

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

by

**Lili Wang<sup>‡</sup>  
Abraham S.C. Chen<sup>‡</sup>  
Gary M. Lewis<sup>§</sup>**

<sup>§</sup>Battelle, Columbus, OH 43201-2693

<sup>‡</sup>ALSA Tech, LLC, Columbus, OH 43219-0693

**Contract No. 68-C-00-185  
Task Order No. 0029**

for

**Thomas J. Sorg  
Task Order Manager**

**Water Supply and Water Resources Division  
National Risk Management Research Laboratory  
Cincinnati, OH 45268**

**National Risk Management Research Laboratory  
Office of Research and Development  
U.S. Environmental Protection Agency  
Cincinnati, OH 45268**

## **DISCLAIMER**

The work reported in this document was funded by the United States Environmental Protection Agency (EPA) under Task Order 0029 of Contract 68-C-00-185 to Battelle. It has been subjected to the Agency's peer and administrative reviews and has been approved for publication as an EPA document. Any opinions expressed in this paper are those of the author(s) and do not, necessarily, reflect the official positions and policies of the EPA. Any mention of products or trade names does not constitute recommendation for use by the EPA.

## FOREWORD

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and groundwater; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director  
National Risk Management Research Laboratory

## ABSTRACT

This report documents the activities performed during and the results obtained from the performance evaluation of an arsenic (As) and uranium (U) removal technology 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  $\text{ft}^3$  of ArsenX<sup>np</sup>, 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 performance evaluation study from October 12, 2005, through March 23, 2007, the HIX system operated for a total of 9,713 hr, treating approximately 13,561,950 gal of water from the Upper Bodfish Well CH2-A. The average daily run time was 18.5 hr/day and the average daily production was 25,783 gal/day (gpd). System flowrates ranged from 20 to 30 gpm and averaged 23 gpm, which was 46% of the system design flowrate of 50 gpm. The lower flowrates experienced resulted in longer empty bed contact times (EBCT), i.e., 6.7 to 10.1 min, and lower hydraulic loading rates, i.e., 2.1 to 3.1  $\text{gpm/ft}^2$ .

Source water from Well CH2-A contained 34.3 to 50.0  $\mu\text{g/L}$  of total arsenic with As(V) being the predominating species at an average concentration of 41.9  $\mu\text{g/L}$ . 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. In addition, source water had near-neutral pH values of 6.7 to 7.2, 88 to 145 mg/L of alkalinity (as  $\text{CaCO}_3$ ), 36 to 51 mg/L of sulfate, and 39.5 to 47.5 mg/L of silica.

Total arsenic concentrations in treated water were reduced initially to  $<0.1 \mu\text{g/L}$  and gradually increased to just over 10  $\mu\text{g/L}$  after treating approximately 33,100 bed volumes (BV) of water through Vessel 1, and 31,700 BV through Vessel 2. These run lengths were 66% and 59% higher than the vendor-estimated run length of 20,000 BV. Meanwhile, uranium was completely removed to below the method detection limit (MDL) of 0.1  $\mu\text{g/L}$  throughout the entire study period. A laboratory rapid small-scale column test (RSSCT) on the Upper Bodfish water using the ArsenX<sup>np</sup> media achieved a similar run length of 28,000 BV for arsenic and over 50,000 BV for uranium. 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 concentration at all three sampling locations, including one residence in the historic Lead and Copper Rule (LCR) sampling network and two non-LCR residences. Arsenic concentrations measured at the taps of these residences mirrored the breakthrough behavior of arsenic in the plant effluent, but were, in general, higher than those of the plant effluent. Although uranium concentrations in the distribution system were not measured both during the baseline sampling and after system startup, its concentrations after system startup were expected to be low because uranium was completely removed by the treatment system. The HIX system did not appear to have any effects on other water quality parameters in the distribution system.

The only residual generated by the HIX system was 54  $\text{ft}^3$  of spent media. Due to the presence of uranium, the spent media was classified as a technologically-enhanced, naturally-occurring radioactive

material (TENORM). Because uranium is considered a “source material,” the uranium-laden spent media may be subject to the Nuclear Regulatory Commission’s (NRC’s) licensing requirements for storage, transportation, and disposal (EPA, 2005).

The vendor originally proposed to regenerate the spent media at an offsite facility and then return the regenerated media to the site for reuse. However, the offsite regeneration would be possible only if the spent media residual stream contains less than 0.05% of uranium. Otherwise, the spent media would be considered a low-level radioactive waste (LLRW) or a non-exempt material, and may have to be partially regenerated onsite (to lower the uranium content to less than 0.05%) before offsite regeneration. Another approach would be to completely regenerate the spent media onsite to remove both uranium and arsenic. Both regeneration approaches would produce uranium and arsenic-laden liquids that would have to be hauled away due to lack of an onsite disposal method. These approaches would greatly increase complexity and cost, thus rendering media regeneration an un-viable option.

As a mixed waste, the spent media was subject to waste profiling and radiological analysis. The spent media passed the federal Toxicity Characteristic Leaching Procedure (TCLP) and the California Soluble Threshold Limit Concentrations (STLC) tests, but failed the California Total Threshold Limit Concentrations (TTLC) test for arsenic. As such, it was classified as a California hazardous waste (although not a Resource Conservation and Recovery Act [RCRA] waste). Results of the radiological analysis were compared against the federal requirements for an exempt source material based on the concentration, radioactivity, and quantity of uranium:

- The uranium concentration in the adsorption vessels was 0.032%, which was below the 0.05% (by weight) concentration limit
- The radioactivity of the spent media was 206 pCi/g for U-238 and 10.6 pCi/g for U-235, which were below the 335 pCi/g limit for an exempt material
- The quantity of uranium in the spent media in both vessels was 1.66 lb, which was below the 15-lb limit for an exempt material.

Because the spent media met all three requirements, it was deemed an “unimportant quantity” and exempt from applicable NRC regulations. Although the spent media, as an exempt material, might be disposed of at a solids waste, hazardous waste, or LLRW landfill, or any landfill licensed by a state to accept TENORM, it was difficult, if not impossible, to locate a solid waste landfill to accept the mixed waste with a radioactivity over 200 pCi/L. After 13 months of efforts, different contractors were secured to collect and analyze spent media samples and extract the spent media from the adsorption vessels. The spent media was transported in 10 55-gal high-density polyethylene (HDPE) drums to a facility in Turlock, CA, for temporary storage and was disposed of five months later at a U.S. Ecology facility in Grandview, ID, as an exempt, non-hazardous material.

Upon completion of the performance evaluation study, the host site, Cal Water, decided to close Well CH2-A, drill two new wells, and install a new 150-gpm HIX system for arsenic treatment. Cal Water also elected not to request transfer of the trailer-mounted system to the company. After removal of the spent media from the adsorption vessels, the trailer-mounted system was hauled away from the site by a subcontractor to Battelle.

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 would include media regeneration or replacement (including disposal) and labor for routine system operation. Spent media regeneration was proposed but not performed; thus, its cost could not be evaluated. The spent media was not replaced with virgin media due to removal of the treatment system from the site. Nonetheless, the media replacement cost was estimated to be \$38,271 based on the cost for virgin media and spent media disposal. By averaging the media replacement cost over the useful life of the media (i.e., 13,089,671 gal), the cost per 1,000 gal of water treated was \$2.92/1,000 gal. 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.

# CONTENTS

DISCLAIMER .....	ii
FOREWORD .....	iii
ABSTRACT .....	iv
APPENDICES .....	viii
FIGURES .....	viii
TABLES .....	viii
ABBREVIATIONS AND ACRONYMS .....	x
ACKNOWLEDGMENTS .....	xiii
1.0 INTRODUCTION .....	1
1.1 Background .....	1
1.2 Technologies Selected for Demonstration .....	2
1.3 Project Objectives .....	2
2.0 SUMMARY AND CONCLUSIONS .....	5
3.0 MATERIALS AND METHODS .....	6
3.1 General Project Approach .....	6
3.2 System O&M and Cost Data Collection .....	7
3.3 Sample Collection Procedures and Schedules .....	7
3.3.1 Source Water .....	9
3.3.2 Treatment Plant Water .....	10
3.3.3 Distribution System Water .....	10
3.3.4 Spent Media Sampling .....	10
3.4 Sampling Logistics .....	11
3.4.1 Preparation of Arsenic Speciation Kits .....	11
3.4.2 Preparation of Sample Coolers .....	11
3.4.3 Sample Shipping and Handling .....	12
3.5 Analytical Procedures .....	12
4.0 RESULTS AND DISCUSSION .....	13
4.1 Facility Description and Pre-Existing Treatment System Infrastructure .....	13
4.1.1 Source Water Quality .....	14
4.1.2 Distribution System .....	16
4.2 Treatment Process Description .....	16
4.3 System Installation .....	22
4.3.1 Permitting .....	22
4.3.2 Building Preparation .....	22
4.3.3 Installation, Shakedown, and Startup .....	23
4.4 System Operation .....	23
4.4.1 Operational Parameters .....	23
4.4.2 Residual Management .....	25
4.4.3 System/Operation Reliability and Simplicity .....	26
4.5 System Performance .....	28
4.5.1 Treatment Plant Sampling .....	28
4.5.2 Distribution System Water Sampling .....	39
4.6 Spent Media Characterization and Disposal .....	41
4.6.1 Spent Media Characterization .....	41
4.6.2 Spent Media Removal, Transportation, and Disposal .....	44

4.7 System Cost .....	45
4.7.1 Capital Cost.....	45
4.7.2 Operation and Maintenance Cost.....	46
5.0: REFERENCES .....	48

## APPENDICES

APPENDIX A: OPERATIONAL DATA
APPENDIX B: ANALYTICAL DATA

## FIGURES

Figure 3-1. Process Flow Diagram and Sampling Locations for Upper Bodfish Site .....	9
Figure 3-2. Distribution Map of Upper Bodfish Site.....	11
Figure 4-1. Upper Bodfish Well CH2-A in Lake Isabella, CA.....	13
Figure 4-2. Pre-Existing Aeration Tank at Upper Bodfish in Lake Isabella, CA .....	14
Figure 4-3. P&ID of HIX Treatment System.....	18
Figure 4-4. HIX System Layout on Trailer.....	19
Figure 4-5. Trailer-Mounted HIX System Under a Canopy .....	20
Figure 4-6. Bag Filter Assemblies .....	21
Figure 4-7. HIX Media Vessel with Pressure Release Port and Media Sampling Ports.....	21
Figure 4-8. HIX System Daily Operating Time.....	24
Figure 4-9. HIX System Flowrates .....	25
Figure 4-10. Decision Tree for Spent Media Disposal .....	27
Figure 4-11. Concentrations of Various Arsenic Species at IN, BF, and AF Sampling Locations During Adsorption Runs 1 and 2 .....	31
Figure 4-12. Total Arsenic Breakthrough Curve During Adsorption Run 1 .....	32
Figure 4-13. Total Arsenic Breakthrough Curve During Adsorption Run 2 .....	33
Figure 4-14. Total Uranium Breakthrough Curve During Adsorption Run 1.....	33
Figure 4-15. Total Uranium Breakthrough Curve During Adsorption Run 2.....	34
Figure 4-16. Total Arsenic Breakthrough Curves – Laboratory RSSCT .....	34
Figure 4-17. Uranium Breakthrough Curves – Laboratory RSSCT .....	35
Figure 4-18. Distribution of Uranium Carbonate and Hydroxide Complexes as a Function of pH .....	37
Figure 4-19. Silica Breakthrough Curve During Adsorption Run 1 .....	38
Figure 4-20. Silica Breakthrough Curve During Adsorption Run 2 .....	38
Figure 4-21. Total As Concentrations in Distribution System at Upper Bodfish .....	41
Figure 4-22. Spent Media Removal from Vessels .....	44
Figure 4-23. Spent Media Replacement and Disposal and O&M Cost Curves .....	47

## TABLES

Table 1-1. Summary of Round 1 and Round 2 Arsenic Removal Demonstration Locations, Technologies, and Source Water Quality.....	3
Table 3-1. Predemonstration Study Activities and Completion Dates .....	6
Table 3-2. General Types of Data .....	7
Table 3-3. Sampling Schedule and Chemical Analytes.....	8
Table 4-1. Upper Bodfish Well CH2-A Source Water Quality Data .....	15

Table 4-2.	Typical Physical and Chemical Properties of ArsenX <sup>np</sup> Media .....	17
Table 4-3.	HIX Treatment System Specifications and Design Parameters .....	17
Table 4-4.	Summary of HIX System Operation .....	23
Table 4-5.	Requirements for Exempt Source Material .....	26
Table 4-6.	Summary of Analytical Results for Arsenic, Uranium, Iron, and Manganese.....	28
Table 4-7.	Summary of Water Quality Parameter Sampling Results .....	29
Table 4-8.	Comparison of Media Run Lengths Between Full-Scale System and Laboratory RSSCT .....	35
Table 4-9.	Distribution System Sampling Results.....	40
Table 4-10.	Results of Spent Media Characterization .....	42
Table 4-11.	Results of Radiological Analysis on Spent Media .....	43
Table 4-12.	Uranium Concentration and Quantity Calculations .....	43
Table 4-13.	Determination of Exempt Source Material .....	43
Table 4-14.	Capital Investment Cost for the HIX System.....	45
Table 4-15.	Operation and Maintenance Cost for HIX System.....	47

## ABBREVIATIONS AND ACRONYMS

AAL	American Analytical Laboratories
AC	asbestos cement
AEA	Atomic Energy Act
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
CCR	California Code of Regulations
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
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
HDPE	high-density polyethylene
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
LLRW	low-level radioactive waste
MCL	maximum contaminant level
MDL	method detection limit
MEI	Magnesium Elektron, Inc.

## ABBREVIATIONS AND ACRONYMS (Continued)

Mg	magnesium
Mn	manganese
MPT	Mobile Processing Technology
Na	sodium
NA	not available
NaOCl	sodium hypochlorite
ND	not detectable
NRC	Nuclear Regulatory Commission's
NRMRL	National Risk Management Research Laboratory
NTU	nephelometric turbidity unit
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 <sub>4</sub>	phosphate
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
RCRA	Resource Conservation and Recovery Act
RO	reverse osmosis
RPD	relative percent difference
RSSCT	rapid small-scale column test
SBA	strong-base anion
SDWA	Safe Drinking Water Act
SiO <sub>2</sub>	silica
SO <sub>4</sub> <sup>2-</sup>	sulfate
STLC	Soluble Threshold Limit Concentrations
STS	Severn Trent Services
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
TENORM	technologically enhanced naturally occurring radioactive materials
TG&A	Thomas Gray and Associates
TOC	total organic carbon
TTLC	Total Threshold Limit Concentrations
U	uranium
V	vanadium

## **ABBREVIATIONS AND ACRONYMS (Continued)**

WET            Waste Extraction Test

## **ACKNOWLEDGMENTS**

The authors wish to extend their sincere appreciation to the staff of the California Water Service Company (Cal Water) in Lake Isabella, California. The primary operator, Mr. Mike Adams, monitored the treatment system and collected samples from the treatment plant and distribution system on a regular schedule throughout this reporting period. This performance evaluation would not have been possible without their support and dedication.

## 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 (As) at 0.05 mg/L. Amended in 1996, the SDWA required that EPA develop an arsenic research strategy and publish a proposal to revise the arsenic MCL by January 2000. On January 18, 2001, EPA finalized the arsenic MCL at 0.01 mg/L (EPA, 2001). 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 for reducing compliance cost. As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, onsite demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems. Shortly thereafter, an announcement published in the *Federal Register* requested water utilities interested in participating in Round 1 of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 out of 115 sites to host the demonstration studies.

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the 17 host sites. EPA received 70 technical proposals for the 17 host sites, with each site receiving one to six proposals. In April 2003, an independent technical panel reviewed the proposals and provided recommendations to EPA on the technologies it determined 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, CA, was one of those selected.

In September 2003, EPA again solicited proposals from engineering firms and vendors for arsenic removal technologies. EPA received 148 technical proposals for the 32 host sites, with each site receiving from two to eight proposals. In April 2004, EPA convened another technical panel to review the proposals and provide recommendations to EPA; the number of proposals per site ranged from none (for two sites) to a maximum of four. Final selection of the treatment technology at sites receiving 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<sup>HP</sup> media was selected for demonstration at the Upper Bodfish facility.

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

## **1.2 Technologies Selected for Demonstration**

The technologies selected for the Rounds 1 and 2 demonstration host sites include 25 adsorptive media (AM) systems (the Oregon Institute of Technology [OIT] site has three AM systems), 13 coagulation/filtration (C/F) systems, two ion exchange (IX) systems, 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, iron [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 Web site at <http://www.epa.gov/ORD/NRMRL/wswrd/dw/arsenic>.

## **1.3 Project Objectives**

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

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

This report summarizes the performance of the HIX system at the Upper Bodfish site in Lake Isabella, CA, from October 12, 2005, through March 23, 2007. 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	38 <sup>(a)</sup>	<25	8.6
Bow, NH	White Rock Water Company	AM (G2)	ADI	70 <sup>(b)</sup>	39	<25	7.7
Goffstown, NH	Orchard Highlands Subdivision	AM (E33)	AdEdge	10	33	<25	6.9
Rollinsford, NH	Rollinsford Water and Sewer District	AM (E33)	AdEdge	100	36 <sup>(a)</sup>	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 <sup>(a)</sup>	48	8.2
Stevensville, MD	Queen Anne's County	AM (E33)	STS	300	19 <sup>(a)</sup>	270 <sup>(c)</sup>	7.3
Houghton, NY <sup>(d)</sup>	Town of Caneadea	C/F (Macrolite)	Kinetico	550	27 <sup>(a)</sup>	1,806 <sup>(c)</sup>	7.6
Buckeye Lake, OH	Buckeye Lake Head Start Building	AM (ARM 200)	Kinetico	10	15 <sup>(a)</sup>	1,312 <sup>(c)</sup>	7.6
Springfield, OH	Chateau Estates Mobile Home Park	AM (E33)	AdEdge	250 <sup>(e)</sup>	25 <sup>(a)</sup>	1,615 <sup>(c)</sup>	7.3
<i>Great Lakes/Interior Plains</i>							
Brown City, MI	City of Brown City	AM (E33)	STS	640	14 <sup>(a)</sup>	127 <sup>(c)</sup>	7.3
Pentwater, MI	Village of Pentwater	C/F (Macrolite)	Kinetico	400	13 <sup>(a)</sup>	466 <sup>(c)</sup>	6.9
Sandusky, MI	City of Sandusky	C/F (Aeralater)	Siemens	340 <sup>(e)</sup>	16 <sup>(a)</sup>	1,387 <sup>(c)</sup>	6.9
Delavan, WI	Vintage on the Ponds	C/F (Macrolite)	Kinetico	40	20 <sup>(a)</sup>	1,499 <sup>(c)</sup>	7.5
Greenville, WI	Town of Greenville	C/F (Macrolite)	Kinetico	375	17	7827 <sup>(c)</sup>	7.3
Climax, MN	City of Climax	C/F (Macrolite)	Kinetico	140	39 <sup>(a)</sup>	546 <sup>(c)</sup>	7.4
Sabin, MN	City of Sabin	C/F (Macrolite)	Kinetico	250	34	1,470 <sup>(c)</sup>	7.3
Sauk Centre, MN	Big Sauk Lake Mobile Home Park	C/F (Macrolite)	Kinetico	20	25 <sup>(a)</sup>	3,078 <sup>(c)</sup>	7.1
Stewart, MN	City of Stewart	C/F&AM (E33)	AdEdge	250	42 <sup>(a)</sup>	1,344 <sup>(c)</sup>	7.7
Lidgerwood, ND	City of Lidgerwood	Process Modification	Kinetico	250	146 <sup>(a)</sup>	1,325 <sup>(c)</sup>	7.2
<i>Midwest/Southwest</i>							
Arnaudville, LA	United Water Systems	C/F (Macrolite)	Kinetico	770 <sup>(e)</sup>	35 <sup>(a)</sup>	2,068 <sup>(c)</sup>	7.0
Alvin, TX	Oak Manor Municipal Utility District	AM (E33)	STS	150	19 <sup>(a)</sup>	95	7.8
Bruni, TX	Webb Consolidated Independent School District	AM (E33)	AdEdge	40	56 <sup>(a)</sup>	<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 <sup>(a)</sup>	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 <sup>(b)</sup>	50	170	7.2
Tohono O'odham Nation, AZ	Tohono O'odham Utility Authority	AM (E33)	AdEdge	50	32	<25	8.2
Valley Vista, AZ	Arizona Water Company	AM (AAFS50/ARM 200)	Kinetico	37	41	<25	7.8

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

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

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

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

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

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

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

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

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

(f) Including nine residential units.

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

## 2.0 SUMMARY AND CONCLUSIONS

Based on the information collected during 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<sup>mp</sup> media is effective at removing arsenic and uranium to below their respective MCLs. The treatment system achieved a run length of 33,100 and 31,700 bed volumes (BV) at 10- $\mu\text{g/L}$  arsenic breakthrough, which is 65 and 59%, respectively, higher than the vendor's projected value. Uranium was 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  $\text{SiO}_2$ ) had little or no effect on ArsenX<sup>mp</sup> performance. Silica removal was observed only during the initial 1,000 BV.
- The use of ArsenX<sup>mp</sup> 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 pre-existing 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, no backwash wastewater or solids were produced.
- The spent media, containing arsenic and uranium, is a mixed waste, and requires waste profiling and radiological analysis to determine the proper disposal methods. Results of Toxicity Characteristic Leaching Procedure (TCLP), Total Threshold Limit Concentration (TTLC), Soluble Threshold Limit Concentration (STLC) and radiological analysis indicated that the spent media be classified as a non-hazardous, exempt material. However, it is difficult to find a solid waste landfill in California to accept the uranium-laden material even if it is exempt material.

### *Cost of the Technology:*

- Based on the system's rated capacity of 50 gal/min (gpm), the capital cost is \$2,281 per gpm of the design capacity (or \$1.58/gal/day [gpd]).
- Cost of media replacement and disposal is the most significant add-on cost at \$2.92/1,000 gal. The labor cost for routine O&M activities was \$0.13/1,000 gal.

### 3.0 MATERIALS AND METHODS

#### 3.1 General Project Approach

Table 3-1 summarizes predemonstration activities and completion dates. The performance evaluation study of the HIX treatment system began on October 12, 2005, and ended on March 23, 2007. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall system performance was evaluated based on its ability to consistently remove arsenic and uranium to their respective MCLs of 10 and 30 µg/L. This was monitored through the collection of water samples across the treatment train, as described in the Study Plan (Battelle, 2005). The reliability of the system was evaluated by tracking unscheduled system downtime and frequency and extent of repair and replacement. The plant operator recorded unscheduled downtime and repair information 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

O&M and operator skill requirements were assessed through a combination of quantitative data and qualitative considerations, including needs 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, site engineering, and installation, as well as the O&M cost for media regeneration or replacement and disposal, chemical supply, electricity usage, and labor.

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

### 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), the plant operator recorded system operation data, such as pressure, flowrate, 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 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 expenditure 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 sampling schedules and chemical analytes measured during each sampling event. Figure 3-1 presents a flow diagram of the treatment system along with the analytes and schedules at each sampling location.

Table 3-3. Sampling Schedule and Chemical Analytes

Sample Type	Sampling Locations <sup>(a)</sup>	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 <sub>3</sub> , NO <sub>3</sub> , NO <sub>2</sub> , Cl, F, SO <sub>4</sub> , SiO <sub>2</sub> , PO <sub>4</sub> , TDS, TOC, turbidity, and alkalinity	10/14/04
Treatment Plant Water	At Wellhead (IN), before HIX Vessel (BF), after HIX Vessel (AF)	3	One to four times a month (Regular Sampling)	Onsite: pH, temperature, DO, and ORP Offsite: As (total), Fe (total), Mn (total), U (total), Ca, Mg, SiO <sub>2</sub> , P, turbidity, and alkalinity	Appendix B
			Monthly during first adsorption run; twice during second adsorption run (Speciation Sampling)	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 <sub>3</sub> , SO <sub>4</sub> , SiO <sub>2</sub> , P, turbidity, and alkalinity	Appendix B
Distribution Water	Three residences including one historic LCR sampling location	3	Monthly <sup>(b)</sup>	Offsite: pH, alkalinity, As (total), Fe (total), Mn (total), Pb (total), and Cu (total)	08/10/05 to 10/12/06
Spent Media	Top, middle, and bottom of each HIX vessel	6 <sup>(c)</sup>	Once	Offsite: TTLC, STLC, and TCLP metals, and gamma spectroscopy (U-235/U-238)	08/30/07

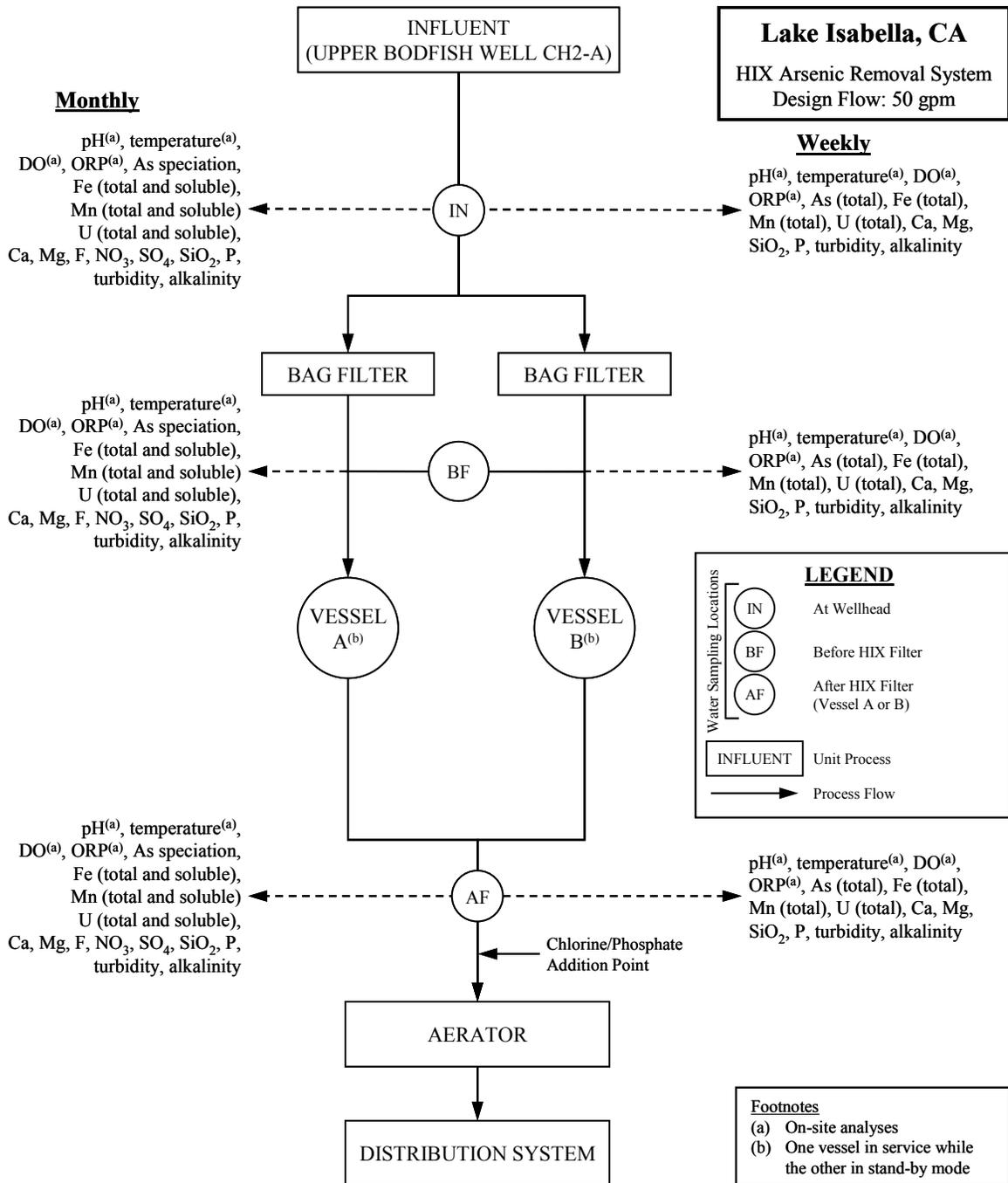
(a) Abbreviations in parentheses corresponding to sample locations shown in Figure 3-1.

