Arsenic Removal from Drinking Water by Adsorptive Media
EPA Demonstration Project at
Golden Hills Community Services District in Tehachapi, CA
Final Performance Evaluation Report

by

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DISCLAIMER

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Sally Gutierrez, Director
National Risk Management Research Laboratory
ABSTRACT

This report documents the activities performed and the results obtained for the arsenic removal treatment technology demonstration project at Golden Hills Community Services District (GHCSD) located in Tehachapi, CA. The objectives of the project were to evaluate (1) the effectiveness of Magnesium Elektron, Inc.’s (MEI) Isolux™ treatment system in removing arsenic to meet the new maximum contaminant level (MCL) of 10 µg/L; (2) the reliability of the treatment system; (3) the required system operation and maintenance (O&M) and operator skill levels; and (4) the capital and O&M cost of the technology. The project also characterized water in the distribution system and residuals generated by the treatment process. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), process residuals, and capital and O&M cost.

The Isolux™ arsenic treatment system consisted of two adsorption modules arranged in parallel, capable of treating up to 150 gal/min (gpm) of flow. Each module, designed for 75 gpm, consisted of a booster pump, a 1-µm bag filter, and two 20-in × 48-in carbon-steel filtration vessels, each containing nine Isolux™-302M media cartridges. Each media cartridge was 4.55-in in diameter and 42.25-in in length and contained 0.32 ft³ of Isolux™-302M—a hydrous zirconium oxide media with amphoteric properties. During the performance evaluation study from October 26, 2005, through March 20, 2007, three media runs were performed, each operating for a total run time of 1,377, 1,900, and 1,422 hr (or 21.9, 20.2, and 16.7 hr/day). Average flowrates for the runs were 79, 74, and 85 gpm. Based on the average flowrates, the empty bed contact times (EBCT) ranged from 0.9 to 1.2 min, compared to the design value of 0.5 min.

Among the 13 active wells at GHCSD, only Well C had elevated arsenic concentrations, which averaged 12.2 µg/L and existed primarily as soluble As(V). The pH values of raw water ranged from 7.4 to 7.9 and averaged 7.6, which is much lower than the zero point of charge for zirconium hydroxide (i.e., 10 to 11).

During Media Run 1, the system treated approximately 61,600 bed volumes (BV) of water before reaching 10 µg/L arsenic breakthrough. This run length was 41% lower than the vendor’s estimated 105,000 BV. An excessive amount of sediment was observed in the well water, necessitating frequent replacement of bag filters prior to the adsorption modules. It was possible that particles passed through the bag filters blocked (or partially blocked) some passages on the media cartridges’ outer membrane, causing preferential flow and the short run length observed. Examination of the well revealed rusty areas on the drop-pipe, which prompted a decision by GHCSD to rehabilitate the well.

Following the well rehabilitation and media cartridge changeout, Media Run 2 began on April 27, 2006. The system treated 92,800 BV of water before reaching 10 µg/L arsenic breakthrough. Since Media Runs 1 and 2 operated under similar conditions, the well rehabilitation might have, in fact, contributed to the more extended media life observed. Following media cartridge changeout, Media Run 3 began on August 17, 2006, and ended on March 20, 2007, with the system operating intermittently due to a lower demand in the winter. The system treated approximately 85,100 BV after reaching 10 µg/L arsenic breakthrough. Similar run lengths were observed during Media Runs 2 and 3. The intermittent system operation (i.e., 16.7 versus 20.2 hr/day) did not seem to affect the media run length.

The treatment system did not require backwash; therefore, spent media cartridges were the only residue generated. Spent Isolux™-302M media passed TCLP tests and therefore could be disposed of as non-hazardous waste. However, MEI opted to send the spent media for beneficial reuse.

Comparison of the distribution system sampling results before and after system startup showed a slight decrease in the average arsenic concentration at each of the three sampling locations (i.e., from 2.8, 6.0, and 5.2 µg/L to 2.0, 3.3, and 3.1 µg/L, respectively). Most of the time, arsenic concentrations were much lower than the new MCL of 10 µg/L.
lower than those of the treatment effluent, presumably due to blending of the treated water with untreated water from wells where arsenic levels were not of concern. Lead and copper concentrations at the three sampling locations did not appear to be significantly impacted by the arsenic treatment system.

The capital investment cost was $76,840, which included $58,500 for equipment, $8,500 for engineering, and $9,840 for installation. Using the system’s rated capacity of 150 gpm, the capital cost was $512/gpm (or $0.36/gpd).

The O&M cost for the Isolux™ system included cost for media cartridge replacement and labor for routine operation. Based on the volumes processed during each media run prior to 10 µg/L arsenic breakthrough, the total O&M cost, including media cartridge replacement for Media Runs 1, 2, and 3, was $1.35, $0.89, and $0.98/1,000 gal, respectively. Routine activities to operate and maintain the system consumed only 2.5 hr per week. Therefore, the estimated labor cost was $0.14/1,000 gal of water treated, assuming that the system operates at 79.3 gpm for 19.6 hr/day and 7 days/week to produce 653,000 gal of water per week.
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# ABBREVIATIONS AND ACRONYMS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAL</td>
<td>American Analytical Laboratories</td>
</tr>
<tr>
<td>AC</td>
<td>asbestos cement</td>
</tr>
<tr>
<td>AM</td>
<td>adsorptive media</td>
</tr>
<tr>
<td>As</td>
<td>arsenic</td>
</tr>
<tr>
<td>ATS</td>
<td>Aquatic Treatment Systems</td>
</tr>
<tr>
<td>bgs</td>
<td>below ground surface</td>
</tr>
<tr>
<td>BV</td>
<td>bed volumes</td>
</tr>
<tr>
<td>Ca</td>
<td>calcium</td>
</tr>
<tr>
<td>CDPH</td>
<td>California Department of Public Health</td>
</tr>
<tr>
<td>CEQA</td>
<td>California Environmental Quality Act</td>
</tr>
<tr>
<td>Cl</td>
<td>chlorine</td>
</tr>
<tr>
<td>C/F</td>
<td>coagulation/filtration</td>
</tr>
<tr>
<td>Cu</td>
<td>copper</td>
</tr>
<tr>
<td>DO</td>
<td>dissolved oxygen</td>
</tr>
<tr>
<td>EBCT</td>
<td>empty bed contact time</td>
</tr>
<tr>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
</tr>
<tr>
<td>F</td>
<td>fluoride</td>
</tr>
<tr>
<td>Fe</td>
<td>iron</td>
</tr>
<tr>
<td>GFH</td>
<td>granular ferric hydroxide</td>
</tr>
<tr>
<td>GHCSD</td>
<td>Golden Hills Community Services District</td>
</tr>
<tr>
<td>gpd</td>
<td>gallons per day</td>
</tr>
<tr>
<td>gpm</td>
<td>gallons per minute</td>
</tr>
<tr>
<td>HIX</td>
<td>hybrid ion exchanger</td>
</tr>
<tr>
<td>hp</td>
<td>horsepower</td>
</tr>
<tr>
<td>ICP-MS</td>
<td>inductively coupled plasma-mass spectrometry</td>
</tr>
<tr>
<td>ID</td>
<td>identification</td>
</tr>
<tr>
<td>IX</td>
<td>ion exchange</td>
</tr>
<tr>
<td>LCR</td>
<td>Lead and Copper Rule</td>
</tr>
<tr>
<td>MCL</td>
<td>maximum contaminant level</td>
</tr>
<tr>
<td>MDL</td>
<td>method detection limit</td>
</tr>
<tr>
<td>MEI</td>
<td>Magnesium Elektron, Inc.</td>
</tr>
<tr>
<td>Mg</td>
<td>magnesium</td>
</tr>
<tr>
<td>mgd</td>
<td>mega gallons per day</td>
</tr>
<tr>
<td>mg/L</td>
<td>milligrams per liter</td>
</tr>
<tr>
<td>µg/L</td>
<td>micrograms per liter</td>
</tr>
<tr>
<td>µm</td>
<td>micrometer</td>
</tr>
<tr>
<td>Mn</td>
<td>manganese</td>
</tr>
<tr>
<td>mV</td>
<td>millivolts</td>
</tr>
</tbody>
</table>
Na  sodium
NA  not available
ND  not detected
NH₃  ammonia
NO₂  nitrite
NO₃  nitrate
NRMRL  National Risk Management Research Laboratory
NSF  NSF International
NTU  nephlemetric turbidity units
O&M  operation and maintenance
OIT  Oregon Institute of Technology
ORD  Office of Research and Development
ORP  oxidation-reduction potential
PE  polyethylene
Pb  lead
PO₄  orthophosphate
POE  point of entry
POU  point of use
psi  pounds per square inch
PVC  polyvinyl chloride
ΔP  pressure differential
QA  quality assurance
QA/QC  quality assurance/quality control
QAPP  Quality Assurance Project Plan
RO  reverse osmosis
RPD  relative percent difference
SDWA  Safe Drinking Water Act
SiO₂  silica
SO₄  sulfate
STS  Severn Trent Services
S.U.  standard unit
TCLP  Toxicity Characteristic Leaching Procedure
TDS  total dissolved solids
TO  task order
TOC  total organic carbon
U  uranium
V  vanadium
WET  whole effluent toxicity
Zpc  zero point of charge
Zr  zirconium
ACKNOWLEDGMENTS

The authors wish to extend their sincere appreciation to the staff of the Golden Hills Community Services District in Tehachapi, California. The staff monitored the treatment system daily and collected samples from the treatment and distribution systems on a regular schedule throughout this reporting period. This performance evaluation would not have been possible without their efforts.
1.0 INTRODUCTION

1.1 Background

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

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

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the 17 host sites. EPA received 70 technical proposals for the 17 host sites, with each site receiving one to six proposals. In April 2003, an independent technical panel reviewed the proposals and provided its recommendations to EPA on the technologies that it determined were acceptable for the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration project. Using the information provided by the review panel, EPA, in cooperation with the host sites and the drinking-water programs of the respective states, selected one technical proposal for each site.

In 2003, EPA initiated Round 2 arsenic technology demonstration projects that were partially funded with Congressional add-on funding to the EPA budget. In June 2003, EPA selected 32 potential demonstration sites, and the community water system at Golden Hills Community Services District (GHCSD) in Tehachapi, 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. The final selection of the treatment technology at sites receiving at least one proposal was made, again through a joint effort of 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 October 2004, Magnesium Elektron, Inc.’s (MEI) Isolux™ arsenic treatment system was selected for demonstration at GHCSD in Tehachapi, CA.

