

**Arsenic and Uranium Removal from Drinking Water by Adsorptive Media
U.S. EPA Demonstration Project at Upper Bodfish in Lake Isabella, CA
Interim Evaluation Report**

by

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Sally Gutierrez, Director
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ABSTRACT

This report documents the activities performed during and the results obtained from the first 10 months of system operation of an arsenic (As) and uranium (U) removal technology being demonstrated at Upper Bodfish in Lake Isabella, CA. The objectives of the project are to evaluate: (1) the effectiveness of a hybrid ion exchange (HIX) technology in removing arsenic and uranium to meet the respective maximum contaminant levels (MCLs) of 10 and 30 $\mu\text{g/L}$, (2) the reliability of the treatment system, (3) the required system operation and maintenance (O&M) and operator skill levels, and (4) the capital and O&M cost of the technology. The project also characterizes water in the distribution system and process residuals produced by the treatment system.

The HIX system designed by VEETech for the Upper Bodfish site consisted of two trailer-mounted, single-stage fiberglass reinforced plastic (FRP) vessels, each capable of treating up to 50 gal/min (gpm) of flow. The vessels were 42-in in diameter and 60-in in height, each containing 27 ft^3 of ArsenX^{np}, a hybrid anion exchange resin impregnated with hydrous iron oxide nano-particles manufactured by Purolite. During normal operation, one vessel was put into service while the other was on standby.

During the study period from October 13, 2005 through August 3, 2006, the HIX system operated for a total of 4,631 hr, treating approximately 6,693,700 gal of water from the Upper Bodfish Well CH2-A. The average daily run time was 15.4 hr/day and the average daily production was 22,300 gal/day (gpd). The system flowrates ranged from 21 to 29 gpm and averaged 24 gpm, which was 48% of the system design flowrate. The lower flowrates resulted in longer empty bed contact times (EBCT), i.e., 9.6 to 7.0 min, and lower hydraulic loading rates, i.e., 2.2 to 3.0 gpm/ft^2 .

Source water from Well CH2-A had near-neutral pH values of 6.8 to 7.2, 88 to 145 mg/L of alkalinity (as CaCO_3), 36 to 41 mg/L of sulfate, and 40 to 48 mg/L of silica. In addition, the well water contained 36.5 to 47.3 $\mu\text{g/L}$ of total arsenic with As(V) being the predominating species at an average concentration of 40.9 $\mu\text{g/L}$. The source water also contained 26.6 to 38.9 $\mu\text{g/L}$ of total uranium, with concentrations exceeding the 30- $\mu\text{g/L}$ MCL most of the time.

During the first 10 months of system operation, total arsenic concentrations in the treated water were reduced to <0.1 $\mu\text{g/L}$ initially and gradually increased to 10.5 $\mu\text{g/L}$ after 33,100 bed volumes (BV) of throughput. This run length was 65% higher than the vendor-provided estimate of 20,000 BV. Meanwhile, uranium was completely removed to below the detection limit of 0.1 $\mu\text{g/L}$ throughout the 10-month study period. A laboratory rapid small-scale column test (RSSCT) on the Upper Bodfish water using the ArsenX^{np} media achieved a similar run length of 28,000 BV for arsenic and over 50,000 BV for uranium. The better-than-expected performance of the full-scale system might have resulted from the lower flowrates and longer EBCTs experienced by the HIX system. The HIX system did not require backwashing due to an insignificant headloss buildup across the adsorption vessel.

Comparison of the distribution system water sampling results before and after system startup showed significant decreases in arsenic concentrations at three residences. The arsenic concentrations measured at the taps of these residences typically were higher than those of the plant effluent and mirrored the breakthrough behavior of arsenic in the plant effluent. Uranium was not present in the distribution system during the baseline sampling when Well CH2-A was not in service, and is not expected to be present after system startup due to the absence of uranium in the treatment effluent. The HIX system did not appear to have any effects on other water quality parameters in the distribution system.

At 33,100 BV, the uranium loading on the ArsenX^{np} media was estimated to be 0.13% (by wet weight). According to EPA's *A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies* (EPA, 2005), uranium is considered "source material" and may be subject

to the Nuclear Regulatory Commission's (NRC's) licensing requirements if a water system generates uranium-containing residuals. However, uranium is exempt from NRC regulations if it makes up less than 0.05% (by weight), or an "unimportant quantity," of the residuals, (10 CFR 40.13). Although it is not clear how this 0.05% is defined and how the "residuals" are quantified, there is a possibility that the spent media may be classified as non-exempt material, and thus can be subject to relevant regulations on storage, transportation, and disposal. If so, the spent media may not be regenerated at Mobile Processing Technology (MPT)'s facility in Memphis, TN as planned because it is not licensed to process non-exempt material. Therefore, three options were proposed by the vendor and are being evaluated for spent media disposition, including 1) partial onsite regeneration to reduce the uranium loading to below the 0.05% "unimportant quantity", followed by offsite regeneration to further remove arsenic and uranium, 2) complete onsite regeneration to remove both arsenic and uranium from the media, and 3) replacement and disposal of the spent media at a permitted facility. The approach for actual spent media disposition will be described in the Final Performance Evaluation Report.

The capital investment cost was \$114,070, which included \$82,470 for equipment, \$12,800 for engineering, and \$18,800 for installation. Using the system's rated capacity of 50 gpm, the capital cost was \$2,281/gpm (or \$1.58/gpd).

The O&M cost for the HIX system included only incremental cost associated with the system operation, such as media regeneration or replacement and disposal as well as labor for routine operation. The vendor estimated \$12,700 for partial onsite regeneration (not including any additional cost for the subsequent offsite regeneration), \$15,900 for complete onsite regeneration, and \$21,950 for media replacement and disposal. By averaging the media regeneration or replacement cost over the useful life of the media (i.e., 33,100 BV or 6,685,000 gal), the cost per 1,000 gal of water treated for these three options would be \$1.90, \$2.38, and \$3.28/1,000 gal, respectively. The HIX system did not require electricity to operate. Routine activities to operate and maintain the system consumed only 50 min per week and the estimated labor cost was \$0.13/1,000 gal of water treated.

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ABBREVIATIONS AND ACRONYMS

AAL	American Analytical Laboratories
AC	asbestos cement
AM	adsorptive media
As	arsenic
ATS	Aquatic Treatment Systems
BAT	best available technology
bgs	below ground surface
BV	bed volume
Ca	calcium
Cal Water	California Water Service Company
CDPH	California Department of Public Health
CEQA	California Environmental Quality Act
C/F	coagulation/filtration process
Cl	chlorine
CRF	capital recovery factor
Cu	copper
DO	dissolved oxygen
EBCT	empty bed contact time
EPA	U.S. Environmental Protection Agency
F	fluorine
Fe	iron
FRP	fiberglass reinforced plastic
GFH	granular ferric hydroxide
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
HIX	hybrid ion exchange(r)
hp	horse-power
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IX	ion exchange
LCR	Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MEI	Magnesium Elektron, Inc.
Mg	magnesium
Mn	manganese
MPT	Mobile Processing Technology

ABBREVIATIONS AND ACRONYMS (Continued)

Na	sodium
NA	not available
ND	not detectable
NRC	Nuclear Regulatory Commission's
NRMRL	National Risk Management Research Laboratory
O&M	operation and maintenance
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
P&ID	pipng and instrumentation diagram
PO ₄	phosphate
POE	point of entry
POU	point of use
psi	pounds per square inch
PVC	polyvinyl chloride
QA	quality assurance
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RO	reverse osmosis
RPD	relative percent difference
RSSCT	rapid small-scale column test
SBA	strong-base anion
SDWA	Safe Drinking Water Act
SiO ₂	silica
SO ₄ ²⁻	sulfate
STS	Severn Trent Services
TDS	total dissolved solids
TOC	total organic carbon
U	uranium
V	vanadium

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1.0 INTRODUCTION

1.1 Background

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

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

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 provided its recommendations to EPA on the technologies that it determined were acceptable for the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration project. Using the information provided by the review panel, EPA, in cooperation with the host sites and the drinking water programs of the respective states, selected one technical proposal for each site.

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 host sites. California Water Service Company (Cal Water)'s Upper Bodfish facility in Lake Isabella, California, was among those selected for the Round 2 demonstration.

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, another technical panel was convened by EPA to review the proposals and provide recommendations to EPA with the number of proposals per site ranging from none (for two sites) to a maximum of four. The final selection of the treatment technology at the sites that received at least one proposal was made, again, 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. In February 2005, VEETech's hybrid ion exchange (HIX) technology using ArsenX^{np} media was selected for removal of arsenic and uranium from source water at the Upper Bodfish site in Lake Isabella, CA.

1.2 Treatment Technologies for Arsenic Removal

The technologies selected for the Round 1 and Round 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, and 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 system modification. Table 1-1 summarizes the locations, technologies, vendors, system flowrates, and key source water quality parameters (including As, Fe, 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 costs are provided in two EPA reports (Wang et al., 2004; Chen et al., 2004), which are posted on the EPA website at <http://www.epa.gov/ORD/NRMRL/wswrd/dw/arsenic/tech/index.html>.

1.3 Project Objectives

The objective of the arsenic demonstration program is to conduct 40 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 HIX system at the Upper Bodfish site in Lake Isabella, CA during the first 10 months of operation from October 12, 2005 through August 3, 2006. The types of data collected include system operation, water quality (both across the treatment train and in the distribution system), residuals, 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.)
<i>Northeast/Ohio</i>							
Wales, ME	Springbrook Mobile Home Park	AM (A/I Complex)	ATS	14	<25	<25	8.6
Bow, NH	White Rock Water Company	AM (G2)	ADI	70 ^(b)	<25	<25	7.7
Goffstown, NH	Orchard Highlands Subdivision	AM (E33)	AdEdge	10	<25	<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 ^(b)	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 ^(c)	25 ^(a)	1,615 ^(c)	7.3
<i>Great Lakes/Interior Plains</i>							
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)	USFilter	340 ^(c)	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
<i>Midwest/Southwest</i>							
Arnaudville, LA	United Water Systems	C/F (Macrolite)	Kinetico	770 ^(c)	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)	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
<i>Far West</i>							
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 ^(b)	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 (Adsorbisia/ARM 200/ArsenX [®]) 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)	Siemens	350	39	<25	7.4
Susanville, CA	Richmond School District	AM (A/I Complex)	ATS	12	37 ^(d)	125	7.5
Lake Isabella, CA	California Water Service Company	AM (HIX or ArsenX [®])	VEETech	50	35	125	7.5
Tehachapi, CA	Golden Hills Community Service District	AM (Isolux)	MEI	150	15	<25	6.9

AM = adsorptive media; C/F = coagulation/filtration; GFH = granular ferric hydroxide; HIX = hybrid ion exchanger; IX = ion exchange; 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% after system was switched from parallel to serial configuration.
- (c) Iron existing mostly as Fe(II).
- (d) Replaced Village of Lyman, NE site which withdrew from program in June 2006.
- (e) Facilities upgraded Springfield, OH system from 150 to 250 gpm, Sandusky, MI system from 210 to 340 gpm, and Arnaudville, LA system from 385 to 770 gpm.
- (f) Including nine residential units.
- (g) Including eight under-the-sink units.

2.0 SUMMARY AND CONCLUSIONS

Based on the information collected from the first 10 months of the HIX system operation, the following was summarized and concluded relating to the overall objectives of the technology demonstration study.

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

- ArsenX^{np} media is effective at removing arsenic and uranium to below their respective MCLs. The treatment system achieves a run length of 33,100 bed volume (BV) at 10- $\mu\text{g/L}$ arsenic breakthrough, which is 65% higher than the vendor projected run length. Uranium is completely removed to below the detection limit of 0.1 $\mu\text{g/L}$ throughout the entire study period.
- The presence of silica at 43.4 mg/L (as SiO_2) has little or no effect on ArsenX^{np} performance. Silica removal was observed only for the initial 1,000 BV.
- The use of ArsenX^{np} does not alter water quality parameters, such as pH, alkalinity, sulfate, fluoride, nitrate, and hardness.

Required system operation and maintenance and operator skill levels:

- The system requires little attention from the operator. The daily demand is only 10 min to visually inspect the system and record operational parameters.
- System operation does not require additional skills beyond those necessary to operate the preexisting water supply equipment. The system is operated by a State-certified operator who possesses Level 2 certifications for both treatment and distribution systems.

Process residuals produced by the technology:

- Because backwash was not required during the entire test run, no backwash wastewater or solids were produced.
- Residuals produced by the treatment system comprise only spent media, which contains arsenic and uranium. The disposition of spent media is still to be determined.

Cost of the Technology:

- Based on the system's rated capacity of 50 gallons per minute (gpm), the capital cost is \$2,281 per gpm of the design capacity (or \$1.58/gallons per day [gpd]).
- Cost of media regeneration or replacement is the most significant add-on cost. The labor cost for routine O&M activities is \$0.13/1,000 gal. Neither chemicals nor electricity are required for the HIX system.

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 HIX treatment system began on October 12, 2005. Table 3-2 summarizes the types of data collected and/or considered as part of the technology evaluation process. The overall performance of the system was determined based on its ability to consistently remove arsenic and uranium to their respective MCLs of 10 µg/L and 30 µg/L; this was monitored through the collection of (bi)weekly and monthly water samples across the treatment train, as described in the Study Plan (Battelle, 2005). The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement activities. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

Table 3-1. Predemonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	October 14, 2004
Project Planning Meeting Held	April 11, 2005
Draft Letter of Understanding Issued	April 18, 2005
Final Letter of Understanding Issued	May 6, 2005
Request for Quotation Issued to Vendor	May 24, 2005
Vendor Quotation received by Battelle	June 2, 2005
Purchase Order Completed and Signed	July 19, 2005
Engineering Plans Submitted to CDPH	August 2, 2005
Final Study Plan Issued	October 4, 2005
System Permit Issued by CDPH	August 24, 2005
HIX System Shipped and Arrived	September 23, 2005
System Installation and Shakedown Completed	October 4, 2005
Performance Evaluation Begun	October 12, 2005

CDPH = California Department of Public Health

The O&M and operator skill requirements were evaluated based on a combination of quantitative data and qualitative considerations, including the need for pre- and/or post-treatment, level of system automation, extent of preventative maintenance activities, frequency of chemical and/or media handling and inventory, and general knowledge needed for relevant chemical processes and related health and safety practices. The staffing requirements for 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 required tracking the capital cost for equipment, engineering, and installation, as well as the O&M cost for media regeneration or replacement and disposal, chemical supply, electricity usage, and labor.

3.2 System O&M and Cost Data Collection

The plant operator performed weekly and monthly system O&M and data collection following the instructions provided by the vendor and Battelle. On a daily basis (except for Saturdays and Sundays),

Table 3-2. General Types of Data

Evaluation Objectives	Data Collection
Performance	-Ability to consistently meet 10 µg/L of arsenic and 30 µg/L of uranium in treated water
Reliability	-Unscheduled downtime for system -Frequency and extent of repairs including a description of problems, materials and supplies needed, and associated labor and cost
System O&M and Operator Skill Requirements	-Pre- and post-treatment requirements -Level of system automation for data collection and system operation -Staffing requirements including number of operators and laborers -Task analysis of preventive maintenance including number, frequency, and complexity of tasks -Chemical handling and inventory requirements -General knowledge needed for relevant chemical processes and health and safety practices
Residuals Management	-Quantity and characteristics of aqueous and solid residuals generated by system operation
System Cost	-Capital cost for equipment, engineering, and installation -O&M cost for chemical usage, electricity consumption, and labor

the plant operator recorded system operation data, such as pressure, flow rate, totalizer, and hour meter readings on a Daily Field Log Sheet and conducted visual inspections to ensure normal system operations. In the event of problems, the operator contacted the Battelle Study Lead, who then determined if the vendor should be contacted for troubleshooting. The operator recorded all relevant information, including the problem encountered, course of actions taken, materials and supplies used, and associated cost and labor incurred, on a Repair and Maintenance Log Sheet. On a weekly basis, the plant operator measured field water quality parameters, including pH, temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP), and residual chlorine, and recorded the data on a Weekly Onsite Water Quality Parameter Log Sheet.

The capital cost for the HIX system consisted of the cost for equipment, site engineering, and system installation. The O&M cost consisted primarily of the cost to regenerate or replace the spent media and the labor to operate the system. No chemicals or electricity was required by the HIX system. Labor for various activities such as routine system O&M, troubleshooting and repairs, and demonstration-related work, were tracked using an Operator Labor Hour Log Sheet. The routine system O&M included activities, such as completing field logs, ordering supplies, performing system inspections, and others as recommended by the vendor. The demonstration-related activities, including performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead and the vendor, were recorded, but not used for the cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate the performance of the HIX system, samples were collected at the wellhead, across the treatment plant, and from the distribution system. Table 3-3 provides the schedules and chemical analytes for each sampling event. In addition, Figure 3-1 presents a flow diagram of the treatment system along with the analytes and schedules at each sampling location. Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2004). The procedure for arsenic speciation is described in Appendix A of the QAPP.

Table 3-3. Sampling Schedule and Chemical Analytes

Sample Type	Sampling Locations ^(a)	No. of Sampling Locations	Frequency	Analytes	Sampling Date
Source Water	At Wellhead (IN)	1	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, NH ₃ , NO ₃ , NO ₂ , Cl, F, SO ₄ , SiO ₂ , PO ₄ , TDS, TOC, turbidity, and alkalinity	10/14/04
Treatment Plant Water	At Wellhead (IN), before HIX Filter (BF), after HIX Filter (AF)	3	Weekly or Biweekly	Onsite: pH, temperature, DO, and ORP Offsite: As (total), Fe (total), Mn (total), U (total), Ca, Mg, SiO ₂ , P, turbidity, and alkalinity	10/19/05, 10/26/05, 11/02/05, 11/16/05, 12/01/05, 12/08/05, 01/04/06, 01/25/06, 02/22/06, 03/22/06, 04/19/06, 05/17/06, 06/01/06, 06/22/06, 07/19/06, 07/26/06 ^(c)
			Monthly	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), Ca, Mg, F, NO ₃ , SO ₄ , SiO ₂ , P, turbidity, and alkalinity	10/13/05, 11/08/05, 12/28/05, 01/11/06, 02/08/06, 03/08/06, 04/04/06, 05/03/06, 06/14/06, 07/06/06, 08/03/06
Distribution Water	Three Residences including One Historic LCR Sampling Location	3	Monthly ^(b)	pH, alkalinity, As (total), Fe (total), Mn (total), Pb (total), and Cu (total)	Baseline sampling: 08/10/05, 08/30/05, 09/13/05, 09/28/05 Monthly sampling: 10/26/05, 12/08/05, 01/04/06, 02/22/06, 03/22/06, 04/26/06, 05/17/06, 06/22/06, 07/19/06

(a) Abbreviations in parentheses corresponding to sample locations shown in Figure 3-1.

(b) Four baseline sampling events performed from August to September 2005 before system became operational.

(c) Analyzed for As (total) only.

