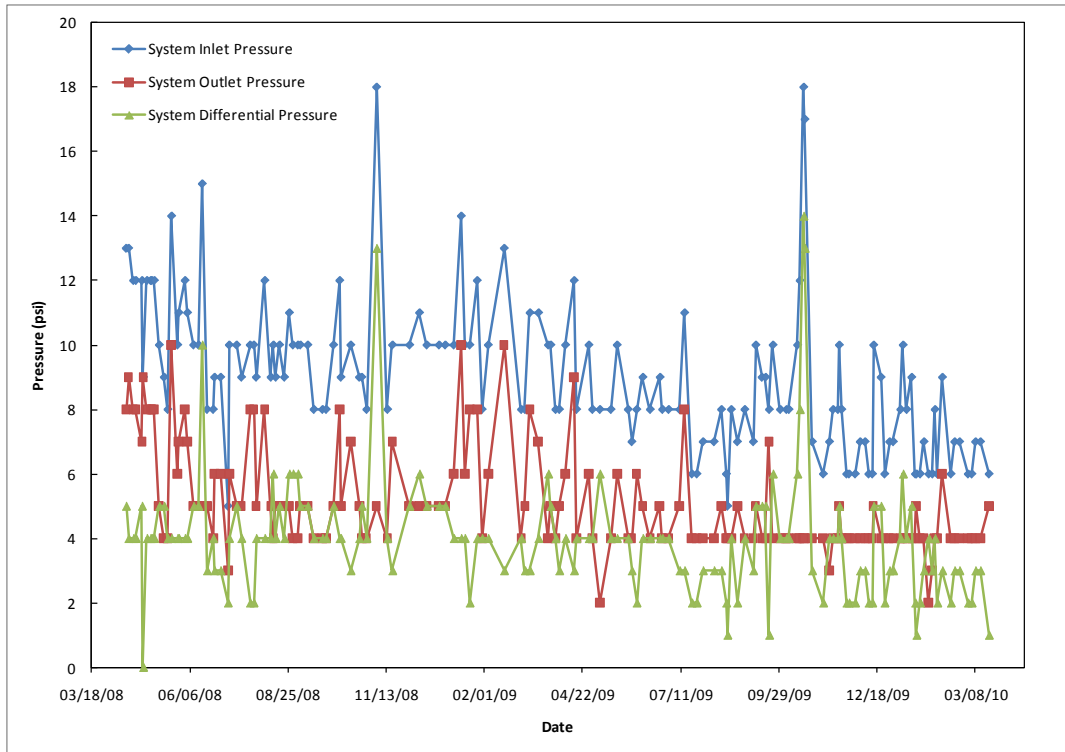


Figure 4-13. System Pressure Readings

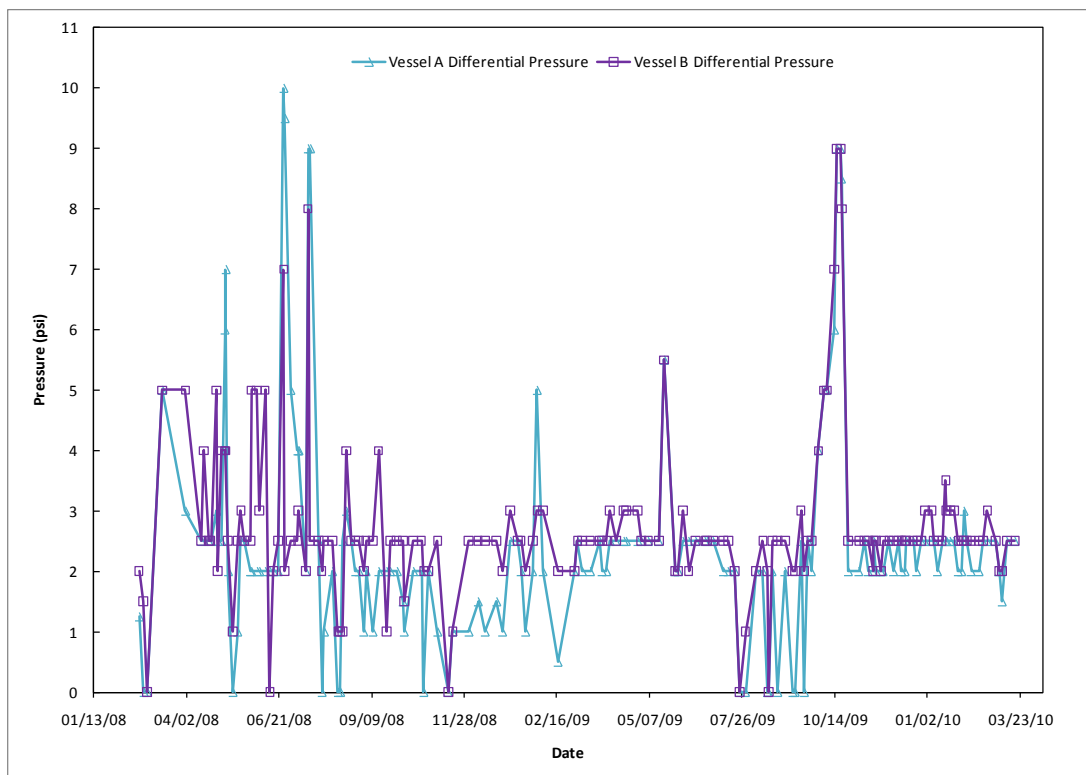


Figure 4-14. Differential Pressures Across Vessels A and B

A number of operational issues arose during the use of the Destin North Bay CO₂ pH adjustment/control system. On May 2, 2008, the operator reported that the display on the Honeywell pH controller was no longer working. After contacting the manufacturer, it was confirmed that there was a batch of pH displays malfunctioning and that they would replace the display free of charge. Also on May 2, 2008, a leak from the connection between the stainless steel piping and pneumatic flow control valve was observed. On May 9, 2008, the CO₂ manifold was found to not be functioning properly. Because of concerns over the operational issues, the vendor proposed on May 30, 2008, to replace the Destin North Bay system with a new CO₂ pH adjustment system designed and assembled by AdEdge. The new system was installed by the vendor on July 10, 2008.

On September 16, 2008, the operator noticed water in tubing in the system control panel, which, according to the vendor, was caused by a malfunctioning check valve and a malfunctioning solenoid valve on the outlet line to the injector. The operator reported again on October 28, 2008, the presence of water in the same tubing and that the system was no longer able to adjust the pH to below 7.1 based on the display on the pH control panel. After checking with the vendor for the status of replacement part shipment, it confirmed that one three-way solenoid valve and two check valves had been shipped on November 7, 2008. The replacement parts were apparently lost during shipping and had to be resent. On December 10, 2008, the operator received one shipment with one three-way solenoid valve, but no check valves. On December 11, 2008, the operator reported continuing presence of water in the tubing even after the installation of the new three-way solenoid. By January 15, 2009, the rotameter on the system control panel stopped working and water had leaked out of the tubing connections into the control panel. In addition, the pH would not go below 7.6 based on the display on the pH control panel. It must be noted, however, that pH measurements by a field pH meter during this period continued to show acceptable pH values as presented in Appendix B (e.g., 7.2 and 7.0 following Vessels A and B, respectively, on November 18, 2008, and 6.9 and 7.0 on December 16, 2008 [see Figure 4-17 in Section 4.5.1]). The differences observed between the field and inline pH measurements are further discussed in Section 4.5.1.

On February 16, 2009, an engineer was dispatched by the vendor to the site to fix the pH adjustment system. An additional solenoid valve was installed on the outlet line and the malfunctioning check valve was replaced. Water was drained from the system control panel and the delivery pressure was increased to approximately 80 psi. When the vendor left the site, the pH display was reading 7.0. No additional issues with the pH adjustment unit were experienced after the onsite visit.

4.4.4 System/Operation Reliability and Simplicity. Operational irregularities experienced during the demonstration study were almost entirely related to the pH adjustment system (as discussed in Section 4.4.3), vessel flow meters/totalizers, Y-strainers, and chlorination addition system.

On April 30, 2009, the paddlewheel in the Vessel A flowmeter/totalizer stopped rotating due to solids buildup, which was cleaned off by the operator on May 27, 2009. Quarterly checking and cleaning of paddlewheels were incorporated into the routine maintenance schedule. Problems also were experienced with the Well No. 2 flowmeter, which stopped working on September 1, 2009. After troubleshooting and cleaning by the Water Department, the meter was placed back into service approximately two weeks later.

Starting on September 30, 2009, higher-than-usual differential pressures (i.e., ≥ 4 psi) were observed across both vessels and had continued to increase to approximately 10 psi within three weeks. The cause of the pressure increase was determined to be accumulation of sediment in the Y-strainers located on the inlet lines to the valve controller on each vessel. Four new strainers were therefore purchased to allow the operator to rotate the strainers on a quarterly basis. The dirty strainers were removed and cleaned for the next changeout.

On October 20, 2009, the operator noticed that chlorine residuals across the system were uncharacteristically low. Upon further inspection, the operator found that there was a hole in the line leading to the injector. The line was repaired and the NaOCl solution was replenished. No further difficulties were encountered with the chlorine addition systems during the study.

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

Pre- and Post-Treatment Requirements. Two pre-treatment processes were required at the Covered Wells site, i.e., pH adjustment and prechlorination. CO₂ was used to lower pH values of raw water from as high as 8.4 to a target value of 7.0 to maintain effective arsenic adsorption by AD-33 media. The CO₂ injection point and inline pH probe used to monitor and control pH were installed downstream of the chlorine injection point. O&M of the pH adjustment system required routine system pressure checks and regular changeout of 50-lb CO₂ cylinders. The operator also recorded daily pH readings from the inline probe and CO₂ gas flowrates from the rotameter on the control panel. The use of CO₂ for pH adjustment also required safety training for and awareness by the operator, due to potential hazards.

For prechlorination, the existing chlorination system at each well was utilized to maintain a target free residual level of 1.0 mg/L (as Cl₂) or less. Since the original chlorine system was used, no additional maintenance or skills were required for its operation. The operator monitored chlorine tank levels and measured residual chlorine levels at different locations across the treatment train.

System Automation. The system was fitted with a valve controller on each vessel, which was capable of performing automatic backwash when triggered. All backwash triggers, however, were disabled to allow for better management of backwash events. The system also was equipped with an automated CO₂ gas flow control system, which included a liquid CO₂ supply assembly, a pH control panel with automatic and manual models, a CO₂ “Venturi style” injector, and an inline pH probe located downstream of the injection point.

Operator Skill Requirements. The skill requirements to operate the system demanded a higher level of awareness and attention than the previous system. The system offered increased operational flexibility, which, in turn, required increased monitoring of system parameters. The operator’s knowledge of the system limitations and typical operational parameters were key to achieve system performance objectives. The operator was onsite typically one to two days a week and spent approximately 1.5 hr/day to perform visual inspections and record system operating parameters. The basis for the operator skills began with onsite training and a thorough review of the system operations manual; however, increased knowledge and system troubleshooting skills were gained through hands-on operational experience.

Preventive Maintenance Activities. Preventive maintenance tasks included periodic checks of flow meters and pressure gauges and inspection of system piping and valves. Checking the CO₂ cylinders and supply lines for leaks and adequate pressure also were performed. Typically, the operator performed these duties while onsite for routine activities.

Chemical/Media Handling and Inventory Requirements. NaOCl was used for prechlorination; the operator ordered chemicals as done prior to the installation of the APU system. CO₂ used for pH adjustment was ordered on an as-needed basis. Typically, four 50-lb cylinders were used per month. The CO₂ cylinders were delivered to TOUA by the CO₂ supplier and then transported to the site approximately 20 miles by the operator. Empty cylinders were returned to the CO₂ supplier for reuse.

4.5 System Performance

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

4.5.1 Treatment Plant Sampling. Table 4-6 summarizes the analytical results of arsenic, iron, manganese, uranium, and vanadium concentrations measured at the five sampling locations across the treatment train. Table 4-7 summarizes the results of other water quality parameters. Appendix B contains a complete set of analytical results through the performance evaluation study. Treatment plant water samples were collected on 28 occasions (including one set of duplicate samples collected during the November 18, 2008 sampling event), with field speciation performed during six of the 28 occasions at IN, AP, TA, TB, and TT sampling locations. Sampling at the TT location occurred only four times due to the absence of a TT tap until June 2008. The results of the water samples collected throughout the treatment plant are discussed below.

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

Parameter	Sampling Location	Sample Count	Concentration (µg/L)			Standard Deviation
			Minimum	Maximum	Average	
As (total)	IN	28	29.0	38.6	34.9	2.2
	AP	28	26.6	39.4	34.9	2.9
	TA	27 ^(a)	<0.1	1.2	0.5	0.3
	TB	28	<0.1	1.3	0.5	0.3
	TT	4	<0.1	1.1	0.5	0.4
As (soluble)	IN	5 ^(b)	33.7	36.8	35.0	1.2
	AP	6	34.2	36.2	35.4	0.9
	TA	6	<0.1	1.1	0.5	0.4
	TB	6	0.2	1.0	0.4	0.3
	TT	4	0.2	1.1	0.5	0.4
As (particulate)	IN	5 ^(c)	0.3	2.0	1.2	0.8
	AP	6	<0.1	2.9	1.5	0.9
	TA	6	<0.1	0.5	0.1	0.2
	TB	6	<0.1	0.3	0.1	0.1
	TT	4	<0.1	0.3	0.1	0.1
As (III)	IN	6	0.1	1.0	0.5	0.3
	AP	6	0.1	1.1	0.5	0.3
	TA	6	<0.1	1.1	0.5	0.3
	TB	6	<0.1	1.0	0.4	0.3
	TT	4	0.3	1.0	0.5	0.3
As (V)	IN	5 ^(d)	33.3	36.4	34.5	1.2
	AP	6	34.0	35.9	35.0	0.8
	TA	6	<0.1	<0.1	<0.1	-
	TB	6	<0.1	<0.1	<0.1	-
	TT	4	<0.1	<0.1	<0.1	-
Fe (total)	IN	24	<25	60	<25	12.5
	AP	24	<25	32	<25	6.3
	TA	24	<25	77	<25	13.8
	TB	24	<25	<25	<25	-
	TT	4	<25	<25	<25	-

Table 4-6. Summary of Analytical Results for Arsenic, Iron, Manganese, Uranium, and Vanadium (Continued)

Parameter	Sampling Location	Sample Count	Concentration (µg/L)			Standard Deviation
			Minimum	Maximum	Average	
Fe (soluble)	IN	6	<25	<25	<25	-
	AP	6	<25	<25	<25	-
	TA	5 ^(e)	<25	<25	<25	-
	TB	6	<25	<25	<25	-
	TT	4	<25	<25	<25	-
Mn (total)	IN	24	0.1	2.8	0.7	0.9
	AP	24	<0.1	3.0	0.7	0.7
	TA	24	<0.1	2.1	0.3	0.5
	TB	24	<0.1	1.3	0.1	0.2
	TT	4	<0.1	<0.1	<0.1	-
Mn (soluble)	IN	6	<0.1	3.2	0.7	1.2
	AP	6	<0.1	0.4	0.2	0.1
	TA	6	<0.1	2.7	0.5	1.1
	TB	6	<0.1	<0.1	<0.1	-
	TT	4	<0.1	0.1	<0.1	0.0
U (total)	IN	7	7.0	8.3	7.7	0.4
	AP	7	7.0	8.4	7.7	0.4
	TA	7	<0.1	<0.1	<0.1	-
	TB	7	<0.1	<0.1	<0.1	-
	TT	0	-	-	-	-
V (total)	IN	20	23.5	38.1	32.2	3.4
	AP	20	25.2	39.7	32.5	3.6
	TA	19 ^(f)	<0.1	6.2	1.6	2.0
	TB	20	<0.1	3.7	1.4	1.5
	TT	4	<0.1	3.7	1.2	1.4

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

- (a) One outlier (i.e., 31.8 µg/L) from 08/18/09 omitted.
- (b) One outlier (i.e., 22.0 µg/L) from 04/01/08 omitted.
- (c) One outlier (i.e., 14.6 µg/L) from 04/01/08 omitted.
- (d) One outlier (i.e., 21.9 µg/L) from 04/01/08 omitted.
- (e) One outlier (i.e., 78 µg/L) from 05/28/08 omitted.
- (f) One outlier (i.e., 31.8 µg/L) from 08/18/09 omitted.