As of November 2009, 39 of the 40 systems were operational, and the performance evaluation of 34 systems was complete.
1.2 Treatment Technologies for Arsenic Removal

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

1.3 Project Objectives

The purpose of the arsenic demonstration program is to conduct full-scale arsenic treatment technology demonstration studies on the removal of arsenic from drinking-water supplies at 40 sites. 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 Isolux™ arsenic treatment system at the GHCSD site in Tehachapi, CA, during the study period from October 25, 2005, through March 20, 2007. The types of data collected included 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 Rounds 1 and 2 Arsenic Removal Demonstration Locations, Technologies, and Source Water Quality

<table>
<thead>
<tr>
<th>Demonstration Location</th>
<th>Site Name</th>
<th>Technology (Media)</th>
<th>Vendor</th>
<th>Design Flowrate (gpm)</th>
<th>Source Water Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>As (µg/L) Fe (µg/L) pH (S.U.)</td>
</tr>
<tr>
<td><strong>Northeast/Ohio</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wales, ME</td>
<td>Springbrook Mobile Home Park</td>
<td>AM (A/I Complex)</td>
<td>ATS</td>
<td>14</td>
<td>38&lt;sup&gt;(a)&lt;/sup&gt; &lt;25 8.6</td>
</tr>
<tr>
<td>Bow, NH</td>
<td>White Rock Water Company</td>
<td>AM (G2)</td>
<td>ADI</td>
<td>70&lt;sup&gt;(b)&lt;/sup&gt;</td>
<td>39 &lt;25 7.7</td>
</tr>
<tr>
<td>Goffstown, NH</td>
<td>Orchard Highlands Subdivision</td>
<td>AM (E33)</td>
<td>AdEdge</td>
<td>10</td>
<td>33 &lt;25 6.9</td>
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<tr>
<td>Rollinsford, NH</td>
<td>Rollinsford Water and Sewer District</td>
<td>AM (E33)</td>
<td>AdEdge</td>
<td>100</td>
<td>36&lt;sup&gt;(c)&lt;/sup&gt; 46 8.2</td>
</tr>
<tr>
<td>Dummerston, VT</td>
<td>Charette Mobile Home Park</td>
<td>AM (A/I Complex)</td>
<td>ATS</td>
<td>22</td>
<td>30 &lt;25 7.9</td>
</tr>
<tr>
<td>Felton, DE</td>
<td>Town of Felton</td>
<td>C/F (Macrolite)</td>
<td>Kinetic</td>
<td>375</td>
<td>30&lt;sup&gt;(d)&lt;/sup&gt; 48 8.2</td>
</tr>
<tr>
<td>Stevensville, MD</td>
<td>Queen Anne’s County</td>
<td>AM (E33)</td>
<td>STS</td>
<td>300</td>
<td>19&lt;sup&gt;(e)&lt;/sup&gt; 270&lt;sup&gt;(f)&lt;/sup&gt; 7.3</td>
</tr>
<tr>
<td>Houghton, NY&lt;sup&gt;(g)&lt;/sup&gt;</td>
<td>Town of Canaedea</td>
<td>C/F (Macrolite)</td>
<td>Kinetic</td>
<td>550</td>
<td>27&lt;sup&gt;(g)&lt;/sup&gt; 1,806&lt;sup&gt;(h)&lt;/sup&gt; 7.6</td>
</tr>
<tr>
<td>Newark, OH</td>
<td>Buckeye Lake Head Start Building</td>
<td>AM (ARM 200)</td>
<td>Kinetico</td>
<td>10</td>
<td>15&lt;sup&gt;(i)&lt;/sup&gt; 1,312&lt;sup&gt;(j)&lt;/sup&gt; 7.6</td>
</tr>
<tr>
<td>Springfield, OH</td>
<td>Chateau Estates Mobile Home Park</td>
<td>AM (E33)</td>
<td>AdEdge</td>
<td>250&lt;sup&gt;(k)&lt;/sup&gt;</td>
<td>25&lt;sup&gt;(l)&lt;/sup&gt; 1,615&lt;sup&gt;(m)&lt;/sup&gt; 7.3</td>
</tr>
<tr>
<td><strong>Great Lakes/Interior Plains</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brown City, MI</td>
<td>City of Brown City</td>
<td>AM (E33)</td>
<td>STS</td>
<td>640</td>
<td>14&lt;sup&gt;(n)&lt;/sup&gt; 127&lt;sup&gt;(o)&lt;/sup&gt; 7.3</td>
</tr>
<tr>
<td>Pentwater, MI</td>
<td>Village of Pentwater</td>
<td>C/F (Macrolite)</td>
<td>Kinetico</td>
<td>400</td>
<td>13&lt;sup&gt;(p)&lt;/sup&gt; 466&lt;sup&gt;(q)&lt;/sup&gt; 6.9</td>
</tr>
<tr>
<td>Sandusky, MI</td>
<td>City of Sandusky</td>
<td>C/F (Aeralater)</td>
<td>Siemens</td>
<td>340&lt;sup&gt;(r)&lt;/sup&gt;</td>
<td>16&lt;sup&gt;(s)&lt;/sup&gt; 1,387&lt;sup&gt;(t)&lt;/sup&gt; 6.9</td>
</tr>
<tr>
<td>Delavan, WI</td>
<td>Vintage on the Ponds</td>
<td>C/F (Macrolite)</td>
<td>Kinetico</td>
<td>40</td>
<td>20&lt;sup&gt;(u)&lt;/sup&gt; 1,499&lt;sup&gt;(v)&lt;/sup&gt; 7.5</td>
</tr>
<tr>
<td>Greenvale, WI</td>
<td>Town of Greenville</td>
<td>C/F (Macrolite)</td>
<td>Kinetico</td>
<td>375</td>
<td>17 7827&lt;sup&gt;(w)&lt;/sup&gt; 7.3</td>
</tr>
<tr>
<td>Climax, MN</td>
<td>City of Climax</td>
<td>C/F (Macrolite)</td>
<td>Kinetico</td>
<td>140</td>
<td>39&lt;sup&gt;(x)&lt;/sup&gt; 546&lt;sup&gt;(y)&lt;/sup&gt; 7.4</td>
</tr>
<tr>
<td>Sabin, MN</td>
<td>City of Sabin</td>
<td>C/F (Macrolite)</td>
<td>Kinetico</td>
<td>250</td>
<td>34 1,470&lt;sup&gt;(z)&lt;/sup&gt; 7.3</td>
</tr>
<tr>
<td>Sauk Centre, MN</td>
<td>Big Sauk Lake Mobile Home Park</td>
<td>C/F (Macrolite)</td>
<td>Kinetico</td>
<td>20</td>
<td>25&lt;sup&gt;(aa)&lt;/sup&gt; 3,078&lt;sup&gt;(ab)&lt;/sup&gt; 7.1</td>
</tr>
<tr>
<td>Stewart, MN</td>
<td>City of Stewart</td>
<td>C/F &amp; AM (E33)</td>
<td>AdEdge</td>
<td>250</td>
<td>42&lt;sup&gt;(ac)&lt;/sup&gt; 1,344&lt;sup&gt;(ad)&lt;/sup&gt; 7.7</td>
</tr>
<tr>
<td>Lidgerwood, ND</td>
<td>City of Lidgerwood</td>
<td>Process Modification</td>
<td>Kinetico</td>
<td>250</td>
<td>146&lt;sup&gt;(ae)&lt;/sup&gt; 1,325&lt;sup&gt;(af)&lt;/sup&gt; 7.2</td>
</tr>
<tr>
<td><strong>Midwest/Southwest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arnaudville, LA</td>
<td>United Water Systems</td>
<td>C/F (Macrolite)</td>
<td>Kinetico</td>
<td>770&lt;sup&gt;(ag)&lt;/sup&gt;</td>
<td>32&lt;sup&gt;(ah)&lt;/sup&gt; 2,068&lt;sup&gt;(ai)&lt;/sup&gt; 7.0</td>
</tr>
<tr>
<td>Alvin, TX</td>
<td>Oak Manor Municipal Utility District</td>
<td>AM (E33)</td>
<td>STS</td>
<td>150</td>
<td>19&lt;sup&gt;(aj)&lt;/sup&gt; 95 7.8</td>
</tr>
<tr>
<td>Bruni, TX</td>
<td>Webb Consolidated Independent School District</td>
<td>AM (E33)</td>
<td>AdEdge</td>
<td>40</td>
<td>56&lt;sup&gt;(ak)&lt;/sup&gt; &lt;25 8.0</td>
</tr>
<tr>
<td>Wellman, TX</td>
<td>City of Wellman</td>
<td>AM (E33)</td>
<td>AdEdge</td>
<td>100</td>
<td>45 &lt;25 7.7</td>
</tr>
<tr>
<td>Anthony, NM</td>
<td>Desert Sands Mutual Domestic Water Consumers Association</td>
<td>AM (E33)</td>
<td>STS</td>
<td>320</td>
<td>23&lt;sup&gt;(al)&lt;/sup&gt; 39 7.7</td>
</tr>
<tr>
<td>Nambe Pueblo, NM</td>
<td>Nambe Pueblo Tribe</td>
<td>AM (E33)</td>
<td>AdEdge</td>
<td>145</td>
<td>33 &lt;25 8.5</td>
</tr>
<tr>
<td>Taos, NM</td>
<td>Town of Taos</td>
<td>AM (E33)</td>
<td>STS</td>
<td>450</td>
<td>14 59 9.5</td>
</tr>
<tr>
<td>Rimrock, AZ</td>
<td>Arizona Water Company</td>
<td>AM (E33)</td>
<td>AdEdge</td>
<td>90&lt;sup&gt;(am)&lt;/sup&gt;</td>
<td>50 170 7.2</td>
</tr>
<tr>
<td>Tohono O’odham Nation, AZ</td>
<td>Tohono O’odham Utility Authority</td>
<td>AM (E33)</td>
<td>Kinetico</td>
<td>50</td>
<td>32 &lt;25 8.2</td>
</tr>
<tr>
<td>Valley Vista, AZ</td>
<td>Arizona Water Company</td>
<td>AM (AAFS50/ARM 200)</td>
<td>Kinetico</td>
<td>37</td>
<td>41 &lt;25 7.8</td>
</tr>
<tr>
<td>Demonstration Location</td>
<td>Site Name</td>
<td>Technology (Media)</td>
<td>Vendor</td>
<td>Design Flowrate (gpm)</td>
<td>Source Water Quality</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------</td>
<td>--------------------</td>
<td>--------</td>
<td>-----------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td><strong>Far West</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three Forks, MT</td>
<td>City of Three Forks</td>
<td>C/F (Macrolite)</td>
<td>Kinetico</td>
<td>250</td>
<td>64</td>
</tr>
<tr>
<td>Fruitland, ID</td>
<td>City of Fruitland</td>
<td>IX (A300E)</td>
<td>Kinetico</td>
<td>250</td>
<td>44</td>
</tr>
<tr>
<td>Homedale, ID</td>
<td>Sunset Ranch Development</td>
<td>POU RO&lt;sup&gt;(f)&lt;/sup&gt;</td>
<td>Kinetico</td>
<td>75 gpd</td>
<td>52</td>
</tr>
<tr>
<td>Okanogan, WA</td>
<td>City of Okanogan</td>
<td>C/F (Electromedia-I)</td>
<td>Filtronics</td>
<td>750</td>
<td>18</td>
</tr>
<tr>
<td>Klamath Falls, OR</td>
<td>Oregon Institute of Technology</td>
<td>POE AM (Adsorbsia/ARM 200/ArсенX&lt;sup&gt;(g)&lt;/sup&gt;) and POU AM (ARM 200)&lt;sup&gt;(g)&lt;/sup&gt;</td>
<td>Kinetico</td>
<td>60/60/30</td>
<td>33</td>
</tr>
<tr>
<td>Vale, OR</td>
<td>City of Vale</td>
<td>IX (Arsenex II)</td>
<td>Kinetico</td>
<td>525</td>
<td>17</td>
</tr>
<tr>
<td>Reno, NV</td>
<td>South Truckee Meadows General Improvement District</td>
<td>AM (GFH/Kemiron)</td>
<td>Siemens</td>
<td>350</td>
<td>39</td>
</tr>
<tr>
<td>Susanville, CA</td>
<td>Richmond School District</td>
<td>AM (A/I Complex)</td>
<td>ATS</td>
<td>12</td>
<td>37&lt;sup&gt;(a)&lt;/sup&gt;</td>
</tr>
<tr>
<td>Lake Isabella, CA</td>
<td>Upper Bodfish Well CH2-A</td>
<td>AM (HIX)</td>
<td>VEEtech</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>Tehachapi, CA</td>
<td>Golden Hills Community Service District</td>
<td>AM (Isolux)</td>
<td>MEI</td>
<td>150</td>
<td>15</td>
</tr>
</tbody>
</table>

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 the program in June 2006.