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

(c) One composite sample was submitted for laboratory analysis.

DO = dissolved oxygen; LCR = Lead and Copper Rule; ORP = oxidation-reduction potential; STLC = Soluble Threshold Limit Concentration; TCLP = Toxicity Characteristic Leaching Procedure; TDS = total dissolved solids; TOC = total organic carbon; TTLC = Total Threshold Limit Concentration.

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.



**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. Table 3-3 lists analytes for the source water samples.

**3.3.2 Treatment Plant Water.** Two single-vessel adsorption runs were conducted during the performance evaluation study. The original Study Plan called for collection of “speciation samples” at the wellhead (IN), before the HIX vessel (BF), and after the HIX vessel (AF) during the first week of each 4-week cycle and collection of “regular samples” from the same three locations during the remaining weeks. However, this sampling schedule was followed only briefly during the initial six weeks of system operation. Since then through the end of the first adsorption run, speciation samples were taken once a month and regular samples were taken one to two times a month. The speciation and regular samples taken were analyzed for the analytes shown in Table 3-3, except for one occasion on July 26, 2006, when the regular samples were measured only for total arsenic.

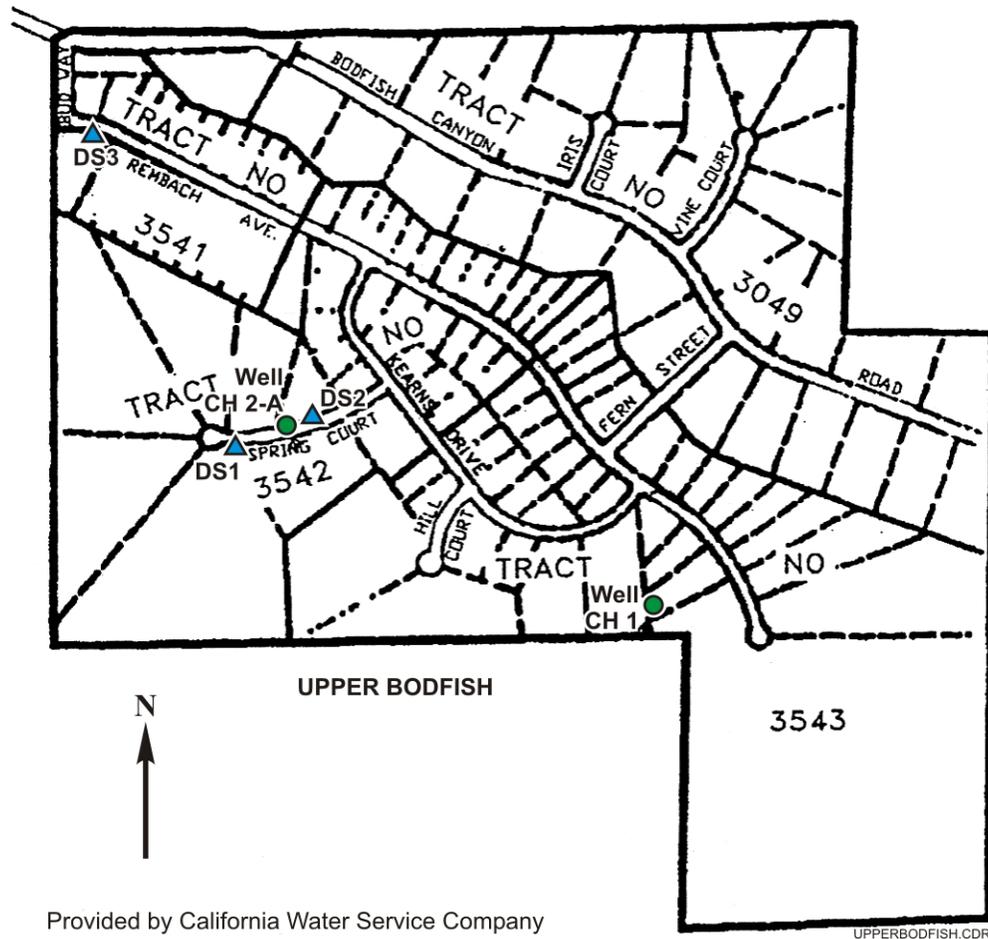
During the second adsorption run, “speciation samples” were taken only twice on August 23 and September 27, 2006, and “regular samples” were taken once every one to four weeks. The speciation and regular samples collected were analyzed for the analytes presented in Table 3-3. Beginning on October 26, 2006, through the end of the performance evaluation study, regular samples were analyzed only for total arsenic and uranium.

**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 sampling events were conducted at three locations in the distribution system. Following startup of the HIX system through October 2006, monthly distribution system water samples were collected at the same three locations.

Three residences were selected for distribution system water sampling: 179 Spring Court (designated as DS1), 66 Spring Court (DS2), and 2216 Rembach Avenue (DS3). Only DS2 was part of the historic Lead and Copper Rule (LCR) sampling network serviced primarily by the source 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. All samples were collected from a cold-water faucet that had not been used for at least 6 hr to ensure that stagnant water was sampled, with the exception of DS2 on March 22, 2006.

**3.3.4 Spent Media Sampling.** Spent media samples were collected from each HIX vessel for radiological analyses and waste characterization for the purpose of determining disposal options for the media. Due to potential concerns with the radioactivity of the spent media, Thomas Gray and Associates (TG&A) in Orange, CA, a licensed radioactive waste broker, was contracted to perform a dose rate radiation survey and collect spent media samples. On August 30, 2007, a TG&A technician was onsite to conduct a dose rate radiation survey over the exterior of both vessels prior to sample collection. The technician used a Bicon MicroRem radiation monitor to take readings from the bottom, center, and top of each vessel. A total of 12 readings were collected from each vessel, ranging from 10 to 15  $\mu\text{rem}$ . These low readings indicated that radiological exposure was not a problem.

After the system was pressurized, the technician collected one 1-L spent media sample from each of the sampling ports located at various depths (6, 18, and 30 in below the top of the media bed) from each vessel. A 1-L composite sample was constructed by mixing an equal amount of each sample in a 1-L container. From this 1-L composite sample, two 8-oz and one 4-oz containers were filled and sent to Teledyne Brown Engineering laboratory in Oak Ridge, TN, for TTLC, STLC, TCLP, and gamma spectroscopy (U-235/U-238) analyses.



**Figure 3-2. Distribution Map of Upper Bodfish Site**

### 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 in accordance with 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, waterproof label consisting of the sample identification (ID), date and time of sample collection, collector's name, site location, sample destination, analysis required, and preservative. The sample ID consisted of a two-letter code for the specific water facility, sampling date, a two-letter code for a specific sampling location, and a one-letter code designating the arsenic speciation bottle (if necessary). The sampling locations at the treatment plant were color-coded for easy identification. The

labeled bottles for each sampling location were placed in separate zip-lock bags and packed in the cooler. When needed, the sample cooler also included bottles for the distribution system water sampling.

In addition, all sampling- and shipping-related materials such as disposable gloves, sampling instructions, chain-of-custody forms, pre-paid/pre-addressed FedEx air bills, and bubble wrap were placed in each cooler. 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 checked sample IDs against the chain-of-custody forms and verified that all samples indicated on the forms were included and intact. The Battelle Study Lead addressed discrepancies noted by the sample custodian with the plant operator. The shipment and receipt of all coolers by Battelle were recorded on a cooler tracking log.

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 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. Prior to the performance evaluation study, the average monthly demand was 1,000,000 gal (or 34,000 gpd) and the peak monthly demand was 1,900,000 gal (or 64,000 gpd). The water demand was 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, had been taken out of service for an extended period of time.

Well CH2-A was selected for this EPA demonstration study due to elevated arsenic and uranium levels in the water. Drilled in 1980, Well CH2-A was 6-in in diameter and 348 ft deep with a static water level of 336 ft below ground surface (bgs). The well was equipped with a 3-horsepower (hp) pump that produced 38 gpm of flow (well pump curve was unavailable). Prior to 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 pre-existing Well CH2-A wellhead and associated piping in a fenced area.



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

The pre-existing 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  $\text{Cl}_2$ ) and the target phosphate level was 0.5 mg/L (as  $\text{PO}_4$ ). The treated water was then pumped to the distribution system by a 10-hp booster pump.



**Figure 4-2. Pre-Existing Aeration Tank at Upper Bodfish in Lake Isabella, CA**

Well CH-1, drilled in August 1986, was located approximately a quarter of a mile southeast of Well CH2-A. Well CH-1 water does 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.** Table 4-1 presents the analytical data of source water samples collected at the wellhead of Well CH2-A on October 14, 2004. Table 4-1 also compares the October 14, 2004, data 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 18-month long 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, arsenic existed almost entirely as soluble As(V), which could be removed directly by the HIX system without preoxidation.

**Uranium.** Total uranium concentrations in Well CH2-A water ranged from 27.0 to 35.0  $\mu\text{g/L}$ , which 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). 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 pre-existing 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  $\mu\text{g/L}$ . Iron concentrations reported by Battelle and CDPH were less than the respective reporting limits of 25 and 100  $\mu\text{g/L}$ . According to VEETech, iron could 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  $\mu\text{g/L}$ , which existed mainly in the soluble form.

**Table 4-1. Upper Bodfish Well CH2-A Source Water Quality Data<sup>(a)</sup>**

Parameter	Unit	CDPH Data	Facility Data <sup>(b)</sup>	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 <sub>3</sub> )	mg/L	NA	85	85
Hardness (as CaCO <sub>3</sub> )	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 <sub>2</sub> )	mg/L	NA	40	44.7
Orthophosphate (as PO <sub>4</sub> )	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) All samples collected at wellhead before aeration tank.

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

DO = dissolved oxygen; NA = not available; NTU = nephelometric turbidity unit; ORP = oxidation-reduction potential; TDS = total dissolved solids; TOC = total organic carbon

**Competing Anions.** Silica and phosphate were potential competing anions in source water. Concentrations of silica in source water ranged from 40 to 44.7 mg/L (as SiO<sub>2</sub>), 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 CaCO<sub>3</sub>) 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 caused by recent drought conditions. A blended poly- and ortho-phosphate solution was used for iron sequestration and corrosion control in the distribution system. Because iron concentrations in source water were low, phosphate addition was probably not needed for iron control; the addition was only for corrosion control. 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 was a fixed-bed adsorption system utilizing a hybrid polymeric-inorganic exchanger, known as ArsenX<sup>np</sup>, for arsenic and uranium removal. Manufactured by Purolite, ArsenX<sup>np</sup> incorporated nanoparticle technology originally developed by Dr. Arup SenGupta of Lehigh University, PA, and further refined by SolmeteX, Inc. of Northborough, MA. ArsenX<sup>np</sup> was NSF International (NSF) 61 certified for use in municipal water treatment systems. Table 4-2 presents physical and chemical properties of the media. ArsenX<sup>np</sup> consisted of hydrous iron oxide nanoparticles impregnated into a standard strong-base anion (SBA) exchange resin. The iron content was approximately 25% (as Fe by dry weight). ArsenX<sup>np</sup> media utilized iron chemistry to adsorb arsenic from water and simultaneously removed uranium by its base material – anionic exchange resin. The SBA resin was 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 was 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 consisted of two single-stage, fiberglass reinforced plastic (FRP) vessels, each loaded with approximately 27 ft<sup>3</sup> of ArsenX<sup>np</sup> media. Each vessel was capable of treating 50 gpm of flow. During normal operation, one vessel was placed in service while the other was on standby. This configuration allowed continuous system operation should one vessel be shipped off site for regeneration. 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.

The HIX treatment system included 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, which was interlocked with the high/low level sensors in the aerator. An hour meter was installed on the well pump to record the operating time.

**Table 4-2. Typical Physical and Chemical Properties of ArsenX<sup>np</sup> 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 <sup>3</sup> [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 <sup>3</sup> ])	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 <sup>np</sup>	
Quantity of Media (ft <sup>3</sup> )	27	Per vessel
Backwash	None	–
Pressure Drop (psi)	3	1 psi/ft of media
Area of Cross Section (ft <sup>2</sup> )	9.6	–
Media Bed Depth (ft)	2.8	–
Design Flowrate (gpm)	50	–
Hydraulic Loading (gpm/ft <sup>2</sup> )	5.2	Based on 50 gpm design flowrate
Specific Service Flow Rate (gpm/ft <sup>3</sup> )	1.9	Based on 50 gpm design flowrate
EBCT (min)	4.0	Based on 50 gpm design 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	–

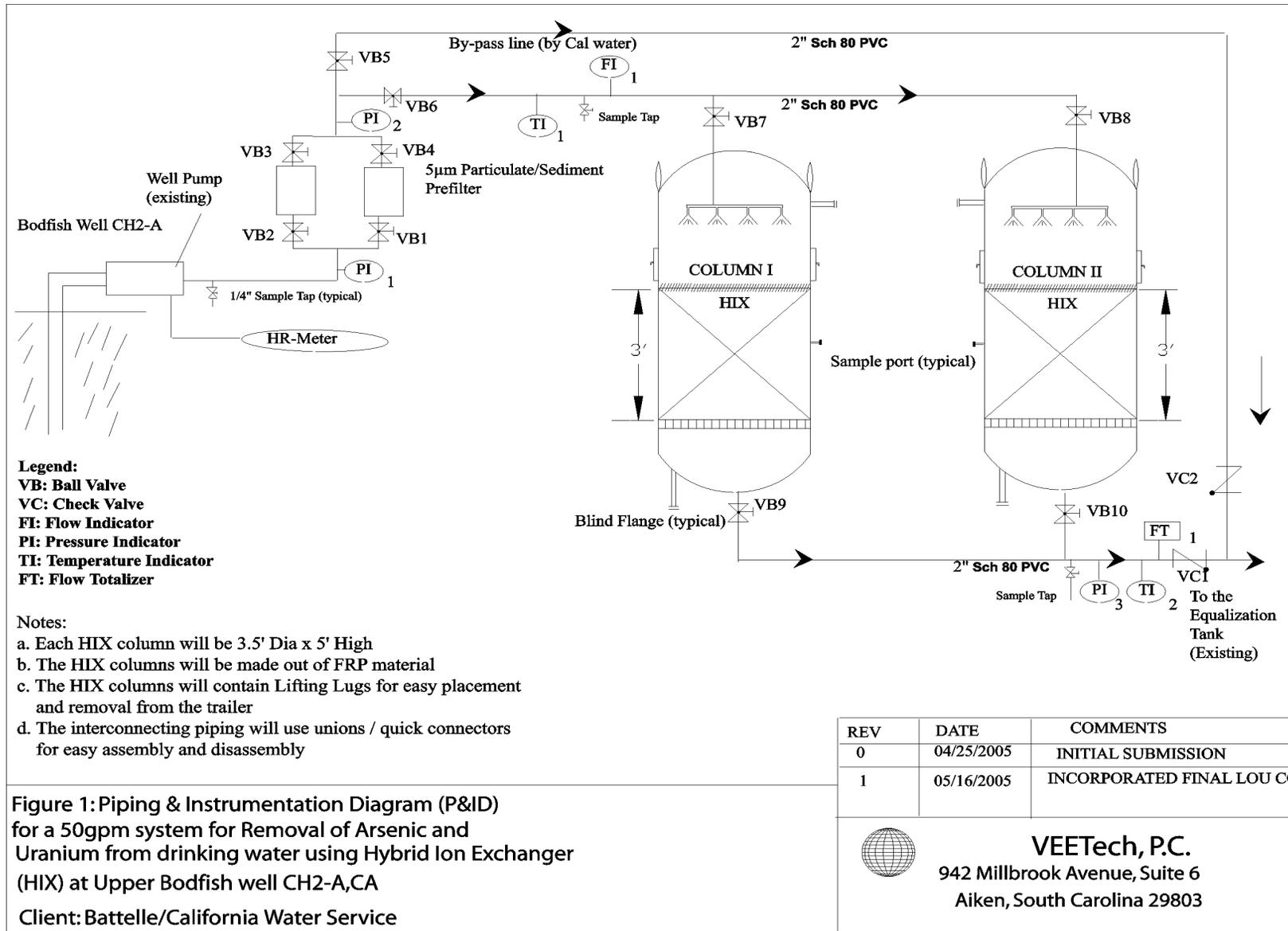
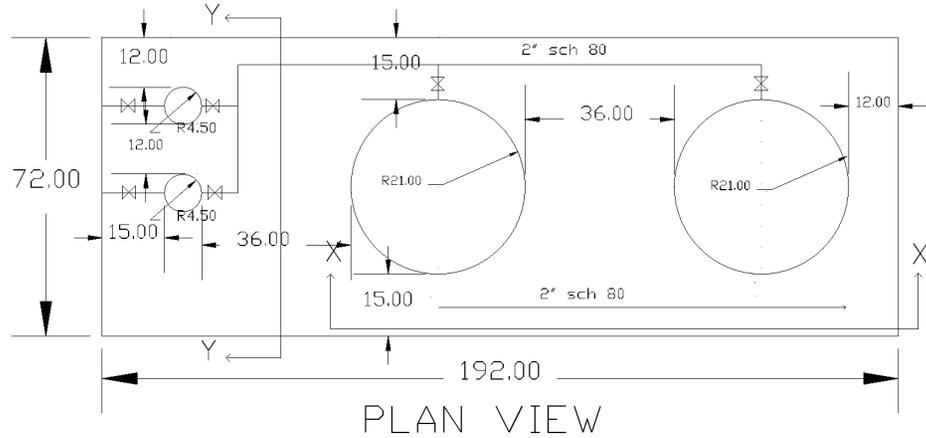
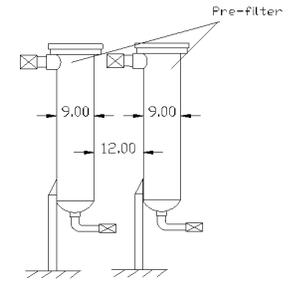


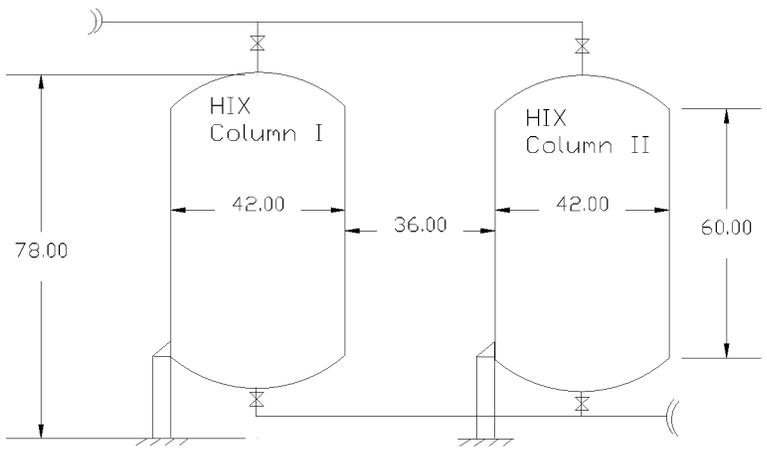
Figure 4-3. P&ID of HIX Treatment System (Provided by VEETech)



PLAN VIEW



VIEW Y-Y



VIEW X-X

Note: All Dimensions are in inches

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

Figure No: <b>2</b>	Drawn By: <b>RS</b>	Checked By: <b>AKS</b>	Date: <b>07/18/2005</b>
------------------------	------------------------	---------------------------	----------------------------



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

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



**Figure 4-5. Trailer-Mounted HIX System Under a Canopy**

- **Bag-Filter** – Two 1- $\mu\text{m}$  bag-filter assemblies were installed before 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 lb/in<sup>2</sup> (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. Insoluble silica might be removed along with sediment 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 high and contained approximately 27 ft<sup>3</sup> of ArsenX<sup>np</sup> 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. Under the peak flow rate of 38 gpm, the hydraulic loading rate to each vessel was 4.0 gpm/ft<sup>2</sup> 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 exceeded the respective MCL, water flow was diverted to the standby vessel for continuous system operation and the spent media vessel was taken offline for regeneration or replacement. According to the vendor, the media could be regenerated and reused for up to 20 cycles based on the water chemistry of Well CH2-A. During the performance evaluation study, bed breakthrough of arsenic at 10  $\mu\text{g/L}$  occurred at approximately 33,100 BV and flow was diverted to the standby column for continuous system operation. Potential options for media regeneration or replacement are further discussed in Section 4.4.2.



**Figure 4-6. Bag Filter Assemblies**



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

- **Chlorine and Phosphate Addition** – Prior to entering the aerator, chlorine was added 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 Cl<sub>2</sub>). 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 PO<sub>4</sub>).
- **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 high 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 pre-existing 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 backwashing 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 to be 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’s (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 distribution system using 2-in diameter polyethylene piping and completed the system installation on September 29, 2005. VEETech was onsite 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 12, 2005. No major mechanical or installation issues were identified at system startup.

**4.4 System Operation**

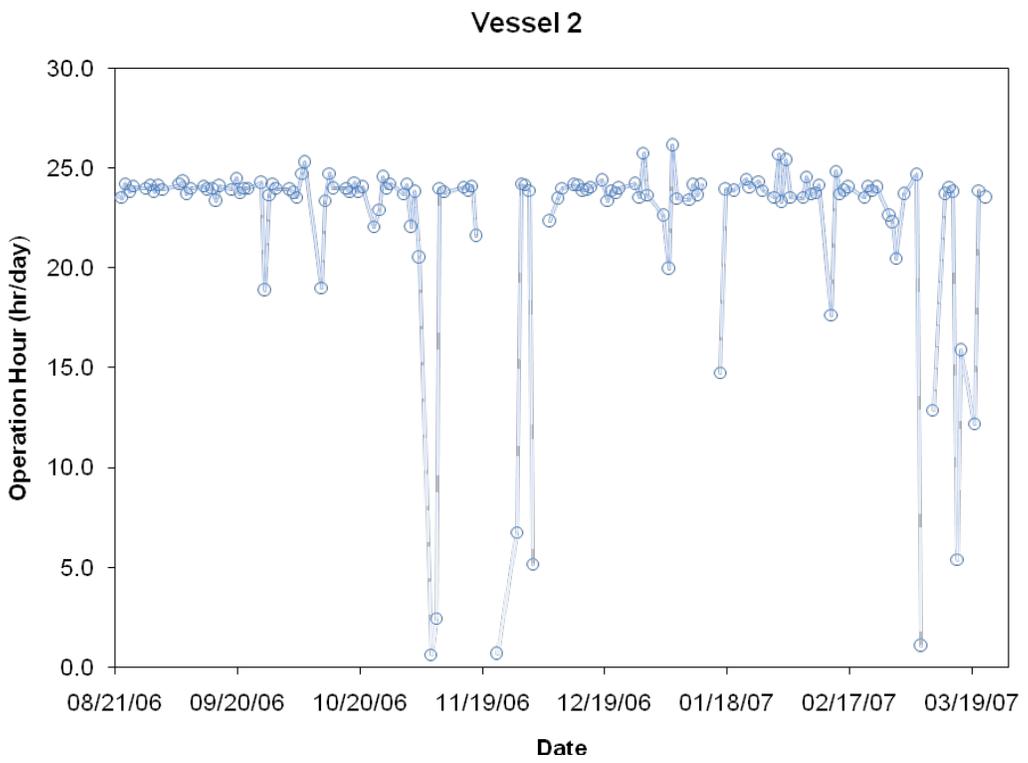
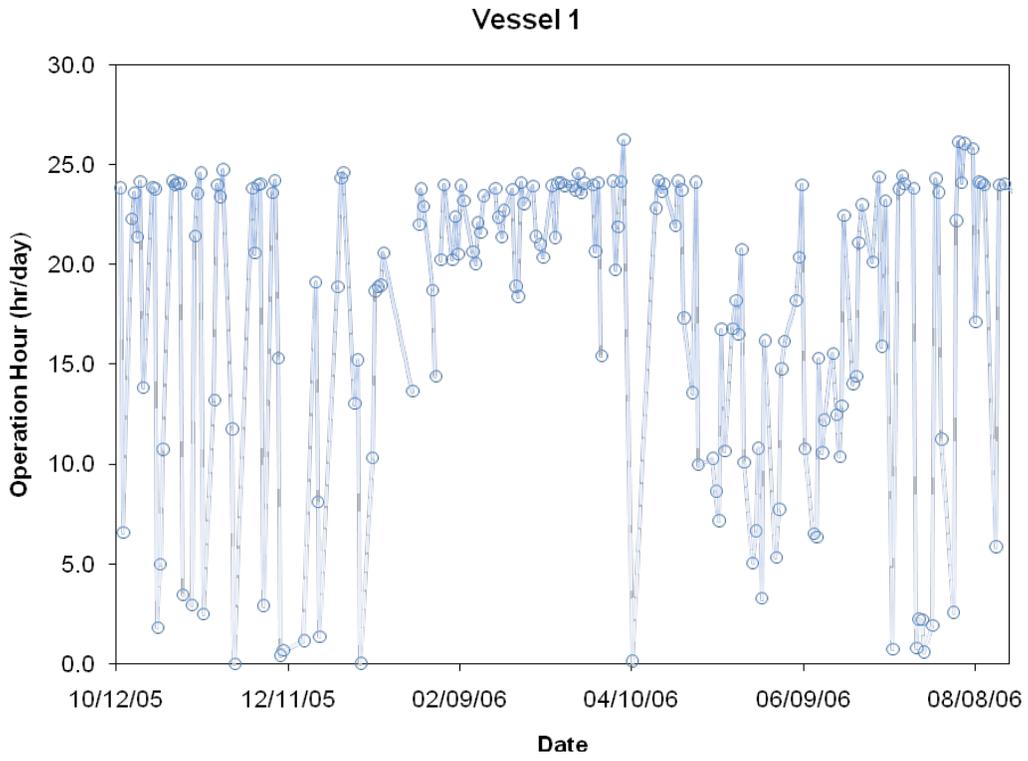
**4.4.1 Operational Parameters.** The operational parameters for the duration of the performance evaluation study were tabulated and are attached as Appendix A. Key parameters are summarized in Table 4-4. Two single-vessel adsorption runs were conducted during the performance evaluation study. The first adsorption run using Vessel 1 began on October 12, 2005, and ended on August 15, 2006. The second adsorption run using Vessel 2 began on August 16, 2006, and ended on March 23, 2007. Between October 12, 2005, and August 15, 2006, approximately 7,095,070 gal of water was processed through Vessel 1, whereupon arsenic concentrations in effluent exceeded 10 µg/L and flow was switched to Vessel 2. An additional 6,446,880 gal of water was then treated by Vessel 2 through March 23, 2007, which marked the end of the study. With a total of 13,561,950 gal of water treated, the average daily demand was 25,783 gpd, equivalent to 36% of the design capacity. The amount of water treated was based on readings from the flow meter/totalizer installed at the effluent side of the filtration vessels.