Arsenic. Figure 4-15 contains three bar charts showing concentrations of particulate arsenic, soluble As(III), and soluble As(V) at the IN, AP, TA, and TB sampling locations. Speciation results at the TT location were not presented in the figure because they were very similar to those at the TA and TB locations. Speciation results at the IN location from the April 1, 2008 sampling event contained outliers and were omitted from Figure 4-15.

Total arsenic concentrations in raw water ranged from 29.0 to 38.6 µg/L and averaged 34.9 µg/L. Soluble As(V) was the predominating species, ranging from 33.3 to 36.4 µg/L and averaging 32.4 µg/L. Soluble As(III) also was present in source water, although very low, ranging from 0.1 to 1.0 µg/L and averaging 0.5 µg/L. Particulate arsenic concentrations also were low, ranging from 0.3 to 2.0 µg/L and averaging 1.2 µg/L. The arsenic concentrations measured were consistent with those collected previously during source water sampling (Table 4-1).

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

Parameter	Sampling Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as CaCO ₃)	IN	mg/L	24	144	156	150	4.1
	AP	mg/L	24	140	156	148	3.9
	TA	mg/L	24	134	201	155	15.1
	TB	mg/L	24	139	196	159	15.9
	TT	mg/L	4	146	192	174	21.4
Fluoride	IN	mg/L	6	1.1	1.2	1.1	0.0
	AP	mg/L	6	1.0	1.4	1.1	0.2
	TA	mg/L	6	1.0	1.2	1.1	0.1
	TB	mg/L	6	1.0	1.2	1.1	0.1
	TT	mg/L	4	1.0	1.1	1.0	0.1
Sulfate	IN	mg/L	6	22.2	24.8	23.8	1.0
	AP	mg/L	6	21.6	24.6	23.6	1.1
	TA	mg/L	6	21.4	27.1	23.7	2.2
	TB	mg/L	6	20.5	28.1	24.0	2.9
	TT	mg/L	4	21.3	23.8	22.4	1.1
Nitrate (as N)	IN	mg/L	6	1.2	1.3	1.2	0.0
	AP	mg/L	6	1.1	1.8	1.3	0.2
	TA	mg/L	6	1.2	1.2	1.2	0.0
	TB	mg/L	6	1.2	1.2	1.2	0.0
	TT	mg/L	4	1.2	1.2	1.2	0.0
P (as P)	IN	µg/L	24	<10	<10	<10	0.0
	AP	µg/L	24	<10	<10	<10	0.0
	TA	µg/L	24	<10	<10	<10	0.0
	TB	µg/L	24	<10	<10	<10	0.0
	TT	µg/L	4	<10	<10	<10	0.0
Silica (as SiO ₂)	IN	mg/L	23	24.4	27.8	26.2	1.1
	AP	mg/L	23	24.5	27.5	26.2	0.9
	TA	mg/L	23	18.7	32.6	26.9	3.0
	TB	mg/L	23	20.7	33.8	27.3	2.9
	TT	mg/L	4	26.6	34.7	31.5	3.8
Turbidity	IN	NTU	24	0.1	1.9	0.5	0.5
	AP	NTU	24	0.1	2.2	0.6	0.7
	TA	NTU	24	<0.1	2.3	0.5	0.7
	TB	NTU	24	<0.1	2.0	0.5	0.6
	TT	NTU	4	<0.1	0.3	0.1	0.1
pH	IN	S.U.	20	7.8	8.4	8.0	0.2
	AP	S.U.	20	6.5	7.9	6.9	0.3
	TA	S.U.	20	6.4	7.5	6.9	0.3
	TB	S.U.	20	6.2	7.6	6.9	0.3
	TT	S.U.	3	6.6	7.1	6.9	0.3
Temperature	IN	°C	11 ^(a)	26.2	34.1	30.6	3.0
	AP	°C	11 ^(a)	27.4	33.7	31.8	2.0
	TA	°C	11 ^(b)	26.8	34.0	31.9	2.3
	TB	°C	11 ^(b)	27.2	34.4	32.3	2.1
	TT	°C	2 ^(c)	30.6	34.7	32.7	2.9

Table 4-7. Summary of Water Quality Parameter Sampling Results (Continued)

Parameter	Sampling Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Dissolved Oxygen (DO)	IN	mg/L	1	3.7	3.7	-	-
	AP	mg/L	1	3.1	3.1	-	-
	TA	mg/L	1	3.0	3.0	-	-
	TB	mg/L	1	3.4	3.4	-	-
	TT	mg/L	0	-	-	-	-
Oxidation-Reduction Potential (ORP)	IN	mV	2	225	243	234	12.3
	AP	mV	2	287	303	295	11.5
	TA	mV	2	289	321	305	23.1
	TB	mV	2	320	351	336	21.5
	TT	mV	0	-	-	-	-
Free Chlorine (as Cl ₂)	IN	mg/L	9	0.0	0.1	0.0	0.0
	AP	mg/L	15	0.1	2.2	1.5	0.5
	TA	mg/L	15	0.0	2.1	1.5	0.5
	TB	mg/L	15	0.0	2.2	1.4	0.6
	TT	mg/L	3	1.1	2.1	1.7	0.5
Total Chlorine (as Cl ₂)	IN	mg/L	9	0.0	0.1	0.0	0.0
	AP	mg/L	16	0.0	2.1	1.4	0.6
	TA	mg/L	15	0.0	2.1	1.5	0.5
	TB	mg/L	15	0.0	2.2	1.4	0.5
	TT	mg/L	3	1.1	1.9	1.6	0.4
Total Hardness (as CaCO ₃)	IN	mg/L	7	29.7	47.3	37.5	5.7
	AP	mg/L	7	32.9	48.8	38.7	5.2
	TA	mg/L	7	33.4	94.5	52.2	28.6
	TB	mg/L	7	30.9	93.0	50.5	27.2
	TT	mg/L	4	37.5	86.7	61.0	25.8
Ca Hardness (as CaCO ₃)	IN	mg/L	7	21.3	36.2	27.4	4.9
	AP	mg/L	7	23.5	37.3	28.3	4.6
	TA	mg/L	7	23.2	67.8	37.3	20.6
	TB	mg/L	7	21.2	66.1	35.6	19.4
	TT	mg/L	4	27.2	60.0	42.5	17.5
Mg Hardness (as CaCO ₃)	IN	mg/L	7	8.4	11.1	10.1	1.0
	AP	mg/L	7	9.4	11.4	10.4	0.7
	TA	mg/L	7	9.2	27.4	14.8	8.1
	TB	mg/L	7	9.5	26.8	14.9	7.9
	TT	mg/L	4	10.3	26.7	18.5	8.4

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

- (a) Nine outliers all at 25.0°C on 05/28/08, 07/08/08, 10/07/08, 11/18/08, 12/16/08, 02/17/09, 04/15/09, 09/15/09, 01/19/10 omitted.
- (b) Eight outliers all at 25.0°C on 07/08/08, 10/07/08, 11/18/08, 12/16/08, 02/17/09, 04/15/09, 09/15/09, 01/19/10 omitted.
- (c) One outlier at 25.0°C on 10/07/08 omitted.

Because most arsenic was present as soluble As(V), oxidation with chlorine was not required. After chlorination, As(III) concentrations exhibited little change. Free and total chlorine residuals were monitored at the IN, AP, TA, TB, and TT locations to ensure that the target chlorine residual level was properly maintained for disinfection purposes. Measurements at the IN location were discontinued after the September 15, 2009 sampling event. Total chlorine levels at the AP location ranged from 0.0 to 2.1 mg/L (as Cl₂) and averaged 1.4 mg/L (as Cl₂); free chlorine levels ranged from 0.1 to 2.2 mg/L (as Cl₂) and averaged 1.5 mg/L (as Cl₂) (Table 4-7). The total and free chlorine measurements from

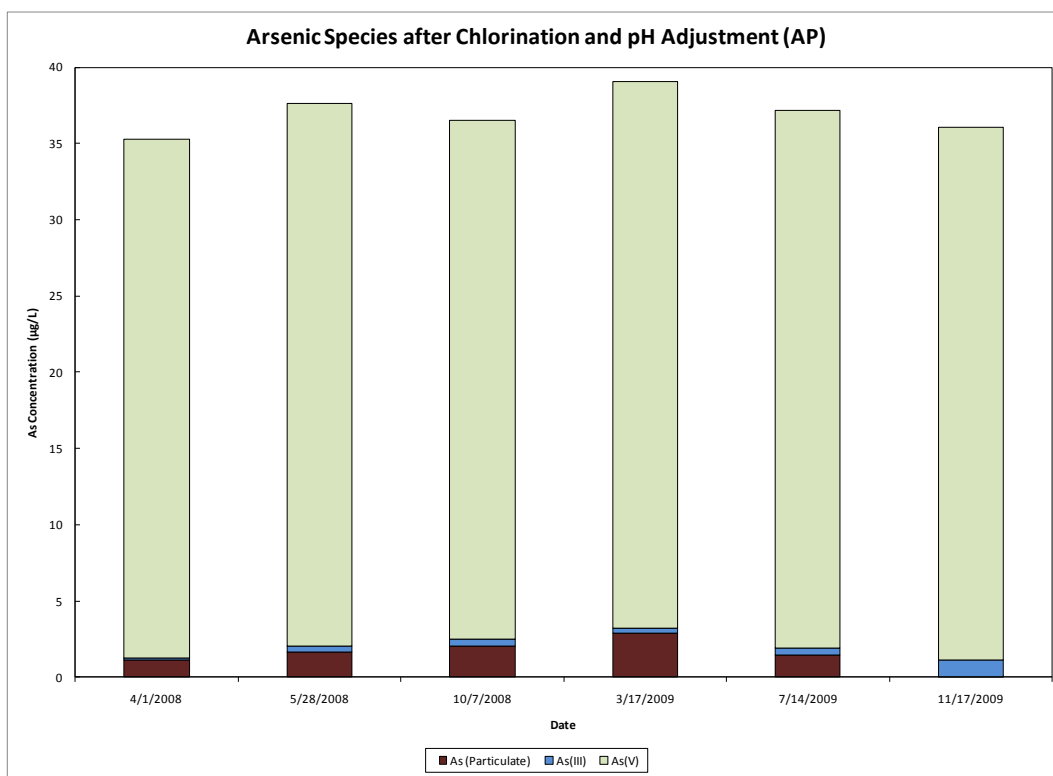
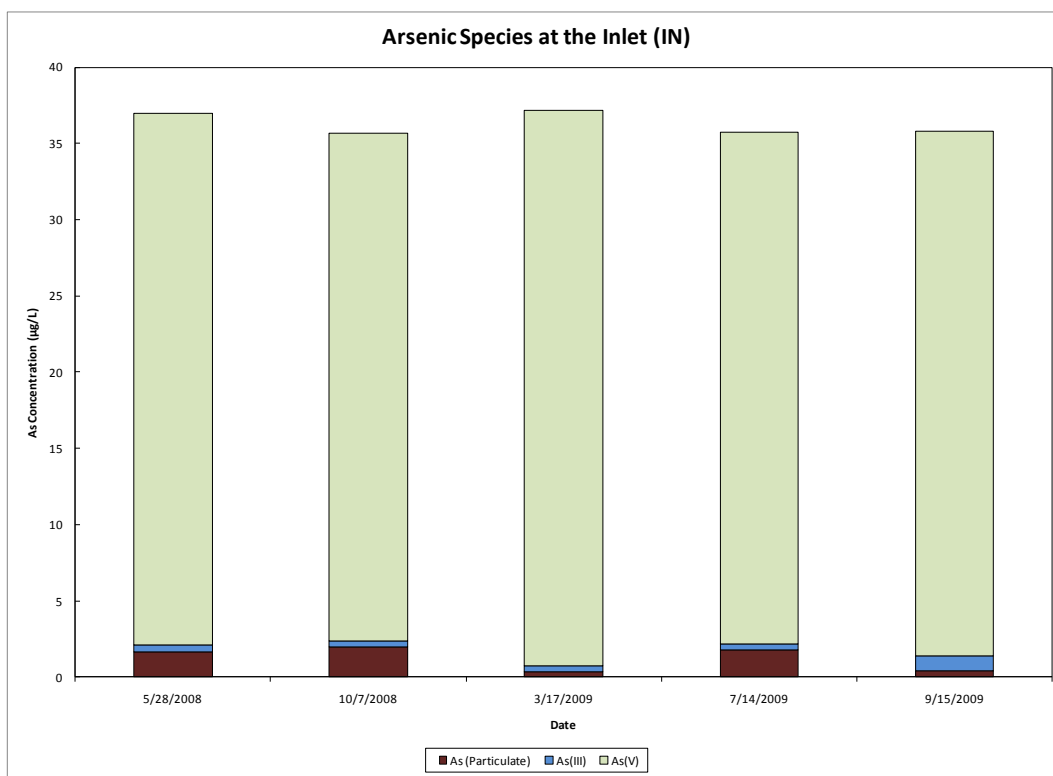


Figure 4-15. Concentrations of Various Arsenic Species at IN, AP, TA, and TB Sampling Locations