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

(f) Including nine residential units.

(g) Including eight under-the-sink units.
2.0 SUMMARY AND CONCLUSIONS

MEI’s Isolux™ arsenic treatment system was installed at GHCSD in Tehachapi, CA, on October 21, 2005, and was put into service on October 25, 2005. Based on the information collected during the performance evaluation study, the following conclusions were drawn relating to the overall project objectives.

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

- The Isolux™-302M media was effective at removing arsenic from drinking water to below the 10 µg/L MCL. The Isolux™ system achieved useful run lengths of 61,600, 92,800, and 85,100 BV during Media Runs 1, 2, and 3, respectively; this is 12 to 41% lower than the vendor-projected run length of 105,000 BV.
- Accumulation of submicron particles on the media cartridges might have caused preferential flow through the media cartridges and the relatively short run length observed during Media Run 1.
- Most of the time, arsenic concentrations in the distribution system were much lower than those of the treatment system effluent, presumably due to blending of the treated water with untreated water from wells where arsenic was not a concern. Lead and copper did not appear to be impacted by the treatment system.

Simplicity of required system O&M and operator skill levels:

- Under normal operating conditions, the system required little attention from the operator. The daily demand for operator labor was approximately 30 min to inspect the system visually and record operational parameters.
- Daily operation of the system did not require additional skills beyond those necessary to operate the existing water-supply equipment. The system was operated by a State of California-certified operator who has Level 2 certifications for both treatment and distribution systems.

Process residuals produced by the technology:

- Residuals produced by the Isolux™ system included spent media cartridges only; backwash was not a system requirement. The spent Isolux™-302M media passed Toxicity Characteristic Leaching Procedure (TCLP) tests and therefore could be disposed of as a non-hazardous waste. However, MEI sent the spent media for beneficial reuse.

Cost-effectiveness of the technology:

- The capital investment cost for the 150-gpm system was $76,840, including $58,500 for equipment, $8,500 for engineering, and $9,840 for installation. This cost equated to $512/gpm (or $0.36/gpd), not including cost for the building.
- The unit capital cost was $0.09/1,000 gal if the system operates at a 100% utilization rate. The system actual unit cost was $0.21/1,000 gal of treated water, based on an average flowrate of 79.3 gpm and an average daily operating time of 19.6 hr/day. The labor cost for routine O&M activities was $0.14/1,000 gal of water treated.
3.0 MATERIALS AND METHODS

3.1 General Project Approach

Following the predemonstration activities summarized in Table 3-1, the performance evaluation study of the Isolux™ arsenic treatment system began on October 25, 2005, and ended on March 20, 2007. Table 3-2 summarizes the types of data collected and/or considered as part of the technology evaluation process. The overall system performance was evaluated based on its ability to consistently remove arsenic to below the target MCL of 10 µg/L for arsenic through the collection of water samples across the treatment train, as described in the Study Plan (Battelle, 2005). System reliability was evaluated by tracking the unscheduled system downtime and the frequency and extent of repair and replacement. The plant operator recorded the unscheduled downtime and repair information on a Repair and Maintenance Log Sheet.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introductory Meeting Held</td>
<td>October 13, 2004</td>
</tr>
<tr>
<td>Project Planning Meeting Held</td>
<td>April 12, 2005</td>
</tr>
<tr>
<td>Draft Letter of Understanding Issued</td>
<td>April 22, 2005</td>
</tr>
<tr>
<td>Final Letter of Understanding Issued</td>
<td>May 6, 2005</td>
</tr>
<tr>
<td>Request for Quotation Issued to Vendor</td>
<td>May 24, 2005</td>
</tr>
<tr>
<td>Vendor Quotation Submitted to Battelle</td>
<td>June 6, 2005</td>
</tr>
<tr>
<td>Purchase Order Completed and Signed</td>
<td>July 5, 2005</td>
</tr>
<tr>
<td>Engineering Package Submitted to CDPH</td>
<td>August 4, 2005</td>
</tr>
<tr>
<td>Final Study Plan Issued</td>
<td>September 23, 2005</td>
</tr>
<tr>
<td>Permit issued by CDPH</td>
<td>September 7, 2005</td>
</tr>
<tr>
<td>System Installation and Shakedown Completed</td>
<td>October 21, 2005</td>
</tr>
<tr>
<td>Performance Evaluation Began</td>
<td>October 26, 2005</td>
</tr>
</tbody>
</table>

CDPH = California Department of Health Services.

<table>
<thead>
<tr>
<th>Evaluation Objective</th>
<th>Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>-Ability to consistently meet 10 µg/L of arsenic in treated water</td>
</tr>
<tr>
<td>Reliability</td>
<td>-Unscheduled system downtime</td>
</tr>
<tr>
<td></td>
<td>-Frequency and extent of repairs, including a description of problems, materials and supplies needed, and associated labor and cost</td>
</tr>
<tr>
<td>System O&amp;M and</td>
<td>-Pre- and post-treatment requirements</td>
</tr>
<tr>
<td>Operator Skill</td>
<td>-Level of automation for system operation and data collection</td>
</tr>
<tr>
<td>Requirements</td>
<td>-Staffing requirements, including number of operators and laborers</td>
</tr>
<tr>
<td></td>
<td>-Task analysis of preventative maintenance, including number, frequency, and complexity of tasks</td>
</tr>
<tr>
<td></td>
<td>-Chemical handling and inventory requirements</td>
</tr>
<tr>
<td></td>
<td>-General knowledge needed for relevant chemical processes and for health and safety practices</td>
</tr>
<tr>
<td>Residual Management</td>
<td>-Quantity and characteristics of aqueous and solid residuals generated by system operation</td>
</tr>
<tr>
<td>System Cost</td>
<td>-Capital cost for equipment, engineering, and installation</td>
</tr>
<tr>
<td></td>
<td>-O&amp;M cost for chemical usage, electricity consumption, and labor</td>
</tr>
</tbody>
</table>
The system O&M and operator skill requirements were assessed through quantitative data and qualitative considerations, including the need for pre- and/or post-treatment; level of system automation; extent of 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 gal/min (gpm) (or gal/day [gpd]) of design capacity and the O&M cost per 1,000 gal of water treated. This task required tracking the capital cost for equipment, engineering, and installation, as well as the O&M cost for media replacement and disposal, chemical supply, electricity usage, and labor.

3.2 System O&M and Cost Data Collection

The plant operator performed daily, weekly, and monthly system O&M and data collection according to instructions provided by MEI and Battelle. Each day, the plant operator recorded system operational data, such as pressure, flowrate, totalizer, and hour meter readings (see Appendix A) on a Daily System Operation Log Sheet, and also conducted visual inspections to ensure normal system operations. If any problem occurred, the plant operator contacted the Battelle Study Lead, who determined if the vendor should be contacted for troubleshooting. The plant operator recorded on the Repair and Maintenance Log Sheet all relevant information, including the problem encountered, course of action taken, materials and supplies used, and associated cost and labor incurred. Each week, the plant operator measured several water quality parameters onsite, including temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and residual chlorine, and recorded the data on a Weekly Onsite Water Quality Parameters Log Sheet.

The capital cost for the Isolux™ system consisted of cost for equipment, site engineering, and system installation. The O&M cost consisted primarily of the cost for the media replacement and spent media disposal, electricity, and labor. Electricity consumption was determined using a kilowatt hour meter. Labor for various activities, such as routine system O&M, troubleshooting, repairs, and demonstration-related work, were tracked using an Operator Labor Hour Log Sheet. Routine O&M included activities such as completing field logs, ordering supplies, performing system inspections, and others as recommended by the equipment vendor. Labor was recorded for demonstration-related work, including activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead and the vendor, but was not used for the cost analysis.

3.3 Sample Collection Procedures and Schedules

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

3.3.1 Source Water. During the initial site visit on October 13, 2004, one set of source water samples was collected and speciated using an arsenic speciation kit (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.
Table 3-3. Sampling and Analysis Schedule for GHCSD Site

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Sample Locations(^{(a)})</th>
<th>No. of Samples</th>
<th>Frequency</th>
<th>Analytes</th>
<th>Sampling Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Water</td>
<td>IN</td>
<td>1</td>
<td>Once during initial site visit</td>
<td>Onsite: pH, temperature, DO, and ORP Offsite: As(III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, Cl, F, NO₂, NO₃, NH₃, SO₄, SiO₂, PO₄, TDS, TOC, turbidity, and alkalinity</td>
<td>10/13/04</td>
</tr>
<tr>
<td>Treatment Plant Water</td>
<td>IN, AC, MA, and MB</td>
<td>4</td>
<td>Second, third, and fourth weeks of each 4-week cycle (regular sampling)</td>
<td>Onsite: pH, temperature, DO, ORP, and Cl₂ (total)(^{(b)}) Offsite: As (total), Fe (total), Mn (total), Zr (total), Ca, Mg, SiO₂, P, turbidity, and alkalinity</td>
<td>See Appendix B</td>
</tr>
<tr>
<td></td>
<td>IN, AC, and TM</td>
<td>3</td>
<td>First week of each 4-week cycle (speciation sampling)</td>
<td>Onsite: pH, temperature, DO, ORP, and Cl₂ (total)(^{(b)}) Offsite: As(III), As (V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), Zr (total and soluble), Ca, Mg, F, NO₃, SO₄, SiO₂, P, turbidity, and alkalinity.</td>
<td>See Appendix B</td>
</tr>
<tr>
<td>Distribution System Water</td>
<td>DS1, DS2, and DS 3</td>
<td>3</td>
<td>Monthly(^{(c)})</td>
<td>As (total), Fe (total), Mn (total), Pb, Cu, pH, and alkalinity</td>
<td>See Table 4-7</td>
</tr>
</tbody>
</table>

(a) Abbreviations corresponding to sample locations shown in Figure 3-1.
(b) Total chlorine residual analyzed at MB or TM beginning on July 5, 2006.
(c) Four baseline sampling events performed from July to August 2005 before the system became operational.