LCR = Lead and Copper Rule; TDS = total dissolved solids; TOC = total organic carbon

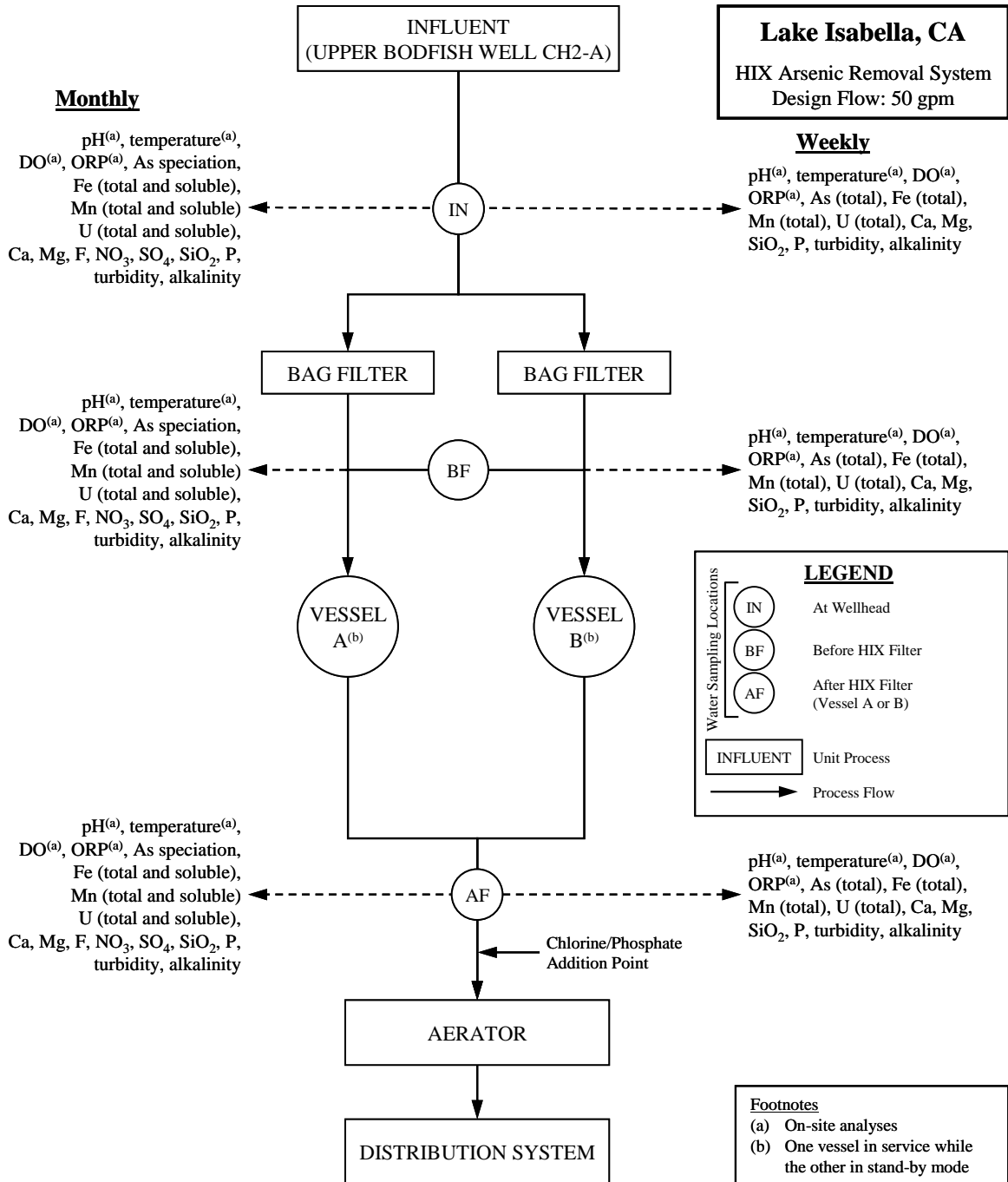


Figure 3-1. Process Flow Diagram and Sampling Locations for Upper Bodfish Site

3.3.1 Source Water. During the initial visit to the site, one set of source water samples was collected and speciation using an arsenic speciation kit was performed (see Section 3.4.1). The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Analytes for the source water samples are listed in Table 3-3.

3.3.2 Treatment Plant Water. During the system performance evaluation study, the plant operator collected samples weekly, on a four-week cycle, from October 13 to December 8, 2005, for on- and offsite analyses. For the first week of each four-week cycle, samples taken at the wellhead (IN), before the HIX filter (BF), and after the HIX filter (AF), were speciated onsite and analyzed for the analytes listed in Table 3-3 for monthly treatment plant water. For the remaining weeks, samples were collected at the same three locations and analyzed for the analytes listed in Table 3-3 for the weekly treatment plant water. Beginning from December 28, 2005 through August 3, 2006, sampling frequency was reduced from weekly to biweekly. For the first biweekly event in each four-week cycle, samples were collected at the three locations and analyzed for the analytes listed under the monthly treatment plant water. For the second biweekly event, samples were collected from the same three locations and analyzed for the analytes listed under the weekly treatment plant water.

3.3.3 Distribution System Water. Samples were collected from the distribution system to determine any impact of the HIX system on the water chemistry in the distribution system, specifically, the arsenic, lead, and copper levels. From August to September 2005, prior to startup of the HIX system, four baseline distribution sampling events were conducted at three locations in the distribution system. Following startup of the HIX system, distribution system sampling continued on a monthly basis at the same three locations, with the exception of DS2 on March 22, 2006.

Three residences were selected for distribution water sampling, including 179 Spring Court (“DS1”), 66 Spring Court (“DS2”), and 2216 Rembach Avenue (“DS3”). Only one residence (i.e., DS2) was part of the historic Lead and Copper Rule (LCR) sampling network serviced primarily by the treatment well. Figure 3-2 is a distribution map showing the three sampling locations. The homeowners of the residences collected samples following an instruction sheet developed according to the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The dates and times of last water usage before sampling and sample collection were recorded for calculation of the stagnation time. It was required that all samples were to be collected from a cold-water faucet that had not been used for at least 6 hr to ensure that stagnant water was sampled.

3.4 Sampling Logistics

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

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

3.4.2 Preparation of Sample 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, colored-coded 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 designating the arsenic speciation bottle (if

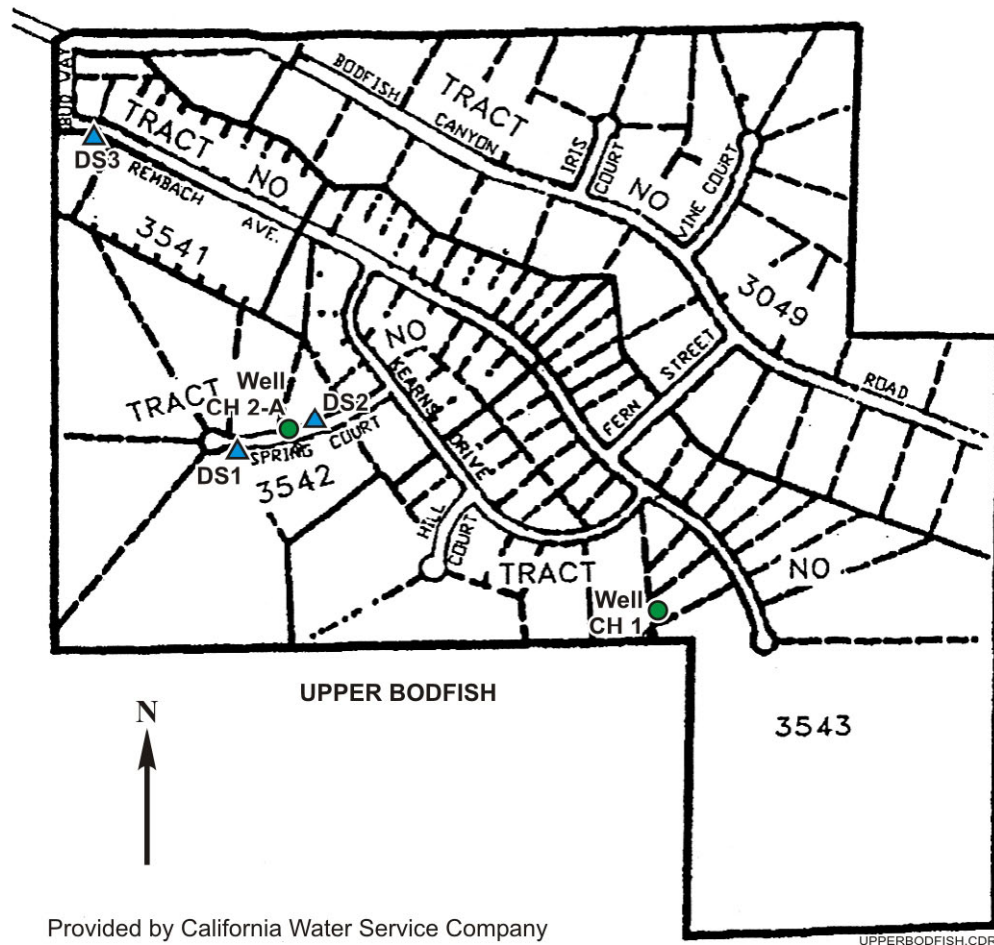


Figure 3-2. Distribution Map of Upper Bodfish Site

necessary). The sampling locations at the treatment plant were color-coded for easy identification. The labeled bottles for each sampling locations were placed in separate Ziplock™ bags and packed in the cooler.

In addition, all sampling- and shipping-related materials, such as disposable gloves, sampling instructions, chain-of-custody forms, prepaid/addressed FedEx air bills, and bubble wrap, were included. The chain-of-custody forms and air bills were complete except for the operator's signature and the sample dates and times. After preparation, the sample cooler was sent to the site via FedEx for the following week's sampling event.

3.4.3 Sample Shipping and Handling. After sample collection, samples for offsite 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 and analyzed at Battelle's inductively coupled plasma-mass spectrometry (ICP-MS) laboratory. Samples for other water quality parameters were packed in separate coolers and picked up by couriers from American Analytical Laboratories (AAL) in Columbus, OH and TCCI Laboratories in New Lexington, OH, both of which were contracted by 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 Section 4.0 of the EPA-endorsed QAPP (Battelle, 2004) were followed by Battelle ICP-MS, AAL, and TCCI Laboratories. Laboratory quality assurance/quality control (QA/QC) of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection limits (MDL), and completeness met the criteria established in the QAPP (i.e., relative percent difference [RPD] of 20%, percent recovery of 80 to 120%, and completeness of 80%). The quality assurance (QA) data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project.

Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a VWR Symphony SP90MS 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 WTW probe in the beaker until a stable value was obtained.

4.0 RESULTS AND DISCUSSION

4.1 Facility Description and Pre-Existing Treatment System Infrastructure

Cal Water's Kern River Valley District owns and operates three wells, i.e., CH-1, CH2-A, and CH-3, which serve approximately 600 residences at Upper Bodfish in Lake Isabella, CA. The population increases in the summer months due to an influx of tourists. The average monthly demand is 1,000,000 gal (or 34,000 gpd) and the peak monthly demand is 1,900,000 gal (or 64,000 gpd). The water demand is met primarily by Well CH-1 (rated at 50 gpm) and Well CH2-A (rated at 38 gpm), which jointly produce a maximum of 86,400 gpd. Well CH-3, located adjacent to CH2-A, has been taken out of service for an extended period of time.

Well CH2-A was selected for this EPA demonstration study due to the elevated arsenic and uranium levels in the water. Drilled in 1980, Well CH2-A is 6-in in diameter and 348 ft deep with a static water level of 336 ft below ground surface (bgs). The well is equipped with a 3-horsepower (hp) pump that produces 38 gpm of flow (well pump curve was unavailable). Prior to the installation of the HIX system, the well operated only during the summer months and had an average, monthly production rate of 190,000 gal and a peak monthly production of 870,000 gal. Figure 4-1 shows the preexisting Well CH2-A wellhead and associated piping in a fenced area.



Figure 4-1. Upper Bodfish Well CH2-A in Lake Isabella, CA

The preexisting treatment for Well CH2-A consisted of aeration, chlorination, and phosphate addition. Aeration was performed in a 7-ft diameter by 12 ft tall 3,500-gal steel tank (Figure 4-2) to remove radon. Prior to entering the aerator, water was injected with chlorine for disinfection and a phosphate blend solution for corrosion and scale control. The target chlorine residual level was 1.0 mg/L (as Cl₂) and the target phosphate level was 0.5 mg/L (as PO₄). The treated water was then pumped to the distribution system by a 10-hp booster pump.



Figure 4-2. Preexisting Aeration Tank at Upper Bodfish in Lake Isabella, CA

Well CH-1, drilled in August 1986, is located approximately a quarter of a mile southeast of Well CH2-A. The well water did not contain elevated arsenic or uranium so the well was previously used as the lead well. Existing treatment consisted of chlorination and phosphate addition at the wellhead.

4.1.1 Source Water Quality. Source water samples were collected from Well CH2-A on October 14, 2004 by a Battelle staff member who attended an introductory meeting for this project. Source water also was filtered for soluble arsenic, iron, manganese, uranium, and vanadium, and speciated for As(III) and As(V) using a field speciation method modified from Edwards (1998) by Battelle (Wang et al., 2000). In addition, pH, temperature, DO, and ORP were measured onsite using a WTW 340i meter which failed to work properly at the time. Thus, these data were not reported in Table 4-1. The analytical results from the source water sampling event are presented in Table 4-1 and compared to those provided by Cal Water for the EPA demonstration site selection and those collected historically by CDPH during September 18, 2002, through November 16, 2005. Source water quality data collected during the 10-month study period are discussed in Section 4.5.1.

Arsenic. Total arsenic concentrations of source water ranged from 35.4 to 41.3 $\mu\text{g/L}$. Based on the October 14, 2004 speciation results, out of 35.4 $\mu\text{g/L}$ of total arsenic (mostly soluble), 35.0 $\mu\text{g/L}$ existed as As(V), which could be removed directly by the HIX system without preoxidation.

Uranium. Total uranium concentrations in Well CH2-A ranged from 27.0 to 35.0 $\mu\text{g/L}$, which potentially could exceed its MCL of 30 $\mu\text{g/L}$ (see discussion in Section 4.5.1 regarding the conversion between the Federal and California MCLs for uranium). Based on the October 14, 2004 speciation results, uranium existed entirely in the soluble form.

Radon. Radon is a radioactive gas released by uranium-bearing rocks and soil. Total radon concentrations in source water ranged from 22,294 to 40,000 pCi/L based on radioactivity analysis conducted from March 9 to November 16, 2004. As noted above, there was a preexisting aeration tank to remove radon from water prior to distribution.

Iron and Manganese. According to the facility data, the total iron concentration of source water was 800 µg/L. Iron concentrations reported by Battelle and CDPH were less than the respective reporting limits of 25 and 100 µg/L. According to VEETech, iron can bind to the surface of the HIX media, thus increasing the capacity and removal efficiency for arsenic. Manganese concentrations in source water were as low as 1.1 µg/L, which existed mainly in the soluble form.

Table 4-1. Upper Bodfish Well CH2-A Source Water Quality Data

Parameter	Unit	CDPH Data	Facility Data ^(a)	Battelle Data
<i>Date</i>		09/18/02–11/16/05	2002	10/14/04
pH	S.U.	7	7	NA
Temperature	°C	NA	NA	NA
DO	mg/L	NA	NA	NA
ORP	mV	NA	NA	NA
Total Alkalinity (as CaCO ₃)	mg/L	NA	85	85
Hardness (as CaCO ₃)	mg/L	83	86	91
Turbidity	NTU	0.1	NA	0.4
TDS	mg/L	229	NA	234
TOC	mg/L	NA	NA	<0.7
Nitrate (as N)	mg/L	1.0	NA	1.2
Nitrite (as N)	mg/L	<0.04	NA	<0.01
Ammonia (as N)	mg/L	NA	NA	<0.05
Chloride	mg/L	10.8	9	11.0
Fluoride	mg/L	1.1	NA	1.1
Sulfate	mg/L	38.6	38	36.0
Silica (as SiO ₂)	mg/L	NA	40	44.7
Orthophosphate (as PO ₄)	mg/L	NA	<0.07	<0.06
As(total)	µg/L	41.3	37	35.4
As (soluble)	µg/L	NA	NA	35.8
As (particulate)	µg/L	NA	NA	<0.1
As(III)	µg/L	NA	NA	0.8
As(V)	µg/L	NA	NA	35.0
Fe (total)	µg/L	<100	800	<25
Fe (soluble)	µg/L	NA	NA	<25
Mn (total)	µg/L	<20	20	1.1
Mn (soluble)	µg/L	NA	NA	0.8
U (total)	µg/L	27-35	30	31.5
U (soluble)	µg/L	NA	NA	31.7
Rn (total)	pCi/L	22,294–40,000	NA	NA
V (total)	µg/L	NA	NA	0.6
V (soluble)	µg/L	NA	NA	0.4
Na (total)	mg/L	27.6	28.0	36.7
Ca (total)	mg/L	35.2	34.0	32.5
Mg (total)	mg/L	1.7	2.0	2.5

(a) Provided by Cal Water to EPA for site selection.

NA = not available; TDS = total dissolved solids; TOC = total organic carbon

Competing Anions. Silica and phosphate are potential competing anions in source water. Concentrations of silica in source water ranged from 40 to 44.7 mg/L (as SiO₂), which, according to the vendor, might

accumulate on the HIX media to adversely affect the removal efficiency of arsenic and uranium. Phosphate concentrations in source water were below the detection limits of 0.06 and 0.07 mg/L as reported by Battelle and the facility, respectively.

Other Water Quality Parameters. pH values of raw water averaged 7.0, which is favorable for arsenic adsorption onto the HIX media; total alkalinity values averaged 85 mg/L (as CaCO₃), and fluoride averaged 1.1 mg/L. Sulfate concentrations ranged from 36 to 38.6 mg/L; sodium from 27.6 to 36.7 mg/L; calcium from 32.5 to 35.2 mg/L; magnesium from 1.7 to 2.5 mg/L; and chloride from 9 to 11.0 mg/L. The presence of these ions in source water was not expected to significantly affect the arsenic removal by the HIX media, however, sulfate and chloride could affect the uranium removal during the IX process.


4.1.2 Distribution System. The distribution system at the Upper Bodfish site consisted of approximately 200 connections supplied by Wells CH-1 and CH2-A (CH-3 was inactive). The distribution system piping materials included steel, polyvinyl chloride (PVC), and asbestos cement (AC). Service lines were typically composed of galvanized steel, copper, or PVC piping. Fire hydrant flushing was not performed regularly due to a water shortage by recent drought conditions. A blended poly- and ortho-phosphate solution has been used for iron sequestration and corrosion control in the distribution system. Due to exceedance over the copper action level, the LCR sampling program was conducted annually at 10 selected residences with the most recent sampling taking place in June 2003 and August 2004. In addition, samples were collected monthly from the distribution system for bacterial analysis.

4.2 Treatment Process Description

The HIX technology marketed by VEETech is a fixed bed adsorption system utilizing a hybrid polymeric-inorganic exchanger, known as ArsenX^{np}, for arsenic and uranium removal. Manufactured by Purolite, ArsenX^{np} incorporates nanoparticle technology originally developed by Dr. Arup SenGupta of Lehigh University, PA and further refined by SolmeteX, Inc., of Northborough, MA. ArsenX^{np} is NSF 61 certified for use in municipal water treatment systems. Table 4-2 presents physical and chemical properties of the media. ArsenX^{np} consists of hydrous iron oxide nanoparticles impregnated into a standard strong-base anion (SBA) exchange resin. The iron content is approximately 25% (as Fe by dry weight). The ArsenX^{np} media utilizes the iron chemistry to adsorb arsenic from water and simultaneously removes uranium by its base material – anionic exchange resin. The SBA resin is known for having a high selectivity and a high capacity for uranium removal (Clifford, 1999). Previous EPA studies suggested that the resin technology would be a cost-effective method for removing uranium from small community water supplies (Sorg, 1988). Ion exchange is listed as one of the Best Available Technologies (BATs) for uranium treatment.

Table 4-3 presents relevant specifications and key design parameters. Figure 4-3 is a piping and instrumentation diagram (P&ID). The system consists of two single-stage, fiberglass reinforced plastic (FRP) vessels connected in parallel. Each vessel is capable of treating 50 gpm of flow. During normal operations, one vessel is placed in service while the other is on standby. This configuration allows continuous system operation should one vessel be shipped off site for regeneration. Approximately 27 ft³ of ArsenX^{np} media was loaded into each vessel to a packing height of 2.8 ft. As water passed downwardly through the media bed, arsenic and uranium were removed via a combination of adsorption and IX processes. Mounted on a 16 ft long and 6 ft wide trailer for easy transportation, the system was instrumented with ball valves, gauges for pressure, temperature, and flow, and sample collection ports. Figure 4-4 presents the layout of the HIX system on the trailer. Figure 4-5 is a photograph of the trailer-mounted HIX system.