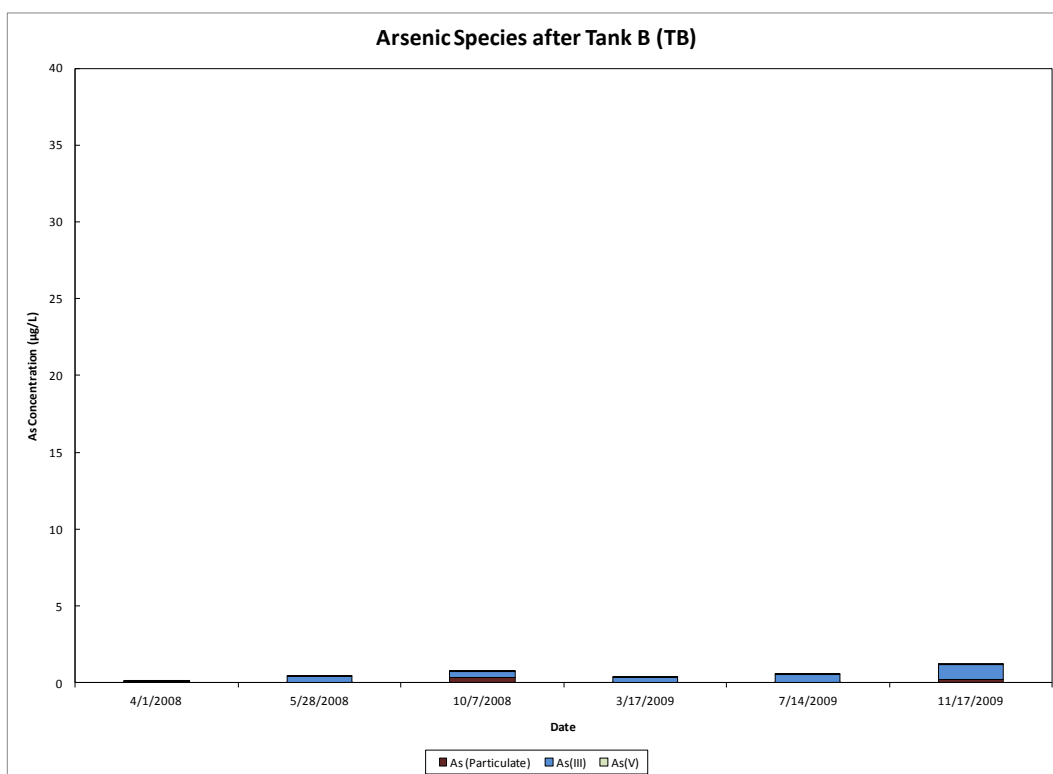
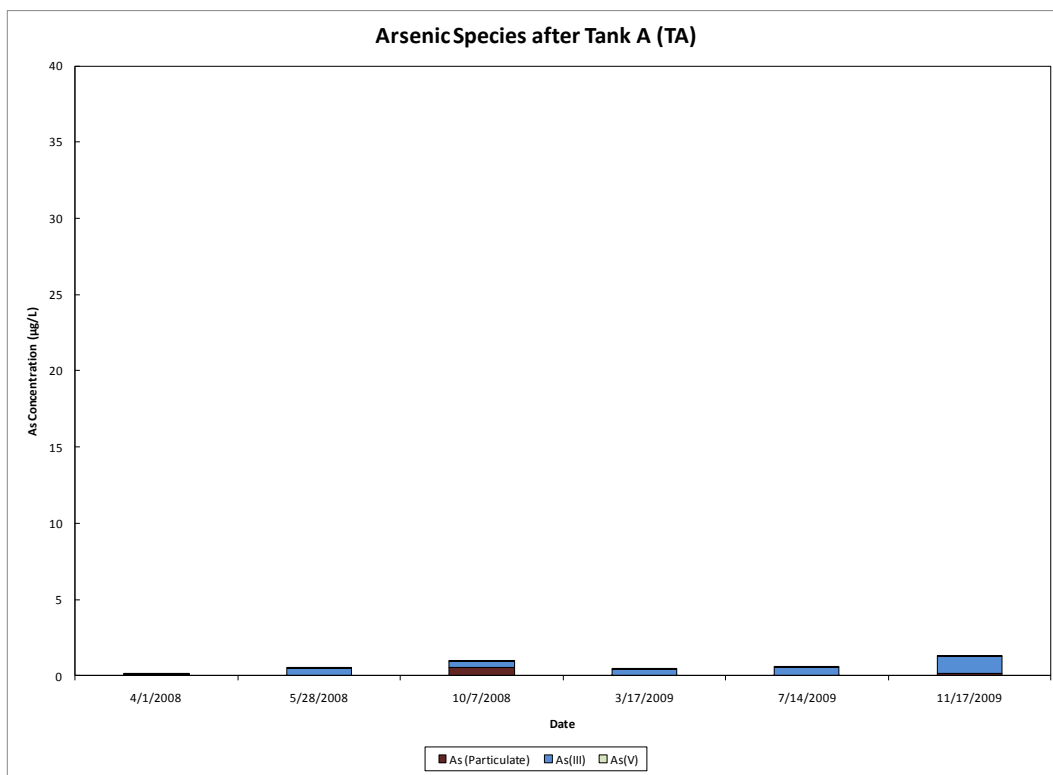


Figure 4-15. Concentrations of Various Arsenic Species at IN, AP, TA, and TB Sampling Locations (Continued)

July 30, 2008, were omitted from all sampling locations due to the uncharacteristically high levels measured. The total and free residual chlorine levels measured at the TA, TB, and TT locations were very similar to those at the AP location, indicating little or no chlorine demand through the AD-33 vessels.

As shown by the samples taken during the last sampling event on March 16, 2010, after treating approximately 41,000 BV of water, total arsenic concentrations following Vessels A and B were still as low as 0.6 and 0.4 µg/L, respectively. Based on the vendor's estimate, total arsenic breakthrough at 10 µg/L would occur at 51,000 BV (or 14,484,000 gal). Figure 4-16 presents total arsenic concentrations at the IN, AP, TA, and TB locations plotted against bed volumes.

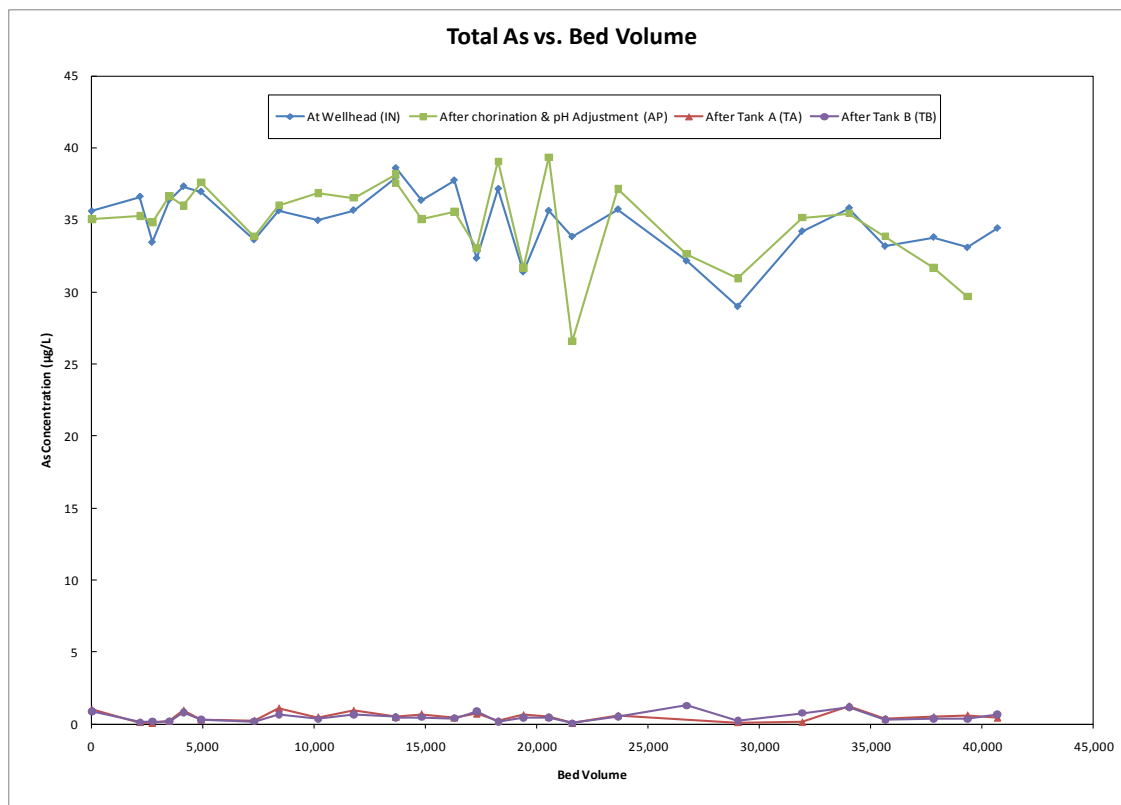


Figure 4-16. Total Arsenic Breakthrough Curves (1BV = 284 gal)

Iron and Manganese. Iron and manganese were analyzed through November 17, 2009. The average total iron concentration in raw water was less than the MDL of 25 µg/L (Table 4-6). Average total iron concentrations across the treatment train also were below the MDL. Total manganese levels in raw water were low, ranging from 0.1 to 2.8 µg/L and averaging 0.7 µg/L. Manganese existed primarily in the soluble form prior to chlorination, after which manganese existed mostly as particulate. Total manganese levels were reduced to an average of 0.3 and 0.1 µg/L following Vessels A and B, respectively.

Uranium and Vanadium. Uranium was detected in the initial source water samples collected by Battelle on December 7, 2004 (Table 4-1) and its levels were monitored through September 2, 2008. Total uranium concentrations in the raw water ranged from 7.0 to 8.3 µg/L and averaged 7.7 µg/L. Total uranium levels were reduced to below the MDL of 0.1 µg/L following each adsorption vessel. Since uranium levels in the raw water were always below their MCL of 30 µg/L and levels in the treated water

were continually below the MDL, uranium analysis was discontinued in favor of vanadium analysis. Total vanadium levels in raw ranged from 23.5 to 38.1 µg/L and averaged 32.2 µg/L. Total vanadium concentrations averaged 1.6 and 1.4 µg/L after Vessels A and B, respectively. Currently, there is no MCL for vanadium.

Competing Anions. Phosphorus and silica, which might influence arsenic adsorption, were measured at the five sampling locations across the treatment train through November 17, 2009, when the list of analytes was reduced to only include arsenic and vanadium. Phosphorus was below its MDL of 10 µg/L for all sampling events during the evaluation period. Silica concentrations in the raw water ranged from 24.4 to 27.8 mg/L and averaged 26.2 mg/L. Little silica removal by the adsorption vessels was observed during the study.

Other Water Quality Parameters. As shown in Table 4-7, pH values of the raw water varied from 7.8 to 8.4 and averaged 8.0. pH values following CO₂ injection for pH adjustment at the AP location varied from 6.5 to 7.9 and averaged 6.9, which is just below the target value of 7.0. Figure 4-17 shows the pH of the well water before and after pH adjustment by CO₂ as measured by the operator with a field pH probe during sampling events. For comparison, pH readings recorded from the inline pH probe, which was connected to the pH controller on the control panel, were plotted alongside the measurements made by the operator. pH values of the adjusted water, as measured by the inline probe, ranged from 5.5 to 8.5 S.U. and averaged 7.1 S.U., which is somewhat higher than that measured with a field pH probe. The discrepancies observed might have been caused by instrumentation errors, being that the field pH probe used by the operator was calibrated before each use and that the inline pH probe connected to the pH controller was calibrated twice during the entire study period. Nonetheless, the higher pH values measured with the field pH probe were to the contrary of those observed at two other arsenic demonstration sites where CO₂ also was used for pH adjustments (Cumming et al., 2009; Williams et al., 2010). Lower pH values measured at these sites were thought to be caused by CO₂ degassing during sample collection and analysis.

Alkalinity, reported as CaCO₃, ranged from 144 to 156 mg/L and averaged 150 mg/L in raw water. As expected, alkalinity after pH adjustment and adsorption remained relatively unchanged at 148 to 159 mg/L (on average), since CO₂, instead of mineral acids, was used for pH adjustment.

Hardness. The treatment plant water samples were analyzed for hardness only on speciation events. Total hardness, reported as CaCO₃, ranged from 29.7 to 47.3 mg/L and averaged 37.5 mg/L in raw water. Total hardness existed primarily as calcium hardness. Total hardness levels remained relatively unchanged from IN to the AP sampling location. On March 17, 2009 and July 14, 2009, significantly elevated total hardness levels (approximately 2-3 times the average concentration at IN and AP) were observed at TA, TB, and TT for unknown reasons. Slightly elevated total hardness levels at TA, TB, and TT also were also seen on November 17, 2009. Due to the elevated levels on the aforementioned sampling dates, the average total hardness increased to 52.2, 50.5, and 61.0 mg/L following Tank A, Tank B, and TT, respectively. The hardness levels at TA, TB, and TT from the remaining four sampling events were somewhat lower or similar to the concentrations at IN and AP.

Sulfate concentrations in raw water ranged from 22.2 to 24.8 mg/L and averaged 23.8 mg/L. After pH adjustment and adsorption, sulfate levels remained unchanged at 23.6 to 24.0 mg/L (on average). Fluoride results ranged from 1.0 to 1.2 mg/L and averaged 1.1 mg/L following both treatment vessels. The results indicated that the adsorptive media did not affect the amount of fluoride in water after treatment.

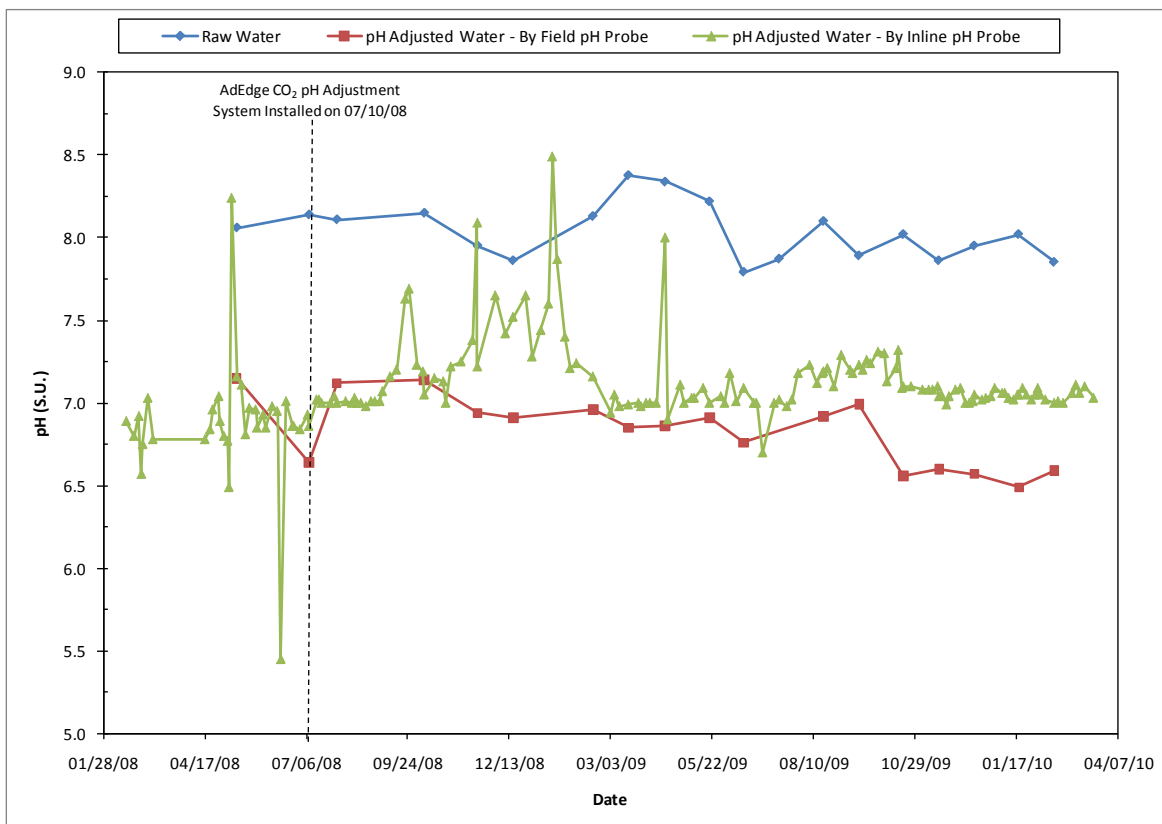


Figure 4-17. pH Values Before and After Adjustment

Due to difficulties experienced by the operator with the equipment, DO was measured only once while ORP was measured twice. On May 28, 2008, both measurements were discontinued. DO levels ranged from 3.0 to 3.7 mg/L throughout the treatment train. ORP readings averaged 234 mV in raw water, but increased to an average of 295 mV after chlorination.