IN = at wellhead; AC = after chlorination; MA = after Module A; MB = after Module B; TM = after Modules A and B combined.
DS1 to 3 = distribution system sampling location 1 to 3.
DO = dissolved oxygen; ORP = oxidation-reduction potential; TDS = total dissolved solids; TOC = total organic carbon.
INFLUENT
(WELL C)

1st Week of 4-Week Cycle

pH(a), temperature(a), DO/ORP(a),
As speciation, Fe (total and soluble),
Mn (total and soluble), Zr (total and soluble),
Ca, Mg, F, NO₃, SO₄, SiO₂, P,
turbidity, and alkalinity

Chlorination
Point

IN

2nd, 3rd, and 4th Week of 4-Week Cycle

pH(a), temperature(a), DO/ORP(a),
As (total), Fe (total), Mn (total),
Zr (total), Ca, Mg, SiO₂, P,
turbidity, and alkalinity

AC

INFLUENT
 Unit Process

BOOSTER PUMP

MODULE A

BAG FILTER

VESSEL
A-1

VESSEL
A-2

BOOSTER PUMP

MODULE B

BAG FILTER

VESSEL
B-1

VESSEL
B-2

DISTRIBUTION SYSTEM

LEGEND

IN

After Chlorination

AC

Module A Effluent

MA

Module B Effluent

MB

Total Combined Effluent

INFLUENT

Unit Process

Process Flow

pH(a), temperature(a), DO/ORP(a),
As speciation, Fe (total and soluble),
Mn (total and soluble), Zr (total and soluble),
Ca, Mg, F, NO₃, SO₄, SiO₂, P,
turbidity, and alkalinity.

TM

Tehachapi, CA

ISOLUX™ Arsenic Removal System
Design Flow: 150 gpm

Footnote
(a) On-site analyses

Figure 3-1. Process Flow Diagram and Sampling Schedule and Locations
3.3.2 Treatment Plant Water. During the system performance evaluation study, water samples were collected weekly, on a 4-week cycle, for onsite and offsite analyses. For the first week of each 4-week cycle, samples taken at the wellhead (IN), after chlorination (AC), and after Modules A and B combined (TM), were speciated onsite and analyzed for the analytes listed in Table 3-3 under speciation sampling. For the next three weeks, samples were collected at IN, AC, after Module A (MA), and after Module B (MB) and analyzed for the analytes listed in Table 3-3 under regular sampling. Speciation was discontinued on October 10, 2006, and since then, samples were collected weekly from IN, AC, MA, and MB and were analyzed only for total arsenic.

3.3.3 Distribution System Water. Samples were collected from the distribution system to determine any impacts of the Isolux™ arsenic treatment system on the water chemistry in the distribution system, specifically arsenic, lead, and copper levels. From July to August 2005, prior to the startup of the treatment system, four baseline distribution sampling events were conducted at three locations in the distribution system. Following system startup, distribution system sampling continued on a monthly basis at the same three locations for nine occasions.

Three residences were selected for distribution water sampling, including one each on San Lucas (“DS1”), Tiffany Circle (“DS2”), and Early Dawn Court (“DS3”). Only one residence (DS1) was part of the historic Lead and Copper Rule (LCR) sampling network serviced by the treatment well. Figure 3-2 is a distribution map showing the three sampling locations. The homeowners of the residences collected samples following an instruction sheet developed according to the Lead and Copper Monitoring and Reporting Guidance for Public Water Systems (EPA, 2002). The dates and times of last water usage before sampling and sample collection were recorded for calculations 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.

3.3.4 Residual Solids. The Isolux™ system did not require backwash; therefore, only spent media were collected for residual solid analysis. Nine spent media cartridges from the first media run (from October 26, 2005, to January 17, 2006) were shipped to Battelle on April 13, 2006. Of the nine spent media cartridges, the outer membrane on one cartridge was opened to expose the media. Spent media was sampled across the annular space of the cartridge from (1) the outer surface (i.e., immediately under the porous outer member where water after chlorination entered the media bed); (2) the subsurface (immediately under the outer surface); (3) the middle; and (4) the inner portion (i.e., where water exited the media bed) of the cartridge. Metal analyses were conducted on air-dried and acid-digested samples. Meanwhile, MEI conducted its own TCLP, total threshold limit concentration (TTLC), and soluble threshold limit concentration (STLC) tests on the spent media and provided the results to Battelle.

3.4 Sampling Logistics

Sampling logistics, including arsenic speciation kit preparation, sample cooler preparation, and sample shipping and handling, are discussed below.

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

3.4.2 Preparation of Sampling Coolers. For each sampling event, a sample cooler was prepared with the appropriate number and type of sample bottles, disc filters, and/or speciation kits. All sample bottles were new and contained appropriate preservatives. Each sample bottle was affixed with a pre-
Figure 3-2. Water Distribution System at GHCSD
printed, colored-coded label consisting of the sample identification (ID), data 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, the sampling date, a two-letter
code for a specific sampling location, and a one-letter code designating the arsenic speciation bottle (if
necessary). The sampling locations at the treatment plant were color-coded for easy identification. The
labeled bottles were separated by sampling location, placed in Ziplock™ bags, and packed in the cooler.

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

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

Samples for metal analyses were stored 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 the Battelle ICP-MS Laboratory, 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 80-120%, and completeness of
80%). The quality assurance (QA) data associated with each analyte will be presented and evaluated in a
QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic
Demonstration Project.

The plant operator conducted field measurements of pH, temperature, DO, and ORP using a VWR
Symphony SP90MS handheld multimeter, which was calibrated for pH and DO prior to use following
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 VWR probe in the beaker until a stable value was
obtained.
4.0 RESULTS AND DISCUSSION

4.1 Facility Description

At an elevation of 3,973 ft above sea level, GHCSD is located immediately west of Tehachapi, CA, and has approximately 7,900 residents. Prior to the demonstration study, there were 13 active wells at GHCSD, but only Well C had elevated arsenic concentrations up to 20 µg/L. Figure 4-1 shows the Well C pump house, which is located near the southeast corner of the district, east of State Route 202.

Drilled in 1997, Well C was 10-in in diameter and 700 ft deep, with a pumping water level of 517 ft below ground surface (bgs) and a static water level of 258 ft bgs. The well was equipped with a 25-horsepower (hp) Grundfos pump rated for 145 gpm. The maximum flowrate of the well, however, was 100 gpm, yielding 81,462 and 71,687 gpd (on average) of water in 2003 and 2004, respectively. The well was controlled by a telemetry system based on time of day (shut off between 12 p.m. and 6 p.m.), level of water in storage tanks, or both. One 1,000,000- and one 500,000-gal storage tanks, located close to the Well C pump house and a dry van container that housed the new arsenic treatment system (Figure 4-2), were used to store water before it entered the distribution system. An existing chlorination system (Figure 4-3) provided a total chlorine residual of 1.25 mg/L (as Cl₂) in the distribution system.

![Well C Pump House](image)

Figure 4-1. Well C Pump House

4.1.1 Source Water Quality. Source water samples were collected from Well C on October 13, 2004, by a Battelle staff member who attended an introductory meeting for this project. Source water also was filtered for soluble arsenic, iron, manganese, uranium, and vanadium and was speciated for As(III) and As(V). In addition, pH, temperature, DO, and ORP were measured onsite using a WTW 340i meter. Table 4-1 presents the analytical results from the source water sampling event and compares them
Figure 4-2. Storage Tanks, Well C Pump House, and Dry Van Container

Figure 4-3. Pre-existing Chlorine Addition System
### Table 4-1. Quality of Well C Source Water and GHCSD Treated Water

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>CDPH Treated Water Data</th>
<th>CDPH Raw Water Data</th>
<th>Facility Raw Water Data&lt;sup&gt;(a)&lt;/sup&gt;</th>
<th>Battelle Raw Water Data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Date</strong></td>
<td></td>
<td>10/11/00</td>
<td>11/19/03</td>
<td>NA</td>
<td>10/13/04</td>
</tr>
<tr>
<td>pH</td>
<td>–</td>
<td>8.0</td>
<td>8.3</td>
<td>8.2</td>
<td>6.9&lt;sup&gt;(b)&lt;/sup&gt;</td>
</tr>
<tr>
<td>DO</td>
<td>mg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1.7</td>
</tr>
<tr>
<td>ORP</td>
<td>mV</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>4.9</td>
</tr>
<tr>
<td>Total Alkalinity (as CaCO&lt;sub&gt;3&lt;/sub&gt;)</td>
<td>mg/L</td>
<td>180</td>
<td>170</td>
<td>175, 180*</td>
<td>171</td>
</tr>
<tr>
<td>Hardness (as CaCO&lt;sub&gt;3&lt;/sub&gt;)</td>
<td>mg/L</td>
<td>183</td>
<td>158</td>
<td>183</td>
<td>179</td>
</tr>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>0.06</td>
<td>0.19</td>
<td>NA</td>
<td>0.2</td>
</tr>
<tr>
<td>TDS</td>
<td>mg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>292</td>
</tr>
<tr>
<td>TOC</td>
<td>mg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>&lt;0.7</td>
</tr>
<tr>
<td>Nitrate (as N)</td>
<td>mg/L</td>
<td>0.34</td>
<td>&lt; 0.44</td>
<td>NA</td>
<td>0.32</td>
</tr>
<tr>
<td>Nitrite (as N)</td>
<td>mg/L</td>
<td>&lt; 0.02</td>
<td>&lt; 0.02</td>
<td>NA</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Ammonia (as N)</td>
<td>mg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Chloride</td>
<td>mg/L</td>
<td>15</td>
<td>14, 15*</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
<td>Fluoride</td>
<td>mg/L</td>
<td>0.23</td>
<td>0.24</td>
<td>NA</td>
<td>0.2</td>
</tr>
<tr>
<td>Sulfate</td>
<td>mg/L</td>
<td>42</td>
<td>45</td>
<td>26, 50*</td>
<td>40.0</td>
</tr>
<tr>
<td>Silica (as SiO&lt;sub&gt;2&lt;/sub&gt;)</td>
<td>mg/L</td>
<td>NA</td>
<td>NA</td>
<td>28*</td>
<td>27.0</td>
</tr>
<tr>
<td>Orthophosphate (as OPO&lt;sub&gt;4&lt;/sub&gt;)</td>
<td>mg/L</td>
<td>NA</td>
<td>NA</td>
<td>&lt;0.065*</td>
<td>&lt;0.06</td>
</tr>
<tr>
<td>As (total)</td>
<td>µg/L</td>
<td>9</td>
<td>14</td>
<td>20, 14*</td>
<td>14.7</td>
</tr>
<tr>
<td>As (soluble)</td>
<td>µg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>13.0</td>
</tr>
<tr>
<td>As (particulate)</td>
<td>µg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1.7</td>
</tr>
<tr>
<td>As(III)</td>
<td>µg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>3.9</td>
</tr>
<tr>
<td>As(V)</td>
<td>µg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>9.2</td>
</tr>
<tr>
<td>Fe (total)</td>
<td>µg/L</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>153, 48*</td>
<td>&lt;25</td>
</tr>
<tr>
<td>Fe (soluble)</td>
<td>µg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>&lt;25</td>
</tr>
<tr>
<td>Mn (total)</td>
<td>µg/L</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>&lt;10, 5*</td>
<td>8.8</td>
</tr>
<tr>
<td>Mn (soluble)</td>
<td>µg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>5.0</td>
</tr>
<tr>
<td>U (total)</td>
<td>µg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>0.8</td>
</tr>
<tr>
<td>U (soluble)</td>
<td>µg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>0.9</td>
</tr>
<tr>
<td>V (total)</td>
<td>µg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2.5</td>
</tr>
<tr>
<td>V (soluble)</td>
<td>µg/L</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2.4</td>
</tr>
<tr>
<td>Na (soluble)</td>
<td>mg/L</td>
<td>29</td>
<td>30</td>
<td>24, 31*</td>
<td>34.8</td>
</tr>
<tr>
<td>Ca (total)</td>
<td>mg/L</td>
<td>52</td>
<td>45</td>
<td>53, 51*</td>
<td>52.3</td>
</tr>
<tr>
<td>Mg (total)</td>
<td>mg/L</td>
<td>13</td>
<td>11</td>
<td>13, 12*</td>
<td>11.8</td>
</tr>
</tbody>
</table>

<sup>(a)</sup> Provided by the facility to EPA for site selection.