Table 4-4. Summary of HIX System Operation

Operational Parameter	Adsorption Run 1	Adsorption Run 2	Combined
Operating Vessel	Vessel 1	Vessel 2	
Duration	10/12/05–08/15/06	08/16/06–03/23/07	10/12/05–03/23/07
Cumulative Operating Time (hr)	4,920	4,793	9,713
Total No. of Days System Operating (day)	307	219	526
Average Daily Operating Time (hr)	16.0	21.9	18.5
Cumulative Throughput (gal)	7,095,070	6,466,880	13,561,950
Cumulative Throughput (BV) <sup>(a)</sup>	35,124	32,014	–
Average (Range) of Flowrate (gpm)	24 (21–29)	21 (20–30)	23 (20–30)
Average (Range) of EBCT (min)	8.5 (6.9–9.5)	9.6 (6.7–10.1)	8.8 (6.7–10.1)
Average (Range) of Inlet Pressure (psi)	8.1 (1–13)	6.5 (3–10)	7.3 (1–13)
Average (Range) of Outlet Pressure (psi)	7.1 (2–11)	8.6 (3–12)	7.9 (2–12)
Average of Δp across System (psi)	1	1	1

(a) Calculated based on 27 ft<sup>3</sup> of media in operating vessel.

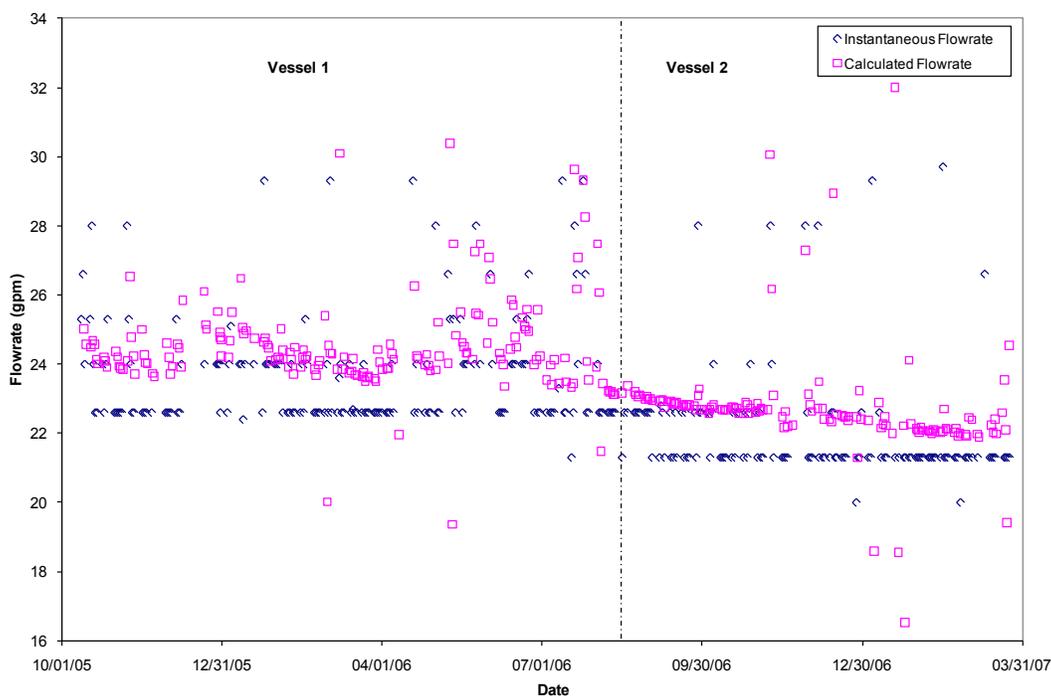
Through the entire study period, the system operated for a total of 9,713 hr based on the wellhead hour meter readings. Average daily operating time during the first adsorption run was 27% shorter than that during the second adsorption run (i.e., 16.0 versus 21.9 hr/day); the differences observed do not appear to have been caused by seasonal variations (see Figure 4-8). The system was operating for more than 20 hr a day during 64% of the study period. Significantly shorter daily run times were experienced through



**Figure 4-8. HIX System Daily Operating Time**

most weekends during the first four months of system operation and through the periods from May to July 2006, November 2006, and March 2007. Review of the field logs did not reveal any particular reasons for these shorter run times.

System flowrates were tracked by both instantaneous readings of a flow meter installed at the system inlet and calculated values based on readings of the wellhead hour meter and a flow totalizer installed at the system outlet. As shown in Figure 4-9, both instantaneous readings and calculated values fluctuated with the calculated values being generally higher than the instantaneous readings throughout the entire study period. Flowrates to the system ranged from 20 to 30 gpm and average 23 gpm, which was 39% lower than the 38-gpm peak flowrate (Table 4-3) or 54% lower than the 50-gpm design flowrate. Based on the flowrates to the system, the EBCT for the operating vessel varied from 6.7 to 10.1 min and averaged 8.8 min. As a result, the average EBCT was 66% and 120% higher than the peak and design EBCT of 5.3 and 4 min, respectively. Inlet and outlet pressure readings of the HIX system averaged 7.3 and 7.9 psi, respectively, with a 1.0 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.



**Figure 4-9. HIX System Flowrates**

**4.4.2 Residual Management.** Backwashing of the HIX media bed was not required, thus, no wastewater was generated. The only residual generated by the HIX system operation was 54 ft<sup>3</sup> of spent media. Depending on whether the spent media is regenerated or replaced, arsenic- and uranium-laden liquid or solid residual streams may be produced. Due to the presence of uranium, these residual streams are classified as technologically enhanced naturally occurring radioactive materials (TENORM). Uranium concentrations in TENORM, types of residual produced (liquid or solid wastes), and applicable federal and state regulations will affect disposal options (EPA, 2005).

According to EPA's *A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies* (EPA, 2005), if a water system generates uranium-containing residuals, this uranium is considered "source material" and may be subject to the Nuclear Regulatory Commission's (NRC's) licensing requirements under the Atomic Energy Act (AEA). If the uranium makes up less than 0.05% (by weight) of the residuals, it is exempt from NRC regulations because it is considered an "unimportant quantity" (10 CFR 40.13). Table 4-5 summarizes source material quantities that are exempt from specific licensing requirements. If a residual contains uranium exceeding the listed requirements, then it is classified as a non-exempt material and is subject to relevant regulations for storage, transportation, and disposal. Possession of the source material in concentrations or quantities greater than those shown requires compliance with 10 CFR 40.19, 20, and 21.

**Table 4-5. Requirements for Exempt Source Material**

Measurement	Requirements
Concentration	<0.05 % by weight of uranium
Radioactivity	<335 pico-Curies per gram (pCi/g)
Quantity	<15 lb at any given time; <150 lb over course of a year

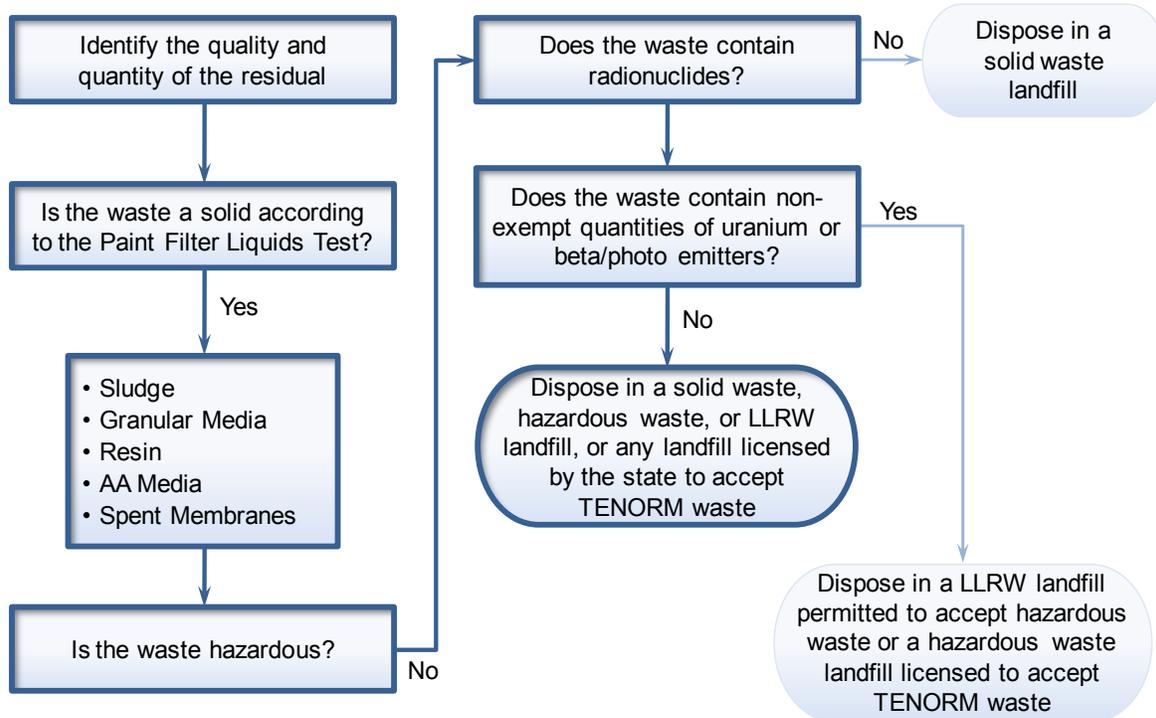
Source: (EPA, 2005)

The HIX vendor originally proposed to regenerate the spent media upon exhaustion for arsenic at 15,000 to 20,000 BV of throughput. The spent media would be extracted from an adsorption vessel and shipped to MPT in Memphis, TN, for regeneration. The regenerated media would then be returned to the site for reuse. Because MPT is licensed to process only non-exempt material, uranium in the residual stream may not exceed the 0.05% (by weight) "unimportant quantity." Otherwise, the spent media might need to be partially regenerated onsite to below the 0.05% limit before taken to MPT for further regeneration. Another approach would be to completely regenerate the media onsite to remove uranium and arsenic. Both regeneration approaches would produce uranium- and arsenic-laden residuals, such as spent brine and rinse water. Due to lack of an onsite disposal method, liquid streams would have to be hauled away for offsite disposal in accordance with applicable regulations.

When seeking a viable option for the spent media, Cal Water drilled two new wells and installed a new 150-gpm HIX skid-mounted system similar to the demonstration unit. Meanwhile, Cal Water opted to close Well CH2-A and return the trailer-mounted system to EPA. This left media disposal to be the only option for handling the spent media. A decision tree for solid residual disposal (EPA, 2005) was used to guide media characterization and disposal and the process adopted was highlighted as shown in Figure 4-10. Spent media samples were collected and submitted to laboratories for waste characterization and radiological analyses. Section 4.6 presents the results of spent media characterization and disposal.

**4.4.3 System/Operation Reliability and Simplicity.** There were no operational problems with the HIX system during the performance evaluation study, 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 accurately 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- $\mu$ m bag filter to remove sediment/particulate matter from raw water. Post-treatments included aeration (for radon



**Figure 4-10. Decision Tree for Spent Media Disposal (Modified after [EPA, 2005])**

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 did 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 changeout 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 46 occasions, including four duplicates, with field speciation performed in 13 of the 46 occasions. Table 4-6 summarizes the analytical results for arsenic, uranium, iron, and manganese; Table 4-7 summarizes the results of other water quality parameters.

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

Parameter	Sampling Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
As (total)	IN	µg/L	46	34.3	50.0	41.7	3.0
	BF	µg/L	46	34.8	47.6	41.5	3.0
	AF-V1	µg/L	30	<0.1	10.5	-(a)	-(a)
	AF-V2	µg/L	16	<0.1	11.7	-(a)	-(a)
As (soluble)	IN	µg/L	13	36.6	49.7	42.3	3.6
	BF	µg/L	13	36.5	47.0	42.2	3.2
	AF-V1	µg/L	11	0.12	10.3	-(a)	-(a)
	AF-V2	µg/L	2	<0.1	<0.1	-(a)	-(a)
As (particulate)	IN	µg/L	13	<0.1	2.1	0.5	0.7
	BF	µg/L	13	<0.1	1.5	0.5	0.6
	AF-V1	µg/L	11	<0.1	<0.1	-(a)	-(a)
	AF-V2	µg/L	2	<0.1	<0.1	-(a)	-(a)
As(III)	IN	µg/L	13	0.13	0.9	0.4	0.3
	BF	µg/L	13	0.13	0.8	0.4	0.2
	AF-V1	µg/L	11	<0.1	1.0	-(a)	-(a)
	AF-V2	µg/L	2	0.11	0.4	-(a)	-(a)
As(V)	IN	µg/L	13	36.3	49.2	41.9	3.6
	BF	µg/L	13	36.2	46.7	41.8	3.2
	AF-V1	µg/L	11	<0.1	10.1	-(a)	-(a)
	AF-V2	µg/L	2	<0.1	<0.1	-(a)	-(a)
U (total)	IN	µg/L	45	26.6	38.9	33.2	2.7
	BF	µg/L	45	26.6	38.7	32.9	2.5
	AF-V1	µg/L	30	<0.1	0.1	<0.1	0.0
	AF-V2	µg/L	15	<0.1	<0.1	<0.1	0.0

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

Parameter	Sampling Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
U (soluble)	IN	µg/L	13	30.7	37.9	33.8	2.2
	BF	µg/L	13	30.5	38.1	33.6	2.4
	AF-V1	µg/L	11	<0.1	<0.1	<0.1	0.0
	AF-V2	µg/L	2	<0.1	<0.1	<0.1	0.0
Fe (total)	IN	µg/L	35 <sup>(b)</sup>	<25	<25	<25	0.0
	BF	µg/L	35 <sup>(c)</sup>	<25	<25	<25	0.0
	AF-V1	µg/L	29	<25	<25	<25	0.0
	AF-V2	µg/L	7	<25	<25	<25	0.0
Fe (soluble)	IN	µg/L	13	<25	<25	<25	0.0
	BF	µg/L	13	<25	<25	<25	0.0
	AF-V1	µg/L	11	<25	<25	<25	0.0
	AF-V2	µg/L	2	<25	<25	<25	0.0
Mn (total)	IN	µg/L	36	<0.1	0.9	0.2	0.2
	BF	µg/L	36	<0.1	1.0	0.2	0.2
	AF-V1	µg/L	29	<0.1	1.7	0.5	0.4
	AF-V2	µg/L	7	<0.1	0.6	0.3	0.2
Mn (soluble)	IN	µg/L	13	<0.1	0.8	0.2	0.3
	BF	µg/L	13	<0.1	1.1	0.3	0.3
	AF-V1	µg/L	11	0.2	1.6	0.5	0.4
	AF-V2	µg/L	2	0.4	0.6	0.5	0.2

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 Figures 4-12 and 4-13.

(b) One outlier, 41.2 µg/L on 01/04/06, omitted.

(c) One outlier, 39.9 µg/L on 01/04/06, omitted.

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

Parameter	Sampling Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as CaCO <sub>3</sub> )	IN	mg/L	35 <sup>(a)</sup>	88.0	145	102	9.1
	BF	mg/L	36	92.0	132	100	7.2
	AF-V1	mg/L	29	88.0	132	101	7.3
	AF-V2	mg/L	7	103	112	108	2.9
Fluoride	IN	mg/L	13	0.9	1.6	1.1	0.2
	BF	mg/L	13	1.0	1.6	1.2	0.2
	AF-V1	mg/L	11	1.0	1.4	1.2	0.1
	AF-V2	mg/L	2	1.2	1.6	1.4	0.3
Sulfate	IN	mg/L	12 <sup>(b)</sup>	36.0	51.0	39.8	4.0
	BF	mg/L	13	35.0	52.0	40.7	4.2
	AF-V1	mg/L	11	35.0	42.0	38.7	2.4
	AF-V2	mg/L	2	42.0	52.0	47.0	7.1
Nitrate (as N)	IN	mg/L	13	0.9	1.3	1.1	0.1
	BF	mg/L	13	0.9	1.3	1.1	0.1
	AF-V1	mg/L	11	0.1	1.7	1.0	0.4
	AF-V2	mg/L	2	0.9	1.1	1.0	0.2
Phosphorus (as P)	IN	µg/L	35	<10	18.4	7.1	4.4
	BF	µg/L	35	<10	18.3	6.9	4.1
	AF-V1	µg/L	28	<10	16.7	6.4	3.2
	AF-V2	µg/L	7	<10	<10	<10	0.0

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

Parameter	Sampling Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Silica (as SiO <sub>2</sub> )	IN	mg/L	36	39.5	47.5	43.4	1.5
	BF	mg/L	36	39.7	48.2	43.4	1.4
	AF-V1	mg/L	29	15.9	46.7	41.4	6.4
	AF-V2	mg/L	7	39.8	44.1	42.1	1.4
Turbidity	IN	NTU	36	<0.1	1.8	0.5	0.4
	BF	NTU	36	<0.1	1.7	0.4	0.3
	AF-V1	NTU	29	<0.1	1.6	0.4	0.3
	AF-V2	NTU	7	<0.1	0.3	0.2	0.1
pH	IN	S.U.	30	6.7	7.2	6.9	0.1
	BF	S.U.	31	6.7	7.1	6.9	0.1
	AF-V1	S.U.	25	6.4	7.3	6.9	0.2
	AF-V2	S.U.	6	6.8	7.1	6.9	0.1
Temperature	IN	°C	30	8.2	27.0	18.2	4.8
	BF	°C	31	9.3	26.2	17.8	4.4
	AF-V1	°C	25	10.6	25.0	17.7	4.2
	AF-V2	°C	6	14.0	26.2	19.2	4.7
DO	IN	mg/L	26	1.6	4.3	2.4	0.7
	BF	mg/L	27	1.2	3.7	2.4	0.6
	AF-V1	mg/L	21	1.5	3.8	2.3	0.6
	AF-V2	mg/L	6	1.3	2.2	1.8	0.4
ORP	IN	mV	29	198	479	383	74.1
	BF	mV	30	195	493	367	92.1
	AF-V1	mV	24	205	495	338	95.9
	AF-V2	mV	6	215	484	375	100
Total Hardness (as CaCO <sub>3</sub> )	IN	mg/L	36	69.6	126.8	93.0	10.4
	BF	mg/L	36	69.3	123.1	92.4	9.0
	AF-V1	mg/L	29	69.9	98.9	90.4	5.9
	AF-V2	mg/L	7	91.0	123.5	106.4	11.4
Ca Hardness (as CaCO <sub>3</sub> )	IN	mg/L	36	60.6	120.6	86.2	10.7
	BF	mg/L	36	60.0	116.9	85.6	9.4
	AF-V1	mg/L	29	60.1	92.3	83.5	6.4
	AF-V2	mg/L	7	84.4	117.3	100.1	11.4
Mg Hardness (as CaCO <sub>3</sub> )	IN	mg/L	36	5.6	10.4	6.8	1.0
	BF	mg/L	36	4.5	10.6	6.8	1.1
	AF-V1	mg/L	29	5.5	10.3	6.9	1.1
	AF-V2	mg/L	7	5.7	6.7	6.3	0.3

(a) One outlier, 356 mg/L on 11/08/05, omitted.

(b) One outlier, <1.0 mg/L on 07/06/06, omitted.

(c) One outlier (i.e., <1.0 on 07/06/06) omitted.

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

Duplicate samples included in calculations.

Appendix B contains a complete set of analytical results through the performance evaluation study. The results of the water samples collected throughout the treatment plant are discussed below.

**Arsenic Removal.** Figure 4-11 contains three bar charts showing the concentrations of various arsenic species at IN, BF, and AF for each of the 11 and two speciation events performed during the first and second adsorption runs, respectively. Total As concentrations in source water ranged from 34.3 to 50.0 µg/L and averaged 41.7 µg/L. Of the soluble fraction, As(V) was the predominating species, ranging from 36.3 to 49.2 µg/L and averaging 41.9 µg/L. Particulate arsenic concentrations were low, ranging

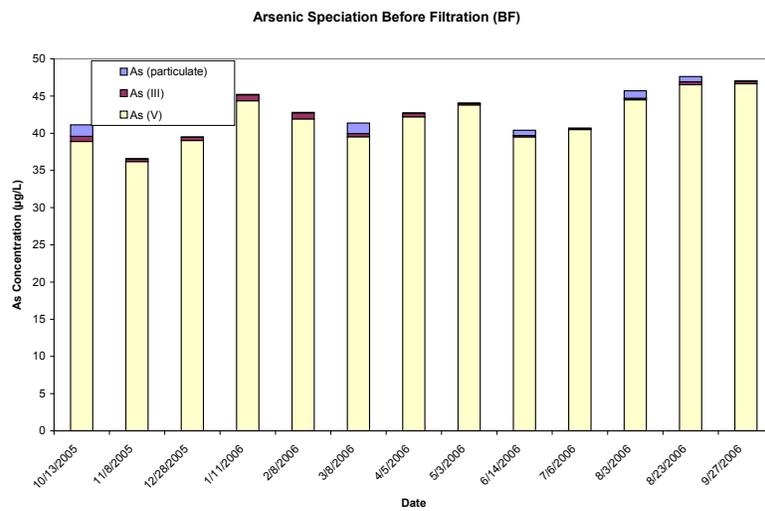
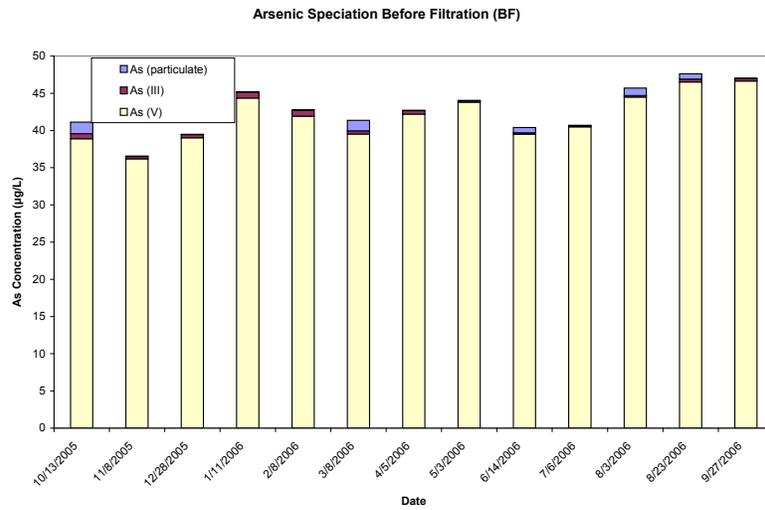
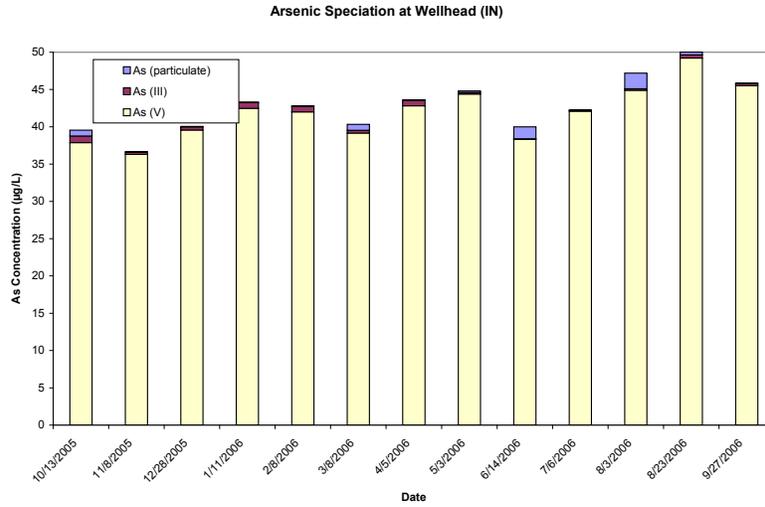


Figure 4-11. Concentrations of Various Arsenic Species at IN, BF, and AF Sampling Locations During Adsorption Runs 1 and 2

from <0.1 to 2.1 µg/L and averaging 0.5 µg/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 4-12 through 4-15. During the first adsorption run, arsenic concentrations following Vessel 1 gradually increased from <0.1 to 10.5 µg/L after treating approximately 6,693,700 gal (or 33,100 BV) of water. During the second adsorption run, arsenic concentrations following Vessel 2 increased from <0.1 to 11.7 µg/L after treating approximately 6,398,500 gal (or 31,700 BV) of water. Run lengths achieved during the adsorption runs were 65 and 58% higher than the vendor’s estimated run length of 20,000 BV. The 66% to 120% longer EBCT as discussed in Section 4.4.1 might have contributed, in part, to the better-than-expected media performance.