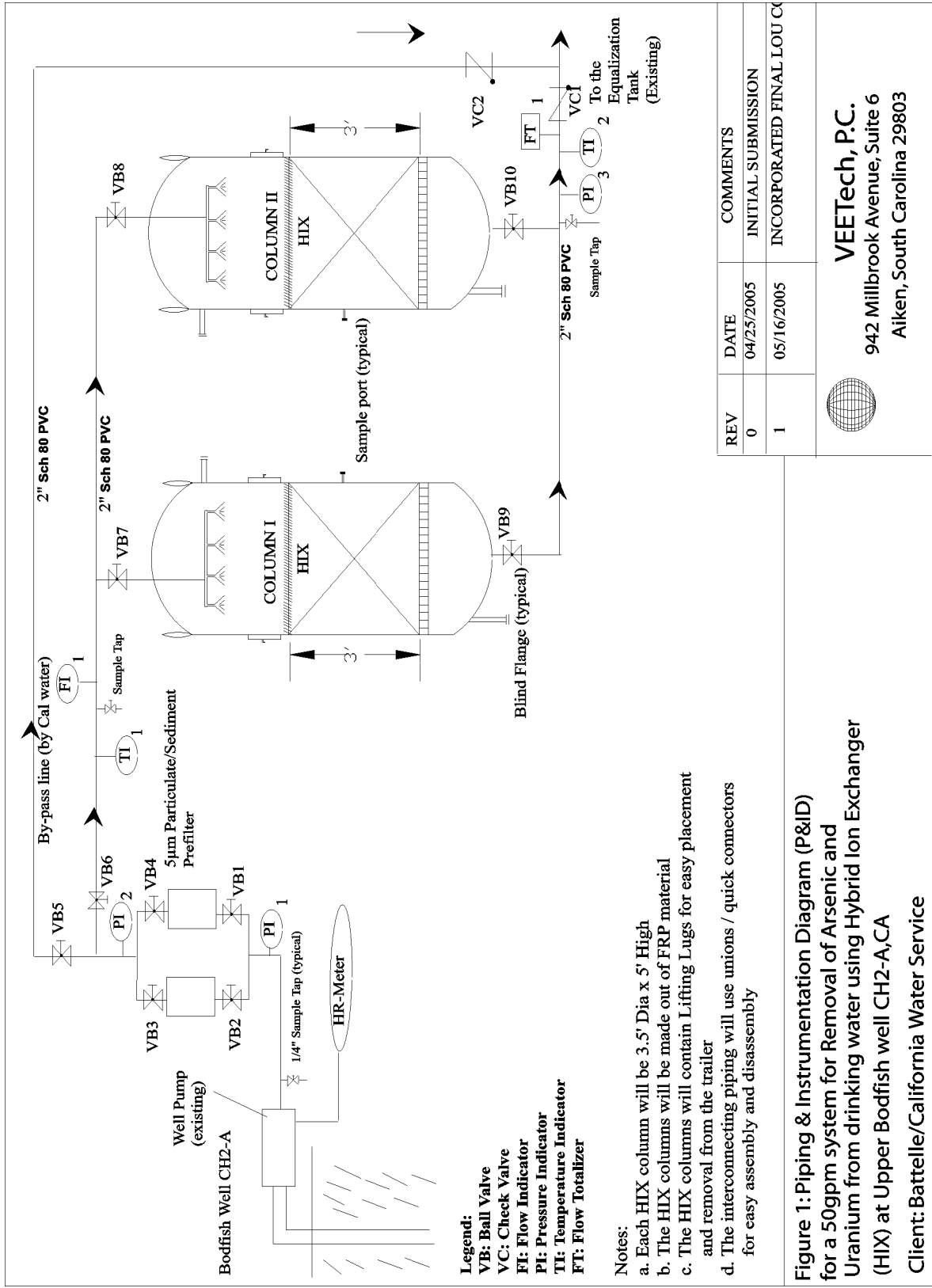
Table 4-2. Typical Physical and Chemical Properties of ArsenX^{np} Media

Parameter	Value
Physical Form and Appearance	Reddish-brown spherical beads 
Polymer Structure	Polystyrene crosslinked with divinyl benzene
Matrix Structure	Macro-porous matrix impregnated with iron nanoparticles
Bead Size (mm [mesh])	0.3–1.2 [16 × 50]
Bulk Density (lb/ft ³ [g/L])	49–52 [790–840]
Moisture Content (%)	55–60
Arsenic Capacity (g As/L)	0.5–4.0 (depending on raw water composition and operating conditions)
Contact Time (min)	2.5 to 3.0
Specific Service Flowrate (BV/h [gpm/ft ³])	Typical 20–24 [2.5–3.0] up to 43 [4.0]
Max. Operating Temperature (°C [°F])	80 [176]
Operational pH (S.U.)	4.5–8.5

Source: Purolite

Table 4-3. HIX System Specifications and Design Parameters

Design Parameter	Value	Remark
No. of Vessels	2	One in operation, one in stand-by
Vessel Size (in)	42 OD × 60 H	–
Type of Media	ArsenX ^{np}	
Quantity of Media (ft ³)	27	Per vessel
Backwash	None	–
Pressure Drop (psi)	3	1 psi/ft of media
Area of Cross Section (ft ²)	9.6	–
Media Bed Depth (ft)	2.8	–
Design Flowrate (gpm)	50	–
Peak Flowrate (gpm)	38	Based on well pump capacity
Hydraulic Loading (gpm/ft ²)	4.0	Based on 38 gpm flowrate
Specific Service Flow Rate (gpm/ft ³)	1.4	Based on 38 gpm flowrate
EBCT (min)	5.3	Based on 38 gpm flowrate
Estimated Working Capacity (BV)	15,000–20,000	Based on 10-µg/L arsenic breakthrough
Estimated Throughput to 10-µg/L As Breakthrough (gal)	3,000,000–4,000,000	1 BV = 202 gal
Average Daily Demand (gal)	22,800–34,200	10–15 hr of operation
Estimated Media Life (month)	4	–
No. of Regenerations (time/year)	3	–



- Legend:**
 VB: Ball Valve
 VC: Check Valve
 FI: Flow Indicator
 PI: Pressure Indicator
 TI: Temperature Indicator
 FT: Flow Totalizer

- Notes:**
 a. Each HIX column will be 3.5' Dia x 5' High
 b. The HIX columns will be made out of FRP material
 c. The HIX columns will contain Lifting Lugs for easy placement and removal from the trailer
 d. The interconnecting piping will use unions / quick connectors for easy assembly and disassembly

REV	DATE	COMMENTS
0	04/25/2005	INITIAL SUBMISSION
1	05/16/2005	INCORPORATED FINAL LOU CC



VEETech, P.C.
 942 Millbrook Avenue, Suite 6
 Aiken, South Carolina 29803

Figure 1: Piping & Instrumentation Diagram (P&ID) for a 50gpm system for Removal of Arsenic and Uranium from drinking water using Hybrid Ion Exchanger (HIX) at Upper Bodfish well CH2-A,CA
 Client: Battelle/California Water Service

Figure 4-3. P&ID of HIX Treatment System (Provided by VEE'Tech)

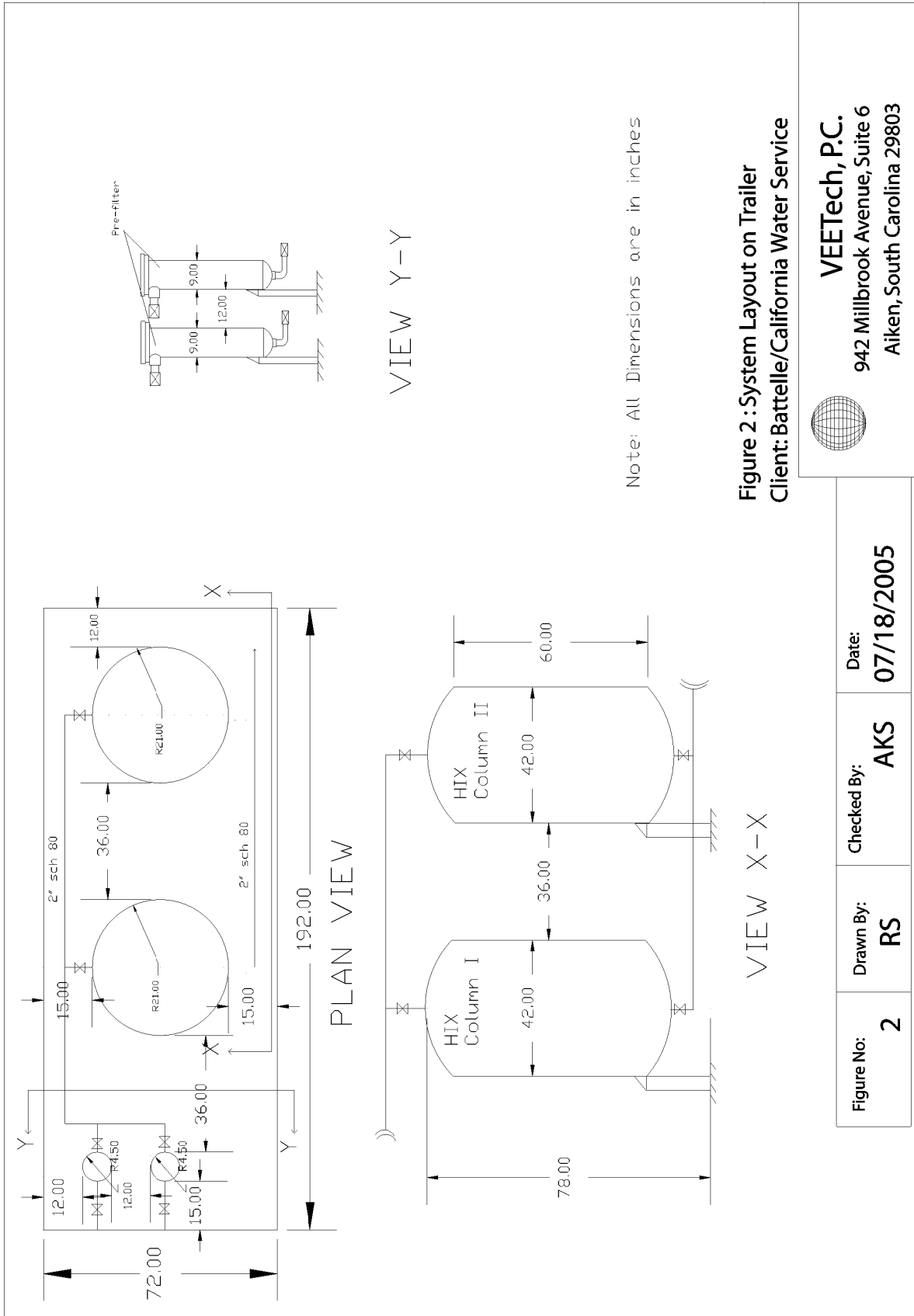


Figure 2 : System Layout on Trailer
Client: Battelle/California Water Service



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Figure 4-4. HIX System Layout on Trailer (Provided by VEETech)



Figure 4-5. Trailer-Mounted HIX System under a Canopy

The HIX treatment system includes the following major process steps and system components:

- **Intake** – Raw water from Well CH2-A was pumped to the system via a 3-hp pump that produced 38 gpm of flow. An hour meter was installed on the well pump to record the operation time.
- **Bag-Filter** – Two 1- μ m bag-filter assemblies were installed prior to the HIX vessels to remove sediment/particulate matter from the influent water. The bag-filter housing was 9-in in diameter and 3 ft high and constructed of stainless steel (Figure 4-6). Water passed through only one bag-filter assembly at any given time. Once the differential pressure reached 5 pounds per square inch (psi), flow was diverted to the second bag-filter assembly to allow the bag filter in the first assembly to be replaced. Historical data for the site indicated the presence of elevated silica concentrations. The insoluble silica can be removed along with sediments by the bag filter, thus eliminating the need for HIX vessel backwash.
- **HIX Media Vessels** – Each media vessel was 42-in in diameter by 60-in tall and contained approximately 27 ft³ of ArsenX^{np} media. Each vessel was equipped with lifting lugs to facilitate removal and placement of the vessel from and to the trailer, one pressure release port, and two sampling ports to draw samples of the media, if needed, for arsenic and uranium analysis. Under the peak flow rate of 38 gpm, the hydraulic loading rate to each vessel was 4.0 gpm/ft² and the empty bed contact time (EBCT) was 5.3 min. Figure 4-7 shows one media vessel and the associated lifting lugs (located at the bottom of the vessel), pressure release port (the left side arm extending from the top of the vessel), and media sampling ports (the middle and right side arms extending from the top of the vessel).
- **Media Vessel Regeneration and Rinsing** – When effluent arsenic or uranium concentrations exceed the respective MCL, water flow is diverted to the stand by vessel for continuous system operation and the spent media vessel is taken off-line and either regenerated or



Figure 4-6. Bag Filter Assemblies



Figure 4-7. HIX Media Vessel with Pressure Release Port and Media Sampling Ports

replaced. According to the vendor, the media can be regenerated and reused for up to 20 cycles based on the water chemistry of Well CH2-A. During this demonstration study period, bed breakthrough of arsenic at 10 µg/L occurred at approximately 33,100 BV and flow was diverted to the stand by column. Potential options for media regeneration or replacement are further discussed in Section 4.4.2.

- **Chlorine and Phosphate Addition** – Prior to entering the aerator, water was injected with chlorine for disinfection and phosphate for corrosion and scale control. A sodium hypochlorite (NaOCl) solution (prepared by adding 1 gal of a 12.5% solution into 15 gal of water) was stored in two 35-gal drums manifolded together and injected by a solenoid-driven metering pump with a maximum capacity of 1.0 gal/hr (gph). The target free chlorine residual was 1.0 to 1.5 mg/L (as Cl₂). A blended phosphate solution, SeaQuest, was diluted by mixing 1 lb of the solution into 7.5 gal of water in a 35-gal drum. The SeaQuest solution consisted of 22.7% (minimum) of polyphosphate and 7.6% (minimum) of orthophosphate, which provided sequestration for iron, manganese and hardness in water and corrosion control by forming a protective film on metal pipes in the distribution system. The diluted solution was injected by a similar solenoid-driven metering pump at a target level of 0.35 to 0.5 mg/L (as PO₄).
- **Aerator** – Effluent from the HIX system passed through the existing aerator to remove radon prior to entering the distribution system. The aerator was 7-ft in diameter and 12 ft tall with a storage capacity of 3,500 gal. Treated water entered the aerator through a 2-in galvanized steel pipe and a screened vent located at the top of the aerator to allow volatilized radon to dissipate to the atmosphere.
- **Booster Pump** – The treated water was pumped to the distribution system by a preexisting 10-hp booster pump.

4.3 System Installation

This section discusses system installation activities including permitting, building construction, and system shakedown.

4.3.1 Permitting. The permit application for the HIX system was simplified and expedited by CDPH because 1) only a “temporary” permit was granted and valid for the duration of the EPA demonstration study, and 2) waste disposal was not anticipated to be an issue considering that the HIX system would not require backwash and that any spent media would be shipped offsite for regeneration as originally proposed by the vendor.

The submittal for the permit application included a site plan prepared by Cal Water and documents prepared by VEETech, including HIX system diagrams, specifications, and an O&M manual. After the vendor incorporated review comments from Cal Water and Battelle, the submittal package was sent to CDPH for review on August 2, 2005. CDPH e-mailed its review comments to Cal Water on August 5, 2005, which were addressed in a revised O&M manual by VEETech on August 9, 2005. CDPH provided Approval-to-Construct on August 24, 2005.

According to CDPH, upon completion of the EPA demonstration study, a permanent permit must be secured by Cal Water if it plans on keeping the HIX system and continuing its operation. Cal Water also must comply with the California Environmental Quality Act (CEQA) requirements as part of the permitting process. A regular water supply permit application takes 30 days for initial completeness review by CDPH. Once the application has been determined complete, it normally takes 90 days to issue a final permit document.

4.3.2 Building Preparation. Cal Water opted to install a canopy-type enclosure around the HIX treatment system (Figure 4-5). Therefore, grading of the ground around the system was the only building preparation required. Manufactured by Carport Cover, the canopy was 12 ft wide, 21 ft long, and 10 ft high, with two extra panels. The cost of the canopy was approximately \$1,860.

4.3.3 Installation, Shakedown, and Startup. Following successful hydraulic testing of the system at Mobile Processing Technology (MPT's) Memphis, TN facility, the trailer-mounted HIX system was hauled to the site by a pickup truck on September 20, 2005, and arrived at the site on September 23, 2005. Cal Water plumbed the system between the well and the distribution system using 2-in diameter polyethylene piping and completed the system installation on September 29, 2005. VEETech was on site on October 3, 2005 to conduct the system shakedown and complete it the next day. The bacteriological test was passed on October 5, 2005.

During the startup trip in October, the vendor conducted operator training for system O&M. Battelle staff arrived at the site on October 12, 2005 to perform system inspections and conduct operator training for sampling and data collection. The first set of samples for the performance evaluation study was collected on October 13, 2005. No major mechanical or installation issues were identified at system start-up.

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters for the first 10 months of system operation were tabulated and are attached as Appendix A. Key parameters are summarized in Table 4-4. From October 13, 2005 through August 3, 2006, the system operated for 4,631 hr, based on the well pump hour meter readings collected daily. This cumulative operating time represents a use rate of 64% during this 43-week period. The system operated for 15.4 hr/day on average.

Table 4-4. Summary of HIX System Operation

Operational Parameter	Value/Condition
Duration	10/13/05–08/03/06
Cumulative Operating Time (hr)	4,631
Average Daily Operating Time (hr)	15.4
Cumulative Throughput (gal)	6,693,716
Cumulative Throughput (BV) ^(a)	33,137
Average (Range) of Flowrate (gpm)	24 (21–29)
Average (Range) of EBCT (min)	8.5 (6.9–9.5)
Average (Range) of Inlet Pressure (psi)	8.1 (1–13)
Average (Range) of Outlet Pressure (psi)	7.1 (2–11)
Average of Δp across System (psi)	1

(a) Calculated based on 27 ft³ of media in operating vessel.

During the first 10 months, the system treated 6,693,716 gal, or 33,137 BV, of water based on the totalizer readings on the operating vessel. Bed volume calculations were based on the 27 ft³ of media in the operating vessel. Flowrates to the system ranged from 21 to 29 gpm and averaged 24 gpm. The average system flowrate was 37% lower than the 38-gpm peak flowrate (Table 4-3) or 52% lower than the 50-gpm design flowrate. Based on the flowrates to the system, the EBCT for the operating vessel varied from 6.9 to 9.5 min and averaged 8.5 min. As a result, the actual EBCT was 37% (based on the peak flowrate) or 52% (based on the design flowrate) higher than the design EBCT of 5.3 min. The inlet and outlet pressure of the HIX system averaged 8.1 and 7.1 psi, respectively, indicating 1 psi of headloss

across the system. The pressure readings, however, were found to be inaccurate due to the use of pressure gauges with a span of 0 to 100 psi for this low pressure system. Prior to the installation of the HIX system, the wellhead pressure was approximately 10 psi, just enough to deliver water to the aerator.

4.4.2 Residual Management. Backwashing of the HIX system was not required, thus no wastewater was generated. The only residual generated by the HIX system operation was 27 ft³ of spent media. Depending on if and how the spent media is to be regenerated or replaced, arsenic- and/or uranium-laden wastewater may be produced. The vendor originally estimated that the media would process approximately 15,000 to 20,000 BV of water before it is taken offline and shipped to and regenerated through a proprietary process at MPT's facility in Memphis, TN. However, because the media actually processed approximately 33,100 BV of water and completely removed uranium from source water, the uranium loading on the HIX media was calculated to be approximately 0.13% (by weight) (see calculations in Section 4.5.1).

According to EPA's *A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies* (EPA, 2005), uranium is considered "source material" and may be subject to the Nuclear Regulatory Commission's (NRC's) licensing requirements if a water system generates uranium-containing residuals. However, uranium is exempt from NRC regulations if it makes up less than 0.05% (by weight), or an "unimportant quantity," of the residuals (10 CFR 40.13). Although it is not clear how this 0.05% is defined and how the "residuals" are quantified, there is a possibility that the spent media may be classified as non-exempt material, and can be subject to relevant regulations on storage, transportation, and disposal. If so, the spent media may not be regenerated at MPT's facility in Memphis, TN as planned because it is not licensed to process non-exempt material.

Three options were proposed by the vendor and are being evaluated for spent media disposition. These options assume that the uranium loading of the spent media indeed exceeds the 0.05% limit.

- Option 1: Partial onsite regeneration
- Option 2: Complete onsite regeneration
- Option 3: Disposal and replacement of spent media

Each of these options is described below.

Option 1: Partial Onsite Regeneration. This option involves regenerating the spent media with a brine solution in situ to reduce the uranium loading to below the "unimportant limit," followed by shipping the partially regenerated media to MPT's facility for further regeneration. Onsite regeneration is accomplished by applying a 10% brine solution at a flowrate of 5 to 6 gpm for over 30 min, rinsing the media with finished water, and collecting the spent brine and rinse water in separate storage tanks. Upon confirming that the uranium loading is below the 0.05% "unimportant limit," the media is shipped to MPT for further regeneration and the uranium-laden spent brine is disposed of in accordance with applicable regulations. According to the vendor, it may take three weeks for the partially-regenerated media to be regenerated and shipped back to the site.

One issue associated with offsite regeneration is that the regenerated media may lose its original NSF 61 certification and, therefore, may need to be recertified before use. A special committee led by NSF International and consisting of EPA officials, state regulators, and media manufacturers is currently preparing guidance documents to address the recertification issue of regenerated media. According to the vendor, regenerated ArsenX^{np} media (up to 10 times of regeneration) have already been certified to the NSF 61 standard by the Water Quality Association. Regardless, the use of regenerated media must be approved by CDPH.