4.5.2 Backwash Wastewater Sampling. Backwash was not performed during the performance evaluation study.

4.5.3 Distribution System Water Sampling. Prior to the installation/operation of the treatment system, four baseline distribution system water samples were collected from three residences, previously used for LCR sampling, on October 19, 2005, November 22, 2005, December 14, 2005, and January 24, 2006. Following startup of the treatment system, distribution system water sampling continued on a quarterly basis at the same three locations, with samples collected from July 2008 through October 2009. Table 4-8 summarizes the results of the distribution system sampling.

The most noticeable change in the distribution system samples since the system began operation was a decrease in arsenic concentration. Baseline arsenic concentrations averaged 35.6, 37.3, and 36.6 $\mu\text{g/L}$ for the first draw samples at the DS1, DS2, and DS3 sampling locations, respectively. After the performance evaluation study began, arsenic concentrations at DS1, DS2, and DS3 averaged 0.5, 1.5, and 0.7 $\mu\text{g/L}$, respectively. Although arsenic concentrations in the distribution system were low, there were three sampling events (i.e., July 8, 2008, April 15, 2009, and October 20, 2009) when the arsenic levels in the distribution water were higher than those in the system effluent. It is surmised that some redissolution

Table 4-8. Distribution System Sampling Results

Sampling Event		DS1								DS2								DS3							
		Tautolo #0020-409-52600								Saraficio #0020-409-51200								Johnson #0020-409-50200							
		LCR								LCR								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	µg/L	hrs	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
BL1	10/19/05	7.0	8.1	158	30.6	<25	1.5	<0.1	36.6	8.9	7.9	158	31.7	<25	2.3	<0.1	4.3	8.2	7.9	158	30.4	<25	1.9	0.1	81.8
BL2	11/22/05 ^(a)	13.3	8.0	154	36.5	<25	1.3	0.1	22.2	12.5	8.1	145	39.5	<25	1.1	0.1	12.8	8.0	8.1	150	40.3	<25	0.9	0.2	1.6
BL3	12/14/05	NA	8.3	154	34.2	<25	0.9	<0.1	9.0	NA	8.2	150	36.3	<25	2.0	0.3	4.0	NA	8.2	145	34.2	<25	0.8	<0.1	10.6
BL4	01/24/06	10.3	8.2	154	41.0	<25	0.6	<0.1	8.2	8.0	8.1	154	41.6	<25	0.3	<0.1	9.1	7.0	8.3	154	41.3	<25	0.1	<0.1	1.2
1	07/08/08	7.2	7.0	163	1.2	<25	1.1	0.3	260	9.0	7.0	160	1.4	<25	0.7	0.7	220	9.5	6.8	147	0.5	<25	0.4	2.9	283
2	10/16/08 ^(b)	NA	NA	NA	NA	NA	NA	NA	NA	8.3	7.3	157	0.5	<25	0.2	0.5	166	7.0	7.2	155	0.4	<25	0.2	1.8	39.5
3	01/20/09	9.0	8.2	142	0.3	<25	<0.1	0.7	34	7.5	7.5	158	0.4	<25	<0.1	0.3	156	7.0	8.0	158	0.6	<25	0.2	0.5	138
4	04/15/09 ^(c)	9.5	7.0	152	0.3	<25	0.2	2.4	99.6	7.8	7.1	161	4.0	<25	0.2	0.4	145	NA	NA	NA	NA	NA	NA	NA	NA
5	07/14/09 ^(d)	7.3	6.8	158	0.2	<25	0.1	2.0	74.8	NA	NA	NA	NA	NA	NA	NA	NA	7.0	6.8	162	0.5	<25	<0.1	1.8	124
6	10/20/09 ^(e)	NA	NA	NA	NA	NA	NA	NA	NA	7.3	7.5	148	1.3	<25	0.7	0.5	169	7.0	7.3	154	1.3	<25	0.5	1.1	78.2

(a) DS2 sampled on 021/21/05.

(b) DS1 not available for sampling on 10/16/08.

(c) DS3 not available for sampling on 04/15/09.

(d) DS2 not available for sampling on 07/14/09.

(e) DS1 not available for sampling on 10/20/09.

BL = baseline sampling; NA = not available.

Lead action level = 15 µg/L; Copper action level = 1,300 µg/L

Alkalinity measured in mg/L as CaCO₃.

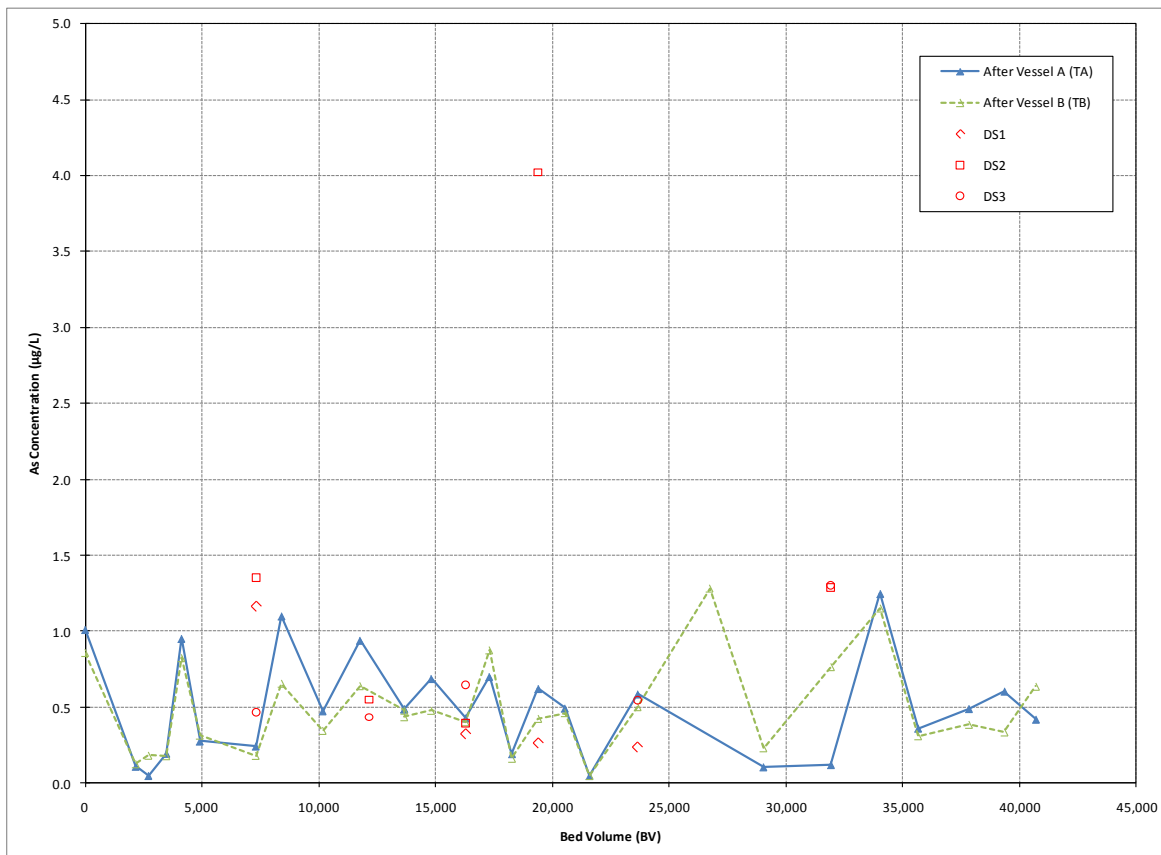


Figure 4-18. Comparison of Arsenic Concentrations in System Effluent and Distribution System

and/or resuspension of arsenic particles might have occurred in the distribution system. Figure 4-18 shows arsenic levels in the system effluent and distribution system plotted against BV.

Lead concentrations ranged from less than the detection limit of 0.1 to 2.9 µg/L, with none of the samples exceeding the action level of 15 µg/L. Copper concentrations ranged from 34.1 to 283 µg/L, with no samples exceeding the 1,300 µg/L action level. Measured pH values ranged from 6.8 to 8.2 and averaged 7.2, which were 0.3 units higher than the average pH value immediately after the adsorption vessels. Higher pH values in the distribution system might be due to CO₂ degassing. Compared to an average value of 8.1 before the treatment system became operational, the lowered pH values appeared to have some effects on the lead and copper concentrations in the distribution system. Lead and copper concentrations were observed to increase slightly after the system was put into service. Before the system was put into service, lead levels averaged <0.1, 0.1, and 0.1 µg/L at DS1, DS2, and DS3, respectively, while copper levels averaged 19.0, 7.6, and 23.8 µg/L, respectively. After the system was put into service, lead levels averaged 1.4, 0.5, and 1.6 µg/L, respectively, and copper levels averaged 117, 171, and 133 µg/L, respectively.

Alkalinity levels exhibited no change, with concentrations ranging from 142 to 163 mg/L (as CaCO₃). Total iron concentrations were always less than the MDL of 25 µg/L for all distribution sampling events, including baseline sampling. Total Mn concentrations in the distribution system samples were typically low, ranging from <0.1 to 1.1 µg/L.

4.6 System Cost

System cost is evaluated based on the capital cost per gpm (or gpd) of the design capacity and the O&M cost per 1,000 gal of water treated. The capital cost includes the cost for equipment, site engineering, and installation. The O&M cost includes the cost for media replacement and disposal, electrical power use, and labor.

4.6.1 Capital Cost. The capital investment for equipment, site engineering, and installation of the treatment system was \$115,306 (see Table 4-9). The equipment cost was \$86,018 (or 75% of the total capital investment), which included \$48,715 for the skid-mounted unit, \$18,402 for the CO₂ pH control system, \$13,861 for the AD-33 media (\$365/ft³ or \$10.42/lb to fill two vessels), \$992 for the gravel underbedding, \$1,339 for additional sample taps and totalizer/meters, and \$2,709 for shipping. The site engineering cost was \$12,897, or 11% of the total capital investment. Because an engineering plan or a permit submittal package was not required for the Covered Wells site, the engineering cost represents a small fraction of total capital cost.

The installation cost included the equipment and labor to unload and install the skid-mounted unit, perform piping tie-ins and electrical work, load and backwash the media, and perform system shakedown and startup. The installation cost was \$16,391, or 14% of the total capital investment.

Table 4-9. Capital Investment Cost for APU Arsenic Adsorption System

Description	Quantity	Cost	% of Capital Investment
<i>Equipment Cost</i>			
APU Skid-Mounted System	1	\$48,715	—
CO ₂ pH Control System	1	\$18,402	—
AD-33 Media	38 ft ³	\$13,861	—
Gravel Underbedding	—	\$992	—
Sample Taps & Totalizer/Meters ^(a)	—	\$1,339	—
Shipping	—	\$2,709	—
Equipment Total	—	\$86,018	75
<i>Engineering Cost</i>			
Vendor Labor	73 hr	\$6,967	—
Vendor Travel	2 day	\$1,008	—
Subcontractor Labor	—	\$4,594	—
Subcontractor Travel	—	\$329	—
Engineering Total	—	\$12,897	11
<i>Installation Cost</i>			
Vendor Labor	60 hr	\$7,256	—
Subcontractor Labor	—	\$9,135	—
Installation Total	—	\$16,391	14
Total Capital Investment	—	\$115,306	100

(a) Additional taps and totalizer/meters for study purposes.

The total capital cost of \$115,306 was normalized to the system's design capacity of 63 gpm (90,720 gpd), which resulted in \$1,830/gpm of design capacity (\$1.27/gpd). The capital cost also was converted to an annualized cost of \$10,884/yr using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-year return period. Assuming that the system operated 24 hours a day, 7 days a

week at the system design flowrate of 63 gpm to produce 33,112,800 gal of water per year, the unit capital cost would be \$0.33/1,000 gal. Because the system operated only 4.38 hr/day at approximately 60 gpm on average (see Table 4-5), producing an estimated 5,755,320 gal of water annually, the unit capital cost increased to \$1.89/1,000 gal at this reduced rate of use.

4.6.2 Operation and Maintenance Cost. The O&M cost included the cost for items such as media replacement and disposal, CO₂ usage, electricity consumption, and labor (Table 4-10). Although media replacement did not occur during the performance evaluation study, the media replacement cost would have represented the majority of the O&M cost and was estimated to be \$18,405 to change out the media in both vessels. This media changeout cost would include the cost for media, the gravel underbedding, freight, labor, travel, spent media analysis, and media disposal fee. This cost was used to estimate the media replacement cost per 1,000 gal of water treated as a function of the projected media run length to the 10 µg/L arsenic breakthrough (Figure 4-19).

The chemical cost associated with system operation included the cost for NaOCl for prechlorination and CO₂ gas for pH adjustment. NaOCl had already been used at the site prior to the installation of the APU unit for disinfection purposes. The presence of the APU system did not affect the use rate of the NaOCl solution. Therefore, the incremental chemical cost for chlorine was negligible. During the performance evaluation period the 50-lb CO₂ cylinders were replaced a total of 91 times, or once every eight days. Each changeout cost \$38.74, which included the replacement and delivery charges. The CO₂ cost for the study period was \$3,525 or \$0.30/1,000 gal of water treated.