As part of another EPA study (Westerhoff et al., 2007), run lengths of five different adsorptive media, including ArsenX<sup>np</sup>, E33, GFH, MetsorbG, and Adsorbisia GTO (the last two are titania-based media), for arsenic and uranium removal from Well CH2-A water were evaluated using a rapid small-scale column test (RSSCT). Figures 4-16 and 4-17 present the arsenic and uranium breakthrough curves from the RSSCT columns, respectively. Table 4-8 summarizes run length data measured during respective RSSCT and full-scale system operations. 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 4-16, the two iron-based media, E33 and GFH, exhibited the best arsenic removal with respective run lengths approaching 44,000 and 50,000 BV. ArsenX<sup>np</sup> achieved a run length of approximately 28,000 BV, similar to the 33,100 and 31,700 BV observed during the two adsorption runs. MetsorbG and Adsorbisia GTO attained short run lengths of approximately 21,000 and 16,000 BV, respectively.

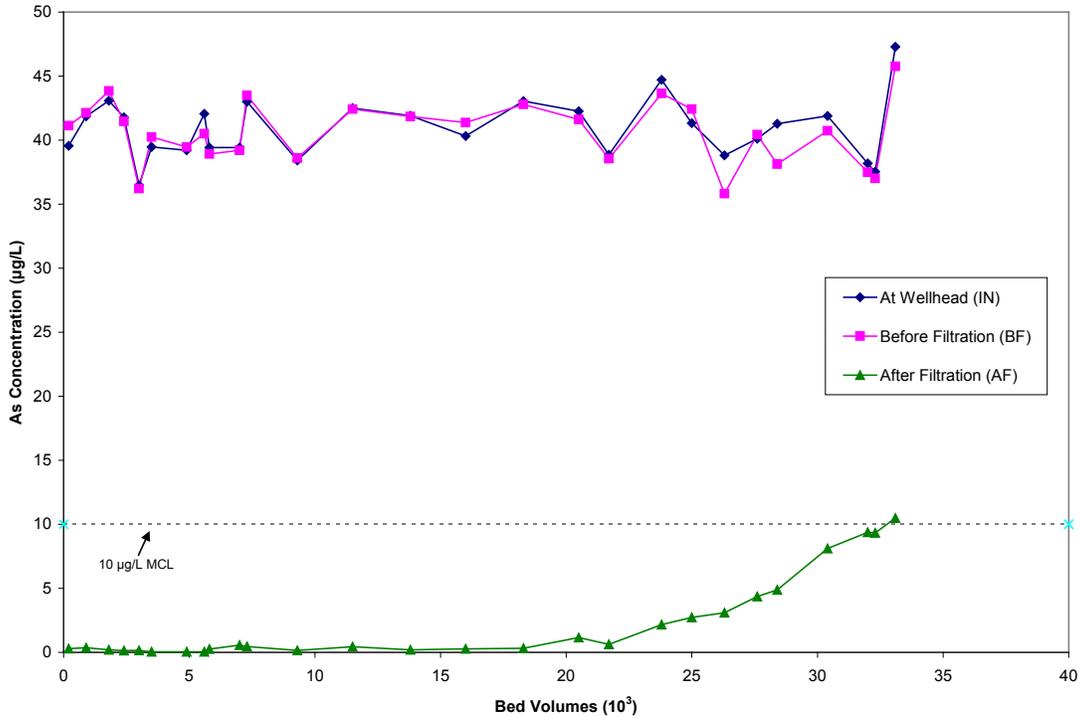


Figure 4-12. Total Arsenic Breakthrough Curve During Adsorption Run 1

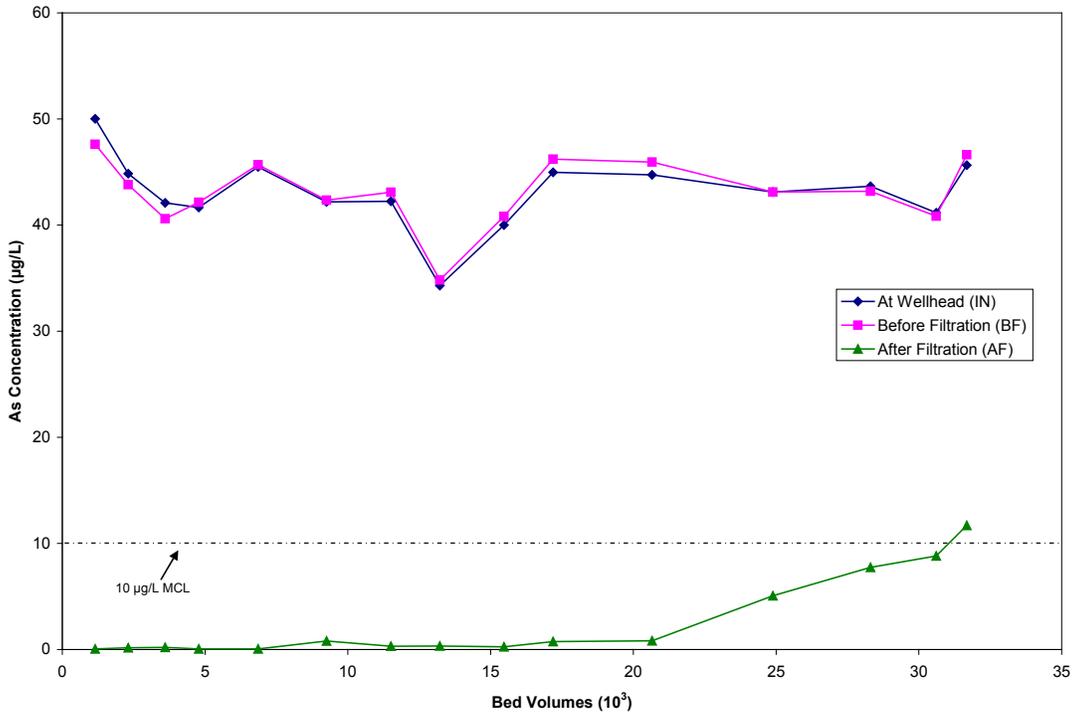


Figure 4-13. Total Arsenic Breakthrough Curve During Adsorption Run 2

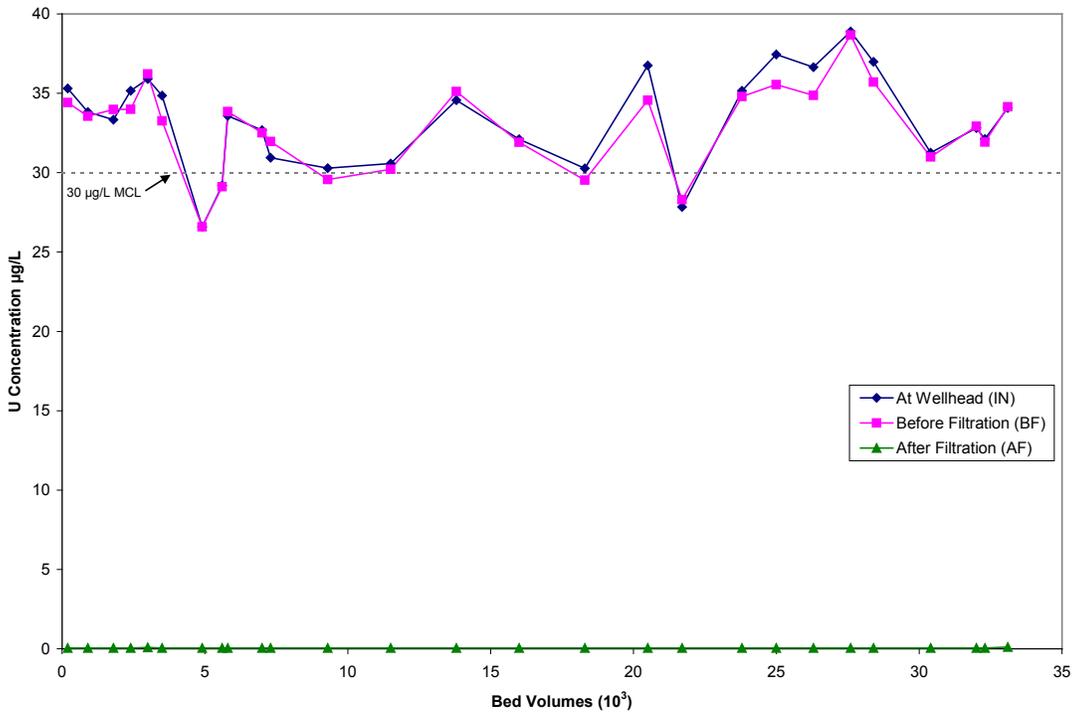


Figure 4-14. Total Uranium Breakthrough Curve During Adsorption Run 1

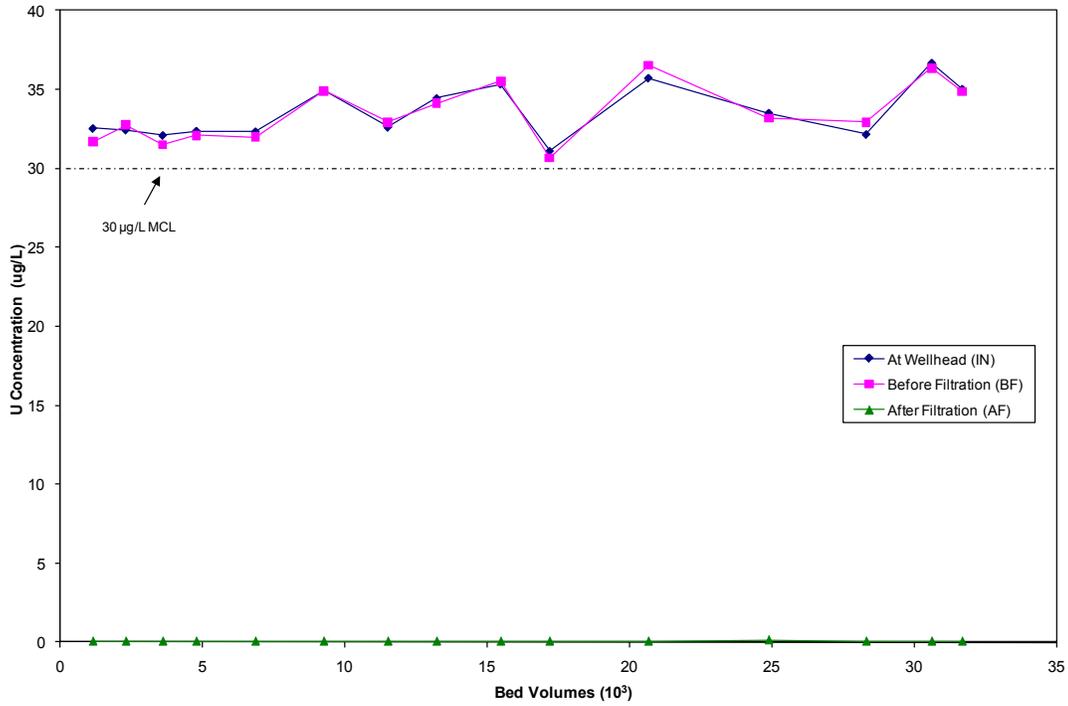
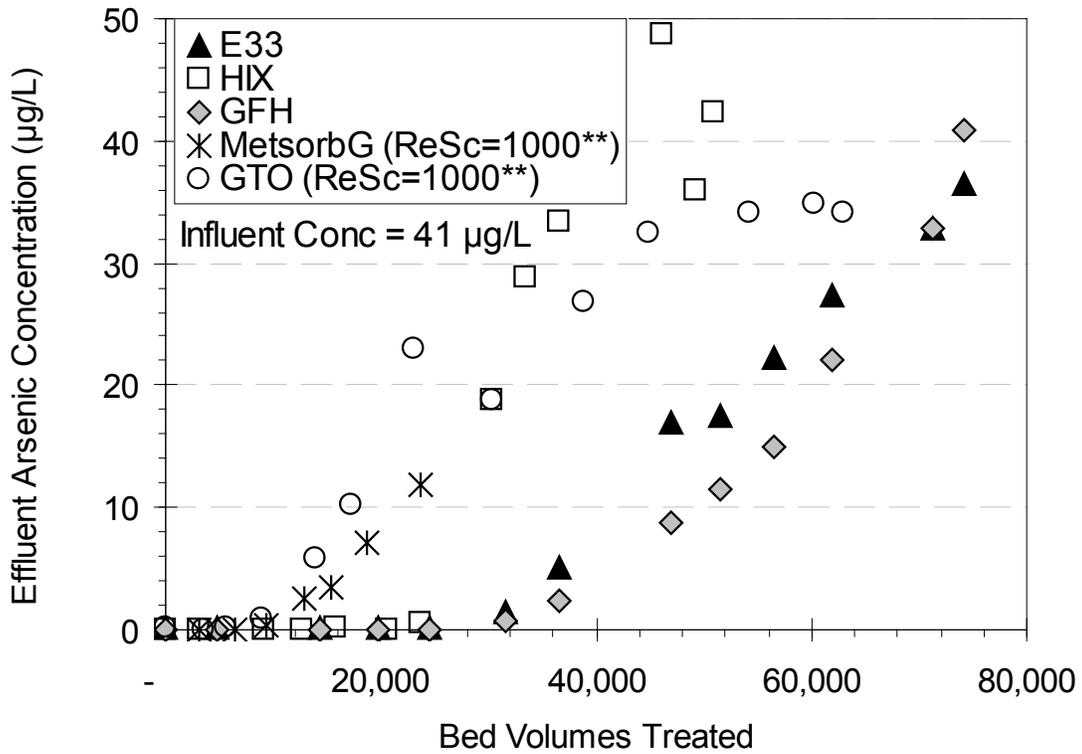
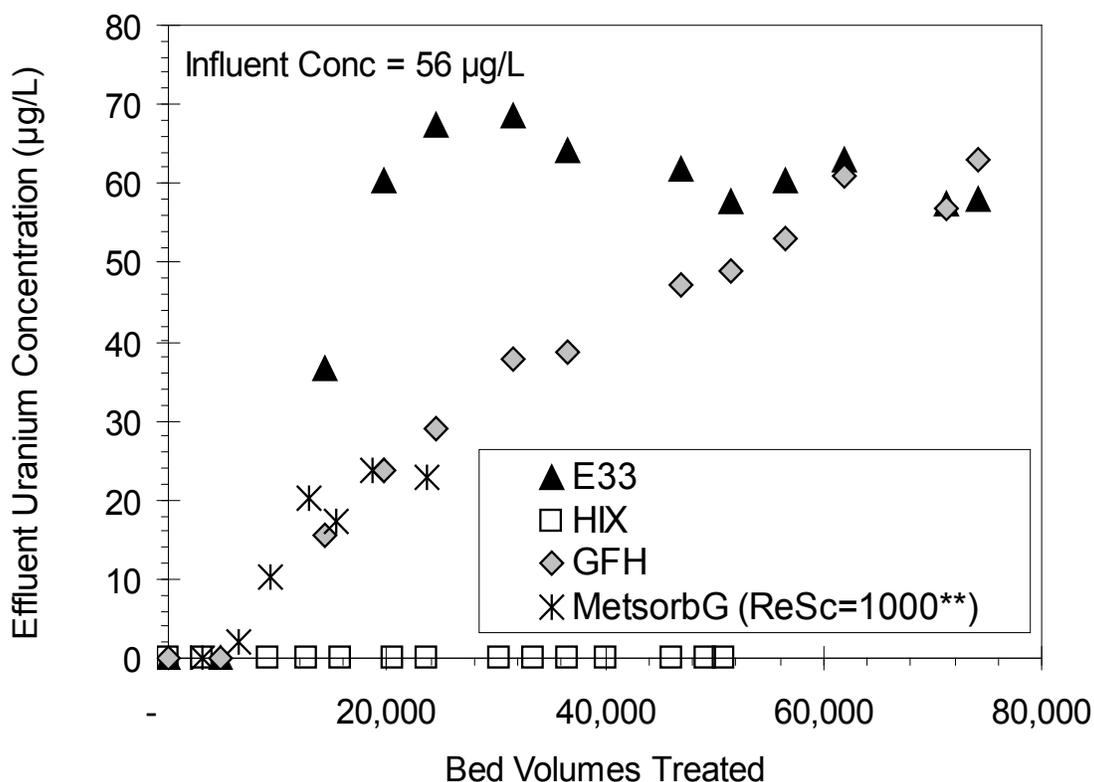


Figure 4-15. Total Uranium Breakthrough Curve During Adsorption Run 2



(Source: Westerhoff et al., 2007)

Figure 4-16. Total Arsenic Breakthrough Curves – Laboratory RSSCT



(Source: Westerhoff et al., 2007)

**Figure 4-17. Uranium Breakthrough Curves – Laboratory RSSCT**

**Table 4-8. Comparison of Media Run Lengths Between Full-Scale System and Laboratory RSSCT**

Test	Media	Media Run Length (BV)	
		10-µg/L Arsenic	30-µg/L Uranium
Full-Scale	ArsenX <sup>np</sup>	33,100	> 33,100
RSSCT	ArsenX <sup>np</sup>	28,000	> 50,000
	E33	44,000	12,000
	GFH	50,000	25,000
	MetsorbG	21,000	> 24,000 <sup>(a)</sup>
	Adsorbsia GTO	16,000	26,000

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

Based on the system throughput and arsenic concentrations before and after the treatment during the performance evaluation study, the mass of arsenic removed by the media was estimated to be 1,961 g with 989 g from Vessel 1 and 972 g from Vessel 2. The weight of 27 ft<sup>3</sup> of media in each vessel was

1,350 lb (i.e., 614 kg) based on the bulk density of 50 lb/ft<sup>3</sup>. Therefore, the arsenic loading onto the media was approximately 1,597 mg/kg of media or 0.16% (by wet weight).

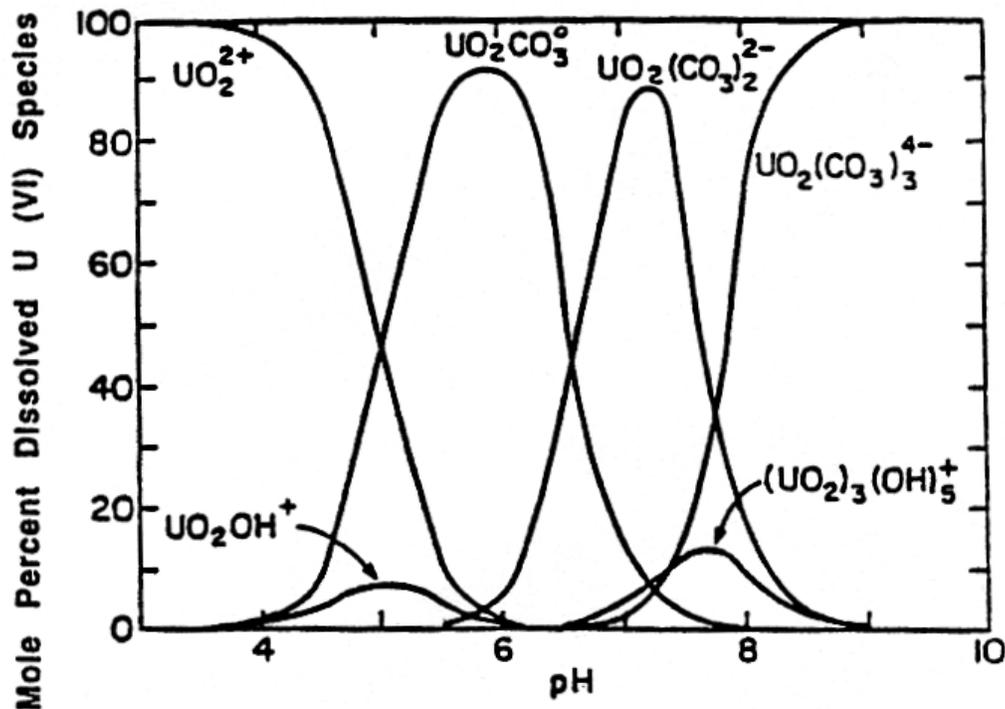
**Uranium Removal.** Originating from rocks and mineral deposits, uranium found in most drinking water sources is naturally occurring and contains three isotopes: U-238 (over 99% by weight), U-235, and U-234. Due to varying amounts of each isotope in the water, the ratio of uranium concentration ( $\mu\text{g/L}$ ) 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  $\mu\text{g/L}$  in 1991 (corresponding to 30 pCi/L based on a mass/activity ratio of 1.5 pCi/ $\mu\text{g}$ ); the final rule was set at 30  $\mu\text{g/L}$  in December 2000 after the conversion factor was revised to 1 pCi/ $\mu\text{g}$  (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  $\mu\text{g/L}$  (same as the federal MCL) using a conversion factor of 0.67 pCi/ $\mu\text{g}$  (Note: in California, a conversion factor of 0.67 pCi/ $\mu\text{g}$  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  $\mu\text{g/L}$ . Uranium activity (pCi/L) was not reported herein to avoid potential confusion associated with the use of different conversion factors.

Total uranium concentrations in source water ranged from 26.6 to 38.9  $\mu\text{g/L}$  and averaged 33.2  $\mu\text{g/L}$ , which were consistent with the data collected during the initial site visit (Table 4-1). As shown in Figures 4-14 and 4-15, uranium was removed to below its MDL of 0.1  $\mu\text{g/L}$  throughout the performance evaluation study. Based on the system throughput and average uranium concentrations before and after the treatment system, the uranium mass removed by Vessels 1 and 2 was 892 and 813 g, respectively. Therefore, the uranium loading on the HIX media was 1.3 mg/kg of media (or 0.13% [by wet weight]), assuming 1,350 lb (i.e., 614 kg) of media in each vessel. The RSSCT results indicated that ArsenX<sup>np</sup> removed uranium far better than the iron-based (E33 and GFH) and titanium-based (Metsorb G) media. ArsenX<sup>np</sup> continued to remove uranium to <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 IV and VI oxidation states are stable. The most stable state of uranium in aerated aqueous solution under acidic conditions (pH <5.0) is  $\text{UO}_2^{2+}$ , which forms soluble complexes with common anions in water, such as  $\text{CO}_3^{2-}$ ,  $\text{F}^-$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ , and  $\text{HPO}_4^{2-}$ . Carbonate is the most important uranium ligand in natural water. Figure 4-18 presents the distribution of uranium carbonate and hydroxide complexes as a function of pH in aerobic groundwater at a  $\text{CO}_2$  partial pressure of 0.01 atmospheres (Langmuir, 1978). Under neutral and slightly alkaline conditions,  $\text{UO}_2^{2+}$  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.

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), an 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  $\mu\text{g/L}$  of uranium, 25 pCi/L of radium, 310 mg/L of TDS, 150 mg/L of alkalinity, 47 mg/L of chloride, and <1 mg/L of sulfate (very low sulfate water). Despite the high uranium capacity, IX systems generally are not operated to complete 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 ArsenX<sup>np</sup> media life decreases significantly as both source water pH and silica concentration increase. It is known that the capacity of iron-based media for arsenic



(Source: Langmuir, 1978)

**Figure 4-18. Distribution of Uranium Carbonate and Hydroxide Complexes as a Function of pH**

decreases as the pH increases. pH values of source water measured at the IN sampling location ranged from 6.7 to 7.2 and averaged 6.9 (Table 4-7). These near-neutral pH values are 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 with arsenic for available adsorptive sites.
- (3) Polymerization of silica may accelerate silica sorption and lower available surface sites for arsenic adsorption.
- (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 was most noticeable at pH values 8 or above and that ArsenX<sup>np</sup> could tolerate the presence of 30 mg/L silica at neutral pH. Silica concentrations in CH2-A source water ranged from 39.5 to 47.5 mg/L and averaged 43.4 mg/L. As shown in Figure 4-19 during the first adsorption run, silica concentrations were reduced by ArsenX<sup>np</sup> during the first few hundred BV of system operation and complete silica breakthrough occurred soon after that. Figure 4-20 presents silica concentrations across the treatment train during the second adsorption

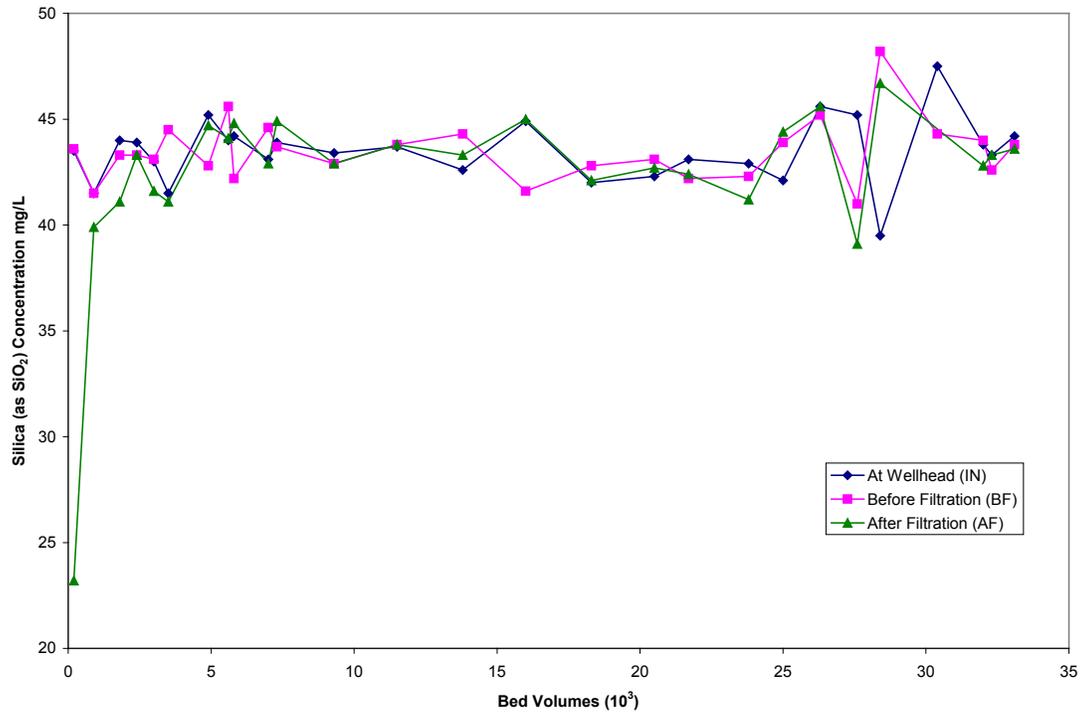


Figure 4-19. Silica Breakthrough Curve During Adsorption Run 1

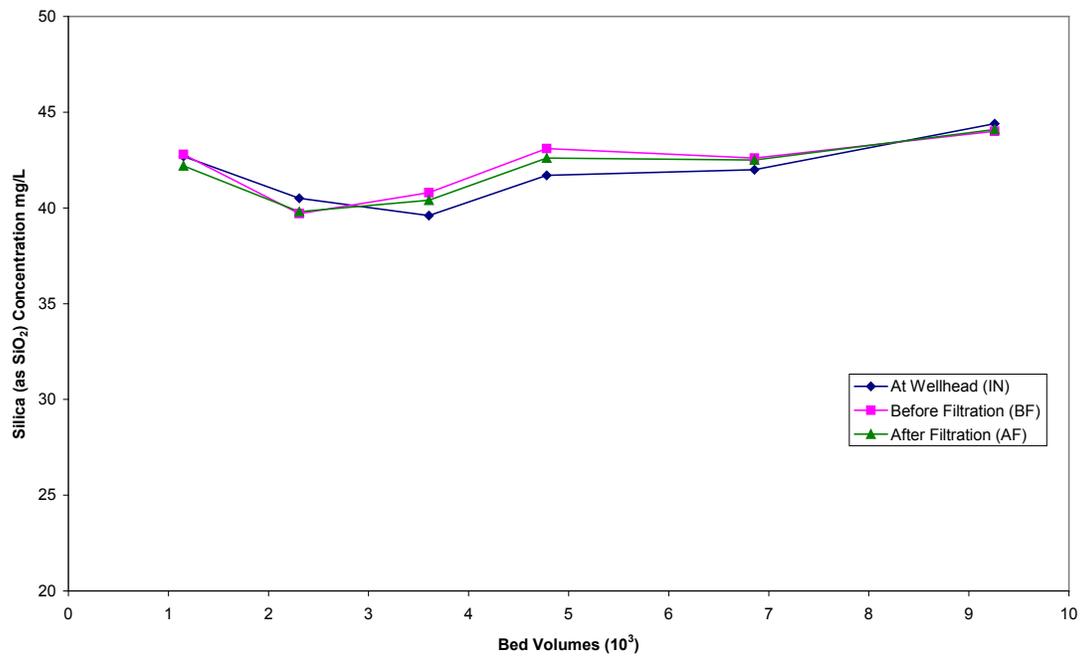


Figure 4-20. Silica Breakthrough Curve During Adsorption Run 2

run. Because no samples were collected immediately after switching from Vessel 1 and Vessel 2, silica had already completely broken through Vessel 2 when treatment plant samples were taken at 1,100 BV of throughput.