<sup>(b)</sup> Data questionable.

CDPH = California Department of Public Health; DO = dissolved oxygen; NA = not available; NTU = nephelometric turbidity unit; ORP = oxidation-reduction potential; TDS = total dissolved solids; TOC = total organic carbon; * = EPA sample analysis

To those provided to EPA for site selection by the California Department of Public Health (CDPH) and the facility.

**Arsenic.** Total arsenic concentrations in source water ranged from 14 to 20 µg/L. Based on the October 13, 2004, speciation results, out of 14.7 µg/L of total arsenic, 13.0 µg/L existed in the soluble form. Of the soluble fraction, 9.2 µg/L existed as As(V) and 3.9 µg/L as As(III). As such, the majority of soluble...
arsenic can be removed directly by Isolux™-302M media without preoxidation. The presence of As(V) as the predominating arsenic species implies that Well C water is rather oxidizing. This is somewhat contradictory to the relatively low DO and ORP levels (i.e., 1.7 mg/L and 4.9 mV, respectively) measured during the October 13, 2004, sampling event. Care was used during the performance evaluation study to confirm that these, in fact, were the results of erroneous field measurements.

**Interfering Ions.** According to MEI, the presence of iron, manganese, phosphate, and silica in source water can potentially impact the performance of Isolux™-302M media. Total iron concentrations in source water ranged from <25 to 153 µg/L. Battelle and CDPH results were less than the respective method reporting limits of 25 and 50 µg/L, respectively. The EPA data was 48 µg/L, close to the Battelle and CDPH data. At 153 µg/L, the facility data was high. Manganese concentrations in raw water were <10 µg/L, and therefore should not impact Isolux™-302M media performance.

Orthophosphate concentrations were below the reporting limit of 0.06 mg/L. Silica levels ranged from 27 to 28 mg/L. Based on the data collected during the pilot study, MEI concluded that the presence of these competing ions did not adversely affect Isolux™-302M media performance.

**Other Water Quality Parameters.** pH values of raw water ranged from 8.2 to 8.3, which is at the high end of the operational range from 4.0 to 8.5, and could potentially impact Isolux™-302M media performance. Sulfate concentrations ranged from 26 to 50 mg/L; sodium from 24 to 34.8 mg/L; calcium from 45 to 53; and magnesium from 11 to 13 mg/L. Total alkalinity concentrations ranged from 170 to 180 mg/L (as CaCO₃); hardnness from 158 to 183 mg/L (as CaCO₃); chloride from 12 to 15 mg/L; and fluoride from 0.2 to 0.24 mg/L. The presence of these ions in source water was not expected to impede arsenic removal by Isolux™-302M media.

**4.1.2 Distribution System.** Prior to and during the performance evaluation study, the distribution system at GHCSD was supplied by 13 wells, of which two were used as stand-by wells and one was used only seasonally. The maximum water demand was 2,050,000 gpd, which usually occurred in July. Water from Well C was pumped first to the 1,000,000- and 500,000-gal storage tanks and then to the distribution system, while water from the other wells was pumped to the distribution system and then to the same storage tanks. The distribution system is composed primarily of polyvinyl chloride (PVC) and asbestos cement (AC) piping. Service lines within residences are mainly copper pipe. Under the U.S. EPA LCR, GHCSD collects samples from customer taps at 20 locations every 3 years. GHCSD also conducts bacterial analysis monthly at 10 specified locations and quarterly at the wellheads.

**4.2 Treatment Process Description**

The 150-gpm Isolux™ arsenic treatment system uses Isolux™-302M powder media developed by MEI for arsenic removal. Table 4-2 presents physical and chemical properties of the media, which has NSF Standard 61 approval for use in drinking-water applications.

The Isolux™ arsenic treatment system at GHCSD consisted of two parallel adsorption modules, each containing a booster pump, a flow regulator, a 1-µm bag filter, and two parallel carbon steel adsorption vessels. Each adsorption vessel contained nine replaceable media cartridges (Figure 4-4), or 36 for the entire system. The system was designed to treat approximately 150 gpm of flow, with 75 gpm by each module. Figure 4-5 is a schematic of MEI’s Isolux™ arsenic treatment system.

Chlorinated water was supplied to the two adsorption modules by a booster pump. As groundwater was pumped through the media cartridges, soluble arsenic was removed via adsorption, thus reducing total arsenic concentration to below the 10 µg/L MCL. A flow totalizer/meter was installed on the downstream end of each adsorption module to measure throughput and flowrate through each module.
Table 4-2. Properties of Isolux™-302M Media

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matrix</td>
<td>Hydrous zirconium oxide</td>
</tr>
<tr>
<td>Physical form</td>
<td>Amorphous powder</td>
</tr>
<tr>
<td>Color</td>
<td>White, bulky powder</td>
</tr>
<tr>
<td>Specific density</td>
<td>3.25</td>
</tr>
<tr>
<td>Bulk density (lb/ft³)</td>
<td>60</td>
</tr>
<tr>
<td>Particle size (micron)</td>
<td>1–3 to 40–50</td>
</tr>
<tr>
<td>Mesoporosity (Å)</td>
<td>20–40</td>
</tr>
<tr>
<td>BET surface area (m²/g)</td>
<td>300–350</td>
</tr>
<tr>
<td>Functional group</td>
<td>Zr-OH</td>
</tr>
<tr>
<td>Ion exchange capacity (meq/g)</td>
<td>8</td>
</tr>
<tr>
<td>Operational pH</td>
<td>4.0–8.5</td>
</tr>
</tbody>
</table>

Source: MEI

Pressure gauges located downstream of the well, flow control valve, bag filter, and adsorption module were used to monitor the system pressure and pressure drop across the treatment modules. The effluent of each module was combined and directed into the storage tanks. The system was instrumented with on/off valves and sample collection ports. The system was installed in an 8-ft × 40-ft enclosure.

Figure 4-4. Replaceable Isolux™-302M Media Cartridges (Provided by MEI)
Independent from this demonstration study, GHCSD hosted a pilot study on Isolux™-302M media from July 2003 to August 2004 at Well C. Figure 4-6 presents the pilot unit (in the wooden structure) and an Isolux™ media cartridge used for the pilot study. The initial testing used a 0.8-gpm, 10-in pilot unit equipped with a 5-µm particulate pre-filter, an activated carbon filter, an Isolux™ media cartridge (containing 1 lb of Isolux™-302M media), a flowmeter, and a flow totalizer. After operating for nearly 90
days and treating approximately 8,300 gal (or 66,578 bed volumes [BV]) of water, over 2 µg/L of arsenic were detected in the treated water. The pilot unit was then scaled up to a 10-gpm unit containing 22 lb of Isolux™-302M media. Operating at 8 gpm, the unit treated 254,887 gal (or 92,934 BV) of water from March 10 through April 3, 2004, prior to reaching 10 µg/L of arsenic breakthrough. A second adsorption run with the 10-gpm unit from July 17 through August 29, 2004, yielded slightly better performance results (i.e., 112,099 BVs) than the first run. Results of the pilot study indicated that:

- The Isolux™ arsenic treatment system could remove arsenic to below a detection limit of 2.0 µg/L. An elevated pH value of 8.2 and competing ions (including silica, phosphate, and iron) in the source water did not adversely affect the performance of Isolux™-302M media.
- Pre-treatment of Well C source water was not required.
- Spent Isolux™-302M media passed EPA TCLP and California whole effluent toxicity (WET) tests, so they could be disposed of as a non-hazardous waste.
- No backwash was required.

Table 4-3 summarizes the key system design parameters for the Isolux™ arsenic treatment system. The treatment system includes the following major process and system components:

- **Intake** – Raw water from Well C was chlorinated and fed to the Isolux™ arsenic treatment system. An hour meter was installed on the well pump to record the operation time.

- **Chlorination** – Prior to entering the system, water was injected with chlorine for disinfection purposes. A 12.5% sodium hypochlorite (NaClO) solution was stored in a 35-gal drum and injected by a solenoid-driven metering pump with a maximum capacity of 1.0 gal/hr (gph). Operation of the chlorine feed system was linked to the well pump such that chlorine was injected only when the well was operating. The system operator monitored chlorine consumption weekly by recording the chlorine levels in the chlorine supply tank and by measuring the volume of chlorine added to the tank. The target total chlorine residual was 1.25 mg/L (as Cl₂).

- **Isolux™ Adsorption** – Two Isolux™ adsorption modules arranged in parallel provided a total of 150-gpm treatment capacity. Figure 4-7 shows the treatment system installed at GHCSD. Each Isolux™ adsorption module contained the following elements:

  - **Booster Pump With Flow Regulator** – Use of two booster pumps with flow regulators (one per module) located prior to the adsorption vessels ensured adequate inlet pressure to the treatment system. Each EBARA Model CDU booster pump was constructed of 304L stainless steel, rated at 3 hp, and could provide a maximum flowrate of 95 gpm. The operation of the booster pumps was synchronized with the well pump so that they would turn on and off at the same time. During the performance evaluation study, operation of the booster pumps was found to be unnecessary.

  - **Bag Filter** – Each Isolux™ module contained a 1-µm bag filter. Source water flowed through the 1-µm bag-type particulate pre-filter to remove any sediment from the source water. The bag filters were changed periodically due to increased pressure readings.