Option 2: Complete Onsite Regeneration. This option involves sequential regeneration of uranium and, then, arsenic from the spent media. The vendor-provided regeneration procedure includes the following steps:

- 1) Backwashing the spent media at 15 gpm for about 20 min
- 2) Applying a 15% brine solution rinse at 2.5 to 3 gpm to strip uranium off the media
- 3) Backwashing the media again for about 10 min
- 4) Applying 500 gal of a 2% caustic and 1% brine solution at 3 gpm to strip arsenic from the media
- 5) Rinsing the media with 400 gal of well water at 15 to 20 gpm
- 6) Rinsing the media with 500 gal of either a 2% acetic acid solution or carbon dioxide-sparged water until a neutral pH is obtained in the effluent.

The HIX vessel can be placed back in service once the regeneration procedure is completed. One advantage of the complete onsite regeneration is that the media maintains its NSF certification after regeneration.

Complete onsite regeneration produces two types of residuals: a uranium- and, perhaps, arsenic-laden spent brine solution from Step 2 (and perhaps Step 3) and an arsenic-laden wastewater (if uranium is completely removed in Step 2) from the rest of the steps (backwashes, rinses, and drains). These wastes are disposed of in accordance with applicable regulations.

Option 3: Disposal and Replacement of Spent Media. This option is to simply remove the spent media from the HIX vessel for disposal and then reload virgin media into the vessel, like other single-use adsorptive media. Although no residuals are to be generated on site, the spent media contains 0.13% of uranium and 0.15% arsenic (both by weight). The spent media handling, including transportation and disposal, is still to be determined. This approach, however, is not economical because it does not take advantage of the regenerability of the resin-based media and it only utilizes a fraction of the media's uranium removal capacity.

System Reconfiguration. Another alternative being considered is to reconfigure the single-stage system into lead/lag operation, in which the effluent from the operating vessel (lead vessel), after arsenic breaks through from the lead vessel, is fed into the stand-by vessel (lag vessel) to further remove arsenic to less than 10 µg/L. The existing interconnecting piping on the system provides such flexibility to operate the vessels in series. Since uranium is preferred by an SBA resin more than any other anions (including sulfate and arsenate), the resin is expected to have a long run length before uranium breakthrough. (Note that a commonly used A300E resin can treat up to 100,000 to 200,000 BV for uranium.) In the lead/lag configuration, the lead vessel acts as the primary treatment for uranium, leaving a minimal uranium loading to the lag vessel. It may be economical to dispose of the uranium-laden media in the lead vessel after a yet-to-be-determined duration (e.g., not necessarily to the 30-µg/L uranium breakthrough) and reload the vessel with A300E, a less-expensive resin than ArsenX^{np}. As stated in an EPA document, "the use of IX for uranium removal required some caution in limiting the time of service of the exchange unit between regeneration cycles and over the full service life so that uranium in the resin does not become a difficult to manage 'source material' as defined by the Atomic Energy Act of 1954 as amended, per 10 CFR 20" (EPA, 2000a). The spent media in the lag vessel contains primarily arsenic which can be regenerated either on- or offsite without complications caused by uranium. The arsenic breakthrough from the lag vessel is likely to occur earlier than the uranium breakthrough from the lead vessel. Therefore, a third vessel may be required for continuous operation while the lag vessel is regenerated on or offsite.

A viable solution to handle the spent media generated at the site is currently being sought collectively by EPA, the vendor, Cal Water, and CDPH. The ultimate decision on spent media handling will be described in a final performance evaluation report.

4.4.3 System/Operation Reliability and Simplicity. There were no operational problems with the HIX system during the first 10 months of system operation, resulting in no unscheduled downtime for the system. The only problem arising during the study period was the inaccurate readings on the pressure gauges so that the pressure drop across the HIX vessel could not be determined. 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. The majority of arsenic at this site existed as As(V). As such, a preoxidation step was not required. The only pretreatment required was the use of a 1- μ m bag filter to remove sediments/particulate matter from the raw water. Post-treatments included aeration (for radon removal), post-chlorination, and zinc orthophosphate addition (for corrosion control), which had been practiced previously at the site.

System Controls. The HIX system was a passive system, requiring only the operation of the supply well pump to feed water through the vessels. The system does not contain any moving or rotating parts or equipment and all valves were manually activated. The inline flowmeter was solar powered so that the only electrical power required was that needed to run the supply well pump. The system operation was controlled manually, but would shut off once the aeration tank was full.

Operator Skill Requirements. Under normal operating conditions, the skill requirements to operate the system were minimal. The operator was on site typically five times a week and spent approximately 10 min each day performing visual inspections and recording system operating parameters on the daily log sheets. The operator replaced the bag filter periodically. Normal operations of the system did not require additional skills beyond those necessary to operate the existing water supply equipment.

The State of California requires that all individuals who operate or supervise the operation of a drinking water treatment facility must possess a water treatment operator certificate and those who make decisions on maintenance and operation of any portion of the distribution system must possess a distribution operator certificate (CDPH, 2001). Operator certifications are granted by CDPH after minimum requirements are met, which include passing an examination and maintaining a minimum amount of hours of specialized training. There are five grades of operators for both the water treatment (i.e., T1 to T5) and distribution (i.e., D1 to D5), with T5 and D5 being the highest. The operator for the Upper Bodfish water system possessed T2 and D2 certifications for treatment and distribution, respectively.

Preventive Maintenance Activities. Preventive maintenance tasks included such items as periodic checks of flowmeters and pressure gauges and inspection of system piping and valves. As recommended by the vendor, bag filters should be replaced after the differential pressure across the filter had reached 5 psi. However, the differential pressure across the filter had been showing negative values due to inaccurate pressure readings. The operator used his own judgment to change out the filter periodically. Typically, the operator performed these duties only when he was on site for routine activities.

Chemical/Media Handling and Inventory Requirements. After installation of the HIX system, chlorine and phosphate addition continued at the Upper Bodfish site. Inventory requirements for these two chemicals remained the same as before. The only inventory requirement associated with the HIX system was to keep additional bag filters onsite to facilitate change-out when needed.

4.5 System Performance

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

4.5.1 Treatment Plant Sampling. Treatment plant water samples were collected at IN, BF, and AF sampling locations across the treatment train on 29 occasions, including three duplicates, with field speciation performed in 11 of the 29 occasions. Table 4-5 summarizes the analytical results for arsenic, uranium, iron, and manganese; Table 4-6 summarizes the results of other water quality parameters. Appendix B contains a complete set of analytical results through this 10-month study period. The results of the water samples collected throughout the treatment plant are discussed below.

Arsenic Removal. Figure 4-8 contains three bar charts showing the concentrations of total As, particulate As, and As(III) and As(V) of the soluble fraction at the IN, BF, and AF sampling locations for each of the 11 speciation events. Total As concentrations in raw water ranged from 36.5 to 47.3 $\mu\text{g/L}$ and averaged 40.8 $\mu\text{g/L}$. Of the soluble fraction, As(V) was the predominating species, ranging from 36.3 to 44.9 $\mu\text{g/L}$ and averaging 40.9 $\mu\text{g/L}$. The particulate As concentrations were low, averaging 0.5 $\mu\text{g/L}$. The arsenic concentrations were consistent with those measured during source water sampling in October 2004 (Table 4-1).

The key parameters for evaluating the effectiveness of the HIX system were arsenic and uranium concentrations in treated water, which were plotted in Figures 4-9 and 4-10, respectively. Arsenic concentrations in treated water gradually increased from <0.1 to 10.5 $\mu\text{g/L}$ after treating approximately 33,100 BV of water, which was 65% higher than the vendor's estimated 20,000 BV. The average flowrate to the system was 52% lower than the 50-gpm design flow value (Table 4-3); thus the actual EBCT was 112% longer than the design EBCT. The longer EBCT may have contributed, in part, to the better-than-expected media performance.

As part of another EPA study (Westerhoff et al., 2007), a rapid small-scale column test (RSSCT) was conducted in the laboratory by Battelle and Arizona State University to evaluate the arsenic and uranium removal from the Upper Bodfish water by five different adsorptive media, including ArsenX^{np}, E33, GFH, MetsorbG, and Adsorbsia GTO (the last two are titania-based media). Figures 4-11 and 4-12 present the arsenic and uranium breakthrough curves from the RSSCT columns, respectively. Table 4-7 summarizes the run length of each media observed in the full-scale system and RSSCTs. All RSSCT columns were scaled to a 5.3 min full-scale EBCT except for the two titania-based media, which were scaled to 2.5 min EBCT. As shown in Figure 4-11, the two iron-based media, E33 and GFH, exhibited the best arsenic removal, with a run length of approximately 44,000 and 50,000 BV, respectively. ArsenX^{np} achieved a run length of approximately 28,000 BV, similar to the 33,100 BV observed from the full-scale system. MetsorbG and Adsorbsia GTO had a rather short run length of approximately 21,000 and 16,000 BV, respectively.

Based on the system throughput and arsenic concentrations before and after the treatment during the 10-month operation, the mass of arsenic removed by the media was estimated to be 984 g. The weight of 27 ft³ of media in one vessel was 1,404 lb (i.e., 637 kg) based on the bulk density of 52 lb/ft³. Therefore, the arsenic loading onto the media was approximately 1.5 g/kg of media or 0.15% (by weight).

Uranium Removal. Originating from rocks and mineral deposits, uranium found in most drinking water sources is naturally occurring and contains three isotopes: U-238 (over 99% by weight), U-235, and U-234. Due to varying amounts of each isotope in the water, the ratio of uranium concentration ($\mu\text{g/L}$) to activity (pCi/L) varies with drinking water sources from region to region. Based on considerations of

kidney toxicity and carcinogenicity, EPA proposed a uranium MCL of 20 µg/L in 1991 (corresponding to 30 pCi/L based on a mass/activity ratio of 1.5 pCi/µg); the final rule was set at 30 µg/L in December 2000 after the conversion factor was revised to 1 pCi/µg (EPA, 2000b). California adopted revisions in the radionuclide regulations in June 2006 (<http://www.dhs.ca.gov/ps/ddwem/Regulations/R-12-02/PDFs/R-12-02-FINALRegText.pdf>). The California current MCL for uranium is 20 pCi/L, which is equivalent to 30 µg/L (same as the federal MCL) using a conversion factor of 0.67 pCi/µg (Note: in California, a conversion factor of 0.67 pCi/µg is used to convert uranium from activity to mass). In this study, uranium was analyzed by an ICP-MS method (EPA Method 200.8) with the results expressed in µg/L. Uranium activity (pCi/L) was not reported herein to avoid potential confusion associated with the use of different conversion factors.

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

Parameter	Sampling Location	Sample Count	Concentration (µg/L)			Standard Deviation
			Minimum	Maximum	Average	
As (total)	IN	29	36.5	47.3	40.8	2.4
	BF	29	35.8	45.8	40.5	2.4
	AF	29	<0.1	10.5	_(a)	_(a)
As (soluble)	IN	11	36.6	45.2	41.4	2.8
	BF	11	36.5	45.2	41.4	2.7
	AF	11	0.12	10.3	_(a)	_(a)
As (particulate)	IN	11	<0.1	2.1	0.5	0.7
	BF	11	<0.1	1.5	0.5	0.6
	AF	11	<0.1	<0.1	_(a)	_(a)
As(III)	IN	11	0.13	0.9	0.5	0.3
	BF	11	0.13	0.8	0.4	0.3
	AF	11	<0.1	1.0	_(a)	_(a)
As(V)	IN	11	36.3	44.9	40.9	2.8
	BF	11	36.2	44.5	41.0	2.7
	AF	11	<0.1	10.1	_(a)	_(a)
U (total)	IN	29	26.6	38.9	33.0	3.1
	BF	29	26.6	38.7	32.6	2.9
	AF	29	<0.1	<0.1	<0.1	0.0
U (soluble)	IN	11	31.2	37.9	34.2	2.0
	BF	11	30.5	38.1	33.9	2.4
	AF	11	<0.1	<0.1	0.05	0.0
Fe (total)	IN	29	<25	41	13	5.3
	BF	29	<25	40	13	5.1
	AF	29	<25	<25	<25	0.0
Fe (soluble)	IN	11	<25	<25	<25	0.0
	BF	11	<25	<25	<25	0.0
	AF	11	<25	<25	<25	0.0
Mn (total)	IN	29	<0.1	0.9	0.3	0.2
	BF	29	<0.1	1.0	0.3	0.3
	AF	29	<0.1	1.7	0.5	0.4
Mn (soluble)	IN	11	<0.1	0.8	0.3	0.3
	BF	11	<0.1	1.1	0.3	0.3
	AF	11	0.2	1.6	0.5	0.4

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

Duplicate samples included in calculations.

(a) Statistics not meaningful; see arsenic breakthrough curves at AF location in Figure 4-9.

Table 4-6. 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	28	88.0	145	101	9.7
	BF	mg/L	29	92.0	132	100	7.2
	AF	mg/L	29	88.0	132	101	7.3
Fluoride	IN	mg/L	11	0.9	1.3	1.1	0.1
	BF	mg/L	11	1.0	1.6	1.2	0.2
	AF	mg/L	11	1.0	1.4	1.2	0.1
Sulfate	IN	mg/L	11	36.0	41.0	38.7	2.0
	BF	mg/L	11	35.0	43.0	39.4	2.5
	AF	mg/L	11	35.0	42.0	38.7	2.4
Nitrate (as N)	IN	mg/L	11	0.9	1.3	1.1	0.1
	BF	mg/L	11	0.9	1.3	1.1	0.1
	AF	mg/L	11	0.1	1.7	1.0	0.4
Total P (as P)	IN	mg/L	28	<0.01	0.02	0.01	0.0
	BF	mg/L	28	<0.01	0.02	0.01	0.0
	AF	mg/L	28	<0.01	<0.01	<0.01	0.0
Silica (as SiO ₂)	IN	mg/L	29	39.5	47.5	43.4	1.5
	BF	mg/L	29	41.0	48.2	43.4	1.4
	AF	mg/L	29	15.9	46.7	41.4	6.4
Turbidity	IN	NTU	29	<0.1	1.8	0.5	0.4
	BF	NTU	29	<0.1	1.7	0.4	0.3
	AF	NTU	29	<0.1	1.6	0.4	0.3
pH	IN	S.U.	25	6.8	7.2	7.0	0.1
	BF	S.U.	25	6.8	7.1	6.9	0.1
	AF	S.U.	25	6.4	7.3	6.9	0.2
Temperature	IN	°C	25	8.2	25.0	18.0	4.7
	BF	°C	25	9.3	25.0	17.6	4.4
	AF	°C	25	10.6	25.0	17.7	4.2
DO	IN	mg/L	21	1.6	4.3	2.5	0.7
	BF	mg/L	21	1.5	3.7	2.4	0.6
	AF	mg/L	21	1.5	3.8	2.3	0.6
ORP	IN	mV	24	198	479	376	75.8
	BF	mV	24	195	489	355	89.0
	AF	mV	24	205	495	338	95.9
Total Hardness (as CaCO ₃)	IN	mg/L	29	69.6	95.7	89.6	5.8
	BF	mg/L	29	60.0	89.3	82.7	6.0
	AF	mg/L	29	60.1	92.3	83.5	6.4
Ca Hardness (as CaCO ₃)	IN	mg/L	29	60.6	90.0	82.7	6.1
	BF	mg/L	29	60.0	89.3	82.7	6.0
	AF	mg/L	29	60.1	92.3	83.5	6.4
Mg Hardness (as CaCO ₃)	IN	mg/L	29	5.6	10.4	6.9	1.1
	BF	mg/L	29	4.5	10.6	6.9	1.2
	AF	mg/L	29	5.5	10.3	6.9	1.1

One-half of detection limit used for concentrations less than detection limit for calculations.
Duplicate samples included in calculations.

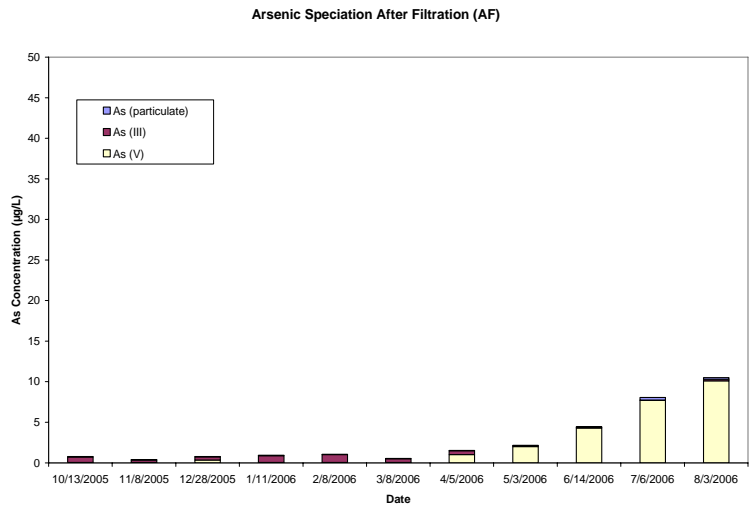
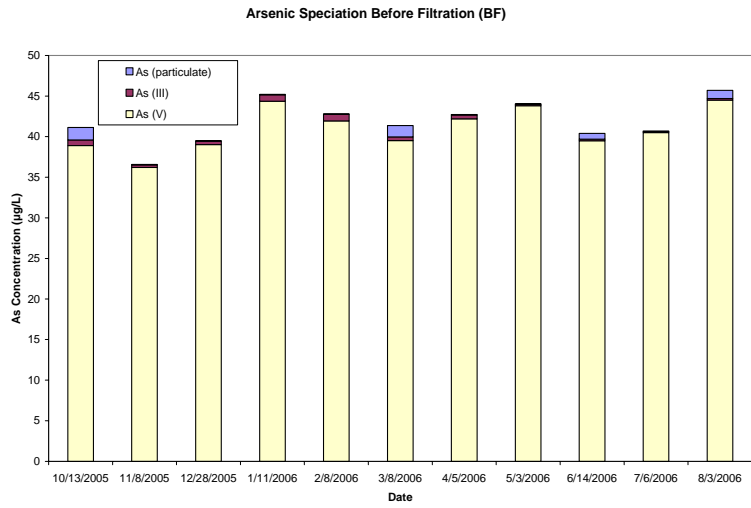
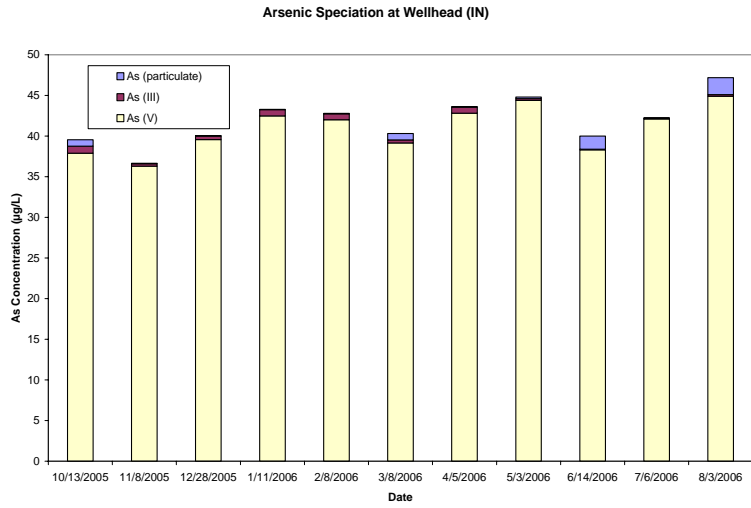


Figure 4-8. Concentrations of Various Arsenic Species at IN, BF, and AF Sampling Locations