***Effect of Other Water Quality Parameters.*** Alkalinity ranged from 88 to 145 mg/L (as CaCO<sub>3</sub>) in source water and remained unchanged after treatment. Sulfate, fluoride, and nitrate concentrations in source water ranged from 36.0 to 51.0 mg/L, from 0.9 to 1.6 mg/L, and from 0.9 to 1.3 mg/L (as N), respectively; their concentrations remained unchanged after treatment. Therefore, ArsenX<sup>np</sup> did not seem to alter the concentrations of these common anions in water. Although it is possible that some sulfate might have been removed by the media's anionic resin substrate, the sulfate concentration in Vessel 1 effluent taken at 200 BV had already reached the source water level.

DO levels in source water ranged from 1.6 to 4.3 mg/L and averaged 2.4 mg/L; ORP readings of source water ranged from 198 to 479 mV and averaged 383 mV. The results indicated that source water was oxidizing, thus causing arsenic to exist primarily as As(V). Although the DO and ORP data showed some variations throughout the performance evaluation study, the range and average of these measurements were essentially unchanged across the treatment train.

Total iron concentrations were below the MDL of 25 µg/L for all measurements, except for one at 41 µg/L at IN and one at 40 µg/L at BF on January 4, 2006 (Appendix B). Total manganese levels ranged from <0.1 to 0.9 µg/L for all measurements with no significant changes after treatment. Total hardness ranged from 69.6 to 127 mg/L (as CaCO<sub>3</sub>), and remained relatively constant across the treatment train.

**4.5.2 Distribution System Water Sampling.** Distribution water samples were collected at three residences before and after system startup to determine whether the HIX system had any impacts on lead and copper levels and water chemistry in the distribution system. Table 4-9 presents the analytical results. Uranium was not monitored because of its absence in the plant effluent.

The most noticeable change in the distribution system after system startup was the reduction in arsenic concentration at each sampling location as shown in Figure 4-21. Baseline arsenic concentrations ranged from 16.2 to 44.2 µg/L and averaged 26.2 µg/L at all three locations. These concentrations were lower than those in Well CH2-A water, which ranged from 34.3 to 50.0 µg/L and averaged 41.7 µg/L measured during the performance evaluation study (Section 4.5.1). As noted in Section 4.1, prior to system startup, the distribution system was supplied by both Well CH-1, which did not contain elevated arsenic or uranium, and Well CH2-A. Well CH-1 was used as a primary well and Well CH2-A as a backup well.

After system startup, arsenic concentrations at all three sampling locations essentially followed the arsenic breakthrough behavior of the plant effluent, although only DS2 was served primarily by Well CH2-A. Arsenic concentrations were noticeably higher than those in the plant effluent most of the time, suggesting possible solubilization, destabilization, and/or desorption of arsenic-laden particles/scales in the distribution system (Lytle, 2005).

Lead concentrations decreased from an average baseline level of 4.6 to 1.6 µg/L after system startup. One exceedance at 16.4 µg/L occurred at DS3 on August 10, 2005, during baseline sampling. Copper concentrations decreased from an average baseline level of 823 to 788 µg/L at DS1, from 67.4 to 49.4 µg/L at DS2, and from 71.0 to 50.7 µg/L at DS3. However, three exceedances occurred at DS1 after system startup (i.e., 1,304 µg/L on October 26, 2005; 1,473 µg/L on January 4, 2006, and 1,390 µg/L on March 22, 2006). Because a concentration of 1,213 µg/L was measured at DS1 on September 28, 2005, before system startup, the HIX system was unlikely to cause the elevated copper concentrations at DS1.

Table 4-9. Distribution System Sampling Results

Sampling Event		DS1 179 Spring Ct. Residence 1st draw								DS2 66 Spring Ct. LCR 1st draw								DS3 2216 Remback Ave. Residence 1st Draw							
		Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu
		hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	Mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
		No.	Date	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	Mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L
BL1	08/10/05 <sup>(a)</sup>	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 <sup>(b)</sup>	NA	6.7	101	44.2	<25	<0.1	0.5	636	6.5	NA <sup>(c)</sup>	NA <sup>(c)</sup>	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	Sample containers broken during shipment							
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 <sup>(d)</sup>	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	Homeowner not present for sample collection.							
10	08/17/06	8.5	7.0	91	16.5	<25	0.3	0.4	826	6.0	7.0	123	15.3	<25	0.8	9.3	63.7	9.3	7.1	121	4.0	<25	0.5	0.4	30.4
11	09/14/06	9.0	7.1	110	2.0	<25	<0.1	0.3	576	7.0	7.0	108	2.4	<25	<0.1	0.9	25.4	7.0	7.1	105	2.1	<25	<0.1	0.4	20.3
12	10/12/06	7.3	7.2	112	1.7	<25	0.5	0.3	866	6.5	7.1	110	6.2	<25	0.4	3.4	38.5	8.3	7.2	110	1.1	<25	0.2	0.2	19.7

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

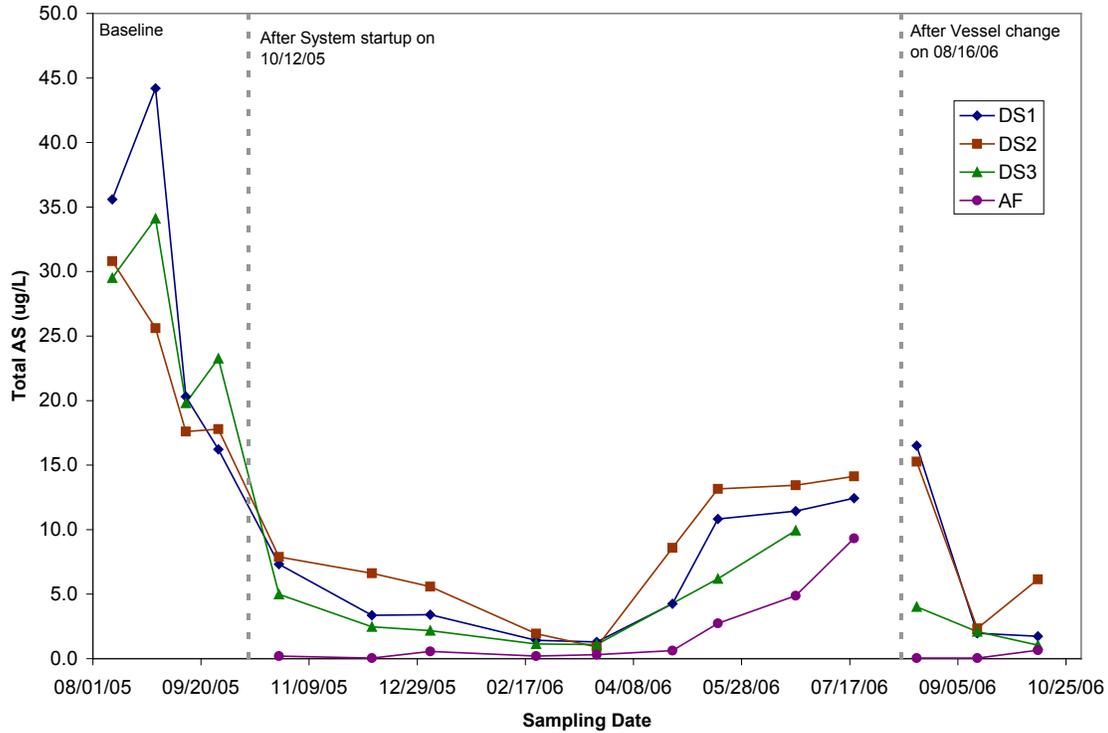
(b) Sample DS2 collected on 08/31/05.

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

(e) 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 4-21. Total As Concentrations in Distribution System at Upper Bodfish**

pH, alkalinity, and manganese remained relatively constant with baseline levels measured at 6.9, 107 mg/L (as CaCO<sub>3</sub>), and 0.9 µg/L, respectively, and after-startup levels measured at 7.2, 103 mg/L (as CaCO<sub>3</sub>), and 0.4 µg/L, respectively. Iron was not detected for all baseline and after-startup samples except for two measurements (630 and 35 µg/L) before system startup and two measurements (34 and 58 µg/L) after system startup.

#### 4.6 Spent Media Characterization and Disposal

**4.6.1 Spent Media Characterization.** A composite spent media sample was analyzed to determine if the spent media was a hazardous waste and if it contained a non-exempt quantity of uranium.

**TCLP, TTLC, and STLC Tests.** TCLP, TTLC, and STLC tests were conducted to determine if the spent media was a hazardous waste. Most arsenic demonstration sites using adsorptive media performed only the TCLP test prior to media disposal per federal guidelines. TTLC and STLC tests also were performed per California State regulations, as outlined in Title 22 of the California Code of Regulations, to determine if the waste would be classified as California hazardous waste.

- TCLP is one of four characteristics used to identify a hazardous waste; the other three are ignitability, corrosivity, and reactivity. TCLP uses acetic acid to simulate the climatic leaching action expected to occur in landfills. The TCLP metal analysis identifies and quantifies eight Resource Conservation and Recovery Act (RCRA) metals with the potential to leach into groundwater. If any substance in the waste extract equals or is greater than the TCLP limit, the waste is classified as a RCRA hazardous waste.

- TTLC determines the total concentration of each target analyte in a waste stream. When any target analyte exceeds the corresponding TTLC limit, the waste is classified as California hazardous waste. The result of TTLC also is compared with 10 times the STLC value to determine if Waste Extraction Test (WET) is necessary. If the TTLC result exceeds 10 times the STLC value, WET is required. If below, the waste is classified as non-hazardous and no further analysis is required.
- STLC determines the amount of each analyte that is soluble in the WET leachate. The WET procedure uses citric acid to mimic climatic conditions in a landfill over time. If any analyte in the WET extract is equal to or greater than the STLC limit, it is considered a California hazardous waste.

Table 4-10 presents the results of TCLP, TTLC, and STLC analyses and the respective regulatory limits. The spent media passed TCLP analysis with concentrations of all eight RCRA metals below the respective quantifiable limits. TTLC results indicated that the total arsenic concentration of the spent media was 2,960 mg/kg, which exceeded the TTLC limit of 500 mg/kg and 10 times the STLC limit for arsenic (i.e., 50). Therefore, WET was required for arsenic; the STLC arsenic level was below the quantifiable limit. In sum, the spent media passed the TCLP limit; therefore, it was classified as a non-RCRA waste. However, since the total arsenic concentration exceeded the TTLC limit (even though it passed STLC), the spent media was considered a California hazardous waste.

**Table 4-10. Results of Spent Media Characterization**

Test	Analytical Method	Analyte	Unit	Regulatory Limit	Result
TCLP	SW6010B	Arsenic	mg/L	5.0	<0.20
		Barium	mg/L	100	<1.0
		Cadmium	mg/L	1.0	<0.06
		Chromium	mg/L	5.0	<0.05
		Lead	mg/L	5.0	<0.10
		Selenium	mg/L	1.0	<0.20
		Silver	mg/L	5.0	<0.05
	SW7471A	Mercury	mg/L	0.2	<0.002
TTLC	SW6010B	Arsenic	mg/kg	500	2,960
		Barium	mg/kg	10,000	2.2
		Cadmium	mg/kg	100	<13.8
		Chromium	mg/kg	2,500	4.4
		Lead	mg/kg	1,000	4.5
		Selenium	mg/kg	100	<46.2
		Silver	mg/kg	500	1.9
	SW7471A	Mercury	mg/kg	20	0.25
STLC	SW6010B	Arsenic	mg/L	5.0	<2.0

**Radiological Analysis.** A gamma spectroscopy analysis was performed to determine if the spent media was an exempt material or a low-level radioactive waste (LLRW). Table 4-11 presents the results and compares them with the requirements for an exempt source material (as discussed in Section 4.4.2 and Table 4-5). Table 4-12 presents the calculations of the uranium concentration and quantity based on laboratory results, the quantity of the media, and the weights of water and media in each vessel. The uranium concentration based on the total weights of water and media was approximately 0.03% and the

quantity of uranium was approximately 0.83 lb per vessel and 1.66 lb for both vessels, which are below the 0.05% concentration limit and 15 lb quantity limit for an exempt material, respectively. Results of the radiological analysis indicated that the radioactivity of the spent media was 206 pCi/g for U-238 and 10.6 pCi/g for U-235, which are below the 335 pCi/g limit for an exempt material. Therefore, all three requirements for an exempt material were met based on the concentration, radioactivity, and quantity of uranium (Table 4-13). The spent media in the vessels was of an “unimportant quantity” and was exempt from NRC regulations. As an exempt material, the spent media could be disposed of in a solids waste, hazardous waste, or LLRW landfill, or any landfill licensed by a state to accept TENORM waste.

**Table 4-11. Results of Radiological Analysis on Spent Media**

Analyte	t <sub>1/2</sub>	Specific Activity (pCi/g)	Activity (pCi/g)	Concentration (µg/g)
U-238	4.47E09	3.37E05	206	611
U-235	7.04E08	2.16E06	10.6	4.87
<b>Total</b>				616

**Table 4-12. Uranium Concentration and Quantity Calculations**

Parameter	Value	
Bulk Density of Media (lb/ft <sup>3</sup> )	50	
Density of Water (lb/ft <sup>3</sup> )	62.4	
Quantity of Media (ft <sup>3</sup> )	27	
Vessel Size (in)	42 OD × 60 H	
Parameter	Equation	Value
Vessel Volume <sup>(a)</sup> (ft <sup>3</sup> )	$\pi r^2 h = \pi(1.75)^2(5)$	48.1
Media Volume (ft <sup>3</sup> )	-	27
Volume of Water in One Vessel (ft <sup>3</sup> )	48.1 – 27	21.1
Weight of Water in One Vessel (lb)	21.1 × 62.4	1,317
Weight of Media in One Vessel (lb)	27 × 50	1,350
Total Weight of Water & Media (lb)	1,317 + 1,350	2,667
U Concentration (µg/g)	Laboratory analytical result	616
Mass of U on Media (lb)	$(616 \times 1,350) / 1,000,000$	0.83 (one vessel) 1.66 (two vessels)
% U by Weight <sup>(b)</sup>	$(0.83 \times 100) / 2,667$	0.03

(a) Volume based on straight height of vessel, not including domes.

(b) Based on combined weight of water and media.

**Table 4-13. Determination of Exempt Source Material**

Measurement	Requirements <sup>(a)</sup>	Result	Requirements Met? (Yes/No)
Concentration	<0.05 % by weight of uranium	0.03% by weight <sup>(b)</sup>	Yes
Radioactivity	<335 pCi/g	U-238: 206 pCi/g U-235: 10.6 pCi/g	Yes
Quantity	<15 lb at any given time; < 150 lb over the course of a year	1.66 lb <sup>(b)</sup>	Yes

(a) EPA, 2005.

(b) See calculations in Table 4-12.

**4.6.2 Spent Media Removal, Transportation, and Disposal.** On April 24, 2008, technicians from Samuel L. Serpa Environmental Consulting and Support were onsite to extract the spent media from the trailer-mounted vessels using a 16-gal, 6-hp Rigid Model WD1665 wet/dry shop vacuum. A vacuum hose connected to the wet/dry vacuum was lowered into the vessels to remove the media, which was temporarily stored in the shop vacuum's 16-gal collection tank. Once the vacuum's collection tank was full, the extracted media was transferred to a 55-gal high-density polyethylene (HDPE) drum (provided by TG&A) for transportation. This process was repeated until all of the spent media had been extracted from the vessels. A total of 10, 55-gal HDPE drums were used to contain the 54 ft<sup>3</sup> of spent media. A TG&A technician loaded the drums on a flat-bed truck and transported them to its facility in Turlock, CA. Figure 4-22 presents a photo of a technician removing the spent media from an adsorption vessel. Throughout the media extraction, packaging, and loading process, representatives from Cal Water, including a member from its Environmental Affairs Office, were present to provide oversight.



**Figure 4-22. Spent Media Removal from Vessels**

On April 29, 2008, the drums of spent media arrived at TG&A's facility in Turlock, CA, where a radiation survey was conducted to determine if solidification of the spent media would be required prior to transport to the disposal facility in Grandview, ID. The radiation survey results indicated that the spent media emitted 10  $\mu$ Rem, which was below the 40  $\mu$ Rem limit. Thus, solidification of the spent media was not necessary. In an effort to minimize transportation cost, the spent media was stored at TG&A's facility in Turlock, CA, until TG&A had accumulated enough materials to schedule a shipment to the disposal facility.

On September 30, 2008, the spent media was shipped to U.S. Ecology in Grandview, ID. Located 70 miles southeast of Boise, ID, U.S. Ecology is a permitted facility to treat and dispose of non-hazardous industrial wastes, hazardous waste, and LLRW. On October 1, 2008, the spent media was disposed of at the landfill as an exempt, non-hazardous material. Technically speaking, the spent media, as an exempt,

non-hazardous material, can be disposed at a solid waste landfill. However, according to TG&A, in the State of Idaho, a solid waste landfill would only accept waste with an activity less than 8 pCi/g, which is considered a non-radiological waste. The spent media had an activity over 200 pCi/g. Although this concentration is below the 335 pCi/g limit, it is very difficult, if not impossible, to find a solid waste landfill that is willing to accept it.

#### 4.7 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.

**4.7.1 Capital Cost.** The capital investment for equipment, site engineering, and installation of the HIX system was \$114,070 (see Table 4-14). 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<sup>HP</sup> media (54 ft<sup>3</sup> of media to fill two vessels at \$400/ft<sup>3</sup>), \$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 troubleshooting for the duration of the study, \$10,000 for initial system hookup 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 4-14. 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 <sup>3</sup> )	54	\$21,600	–
Shipping	–	\$2,500	–
Vendor Labor	–	\$33,120	–
<b>Equipment Total</b>	–	<b>\$82,470</b>	<b>73%</b>
<i>Engineering Cost</i>			
Vendor Labor	–	\$12,800	–
<b>Engineering Total</b>	–	<b>\$12,800</b>	<b>11%</b>
<i>Installation Cost</i>			
Material	–	\$1,500	–
Subcontractor Labor	–	\$10,000	–
Subcontractor Travel	–	\$500	–
Vendor Labor	–	\$4,800	–
Vendor Travel	–	\$2,000	–
<b>Installation Total</b>	–	<b>\$18,800</b>	<b>16%</b>
<b>Total Capital Investment</b>	–	<b>\$114,070</b>	<b>100%</b>

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 18.5 hr/day at 23 gpm (see Table 4-4). Based on this reduced use rate, the system would produce only 9,318,450 gal of water in one year (assuming 365 days per year) and the unit capital cost would increase to \$1.16/1,000 gal.

**4.7.2 Operation and Maintenance Cost.** The O&M cost for the HIX system should include media regeneration or replacement and labor for routine operation. Media regeneration was proposed, but not performed. Thus, its cost could not be evaluated. Media replacement, although was not performed due to returning of the system to EPA, could be estimated based on the cost for new media and spent media disposal. The cost of 54 ft<sup>3</sup> of media was \$21,600 according to the vendor's cost breakdowns (Table 4-14). The total cost for media disposal was \$16,671, including \$1,650 for sample collection, \$1,177 for laboratory analysis, \$2,827 for media extraction, and \$11,017 for pickup, transportation, and disposal (Table 4-15). Therefore, the media replacement and disposal cost totaled \$38,271 for both vessels (or \$19,136 per vessel). By dividing the media replacement and disposal cost by 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 as shown in Figure 4-23. The media run length in BV was calculated by dividing the system throughput in each vessel by the quantity of media in each vessel, i.e., 27 ft<sup>3</sup>. On average, each HIX vessel processed approximately 32,400 BV (or 6,544,836 gal) prior to reaching the 10-μg/L arsenic breakthrough; based on this volume, the unit cost for spent media disposal was \$2.92/1,000 gal.

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. The total O&M cost including media replacement and disposal and labor was \$3.05/1,000 gal (Figure 4-23).

Table 4-15. Operation and Maintenance Cost for HIX System

Cost Category	Value	Assumptions
Volume processed (kgal)	13,090	Through March 21, 2007
<b>Media Replacement</b>		
54 ft <sup>3</sup> of HIX Media	\$21,600	See Table 4-12
<b>Spent Media Sample Collection</b>		
Labor (\$)	\$1,650	-
<b>Spent Media Characterization</b>		
Subtotal (\$)	\$1,177	-
<b>Spent Media Removal</b>		
Labor (\$)	\$1,840	-
Materials (\$)	\$632	-
Travel (\$)	\$233	-
Miscellaneous (\$)	\$122	-
Subtotal (\$)	\$2,827	-
<b>Pick-up, Transportation, and Disposal of Spent Media</b>		
Labor (\$)	\$750	-
Transportation (\$)	\$3,500	-
Disposal of Spent Media (\$)	\$6,000	10, 55-gal drums
Materials and Tax (\$)	\$767	-
Subtotal (\$)	\$11,017	-
Total Media Disposal (\$)	\$16,671	-
Total Media Replacement and Disposal (\$)	\$38,271	-
<b>Labor for Routine O&amp;M</b>		
Average Weekly Labor (hr)	0.83	50 min/wk
Labor (\$/1,000 gal)	\$0.13	Labor rate = \$26/hr

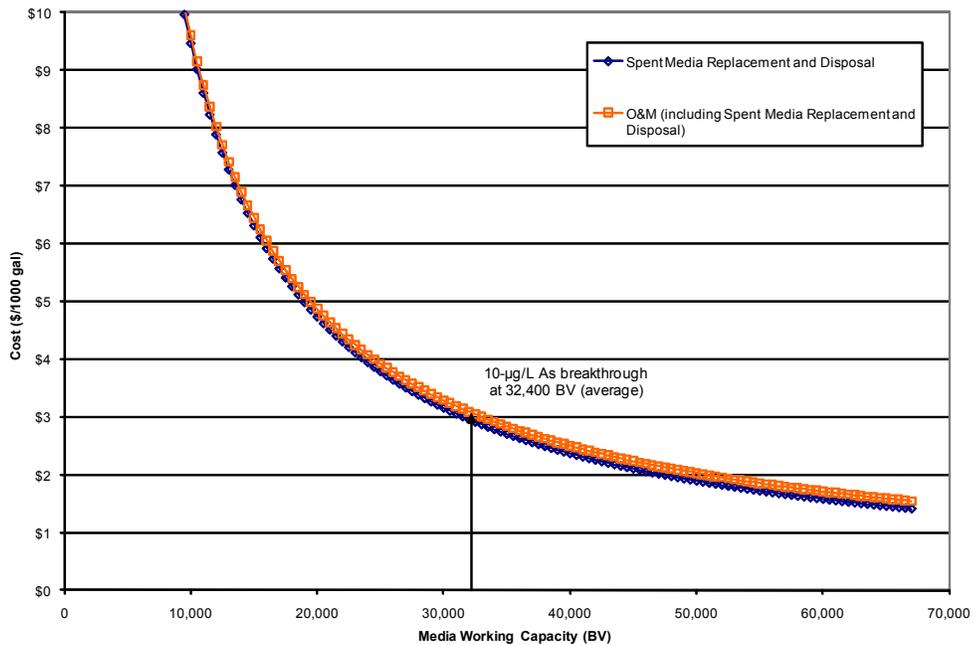


Figure 4-23. Spent Media Replacement and Disposal and O&M Cost Curves

## 5.0: REFERENCES

- Battelle. 2004. *Revised Quality Assurance Project Plan for Evaluation of Arsenic Removal Technology*. Prepared under Contract No. 68-C-00-185, Task Order No. 0029, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Battelle. 2005. *Study Plan for Evaluation of Arsenic Removal Technology at Lake Isabella, CA*. Prepared under Contract No. 68-C-00-185, Task Order No. 0029, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- CDPH. 2001. California Code of Regulations (CCR). Title 22, Division 4, Chapter 13. Operator Certification Regulations. California Department of Public Health.
- Chen, A.S.C., L. Wang, J.L. Oxenham, and W.E. Condit. 2004. *Capital Costs of Arsenic Removal Technologies: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1*. EPA/600/R-04/201. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Clifford, D.A. 1999. "Ion Exchange and Inorganic Adsorption." Chapter 9 in R. Letterman (ed.), *Water Quality and Treatment Fifth Edition*. McGraw Hill, Inc., New York, NY.
- Clifford, D.A., and Z. Zhang, 1995. "Removing Uranium and Radium from Ground Water by Ion Exchange Resins." In *Ion Exchange Technology: Recent Advances in Pollution Control* by A.K. Sengupta, Lancaster, Pennsylvania: Technomic Publishing Company, 1-59.
- Edwards, M., S. Patel, L. McNeill, H. Chen, M. Frey, A.D. Eaton, R.C. Antweiler, and H.E. Taylor. 1998. "Considerations in As Analysis and Speciation." *J. AWWA*, 90(3): 103-113.
- EPA. 2005. *A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies*. EPA/816/R/05/004. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.
- EPA. 2003. "Minor Clarification of the National Primary Drinking Water Regulation for Arsenic." *Federal Register*, 40 CFR Part 141.
- EPA. 2002. *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems*. EPA/816/R-02/009. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.
- EPA. 2001. "National Primary Drinking Water Regulations: Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring." *Federal Register*, 40 CFR Parts 9, 141, and 142.
- EPA, 2000a. *Radionuclides Notice of Data Availability Technical Support Document*. U.S. Environmental Protection Agency, Office of Water, Washington, DC.
- EPA. 2000b. "National Primary Drinking Water Regulations: Radionuclides Final Rule." *Federal Register*, 40 CFR Parts 9, 141, and 142.
- Langmuir, D. 1978. "Uranium Solution –Mineral Equilibrium at Low Temperatures with Applications to Sedimentary Ore Deposits." *Geochimica et Cosmochimica*, 42: 547-569.