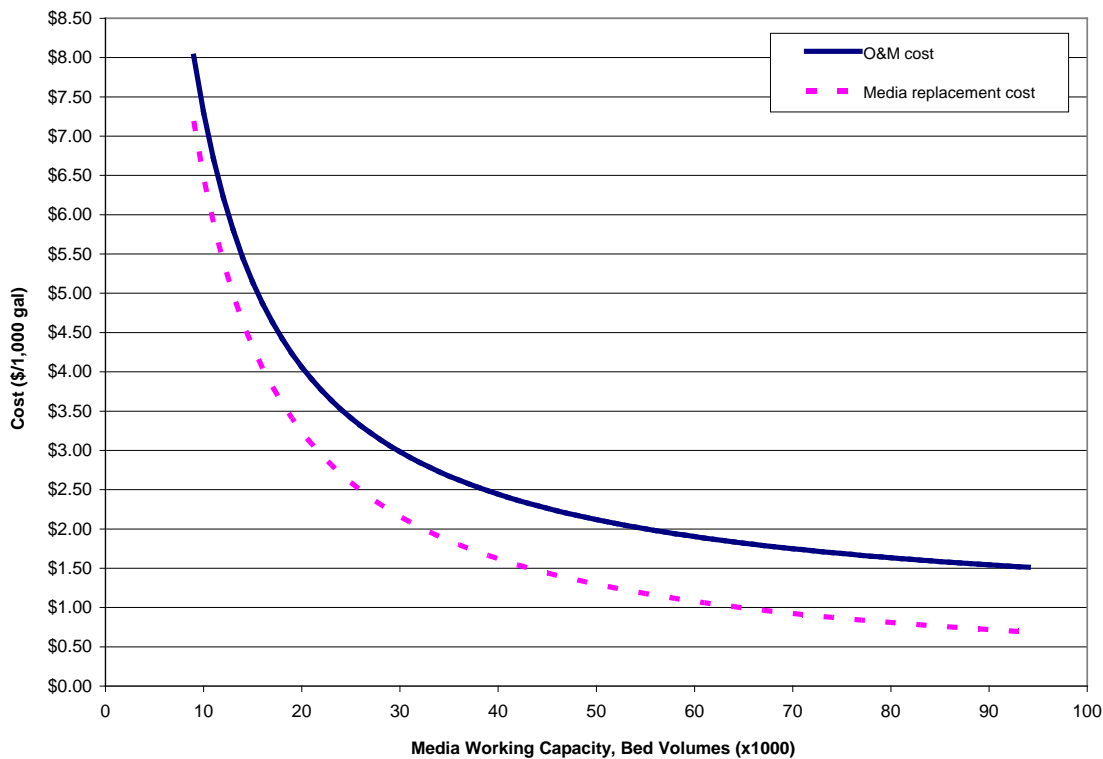
Table 4-10. Operation and Maintenance Cost for APU Arsenic Adsorption System

Cost Category	Value	Assumptions
Estimated Volume Processed (gal)	11,686,000	During 765-day study period; equivalent to 5,576,000 gal annually
Media Replacement and Disposal Cost		
Media Replacement (\$)	\$13,861	\$365/ft ³ for 38 ft ³
Labor, Travel, Freight, & Disposal (\$)	\$4,544	
Media Replacement and Disposal (\$/1,000 gal)	See Figure 4-19	Based upon media run length at 10-µg/L arsenic breakthrough
CO₂ Cost		
CO ₂ Cost (\$)	\$3,525	Based on cost of CO ₂ cylinders (50-lb) for pH adjustment
Unit CO ₂ Cost (\$/1,000 gal)	\$0.30	
Electricity Cost		
Electricity (\$/1,000 gal)	\$0.05	Includes power used by the booster pumps
Labor Cost		
Average Weekly Labor (hr)	2.3	1.5 hr/visit, 1.5 visit/week (on average)
Labor through Study (hr)	251	109 week through study
Labor Cost (\$)	\$5,522	Labor rate = \$22.00/hr
Unit Labor Cost (\$/1,000 gal)	\$0.47	
Total O&M Cost/1,000 gal	See Figure 4-19	Media replacement cost (based upon media run length at 10-µg/L arsenic breakthrough) + \$0.30 (CO ₂ cost) + \$0.05 (electrical cost)+ \$0.47 (labor cost)

Comparison of electrical bills supplied by TOUA prior to system installation and since startup indicated an additional 3,304 kWh per year was required to run the system. The cost of the additional electricity

was \$299.75, which included the power necessary to run the three booster pumps. The electrical cost associated with the operation of the system was calculated to be \$0.05/1,000 gal of water treated.

Under normal operating conditions, routine labor activities to operate and maintain the system consumed 1.5 hr/day, 1 to 2 days per week, or 2.3 hr/week (on average). The labor cost incurred during the performance evaluation study was \$5,522 or \$0.47/1,000 gal of water treated. This estimation assumed that maintenance and operational procedures were consistently performed through the completion of the performance evaluation study.



Note: One bed volume equals 38 ft³ (284 gal)

Figure 4-19. Media Replacement and Other Operation and Maintenance Cost

5.0 REFERENCES

- Battelle. 2004. *Revised Quality Assurance Project Plan for Evaluation of Arsenic Removal Technology*. Prepared under Contract No. 68-C-00-185, Task Order No. 0029, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Battelle. 2006. *Final System Performance Evaluation Study Plan: U.S. EPA Demonstration of Arsenic Removal Technology at Covered Wells, Tohono O'odham Nation, Arizona*. Prepared under Contract No. 68-C-00-185, Task Order No. 0029 for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Chen, A.S.C., L. Wang, J.L. Oxenham, and W.E. Condit. 2004. *Capital Costs of Arsenic Removal Technologies: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1*. EPA/600/R-04/201. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Edwards, M., S. Patel, L. McNeill, H. Chen, M. Frey, A.D. Eaton, R.C. Antweiler, and H.E. Taylor. 1998. "Considerations in As Analysis and Speciation." *J. AWWA*, 90(3):103-113.
- EPA. 2001. National Primary Drinking Water Regulations: Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring. *Fed. Register*, 40 CFR Parts 9, 141, and 142.
- EPA. 2002. *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems*. EPA/816/R-02/009. U.S. Environmental Protection Agency, Office of Water, Washington, DC.
- EPA. 2003. Minor Clarification of the National Primary Drinking Water Regulation for Arsenic. *Federal Register*, 40 CFR Part 141.
- Farley, D. 2004. *Preliminary Arsenic Feasibility Study: A Study to Evaluate and Recommend Options for Reducing Arsenic Levels in Drinking Water on the Tohono O'odham Nation, Indian Health Services, Sells, AZ*.
- Cumming, L.J., A.S.C. Chen, and L. Wang. 2009. *Arsenic Removal from Drinking Water by Adsorptive Media, U.S. EPA Demonstration Project at Rollinsford, NH, Final Performance Evaluation Report*. EPA/600/R-09/017. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Wang, L., W.E. Condit, and A.S.C. Chen. 2004. *Technology Selection and System Design: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1*. EPA/600/R-05/001. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Williams, S., A.S.C. Chen, and L. Wang. 2010. *Arsenic Removal from Drinking Water by Adsorptive Media, U.S. EPA Demonstration Project at Webb Consolidated Independent School District in Bruni, TX, Final Performance Evaluation Report*. EPA/600/R-10/040. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.

APPENDIX A

OPERATIONAL DATA

Table A-1. EPA Arsenic Demonstration Project at Covered Wells in Tohono O’odham Nation, AZ - Daily System Operation Log Sheet

Week No.	Date	Time	Well Running Well # 1 or 2	Well No. 1			Well No. 2			Instrument Panel								System Pressure (psi)		Pressure Differential for Vessel (psi)	
				Cum. Hours Well	Cum. Volume	Average Flowrate	Cum. Hours Well	Cum. Volume	Average Flowrate	Vessel A				Vessel B							
										Inst. Flowrate	Incremental Volume	Bed Volume	Average Flowrate	Inst. Flowrate	Incremental Volume	Bed Volume	Average Flowrate	Inlet	Outlet	A	B
1	02/13/08	NA	NA	0.0	NA	NA	0.0	NA	NA	NA	0	0	0.0	NA	0	0	0.0	NA	NA	NA	NA
2	02/20/08	13:31	NR	0.0	NA	NA	0.0	NA	NA	NA	35,920	253	NA	NA	35,098	247	NA	NA	NA	NA	NA
	02/21/08	11:18	2	0.0	NA	NA	0.0	NA	NA	30.3	6,848	301	NA	28.4	6,837	295	NA	NA	NA	1.3	2.0
	02/22/08	12:47	NR	0.0	NA	NA	0.0	NA	NA	NA	7,046	351	NA	NA	6,991	345	NA	NA	NA	NA	NA
3	02/25/08	15:00	2	0.0	NA	NA	0.0	NA	NA	30.0	13,444	445	NA	31.2	13,103	437	NA	NA	NA	0.0	1.5
	02/27/08	10:00	NR	0.0	NA	NA	0.0	NA	NA	NA	11,926	529	NA	NA	11,542	518	NA	NA	NA	NA	NA
	02/28/08	13:00	2	0.0	NA	NA	0.0	NA	NA	29.3	9,798	598	NA	31.0	9,584	586	NA	NA	NA	0.0	0.0
4	03/03/08	15:35	2	0.0	NA	NA	0.0	NA	NA	27.2	24,162	769	NA	31.2	23,474	751	NA	NA	NA	NA	NA
	03/07/08	14:32	2	0.0	NA	NA	0.0	NA	NA	29.3	31,496	990	NA	31.2	30,514	960	NA	NA	NA	NA	NA
5	03/10/08	13:53	NR	0.0	NA	NA	0.0	NA	NA	NA	20,122	1,132	NA	NA	19,721	1,105	NA	NA	NA	NA	NA
	03/12/08	14:20	2	0.0	NA	NA	0.0	NA	NA	30.3	21,931	1,287	NA	31.6	21,707	1,258	NA	9	NA	5.0	5.0
	03/13/08	10:31	NR	0.0	NA	NA	0.0	NA	NA	NA	1,577	1,298	NA	NA	1,532	1,268	NA	NA	NA	NA	NA
	03/14/08	11:02	NR	0.0	NA	NA	0.0	NA	NA	NA	6,453	1,343	NA	NA	6,389	1,313	NA	NA	NA	NA	NA
6	03/17/08	9:45	NR	0.0	NA	NA	0.0	NA	NA	NA	20,274	1,486	NA	NA	19,947	1,454	NA	NA	NA	NA	NA
	03/18/08	10:22	NR	0.0	NA	NA	0.0	NA	NA	NA	6,978	1,535	NA	NA	6,937	1,503	NA	NA	NA	NA	NA
	03/19/08	9:42	NR	0.0	NA	NA	0.0	NA	NA	NA	2,354	1,552	NA	NA	3,296	1,526	NA	NA	NA	NA	NA
	03/20/08	14:38	1	0.0	NA	NA	0.0	NA	NA	36.4	8,636	1,612	NA	30.7	8,542	1,586	NA	NA	NA	NA	NA
7	03/24/08	10:15	NR	0.0	NA	NA	0.0	NA	NA	NA	26,196	1,797	NA	NA	26,082	1,770	NA	NA	NA	NA	NA
	03/27/08	13:05	1	0.0	NA	NA	0.0	NA	NA	NA	20,815	1,943	NA	NA	20,035	1,911	NA	NA	NA	NA	NA
8	03/31/08	9:26	NR	0.0	NA	NA	0.0	NA	NA	NA	26,914	2,133	NA	NA	25,972	2,094	NA	NA	NA	NA	NA
	04/01/08	10:25	2	0.0	NA	NA	0.0	NA	NA	29.3	7,248	2,184	NA	31.4	7,447	2,146	NA	NA	NA	3.0	5.0
	04/04/08	10:25	NR	0.0	NA	NA	0.0	NA	NA	NA	19,874	2,324	NA	NA	21,480	2,297	NA	NA	NA	NA	NA
9	04/07/08	9:03	NR	0.0	NA	NA	0.0	NA	NA	NA	17,185	2,445	NA	NA	13,841	2,395	NA	NA	NA	NA	NA
	04/11/08	11:36	NR	0.0	NA	NA	0.0	NA	NA	NA	26,330	2,630	NA	NA	26,146	2,579	NA	NA	NA	NA	NA
10	04/15/08	10:35	1	0.0	NA	NA	0.0	NA	NA	35.5	14,924	2,736	NA	31.6	14,579	2,682	NA	13	8	2.5	2.5
	04/17/08	15:27	1	0.0	1,320	NA	0.0	53,210	NA	32.3	27,467	2,929	NA	34.1	26,725	2,870	NA	13	9	2.5	4.0
11	04/21/08	10:58	2	0.0	25,070	NA	0.0	79,450	NA	30.2	25,444	3,108	NA	32.1	24,891	3,045	NA	12	8	2.5	2.5
	04/23/08	11:44	1	0.0	42,240	NA	0.0	91,490	NA	30.9	14,987	3,214	NA	32.9	14,352	3,146	NA	12	8	2.5	2.5
12	04/28/08	15:15	1	0.0	95,770	NA	0.0	115,180	NA	32.2	40,104	3,496	NA	32.7	40,351	3,430	NA	12	7	3.0	5.0
	04/29/08	10:15	2	0.0	98,990	NA	0.0	116,390	NA	31.6	2,090	3,511	NA	27.0	1,969	3,444	NA	9	9	2.5	2.0
	05/02/08	12:16	1	0.0	116,110	NA	0.0	140,540	NA	32.2	21,686	3,664	NA	34.4	20,637	3,590	NA	12	8	2.5	4.0
13	05/05/08	9:45	2	0.0	134,390	NA	0.0	157,300	NA	30.6	18,374	3,793	NA	30.5	17,761	3,715	NA	12	8	6.0	4.0
	05/06/08	15:02	1	0.0	134,520	NA	0.0	171,620	NA	31.2	8,137	3,850	NA	30.5	7,675	3,769	NA	12	8	7.0	4.0
	05/08/08	10:50	1	0.0	152,960	NA	0.0	180,000	NA	35.7	14,532	3,953	NA	34.7	14,117	3,868	NA	12	8	2.0	2.5
14	05/12/08	12:40	2	0.0	174,770	NA	0.0	219,380	NA	33.3	30,676	4,169	NA	31.5	29,496	4,076	NA	10	5	0.0	1.0
	05/16/08	14:20	1	0.0	196,040	NA	0.0	232,150	NA	31.4	17,365	4,291	NA	30.2	16,733	4,194	NA	9	4	1.0	2.5
15	05/19/08	14:36	2	0.0	227,840	NA	0.0	271,210	NA	31.9	35,648	4,542	NA	29.0	34,219	4,435	NA	8	4	2.5	3.0
	05/22/08	10:30	1	0.0	249,540	NA	0.0	282,290	NA	36.0	17,736	4,667	NA	31.0	17,177	4,556	NA	14	10	2.5	2.5
16	05/27/08	11:00	2	0.0	272,060	NA	0.0	315,300	NA	31.0	28,592	4,868	NA	30.8	27,256	4,748	NA	10	6	2.0	2.5
	05/28/08	13:05	1	0.0	277,550	NA	0.0	337,140	NA	33.9	14,025	4,967	NA	30.2	13,502	4,843	NA	11	7	2.0	5.0
17	06/02/08	9:04	1	0.0	325,240	NA	0.0	356,230	NA	33.1	34,344	5,209	NA	33.8	32,940	5,075	NA	12	8	2.0	5.0
	06/04/08	10:50	2	0.0	340,740	NA	0.0	375,030	NA	29.0	18,521	5,339	NA	30.4	17,689	5,199	NA	11	7	2.0	3.0
18	06/09/08	15:30	1	0.0	371,280	NA	0.0	427,630	NA	33.0	45,040	5,656	NA	31.0	43,622	5,506	NA	10	5	2.0	5.0
	06/13/08	11:52	2	0.0	402,610	NA	0.0	457,990	NA	27.3	28,971	5,860	NA	30.3	27,974	5,703	NA	10	5	2.0	0.0
19	06/16/08	14:00	2	0.0	421,540	NA	0.0	492,170	NA	30.0	27,549	6,055	NA	29.5	26,482	5,890	NA	15	5	2.0	2.0
	06/20/08	15:03	2	0.0	445,450	NA	0.0	535,650	NA	29.9	34,938	6,301	NA	28.4	33,558	6,126	NA	8	5	2.0	2.5
20	06/25/08	15:00	1	0.0	477,400	NA	0.0	593,160	NA	35.0	47,183	6,633	NA	31.0	45,585	6,447	NA	8	4	10.0	7.0
	06/26/08	12:20	2	0.0	480,920	NA	0.0	595,940	NA	31.0	2,081	6,647	NA	29.0	1,981	6,461	NA	9	6	9.5	2.0
21	07/01/08	13:53	2	0.0	510,040	NA	0.0	665,130	NA	30.7	49,946	6,999	NA	27.5	47,898	6,798	NA	9	6	5.0	2.5
22	07/07/08	12:20	2	0.0	556,950	NA	0.0	711,700	NA	28.1	48,692	7,342	NA	31.1	46,734	7,128	NA	5	3	4.0	2.5
	07/08/08	12:08	1	0.0	556,990	NA	0.0	729,330	NA	30.7	9,602	7,410	NA	29.9	9,275	7,193	NA	10	6	4.0	3.0
23	07/14/08	14:47	2	7.0	583,750	63.7	17.0	791,340	60.8	31.1	44,530	7,723	30.9	31.5	42,747	7,494	29.7	10	5	2.0	2.0
	07/16/08	16:00	1	9.8	594,780	65.7	22.3	810,290	59.6	52.8	16,296	7,838	33.5	54.2	15,634	7,604	32.2	NA	NA	9.0	8.0
	07/18/08	11:45	2	10.9	598,910	62.6	25.2	820,990	61.5	30.1	7,221	7,889	30.1	31.3	6,933	7,653	28.9	9	5	9.0	2.5
24	07/25/08	11:50	1	17.5	624,380	64.3	44.5	891,650	61.0	31.4	49,507	8,238	31.9	30.9	47,550	7,988	30.6	10	8	2.5	2.5
25	07/28/08	11:10	2	20.0	633,730	62.3	52.7	921,860	61.4	27.7	19,887	8,378	31.0	29.5	19,090	8,122	29.7	10	8	0.0	2.0
	07/30/08	NA	2	24.9	653,050	65.7	59.9	947,730	59.9	29.0	22,701	8,537	31.3	28.2	21,743	8,275	29.9	9	5	1.0	2.5
26	08/06/08	9:42	1	32.3	681,710	64.5	83.0	1,032,480	61.1	34.7	57,903	8,945	31.6	33.6	55,557	8,667	30.4	12	8	2.0	2.5
27	08/11/08	14:35	2	36.2	696,520	63.3	98.9	1,090,530	60.8	28.4	36,954	9,205	31.1	27.6	35,317	8,915	29.7	9	5	0.0	1.0
	08/13/08	16:00	2	38.5	704,490	57.8	104.2	1,109,990	61.2	27.8	14,360	9,307									