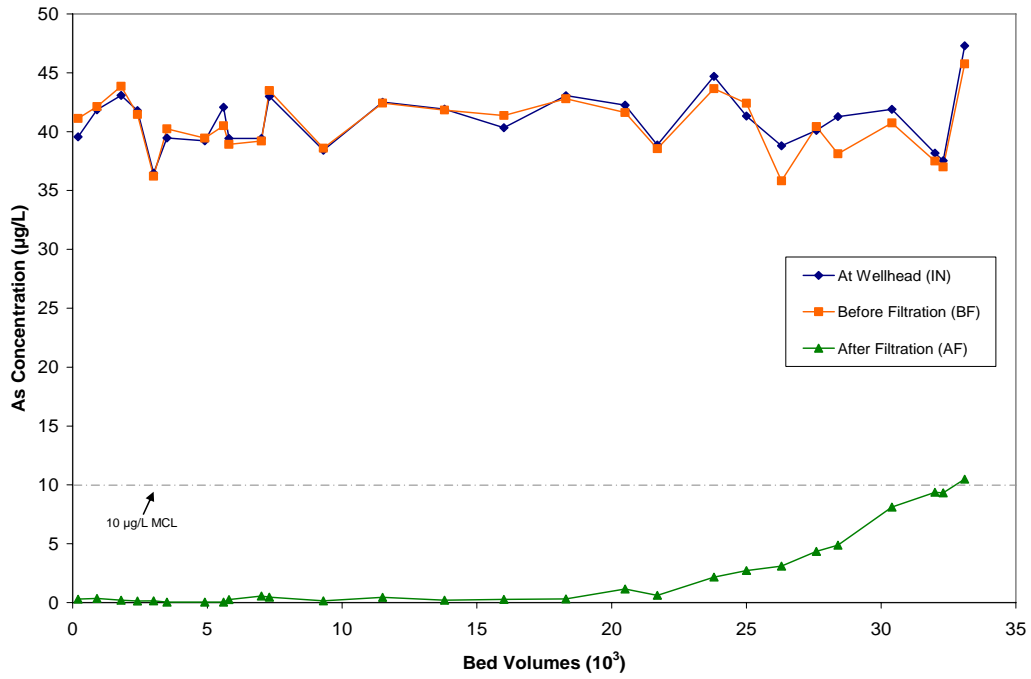


Figure 4-9. Total Arsenic Breakthrough Curve – Full-Scale System

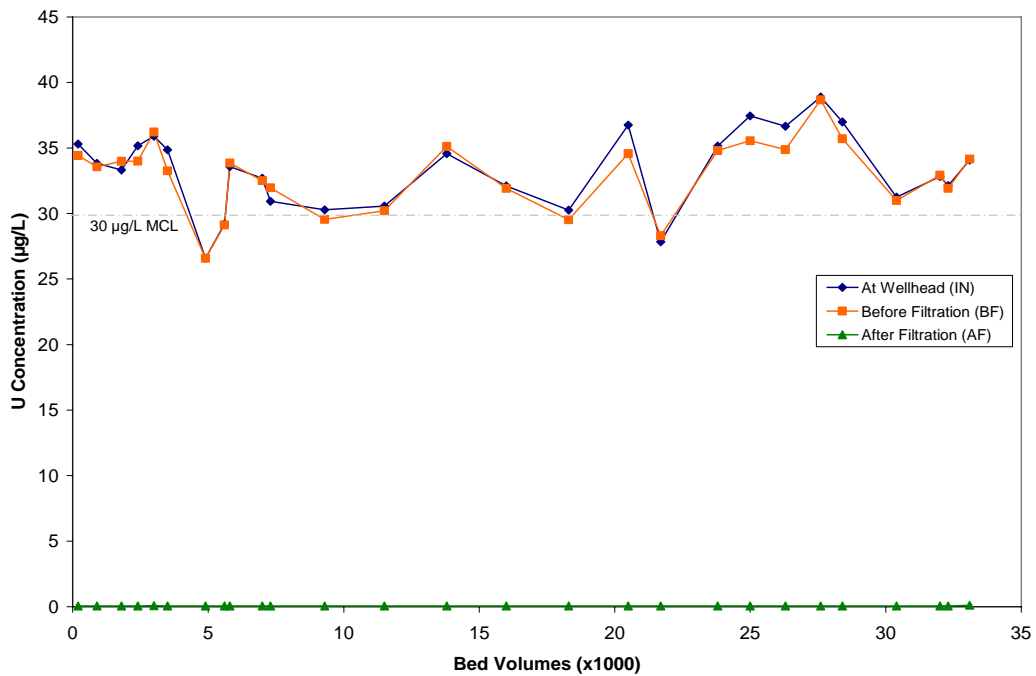
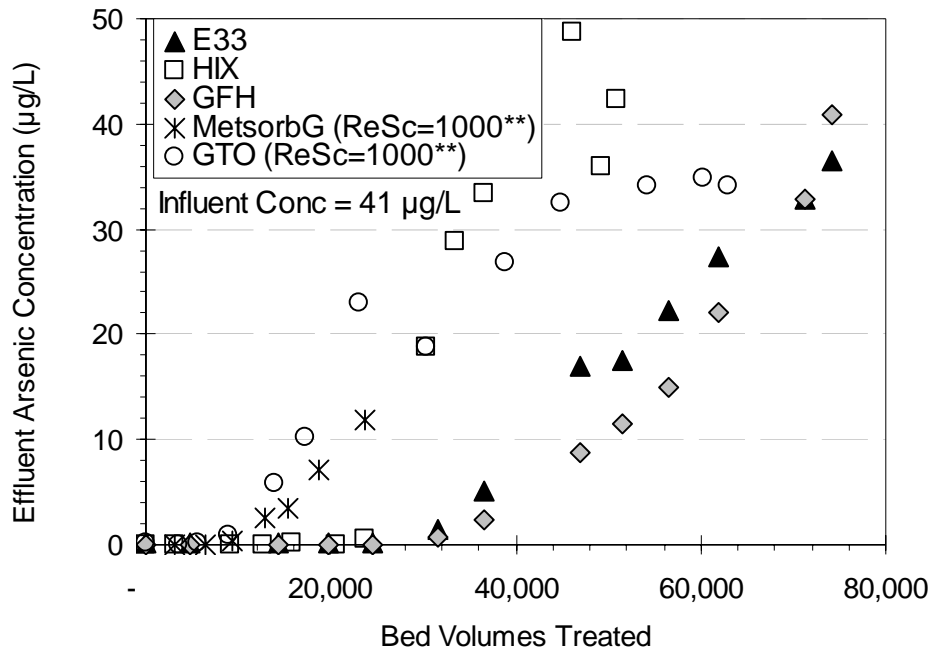
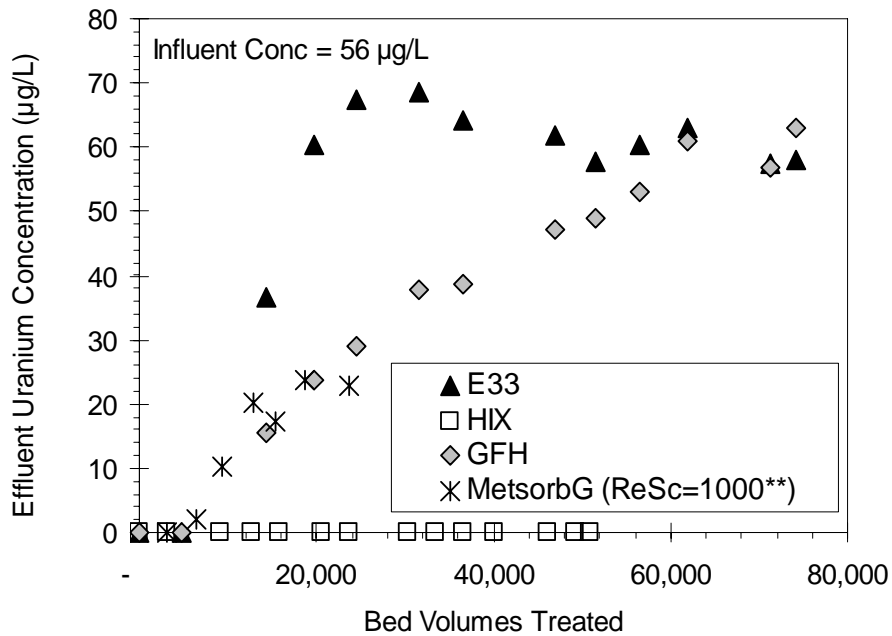


Figure 4-10. Total Uranium Breakthrough Curve – Full-Scale System



(Source: Westerhoff et al., 2007)

Figure 4-11. Total Arsenic Breakthrough Curves – Laboratory RSSCT



(Source: Westerhoff et al., 2007)

Figure 4-12. Uranium Breakthrough Curves – Laboratory RSSCT

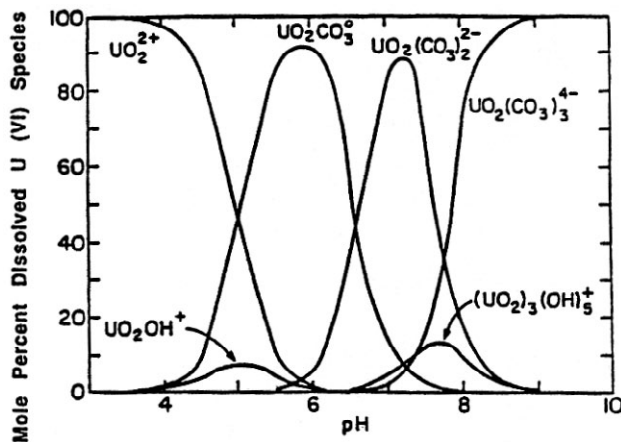
Table 4-7. Comparison of Full-Scale System and Laboratory RSSCT Media Run Lengths

Test	Media	Media Run Length (BV)	
		10- $\mu\text{g/L}$ Arsenic	30- $\mu\text{g/L}$ Uranium
Full-Scale	ArsenX ^{np}	33,100	> 33,100
RSSCT	ArsenX ^{np}	28,000	> 50,000
	E33	44,000	12,000
	GFH	50,000	25,000
	MetsorbG	21,000	> 24,000 ^(a)
	Adsorbsia GTO	16,000	26,000

(a) Column failed at about 24,000 BV due to pressure buildup and bed compaction

Total uranium concentrations in raw water ranged from 26.6 to 38.9 $\mu\text{g/L}$ and averaged 33.0 $\mu\text{g/L}$, which were consistent with previous data shown in Table 4-1. Figure 4-10 shows that uranium was completely removed to below the 0.1- $\mu\text{g/L}$ detection limit throughout the 10-month period. Based on the system throughput and the average uranium concentrations before and after the treatment system, the mass of uranium removed by ArsenX^{np} media was estimated to be 835 g. The weight of 27 ft³ of media in one vessel was calculated to be 1,404 lb (i.e., 637 kg) based on the bulk density of 52 lb/ft³. Therefore, the uranium loading on the HIX media was calculated to be 1.3 $\mu\text{g/mg}$ of media or 0.13% (by weight). Figure 4-12 presents the uranium breakthrough curves from the RSSCT columns. ArsenX^{np} removed uranium better than the other four media and it continued to remove uranium to less than 1 $\mu\text{g/L}$ as sampling was discontinued at about 50,000 BV due to complete arsenic breakthrough.

Uranium has four oxidation states: III, IV, V, and VI; only the IV and VI oxidation states are stable. The most stable state of uranium in aerated aqueous solution under acidic conditions (pH < 5.0) is UO_2^{2+} , which forms soluble complexes with common anions in water, such as CO_3^{2-} , F⁻, Cl⁻, NO_3^- , SO_4^{2-} , and HPO_4^{2-} . Carbonate is the most important uranium ligand in natural water. Figure 4-13 presents the distribution of uranium carbonate and hydroxide complexes as a function of pH in aerobic groundwater at a CO_2 partial pressure of 0.01 atmospheres (Langmuir, 1978). Under neutral and slightly alkaline conditions, UO_2^{2+} combines with bicarbonate and carbonate anions to form uranyl carbonates, $\text{UO}_2(\text{CO}_3)_2^{2-}$ and $\text{UO}_2(\text{CO}_3)_3^{4-}$, which have a strong affinity for IX resins.



(Source: Langmuir, 1978)

Figure 4-13. Distribution of Uranium Carbonate and Hydroxide Complexes as a Function of pH

In many bench, pilot, and full-scale uranium IX studies, SBA resins have demonstrated enormous capacities for the uranyl carbonate complexes – $\text{UO}_2(\text{CO}_3)_2^{2-}$ and $\text{UO}_2(\text{CO}_3)_3^{4-}$. For example, in a pilot-scale study conducted at Chimney Hill, Texas (Zhang and Clifford, 1994; Clifford and Zhang, 1995), a SBA column was operated continuously for 478 days for a total throughput of 302,000 BV at pH 7.6 to 8.2. The feed water contained 120 $\mu\text{g/L}$ uranium and 25 pCi/L of radium in a background water quality of 310 mg/L TDS, 150 mg/L alkalinity, 47 mg/L chloride, and <1 mg/L sulfate (very low sulfate water). Despite the high uranium capacity, IX systems generally are not operated for 500 days to uranium breakthrough because of problems with resin fouling and excessive pressure drop. Run lengths in the range of 30,000 to 50,000 BV would be more appropriate for uranium removal from drinking water (Clifford, 1999).

Effect of pH and Silica. The effective operational life of ArsenX^{np} is strongly influenced by the pH and silica concentration of the water, and decreases strongly as both pH and silica increase. It is known that the capacity of iron-based media for arsenic decreases as the pH increases. The pH values of raw water measured at the IN sampling location ranged from 6.8 to 7.2 and averaged 7.0 (Table 4-6). This near-neutral pH condition is desirable for metal oxide adsorptive media to remove arsenic.

Several batch and column studies found that silica reduced arsenic adsorptive capacity of ferric oxides/hydroxides and activated alumina (Meng et al., 2000; Meng et al., 2002; Smith and Edwards, 2005). Mechanisms proposed to describe the role of silica in iron-silica and iron-arsenic-silica systems included: 1) adsorption of silica may change the surface properties of adsorbents by lowering the isoelectric point or pH_{zpc} , 2) silica may compete for arsenic adsorptive sites, 3) polymerization of silica may accelerate silica sorption and lower the available surface sites for arsenic adsorption, and 4) reaction of silica with divalent cations, such as calcium, magnesium and barium, may form precipitates. Laboratory data provided by Solmetex showed that the effect of silica is most noticeable at pH values 8 or above and that ArsenX^{np} can tolerate the presence of 30 mg/L silica at neutral pH. Figure 4-14 plots the silica concentrations across the treatment train. The HIX system initially reduced silica concentrations; however, silica breakthrough occurred after treating approximately 1,000 BV. Silica concentrations in raw water and treated water averaged 43.4 and 41.4 mg/L, respectively.

Effect of Other Water Quality Parameters. Alkalinity ranged from 88 to 145 mg/L (as CaCO_3) in raw water and remained unchanged after treatment. Sulfate, fluoride, and nitrate were measured monthly; their concentrations in raw water ranged from 36 to 41 mg/L for sulfate, 0.9 to 1.3 mg/L for fluoride, and 0.9 to 1.3 mg/L (as N) for nitrate and remained unchanged after treatment. Therefore, ArsenX^{np} did not seem to alter the concentrations of these common anions in the water. Although it is possible that some sulfate might have been removed by the anionic resin substrate of ArsenX^{np}, the sulfate breakthrough had occurred so quickly that even the first sample (collected at 200 BV) did not show apparent sulfate removal.

DO levels in raw water ranged from 1.6 to 4.3 mg/L and averaged 2.5 mg/L; ORP readings of raw water ranged from 198 to 479 mV and averaged 376 mV (excluding one outlier on November 2, 2005). Both parameters indicated that the well water was oxidizing, which was consistent with the presence of As(V) in water. Although the data showed some variations from time to time, the range and average of the DO and ORP measurements at IN, BF, and AF locations were very similar, resulting in little or no changes after treatment.

Total iron concentrations were below the detection limit of 25 $\mu\text{g/L}$ for all the measurements, except for one detection of 41 $\mu\text{g/L}$ at IN and 40 $\mu\text{g/L}$ at BF on January 4, 2006 (Appendix B). Total manganese levels ranged from below 0.1 $\mu\text{g/L}$ to 1.7 $\mu\text{g/L}$ for all the measurements with no significant changes after treatment. Total hardness ranged from 60.0 to 95.7 mg/L (as CaCO_3), and also remained relatively constant throughout the treatment train.

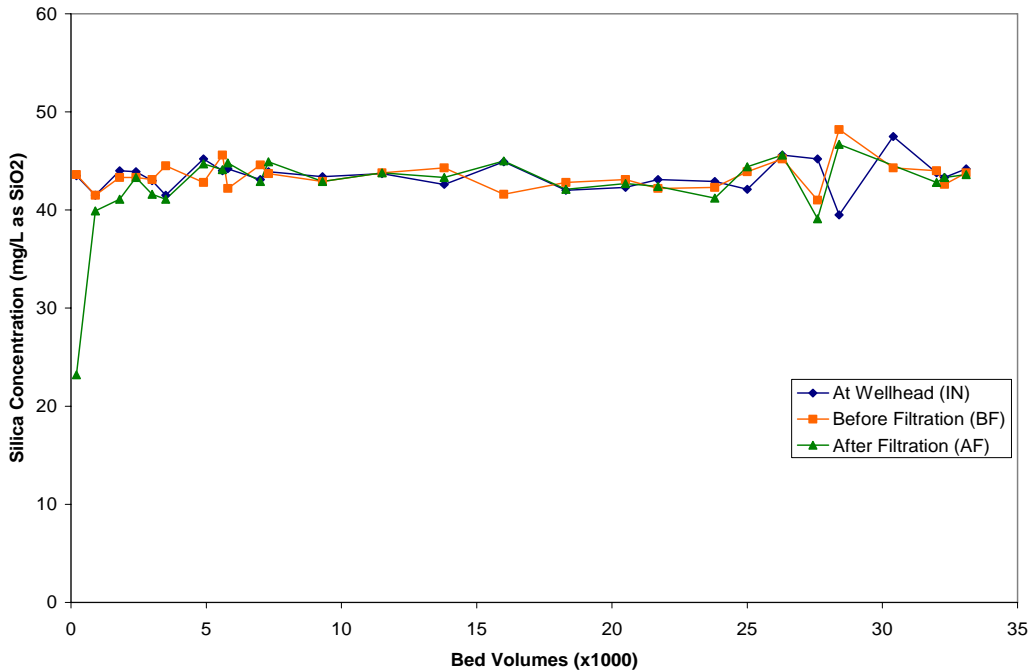


Figure 4-14. Silica Breakthrough Curve – Full-Scale System

4.5.2 Distribution System Water Sampling. Distribution water samples were collected at three residences before and after the installation/operation of the HIX system to determine whether the HIX system had any impacts on the lead and copper levels and water chemistry in the distribution system. The samples were analyzed for pH, alkalinity, arsenic, iron, manganese, lead, and copper; the results are presented in Table 4-8. Uranium was not monitored because of its absence in the plant effluent.

The most noticeable change in the distribution system after HIX system startup was the reduction in arsenic concentrations at each of the sampling locations, as shown in Figure 4-15. Baseline arsenic concentrations ranged from 16.2 to 44.2 $\mu\text{g/L}$ and averaged 26.2 $\mu\text{g/L}$ at all three locations, which did not resemble those of Well CH2-A, which ranged from 36.5 to 47.3 $\mu\text{g/L}$ and averaged 40.8 $\mu\text{g/L}$ during the study period (Section 4.5.1). The distribution system was supplied primarily by Well CH-1 (it did not contain elevated arsenic or uranium) with Well CH2-A as a backup well prior to the HIX system startup (see Section 4.1). Although only DS2 was served primarily by Well CH2-A, all three locations exhibited similar trends in arsenic concentrations after the HIX system startup: the arsenic concentrations at the DS locations initially decreased gradually but were much higher than those in the plant effluent, which were below 1 $\mu\text{g/L}$; then the arsenic concentrations at the DS locations began to climb, following the arsenic breakthrough behavior of the plant effluent. The arsenic concentrations were higher than those in the plant effluent most of the time, suggesting that possible solubilization, destabilization, and/or desorption of arsenic-laden particles/scales might have occurred in the distribution system (Lytle, 2005).