- Lytle, D.A. 2005. *Coagulation/Filtration: Iron Removal Processes Full-Scale Experience*. EPA Workshop on Arsenic Removal from Drinking Water in Cincinnati, OH, August 16-18.
- Meng, X.G., G.P. Korfiatis, S.B. Bang, and K.W. Bang. 2002. "Combined Effects of Anions on Arsenic Removal by Iron Hydroxides." *Toxicology Letters*, 133(1): 103-111.
- Meng, X.G., S. Bang, and G.P. Korfiatis. 2000. "Effects of Silicate, Sulfate, and Carbonate on Arsenic Removal by Ferric Chloride." *Water Research*, 34(4): 1255-1261.
- Narasimhan R., J. D. Lowry, J. Culley, and N. Young-Pong. 2005. *Management of the Disposal of Radioactive Residuals in Drinking Water Treatment*. American Water Works Association Research Foundation, Denver, CO.
- Smith, S.D., and M. Edwards. 2005. "The Influence of Silica and Calcium on Arsenate Sorption to Oxide Surfaces." *Journal of Water Supply: Research and Technology - AQUA*, 54(4): 201-211.
- Sorg, T.J. 1988. "Methods for Removing Uranium from Drinking Water." *J. AWWA*, 80(7):105.
- L Wang, L., W.E. Condit, and A.S.C. Chen. 2004. *Technology Selection and System Design: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1*. EPA/600/R-05/001. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Wang, L., A.S.C. Chen, and K.A. Fields. 2000. *Arsenic Removal from Drinking Water by Ion Exchange and Activated Alumina Plants*. EPA/600/R-00/088. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Westerhoff, P.K., T.M. Benn, A.S.C. Chen, L. Wang, and L.J. Cumming. 2007. *Assessing Arsenic Removal by Metal (Hydr)Oxide Adsorptive Media Using Rapid Small Scale Column Tests*. Prepared under Contract No. 68-C-00-185, Task Order No. 0019, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Zhang, Z., and D.A. Clifford. 1994. "Exhaustion and Regeneration of Resins for Uranium Removal." *J. AWWA*, 86(4): 228-241.

**APPENDIX A**

**OPERATIONAL DATA**

**Table A-1. US EPA Arsenic Demonstration Project at Lake Isabella, CA - Daily System Operation Log Sheet**

A-1

Week	Day of Week	Date	Well CH2-A				Treatment System									
			Hour Meter hr	Opt Hour hr	Working Column	Working Bag Filter	Pressure			Inst. Flowrate gpm	Influent Totalizer gal	Volume In gal	Effluent Totalizer gal	Volume Out gal	Cum Bed Volumes <sup>(a)</sup> BV	Average Flowrate gpm
							Influent psig	Post Bag Filter psig	Effluent psig							
1	W	10/12/05	20.1	NA	1	1	7.5	8	8.5	25.3	21,460	NA	21,365	NA	0	NA
	R	10/13/05	35.5	15.4	1	1	7.5	10	9.5	26.6	44,158	22,698	44,475	23,110	114	25.01
	F	10/14/05	59.1	23.6	1	1	7	8	9	24.0	78,353	34,195	79,280	34,805	287	24.58
2	M	10/17/05	78.9	19.8	1	1	7	10	8	25.3	106,979	28,626	108,370	29,090	431	24.49
	T	10/18/05	101.5	22.6	1	1	9	10	10	28.0	139,895	32,916	141,820	33,450	596	24.67
	W	10/19/05	125.1	23.6	1	1	6	8	7	24.0	174,136	34,241	176,600	34,780	768	24.56
	R	10/20/05	146.4	21.3	1	1	7	8	8	22.6	204,479	30,343	207,420	30,820	921	24.12
3	F	10/21/05	169.3	22.9	1	1	7.5	8	8.5	22.6	236,966	32,487	240,410	32,990	1,084	24.01
	M	10/24/05	216	46.7	1	1	6	7	7	24.0	303,691	66,725	308,195	67,785	1,420	24.19
	T	10/25/05	235.4	19.4	1	1	6	8	7	22.6	331,448	27,757	336,237	28,042	1,559	24.09
	W	10/26/05	256.7	21.3	1	1	7	8	8	24.0	361,589	30,141	366,785	30,548	1,710	23.90
	R	10/27/05	258.3	1.6	1	1	8	9	8	25.3	392,204	30,615	397,835	31,050	1,864	NA
4	F	10/28/05	263.5	5.2	1	1	3	5	6	0.0	414,099	21,895	420,000	22,165	1,973	NA
	M	10/31/05	298.5	35.0	1	1	6	8	6	22.6	421,861	7,762	427,870	7,870	2,012	24.36
	T	11/01/05	317.4	18.9	1	1	7	9	8	22.6	448,938	27,077	455,330	27,460	2,148	24.22
	W	11/02/05	342.7	25.3	1	1	6.5	8	7.5	22.6	484,773	35,835	491,670	36,340	2,328	23.94
5	R	11/03/05	363.6	20.9	1	1	8	8	8.5	22.6	514,319	29,546	521,635	29,965	2,477	23.90
	F	11/04/05	387.8	24.2	1	1	8	9	9	22.6	548,447	34,128	556,260	34,625	2,648	23.85
	M	11/07/05	398.4	10.6	1	1	9	10	10	28.0	563,456	15,009	571,585	15,325	2,724	24.10
	T	11/08/05	401.7	3.3	1	1	8	9	8	25.3	568,738	5,282	576,840	5,255	2,750	26.54
	W	11/09/05	419.1	17.4	1	1	7.5	9	8	24.0	594,270	25,532	602,720	25,880	2,878	24.79
6	R	11/10/05	446.1	27.0	1	1	7	8	8	22.6	632,950	38,680	641,975	39,255	3,072	24.23
	F	11/11/05	467.6	21.5	1	1	8	8.5	8.5	22.6	663,107	30,157	672,570	30,595	3,224	23.72
	T	11/15/05	477.4	9.8	1	1	8	9	8	NM	NM	NA	687,270	14,700	3,297	25.00
	W	11/16/05	492	14.6	1	1	7.5	9	8	22.6	698,570	35,463	708,520	21,250	3,402	24.26
7	R	11/17/05	516.4	24.4	1	1	8	9	9	22.6	733,267	34,697	743,715	35,195	3,576	24.04
	F	11/18/05	539.3	22.9	1	1	8	9	8.5	22.6	765,793	32,526	776,720	33,005	3,739	24.02
	M	11/21/05	616.4	77.1	1	1	7	9	7	22.6	873,942	108,149	886,510	109,790	4,283	23.73
8	T	11/22/05	627.3	10.9	1	1	0	4	6	0	889,186	15,244	901,977	15,467	4,359	23.65
	M	11/28/05	627.3	0.0	1	1	0	0	3	0.0	889,269	83	902,059	82	4,360	NA
	T	11/29/05	645	17.7	1	1	9	8	8	22.6	915,013	25,744	928,200	26,141	4,489	24.61
	W	11/30/05	669.6	24.6	1	1	9	8	8	22.6	950,174	35,161	963,900	35,700	4,666	24.19
9	R	12/01/05	690.3	20.7	1	1	10	9	9	22.6	979,185	29,011	993,344	29,444	4,812	23.71
	F	12/02/05	713.6	23.3	1	2	7	9	10	22.6	1,012,129	32,944	1,026,800	33,456	4,977	23.93
	M	12/05/05	19:12	9.2	1	2	7	10	10	25.3	1,025,500	13,371	1,040,370	13,570	5,045	24.58
	T	12/06/05	743.2	20.4	1	2	7	9	11	22.6	1,057,988	32,488	1,070,330	29,960	5,193	24.48
	W	12/07/05	772.7	29.5	1	2	7	9	9.5	22.6	1,096,712	38,724	1,112,680	42,350	5,403	23.93
10	R	12/08/05	784.5	11.8	1	2	7	9	10	24.0	1,114,464	17,752	1,130,985	18,305	5,493	25.85
	F	12/09/05	784.9	0.4	1	2	2	4	8	0.0	1,114,479	15	1,130,995	10	5,493	0.42
	F	12/16/05	789.7	4.8	1	2	0	0	2	0.0	1,114,524	45	1,131,038	43	5,493	0.15
	T	12/20/05	794.4	4.7	1	2	7.5	10	10	0.0	NA	NA	1,138,400	7,362	5,530	26.11
11	W	12/21/05	809.4	15.0	1	2	7	10	10	24.0	1,144,320	NA	1,161,030	22,630	5,642	25.14
	R	12/22/05	813.5	4.1	1	2	0	4	6	0.0	1,150,323	6,003	1,167,180	6,150	5,672	25.00
	W	12/28/05	822.2	8.7	1	2	8	9	10	24.0	1,163,522	13,199	1,180,500	13,320	5,738	25.52
12	R	12/29/05	845.8	23.6	1	2	7	10	10	24.0	1,198,051	34,529	1,215,603	35,103	5,912	24.79
	F	12/30/05	863.8	18.0	1	2	8	9	10	22.6	1,223,845	25,794	1,241,759	26,156	6,042	24.22
	T	01/03/06	962.5	98.7	1	2	8	9	10	22.6	1,364,839	140,994	1,384,980	143,221	6,751	24.18
	W	01/04/06	975.8	13.3	1	2	9	10	11	24.0	1,384,236	19,397	1,404,678	19,698	6,848	24.68
13	R	01/05/06	990.8	15.0	1	2	9	10	11	25.1	1,406,828	22,592	1,427,620	22,942	6,962	25.49
	M	01/09/06	990.9	0.1	1	2	0	0	4	0.0	1,406,860	32	1,427,634	14	6,962	NA
	T	01/10/06	1001.2	10.3	1	2	8	9	10	24.0	1,422,957	16,097	1,444,000	16,366	7,043	26.48
	W	01/11/06	1018.2	17.0	1	2	8.5	9	10.5	24.0	1,448,132	25,175	1,469,550	25,550	7,169	25.05
	R	01/12/06	1036.3	18.1	1	1	7.5	9.5	10.5	22.4	1,474,734	26,602	1,496,575	27,025	7,303	24.88
14	F	01/13/06	1054.6	18.3	1	1	8	9.5	11	24.0	1,501,617	26,883	1,523,985	27,410	7,439	24.96
	T	01/18/06	1136.7	82.1	1	1	8	10	11	24.0	1,621,670	120,053	1,645,860	121,875	8,042	24.74
	R	12/29/05	1175.1	38.4	1	1	7.5	10	11	24.0	1,678,129	56,459	1,703,275	57,415	8,326	24.92
	F	12/30/05	1193.4	18.3	1	1	8	10	11.5	24.0	1,704,885	26,756	1,730,405	27,130	8,461	24.71

**Table A-1. US EPA Arsenic Demonstration Project at Lake Isabella, CA - Daily System Operation Log Sheet (Continued)**

Week	Day of Week	Date	Well CH2-A		Working Column	Working Bag Filter	Pressure			Treatment System						Volume Out gal	Cum Bed Volumes <sup>(a)</sup> BV	Average Flowrate gpm
			Hour Meter hr	Opt Hour hr			Influent psig	Post Bag Filter psig	Effluent psig	Inst. Flowrate gpm	Influent Totalizer gal	Volume In gal	Effluent Totalizer gal					
16	M	01/23/06	1265.4	72.0	1	F-1	6	9	9	22.6	1,808,419	306,802	1,835,600	311,615	10,003	72.13		
	T	01/24/06	1278.4	13.0	1		8.5	12	11	29.3	1,827,416	18,997	1,854,915	19,315	10,099	24.76		
	W	01/25/06	1299.3	20.9	1	1	7.5	9	10	24.0	1,857,715	30,299	1,885,705	30,790	10,251	24.55		
	R	01/26/06	1321	21.7	1	1	7.5	9.5	10.5	24.0	1,889,065	31,350	1,917,570	31,865	10,409	24.47		
	F	01/27/06	1342.3	21.3	1	1	8	10	10	24.0	1,919,352	30,287	1,948,350	30,780	10,561	24.08		
17	M	01/30/06	1414	71.7	1	1	7	9	10	24.0	2,021,455	102,103	2,052,160	103,810	11,075	24.13		
	T	01/31/06	1434.2	20.2	1	1	8	10	10.5	24.0	2,050,323	28,868	2,081,510	29,350	11,221	24.22		
	W	02/01/06	1452.3	18.1	1	1	8	9.5	10.5	24.0	2,076,107	25,784	2,107,724	26,214	11,350	24.14		
	R	02/02/06	1472	19.7	1	1	7	9.5	10	24.0	2,105,097	28,990	2,137,290	29,566	11,497	25.01		
18	F	02/03/06	1493.8	21.8	1	1	6	9.5	9.5	22.6	2,136,616	31,519	2,169,200	31,910	11,655	24.40		
	M	02/06/06	1561.9	68.1	1	1	7	9	10	22.6	2,232,824	96,208	2,266,950	97,750	12,139	23.92		
	T	02/07/06	1583.2	21.3	1	1	7.5	9.5	10	22.6	2,263,455	30,631	2,298,070	31,120	12,293	24.35		
	W	02/08/06	1604.2	21.0	1	1	8	10	10	24.0	2,293,349	29,894	2,328,465	30,395	12,443	24.12		
	R	02/09/06	1625	20.8	1	1	8	9	10	22.6	2,323,370	30,021	2,358,060	29,595	12,590	23.71		
19	F	02/10/06	1647.8	22.8	1	1	8	9	10	22.6	2,355,451	32,081	2,391,558	33,498	12,756	24.49		
	M	02/13/06	1722.5	74.7	1	1	6	9	9	22.6	2,460,961	105,510	2,498,700	107,142	13,286	23.90		
	T	02/14/06	1742.8	20.3	1	1	7.5	10	9	24.0	2,499,993	39,032	2,528,180	29,480	13,432	24.20		
	W	02/15/06	1758.6	15.8	1	1	9	10	10	22.6	2,512,792	12,799	2,551,325	23,145	13,546	24.41		
	R	02/16/06	1781.3	22.7	1	1	10	11	11.5	25.3	2,545,191	32,399	2,584,212	32,887	13,709	24.15		
20	F	02/17/06	1802.3	21.0	1	1	9	10	11	24.0	2,575,305	30,114	2,614,750	30,538	13,860	24.24		
	T	02/21/06	1899.3	97.0	1	1	8	9.5	10.5	22.6	2,712,176	136,871	2,753,570	138,820	14,548	23.85		
	W	02/22/06	1922.3	23.0	1	1	8.5	10	10	22.6	2,744,409	32,233	2,786,260	32,690	14,709	23.69		
	R	02/23/06	1950.1	27.8	1	1	7	9.5	9	22.6	2,783,841	39,432	2,826,250	39,990	14,907	23.97		
21	F	02/24/06	1967.7	17.6	1	1	7.5	9.5	9.5	22.6	2,808,971	25,130	2,851,700	25,450	15,033	24.10		
	M	02/27/06	2033.4	65.7	1	1	8	9	9	22.6	2,907,667	98,696	2,951,775	100,075	15,529	25.39		
	T	02/28/06	2063.6	30.2	1	1	9	10	10	24.0	2,943,459	35,792	2,988,045	36,270	15,708	20.02		
	W	03/01/06	2077	13.4	1	1	9	10	10	22.6	2,962,922	19,463	3,007,765	19,720	15,806	24.53		
	R	03/02/06	2097.5	20.5	1	1	12	12	7.5	29.3	2,992,447	29,525	3,037,675	29,910	15,954	24.32		
22	F	03/03/06	2118.5	21.0	1	1	10	10	6	22.6	3,022,606	30,159	3,068,283	30,608	16,106	24.29		
	M	03/06/06	2191.6	73.1	1	1	10	9.5	7	22.6	3,125,905	103,299	3,172,900	104,617	16,624	23.85		
	T	03/07/06	2217.4	25.8	1	1	10	10	5.5	23.6	3,162,045	36,140	3,219,480	46,580	16,854	30.09		
	W	03/08/06	2233.3	15.9	1	1	11	10	6	24.0	3,184,636	22,591	3,232,360	12,880	16,918	13.50		
	R	03/09/06	2262.9	29.6	1	2	8	10	6	22.6	3,226,762	42,126	3,274,705	42,345	17,128	23.84		
23	F	03/10/06	2284.5	21.6	1	2	8	10	6	22.6	3,257,453	30,691	3,306,085	31,380	17,283	24.21		
	M	03/13/06	2350.7	66.2	1	2	8	10	6	24.0	3,350,650	93,197	3,400,410	94,325	17,750	23.75		
	T	03/14/06	2375.9	25.2	1	2	8	9	6	22.6	3,386,100	35,450	3,436,390	35,980	17,928	23.80		
	W	03/15/06	2396.5	20.6	1	2	8	10	6	22.7	3,415,704	29,604	3,466,250	29,860	18,076	24.16		
	R	03/16/06	2420.9	24.4	1	2	8	10	6	22.6	3,449,970	34,266	3,500,940	34,690	18,248	23.70		
24	F	03/17/06	2450.3	29.4	1	F-2	8	9.5	5.5	22.6	3,491,260	41,290	3,542,700	41,760	18,454	23.67		
	M	03/20/06	2516.6	66.3	1	2	8	10	5.5	22.6	3,584,167	92,907	3,636,767	94,067	18,920	23.65		
	T	03/21/06	2541.6	25.0	1	2	8	10	6	24.0	3,619,446	35,279	3,672,420	35,653	19,096	23.77		
	W	03/22/06	2564.1	22.5	1	2	8	9.5	6	22.6	3,650,763	31,317	3,704,155	31,735	19,254	23.51		
	R	03/23/06	2590.7	26.6	1	2	8	10	6	22.6	3,687,990	37,227	3,741,835	37,680	19,440	23.61		
25	F	03/24/06	2612.8	22.1	1	2	8	10	5	22.6	3,718,953	30,963	3,773,173	31,338	19,595	23.63		
	M	03/27/06	2690.1	77.3	1	2	8	9.5	5	22.6	3,827,078	108,125	3,882,500	109,327	20,136	23.57		
	T	03/28/06	2708.0	17.9	1	2	8	9.5	5	22.6	3,851,985	24,907	3,907,746	25,246	20,261	23.51		
	W	03/29/06	2729.1	21.1	1	2	7.5	9.5	5.5	22.6	3,882,525	30,540	3,938,655	30,909	20,414	24.41		
	R	03/30/06	2755.7	26.6	1	2	8.5	9.5	5.5	22.6	3,920,498	37,973	3,977,063	38,408	20,605	24.07		
26	F	03/31/06	2776.9	21.2	1	2	8.5	9.5	5.5	22.6	3,950,515	30,017	4,007,411	30,348	20,755	23.86		
	M	04/03/06	2854.1	77.2	1	2	8	10	5	22.6	4,059,818	109,303	4,118,000	110,589	21,302	23.88		
	T	04/04/06	2873.0	18.9	1	2	8.5	9.5	5.5	22.6	4,086,615	26,797	4,145,070	27,070	21,436	23.87		
	W	04/05/06	2892.4	19.4	1	2	8.5	10	6	22.6	4,114,886	28,271	4,173,670	28,600	21,578	24.57		
	R	04/06/06	2914.9	22.5	1	2	9	10	6	24.0	4,147,332	32,446	4,206,475	32,805	21,740	24.30		
27	F	04/07/06	2937.7	22.8	1	2	9	10	6	22.6	4,180,043	32,711	4,239,500	33,025	21,904	24.14		
	M	04/10/06	3016.8	79.1	1	2	0	4	0	0.0	4,283,049	103,006	4,343,718	104,218	22,420	21.96		
	T	04/18/06	3017.9	1.1	1	1	11	13	5	29.3	4,283,460	411	4,344,120	402	22,422	6.09		
	W	04/19/06	3037.4	19.5	1	1	8	10	6	22.6	4,313,826	30,366	4,374,850	30,730	22,574	26.26		
	R	04/20/06	3065.4	28.0	1	1	8.5	10	4	24.0	4,354,105	40,279	4,415,565	40,715	22,775	24.24		
28	F	04/21/06	3085.1	19.7	1	1	8	10	5	22.6	4,382,345	28,240	4,444,120	28,555	22,917	24.16		

**Table A-1. US EPA Arsenic Demonstration Project at Lake Isabella, CA - Daily System Operation Log Sheet (Continued)**

Week	Day of Week	Date	Well CH2-A				Treatment System									
			Hour Meter hr	Opt Hour hr	Working Column	Working Bag Filter	Pressure			Inst. Flowrate gpm	Influent Totalizer gal	Volume In gal	Effluent Totalizer gal	Volume Out gal	Cum Bed Volumes <sup>(a)</sup> BV	Average Flowrate gpm
							Influent psig	Post Bag Filter psig	Effluent psig							
29	T	04/25/06	3181.5	96.4	1	1	8	10	5	22.6	4,519,479	137,134	4,582,755	138,635	23,603	23.97
	W	04/26/06	3204.8	23.3	1	1	8	10	5	24.0	4,553,055	33,576	4,616,705	33,950	23,771	24.28
	R	04/27/06	3231.5	26.7	1	1	8	10	5	22.6	4,590,982	37,927	4,655,060	38,355	23,961	23.94
30	F	04/28/06	3252.1	20.6	1	1	8.5	10	5	22.6	4,620,088	29,106	4,684,480	29,420	24,107	23.80
	M	05/01/06	3304.2	52.1	1	1	11	12	5.5	28.0	4,693,732	73,644	4,758,970	74,490	24,475	23.83
	T	05/02/06	3319.2	15.0	1	1	8	10	4	22.6	4,716,205	22,473	4,781,661	22,691	24,588	25.21
31	W	05/03/06	3339.3	20.1	1	1	8.5	10	5	22.6	4,745,085	28,880	4,810,880	29,219	24,732	24.23
	M	05/08/06	3389.5	50.2	1	1	11	12	4	26.6	4,818,258	73,173	4,884,850	73,970	25,099	24.56
	T	05/09/06	3401.9	12.4	1	1	10	11	4	25.3	4,837,679	19,421	4,907,455	22,605	25,210	30.38
32	W	05/10/06	3411.6	9.7	1	1	0	4	0	0.0	4,851,814	14,135	4,918,723	11,268	25,266	19.36
	R	05/11/06	3416.7	5.1	1	1	10	11	4	25.3	4,868,128	16,314	4,927,133	8,410	25,308	27.48
	F	05/12/06	3436.7	20.0	1	1	9	10	3	22.6	4,889,616	21,488	4,956,925	29,792	25,455	24.83
33	M	05/15/06	3466.7	30.0	1	1	10	11	4	25.3	4,935,042	45,426	5,002,840	45,915	25,683	25.51
	T	05/16/06	3486.4	19.7	1	1	9	10	2	22.6	4,963,852	28,810	5,031,944	29,104	25,827	24.62
	W	05/17/06	3500.3	13.9	1	1	10	11	4	24.0	4,984,070	20,218	5,052,380	20,436	25,928	24.50
34	R	05/18/06	3519.9	19.6	1	1	10	10	3	24.0	5,012,372	28,302	5,080,975	28,595	26,069	24.32
	F	05/19/06	3535.9	16.0	1	1	9	9	2.5	24.0	5,035,475	23,103	5,104,330	23,355	26,185	24.33
	M	05/22/06	3566.5	30.6	1	1	1	4	1	0.0	5,079,362	43,887	5,148,661	44,331	26,405	24.15
35	T	05/23/06	3572.3	5.8	1	1	9	9	3	24.0	5,088,729	9,367	5,158,145	9,484	26,451	27.25
	W	05/24/06	3577.9	5.6	1	1	10.5	10	3	28.0	5,097,146	8,417	5,166,700	8,555	26,494	25.46
	R	05/25/06	3591.5	13.6	1	1	0	4	0	0.0	5,117,726	20,580	5,187,439	20,739	26,597	25.42
36	F	05/26/06	3594.8	3.3	1	1	9.5	9	3	24.0	5,123,001	5,275	5,192,880	5,441	26,623	27.48
	T	05/30/06	3659.0	64.2	1	1	2	4	0	0.0	5,216,890	93,889	5,287,675	94,795	27,093	24.61
	W	05/31/06	3665.1	6.1	1	1	2	4	0	0.0	5,226,600	9,710	5,297,587	9,912	27,142	27.08
37	R	06/01/06	3670.6	5.5	1	1	11	10	2	26.6	5,235,326	8,726	5,306,320	8,733	27,185	26.46
	F	06/02/06	3686.8	16.2	1	1	11	8.5	3	24.0	5,259,562	24,236	5,330,825	24,505	27,306	25.21
	T	06/06/06	3752.3	65.5	1	1	12	9	2	22.6	5,354,161	94,599	5,426,400	95,575	27,779	24.32
38	W	06/07/06	3770.8	18.5	1	1	12	9	1	22.6	5,380,687	26,526	5,453,200	26,800	27,912	24.14
	R	06/08/06	3790.6	19.8	1	1	12.5	9	7	22.6	5,408,836	28,149	5,481,700	28,500	28,053	23.99
	F	06/09/06	3813.8	23.2	1	1	13	9	7	22.6	5,441,054	32,218	5,514,200	32,500	28,214	23.35
39	M	06/12/06	3847.9	34.1	1	1	0	5	0	0.0	5,490,471	49,417	5,564,209	50,009	28,462	24.44
	T	06/13/06	3854.4	6.5	1	2	7.5	9	3	24.0	5,500,323	9,852	5,574,295	10,086	28,512	25.86
	W	06/14/06	3858.9	4.5	1	2	8	9	6	24.0	5,507,199	6,876	5,581,237	6,942	28,546	25.71
40	R	06/15/06	3877.7	18.8	1	2	7	9	5.5	24.0	5,534,851	27,652	5,609,180	27,943	28,684	24.77
	F	06/16/06	3885.4	7.7	1	2	8.5	10	6	25.3	5,546,040	11,189	5,620,494	11,314	28,740	24.49
	M	06/19/06	3922.3	36.9	1	2	8	9	6	24.0	5,601,725	55,685	5,676,600	56,106	29,018	25.34
41	T	06/20/06	3942.7	20.4	1	2	7.5	9	6	24.0	5,632,062	30,337	5,707,322	30,722	29,170	25.10
	W	06/21/06	3955.7	13.0	1	2	8	9.5	6	24.0	5,651,758	19,696	5,726,827	19,505	29,267	25.01
	R	06/22/06	3962.3	6.6	1	2	8.5	9.5	6	25.3	5,661,336	9,578	5,736,960	10,133	29,317	25.59
42	F	06/23/06	3974	11.7	1	2	9	10	6.5	26.6	5,678,719	17,383	5,754,480	17,520	29,404	24.96
	M	06/26/06	4045.4	71.4	1	2	8.5	9	6	22.6	5,780,398	101,679	5,857,250	102,770	29,912	23.99
	T	06/27/06	4060.7	15.3	1	2	0	4	4	0.0	5,802,229	21,831	5,879,398	22,148	30,022	24.13
43	W	06/28/06	4073.6	12.9	1	2	8	9	6	22.6	5,824,807	22,578	5,899,185	19,787	30,120	25.56
	R	06/29/06	4096.9	23.3	1	2	8	9	5.5	22.6	5,855,403	30,596	5,933,050	33,865	30,288	24.22
	M	07/03/06	4183.5	86.6	1	2	8	9	6	22.6	5,976,964	121,561	6,055,400	122,350	30,893	23.55
44	T	07/05/06	4228.3	44.8	1	2	8	9	6	22.6	6,040,185	63,221	6,119,835	64,435	31,212	23.97
	W	07/06/06	4249.8	21.5	1	2	9	10	6.5	22.6	6,070,087	29,902	6,150,035	30,200	31,362	23.41
	R	07/07/06	4270.0	20.2	1	2	9.5	10	6.5	22.6	6,099,002	28,915	6,179,270	29,235	31,507	24.12
45	M	07/10/06	4330.4	60.4	1	1	8	10	6	23.3	6,183,043	84,041	6,264,222	84,952	31,927	23.44
	W	07/12/06	4331.9	1.5	1	1	9	11	6	29.3	6,184,304	1,261	6,265,595	1,373	31,934	15.26
	R	07/13/06	4361.3	29.4	1	1	7	9	5.5	22.6	6,226,584	42,280	6,308,250	42,655	32,145	24.18
46	F	07/14/06	4378.1	16.8	1	1	7.5	9	6	22.6	6,250,016	23,432	6,331,925	23,675	32,262	23.49
	M	07/17/06	4457.1	79.0	1	1	7	9	6	21.3	6,359,387	109,371	6,442,530	110,605	32,810	23.33
	T	07/18/06	4481.4	24.3	1	1	7	9	5.5	22.6	6,393,072	33,685	6,476,693	34,163	32,979	23.43
47	W	07/19/06	4482.0	0.6	1	1	9	11	6.5	28.0	6,394,208	1,136	6,477,760	1,067	32,984	29.64
	R	07/20/06	4484.7	2.7	1	1	9	11	6	26.6	6,398,487	4,279	6,482,000	4,240	33,005	26.17
	F	07/21/06	4486.3	1.6	1	1	8	9	6	24.0	6,401,006	2,519	6,484,600	2,600	33,018	27.08
48	M	07/24/06	4488	1.7	1	1	10	11	6.5	29.3	6,403,868	2,862	6,487,590	2,990	33,033	29.31
	W	07/25/06	4490.3	2.3	1	1	9	10	6	26.6	6,407,735	3,867	6,491,490	3,900	33,052	28.26
	R	07/26/06	4511.4	21.1	1	1	8	9	6	22.6	6,438,010	30,275	6,521,973	30,483	33,203	24.08
49	F	07/27/06	4536.5	25.1	1	1	8	9	6	22.6	6,473,107	35,097	6,557,420	35,447	33,379	23.54