Table A-1. EPA Arsenic Demonstration Project at Covered Wells in Tohono O’odham Nation, AZ - Daily System Operation Log Sheet

Week No.	Date	Time	Well Running Well # 1 or 2	Well No. 1			Well No. 2			Instrument Panel				System Pressure (psi)		Pressure Differential for Vessel (psi)					
				Cum. Hours Well	Cum. Volume	Average Flowrate	Cum. Hours Well	Cum. Volume	Average Flowrate	Vessel A			Vessel B								
										Inst. Flowrate	Incremental Volume	Bed Volume	Average Flowrate	Inst. Flowrate	Incremental Volume	Bed Volume	Average Flowrate				
																		gpm	gal	no.	gpm
Inlet	Outlet	A	B																		
29	08/26/08	14:25	1	70.4	823,450	60.6	122.2	1,175,720	60.2	32.5	24,423	9,971	31.1	30.8	23,374	9,648	29.7	11	5	2.0	2.5
30	08/29/08	12:15	NA	NA	NA	NA	NA	NA	NA	30.8	16,509	10,087	NA	33.3	15,784	9,759	NA	10	4	2.0	2.5
	09/02/08	10:32	2	85.2	877,370	60.7	135.7	1,224,150	59.8	27.9	35,387	10,336	20.8	29.7	33,755	9,997	19.9	10	4	1.0	2.0
	09/04/08	14:50	1	89.1	891,860	61.9	138.2	1,234,170	66.8	30.0	12,140	10,421	31.6	31.1	1,599	10,008	4.2	10	5	2.0	2.5
31	09/10/08	15:15	1	98.7	926,760	60.6	145.9	1,270,070	77.7	29.7	33,866	10,660	32.6	30.4	42,316	10,306	40.8	10	5	1.0	2.5
32	09/15/08	12:30	1	107.9	960,140	60.5	154.6	1,294,270	46.4	30.9	32,223	10,887	30.0	29.0	30,730	10,523	28.6	8	4	2.0	4.0
33	09/22/08	10:00	2	115.2	986,300	59.7	169.5	1,348,560	60.7	30.3	40,837	11,174	30.7	29.8	39,165	10,798	29.4	8	4	2.0	1.0
	09/25/08	10:15	1	119.5	1,001,820	60.2	176.3	1,373,380	60.8	31.2	19,800	11,314	29.7	29.4	19,053	10,932	28.6	8	4	2.0	2.5
34	10/01/08	12:40	1	137.7	1,068,040	60.6	183.7	1,400,240	60.5	30.6	48,473	11,655	31.6	27.1	46,620	11,261	30.4	10	5	2.0	2.5
35	10/06/08	10:47	1	144.5	1,092,500	60.0	191.8	1,429,890	61.0	31.2	27,743	11,851	31.0	31.8	26,853	11,450	30.0	12	8	1.5	2.5
	10/07/08	11:00	2	145.3	1,095,140	55.0	199.3	1,457,100	60.5	31.1	15,610	11,961	31.3	25.9	15,113	11,556	30.3	9	5	1.0	1.5
36	10/15/08	14:37	1	156.5	1,135,090	59.4	218.4	1,526,840	60.9	30.8	55,395	12,351	30.5	31.1	53,108	11,930	29.2	10	7	2.0	2.5
37	10/22/08	9:21	2	167.7	1,174,710	59.0	232.5	1,578,470	61.0	28.7	47,133	12,683	31.0	29.5	45,211	12,249	29.8	9	5	2.0	2.5
	10/24/08	15:00	2	171.6	1,188,610	59.4	236.9	1,594,630	61.2	31.3	15,048	12,789	30.2	29.3	14,406	12,350	28.9	9	4	0.0	2.0
38	10/28/08	13:49	2	179.6	1,216,850	58.8	241.5	1,611,410	60.8	29.7	23,294	12,953	30.8	29.8	22,420	12,508	29.7	8	4	2.0	2.0
39	11/05/08	15:24	1	193.3	1,265,620	59.3	257.4	1,671,140	62.6	31.2	55,911	13,346	31.5	31.4	53,758	12,887	30.3	18	5	1.0	2.5
40	11/14/08	9:27	2	210.1	1,326,340	60.2	268.5	1,710,270	58.8	29.9	50,220	13,700	30.0	26.6	48,191	13,226	28.8	8	4	0.0	0.0
41	11/18/08	9:46	1	215.6	1,345,370	57.7	278.0	1,744,730	60.5	29.5	28,308	13,899	31.5	28.7	27,190	13,417	30.2	10	7	1.0	1.0
43	12/02/08	14:31	1	235.8	1,417,120	59.2	307.5	1,852,180	60.7	30.6	91,524	14,544	30.7	29.2	88,256	14,039	29.6	10	5	1.0	2.5
44	12/10/08	13:53	1	247.3	1,458,240	59.6	320.1	1,898,280	61.0	30.1	43,984	14,854	30.4	29.3	42,417	14,338	29.3	11	5	1.5	2.5
45	12/16/08	9:33	1	256.6	1,490,860	58.5	327.0	1,923,440	60.8	31.9	30,197	15,066	31.1	29.8	29,858	14,548	30.7	10	5	1.0	2.5
46	12/26/08	14:50	2	274.4	1,555,830	60.8	339.2	1,966,920	59.4	30.7	55,153	15,455	30.6	28.6	52,687	14,919	29.3	10	5	1.5	2.5
47	12/31/08	9:15	2	286.6	1,593,650	51.7	347.2	2,001,500	72.0	31.7	36,984	15,715	30.5	30.1	35,870	15,172	29.6	10	5	1.0	2.0
48	01/07/09	14:05	1	295.1	1,631,470	74.2	358.0	2,036,100	53.4	32.1	37,088	15,976	32.0	31.7	35,667	15,423	30.8	10	6	2.5	3.0
48	01/13/09	11:35	1	304.0	1,661,860	56.9	371.9	2,087,330	61.4	30.6	41,441	16,268	30.3	31.8	39,888	15,704	29.2	14	10	2.5	2.5
	01/16/09	13:05	2	314.1	1,697,880	59.4	372.9	2,093,600	104.5	30.0	21,762	16,421	32.7	29.0	20,884	15,851	31.4	10	6	2.0	2.5
49	01/20/09	8:54	2	320.1	1,722,340	67.9	377.9	2,110,150	55.2	29.9	20,775	16,568	31.5	28.9	19,966	15,991	30.3	10	8	1.0	2.0
50	01/26/09	15:25	1	330.7	1,758,240	56.4	384.9	2,136,140	61.9	32.1	31,504	16,790	29.8	30.0	30,204	16,204	28.6	12	8	2.0	2.5
	01/30/09	16:00	1	335.8	1,776,480	59.6	390.9	2,159,670	65.4	27.5	21,074	16,938	31.6	33.6	20,152	16,346	30.3	8	4	5.0	3.0
51	02/04/09	12:15	1	344.7	1,809,160	61.2	397.9	2,182,040	53.3	31.0	27,922	17,135	29.3	30.1	27,729	16,541	29.1	10	6	2.0	3.0
53	02/17/09	8:48	2	361.6	1,868,860	58.9	416.9	2,251,340	60.8	29.1	65,833	17,598	30.6	27.1	63,277	16,987	29.4	13	10	0.5	2.0
55	03/03/09	11:05	1	382.0	1,945,620	62.7	436.9	2,324,110	60.6	29.7	71,654	18,103	29.6	28.6	69,244	17,475	28.6	8	4	2.0	2.0
	03/06/09	13:22	NA	NA	NA	NA	NA	NA	NA	30.7	12,635	18,192	NA	28.7	12,193	17,560	NA	8	5	2.5	2.5
56	03/10/09	11:12	1	389.3	1,959,750	32.3	446.9	2,364,550	67.4	29.8	20,407	18,336	19.7	26.7	19,594	17,698	18.9	11	8	2.0	2.5
57	03/17/09	9:35	2	399.5	1,992,250	53.1	NA	2,401,840	NA	30.7	36,613	18,593	NA	27.2	35,269	17,947	NA	11	7	2.0	2.5
58	03/25/09	15:30	1	409.5	2,025,260	55.0	472.9	2,456,970	35.3	31.0	44,624	18,908	20.7	32.0	43,068	18,250	19.9	10	4	2.5	2.5
	03/27/09	14:40	2	413.0	2,037,470	58.1	476.9	2,468,790	49.3	29.9	12,765	18,998	28.4	30.0	12,338	18,337	27.4	10	5	2.0	2.5
59	03/31/09	11:50	2	419.5	2,060,490	59.0	480.9	2,485,070	67.8	28.9	20,021	19,139	31.8	29.5	19,323	18,473	30.7	8	4	2.0	2.5
	04/03/09	12:40	1	424.5	2,076,940	54.8	484.9	NA	NA	31.6	16,516	19,255	30.6	29.0	16,048	18,586	29.7	8	5	2.5	3.0
60	04/08/09	9:44	NA	431.6	2,103,650	62.7	490.9	2,523,020	63.3	29.0	25,372	19,434	32.3	26.8	24,603	18,759	31.3	10	6	2.5	2.5
61	04/15/09	12:10	1	442.3	2,141,950	59.7	502.9	2,565,390	58.8	31.0	42,696	19,734	31.3	30.9	41,131	19,049	30.2	12	9	2.5	3.0
	04/17/09	14:50	2	446.3	2,155,780	57.6	505.9	2,576,260	60.4	31.0	10,886	19,811	25.9	29.6	10,561	19,123	25.1	8	4	2.5	3.0
63	04/27/09	15:45	1	465.6	2,223,690	58.6	518.9	2,622,890	59.8	29.4	59,584	20,230	30.7	29.0	57,560	19,529	29.7	10	6	2.5	3.0
	04/30/09	14:21	1	475.0	2,258,180	61.2	522.9	2,639,250	68.2	0.0	20,426	20,374	25.4	30.2	24,883	19,704	30.9	8	4	2.5	2.5
64	05/06/09	14:45	2	488.4	2,304,510	57.6	533.9	2,677,790	58.4	0.0	0	20,374	0.0	30.6	42,268	20,002	28.9	8	2	2.5	2.5
	05/08/09	14:42	2	496.3	2,319,690	32.0	538.9	2,682,570	15.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
65	05/15/09	14:00	1 & 2	510.6	2,386,040	77.3	548.9	2,732,020	82.4	0.0	0	20,374	0.0	29.8	66,530	20,470	45.6	8	4	2.5	2.5
66	05/20/09	11:42	1	522.1	2,4292,06																

Table A-1. EPA Arsenic Demonstration Project at Covered Wells in Tohono O’odham Nation, AZ - Daily System Operation Log Sheet