Table 4-8. Distribution System Sampling Results

Sampling Event	DS1										DS2										DS3													
	Non-LCR Residence					LCR Residence					Non-LCR Residence					LCR Residence					Non-LCR Residence					LCR Residence								
	1st draw					1st draw					1st draw					1st draw					1st draw					1st draw								
No.	Date	Stagnation Time	pH	Alkalinity (as CaCO ₃)	As	Tb	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity (as CaCO ₃)	As	Tb	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity (as CaCO ₃)	As	Tb	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity (as CaCO ₃)	As	Tb	Mn	Pb	Cu	
	hrs	S.U.	mg/L	µg/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	µg/L	hrs	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	
BL1	08/10/05 ^(a)	7.5	7.1	106	35.6	<25	0.2	0.4	585	7.0	7.1	101	30.8	<25	1.0	13.9	57.0	8.8	7.1	128	29.5	630	4.1	16.4	42.4									
BL2	08/30/05 ^(b)	NA	6.7	101	44.2	<25	<0.1	0.5	636	6.5	NA ^(c)	NA ^(c)	25.6	<25	2.8	6.1	23.2	8.6	7.0	97	34.1	<25	0.2	1.1	54.1									
BL3	09/13/05	NA	7.0	101	20.3	<25	0.2	0.8	860	7.5	7.1	114	17.6	35	1.1	2.9	92.2	7.3	6.8	110	19.8	<25	0.2	1.5	74.5									
BL4	09/28/05	NA	6.7	110	16.2	<25	0.3	0.8	1213	8.8	6.9	101	17.8	<25	0.6	9.2	97.2	7.5	6.9	110	23.3	<25	0.3	2.2	113									
1	10/26/05	NA	7.1	92	7.3	<25	0.5	0.7	1304	6.8	7.1	92	7.9	<25	0.9	2.1	91.9	7.7	7.1	88	5.0	<25	0.1	0.9	84.4									
2	12/08/05	NA	7.2	88	3.4	<25	0.4	<0.1	592	6.0	7.3	101	6.6	<25	2.5	2.3	14.6	8.0	7.4	110	2.5	<25	0.2	0.3	14.8									
3	01/04/06	8.0	7.4	101	3.4	<25	<0.1	0.8	1473	8.2	7.5	106	5.6	34	<0.1	6.4	68.6	6.0	7.4	101	2.2	<25	<0.1	1.0	100									
4	02/22/06	5.8	7.6	104	1.4	<25	<0.1	0.1	528	6.0	7.6	104	1.9	<25	0.5	1.1	50.1	7.7	7.4	104	1.1	<25	<0.1	0.7	49.8									
5	03/22/06	7.0	7.5	103	1.3	<25	0.3	0.3	1390	1.9	7.4	103	0.9	<25	0.5	1.3	49.0	6.5	7.3	103	1.1	<25	0.7	1.9	136									
6	04/26/06	13.0	7.3	104	4.3	<25	0.3	0.1	540	6.5	7.3	104	8.6	<25	0.6	6.2	73.2																	
7	05/17/06	8.0	7.1	101	10.8	<25	0.2	<0.1	141	6.0	7.2	101	13.2	<25	0.2	1.3	10.1	7.5	7.2	97	6.2	<25	<0.1	0.2	26.5									
8	06/22/06	8.5	7.1	100	11.4	<25	0.1	<0.1	190	NA ^(d)	7.1	96	13.4	<25	0.1	1.3	6.6	7.0	7.1	100	9.9	<25	0.2	0.8	24.6									
9	07/19/06	8.3	7.3	101	12.4	<25	0.5	0.6	1035	7.0	7.2	109	14.1	58	1.0	6.8	101																	

(a) Sample DS1 collected on 08/11/05.

(b) Sample DS2 collected on 08/31/05.

(c) Sample outside of holding time for laboratory analysis.

(d) Blending with untreated Well CH-1 due to increased water demand.

BL = baseline sampling; NA = data not available; NS = not sampled

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

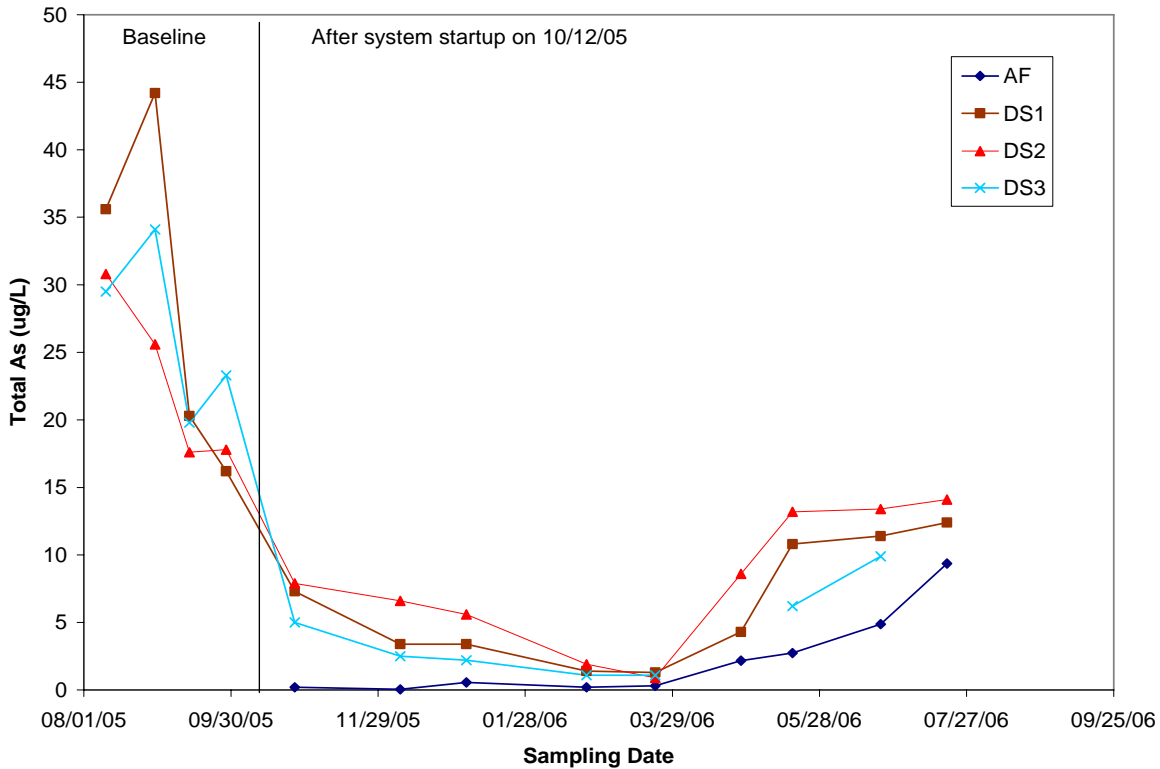


Figure 4-15. Total As Concentrations in Distribution System at Upper Bodfish

Lead concentrations decreased from an average baseline level of 4.6 $\mu\text{g/L}$ to 1.7 $\mu\text{g/L}$ after system startup. Copper concentrations remained fairly low at the DS2 and DS3 residences. However, at the DS1 residence, the copper concentrations exceeded the action level of 1,300 $\mu\text{g/L}$ on October 26, 2005 and January 4 and March 22, 2006. A copper concentration of 1,213 $\mu\text{g/L}$ was reported prior to system installation; therefore, it was unlikely that the HIX system had contributed to the elevated copper concentrations at the DS1 residence.

pH, alkalinity, and manganese concentrations remained fairly consistent; baseline levels were 6.9, 107 mg/L, and 0.9 $\mu\text{g/L}$ and stayed at 7.3, 101 mg/L, and 0.5 $\mu\text{g/L}$, respectively, after system startup. Iron was not detected for all baseline samples except for measurements of 630 and 35 $\mu\text{g/L}$ on August 10 and September 13, 2005 and for all samples collected after system startup except for measurements of 34 and 58 $\mu\text{g/L}$ on January 4 and July 19, 2006.

4.6 System Cost

The system cost was evaluated based on the capital cost per gpm (or gpd) of the design capacity and the O&M cost per 1,000 gal of water treated. The capital cost included the cost for equipment, site engineering, and installation. The O&M cost included the estimated costs for three different options of residual management (i.e., partial media regeneration, complete media regeneration, and media replacement) and labor cost.

4.6.1 Capital Cost. The capital investment for equipment, site engineering, and installation of the HIX system was \$114,070 (see Table 4-9). The equipment cost was \$82,470 (or 73% of the total capital investment), which included \$25,250 for the trailer-mounted HIX unit, \$21,600 for the ArsenX^{np} media (54 ft³ of media to fill two vessels at \$400/ft³), \$2,500 for shipping, and \$33,120 for labor. The labor cost included \$1,920 for procurement of the system, \$19,200 for technical support and trouble shooting for the duration of the study, \$10,000 for initial system hook-up on the trailer, and \$2,000 for travel.

The engineering cost included the cost for preparation of a process flow diagram of the treatment system, equipment drawings, and a schematic of the equipment layout used as part of the permit application submittal (see Section 4.3.1). The engineering cost was \$12,800, or 11% of the total capital investment.

The installation cost included the cost for providing equipment and labor to anchor the trailer-mounted unit, to perform piping tie-ins and electrical work, to perform system shakedown and startup, and to conduct operator training. The installation was performed jointly by VEETech and Cal Water. The installation cost was \$18,800, or 16% of the total capital investment.

Table 4-9. Capital Investment Cost for the HIX System

Description	Quantity	Cost	% of Capital Investment
<i>Equipment Cost</i>			
HIX Trailer-Mounted Unit	1	\$25,250	–
HIX media(ft ³)	54	\$21,600	–
Shipping	–	\$2,500	–
Vendor Labor	–	\$33,120	–
Equipment Total	–	\$82,470	73%
<i>Engineering Cost</i>			
Vendor Labor	–	\$12,800	–
Engineering Total	–	\$12,800	11%
<i>Installation Cost</i>			
Material	–	\$1,500	–
Subcontractor Labor	–	\$10,000	–
Subcontractor Travel	–	\$500	–
Vendor Labor	–	\$4,800	–
Vendor Travel	–	\$2,000	–
Installation Total	–	\$18,800	16%
Total Capital Investment	–	\$114,070	100%

The total capital cost of \$114,070 was normalized to the system’s rated capacity of 50 gpm (72,000 gpd), which resulted in \$2,281/gpm of design capacity (or \$1.58/gpd). The capital cost also was converted to an annualized cost of \$10,767/year by multiplying by 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 design flowrate of 50 gpm to produce 26,280,000 gal of water per year, the unit capital cost would be \$0.41/1,000 gal. The system operated 15.4 hr/day at 24 gpm (see Table 4-4). Based on this reduced use rate, the system would produce only 8,094,240 gal of water in one year (assuming 365 days per year) and the unit capital cost would increase to \$1.33/1,000 gal.

4.6.2 Operation and Maintenance Cost. Table 4-10 presents the vendor-provided cost breakdowns for each of three residual management options and the labor cost for routine O&M. Although regeneration did not occur during the first 10 months of the study, the cost to either regenerate

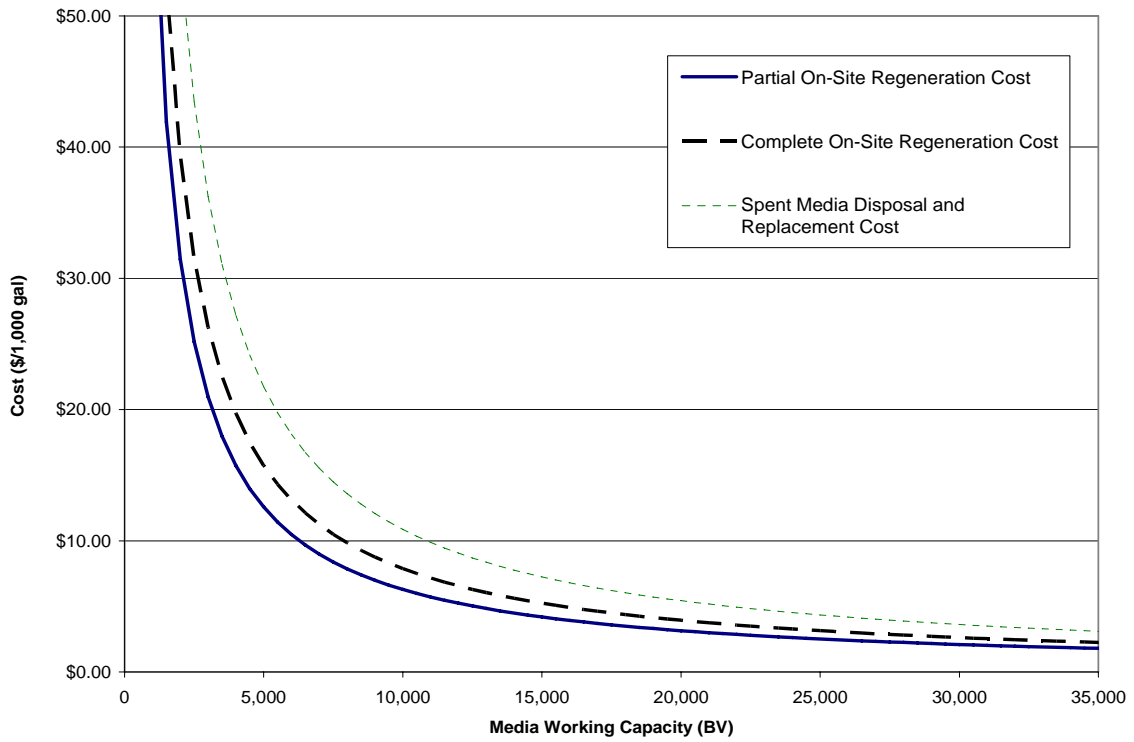
or replace the spent media would represent the majority of the O&M cost. The vendor estimated \$12,700 for partial onsite regeneration not including any additional cost for the subsequent offsite regeneration, \$15,900 for complete onsite regeneration, and \$21,950 for spent media replacement and disposal. By averaging the media regeneration or replacement costs over the useful life of the media, the cost per 1,000 gal of water treated was plotted as a function of the media run length in BV (or the system throughput in gal) as shown in Figure 4-16. The media run length in BV was calculated by dividing the system throughput by the quantity of media in the operating tank, i.e., 27 ft³. The HIX system processed approximately 33,100 BV (or 6,685,000 gal) prior to reaching the 10-μg/L arsenic breakthrough; based on this volume, the unit cost for partial onsite regeneration, complete onsite regeneration, and spent media replacement/disposal would be \$1.90, \$2.38, and \$3.28/1,000 gal, respectively.

Table 4-10. Operation and Maintenance Cost for HIX System

Cost Category	Value	Assumptions
Volume processed (kgal)	6,694	Through August 3, 2006
<i>Partial Onsite Regeneration</i>		
Labor (\$)	\$3,000	
Material and supplies (\$)	\$100	
Transportation (\$)	\$2,000	
Equipment and piping (\$)	\$2,300	
Field supervision	\$2,500	
Radiation monitoring and health physics support	\$2,800	
Subtotal	\$12,700	
<i>Complete Onsite Regeneration</i>		
Labor (\$)	\$2,300	
Travel (\$)	\$1,100	
Material and supplies (\$)	\$300	
Transportation and disposal cost for uranium wastes (\$)	\$5,600	
Equipment and piping (\$)	\$2,300	
Field supervision (\$)	\$1,600	
Radiation monitoring and health physics support (\$)	\$1,700	
Sampling and analysis (\$)	\$1,000	
Subtotal	\$15,900	
<i>Media Replacement</i>		
Labor (\$)	\$1,000	
Travel and field supervision (\$)	\$2,000	
Material and supplies (\$)	\$200	
Disposal of 27 ft ³ spent media	\$9,000	
Sample analysis	\$300	
Virgin HIX media	\$9,450	Unit cost of \$350/ ft ³
Subtotal	\$21,950	
<i>Labor for Routine O&M</i>		
Average weekly labor (hr)	0.83	50 min/wk
Labor (\$/1,000 gal)	\$0.13	Labor rate = \$26/hr

The HIX treatment system did not contain any parts or equipment requiring electricity. Therefore, no additional electrical cost was incurred by the HIX system operation.

Under normal operating conditions, routine labor activities to operate and maintain the system consumed only 50 min per week, as noted in Section 4.4.3. Therefore, the estimated labor cost was \$0.13/1,000 gal of water treated.



Note: 1 BV = media volume in active vessel

Figure 4-16. Media Regeneration and Replacement Cost Curves

5.0: REFERENCES

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APPENDIX A

OPERATIONAL DATA

Table A-1. US EPA Arsenic Demonstration Project at Lake Isabella, CA

Week	Day of Week	Date & Time	Treatment System												
			Hour Meter		Pressure Filtration			ΔP Bag-Filter	ΔP HIX Vessel	ΔP System	Influent Flow Totalizer	Throughput	Cumulative Throughput	Cumulative Bed Volumes	Average Flowrate
			Op Hours	Cumulative Op Hours	Influent psig	Post-Bag-Filter psig	Effluent psig								
1	W	10/12/05 10:40	NA	NA	7.5	8	8.5	-0.5	-0.5	1	25.3	NA	NA	106	NA
	R	10/13/05 9:00	15.4	15.4	7.5	10	9.5	-2.5	0.5	2	26.6	22,698	22,698	220	25.0
	F	10/14/05 8:45	23.6	39.0	7	8	9	-1	-1	2	24.0	34,195	56,893	392	24.6
2	M	10/17/05 9:00	19.8	58.8	7	10	8	-3	2	1	25.3	28,626	85,519	536	24.5
	T	10/18/05 9:20	22.6	81.4	9	10	10	-1	0	1	28.0	32,916	118,435	702	24.7
	W	10/19/05 12:00	23.6	105.0	6	8	7	-2	1	1	24.0	34,241	152,676	874	24.6
	R	10/20/05 9:15	21.3	126.3	7	8	8	-1	0	1	22.6	30,343	183,019	1,027	24.1
	F	10/21/05 8:00	22.9	149.2	7.5	8	8.5	-0.5	-0.5	1	22.6	32,487	215,506	1,190	24.0
3	M	10/24/05 17:00	46.7	195.9	6	7	7	-1	0	1	24.0	66,725	282,231	1,526	24.2
	T	10/25/05 12:30	19.4	215.3	6	8	7	-2	1	1	22.6	27,757	309,988	1,665	24.1
	W	10/26/05 10:00	21.3	236.6	7	8	8	-1	0	1	24.0	30,141	340,129	1,816	23.9
	R	10/27/05 7:15	1.6	238.2	8	9	8	-1	1	0	25.3	30,615	370,744	1,969	NA
	F	10/28/05 8:16	5.2	243.4	3	5	6	-2	-1	3	0.0	21,895	392,639	2,079	NA
4	M	10/31/05 14:30	35.0	278.4	6	8	6	-2	2	0	22.6	7,762	400,401	2,118	24.4
	T	11/01/05 9:15	18.9	297.3	7	9	8	-2	1	1	22.6	27,077	427,478	2,254	24.2
	W	11/02/05 10:35	25.3	322.6	6.5	8	7.5	-1.5	0.5	1	22.6	35,835	463,313	2,434	23.9
	R	11/03/05 7:25	20.9	343.5	8	8	8.5	0	-0.5	0.5	22.6	29,546	492,859	2,582	23.9
	F	11/04/05 7:35	24.2	367.7	8	9	9	-1	0	1	22.6	34,128	526,987	2,754	23.8
5	M	11/07/05 9:00	10.6	378.3	9	10	10	-1	0	1	28.0	15,009	541,996	2,830	24.1
	T	11/08/05 12:00	3.3	381.6	8	9	8	-1	1	0	25.3	5,282	547,278	2,856	26.5
	W	11/09/05 7:30	17.4	399.0	7.5	9	8	-1.5	1	0.5	24.0	25,532	572,810	2,984	24.8
	R	11/10/05 11:00	27.0	426.0	7	8	8	-1	0	1	22.6	38,680	611,490	3,178	24.2
	F	11/11/05 8:00	21.5	447.5	8	8.5	8.5	-0.5	0	0.5	22.6	30,157	641,647	3,330	23.7
6	T	11/15/05 6:35	9.8	457.3	8	9	8	-1	1	0	NM	NA	NA	3,402	25.0
	W	11/16/05 9:05	14.6	471.9	7.5	9	8	-1.5	1	0.5	22.6	35,463	677,110	3,508	24.3
	R	11/17/05 9:30	24.4	496.3	8	9	9	-1	0	1	22.6	34,697	711,807	3,682	24.0
	F	11/18/05 9:00	22.9	519.2	8	9	8.5	-1	0.5	0.5	22.6	32,526	744,333	3,845	24.0
	M	11/21/05 11:45	77.1	596.3	7	9	7	-2	-2	0	22.6	108,149	852,482	4,388	23.7
7	T	11/22/05 10:00	10.9	607.2	0	4	6	-4	-2	6	0	15,244	867,726	4,466	23.6
	M	11/28/05 15:00	0.0	607.2	0	0	3	0	-3	3	0.0	83	867,809	4,466	NA
	T	11/29/05 8:50	17.7	624.9	9	8	8	1	0	-1	22.6	25,744	893,553	4,595	24.6
	W	11/30/05 13:32	24.6	649.5	9	8	8	1	0	-1	22.6	35,161	928,714	4,772	24.2
	R	12/01/05 10:15	20.7	670.2	10	9	9	1	0	-1	22.6	29,011	957,725	4,918	23.9
8	F	12/02/05 9:30	23.3	693.5	7	9	10	-2	-1	3	22.6	32,944	990,669	5,083	23.7
	M	12/05/05 13:30	9.2	702.7	7	10	10	-3	0	3	25.3	13,371	1,004,040	5,150	24.6
	T	12/06/05 10:15	20.4	723.1	7	9	11	-2	-2	4	22.6	32,488	1,036,528	5,299	24.5
	W	12/07/05 15:30	29.5	752.6	7	9	9.5	-2	-0.5	2.5	22.6	38,724	1,075,252	5,508	23.9
	R	12/08/05 10:00	11.8	764.4	7	9	10	-2	-1	3	24.0	17,752	1,093,004	5,599	25.9
9	F	12/09/05 9:00	0.4	764.8	2	4	8	-2	-4	6	0.0	15	1,093,019	5,599	NA
	F	12/16/05 14:30	4.8	769.6	0	0	2	0	-2	2	0.0	45	1,093,064	5,599	NA