**Table A-1. US EPA Arsenic Demonstration Project at Lake Isabella, CA - Daily System Operation Log Sheet (Continued)**

Week	Day of Week	Date	Well CH2-A		Working Column	Working Bag Filter	Pressure			Treatment System						Volume Out gal	Cum Bed Volumes <sup>(a)</sup> BV	Average Flowrate gpm
			Hour Meter hr	Opt Hour hr			Influent psig	Post Bag Filter psig	Effluent psig	Inst. Flowrate gpm	Influent Totalizer gal	Volume In gal	Effluent Totalizer gal					
43	M	07/31/06	4584.3	47.8	1	1	0	3	0	0.0	6,540,923	67,816	6,625,993	68,573	33,718	23.91		
	T	08/01/06	4586.5	2.2	1	1	8.5	9.5	6	24.0	6,544,602	3,679	6,629,620	3,627	33,736	27.48		
	W	08/02/06	4607.3	20.8	1	1	8	9	6	22.6	6,576,818	32,216	6,662,150	32,530	33,897	26.07		
	R	08/03/06	4631.8	24.5	1	1	8.5	9	6	22.6	6,608,077	31,259	6,693,716	31,566	34,053	21.47		
	F	08/04/06	4654.9	23.1	1	1	8.5	9	6	22.6	6,640,134	32,057	6,726,185	32,469	34,214	23.43		
44	M	08/07/06	4733.6	78.7	1	1	8.5	9	6	22.6	6,748,808	108,674	6,835,850	109,665	34,757	23.22		
	T	08/08/06	4759.4	25.8	1	1	8.5	9	6	22.6	6,789,355	40,547	6,871,730	35,880	34,935	23.18		
	W	08/09/06	4780.1	20.7	1	1	8.5	9	6	22.6	6,812,858	23,503	6,900,545	28,815	35,077	23.20		
	R	08/10/06	4799.2	19.1	1	1	9	9	6	22.6	6,839,085	26,227	6,927,045	26,500	35,208	23.12		
45	F	08/11/06	4822.8	23.6	1	1	9	9	6	22.6	6,871,485	32,400	6,959,773	32,728	35,370	23.11		
	T	08/15/06	4920.2	97.4	1	2	7	9	6	21.3	7,005,409	133,924	7,095,070	135,297	36,040	23.15		
	W	08/16/06 <sup>(p)</sup>	4927.2	7.0	2	2	6.5	8	6	22.6	7,010,088	4,679	7,099,822	4,752	36,064	11.31		
46	F	08/18/06	4970	42.8	2	2	6	8	6	22.6	7,069,564	59,476	7,159,850	60,028	297	23.38		
	T	08/22/06	5068.4	98.4	2	2	6	8	6	22.6	7,205,235	135,671	7,296,865	137,015	975	23.21		
	W	08/23/06	5090.2	21.8	2	2	6	8	6	22.6	7,235,058	29,823	7,327,093	30,228	1,125	23.11		
	R	08/24/06	5117.7	27.5	2	2	6	8	6	22.6	7,272,806	37,748	7,365,130	38,037	1,313	23.05		
	F	08/25/06	5138.8	21.1	2	2	6	8	5	22.6	7,301,676	28,870	7,394,390	29,260	1,458	23.11		
47	M	08/28/06	5212.4	73.6	2	2	6	8	6	22.6	7,402,316	100,640	7,495,900	101,510	1,961	22.99		
	T	08/29/06	5239.3	26.9	2	2	6	8	6	22.6	7,439,042	36,726	7,533,100	37,200	2,145	23.05		
	W	08/30/06	5259.6	20.3	2	2	6.5	8	6	22.6	7,466,761	27,719	7,561,100	28,000	2,284	22.99		
	R	08/31/06	5285.6	26.0	2	2	6	8	6	22.6	7,502,291	35,530	7,597,000	35,900	2,461	23.01		
	F	09/01/06	5306.8	21.2	2	2	6	8	6	21.3	7,531,162	28,871	7,626,180	29,180	2,606	22.94		
48	T	09/05/06	5408.0	101.2	2	2	6	8	6	21.3	7,668,884	137,722	7,765,340	139,160	3,295	22.92		
	W	09/06/06	5428.5	20.5	2	2	6.5	8	6	22.8	7,696,849	27,965	7,793,600	28,260	3,435	22.98		
	R	09/07/06	5449.9	21.4	2	2	6.5	8	6	22.6	7,725,928	29,079	7,823,090	29,490	3,581	22.97		
	F	09/08/06	5476.2	26.3	2	2	6.5	8	6	21.3	7,761,121	35,193	7,859,000	35,910	3,758	22.76		
49	M	09/11/06	5552.2	76.0	2	2	6	8	6	22.6	7,864,923	103,802	7,963,500	104,500	4,276	22.92		
	T	09/12/06	5571.3	19.1	2	2	6	8	5.5	21.3	7,890,953	26,030	7,989,750	26,250	4,406	22.91		
	W	09/13/06	5601.5	30.2	2	2	6	8	5	21.3	7,931,933	40,980	8,031,150	41,400	4,611	22.85		
	R	09/14/06	5623	21.5	2	2	6.5	8	5.5	22.6	7,961,119	29,186	8,060,625	29,475	4,756	22.85		
50	F	09/15/06	5642	19.0	2	2	6.5	8	5.5	21.3	7,986,929	25,810	8,086,705	26,080	4,886	22.88		
	M	09/18/06	5714.9	72.9	2	2	7	8	6	22.6	8,085,628	98,699	8,186,440	99,735	5,379	22.80		
	T	09/19/06	5744.8	29.9	2	2	6.5	8	6	21.3	8,126,196	40,568	8,227,411	40,971	5,582	22.84		
	W	09/20/06	5764.2	19.4	2	2	6.5	8	6	22.6	8,152,416	26,220	8,253,905	26,494	5,713	22.76		
	R	09/21/06	5787.7	23.5	2	2	6.5	8	6	21.3	8,184,242	31,826	8,286,070	32,165	5,873	22.81		
51	F	09/22/06	5813.4	25.7	2	2	6.5	8	6	21.3	8,219,078	34,836	8,321,260	35,190	6,047	22.82		
	M	09/25/06	5888.2	74.8	2	2	6.5	8	6	22.6	8,320,200	101,122	8,423,470	102,210	6,553	22.77		
	T	09/26/06	5910.7	22.5	2	2	6.5	8	6	21.3	8,350,536	30,336	8,454,075	30,605	6,704	22.67		
	W	09/27/06	5929.6	18.9	2	2	9	10	6	28.0	8,376,375	25,839	8,480,265	26,190	6,834	23.10		
	R	09/28/06	5950.3	20.7	2	2	7	8	6	22.6	8,405,039	28,664	8,509,180	28,915	6,977	23.28		
52	F	09/29/06	5972	21.7	2	2	7	8	6	22.6	8,434,260	29,221	8,538,700	29,520	7,123	22.67		
	M	10/02/06	6051.4	79.4	2	2	7	8	6	22.6	8,541,196	106,936	8,646,730	108,030	7,658	22.68		
	T	10/03/06	6076.1	24.7	2	2	7	8	5.5	22.6	8,574,278	33,082	8,680,170	33,440	7,824	22.56		
	W	10/04/06	6092.7	16.6	2	2	7	8	5.5	21.3	8,596,645	22,367	8,702,760	22,590	7,935	22.68		
	R	10/05/06	6122.6	29.9	2	2	7	8	5.5	22.6	8,637,014	40,369	8,743,565	40,805	8,137	22.75		
53	F	10/06/06	6139.6	17.0	2	2	7.5	8	6	24.0	8,660,046	23,032	8,766,845	23,280	8,253	22.82		
	T	10/10/06	6242.4	102.8	2	1	6	8	6	21.3	8,798,565	138,519	8,906,840	139,995	8,946	22.70		
	W	10/11/06	6262	19.6	2	1	6	8	5.5	21.3	8,824,943	26,378	8,933,500	26,660	9,078	22.67		
	R	10/12/06	6285.1	23.1	2	1	6.5	8.5	5.5	21.3	8,856,023	31,080	8,964,910	31,410	9,233	22.66		
	F	10/13/06	6308.1	23.0	2	1	6	8	6	21.3	8,886,976	30,953	8,996,205	31,295	9,388	22.68		
54	M	10/16/06	6386.4	78.3	2	1	6	8	5.5	21.3	8,992,689	105,713	9,103,050	106,845	9,917	22.74		
	T	10/17/06	6406.3	19.9	2	1	6	8	5.5	22.6	9,019,593	26,904	9,130,212	27,162	10,051	22.75		
	W	10/18/06	6430.6	24.3	2	1	6	8	5.5	21.3	9,052,342	32,749	9,163,320	33,108	10,215	22.71		
	R	10/19/06	6453.6	23.0	2	1	6	8	5.5	22.6	9,083,293	30,951	9,194,690	31,370	10,371	22.73		
	F	10/20/06	6481.4	27.8	2	1	6	8	6	22.6	9,120,673	37,380	9,232,360	37,670	10,557	22.58		
55	M	10/23/06	6549.1	67.7	2	1	6.5	8	6	21.3	9,211,471	90,798	9,324,110	91,750	11,011	22.59		
	T	10/24/06	6575.5	26.4	2	1	7	8.5	6	22.6	9,247,342	35,871	9,360,355	36,245	11,191	22.88		
	W	10/25/06	6598.4	22.9	2	1	6.5	8	5.5	21.3	9,278,384	31,042	9,391,715	31,360	11,346	22.82		
	R	10/26/06	6619.4	21.0	2	1	6	8	5.5	22.6	9,306,543	28,159	9,420,160	28,445	11,487	22.58		
F	10/27/06	6640.9	21.5	2	1	6.5	8	5.5	24.0	9,334,493	27,950	9,449,490	29,330	11,632	22.74			

**Table A-1. US EPA Arsenic Demonstration Project at Lake Isabella, CA - Daily System Operation Log Sheet (Continued)**

Week	Day of Week	Date	Well CH2-A				Treatment System									
			Hour Meter hr	Opt Hour hr	Working Column	Working Bag Filter	Pressure			Inst. Flowrate gpm	Influent Totalizer gal	Volume In gal	Effluent Totalizer gal	Volume Out gal	Cum Bed Volumes <sup>(a)</sup> BV	Average Flowrate gpm
							Influent psig	Post Bag Filter psig	Effluent psig							
56	M	10/30/06	6719.3	78.4	2	2	6	8	6	22.6	9,440,817	106,324	9,555,830	106,340	12,158	22.61
	T	10/31/06	6738.4	19.1	2	2	6	8	5.5	21.3	9,466,725	25,908	9,582,008	26,178	12,288	22.84
	W	11/01/06	6762.6	24.2	2	2	6	8	5.5	22.6	9,499,249	32,524	9,614,875	32,867	12,451	22.64
	R	11/02/06	6785.6	23.0	2	2	6	8	5.5	21.3	9,530,275	31,026	9,646,210	31,335	12,606	22.71
	F	11/03/06	6808.2	22.6	2	2	6	8	5.5	21.3	9,560,728	30,453	9,676,970	30,760	12,758	22.68
57	M	11/06/06	6870.1	61.9	2	2	0	4	2	0.0	9,644,147	83,419	9,761,232	84,262	13,175	22.69
	T	11/07/06	6870.9	0.8	2	2	8	9	6	28.0	9,645,562	1,415	9,762,675	1,443	13,182	30.06
	W	11/08/06	6872.7	1.8	2	2	7	8	6	24.0	9,648,339	2,777	9,765,502	2,827	13,196	26.18
	R	11/09/06	6897.6	24.9	2	2	6.5	8	5.5	21.3	9,682,419	34,080	9,799,990	34,488	13,367	23.08
58	T	11/14/06	7016.2	118.6	2	2	6	8	5.5	21.3	9,840,915	158,496	9,959,945	159,955	14,159	22.48
	W	11/15/06	7040.5	24.3	2	2	6	8	5.5	21.3	9,872,919	32,004	9,992,265	32,320	14,319	22.17
	R	11/16/06	7062.9	22.4	2	2	6	8	5.5	21.3	9,902,945	30,026	10,022,680	30,415	14,470	22.63
	F	11/17/06	7087.5	24.6	2	2	6	8	5.5	21.3	9,935,474	32,529	10,055,450	32,770	14,632	22.20
59	M	11/20/06	7156.7	69.2	2	2	0	3	2	0.0	10,026,811	91,337	10,147,790	92,340	15,089	22.24
	T	11/21/06	7156.7	0.0	2	2	0	3	2	0.0	10,026,811	0	10,147,790	0	15,089	NA
	W	11/22/06	7156.7	0.0	2	2	0	3	2	0.0	10,026,811	0	10,147,790	0	15,089	NA
60	M	11/27/06	7160.2	3.5	2	2	9	11	6	28.0	10,032,586	5,775	10,153,520	5,730	15,117	27.29
	T	11/28/06	7168.0	7.8	2	2	7	10	6	22.6	10,039,435	6,849	10,160,450	6,930	15,152	14.81
	W	11/29/06	7186.4	18.4	2	2	7.5	9.5	5.5	21.3	10,064,699	25,264	10,185,980	25,530	15,278	23.13
	R	11/30/06	7211.8	25.4	2	2	7	9	5.5	21.3	10,099,125	34,426	10,220,770	34,790	15,450	22.83
61	F	12/01/06	7233.6	21.8	2	2	8	9	5.5	21.3	10,128,384	29,259	10,250,365	29,595	15,597	22.63
	M	12/04/06	7250.8	17.2	2	2	10	11	6.5	28.0	10,151,620	23,236	10,273,808	23,443	15,713	22.72
	T	12/05/06	7269.0	18.2	2	2	9	9	5.5	21.3	10,176,917	25,297	10,299,455	25,647	15,840	23.49
	R	12/07/06	7317	48.0	2	2	9	9	5.5	21.3	10,248,550	71,633	10,364,855	65,400	16,164	22.71
	F	12/08/06	7340.5	23.5	2	2	8.5	10	5.5	21.3	10,279,420	30,870	10,396,440	31,585	16,320	22.40
62	M	12/11/06	7410.7	70.2	2	2	9	10	5.5	21.3	10,366,310	86,890	10,490,810	94,370	16,787	22.41
	T	12/12/06	7434.3	23.6	2	2	9	10	5.5	22.6	10,397,622	31,312	10,522,445	31,635	16,944	22.34
	W	12/13/06	7459.7	25.4	2	2	6	9.5	5.5	22.6	10,431,372	33,750	10,566,560	44,115	17,162	28.95
	R	12/14/06	7487.1	27.4	2	2	6	9.5	5.5	21.3	10,468,030	36,658	10,593,610	27,050	17,296	16.45
63	F	12/15/06	7506.1	19.0	2	2	6	9.5	5.5	21.3	10,493,461	25,431	10,619,320	25,710	17,423	22.55
	M	12/18/06	7577.7	71.6	2	2	6	10	5.5	21.3	10,589,154	95,693	10,716,035	96,715	17,902	22.51
	T	12/19/06	7608.2	30.5	2	2	6	10	5.5	21.3	10,628,856	39,702	10,757,175	41,140	18,106	22.48
	W	12/20/06	7630.6	22.4	2	2	6	9.5	5.5	21.3	10,659,719	30,863	10,787,370	30,195	18,255	22.47
	R	12/21/06	7657.7	27.1	2	2	6	9	5.5	NA	NA	NA	10,823,760	36,390	18,435	22.38
64	F	12/22/06	7672.8	15.1	2	2	6	9	5.5	NA	NA	NA	10,844,135	20,375	18,536	22.49
	T	12/26/06	7772.0	99.2	2	2	6.5	9	5.5	20.0	10,847,807	188,088	10,977,850	133,715	19,198	22.47
	W	12/27/06	7795.6	23.6	2	2	6	9.5	5.5	21.3	10,879,018	31,211	11,008,000	30,150	19,347	21.29
	R	12/28/06	7818.8	23.2	2	2	6	9.5	5.5	21.3	10,910,008	30,990	11,040,322	32,322	19,507	23.22
	F	12/29/06	7843.3	24.5	2	2	6	9.5	5.5	22.6	10,942,613	32,605	11,073,270	32,948	19,671	22.41
65	T	01/02/07	7937.6	94.3	2	2	6	9.5	5.5	21.3	11,106,782	164,169	11,199,810	126,540	20,297	22.36
	W	01/03/07	7966.7	29.1	2	2	6	9.5	5.5	21.3	11,106,896	114	11,219,310	19,500	20,394	11.17
	R	01/04/07	7984.6	17.9	2	2	8	11	6.5	29.3	11,130,874	23,978	11,267,585	48,275	20,632	44.95
	F	01/05/07	8012.4	27.8	2	2	6.5	9.5	5.5	NA	11,165,589	34,715	11,298,605	31,020	20,786	18.60
66	M	01/08/07	8082.8	70.4	2	2	6	9	5.5	22.6	11,261,248	95,659	11,395,270	96,665	21,265	22.88
	T	01/09/07	8106.7	23.9	2	2	6	9	5.5	21.3	11,292,678	31,430	11,427,030	31,760	21,422	22.15
	W	01/10/07	8133.4	26.7	2	2	7	10	5.5	NA	NA	NA	11,462,720	35,690	21,599	22.28
	R	01/11/07	8154.6	21.2	2	2	6	9	5.5	21.3	11,356,288	63,610	11,491,310	28,590	21,740	22.48
67	F	01/12/07	8178.5	23.9	2	2	6	9.5	5.5	21.3	11,387,806	31,518	11,523,170	31,860	21,898	22.22
	T	01/16/07	8277.2	98.7	2	2	7	10	6	NA	NA	NA	11,653,450	130,280	22,543	22.00
	W	01/17/07	8296.3	19.1	2	2	6	10	6	21.3	11,543,875	156,069	11,690,120	36,670	22,724	32.00
	F	01/19/07	8345.6	49.3	2	2	6	9	6	21.3	11,689,632	145,757	11,744,975	54,855	22,996	18.54
68	M	01/22/07	8418.9	73.3	2	2	6.5	9.5	6	21.3	11,705,753	16,121	11,842,705	97,730	23,480	22.22
	T	01/23/07	8436.9	18.0	2	2	6	9.5	6	21.3	11,729,338	23,585	11,860,550	17,845	23,568	16.52
	R	01/25/07	8489	52.1	2	2	6	9.5	5.5	21.3	11,797,974	68,636	11,935,920	75,370	23,941	24.11
	F	01/26/07	8515.1	26.1	2	2	6.5	9.5	5.5	21.3	11,832,391	34,417	11,970,790	34,870	24,114	22.27
69	M	01/29/07	8584.7	69.6	2	2	6	9.5	5.5	21.3	11,923,819	91,428	12,063,190	92,400	24,571	22.13
	T	01/30/07	8610.5	25.8	2	2	6	9.5	6	21.3	11,957,758	33,939	12,097,375	34,185	24,740	22.08
	W	01/31/07	8628.7	18.2	2	2	6	9	6	21.3	11,981,559	23,801	12,121,430	24,055	24,859	22.03
	R	02/01/07	8653	24.3	2	2	6	9.5	6	21.3	12,013,527	31,968	12,153,735	32,305	25,019	22.16
F	02/02/07	8679.4	26.4	2	2	6	9.5	5.5	21.3	12,048,124	34,597	12,188,700	34,965	25,192	22.07	

**Table A-1. US EPA Arsenic Demonstration Project at Lake Isabella, CA - Daily System Operation Log Sheet (Continued)**

Week	Day of Week	Date	Well CH2-A		Working Column	Working Bag Filter	Treatment System					Volume Out gal	Cum Bed Volumes <sup>(a)</sup> BV	Average Flowrate gpm		
			Hour Meter hr	Opt Hour hr			Pressure			Inst. Flowrate gpm	Influent Totalizer gal				Volume In gal	Effluent Totalizer gal
							Influent psig	Post Bag Filter psig	Effluent psig							
70	M	02/05/07	8754.9	75.5	2	2	6	9.5	5.5	21.3	12,147,126	99,002	12,288,730	100,030	25,688	22.08
	T	02/06/07	8774.5	19.6	2	2	6	9.5	5.5	21.3	12,172,778	25,652	12,314,650	25,920	25,816	22.04
	W	02/07/07	8798.8	24.3	2	2	6.5	9.5	5.5	21.3	12,204,521	31,743	12,346,720	32,070	25,975	22.00
	R	02/08/07	8825.8	27.0	2	2	6	9.5	6	21.3	12,239,969	35,448	12,382,540	35,820	26,152	22.11
	F	02/09/07	8845.6	19.8	2	2	6.5	9.5	6	21.3	12,265,903	25,934	12,408,740	26,200	26,282	22.05
71	M	02/12/07	8917.6	72.0	2	2	6.5	9.5	6	21.3	12,360,043	94,140	12,503,865	95,125	26,753	22.02
	T	02/13/07	8940.2	22.6	2	2	9	12	6	29.7	12,389,559	29,516	12,533,778	29,913	26,901	22.06
	W	02/14/07	8962.2	22.0	2	2	6.5	9	6	21.3	12,419,313	29,754	12,563,740	29,962	27,049	22.70
	R	02/15/07	8986.4	24.2	2	2	6.5	9	6	21.3	12,451,008	31,695	12,595,875	32,135	27,208	22.13
	F	02/16/07	9011.3	24.9	2	2	6.5	9.5	6	21.3	12,483,874	32,866	12,628,915	33,040	27,372	22.12
72	T	02/20/07	9107.1	95.8	2	2	6.5	9.5	6	21.3	12,609,172	125,298	12,755,530	126,615	27,999	22.03
	W	02/21/07	9125	17.9	2	2	6.5	9	5.5	21.3	12,632,594	23,422	12,779,290	23,760	28,116	22.12
	R	02/22/07	9150.6	25.6	2	2	6.5	9.5	5.5	21.3	12,666,019	33,425	12,812,960	33,670	28,283	21.92
	F	02/23/07	9179.2	28.6	2	2	7	9	6	20.0	12,703,262	37,243	12,850,680	37,720	28,470	21.98
73	M	02/26/07	9249.6	70.4	2	2	6.5	9.5	5.5	21.3	12,795,020	91,758	12,943,390	92,710	28,929	21.95
	T	02/27/07	9268.8	19.2	2	2	6.5	9	6	21.3	12,828,097	33,077	12,968,625	25,235	29,053	21.91
	W	02/28/07	9291.1	22.3	2	2	6.5	9	6	21.3	12,849,845	21,748	12,998,670	30,045	29,202	22.46
	F	03/02/07	9331.2	40.1	2	2	6	9	6	21.3	12,903,158	53,313	13,052,525	53,855	29,469	22.38
74	M	03/05/07	9403.4	72.2	2	2	6	9	6	21.3	12,997,399	94,241	13,147,735	95,210	29,940	21.98
	T	03/06/07	9428.6	25.2	2	2	0	5.5	4	0.0	13,030,177	32,778	13,180,840	33,105	30,104	21.89
	W	03/07/07	9430	1.4	2	2	0	5	0	0.0	13,030,395	218	13,181,065	225	30,105	2.68
	R	03/08/07	9430	0.0	2	2	0	5	0	6.0	13,030,395	0	13,181,065	0	30,105	0.00
	F	03/09/07	9463.1	33.1	2	2	6.5	11	6	26.6	13,032,083	1,688	13,182,780	1,715	30,114	0.86
75	M	03/12/07	9501.1	38.0	2	2	6	9	6	21.3	13,126,007	93,924	13,277,640	94,860	30,583	41.61
	T	03/13/07	9526.3	25.2	2	2	6	9	6	21.3	13,159,298	33,291	13,311,270	33,630	30,750	22.24
	W	03/14/07	9549.6	23.3	2	2	6	9.5	6	21.3	13,189,791	30,493	13,342,075	30,805	30,902	22.04
	R	03/15/07	9573.2	23.6	2	2	6	9	6	21.3	13,221,171	31,380	13,373,800	31,725	31,059	22.40
	F	03/16/07	9578.3	5.1	2	2	3	6	4	0.0	13,227,853	6,682	13,380,525	6,725	31,093	21.98
76	M	03/19/07	9631.5	53.2	2	2	3	6	0	0.0	13,299,249	71,396	13,452,660	72,135	31,450	22.60
	T	03/20/07	9643.7	12.2	2	2	6	9	6	21.3	13,316,197	16,948	13,469,890	17,230	31,535	23.54
	W	03/21/07	9661.6	17.9	2	2	6	9	6	21.3	13,339,786	23,589	13,493,615	23,725	31,652	22.09
	R	03/22/07	9687.4	25.8	2	2	6	9	6	21.3	13,369,523	29,737	13,523,660	30,045	31,801	19.41
F	03/23/07	9713.4	26.0	2	2	6	9	6	21.3	13,407,425	37,902	13,561,950	38,290	31,991	24.54	

(a) Bed volume = 27 ft<sup>3</sup> or 202 gallons  
 (b) Flow was switched to Vessel 2  
 NA = not available  
 NM = not measured

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

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

Sampling Date		10/13/05			10/19/05			10/26/05			11/02/05			11/08/05			11/16/05			
Sampling Location	Parameter	Unit	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF
Bed Volume (10 <sup>3</sup> )	BV		-	-	0.2	-	-	0.9	-	-	1.8	-	-	2.4	-	-	3.0	-	-	3.5
Alkalinity (as CaCO <sub>3</sub> )	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 <sub>2</sub> )	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 <sup>(b)</sup>	NA <sup>(b)</sup>	NA <sup>(b)</sup>
ORP	mV		198	213	230	258	195	205	370	298	268	NA <sup>(a)</sup>	NA <sup>(a)</sup>	NA <sup>(a)</sup>	303	336	321	293	291	294
Total Hardness (as CaCO <sub>3</sub> )	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 <sub>3</sub> )	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 <sub>3</sub> )	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.