Week No.	Date	Time	Well Running Well # 1 or 2	Well No. 1			Well No. 2			Instrument Panel								System Pressure (psi)		Pressure Differential for Vessel (psi)	
				Cum. Hours Well	Cum. Volume	Average Flowrate	Cum. Hours Well	Cum. Volume	Average Flowrate	Vessel A				Vessel B							
										Inst. Flowrate	Incremental Volume	Bed Volume	Average Flowrate	Inst. Flowrate	Incremental Volume	Bed Volume	Average Flowrate	Inlet	Outlet	A	B
78	08/13/09	14:45	1	739.1	3,201,820	59.5	798.9	3,647,560	59.9	32.5	74,813	26,014	30.4	30.0	71,185	26,516	28.9	8	5	2.0	2.5
79	08/17/09	14:50	2	749.1	3,237,550	59.6	819.9	3,726,500	62.7	29.5	57,378	26,418	30.8	31.1	55,823	26,909	30.0	6	4	0.0	2.0
	08/18/09	10:25	1	750.1	3,241,750	70.0	822.9	3,738,650	67.5	29.2	8,593	26,479	35.8	30.8	8,286	26,968	34.5	5	4	0.0	0.0
	08/21/09	10:02	1	758.1	3,271,410	61.8	834.9	3,780,990	58.8	31.7	36,538	26,736	30.4	32.2	17,450	27,090	14.5	8	4	2.0	2.5
80	08/26/09	9:45	2	770.1	3,315,340	61.0	853.9	3,833,140	45.7	30.4	58,651	27,149	31.5	29.8	74,761	27,617	40.2	7	5	0.0	2.5
81	09/01/09	15:13	1	790.1	3,384,910	58.0	874.9	3,833,180	0.0	30.9	74,656	27,675	30.3	31.9	71,975	28,124	29.3	8	4	2.0	2.5
82	09/08/09	11:45	2	808.1	3,450,680	60.9	902.9	3,833,640	0.3	30.8	84,960	28,273	30.8	27.4	81,126	28,695	29.4	7	4	0.0	2.0
	09/10/09	10:39	2	814.1	3,472,230	59.9	909.9	3,833,140	-1.2	31.1	24,093	28,443	30.9	30.0	23,134	28,858	29.7	10	5	0.0	2.0
83	09/15/09	9:30	1	829.1	3,524,770	58.4	923.9	3,833,140	0.0	31.5	55,099	28,831	31.7	29.6	52,164	29,225	30.0	9	4	2.5	3.0
	09/18/09	9:55	2	836.1	3,549,980	60.0	931.9	3,833,640	1.0	30.3	28,097	29,029	31.2	29.3	26,550	29,412	29.5	9	4	0.0	2.0
84	09/21/09	9:52	1	845.1	3,583,380	61.9	942.9	3,833,680	0.1	31.3	37,616	29,294	31.3	31.4	35,529	29,663	29.6	8	7	2.5	2.5
	09/24/09	13:10	NA	NA	NA	NA	NA	NA	NA	32.9	40,279	29,577	NA	29.8	37,702	29,928	NA	10	4	2.0	2.5
85	09/30/09	10:00	2	875.1	3,694,100	61.5	968.9	3,841,740	5.2	26.9	63,970	30,028	19.0	32.3	62,619	30,369	18.6	8	4	4.0	4.0
86	10/05/09	15:00	2	891.1	3,749,490	57.7	985.9	3,904,700	61.7	28.4	49,339	30,375	24.9	34.8	69,111	30,856	34.9	8	4	5.0	5.0
	10/07/09	11:00	1	898.1	3,775,150	61.1	994.9	3,938,680	62.9	24.2	23,728	30,542	24.7	34.1	36,343	31,112	37.9	8	4	5.0	5.0
87	10/14/09	11:00	1	917.1	3,843,400	59.9	1015.9	4,016,050	61.4	18.1	47,058	30,874	19.6	44.1	97,247	31,797	40.5	10	4	6.0	7.0
	10/16/09	11:10	2	921.1	3,856,490	54.5	1023.9	4,045,750	61.9	9.5	8,889	30,936	12.3	44.9	33,031	32,029	45.9	12	4	9.0	9.0
88	10/19/09	9:30	2	931.1	3,892,180	59.5	1032.9	4,074,470	53.2	9.4	10,229	31,008	9.0	46.9	51,011	32,388	44.7	18	4	9.0	9.0
	10/20/09	10:32	2	936.1	3,908,360	53.9	1036.9	4,089,010	60.6	11.0	32,599	31,238	60.4	40.2	29,982	32,600	55.5	17	4	8.5	8.0
89	10/26/09	13:48	1	950.1	3,961,280	63.0	1058.9	4,172,410	63.2	33.8	67,234	31,712	31.1	32.9	65,845	33,063	30.5	7	4	2.0	2.5
90	11/04/09	9:45	2	974.1	4,048,590	60.6	1086.9	4,274,680	60.9	34.3	97,271	32,397	31.2	29.5	92,446	33,714	29.6	6	4	2.0	2.5
91	11/09/09	10:35	2	985.1	4,087,620	59.1	1105.9	4,345,590	62.2	29.0	55,672	32,789	30.9	28.5	51,829	34,079	28.8	7	3	2.5	2.5
	11/12/09	15:28	1	995.1	4,123,480	59.8	1114.9	4,377,360	58.8	32.2	34,733	33,033	30.5	30.8	33,328	34,314	29.2	8	4	2.0	2.5
92	11/16/09	10:30	1	1005.1	4,162,890	65.4	1127.9	4,426,370	62.8	31.2	43,532	33,340	31.5	31.0	41,625	34,607	30.2	8	4	2.0	2.0
	11/17/09	9:12	1	1007.1	4,166,950	35.5	NA	NA	NA	31.5	8,366	33,399	NA	32.7	8,014	34,664	NA	10	5	2.5	2.5
	11/19/09	15:05	2	1014.1	4,173,210	14.9	1135.9	4,499,880	153.1	32.2	24,206	33,569	26.9	28.9	22,960	34,825	25.5	8	4	2.0	2.5
93	11/23/09	13:15	2	1018.1	4,208,650	147.7	1150.9	4,508,610	9.7	0.0	3,579	33,594	3.1	30.9	33,078	35,058	29.0	6	4	2.0	2.0
	11/25/09	12:20	1	1021.1	4,226,370	98.4	1158.9	4,513,070	9.3	31.2	8,335	33,653	12.6	28.5	15,214	35,165	23.1	6	4	2.0	2.5
94	11/30/09	9:50	2	1035.1	4,267,520	49.0	1167.9	4,570,030	105.5	30.4	43,514	33,959	31.5	29.1	43,016	35,468	31.2	6	4	2.5	2.5
	12/04/09	11:25	1	1044.1	4,302,160	64.1	1179.9	4,616,770	64.9	31.4	39,267	34,236	31.2	29.3	39,064	35,743	31.0	7	4	2.0	2.5
95	12/08/09	9:26	2	1055.1	4,341,080	59.0	1187.9	4,644,540	57.9	31.2	32,116	34,462	28.2	29.7	32,214	35,970	28.3	7	4	2.5	2.5
	12/11/09	10:10	1	1064.1	4,374,550	62.0	1193.9	4,667,040	62.5	30.9	27,558	34,656	30.6	29.9	27,925	36,167	31.0	6	4	2.0	2.5
96	12/14/09	14:15	2	1077.1	4,420,850	59.4	1196.9	4,677,880	60.2	28.9	26,544	34,843	27.7	20.1	26,918	36,356	28.0	6	4	2.0	2.5
	12/15/09	8:52	1	1080.1	4,432,280	63.5	1197.9	4,679,790	31.8	27.5	7,077	34,893	29.5	31.5	7,188	36,407	30.0	10	5	2.5	2.5
97	12/21/09	10:45	1	1099.1	4,501,290	60.5	1208.9	4,720,090	61.1	31.7	52,494	35,263	29.2	30.4	52,596	36,777	29.2	9	4	2.5	2.5
	12/24/09	12:00	2	1109.1	4,540,340	65.1	1213.9	4,740,310	67.4	29.6	28,265	35,462	31.4	29.1	28,361	36,977	31.5	6	4	2.0	2.5
98	12/28/09	10:00	1	1126.1	4,603,770	62.2	1217.9	4,754,820	60.5	32.1	36,399	35,718	28.9	29.4	36,531	37,234	29.0	7	4	2.5	2.5
	12/31/09	12:04	1	1135.1	4,639,310	65.8	1223.9	4,776,990	61.6	31.4	28,507	35,919	31.7	29.7	28,821	37,437	32.0	7	4	2.5	3.0
99	01/06/10	12:01	1	1159.1	4,722,520	57.8	1231.9	4,804,120	56.5	33.2	55,173	36,307	28.7	30.8	54,735	37,823	28.5	8	4	2.5	3.0
	01/08/10	9:05	2	1162.1	4,734,300	65.4	1237.9	4,826,900	63.3	31.9	17,194	36,428	31.8	29.2	16,825	37,941	31.2	10	4	2.5	2.5
100	01/11/10	11:10	1	1172.1	4,769,500	58.7	1242.9	4,845,970	63.6	33.1	27,727	36,624	30.8	30.0	27,067	38,132	30.1	8	4	2.0	2.5
	01/15/10	15:10	2	1185.1	4,817,990	62.2	1248.9	4,866,570	57.2	31.3	34,442	36,866	30.2	28.9	33,692	38,369	29.6	9	4	2.5	2.5
101	01/18/10	11:10	1	1192.1	4,843,800	61.5	1252.9	4,883,160	69.1	29.8	20,730	37,012	31.4	28.9	20,695	38,515	31.4	6	4	2.5	3.5
	01/19/10	9:10	1	1193.1	4,845,400	26.7	1256.9	4,897,180	58.4	33.0	7,820	37,067	26.1	28.5	9,794	38,584	32.6	6	5	2.5	3.0
	01/22/10	11:00	1	1200.1	4,873,380	66.6	1263.9	4,921,620	58.2	32.0	24,765	37,242	29.5	29.5	22,608	38,743	26.9	6	4	2.5	3.0
102	01/25/10	10:30	1	1206.1	4,893,040	54.6	1270.9	4,950,360	68.4	29.4	23,236	37,405	29.8	32.6	22,835	38,904	29.3	7	4	2.5	3.0
	01/29/10	13:30	1	1213.1	4,918,680	61.0	1279.9	4,981,220	57.1	31.5	27,781	37,601	28.9	30.3	27,143	39,095	28.3	6	2	2.0	2.5
103	02/01/10	14:00	1	1223.1	4,957,880	65.3	1280.9	4,985,110	64.8	31.8	21,967	37,756	33.3	28.9	21,736	39,248	32.9	6	3	2.0	2.5
	02/03/10	10:30	1	1227.1	4,969,930	50.2	1286.9	5,006,090	58.3	31.1	16,937	37,875	28.2	31.0	15,993	39,361	26.7	8	4	3.0	2.5
	02/05/10	12:40	1	1232.1	4,988,450	61.7	1291.9	5,026,220	67.1	32.1	19,658	38,013	32.8	29.9	18,758	39,493	31.3	6	4	2.5	2.5
104	02/09/10	14:30	2	1246.1	5,039,940	61.3	1294.9	5,038,010	65.5	30.1	32,676	38,244	3								

APPENDIX B
ANALYTICAL DATA

Table B-1. Analytical Results from Treatment Plant Sampling at Covered Wells in Tohono O’odham Nation, AZ

Sampling Date		02/13/08				04/01/08				04/15/08				04/29/08				05/12/08			
Sampling Location		IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB
Parameter	Unit																				
Bed Volume	10 ³	-	-	0.0	0.0	-	-	2.2	2.1	-	-	2.7	2.7	-	-	3.5	3.4	-	-	4.2	4.1
Alkalinity	mg/L ^(a)	145	146	158	172	149	147	143	139	155	151	151	153	145	147	165	165	151	151	147	147
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	1.2	1.0	1.2	1.2	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	23.3	24.0	27.1	26.8	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	1.3	1.2	1.2	1.2	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	NA ^(b)	NA ^(b)	NA ^(b)	NA ^(b)	27.7	27.5	25.0	20.7	24.7	25.1	25.0	24.6	24.7	24.7	26.9	26.7	26.6	26.0	26.2	26.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	1.4	1.9	1.9	2.0	1.9	0.6	0.4	0.5	1.0	0.9	0.8	0.8	0.6	1.0	1.4	2.0	0.5	0.6	0.9	0.8
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	8.1	6.8	6.4	6.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8.1	7.2	7.1	7.0
Temperature	°C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	31.1	32.6	32.9	33.0
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.7	3.1	3.0	3.4
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	243	287	321	351
Free Chlorine	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Chlorine	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Hardness	mg/L ^(a)	-	-	-	-	39.0	38.3	35.2	33.8	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness	mg/L ^(a)	-	-	-	-	28.0	27.3	25.2	23.9	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness	mg/L ^(a)	-	-	-	-	11.1	10.9	10.0	9.8	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L	35.6	35.1	1.0	0.9	36.6	35.3	0.1	0.1	33.4	34.8	<0.1	0.2	36.4	36.7	0.2	0.2	37.3	36.0	1.0	0.8
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	22.0	34.2	<0.1	0.2	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	14.6	1.1	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	0.1	0.1	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	21.9	34.0	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	49	<25	<25	<25	<25	<25	<25	<25	60	<25	<25	<25	<25	32	37	<25	<25	<25	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	<25	<25	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	1.3	0.7	0.5	0.3	0.3	0.2	0.2	<0.1	2.8	0.3	<0.1	<0.1	0.5	1.2	0.7	0.2	0.2	1.1	<0.1	<0.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	0.3	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
U (total)	µg/L	7.0	7.0	<0.1	<0.1	7.9	7.7	<0.1	<0.1	8.3	8.4	<0.1	<0.1	7.9	7.9	<0.1	<0.1	7.8	7.5	<0.1	<0.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (total)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(a) As CaCO ₃		(b) Silica not measured on 02/13/08.																			

Table B-1. Analytical Results from Treatment Plant Sampling at Covered Wells in Tohono O’odham Nation, AZ (Continued)

Sampling Date		05/28/08				07/08/08				07/30/08				09/02/08				10/07/08				
Sampling Location		IN	AP	TA	TB ^(b)	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB	TT
Parameter	Unit																					
Bed Volume	10 ³	-	-	5.0	4.8	-	-	7.4	7.2	-	-	8.5	8.3	-	-	10.3	10.0	-	-	12.0	11.6	11.8
Alkalinity	mg/L ^(a)	156	149	145	149	147	145	145	143	147	149	149	151	148	146	151	146	146	144	144	146	146
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	1.1	1.4	1.2	1.2	-	-	-	-	-	-	-	-	-	-	-	-	1.1	1.1	1.0	1.1	1.1
Sulfate	mg/L	24.8	23.7	25.0	28.1	-	-	-	-	-	-	-	-	-	-	-	-	23.7	24.3	24.2	23.1	23.8
Nitrate (as N)	mg/L	1.2	1.8	1.2	1.2	-	-	-	-	-	-	-	-	-	-	-	-	1.2	1.2	1.2	1.2	1.2
Total P (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	26.9	27.0	26.4	26.0	27.8	27.2	28.4	28.2	26.5	26.7	27.1	27.2	26.7	26.7	27.0	26.9	27.0	26.8	26.8	26.5	26.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	0.6	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.2	0.1	<0.1	0.1	0.2	<0.1	<0.1	0.2	0.3	0.1	<0.1	0.3
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	NA	NA	NA	NA	8.1	6.6	6.6	6.6	8.1	7.1	7.1	7.1	NA	NA	NA	NA	8.2	7.1	7.1	7.1	7.0
Temperature	°C	NA	NA	NA	NA	25.0	25.0	25.0	25.0	32.9	32.6	32.9	33.1	NA	NA	NA	NA	25.0	25.0	25.0	25.0	25.0
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	225	303	289	320	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Free Chlorine	mg/L	-	NA	NA	NA	-	NA	NA	NA	-	6.3 ^(c)	7.6 ^(c)	7.8 ^(c)	-	NA	NA	NA	0.0	1.8	2.0	2.1	2.1
Total Chlorine	mg/L	-	NA	NA	NA	-	0.0	0.0	0.0	-	6.7 ^(c)	6.7 ^(c)	7.2 ^(c)	-	NA	NA	NA	0.0	1.7	1.9	2.0	1.8
Total Hardness	mg/L ^(a)	39.3	39.3	34.5	31.3	-	-	-	-	-	-	-	-	-	-	-	-	34.6	37.3	36.9	36.4	37.5
Ca Hardness	mg/L ^(a)	28.3	28.5	25.3	21.8	-	-	-	-	-	-	-	-	-	-	-	-	25.1	27.1	26.9	26.4	27.2
Mg Hardness	mg/L ^(a)	11.0	10.9	9.2	9.5	-	-	-	-	-	-	-	-	-	-	-	-	9.5	10.2	10.0	10.0	10.3
As (total)	µg/L	36.9	37.6	0.3	0.3	33.6	33.9	0.2	0.2	35.6	36.0	1.1	0.7	35.0	36.8	0.5	0.3	35.7	36.5	0.9	0.6	0.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	35.3	36.0	0.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-	33.7	34.5	0.4	0.3	0.2
As (particulate)	µg/L	1.6	1.6	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	2.0	2.1	0.5	0.3	0.3
As (III)	µg/L	0.5	0.4	0.4	0.4	-	-	-	-	-	-	-	-	-	-	-	-	0.4	0.4	0.4	0.4	0.4
As (V)	µg/L	34.8	35.6	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	33.3	34.0	<0.1	<0.1	<0.1
Fe (total)	µg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	<25	<25	78	<25	-	-	-	-	-	-	-	-	-	-	-	-	<25	<25	<25	<25	<25
		0.4	0.3	<0.1	<0.1	1.3	0.6	<0.1	<0.1	0.3	0.4	<0.1	<0.1	0.2	0.2	<0.1	<0.1	0.2	0.4	<0.1	<0.1	<0.1
Mn (total)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	0.3	0.4	2.7	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	<0.1	<0.1	<0.1
U (total)	µg/L	NA	NA	NA	NA	7.8	7.8	<0.1	<0.1	NA	NA	NA	NA	7.5	7.5	<0.1	<0.1	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (total)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	30.2	30.2	0.1	<0.1	29.4	30.4	0.7	0.4	0.4
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(a) As CaCO ₃		(b) All metals re-analyzed on 08/28/08 from TB																				
		(c) Uncharacteristically high levels																				