  - **Media Vessel** – Each module contained two 20-in × 48-in media vessels, with each vessel containing nine Isolux™-302M media cartridges.
<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Value</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of modules</td>
<td>2</td>
<td>Arranged in parallel</td>
</tr>
<tr>
<td>Module size (in.)</td>
<td><strong>48 W × 48L × 60 H</strong></td>
<td></td>
</tr>
<tr>
<td>Module weight (lb)</td>
<td>1,500</td>
<td>As shipped (dry with no media)</td>
</tr>
<tr>
<td>Module weight (lb)</td>
<td>3,200</td>
<td>In operation</td>
</tr>
<tr>
<td>No. of vessels</td>
<td>4</td>
<td>Two vessels arranged in parallel per module; 100 psi-rated carbon steel with NSF-rated epoxy coating</td>
</tr>
<tr>
<td>Vessel size (in.)</td>
<td><strong>20 OD × 48 H</strong></td>
<td></td>
</tr>
<tr>
<td>No. of cartridges per vessel</td>
<td>9</td>
<td>36 cartridges total</td>
</tr>
<tr>
<td>Cartridge length (in)</td>
<td>42.25</td>
<td></td>
</tr>
<tr>
<td>Cartridge OD (in)</td>
<td>4.55</td>
<td></td>
</tr>
<tr>
<td>Cartridge ID (in)</td>
<td>4.35</td>
<td></td>
</tr>
<tr>
<td>Cartridge outer membrane nominal pore size (µm)</td>
<td>30</td>
<td>Constructed of polyethylene porous membrane</td>
</tr>
<tr>
<td>Cartridge inner membrane nominal pore size (µm)</td>
<td>10</td>
<td>Constructed of polyethylene porous membrane</td>
</tr>
<tr>
<td>Cartridge outer membrane thickness (in)</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Cartridge inner membrane thickness (in)</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>Cartridge weight (lb)</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Type of media used</td>
<td>Isolux™-302M</td>
<td>Particle size of 20–40 µm</td>
</tr>
<tr>
<td>Quantity of media per vessel (ft³)</td>
<td>2.88</td>
<td>Each cartridge contained 0.32 ft³; two modules each contained 5.7 ft³; total was 11.4 ft³</td>
</tr>
<tr>
<td>Internal piping</td>
<td>2-in schedule 40 PVC glued</td>
<td></td>
</tr>
<tr>
<td>Inlet and outlet connections</td>
<td>1.5-in PVC female national pipe thread</td>
<td></td>
</tr>
<tr>
<td>Backwashing requirements</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Inlet pressure (psi)</td>
<td>80</td>
<td>Into vessels</td>
</tr>
<tr>
<td>Outlet pressure (psi)</td>
<td>45</td>
<td>Outlet from vessels</td>
</tr>
<tr>
<td>Pressure drop (psi)</td>
<td>&lt;30</td>
<td>Across vessels</td>
</tr>
<tr>
<td>Area of contact (ft²)</td>
<td>4.1</td>
<td>Per cartridge</td>
</tr>
<tr>
<td>Hydraulic loading rate (gpm/ft²)</td>
<td>1.0</td>
<td>Per cartridge</td>
</tr>
<tr>
<td>Estimated bed contact time (min)</td>
<td>0.5</td>
<td>Per cartridge</td>
</tr>
<tr>
<td>Peak flowrate (gpm)</td>
<td>150</td>
<td>Maximum flowrate of system</td>
</tr>
<tr>
<td>Average daily throughput to system (gpd)</td>
<td>100,000</td>
<td>Estimate provided by GHCSD</td>
</tr>
<tr>
<td>Estimated working capacity (BV)</td>
<td>105,000</td>
<td>Bed volumes to 10 µg/L arsenic breakthrough</td>
</tr>
<tr>
<td>Estimated volume to breakthrough (gal)</td>
<td>8,950,000</td>
<td>1 BV = 11.4 ft³ = 85.3 gal</td>
</tr>
<tr>
<td>Estimated media life (months)</td>
<td>3</td>
<td>Estimated frequency of media cartridge changeout based on average throughput of 100,000 gpd</td>
</tr>
<tr>
<td>No. of BV/day</td>
<td>1,200</td>
<td>Based on estimated working capacity versus estimated media life</td>
</tr>
</tbody>
</table>
Isolux™ Media Cartridges – Each media cartridge was 4.5-in in diameter by 42-in in height and contained approximately 0.32 ft³ of Isolux™-302M media. The total amount of media in each module was 5.7 ft³, providing about 0.5 min of contact time at the specified flowrate of 75 gpm. The media are sandwiched between two thin layers of tubular membranes constructed of porous polyethylene (PE). The outer membrane measured 4.55 in diameter by 42.25 in length and had a nominal pore size of 30 µm. The inner membrane measured 1.60 in diameter by 42.25 in length and had a nominal pore size of 10 µm. The upper end of the cartridge was completely sealed with a PE end-cap; the lower end also was sealed with a PE end-cap but with a discharge tube. Untreated water entered the vessel and passed through the porous outer membrane, coming into contact with the media within the annular space of the cartridge. After contacting the media, the water flowed through the porous inner membrane and into the hollow center portion of the cartridge before flowing downward in the lower (discharge) portion of the vessel. Figure 4-8 presents a schematic of an assembled Isolux™-302M media cartridge.

Media Cartridge Replacement – When the capacity of the media cartridges in the vessels was exhausted, the operator replaced the spent media cartridges with virgin ones. Cartridges for both modules were replaced at the same time. Thus, 36 cartridges were needed for complete replacement. One module was completely serviced before service on the second module began. The spent media cartridges were stored at the facility until enough cartridges accumulated to facilitate efficient shipment to MEI.
• **Storage Tanks** – Treated water from Well C was stored in the 1,000,000- and 500,000-gal storage tanks before it entered the distribution system.

### 4.3 Treatment System Installation

#### 4.3.1 System Permitting

The permit application for the Isolux™ 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 Isolux™ system would not require backwashing and that any spent media cartridges would be returned to MEI for disposal.

The submittal for the permit application included a schematic of MEI’s Isolux™ arsenic treatment system, a written description of the system, and an O&M manual. After the vendor incorporated review comments from GHCSD and Battelle, the submittal package was sent to CDPH for review on August 4, 2005. CDPH provided Approval-to-Construct on September 7, 2005.

According to CDPH, upon completion of the EPA demonstration study, GHCSD must secure a permanent permit if it plans to keep the Isolux™ system and continue its operation. GHCSD must also comply with the California Environmental Quality Act (CEQA) requirements as part of the permitting process. A regular water supply permit application takes 30 days for initial completeness review by CDPH. Once the application has been determined complete, it normally takes 90 days to issue a final permit document.
4.3.2 Building Construction. GHCSD installed the Isolux™ system in a steel, dry, van container. Required building preparation included grading of the ground, installation of floor drains, interconnection of the piping, and provision of an electrical supply. Distributed by On Site Storage Solutions, the container was 8 ft wide, 40 ft long, and 8 ft high (Figure 4-9). The cost of the container was approximately $4,218, including delivery.

4.3.3 Installation, Shakedown, and Startup. The Isolux™ arsenic treatment system was delivered to the site on September 16, 2005. The staff of GHCSD performed the off-loading and installation under the supervision of MEI's local engineer. Installation included piping connections to the existing entry and distribution system. System installation was completed on October 21, 2005.

![Figure 4-9. Isolux™ Treatment System Enclosure (Storage Tank in Background)](image)

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters for the performance evaluation study were tabulated and are attached as Appendix A. Key parameters for each media run are summarized in Table 4-4. Media Run 1 began on October 26, 2005, and ended on January 17, 2006, after the arsenic concentration in the system effluent had reached that of system influent. The well was producing a significant amount of sediment/particulate matter, making it necessary to replace the bag filters rather frequently (see Section 4.5.3). Accumulation of well sediment caused a rapid increase in differential pressure (Δp) across the bag filters.

A video log on Well C was conducted by Bakersfield Well and Pump Company on February 13, 2006, to determine if any corrective actions would be necessary. The result revealed rusty areas on the drop-pipe, which prompted GHCSD’s decision to rehabilitate the well. From March 7 to 8, 2006, Bakersfield Well and Pump Company performed well rehabilitation, which included (1) pulling the submersible pump and
drop-pipe, (2) wire-brushing and bailing the well casing, and (3) installing 651 ft of new 3-in galvanized-steel drop-pipe and a new 25-hp Franklin submersible pump rated at 120 gpm. GHCSD also installed a wire strainer upstream of the system to further reduce the amount of sediment/particulate matter to the system. Once the well was rehabilitated and the media cartridges were replaced, Media Run 2 began on April 27, 2006. The treatment system produced water below the arsenic MCL until August 8, 2006, whereupon arrangements were made to replace the media cartridges, again in both modules. Media Run 3 began on August 17, 2006, and continued through March 20, 2007, which concluded the performance evaluation study.

<table>
<thead>
<tr>
<th>Operational Parameter</th>
<th>Media Run 1</th>
<th>Media Run 2</th>
<th>Media Run 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (a)</td>
<td>10/26/05–01/17/06</td>
<td>04/27/06–08/15/06</td>
<td>08/17/06–03/20/07</td>
</tr>
<tr>
<td>Module</td>
<td>A / B</td>
<td>A / B</td>
<td>A / B</td>
</tr>
<tr>
<td>Total operating time (hr)</td>
<td>1,377</td>
<td>1,377</td>
<td>1,900</td>
</tr>
<tr>
<td>No. of days in operation (day)</td>
<td>63</td>
<td>63</td>
<td>94</td>
</tr>
<tr>
<td>Average daily operating time (hr/day) (b)</td>
<td>21.9</td>
<td>21.9</td>
<td>20.2</td>
</tr>
<tr>
<td>Throughput to 10µg/L As breakthrough (gal)</td>
<td>2,676,700</td>
<td>2,579,100</td>
<td>3,903,400</td>
</tr>
<tr>
<td>Throughput to 10µg/L As breakthrough (BV)(c)</td>
<td>62,760</td>
<td>60,470</td>
<td>91,520</td>
</tr>
<tr>
<td>Range of/average EBCT (min)</td>
<td>0.72–1.4/0.72–1.6</td>
<td>0.75–1.9/0.75–1.6</td>
<td>0.62–2.1/0.62–2.1</td>
</tr>
<tr>
<td>Range of/average Δp across module (psi)</td>
<td>12–26/17</td>
<td>8–26/16</td>
<td>2–18/11</td>
</tr>
<tr>
<td>Range of/average Δp across bag filter (psi)</td>
<td>0–38/6</td>
<td>0–40/7</td>
<td>0–53/8</td>
</tr>
<tr>
<td>Range of/average daily flowrate (gpm)(f)</td>
<td>70–97/94</td>
<td>NA/NA</td>
<td>55–142/81</td>
</tr>
<tr>
<td>Cumulative throughput to 10µg/L As breakthrough (gal)(g)</td>
<td>5,255,800</td>
<td>7,915,800</td>
<td>7,256,800</td>
</tr>
<tr>
<td>Media run length to 10µg/L As breakthrough (BV)(h)</td>
<td>61,600</td>
<td>92,800</td>
<td>85,100</td>
</tr>
</tbody>
</table>

NA=not available.