B-1

IN = influent; BF = before filter; AF = after filter.  
NA = not available.

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

Sampling Date		12/01/05			12/08/05			12/28/05			01/04/06			01/11/06			01/25/06			
Sampling Location	Parameter	Unit	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF
Bed Volume (10 <sup>3</sup> )	BV		-	-	4.9	-	-	5.6	-	-	5.8	-	-	7.0	-	-	7.3	-	-	9.3
Alkalinity (as CaCO <sub>3</sub> )	mg/L		88	92	88	97	97	106	97	101	97	97	97	97	101	97	101	101	101	101
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	101	101
Fluoride	mg/L		-	-	-	-	-	-	1.1	1.1	1.1	-	-	-	1.1	1.1	1.1	-	-	-
Sulfate	mg/L		-	-	-	-	-	-	36	36	36	-	-	-	37	38	36	-	-	-
Nitrate (as N)	mg/L		-	-	-	-	-	-	1.0	1.0	1.0	-	-	-	1.3	1.3	1.7	-	-	-
Total P (as P)	µg/L		<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	14	13	<10	<10	<10	<10
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<10	<10
Silica (as SiO <sub>2</sub> )	mg/L		45.2	44.5	44.7	44.0	42.8	44.1	44.2	45.6	44.8	43.1	42.2	42.9	43.9	44.6	44.9	43.4	43.7	42.9
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	43.7	42.9
Turbidity	NTU		0.1	0.1	<0.1	0.3	0.2	0.1	0.6	0.7	0.7	1.8	1.7	1.6	0.4	0.4	0.4	0.5	0.2	0.3
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2
pH	S.U.		7.1	7.0	7.0	7.0	7.0	7.0	NA	NA	NA	7.0	7.0	7.0	6.8	6.9	6.9	6.8	6.9	7.0
Temperature	°C		19.1	18.2	17.4	12.9	14.1	14.4	NA	NA	NA	17.0	16.6	13.7	11.9	12.1	12.4	12.2	12.4	12.5
DO	mg/L		3.9	3.0	3.0	NA <sup>(a)</sup>	NA <sup>(a)</sup>	NA <sup>(a)</sup>	NA	NA	NA	NA <sup>(a)</sup>	NA <sup>(a)</sup>	NA <sup>(a)</sup>	3.1	3.5	2.7	2.1	2.0	2.4
ORP	mV		415	453	453	332	411	426	NA	NA	NA	478	489	490	378	265	245	432	471	445
Total Hardness (as CaCO <sub>3</sub> )	mg/L		88.6	87.9	91.5	92.2	89.9	89.5	93.6	93.7	92.6	89.5	90.7	90.9	79.9	82.4	80.3	94.9	94.9	94.3
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	95.4	94.3
Ca Hardness (as CaCO <sub>3</sub> )	mg/L		81.5	81.0	84.4	85.8	83.6	83.3	87.3	87.3	86.2	82.2	83.2	83.3	72.7	75.2	73.1	88.5	88.5	88.1
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	89.0	88.1
Mg Hardness (as CaCO <sub>3</sub> )	mg/L		7.0	7.0	7.1	6.4	6.3	6.2	6.3	6.5	6.5	7.3	7.4	7.6	7.2	7.2	7.2	6.5	6.4	6.2
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.5	6.3
As (total)	µg/L		39.2	39.5	<0.1	42.1	40.5	<0.1	39.4	38.9	0.3	39.4	39.2	0.6	43.0	43.5	0.5	38.4	38.6	0.2
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	37.4	37.9
As (soluble)	µg/L		-	-	-	-	-	-	40.0	39.4	0.7	-	-	-	43.2	45.2	0.4	-	-	-
As (particulate)	µg/L		-	-	-	-	-	-	<0.1	<0.1	<0.1	-	-	-	<0.1	<0.1	<0.1	-	-	-
As (III)	µg/L		-	-	-	-	-	-	0.4	0.4	0.4	-	-	-	0.8	0.8	0.8	-	-	-
As (V)	µg/L		-	-	-	-	-	-	39.6	39.0	0.4	-	-	-	42.5	44.4	<0.1	-	-	-
Fe (total)	µg/L		<25	<25	<25	<25	<25	<25	<25	<25	<25	41.2	39.9	<25	<25	<25	<25	<25	<25	<25
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<25	<25
Fe (soluble)	µg/L		-	-	-	-	-	-	<25	<25	<25	-	-	-	<25	<25	<25	-	-	-
Mn (total)	µg/L		<0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.6	0.7	1.3	0.5	0.5	0.4	0.2	<0.1	0.6	<0.1	<0.1	0.4
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.1	<0.1
Mn (soluble)	µg/L		-	-	-	-	-	-	0.8	1.1	1.6	-	-	-	0.1	0.1	0.7	-	-	-
U (total)	µg/L		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	30.3	29.6	<0.1
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29.8	29.5
U (soluble)	µg/L		-	-	-	-	-	-	33.6	33.6	<0.1	-	-	-	32.6	32.8	<0.1	-	-	-

(a) DO probe was not operational.

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

Sampling Date		02/08/06			02/22/06			03/08/06			03/22/06			04/04/06 <sup>(a)</sup>			04/19/06			
Sampling Location	Parameter	Unit	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF
Bed Volume (10 <sup>3</sup> )	BV		-	-	11.5	-	-	13.8	-	-	16.0	-	-	18.3	-	-	20.5	-	-	21.7
Alkalinity (as CaCO <sub>3</sub> )	mg/L		96	100	100	100	104	100	100	100	100	103	99	99	95	95	99	106	106	106
			-	-	-	-	-	-	-	-	-	-	103	99	99	-	-	-	-	-
Fluoride	mg/L		1.0	1.0	1.0	-	-	-	1.1	1.1	1.1	-	-	-	1.2	1.2	1.2	-	-	-
Sulfate	mg/L		36	35	35	-	-	-	41	40	39	-	-	-	40	40	40	-	-	-
Nitrate (as N)	mg/L		1.1	1.1	1.0	-	-	-	1.1	1.1	1.0	-	-	-	1.3	1.2	1.2	-	-	-
Total P (as P)	µg/L		<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	-	-	-	18	17	<10
			-	-	-	-	-	-	-	-	-	-	<10	<10	<10	-	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L		42.6	43.8	43.3	44.9	44.3	45.0	42.0	41.6	42.1	42.3	42.8	42.7	42.9	42.2	42.4	42.1	42.3	41.2
			-	-	-	-	-	-	-	-	-	-	43.1	43.1	42.6	-	-	-	-	-
Turbidity	NTU		0.8	0.6	0.5	0.6	0.6	0.3	1.0	0.8	0.6	0.3	0.4	0.3	1.0	0.6	0.8	0.3	0.4	0.2
			-	-	-	-	-	-	-	-	-	-	0.3	0.3	0.5	-	-	-	-	-
pH	S.U.		7.0	6.9	7.0	7.2	7.0	7.1	7.0	7.0	7.1	7.2	7.1	7.3	6.9	6.9	6.4	6.8	6.8	6.8
Temperature	°C		14.7	14.6	14.8	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	12.7	17.9
DO	mg/L		4.3	3.7	2.9	3.4	3.2	3.4	2.9	3.4	3.8	NA <sup>(b)</sup>	NA <sup>(b)</sup>	NA <sup>(b)</sup>	266	1.8	1.6	1.6	2.1	1.5
ORP	mV		436	338	315	416	411	390	300	305	325	443	486	495	285	264	232	384	345	254
Total Hardness (as CaCO <sub>3</sub> )	mg/L		69.6	69.3	69.9	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
			-	-	-	-	-	-	-	-	-	-	92.3	93.0	93.2	-	-	-	-	-
Ca Hardness (as CaCO <sub>3</sub> )	mg/L		60.6	60.0	60.1	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
			-	-	-	-	-	-	-	-	-	-	86.7	87.3	87.6	-	-	-	-	-
Mg Hardness (as CaCO <sub>3</sub> )	mg/L		9.0	9.3	9.8	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
			-	-	-	-	-	-	-	-	-	-	5.6	5.6	5.6	-	-	-	-	-
As (total)	µg/L		42.5	42.4	0.4	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
			-	-	-	-	-	-	-	-	-	-	41.5	41.6	0.3	-	-	-	-	-
As (soluble)	µg/L		42.7	42.8	0.4	-	-	-	39.5	40.0	0.2	-	-	-	43.6	42.7	1.5	-	-	-
As (particulate)	µg/L		<0.1	<0.1	<0.1	-	-	-	0.8	1.4	<0.1	-	-	-	<0.1	<0.1	<0.1	-	-	-
As (III)	µg/L		0.7	0.8	1.0	-	-	-	0.4	0.4	0.5	-	-	-	0.8	0.5	0.5	-	-	-
As (V)	µg/L		42.0	41.9	<0.1	-	-	-	39.2	39.5	<0.1	-	-	-	42.8	42.2	1.0	-	-	-
Fe (total)	µg/L		<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
			-	-	-	-	-	-	-	-	-	-	<25	<25	<25	-	-	-	-	-
Fe (soluble)	µg/L		<25	<25	<25	-	-	-	<25	<25	<25	-	-	-	<25	<25	<25	-	-	-
Mn (total)	µg/L		<0.1	<0.1	0.2	<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	0.1	0.4	-	-	-	-	-	-
Mn (soluble)	µg/L		<0.1	<0.1	0.2	-	-	-	0.3	0.2	0.4	-	-	-	0.1	<0.1	0.5	-	-	-
U (total)	µg/L		30.6	30.2	<0.1	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
			-	-	-	-	-	-	-	-	-	-	28.4	27.8	<0.1	-	-	-	-	-
U (soluble)	µg/L		32.7	30.7	<0.1	-	-	-	32.1	31.9	<0.1	-	-	-	35.6	36.4	<0.1	-	-	-

(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		05/03/06			05/17/06			06/01/06			06/14/06			06/22/06			07/06/06			
Sampling Location	Parameter	Unit	IN	BF	AF	IN	BF	AF												
Bed Volume (10 <sup>3</sup> )	BV		-	-	23.8	-	-	25.0	-	-	26.3	-	-	27.6	-	-	28.4	-	-	30.4
Alkalinity (as CaCO <sub>3</sub> )	mg/L		105	97	105	97	97	97	96	96	100	106	102	106	100	100	100	100	100	100
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L		1.0	1.0	1.0	-	-	-	-	-	-	0.9	1.0	1.0	-	-	-	1.1	1.6	1.4
Sulfate	mg/L		40	40	40	-	-	-	-	-	-	41	42	42	-	-	-	<1	43	41
Nitrate (as N)	mg/L		0.9	1.0	1.0	-	-	-	-	-	-	1.0	1.0	0.9	-	-	-	0.9	1.0	1.0
Total P (as P)	µg/L		<10	<10	<10	<10	<10	<10	15	14	10.0	17	17	17	<10	<10	<10	<10	<10	<10
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L		45.6	43.9	44.4	45.2	45.2	45.6	39.5	41.0	39.1	47.5	48.2	46.7	43.8	44.3	15.9	43.3	44.0	42.8
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU		0.2	0.4	0.4	0.6	0.7	0.4	0.5	0.2	0.9	0.7	0.5	0.5	0.8	0.6	0.4	0.7	0.4	0.4
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.		7.0	6.9	6.9	7.0	6.9	7.1	6.8	6.8	6.9	6.9	6.9	7.0	6.9	6.9	6.9	7.0	7.0	7.0
Temperature	°C		19.9	19.5	19.9	23.6	23.2	23.4	20.3	20.0	19.7	18.6	18.1	18.3	23.3	23.1	2.3	24.3	23.5	22.8
DO	mg/L		2.7	2.1	1.9	2.7	2.9	2.3	1.9	2.2	2.0	3.0	2.8	2.6	1.8	2.1	2.0	2.1	2.1	2.0
ORP	mV		408	407	386	471	474	494	305	276	278	401	386	277	415	345	310	453	470	470
Total Hardness (as CaCO <sub>3</sub> )	mg/L		90.8	88.0	86.6	80.9	85.1	82.8	90.2	86.1	91.1	90.7	89.5	90.0	95.4	90.4	94.3	86.3	85.2	88.9
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO <sub>3</sub> )	mg/L		83.8	81.1	79.7	73.7	77.8	75.5	80.7	76.6	82.0	83.5	82.5	83.2	87.8	82.8	87.5	80.5	79.5	82.8
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO <sub>3</sub> )	mg/L		7.0	6.8	6.9	7.2	7.3	7.3	9.5	9.6	9.2	7.2	7.0	6.8	7.5	7.5	6.8	5.8	5.7	6.1
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L		44.7	43.6	2.2	41.3	42.4	2.7	38.8	35.8	3.1	40.1	40.4	4.4	41.3	38.1	4.9	41.9	40.7	8.1
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L		44.5	44.0	2.2	-	-	-	-	-	-	38.5	39.7	4.4	-	-	-	42.2	40.6	7.8
As (particulate)	µg/L		0.2	<0.1	<0.1	-	-	-	-	-	-	1.6	0.7	<0.1	-	-	-	<0.1	0.1	0.3
As (III)	µg/L		0.2	0.2	0.1	-	-	-	-	-	-	0.1	0.2	0.1	-	-	-	0.1	0.1	<0.1
As (V)	µg/L		44.4	43.8	2.0	-	-	-	-	-	-	38.3	39.5	4.3	-	-	-	42.1	40.5	7.7
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	-	-	-	<25	<25	<25
Mn (total)	µg/L		0.1	0.1	0.5	0.3	0.3	0.4	<0.1	<0.1	<0.1	0.4	0.3	0.2	0.6	0.5	0.2	0.6	0.5	0.6
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L		0.1	0.1	0.5	-	-	-	-	-	-	0.4	0.3	0.2	-	-	-	<0.1	<0.1	0.2
U (total)	µg/L		35.2	34.8	<0.1	37.4	35.5	<0.1	36.6	34.9	<0.1	38.9	38.7	<0.1	37.0	35.7	<0.1	31.3	31.0	<0.1
			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
U (soluble)	µg/L		35.3	35.6	<0.1	-	-	-	-	-	-	37.9	38.1	<0.1	-	-	-	31.2	30.5	<0.1

IN = influent; BF = before filter; AF = after filter.  
 NA = not available.

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

Sampling Date		07/19/06			7/26/2006 <sup>(a)</sup>			08/03/06			8/23/06 <sup>(b)</sup>			08/30/06			09/07/06			
Sampling Location	Parameter	Unit	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF
Bed Volume (10 <sup>3</sup> )	BV		-	-	32.0	-	-	32.3	-	-	33.1	-	-	1.1	-	-	2.3	-	-	3.6
Alkalinity (as CaCO <sub>3</sub> )	mg/L		97	101	97	-	-	-	101	101	101	105	105	103	107	110	112	111	109	109
			97	92	101	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L		-	-	-	-	-	-	1.3	1.4	1.4	1.6	1.6	1.6	-	-	-	-	-	-
Sulfate	mg/L		-	-	-	-	-	-	40	40	41	51	52	52	-	-	-	-	-	-
Nitrate (as N)	mg/L		-	-	-	-	-	-	0.9	0.9	0.9	1.1	1.1	1.1	-	-	-	-	-	-
Total P (as P)	µg/L		<10	<10	<10	-	-	-	15	13	13	<10	<10	<10	11.5	10.9	<10	<10	<10	<10
			<10	<10	12.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L		44.2	42.6	43.3	-	-	-	42.6	42.4	41.8	42.7	42.8	42.2	40.5	39.7	39.8	39.6	40.4	40.8
			43.0	43.8	43.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU		0.4	0.3	0.5	-	-	-	0.1	0.1	0.1	0.2	0.1	<0.1	0.3	0.4	0.2	<0.1	0.2	<0.1
			0.3	0.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.		6.9	6.9	6.9	-	-	-	6.9	6.8	6.8	6.9	6.9	6.9	-	-	-	-	-	-
Temperature	°C		24.2	23.1	22.3	-	-	-	23.4	22.7	22.3	27.0	26.2	26.2	-	-	-	-	-	-
DO	mg/L		2.0	2.1	2.0	-	-	-	1.8	1.5	1.5	1.9	2.0	2.2	-	-	-	-	-	-
ORP	mV		479	317	251	-	-	-	372	277	269	463	468	437	-	-	-	-	-	-
Total Hardness (as CaCO <sub>3</sub> )	mg/L		86.4	85.1	84.3	-	-	-	93.3	95.3	93.6	102	99.9	101	109	106	110	102	102	103
			86.7	86.1	91.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO <sub>3</sub> )	mg/L		79.6	78.3	77.8	-	-	-	86.7	89.3	87.6	96.0	94.2	94.8	102	100	104	95.5	95.3	97.0
			79.9	79.2	84.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO <sub>3</sub> )	mg/L		6.8	6.8	6.5	-	-	-	6.6	6.0	5.9	5.9	5.7	5.7	6.4	6.2	6.3	6.5	6.4	6.4
			6.8	6.8	6.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L		38.2	37.5	9.4	46.0	46.0	9.2	47.3	45.8	10.5	50.0	47.6	<0.1	44.8	43.8	0.2	42.1	40.6	0.2
			37.5	37.0	9.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L		-	-	-	-	-	-	45.2	44.8	10.3	49.7	46.9	<0.1	-	-	-	-	-	-
As (particulate)	µg/L		-	-	-	-	-	-	2.1	1.0	0.2	0.4	0.7	<0.1	-	-	-	-	-	-
As (III)	µg/L		-	-	-	-	-	-	0.2	0.2	0.2	0.4	0.4	0.4	-	-	-	-	-	-
As (V)	µg/L		-	-	-	-	-	-	44.9	44.5	10.1	49.2	46.5	<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		0.5	0.5	0.2	-	-	-	0.2	0.1	0.2	<0.1	<0.1	0.6	0.1	<0.1	0.5	<0.1	<0.1	0.4
			0.5	0.5	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L		-	-	-	-	-	-	0.1	0.2	0.2	<0.1	<0.1	0.6	-	-	-	-	-	-
U (total)	µg/L		32.8	32.9	<0.1	-	-	-	34.1	34.2	0.1	32.5	31.7	<0.1	32.4	32.8	<0.1	32.1	31.5	<0.1
			32.1	31.9	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
U (soluble)	µg/L		-	-	-	-	-	-	34.3	33.4	<0.1	30.7	30.9	<0.1	-	-	-	-	-	-

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

(b) Flow switched to Vessel 2 on August 16, 2006.

B-5

IN = influent; BF = before filter; AF = after filter.  
NA = not available.

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

Sampling Date		09/14/06			09/27/06			10/12/06			10/26/06 <sup>(a)</sup>			11/08/06			11/30/06			
Sampling Location	Parameter	Unit	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF
Bed Volume (10 <sup>3</sup> )	BV		-	-	4.8	-	-	6.8	-	-	9.3	-	-	11.5	-	-	13.2	-	-	15.5
Alkalinity (as CaCO <sub>3</sub> )	mg/L		105	105	105	106	104	109	108	105	108	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	110	108	108	-	-	-	-	-	-	-	-
Fluoride	mg/L		-	-	-	1.1	1.2	1.2	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L		-	-	-	41	43	42	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L		-	-	-	0.9	0.9	0.9	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as P)	µg/L		<10	<10	<10	<10	<10	<10	<10	<10	<10	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	<10	<10	<10	-	-	-	-	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L		41.7	43.1	42.6	42.0	42.6	42.5	44.4	43.7	44.1	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	44.4	44.0	42.6	-	-	-	-	-	-	-	-
Turbidity	NTU		0.9	0.2	0.1	0.3	0.2	0.3	0.6	0.3	0.2	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	0.1	0.2	0.2	-	-	-	-	-	-	-	-
pH	S.U.		-	-	-	6.9	7.0	7.1	6.7	6.7	6.7	NA	NA	NA	6.8	6.8	6.8	6.8	6.8	6.9
Temperature	°C		-	-	-	22.4	22.3	22.9	18.1	18.1	19.1	NA	NA	NA	17.9	17.8	18.1	12.5	13.8	14.0
DO	mg/L		-	-	-	1.6	1.7	2.2	1.6	1.7	1.8	NA	NA	NA	1.7	2.7	1.9	2.6	1.2	1.5
ORP	mV		-	-	-	344	463	445	465	395	320	NA	NA	NA	400	493	484	287	231	215
Total Hardness (as CaCO <sub>3</sub> )	mg/L		89.7	90.6	91.0	94.2	95.2	98.9	124	123	124	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	127	113	118	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO <sub>3</sub> )	mg/L		83.3	84.1	84.4	87.7	88.5	92.2	117	117	117	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	121	107	112	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO <sub>3</sub> )	mg/L		6.4	6.5	6.5	6.5	6.6	6.7	6.1	6.2	6.2	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	6.2	6.1	6.3	-	-	-	-	-	-	-	-
As (total)	µg/L		41.7	42.1	<0.1	45.5	45.7	<0.1	42.0	42.4	0.7	42.2	43.1	0.3	34.3	34.8	0.3	40.0	40.8	0.3
			-	-	-	-	-	-	42.2	42.0	0.8	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L		-	-	-	45.8	47.0	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L		-	-	-	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	µg/L		-	-	-	0.3	0.3	0.1	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	µg/L		-	-	-	45.5	46.7	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L		<25	<25	<25	<25	<25	<25	<25	<25	<25	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	<25	<25	<25	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L		-	-	-	<25	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L		<0.1	<0.1	0.3	<0.1	<0.1	0.4	<0.1	<0.1	0.3	-	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	0.1	<0.1	0.3	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L		-	-	-	<0.1	<0.1	0.4	-	-	-	-	-	-	-	-	-	-	-	-
U (total)	µg/L		32.4	32.1	<0.1	32.3	32.0	<0.1	34.5	34.9	<0.1	32.6	32.9	<0.1	34.4	34.1	<0.1	35.3	35.5	<0.1
			-	-	-	-	-	-	34.9	34.3	<0.1	-	-	-	-	-	-	-	-	-
U (soluble)	µg/L		-	-	-	31.8	32.2	<0.1	-	-	-	-	-	-	-	-	-	-	-	-

(a) Water samples only analyzed for total arsenic and uranium.

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

Sampling Date		12/13/06			01/04/07			01/31/07			02/22/07			03/12/07			03/21/07			
Sampling Location	Parameter	Unit	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF	IN	BF	AF
Bed Volume (10 <sup>3</sup> )	BV		-	-	17.2	-	-	NA	-	-	24.9	-	-	28.3	-	-	30.6	-	-	31.7
Alkalinity (as CaCO <sub>3</sub> )	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as P)	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.		6.8	6.8	6.8	NA	NA	NA	7.0	6.9	7.1									
Temperature	°C		14.2	1.5	14.9	NA	NA	NA	13.3	13.2	13.7									
DO	mg/L		2.8	1.8	1.3	NA	NA	NA	2.8	2.4	4.3									
ORP	mV		434	442	346	NA	NA	NA	464	466	446									
Total Hardness (as CaCO <sub>3</sub> )	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO <sub>3</sub> )	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO <sub>3</sub> )	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L		45.0	46.2	0.8	44.7	45.9	0.8	43.1	43.1	5.1	43.7	43.2	7.7	41.2	40.8	8.8	45.6	46.6	11.7
As (soluble)	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
U (total)	µg/L		31.1	30.7	<0.1	35.7	36.5	<0.1	33.5	33.2	0.1	32.2	32.9	<0.1	36.7	36.4	<0.1	35.0	34.9	<0.1
U (soluble)	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			NA = not available																	

B-7

IN = influent; BF = before filter; AF = after filter.  
NA = not available.