Table A-1. US EPA Arsenic Demonstration Project at Lake Isabella, CA (Continued)

Week	Day of Week	Date & Time	Treatment System										Average Flowrate		
			Hour Meter		Pressure Filtration		ΔP Bag-Filter	ΔP HIX Vessel	ΔP System	Influent Flow Totalizer	Throughput	Cumulative Throughput		Cumulative Bed Volumes	
			Op Hours	Cumulative Op Hours	Influent psig	Post Bag-Filter psig									Effluent psig
11	T	12/20/05 17:00	4.7	774.3	7.5	10	10	-2.5	0	2.5	0.0	NA	NA	5,636	26.1
	W	12/21/05 11:50	15.0	789.3	7	10	10	-3	0	3	24.0	NA	NA	5,748	25.1
	R	12/22/05 0:00	4.1	793.4	0	4	6	-4	-2	6	0.0	6,003	1,099,067	5,778	25.0
12	W	12/28/05 9:00	8.7	802.1	8	9	10	-1	-1	2	24.0	13,199	1,112,266	5,844	25.5
	R	12/29/05 15:00	23.6	825.7	7	10	10	-3	0	3	24.0	34,529	1,148,795	6,018	24.8
	F	12/30/05 8:45	18.0	843.7	8	9	10	-1	-1	2	22.6	25,794	1,172,589	6,147	24.2
13	T	01/03/06 9:00	98.7	942.4	8	9	10	-1	-1	2	22.6	140,994	1,313,583	6,856	24.2
	W	01/04/06 9:30	13.3	955.7	9	10	11	-1	-1	2	24.0	19,397	1,332,980	6,954	24.7
	R	01/05/06 9:10	15.0	970.7	9	10	11	-1	-1	2	25.1	22,592	1,355,572	7,067	25.5
14	M	01/09/06 12:30	0.1	970.8	0	0	4	0	-4	4	0.0	32	1,355,604	7,067	NA
	T	01/10/06 12:30	10.3	981.1	8	9	10	-1	-1	2	24.0	16,097	1,371,701	7,149	26.5
	W	01/11/06 10:20	17.0	998.1	8.5	9	10.5	-0.5	-1.5	2	24.0	25,175	1,396,876	7,275	25.0
	R	01/12/06 9:20	18.1	1,016.2	7.5	9.5	10.5	-2	-1	3	22.4	26,602	1,423,478	7,409	24.9
	F	01/13/06 8:30	18.3	1,034.5	8	9.5	11	-1.5	-1.5	3	24.0	26,883	1,450,361	7,544	25.0
15	T	01/18/06 9:00	82.1	1,116.6	8	10	11	-2	-1	3	24.0	120,053	1,570,414	8,148	24.7
	R	12/29/05 15:00	38.4	1,155.0	7.5	10	11	-2.5	-1	3.5	24.0	56,459	1,626,873	8,432	24.9
	F	12/30/05 8:45	18.3	1,173.3	8	10	11.5	-2	-1.5	3.5	24.0	26,756	1,653,629	8,566	24.7
16	M	01/23/06 14:08	210.8	1,384.1	6	9	9	-3	0	3	22.6	306,802	1,960,431	9,087	24.6
	T	01/24/06 13:00	13.0	1,397.1	8.5	12	11	-3.5	1	2.5	29.3	18,997	1,979,428	9,183	24.8
	W	01/25/06 21:48	20.9	1,418.0	7.5	9	10	-1.5	-1	2.5	24.0	30,299	2,009,727	9,335	24.6
	R	01/26/06 11:30	21.7	1,439.7	7.5	9.5	10.5	-2	-1	3	24.0	31,350	2,041,077	9,493	24.5
	F	01/27/06 9:00	21.3	1,461.0	8	10	10	-2	0	2	24.0	30,287	2,071,364	9,645	24.1
17	M	01/30/06 12:05	71.7	1,532.7	7	9	10	-2	-1	3	24.0	102,103	2,173,467	10,159	24.1
	T	01/31/06 14:00	20.2	1,552.9	8	10	10.5	-2	-0.5	2.5	24.0	28,868	2,202,335	10,305	24.2
	W	02/01/06 20:10	18.1	1,571.0	8	9.5	10.5	-1.5	-1	2.5	24.0	25,784	2,228,119	10,434	24.1
	R	02/02/06 11:15	19.7	1,590.7	7	9.5	10	-2.5	-0.5	3	24.0	28,990	2,257,109	10,581	25.0
	F	02/03/06 13:07	21.8	1,612.5	6	9.5	9.5	-3.5	0	3.5	22.6	31,519	2,288,628	10,739	24.4
18	M	02/06/06 9:15	68.1	1,680.6	7	9	10	-2	-1	3	22.6	96,208	2,384,836	11,223	23.9
	T	02/07/06 10:30	21.3	1,701.9	7.5	9.5	10	-2	-0.5	2.5	22.6	30,631	2,415,467	11,377	24.4
	W	02/08/06 9:00	21.0	1,722.9	8	10	10	-2	0	2	24.0	29,894	2,445,361	11,527	24.1
	R	02/09/06 9:20	20.8	1,743.7	8	9	10	-1	-1	2	22.6	30,021	2,475,382	11,674	23.7
	F	02/10/06 8:10	22.8	1,766.5	8	9	10	-1	-1	2	22.6	32,081	2,507,463	11,839	24.5
19	M	02/13/06 13:29	74.7	1,841.2	6	9	9	-3	0	3	22.6	105,510	2,612,973	12,370	23.9
	T	02/14/06 13:05	20.3	1,861.5	7.5	10	9	-2.5	1	1.5	24.0	39,032	2,652,005	12,516	24.2
	W	02/15/06 8:00	15.8	1,877.3	9	10	10	-1	0	1	22.6	12,799	2,664,804	12,630	24.4
	R	02/16/06 8:40	22.7	1,900.0	10	11	11.5	-1	-0.5	1.5	25.3	32,399	2,697,203	12,793	24.1
	F	02/17/06 8:00	21.0	1,921.0	9	10	11	-1	-1	2	24.0	30,114	2,727,317	12,944	24.2
20	T	02/21/06 11:20	97.0	2,018.0	8	9.5	10.5	-1.5	-1	2.5	22.6	136,871	2,864,188	13,632	23.9
	W	02/22/06 10:30	23.0	2,041.0	8.5	10	10	-1.5	0	1.5	22.6	32,233	2,896,421	13,793	23.7
	R	02/23/06 16:20	27.8	2,068.8	7	9.5	9	-2.5	0.5	2	22.6	39,432	2,935,853	13,991	24.0
	F	02/24/06 12:05	17.6	2,086.4	7.5	9.5	9.5	-2	0	2	22.6	25,130	2,960,983	14,117	24.1

Table A-1. US EPA Arsenic Demonstration Project at Lake Isabella, CA (Continued)

Week	Day of Week	Date & Time	Treatment System													
			Hour Meter		Pressure Filtration		ΔP Bag-Filter	ΔP HIX Vessel	ΔP System	Influent Flow Totalizer	Throughput	Cumulative Throughput	Cumulative Bed Volumes	Average Flowrate		
			Op Hours	Cumulative Op Hours	Influent psig	Post Bag-Filter psig									Effluent psig	gal
21	M	02/27/06 9:30	65.7	2,152.1	8	9	9	-1	0	1	22.6	98,696	3,059,679	14,613	25.4	
	T	02/28/06 16:00	30.2	2,182.3	9	10	10	-1	0	1	24.0	35,792	3,095,471	14,792	20.0	
	W	03/01/06 9:00	13.4	2,195.7	9	10	10	-1	0	1	22.6	19,463	3,114,934	14,890	24.5	
	R	03/02/06 11:45	20.5	2,216.2	12	12	7.5	0	4.5	-4.5	29.3	29,525	3,144,459	15,038	24.3	
	F	03/03/06 8:40	21.0	2,237.2	10	10	6	0	4	-4	22.6	30,159	3,174,618	15,190	24.3	
	M	03/06/06 12:48	73.1	2,310.3	10	9.5	7	0.5	2.5	-3	22.6	103,299	3,277,917	15,707	23.9	
	T	03/07/06 14:40	25.8	2,336.1	10	10	5.5	0	4.5	-4.5	23.6	36,140	3,314,057	15,938	30.1	
22	W	03/08/06 8:30	15.9	2,352.0	11	10	6	1	4	-5	24.0	22,880	3,336,937	16,002	24.0	
	R	03/09/06 2:00	29.6	2,381.6	8	10	6	-2	4	-2	22.6	42,126	3,379,063	16,211	23.8	
	F	03/10/06 2:40	21.6	2,403.2	8	10	6	-2	4	-2	22.6	30,691	3,409,754	16,367	24.2	
	M	03/13/06 8:45	66.2	2,469.4	8	10	6	-2	4	-2	24.0	93,197	3,502,951	16,834	23.7	
	T	03/14/06 10:00	25.2	2,494.6	8	9	6	-1	3	-2	22.6	35,450	3,538,401	17,012	23.8	
	W	03/15/06 9:10	20.6	2,515.2	8	10	6	-2	4	-2	22.7	29,604	3,568,005	17,160	24.2	
	R	03/16/06 9:30	24.4	2,539.6	8	10	6	-2	4	-2	22.6	34,266	3,602,271	17,331	23.7	
23	F	03/17/06 14:46	29.4	2,569.0	8	9.5	5.5	-1.5	4	-2.5	22.6	41,290	3,643,561	17,538	23.7	
	M	03/20/06 9:10	66.3	2,635.3	8	10	5.5	-2	4.5	-2.5	22.6	92,907	3,736,468	18,004	23.6	
	T	03/21/06 10:15	25.0	2,660.3	8	10	6	-2	4	-2	24.0	35,279	3,771,747	18,180	23.8	
	W	03/22/06 9:00	22.5	2,682.8	8	9.5	6	-1.5	3.5	-2	22.6	31,317	3,803,064	18,337	23.5	
	R	03/23/06 11:00	26.6	2,709.4	8	10	6	-2	4	-2	22.6	37,227	3,840,291	18,524	23.6	
	F	03/24/06 9:30	22.1	2,731.5	8	10	5	-2	5	-3	22.6	30,963	3,871,254	18,679	23.6	
	M	03/27/06 14:35	77.3	2,808.8	8	9.5	5	-1.5	4.5	-3	22.6	108,125	3,979,379	19,220	23.6	
24	T	03/28/06 8:30	17.9	2,826.7	8	9.5	5	-1.5	4.5	-3	22.6	24,907	4,004,286	19,345	23.5	
	W	03/29/06 9:00	21.1	2,847.8	7.5	9.5	5.5	-2	4	-2	22.6	30,540	4,034,826	19,498	24.4	
	R	03/30/06 11:30	26.6	2,874.4	8.5	9.5	5.5	-1	4	-3	22.6	37,973	4,072,799	19,688	24.1	
	F	03/31/06 20:30	21.2	2,895.6	8.5	9.5	5.5	-1	4	-3	22.6	30,017	4,102,816	19,839	23.9	
	M	04/03/06 15:00	77.2	2,972.8	8	10	5	-2	5	-3	22.6	109,303	4,212,119	20,386	23.9	
	T	04/04/06 9:45	18.9	2,991.7	8.5	9.5	5.5	-1	4	-3	22.6	26,797	4,238,916	20,520	23.9	
	W	04/05/06 9:20	19.4	3,011.1	8.5	10	6	-1.5	4	-2.5	22.6	26,271	4,267,187	20,662	24.6	
25	R	04/06/06 10:00	22.5	3,033.6	9	10	6	-1	4	-3	24.0	32,446	4,299,633	20,824	24.3	
	F	04/07/06 8:40	22.8	3,056.4	9	10	6	-1	4	-3	22.6	32,711	4,332,344	20,988	24.1	
	M	04/10/06 9:00	79.1	3,135.5	0	4	0	-4	4	0	0.0	103,006	4,435,350	21,504	22.0	
	T	04/18/06 12:30	1.1	3,136.6	11	13	5	-2	8	-6	29.3	411	4,435,761	21,506	NA	
	W	04/19/06 9:00	19.5	3,156.1	8	10	6	-2	4	-2	22.6	30,366	4,466,127	21,658	26.3	
	R	04/20/06 12:45	28.0	3,184.1	8.5	10	4	-1.5	6	-4.5	24.0	40,279	4,506,406	21,859	24.2	
	F	04/21/06 8:45	19.7	3,203.8	8	10	5	-2	5	-3	22.6	28,240	4,534,646	22,001	24.2	
26	T	04/25/06 9:00	96.4	3,300.2	8	10	5	-2	5	-3	22.6	137,134	4,671,780	22,687	24.0	
	W	04/26/06 10:30	23.3	3,323.5	8	10	5	-2	5	-3	24.0	33,576	4,705,356	22,855	24.3	
	R	04/27/06 13:00	26.7	3,350.2	8	10	5	-2	5	-3	22.6	37,927	4,743,283	23,045	23.9	
	F	04/28/06 9:50	20.6	3,370.8	8.5	10	5	-1.5	5	-3.5	22.6	29,106	4,772,389	23,190	23.8	
	M	05/01/06 10:00	52.1	3,422.9	11	12	5.5	-1	6.5	-5.5	28.0	73,644	4,846,033	23,559	23.8	
	T	05/02/06 12:30	15.0	3,437.9	8	10	4	-2	6	-4	22.6	22,473	4,868,506	23,672	25.2	
	W	05/03/06 8:30	20.1	3,458.0	8.5	10	5	-1.5	5	-3.5	22.6	28,890	4,897,386	23,816	24.2	
27	M	05/06/06 9:25	50.2	3,508.2	11	12	4	-1	8	-7	26.6	73,173	4,970,559	24,182	24.0	
	T	05/09/06 14:20	12.4	3,520.6	10	11	4	-1	7	-6	25.3	19,421	4,989,980	24,294	30.4	
	W	05/10/06 17:15	9.7	3,530.3	0	4	0	-4	4	0	0.0	14,135	5,004,115	24,350	24.3	
	R	05/11/06 10:20	5.1	3,535.4	10	11	4	-1	7	-6	25.3	16,314	5,020,429	24,392	27.5	
	F	05/12/06 15:00	20.0	3,555.4	9	10	3	-1	7	-6	22.6	21,468	5,041,917	24,539	24.8	
	M	05/15/06 10:30	30.0	3,585.4	10	11	4	-1	7	-6	25.3	45,426	5,087,343	24,767	25.5	
	T	05/16/06 14:40	19.7	3,605.1	9	10	2	-1	8	-7	22.6	28,810	5,116,153	24,911	24.6	
28	W	05/17/06 9:00	13.9	3,619.0	10	11	4	-1	7	-6	24.0	20,218	5,136,371	25,012	24.5	
	R	05/18/06 13:30	19.6	3,638.6	10	10	3	0	7	-7	24.0	28,302	5,164,673	25,153	24.3	
	F	05/19/06 8:00	16.0	3,654.6	9	9	2.5	0	6.5	-6.5	24.0	23,103	5,187,776	25,269	24.3	

Table A-1. US EPA Arsenic Demonstration Project at Lake Isabella, CA (Continued)

Week	Day of Week	Date & Time	Treatment System														Average Flowrate
			Hour Meter		Pressure Filtration		AP Bag-Filter	AP HIX Vessel	AP System	Influent Flow Totalizer	Throughput	Cumulative Throughput	Cumulative Bed Volumes	Average Flowrate			
			Op Hours	Cumulative Op Hours	Influent psig	Post Bag-Filter psig									Effluent psig	psig	
33	M	05/22/06 8:45	30.6	3,685.2	1	4	1	-3	3	0	0.0	43,887	5,231,663	25,488	24.1		
	T	05/23/06 12:20	5.8	3,691.0	9	3	0	6	-6	24.0	24.0	9,367	5,241,030	25,535	27.3		
	W	05/24/06 8:30	5.6	3,696.6	10.5	3	0.5	7	-7.5	28.0	28.0	8,417	5,249,447	25,578	25.5		
	R	05/25/06 14:45	13.6	3,710.2	0	4	0	-4	4	0	0.0	20,580	5,270,027	25,680	25.4		
	F	05/26/06 15:00	3.3	3,713.5	9.5	3	0.5	6	-6.5	24.0	24.0	5,275	5,275,302	25,707	27.5		
	T	05/30/06 14:15	64.2	3,777.7	2	4	0	-2	4	0	0.0	93,889	5,369,191	26,177	24.6		
	W	05/31/06 17:45	6.1	3,783.8	2	4	0	-2	4	0	0.0	9,710	5,378,901	26,226	27.1		
34	R	06/01/06 10:50	5.5	3,789.3	11	10	2	1	8	-9	26.6	8,226	5,387,627	26,269	26.5		
	F	06/02/06 13:11	16.2	3,805.5	11	8.5	3	2.5	5.5	-8	24.0	24,236	5,411,863	26,390	25.2		
	T	06/06/06 14:31	65.5	3,871.0	12	9	2	3	7	-10	22.6	94,599	5,506,462	26,863	24.3		
	W	06/07/06 14:54	18.5	3,889.5	12	9	1	3	8	-11	22.6	26,526	5,532,988	26,996	24.1		
	R	06/08/06 14:15	19.8	3,909.3	12.5	9	7	3.5	2	5	22.6	28,149	5,561,137	27,137	24.0		
	F	06/09/06 13:28	23.2	3,932.5	13	9	7	4	2	6	22.6	32,218	5,593,355	27,298	23.3		
	M	06/12/06 17:30	34.1	3,966.6	0	5	0	-5	5	0	0.0	49,417	5,642,772	27,546	24.4		
35	T	06/13/06 17:30	6.5	3,973.1	7.5	3	-1.5	6	-4.5	24.0	24.0	9,852	5,652,624	27,596	25.9		
	W	06/14/06 10:30	4.5	3,977.6	8	9	6	-1	3	-2	24.0	6,876	5,659,500	27,630	25.7		
	R	06/15/06 16:00	18.8	3,996.4	7	9	5.5	-2	3.5	-1.5	24.0	27,652	5,687,152	27,768	24.8		
	F	06/16/06 9:30	7.7	4,004.1	8.5	10	6	-1.5	4	-2.5	25.3	11,189	5,698,341	27,824	24.5		
	M	06/19/06 10:00	36.9	4,041.0	8	9	6	-1	3	-2	24.0	55,685	5,754,026	28,102	25.3		
	T	06/20/06 17:30	20.4	4,061.4	7.5	9	6	-1.5	3	-1.5	24.0	30,337	5,784,363	28,254	25.1		
	W	06/21/06 18:30	13.0	4,074.4	8	9.5	6	-1.5	3.5	-2	24.0	19,696	5,804,059	28,351	25.0		
36	R	06/22/06 9:45	6.6	4,081.0	8.5	9.5	6	-1	3.5	-2.5	25.3	9,578	5,813,637	28,401	25.6		
	F	06/23/06 7:30	11.7	4,092.7	9	10	6.5	-1	3.5	-2.5	26.6	17,383	5,831,020	28,488	25.0		
	M	06/26/06 11:50	71.4	4,164.1	8.5	9	6	-0.5	3	-2.5	22.6	101,679	5,932,699	28,996	24.0		
	T	06/27/06 14:00	15.3	4,179.4	0	4	4	0	0	4	0.0	21,831	5,954,530	29,106	24.1		
	W	06/28/06 11:30	12.9	4,192.3	8	9	6	-1	3	-2	22.6	22,578	5,977,108	29,204	25.6		
	R	06/29/06 14:00	23.3	4,215.6	8	9	5.5	-1	3.5	-2.5	22.6	30,596	6,007,704	29,372	24.2		
	M	07/03/06 8:25	86.6	4,302.2	8	9	6	-1	3	-2	22.6	121,561	6,129,265	29,977	23.5		
37	T	07/05/06 13:50	44.8	4,347.0	8	9	6	-1	3	-2	22.6	63,221	6,192,486	30,296	24.0		
	W	07/06/06 11:00	21.5	4,368.5	9	10	6.5	-1	3.5	-2.5	22.6	29,902	6,222,388	30,446	23.4		
	R	07/07/06 17:30	20.2	4,388.7	9.5	10	6.5	-0.5	3.5	-3	22.6	28,915	6,251,303	30,590	24.1		
	M	07/10/06 8:00	60.4	4,449.1	8	10	6	-2	4	-2	23.3	84,041	6,335,344	31,011	23.4		
	W	07/12/06 9:30	1.5	4,450.6	9	11	6	-2	5	-3	29.3	1,261	6,336,605	31,018	N/A		
	R	07/13/06 15:10	29.4	4,480.0	7	9	5.5	-2	3.5	-1.5	22.6	42,280	6,378,885	31,229	24.2		
	F	07/14/06 7:40	16.8	4,496.8	7.5	9	6	-1.5	3	-1.5	22.6	23,432	6,402,317	31,346	23.5		
38	M	07/17/06 14:30	79.0	4,575.8	7	9	6	-2	3	-1	21.3	109,371	6,511,688	31,894	23.3		
	T	07/18/06 15:00	24.3	4,600.1	7	9	5.5	-2	3.5	-1.5	22.6	33,685	6,545,373	32,063	23.4		
	W	07/19/06 9:00	0.6	4,600.7	9	11	6.5	-2	4.5	-2.5	28.0	1,136	6,546,509	32,068	29.6		
	R	07/20/06 14:00	2.7	4,603.4	9	11	6	-2	5	-3	26.6	4,279	6,550,788	32,089	26.2		
	F	07/21/06 7:30	1.6	4,605.0	8	9	6	-1	3	-2	24.0	2,519	6,553,307	32,102	27.1		
	M	07/24/06 6:00	1.7	4,606.7	10	11	6.5	-1	4.5	-3.5	29.3	2,862	6,556,169	32,117	29.3		
	W	07/25/06 10:40	2.3	4,609.0	9	10	6	-1	4	-3	26.6	3,867	6,560,036	32,136	28.3		
39	R	07/26/06 7:30	21.1	4,630.1	8	9	6	-1	3	-2	22.6	30,275	6,590,311	32,287	24.1		
	F	07/27/06 9:00	25.1	4,655.2	8	9	6	-1	3	-2	22.6	35,097	6,625,408	32,462	23.5		
	M	07/31/06 15:00	47.8	4,703.0	0	3	0	-3	3	0	0.0	67,816	6,693,224	32,802	23.9		
	T	08/01/06 11:30	2.2	4,705.2	8.5	9.5	6	-1	3.5	-2.5	24.0	3,679	6,696,903	32,820	27.5		
	W	08/02/06 10:00	20.8	4,726.0	8	9	6	-1	3	-2	22.6	32,216	6,729,119	32,981	26.1		
	R	08/03/06 8:30	24.5	4,750.5	8.5	9	6	-0.5	3	-2.5	22.6	31,259	6,760,378	33,137	21.5		
	F	08/04/06 7:30	23.1	4,773.6	8.5	9	6	-0.5	3	-2.5	22.6	32,057	6,792,435	33,298	23.4		