(a) System shutdown from January 18 through April 26, 2006, due to well rehabilitation activities.
(b) Calculated based on total operating time and number of days in operation.
(c) Calculated based on throughput from individual totalizer and 5.7 ft³ (or 42.65 gal) of media in each module.
(d) Instantaneous flowrate readings from individual flow meters.
(e) Combined instantaneous flowrate readings from both modules.
(f) Calculated by dividing incremental wellhead volume readings by corresponding operating times.
(g) Breakthrough when average arsenic concentration from both modules exceeded 10 µg/L.
(h) Calculated based on throughput from individual totalizers and 11.4 ft³ (or 85.3 gal) of media in both modules combined.

The Isolux™ treatment system operated for 1,377, 1,900, and 1,422 hr during Media Runs 1, 2, and 3, respectively, based on the system throughput and average instantaneous flowrate from both modules.
combined. During Media Runs 1 and 2, from October 26, 2005, through August 15, 2006 (except when the system was shut down for well rehabilitation), the system operated daily (with some weekends); average operating times were 21.9 and 20.2 hr/day, respectively. Due to seasonal fluctuation in water demand, the system only operated periodically during Media Run 3, with an average operating time of 16.7 hr/day.

During the performance evaluation study, the system throughput values at 10 µg/L arsenic breakthrough in the combined effluent of both modules were 5,255,800 gal (or 61,600 BV), 7,915,800 gal (or 92,800 BV), and 7,256,800 (or 85,100 BV) during Media Runs 1, 2, and 3, respectively. The BV for the system was calculated based on a total of 11.4 ft³ (or 85.3 gal) of media in both modules, while the BV for each module was based on 5.7 ft³ (or 42.65 gal) of media in each module. The total flow processed through the system was based on the sum of the throughput values through each of the two modules measured, with individual totalizers installed on the modules. Individually, the number of BV processed through each module during each media run was slightly different. During Media Runs 1, 2, and 3, Module A processed 62,760, 91,520, and 91,100 BV, or 4%, 6%, and 20% more water than Module B, respectively. This indicated an imbalanced flow between Modules A and B.

Figure 4-10 compares instantaneous flowrates through Module A, Module B, combined instantaneous flowrates, and average flowrates at the wellhead (when the hour meter was functioning correctly). The average flowrates at the wellhead were calculated by dividing incremental volume readings that the wellhead totalizer recorded by the corresponding operating times recorded by the hour meter. Due to lack of equipment and/or equipment failure, hour meter readings used to calculate the average flowrates were available only from December 8, 2005, through January 17, 2006, and from December 26, 2006, through March 20, 2007. The flowrates through each module recorded by the individual flow meters/totalizers

![Figure 4-10. Isolux™ Treatment System Daily Flowrates](image-url)
installed on the adsorption modules varied significantly, ranging from 17 to 71 gpm through Module A and from 20 to 69 gpm through Module B. The average flowrate for all media runs was 42 and was 38 gpm for Modules A and B, respectively. The average flowrate through Module A was 10% higher than that through Module B, again indicating imbalanced flow. Flowrates calculated based on the totalizer at the wellhead averaged 94 and 81 gpm for Media Runs 1 and 3, respectively, which was approximately 19% higher than the 79 gpm measured by individual flow meters during Media Run 1 and 4.7% lower than the 85 gpm measured by individual flow meters during Media Run 3, respectively. Based on the respective average flowrates, the average EBCTs in Modules A and B were 1.0 and 1.1 min, respectively, which were 100% and 120% higher than the design value of 0.5 min as shown in Table 4-3.

Figure 4-11 presents measured pressure readings across the Isolux™ Treatment System. The pressure readings prior to the bag filter at each module varied significantly due to the accumulation of particulate/sediment matter in the bag filter and periodic replacement of the bag filter. Prior to the bag filter, pressure readings ranged from 14 to 106 psi. Inlet or after bag-filter pressure readings varied somewhat, ranging from 11 to 46 psi; outlet pressures remained relatively constant, ranging from 8 to 17 psi.

Figures 4-12 and 4-13, respectively, presents differential pressure (Δp) readings across bag filters and across Modules A and B. Δp readings across the bag filters varied significantly, ranging from 0 to 84 psi. The variation in Δp readings was due mainly to the accumulation of particulates in the bag filter and replacement of the bag filters. The Δp readings across Modules A and B also varied significantly, ranging from 2 to 26 psi and averaging 13 and 14 psi, respectively. The variance in Δp readings across the modules most likely was caused by the significant variation in instantaneous flowrate readings. As shown in Figure 4-14, there is a direct relationship between Δp across Modules A and B and the instantaneous flowrate readings.

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

Pre- and Post-Treatment Requirements. The majority of arsenic in raw water existed as As(V). As such, a pre-oxidation step was not required. However, the facility has a pre-chlorination system in place for disinfectant purposes. The only pre-treatment required was the use of 1-µm bag filters to remove sediments/particulate matter from raw water.

System Automation. All major functions of the treatment system were automated and would require only minimal operator oversight and intervention if all functions were operating as intended. The operator controlled the system operation manually. Once the treated water in the storage tanks reached a determined level, the high-level alarm was triggered, notifying the operator to shut down the system.

Operator Skill Requirements. Under normal operating conditions, the skill requirements to operate the system were minimal. The operator was typically onsite five times per week and spent approximately 30 min each day performing visual inspections and recording system operating parameters on the daily log sheets. The operator replaced the bag filter periodically. Normal operation 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 possess a water treatment operator certificate. The state also requires those who make decisions on maintenance and operation of any portion of the distribution system possess a
Figure 4-11. Pressure Readings Across Bag Filter and Module A (top) and Bag Filter and Module B (bottom)
System shutdown due to well rehabilitation activities

Figure 4-12. Differential Pressure Readings Across Bag Filters

Figure 4-13. Differential Pressure Readings Across Modules A and B
distribution operator certificate (CDPH, 2001). Operator certifications are granted by CDPH after minimum requirements are met; these include passing an examination and maintaining a minimum number 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 of the Isolux™ system possessed T2 and D2 certifications for treatment and distribution, respectively.

Preventive Maintenance Activities. Preventive maintenance tasks included items such as periodic checks of flowmeters and pressure gauges and inspection of system piping and valves. The vendor recommended replacing the bag filters once it was necessary to replace the media cartridges; however, the operator had to replace the bag filters periodically due to increased differential pressure readings.

Chemical/Media Handling and Inventory Requirements. After installation of the Isolux™ treatment system, chlorine addition continued at the GHCSD site. Inventory requirements for chlorine addition remained the same as before. To facilitate change-out when needed, the only onsite inventory requirements associated with the Isolux™ system were bag filters and media cartridges.

4.5 System Performance

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

4.5.1 Treatment Plant Sampling. The treatment plant water was sampled on 54 occasions (including one duplicate sampling), with field speciation performed 11 times. Table 4-5 summarizes the analytical results for arsenic, iron, manganese, and zirconium.
Table 4-5. Summary of Analytical Results for Arsenic, Iron, Manganese, and Zirconium

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sampling Location</th>
<th>Unit</th>
<th>Count</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
<th>Standard Deviation</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>As (total)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN - R1</td>
<td>µg/L</td>
<td></td>
<td>9</td>
<td>11.4</td>
<td>14.0</td>
<td>12.7</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>IN - R2</td>
<td>µg/L</td>
<td></td>
<td>16</td>
<td>10.0</td>
<td>14.4</td>
<td>11.5</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>IN - R3</td>
<td>µg/L</td>
<td></td>
<td>29</td>
<td>9.8</td>
<td>16.9</td>
<td>12.3</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>AC - R1</td>
<td>µg/L</td>
<td></td>
<td>9</td>
<td>11.5</td>
<td>13.9</td>
<td>12.5</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>AC - R2</td>
<td>µg/L</td>
<td></td>
<td>16</td>
<td>10.0</td>
<td>12.8</td>
<td>11.3</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>AC - R3</td>
<td>µg/L</td>
<td></td>
<td>29</td>
<td>10.4</td>
<td>16.1</td>
<td>12.1</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>MA - R1</td>
<td>µg/L</td>
<td></td>
<td>5</td>
<td>0.3</td>
<td>12.4</td>
<td>2(0)</td>
<td>2(0)</td>
<td></td>
</tr>
<tr>
<td>MA - R2</td>
<td>µg/L</td>
<td></td>
<td>11</td>
<td>5.2</td>
<td>9.3</td>
<td>2(0)</td>
<td>2(0)</td>
<td></td>
</tr>
<tr>
<td>MA - R3</td>
<td>µg/L</td>
<td></td>
<td>27</td>
<td>5.0</td>
<td>11.1</td>
<td>2(0)</td>
<td>2(0)</td>
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<tr>
<td>MB - R1</td>
<td>µg/L</td>
<td></td>
<td>5</td>
<td>0.4</td>
<td>11.9</td>
<td>2(0)</td>
<td>2(0)</td>
<td></td>
</tr>
<tr>
<td>MB - R2</td>
<td>µg/L</td>
<td></td>
<td>11</td>
<td>3.0</td>
<td>12.2</td>
<td>2(0)</td>
<td>2(0)</td>
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<tr>
<td>MB - R3</td>
<td>µg/L</td>
<td></td>
<td>27</td>
<td>0.4</td>
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<td>2(0)</td>
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<tr>
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<td>4</td>
<td>0.4</td>
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<td>TM - R2</td>
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</tr>
<tr>
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<td></td>
<td>4</td>
<td>11.1</td>
<td>13.9</td>
<td>12.5</td>
<td>1.3</td>
<td></td>
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<td>11.9</td>
<td>1.6</td>
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<tr>
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<td>11.7</td>
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<td>11.7</td>
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<td>11.4</td>
<td>12.0</td>
<td>11.7</td>
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<tr>
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<td></td>
<td>4</td>
<td>0.4</td>
<td>13.1</td>
<td>2(0)</td>
<td>2(0)</td>
<td></td>
</tr>
<tr>
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<td></td>
<td>5</td>
<td>1.3</td>
<td>10.5</td>
<td>2(0)</td>
<td>2(0)</td>
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<tr>
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<td></td>
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<td></td>
</tr>
<tr>
<td>IN - R1</td>
<td>µg/L</td>
<td></td>
<td>4</td>
<td>&lt;0.1</td>
<td>0.99</td>
<td>0.49</td>
<td>0.5</td>
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</tr>
<tr>
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<td>0.24</td>
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<tr>
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<td></td>
<td>2</td>
<td>&lt;0.1</td>
<td>1.7</td>
<td>1.1</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>AC - R1</td>
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<td>&lt;0.1</td>
<td>0.31</td>
<td>0.15</td>
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</tr>
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<td></td>
<td>5</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>-</td>
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<tr>
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<td></td>
<td>2</td>
<td>0.26</td>
<td>0.78</td>
<td>0.52</td>
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</tr>
<tr>
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<td>&lt;0.1</td>
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</tr>
<tr>
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<td>&lt;0.1</td>
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<td>1.6</td>
<td>0.61</td>
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<td>Maximum</td>
<td>Average</td>
<td>Standard Deviation <em>(a)</em></td>
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<tr>
<td>Mn (soluble)</td>
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Table 4-5. Summary of Analytical Results for Arsenic, Iron, Manganese, and Zirconium (Continued)

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<th>Unit</th>
<th>Count</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
<th>Standard Deviation (a)</th>
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<td>0.53</td>
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<tr>
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<tr>
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<tr>
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<td>&lt;0.1</td>
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<tr>
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<td>µg/L</td>
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<td>&lt;0.1</td>
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<tr>
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<td>&lt;0.1</td>
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<tr>
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<td>µg/L</td>
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<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
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<tr>
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<td>MA - R2</td>
<td>µg/L</td>
<td>11</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
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<tr>
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<td>MA - R3</td>
<td>µg/L</td>
<td>5</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
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</tr>
<tr>
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<td>MB - R1</td>
<td>µg/L</td>
<td>5</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
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</tr>
<tr>
<td></td>
<td>MB - R2</td>
<td>µg/L</td>
<td>11</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
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<tr>
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<td>MB - R3</td>
<td>µg/L</td>
<td>5</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
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<tr>
<td></td>
<td>TM - R1</td>
<td>µg/L</td>
<td>4</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>-</td>
</tr>
<tr>
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<td>TM - R2</td>
<td>µg/L</td>
<td>5</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
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</tr>
<tr>
<td></td>
<td>TM - R3</td>
<td>µg/L</td>
<td>2</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>-</td>
</tr>
</tbody>
</table>

(a) Standard deviation for parameters that were non-detect for all samples or had <3 sample counts are not meaningful and therefore are not presented.