Table B-1. Analytical Results from Treatment Plant Sampling at Covered Wells in Tohono O’odham Nation, AZ (Continued)

Sampling Date		11/18/08				12/16/08				01/20/09				02/17/09				03/17/09				
Sampling Location		IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB	TT
Parameter	Unit																					
Bed Volume	10 ³	-	-	13.9	13.4	-	-	15.1	14.5	-	-	16.6	16.0	-	-	17.6	17.0	-	-	18.6	17.9	18.3
Alkalinity	mg/L ^(a)	145	145	156	156	147	147	145	145	144	140	140	142	149	147	151	158	148	146	195	193	189
		145	148	156	159	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.2	1.1	1.0	1.0	1.0
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23.7	23.5	21.4	20.5	21.3
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.3	1.1	1.2	1.2	1.2
Total P (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
		<10	<10	<10	<10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	25.1	25.7	26.9	27.3	25.0	25.2	25.1	25.4	24.4	25.5	23.0	23.3	26.0	25.9	28.6	27.1	25.2	25.2	31.4	32.0	34.7
		25.6	25.9	25.9	27.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	0.1	0.2	<0.1	0.2	0.2	0.2	0.1	0.1	0.2	0.3	<0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1	<0.1	<0.1	<0.1
		0.1	0.1	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	8.0	6.9	7.2	7.0	7.9	6.9	6.9	7.0	NA ^(d)	NA ^(d)	NA ^(d)	NA ^(d)	8.1	7.0	7.1	7.1	8.4	6.9	7.5	7.4	NM
Temperature	°C	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	NA ^(d)	NA ^(d)	NA ^(d)	NA ^(d)	25.0	25.0	25.0	25.0	26.6	28.9	30.3	31.4	NM
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Free Chlorine	mg/L	0.0	2.2	2.1	1.9	0.0	1.7	1.8	1.9	NA ^(d)	NA ^(d)	NA ^(d)	NA ^(d)	0.0	2.1	2.0	2.2	0.1	1.6	1.6	1.5	NM
Total Chlorine	mg/L	0.0	2.1	2.0	1.8	0.0	1.6	1.7	1.8	NA ^(d)	NA ^(d)	NA ^(d)	NA ^(d)	0.0	2.1	2.1	2.2	0.1	1.6	1.6	1.3	NM
Total Hardness	mg/L ^(a)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	47.3	48.8	93.6	93.0	86.7
Ca Hardness	mg/L ^(a)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36.2	37.3	67.8	66.1	60.0
Mg Hardness	mg/L ^(a)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11.1	11.4	25.8	26.8	26.7
As (total)	µg/L	37.9	38.2	0.5	0.5	36.3	35.1	0.7	0.5	37.7	35.6	0.4	0.4	32.3	33.0	0.7	0.9	37.1	39.1	0.2	0.2	<0.1
		38.6	37.6	0.5	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36.8	36.2	0.3	0.3	0.2
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	2.9	<0.1	<0.1	<0.1
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	0.3	0.4	0.3	0.3
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36.4	35.9	<0.1	<0.1	<0.1
Fe (total)	µg/L	<25	<25	<25	<25	30	28	77	<25	<25	<25	<25	<25	<25	<25	<25	<25	31	<25	<25	<25	<25
		<25	<25	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<25	<25	<25	<25	<25
Mn (total)	µg/L	0.3	<0.1	<0.1	0.1	2.6	1.3	2.1	0.2	1.0	<0.1	<0.1	<0.1	0.2	0.5	<0.1	0.1	1.8	0.8	<0.1	<0.1	<0.1
		0.3	0.2	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.2	0.4	<0.1	<0.1	<0.1
U (total)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (total)	µg/L	35.5	36.6	0.5	0.5	33.2	32.5	0.7	0.5	31.9	30.5	0.5	0.5	27.5	28.6	0.8	0.9	33.2	31.8	0.5	0.5	0.3
		34.2	36.6	0.5	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(a) As CaCO ₃		(d) pH, temperature, free chlorine & total chlorine not measured																				

Table B-1. Analytical Results from Treatment Plant Sampling at Covered Wells in Tohono O’odham Nation, AZ (Continued)

Sampling Date		04/15/09				05/20/09				06/16/09				07/14/09					08/18/09			
Sampling Location		IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB	TT	IN	AP	TA	TB
Parameter	Unit																					
Bed Volume	10 ³	-	-	19.7	19.0	-	-	20.4	20.7	-	-	21.3	21.9	-	-	23.3	24.0	23.6	-	-	26.5	27.0
Alkalinity	mg/L ^(a)	148	150	161	161	155	150	155	155	154	156	156	158	151	151	201	196	192	154	154	152	154
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	1.2	1.2	1.0	1.1	1.0	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	24.8	24.6	22.3	23.5	22.7	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	1.2	1.2	1.2	1.2	1.2	-	-	-	-
Total P (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Silica (as SiO ₂)	mg/L	27.4	27.0	32.6	31.7	27.3	26.7	28.9	28.8	26.5	27.1	26.1	25.8	26.7	27.2	32.1	33.8	34.3	26.3	25.9	25.9	25.8
Turbidity	NTU	0.5	0.3	0.3	0.6	0.3	1.4	0.1	0.2	0.7	2.2	2.3	0.8	0.2	0.1	0.1	0.4	<0.1	0.7	0.2	0.4	0.4
pH	S.U.	8.3	6.9	7.2	7.2	8.2	6.9	6.8	6.8	7.8	6.8	6.8	6.8	7.9	7.9	7.1	7.1	7.1	8.1	6.9	6.9	7.0
Temperature	°C	25.0	25.0	25.0	25.0	31.4	33.3	33.5	33.8	32.0	32.1	33.3	33.2	33.7	33.7	34.0	34.4	34.7	34.1	32.4	30.9	32.1
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Free Chlorine	mg/L	0.0	2.1	2.0	2.2	0.0	1.5	1.6	1.5	0.0	0.8	1.0	0.8	NA	1.7	1.7	1.8	1.9	NA	NA ^(e)	NA ^(e)	NA ^(e)
Total Chlorine	mg/L	0.0	2.1	2.1	2.2	0.0	1.5	1.6	1.5	0.0	1.0	1.0	1.0	NA	1.8	1.8	1.9	1.9	NA	NA ^(e)	NA ^(e)	NA ^(e)
Total Hardness	mg/L ^(a)	-	-	-	-	-	-	-	-	-	-	-	-	39.1	40.4	94.5	87.0	79.8	-	-	-	-
Ca Hardness	mg/L ^(a)	-	-	-	-	-	-	-	-	-	-	-	-	29.3	30.2	67.1	61.1	55.1	-	-	-	-
Mg Hardness	mg/L ^(a)	-	-	-	-	-	-	-	-	-	-	-	-	9.8	10.2	27.4	25.8	24.6	-	-	-	-
As (total)	µg/L	31.4	31.7	0.6	0.4	35.6	39.4	0.5	0.5	33.8	26.6	<0.1	<0.1	35.7	37.2	0.6	0.5	0.4	32.2	32.6	31.8	1.3
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	1.8	1.5	<0.1	<0.1	<0.1	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.4	0.4	0.5	0.5	0.5	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	33.6	35.3	<0.1	<0.1	<0.1	-	-	-	-
Fe (total)	µg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	28	<25	<25	<25	<25	<25	<25	<25
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	0.3	0.3	<0.1	<0.1	0.3	0.8	0.1	0.2	0.2	0.2	<0.1	0.2	0.2	3.0	<0.1	<0.1	<0.1	2.6	1.9	1.7	1.3
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
U (total)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (total)	µg/L	27.9	27.6	<0.1	<0.1	33.6	34.8	0.5	0.5	35.1	35.2	0.6	<0.1	34.4	35.2	0.1	<0.1	<0.1	33.3	32.9	31.8	0.2
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(a) As CaCO ₃		(e) Operator did not have chlorine kit at time of sampling																				

Table B-1. Analytical Results from Treatment Plant Sampling at Covered Wells in Tohono O’odham Nation, AZ (Continued)

Sampling Date		09/15/09				10/20/09				11/17/09					12/15/09				01/19/10			
Sampling Location		IN	AP	TA	TB	IN	AP	TA	TB	IN	AP	TA	TB	TT	IN	AP	TA	TB	IN	AP	TA	TB
Parameter	Unit																					
Bed Volume	10 ⁶	-	-	28.8	29.2	-	-	31.2	32.6	-	-	33.4	34.7	34.0	-	-	34.9	36.4	-	-	37.1	38.5
Alkalinity	mg/L ^(a)	156	156	154	152	148	142	134	190	156	147	159	174	168	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	1.1	1.1	1.1	1.0	1.1	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	22.2	21.6	21.9	21.7	21.9	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	1.2	1.2	1.2	1.2	1.2	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	26.1	26.2	26.2	26.2	24.6	24.5	18.7	29.3	27.7	27.1	29.5	30.9	30.3	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	0.6	2.1	2.1	1.1	1.3	0.8	0.7	0.2	0.1	0.5	0.3	0.2	<0.1	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	7.9	7.0	7.0	6.9	8.0	6.6	7.2	7.6	7.9	6.6	6.8	6.8	6.6	8.0	6.6	6.6	6.6	8.0	6.5	6.5	6.5
Temperature	°C	25.0	25.0	25.0	25.0	32.5	32.5	34.0	34.4	26.5	30.5	29.0	30.7	30.6	29.4	27.4	26.8	27.2	25.0	25.0	25.0	25.0
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Free Chlorine	mg/L	0.0	1.0	0.9	1.0	NA	0.1	0.0	0.0	NA	1.1	1.1	1.1	1.1	NA	1.7	1.4	1.4	NA	1.8	1.8	1.7
Total Chlorine	mg/L	0.0	1.1	1.0	1.0	NA	0.0	NA	NA	NA	1.1	1.1	1.1	1.1	NA	1.6	1.3	1.4	NA	1.8	1.8	1.8
Total Hardness	mg/L ^(a)	33.1	34.0	33.4	30.9	-	-	-	-	29.7	32.9	36.9	41.5	40.2	-	-	-	-	-	-	-	-
Ca Hardness	mg/L ^(a)	23.3	24.1	23.2	21.2	-	-	-	-	21.3	23.5	25.9	28.8	27.8	-	-	-	-	-	-	-	-
Mg Hardness	mg/L ^(a)	9.8	9.9	10.2	9.7	-	-	-	-	8.4	9.4	11.0	12.7	12.4	-	-	-	-	-	-	-	-
As (total)	µg/L	29.0	31.0	0.1	0.2	34.2	35.2	0.1	0.8	35.8	35.5	1.2	1.2	1.1	33.2	33.9	0.4	0.3	33.8	31.7	0.5	0.4
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	-	-	35.4	36.0	1.1	1.0	1.1	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	0.4	<0.1	0.1	0.2	<0.1	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	1.0	1.1	1.1	1.0	1.0	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	34.4	34.9	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-
Fe (total)	µg/L	<25	<25	<25	<25	<25	27	<25	<25	<25	<25	<25	<25	<25	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	<25	<25	<25	<25	<25	-	-	-	-	-	-	-	-
Mn (total)	µg/L	0.1	0.4	<0.1	<0.1	0.3	2.0	<0.1	0.1	0.3	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	<0.1	0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
U (total)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (total)	µg/L	23.5	25.2	<0.1	<0.1	28.5	28.8	1.3	3.6	38.1	39.7	4.2	3.0	3.7	34.6	34.6	3.1	2.0	35.0	35.6	4.7	3.0
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(a) As CaCO₃

Table B-1. Analytical Results from Treatment Plant Sampling at Covered Wells in Tohono O’odham Nation, AZ (Continued)

Sampling Date		02/16/10				03/16/10 ^(f)			
Sampling Location		IN	AP	TA	TB	IN	AP	TA	TB
Parameter	Unit								
Bed Volume	10 ³	-	-	39.0	40.5	-	-	40.0	41.4
Alkalinity	mg/L ^(a)	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	-	-	-	-	-	-	-	-
Turbidity	NTU	-	-	-	-	-	-	-	-
pH	S.U.	7.9	6.6	6.9	6.9	NA	NA	NA	NA
Temperature	°C	26.2	33.5	32.9	32.5	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA
Free Chlorine	mg/L	NA	1.5	1.5	1.5	NA	1.1	0.6	1.2
Total Chlorine	mg/L	NA	1.5	1.6	1.6	NA	1.3	0.7	1.3
Total Hardness	mg/L ^(a)	-	-	-	-	-	-	-	-
Ca Hardness	mg/L ^(a)	-	-	-	-	-	-	-	-
Mg Hardness	mg/L ^(a)	-	-	-	-	-	-	-	-
As (total)	µg/L	33.1	29.7	0.6	0.3	34.4	34.6	0.6	0.4
As (soluble)	µg/L	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-
Fe (total)	µg/L	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-
Mn (total)	µg/L	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-
U (total)	µg/L	-	-	-	-	-	-	-	-
V (total)	µg/L	32.0	31.2	6.2	3.7	33.4	32.6	5.2	3.3
(a) As CaCO ₃		(f) bed volume from 03/12/10							