APPENDIX B
ANALYTICAL DATA

Table B-1. Analytical Results from Long-Term Sampling at Lake Isabella, CA

Sampling Date Sampling Location Parameter	Unit	10/13/05			10/19/05			10/26/05			11/02/05			11/08/05			11/16/05		
		IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF
Bed Volume (10 ³)	BV	-	-	0.2	-	-	0.9	-	-	1.8	-	-	2.4	-	-	3.0	-	-	3.5
Alkalinity (as CaCO ₃)	mg/L	106	101	101	145	132	132	92	97	101	92	92	88	356	92	101	101	97	97
Fluoride	mg/L	1.2	1.2	1.2	-	-	-	-	-	-	-	-	-	1.1	1.1	1.2	-	-	-
Sulfate	mg/L	38	42	40	-	-	-	-	-	-	-	-	-	37	38	37	-	-	-
Nitrate (as N)	mg/L	1.1	1.1	0.1	-	-	-	-	-	-	-	-	-	1.1	1.1	1.0	-	-	-
Total P (as P)	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	30	30	<10	18	18	<10	<10	<10	<10
Silica (as SiO ₂)	mg/L	43.5	43.6	23.2	41.5	41.5	39.9	44.0	43.3	41.1	43.9	43.3	43.3	43.0	43.1	41.6	41.5	42.1	41.1
Turbidity	NTU	0.3	0.3	0.2	0.7	0.4	0.4	0.1	<0.1	<0.1	0.1	0.3	<0.1	0.4	0.4	0.1	<0.1	<0.1	<0.1
pH	S.U.	6.8	6.9	6.8	7.0	7.0	7.0	7.0	7.0	6.9	6.9	7.0	6.9	7.0	7.0	6.9	7.0	7.0	7.0
Temperature	°C	18.2	17.8	18.0	20.2	19.7	19.5	16.6	16.4	16.4	21.1	19.9	19.7	16.4	16.4	16.4	17.6	17.1	17.1
DO	mg/L	2.0	1.9	1.9	2.1	1.9	2.2	2.0	2.1	2.0	2.3	2.5	2.2	2.5	2.1	2.0	NA ^(b)	NA ^(b)	NA ^(b)
ORP	mV	198	213	230	258	195	205	370	298	268	NA ^(b)	NA ^(b)	NA ^(b)	303	336	321	293	291	294
Total Hardness (as CaCO ₃)	mg/L	83.6	85.0	88.3	89.3	90.0	88.4	91.8	93.8	93.9	93.3	94.4	98.9	93.5	93.8	95.2	92.9	91.0	97.3
Ca Hardness (as CaCO ₃)	mg/L	77.0	78.4	81.1	83.0	83.7	82.3	85.6	87.5	87.7	87.1	88.0	92.3	86.7	86.8	88.3	87.2	86.5	91.4
Mg Hardness (as CaCO ₃)	mg/L	6.6	6.6	7.2	6.3	6.3	6.2	6.2	6.3	6.2	6.2	6.4	6.6	6.8	7.0	6.9	5.7	4.5	5.9
As (total)	µg/L	39.6	41.1	0.3	41.9	42.1	0.4	43.1	43.8	0.2	41.8	41.5	0.1	36.5	36.2	0.1	39.5	40.2	<0.1
As (soluble)	µg/L	38.8	39.6	0.3	-	-	-	-	-	-	-	-	-	36.6	36.5	0.1	-	-	-
As (particulate)	µg/L	0.8	1.5	<0.1	-	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	-	-	-
As (III)	µg/L	0.9	0.7	0.7	-	-	-	-	-	-	-	-	-	0.3	0.3	0.3	-	-	-
As (V)	µg/L	37.9	38.9	<0.1	-	-	-	-	-	-	-	-	-	36.3	36.2	<0.1	-	-	-
Fe (total)	µg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Fe (soluble)	µg/L	<25	<25	<25	-	-	-	-	-	-	-	-	-	<25	<25	<25	-	-	-
Mn (total)	µg/L	0.4	0.4	0.6	<0.1	<0.1	0.4	0.1	0.1	0.5	<0.1	<0.1	0.5	0.9	1.0	0.9	0.4	0.7	0.7
Mn (soluble)	µg/L	0.3	0.3	0.4	-	-	-	-	-	-	-	-	-	0.7	0.7	0.8	-	-	-
U (total)	µg/L	35.3	34.4	<0.1	33.8	33.6	<0.1	33.3	34.0	<0.1	35.2	34.0	-	35.9	36.2	0.1	34.9	33.3	<0.1
U (soluble)	µg/L	35.6	34.3	<0.1	-	-	-	-	-	-	-	-	-	35.7	35.9	0.1	-	-	-

(a) ORP probe not operational.

(b) DO probe was not operational.

Table B-1. Analytical Results from Long-Term Sampling at Lake Isabella, CA (Continued)

Sampling Date	12/01/05		12/09/05		12/28/05		01/04/06		01/11/06		01/25/06		02/08/06			
	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	
Bed Volume (10 ³)	-	-	4.9	-	-	5.6	-	-	7.0	-	-	7.3	-	-	9.3	11.5
Alkalinity (as CaCO ₃)	88	92	88	97	101	106	97	97	97	101	97	101	101	101	101	100
Fluoride	-	-	-	-	1.1	1.1	1.1	-	-	1.1	1.1	1.1	-	-	-	1.0
Sulfate	-	-	-	-	36	36	36	-	-	37	38	36	-	-	-	36
Nitrate (as N)	-	-	-	-	1.0	1.0	1.0	-	-	1.3	1.3	1.7	-	-	-	1.1
Total P (as P)	<10	<10	<10	<10	<10	<10	<10	<10	<10	14	13	<10	<10	<10	<10	<10
Silica (as SiO ₂)	45.2	44.5	44.7	44.0	42.8	44.1	44.2	42.2	42.9	43.9	44.6	44.9	43.4	43.7	42.9	42.6
Turbidity	0.1	0.1	<0.1	0.3	0.2	0.1	0.6	0.7	1.6	1.8	1.7	1.6	0.4	0.4	0.3	0.8
pH	7.1	7.0	7.0	7.0	7.0	7.0	NA	NA	7.0	7.0	7.0	7.0	6.8	6.9	7.0	7.0
Temperature	19.1	18.2	17.4	12.9	14.1	14.4	NA	NA	13.7	11.9	12.1	12.4	12.2	12.4	12.5	14.7
DO	3.9	3.0	3.0	NA ^(a)	NA ^(a)	NA ^(a)	NA	NA	NA ^(a)	3.1	3.5	2.7	2.1	2.0	2.4	4.3
ORP	415	453	453	332	411	426	NA	NA	490	378	265	245	432	471	445	436
Total Hardness (as CaCO ₃)	88.6	87.9	91.5	92.2	89.9	89.5	93.6	93.7	90.9	79.9	82.4	80.3	94.9	94.9	94.3	69.6
Ca Hardness (as CaCO ₃)	81.5	81.0	84.4	85.8	83.6	83.3	87.3	87.3	83.2	82.2	75.2	73.1	88.5	88.5	88.1	60.6
Mg Hardness (as CaCO ₃)	7.0	7.0	7.1	6.4	6.3	6.2	6.3	6.5	7.4	7.3	7.2	7.2	7.2	7.2	6.2	9.0
As (total)	39.2	39.5	<0.1	42.1	40.5	<0.1	39.4	38.9	0.3	39.4	43.5	0.5	38.4	38.6	0.2	42.5
As (soluble)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	-	-	-	-	-	-	40.0	39.4	0.7	-	43.2	45.2	0.4	-	-	42.7
As (III)	-	-	-	-	-	-	<0.1	<0.1	<0.1	-	<0.1	<0.1	-	-	-	<0.1
As (V)	-	-	-	-	-	-	0.4	0.4	0.4	0.8	0.8	0.8	-	-	-	0.7
Fe (total)	<25	<25	<25	<25	<25	<25	<25	<25	<25	41.2	39.9	<25	<25	<25	<25	42.0
Fe (soluble)	-	-	-	-	-	-	<25	<25	<25	-	-	-	-	-	-	41.9
Mn (total)	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.6	0.7	1.3	0.5	0.5	0.4	<0.1	<0.1	0.4	<0.1
Mn (soluble)	-	-	-	-	-	-	0.8	1.1	1.6	-	-	-	<0.1	<0.1	0.4	<0.1
U (total)	26.6	26.6	<0.1	29.2	29.1	<0.1	33.6	33.8	<0.1	32.7	32.5	<0.1	30.9	32.0	<0.1	30.6
U (soluble)	-	-	-	-	-	-	33.6	33.6	<0.1	-	-	<0.1	32.6	32.8	<0.1	32.7

(a) DO probe was not operational.

Table B-1. Analytical Results from Long-Term Sampling at Lake Isabella, CA (Continued)

Sampling Date	02/22/06		03/08/06		03/22/06		04/04/06 ^(a)		04/19/06		05/03/06		05/17/06			
	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	
Bed Volume (10 ³)	-	-	13.8	-	-	18.3	-	-	20.5	-	-	21.7	-	-	23.8	25.0
Alkalinity (as CaCO ₃)	100	104	100	100	103	99	95	99	106	106	105	106	97	97	105	97
Fluoride	-	-	-	1.1	1.1	-	1.2	1.2	1.2	-	-	-	-	-	1.0	-
Sulfate	-	-	-	41	40	-	40	40	40	-	-	-	-	-	40	-
Nitrate (as N)	-	-	-	1.1	1.1	-	1.3	1.2	1.2	-	-	-	-	-	0.9	-
Total P (as P)	<10	<10	<10	<10	<10	<10	<10	<10	<10	18	17	<10	<10	<10	<10	<10
Silica (as SiO ₂)	44.9	44.3	45.0	42.0	42.3	42.7	42.9	42.2	42.4	42.1	42.3	41.2	45.6	43.9	44.4	45.2
Turbidity	0.6	0.6	0.3	1.0	0.8	0.6	0.3	1.0	0.6	0.8	0.4	0.2	0.2	0.4	0.4	0.6
pH	7.2	7.0	7.1	7.0	7.0	7.1	7.2	7.1	7.3	6.9	6.8	6.8	7.0	6.9	6.9	7.0
Temperature	12.1	12.1	12.0	11.2	11.2	11.6	25.0	25.0	25.0	8.2	9.3	10.6	17.7	17.9	19.9	23.6
DO	3.4	3.2	3.4	2.9	3.4	3.8	NA ^(b)	NA ^(b)	NA ^(b)	266	1.8	1.6	1.6	2.1	2.7	2.1
ORP	416	411	390	300	305	325	443	486	495	285	264	232	384	345	254	408
Total Hardness (as CaCO ₃)	88.9	91.5	88.8	94.8	95.8	96.9	95.7	93.6	93.8	84.4	85.4	86.5	94.7	95.4	93.2	90.8
Ca Hardness (as CaCO ₃)	82.3	84.8	82.2	87.5	88.5	89.4	90.0	88.1	88.3	77.9	78.7	79.8	84.2	84.8	82.8	83.8
Mg Hardness (as CaCO ₃)	6.6	6.7	6.6	7.3	7.3	7.6	5.7	5.6	5.5	6.5	6.7	6.7	10.4	10.6	10.3	7.0
As (total)	41.9	41.8	0.2	40.3	41.4	0.3	43.1	42.8	0.3	42.3	41.6	1.2	38.9	38.6	0.6	44.7
As (soluble)	-	-	-	39.5	40.0	0.2	-	-	-	43.6	42.7	1.5	-	-	-	44.5
As (particulate)	-	-	-	0.8	1.4	<0.1	-	-	-	<0.1	<0.1	<0.1	-	-	-	0.2
As (III)	-	-	-	0.4	0.4	0.5	-	-	-	0.8	0.5	0.5	-	-	-	0.2
As (V)	-	-	-	39.2	39.5	<0.1	-	-	-	42.8	42.2	1.0	-	-	-	44.4
Fe (total)	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Fe (soluble)	-	-	-	<25	<25	<25	-	-	-	<25	<25	<25	-	-	<25	<25
Mn (total)	<0.1	<0.1	0.3	0.4	0.4	0.5	0.2	0.1	0.4	<0.1	0.1	0.4	0.2	0.2	1.7	0.1
Mn (soluble)	-	-	-	-	-	-	0.1	0.1	0.4	-	-	-	-	-	-	-
U (total)	34.6	35.1	<0.1	32.1	31.9	<0.1	30.3	29.5	<0.1	36.7	34.6	<0.1	27.8	28.3	<0.1	35.2
U (soluble)	-	-	-	32.1	31.9	<0.1	-	-	-	35.6	36.4	<0.1	-	-	-	35.3

(a) Water quality measurements taken on 04/05/06.

(b) Measurements not taken.

Table B-1. Analytical Results from Long-Term Sampling at Lake Isabella, CA (Continued)

Sampling Date	Sampling Location	Parameter	Unit	06/01/06			06/14/06			06/22/06			07/06/06			07/19/06			7/26/2006 ^(a)			08/03/06		
				IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF
		Bed Volume (10 ³)	BV	-	-	26.3	-	-	27.6	-	-	28.4	-	-	30.4	-	-	32.0	-	-	32.3	-	-	33.1
		Alkalinity (as CaCO ₃)	mg/L	96	96	100	106	102	106	100	100	100	100	100	100	100	97	101	97	-	-	-	101	101
		Fluoride	mg/L	-	-	-	0.9	1.0	1.0	-	-	-	1.1	1.6	1.4	-	-	-	-	-	-	-	1.3	1.4
		Sulfate	mg/L	-	-	-	41	42	42	-	-	-	<1	43	41	-	-	-	-	-	-	-	40	40
		Nitrate (as N)	mg/L	-	-	-	1.0	1.0	0.9	-	-	-	0.9	1.0	1.0	-	-	-	-	-	-	-	0.9	0.9
		Total P (as P)	µg/L	15	14	10.0	17	17	17	-	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	15	13	
		Silica (as SiO ₂)	mg/L	39.5	41.0	39.1	47.5	48.2	46.7	43.8	44.3	15.9	43.3	44.0	42.8	44.2	42.6	43.3	43.3	43.6	43.6	42.6	42.4	
		Turbidity	NTU	0.5	0.2	0.9	0.7	0.5	0.5	0.8	0.6	0.4	0.7	0.4	0.4	0.4	0.3	0.5	0.3	0.3	0.3	0.1	0.1	
		pH	S.U.	6.8	6.8	6.9	6.9	6.9	7.0	6.9	6.9	6.9	7.0	7.0	7.0	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.8	
		Temperature	°C	20.3	20.0	19.7	18.6	18.1	18.3	23.3	23.1	2.3	24.3	23.5	22.8	24.2	23.1	22.3	-	-	-	23.4	22.7	
		DO	mg/L	1.9	2.2	2.0	3.0	2.8	2.6	1.8	2.1	2.0	2.1	2.1	2.0	2.0	2.1	2.0	2.0	2.0	2.0	1.8	1.5	
		ORP	mV	305	276	278	401	386	277	415	345	310	453	470	470	479	317	251	251	251	251	372	277	
		Total Hardness (as CaCO ₃)	mg/L	90.2	86.1	91.1	90.7	89.5	90.0	95.4	90.4	94.3	86.3	85.2	88.9	86.4	85.1	84.3	84.3	84.3	84.3	93.3	95.3	
		Ca Hardness (as CaCO ₃)	mg/L	80.7	76.6	82.0	83.5	82.5	83.2	87.8	82.8	87.5	80.5	79.5	82.8	79.6	78.3	77.8	77.8	77.8	77.8	86.7	89.3	
		Mg Hardness (as CaCO ₃)	mg/L	9.5	9.6	9.2	7.2	7.0	6.8	7.5	7.5	6.8	5.8	5.7	6.1	6.8	6.8	6.5	6.5	6.5	6.5	6.6	6.0	
		As (total)	µg/L	38.8	35.8	3.1	40.1	40.4	4.4	41.3	38.1	4.9	41.9	40.7	8.1	38.2	37.5	9.4	46.0	46.0	9.2	47.3	45.8	
		As (soluble)	µg/L	-	-	-	38.5	39.7	4.4	-	-	-	42.2	40.6	7.8	-	-	-	-	-	-	45.2	44.8	
		As (particulate)	µg/L	-	-	-	1.6	0.7	<0.1	-	-	-	<0.1	0.1	0.3	-	-	-	-	-	-	2.1	1.0	
		As (III)	µg/L	-	-	-	0.1	0.2	0.1	-	-	-	0.1	0.1	<0.1	-	-	-	-	-	-	0.2	0.2	
		As (V)	µg/L	-	-	-	38.3	39.5	4.3	-	-	-	42.1	40.5	7.7	-	-	-	-	-	-	44.9	44.5	
		Fe (total)	µg/L	<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	<25	-	-	-	<25	<25	<25	-	-	-	-	-	-	<25	<25	
		Mn (total)	µg/L	<0.1	<0.1	<0.1	0.4	0.3	0.2	0.6	0.5	0.2	0.6	0.5	0.6	0.5	0.5	0.2	-	-	-	0.2	0.1	
		Mn (soluble)	µg/L	-	-	-	0.4	0.3	0.2	-	-	-	<0.1	<0.1	0.2	-	-	-	-	-	-	0.1	0.2	
		U (total)	µg/L	36.6	34.9	<0.1	38.9	38.7	<0.1	37.0	35.7	<0.1	31.3	31.0	<0.1	32.8	32.9	<0.1	-	-	-	34.1	34.2	
		U (soluble)	µg/L	-	-	-	37.9	38.1	<0.1	-	-	-	31.2	30.5	<0.1	-	-	-	-	-	-	34.3	33.4	

(a) Sampling conducted for Total As only between bi-weekly sampling event due to As levels approaching 10 µg/L.