(b) Statistics not meaningful; see arsenic breakthrough curves at MA, MB, and TM locations in Figure 4-16.

See Appendix B for complete analytical results.

One-half of the detection limit was used for non-detect results, duplicate samples were included for calculations.

R1 = Media Run 1; R2 = Media Run 2; R3 = Media Run 3.

Table 4-6 summarizes the results of other water quality parameters. Appendix B contains a complete set of analytical results for the study. Results of the water samples collected throughout the treatment plant are discussed below.

**Arsenic Removal.** Figure 4-15 contains three bar charts showing the concentrations of total As, particulate As, As(III), and As(V) at the IN, AC, and TM locations for each of the 11 speciation events. Arsenic concentrations in source water were consistent for Media Runs 1, 2, and 3 (Table 4-5). Total arsenic concentrations in source water ranged from 9.8 to 16.9 µg/L and averaged 12.2 µg/L. As expected, of the soluble fraction, As(V) was the predominating species, ranging from 8.3 to 13.8 µg/L and averaging 10.4 µg/L. As(III) concentrations ranged from 0.14 to 2.8 µg/L and averaged 1.6 µg/L. Particulate As concentrations were low, averaging 0.61 µg/L. The arsenic concentrations measured during the study were consistent with those of the source water sample collected by Battelle on October 13, 2004 (Table 4-1).

As expected, arsenic concentrations at the AC locations were essentially the same as those in source water and were consistent for Media Runs 1, 2, and 3 (Table 4-5). Total arsenic concentrations ranged from 10.0 to 16.1 µg/L and averaged 12.0 µg/L. Of the soluble fraction, As(V) was the predominating species, ranging from 10.2 to 13.4 µg/L and averaging 11.6 µg/L. Due to prechlorination, and thus oxidation of As(III) to As(V), As(III) concentrations were slightly lower than for source water, ranging from 0.14 to 1.2 µg/L and averaging 0.49 µg/L. Particulate As concentrations were low, averaging 0.24 µg/L.
Table 4-6. Summary of Water Quality Parameter Sampling Results

<table>
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<tr>
<th>Parameter</th>
<th>Sampling Location</th>
<th>Unit</th>
<th>Count</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
<th>Standard Deviation&lt;sup&gt;(a)&lt;/sup&gt;</th>
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</thead>
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<tr>
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<td>mg/L</td>
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<td>330</td>
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<tr>
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<td>mg/L</td>
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<td>188</td>
<td>200</td>
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<tr>
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<td>mg/L</td>
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<td>190</td>
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<tr>
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<td>176</td>
<td>198</td>
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<tr>
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<td>mg/L</td>
<td>16</td>
<td>184</td>
<td>205</td>
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<tr>
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<td>mg/L</td>
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<td>208</td>
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<td>194</td>
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<td>203</td>
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<td>189</td>
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<td>TM - R2</td>
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Table 4-6: Summary of Water Quality Parameter Sampling Results (Continued)

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43
Table 4-6. Summary of Water Quality Parameter Sampling Results (Continued)

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Table 4-6. Summary of Water Quality Parameter Sampling Results (Continued)

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<sup>(a)</sup> Standard deviation for parameters that were non-detect for all samples or had <3 sample counts are not meaningful, and therefore are not presented.
See Appendix B for complete analytical results.
One-half detection limit used for nondetect results; duplicate samples were included for calculations.
R1 = Media Run 1; R2 = Media Run 2; R3 = Media Run 3.

The key parameter for evaluating the effectiveness of the Isolux™ system was the concentration of arsenic in the treated water. The arsenic breakthrough curves for each media run are shown in Figure 4-16, in which total arsenic concentrations are plotted against the volume of water treated in gallons and bed volumes (BV).

Bed volumes for MA and MB were calculated based on 5.7 ft³ or 42.65 gal of media in each module; however, bed volumes of the combined effluent (TM) were calculated based on the combined media volume and throughput of both modules, since water at the sampling location had been treated by the entire media volume.

Media Run 1 began with system start-up on October 26, 2005, and ended on January 17, 2006. During Media Run 1, arsenic concentrations at MA and MB reached 10 µg/L at approximately 61,600 BV, which was 41% lower than the 105,000 BV estimated by the vendor. The bag-filters were changed six times due to increased differential pressure readings caused by the build-up of sediments and particulates. Thus, it was possible that sub-micron particulates that passed through the bag filters accumulated in and partially blocked some of the passages on the media cartridges’ outer membrane, causing preferential flow through the media cartridges. Preferential flow could cause portions of a media cartridge to filter a larger amount of water, thus exhausting the media at a higher rate. To investigate the cartridges, analyses were conducted on a spent media cartridge; results are presented in Section 4.5.3.

Media Run 2 began on April 27, 2006, following media cartridge change-out and ended on August 15, 2006. Prior to the start of Media Run 2, the well was bailed and wire-brushed on March 7, 2006, and a wire strainer was installed upstream of the Isolux™ system to reduce the amount of sediment/particulate matter produced by the well and introduced into the treatment system. During Media Run 2, the initial
Figure 4-15. Concentrations of Various Arsenic Species at IN, AC, and TM Sampling Locations
Figure 4-16. Total Arsenic Concentrations Through Treatment System During Media Runs 1 to 3
arsenic concentrations measured at MA and MB were approximately 6.0 and 4.0 µg/L, respectively, where they remained until gradually increasing to 10 µg/L breakthrough. Arsenic concentrations at MB reached 10 µg/L at about 86,700 BV; arsenic concentrations at MA increased to 9.3 µg/L after approximately 91,520 BV. However, the average effluent of MA and MB did not exceed 10 µg/L until August 8, 2006, after approximately 92,800 BV of throughput. Longer media run lengths were observed during Media Run 2; however, the calculated system operating time (i.e., 21.9 versus 20.2 hr/day) and EBCT (i.e., 1.1 versus 1.2 min) were similar. The well thereby rehabilitation might have reduced the amount of sediments and particulates produced by the well, thereby reducing the potential for preferential flow through the media cartridges and thus extending the life of the media.

Media Run 3 began on August 17, 2006, following media cartridge change-out and ended with the conclusion of the performance evaluation study on March 20, 2007. During Media Run 3, initial arsenic concentrations at MA and MB also were elevated at 7.0 and 3.0 µg/L, respectively. Arsenic concentrations at MA spiked above 10 µg/L at about 49,700 BV before gradually decreasing to 6.8 µg/L at 63,600 BV. On March 13, 2007, arsenic concentrations at MB reached 10 µg/L at about 76,200 BV, while arsenic concentration at MA remained below 10 µg/L at 7.4 µg/L after the system had treated approximately 82,000 BV of water. The average effluent of MA and MB exceeded 10 µg/L on March 20, 2007, after treating approximately 85,100 BV of water. Similar media run lengths were observed during Media Runs 2 and 3; the intermittent system operation (i.e., 16.7 versus 20.2 hr/day) did not seem to affect the media run length.

Iron, Manganese, and Zirconium. The treatment plant water samples were analyzed for total iron, manganese, and zirconium at each sampling event and for soluble iron, manganese, and zirconium during speciation sampling. Total and soluble iron concentrations were below the method detection limit of 25 µg/L in source water and throughout the treatment train. Manganese concentrations in source water ranged from 2.9 to 5.3 µg/L, which existed primarily in the soluble form at an average concentration of 4.1 µg/L. Total manganese concentrations in the effluent of MA and MB averaged 0.6 and 0.3 µg/L, respectively. Figure 4-17 presents total manganese concentrations versus bed volumes across the treatment train for all media runs. Zirconium concentrations in raw water and across the treatment train were below its detection limit of 0.1 µg/L, indicating zirconium was not leached from the Isolux™-302M media.

pH. The pH of Zero Point of Charge (pH_{zpc}) for zirconium hydroxide based media such as Isolux™-302M is 10 to 11. Above the pH of the ZPC, the media surface is negatively charged, and electrostatic repulsion will occur between the surface and an anion; this repulsion must be overcome for sorption to occur by a specific chemical bond. As(V) is more strongly sorbed and affected by pH in the range of 4 to 9 (Siegel, et al., 2007). pH of source water ranged from 7.4 to 7.9 and averaged 7.6, which is well below the pH of the ZPC and within the operational range of 4 to 8.5 (Figure 4-18).

DO and ORP. DO and ORP readings averaged 2.6 mg/L and 359 millivolts (mV), respectively, in source water. Both parameters indicated that the well water was oxidizing, which was consistent with the presence of As(V) in raw water. As a result of prechlorination, the ORP readings at AC, MA, MB, and TM increased to an average of 597 mV.

Other Water Quality Parameters. Alkalinity ranged from 176 to 330 mg/L (as CaCO₃) in raw water and remained unchanged after treatment. Sulfate, fluoride, and nitrate were measured during speciation sampling, and silica was measured at each sampling event. Their concentrations in raw water ranged from 39 to 52 mg/L for sulfate; 0.1 to 0.9 mg/L for fluoride, with one outlier of 10.2 mg/L; 0.4 to 0.7 mg/L (as N) for nitrate; and 26.4 to 31.7 mg/L for silica (as SiO₂) and remained unchanged after treatment.
Figure 4-17. Total Mn Concentrations Through Treatment System During Media Runs 1 to 3
Total phosphorous (as P) concentrations were below the detection limit of 10 µg/L for all measurements, except for four detections of (10.2, 10.6, 15.7, and 11.1 µg/L on March 30, June 13, June 21, and October 4, 2006, respectively) at the IN location and 11.3 and 11.4 µg/L on June 13 and October 4, 2006, respectively, at the AC location (Appendix B). Total hardness ranged from 153 to 220 mg/L (as CaCO₃), and remained relatively constant throughout the treatment train.

4.5.2 Distribution System Sampling. Distribution water samples were collected at three residences before and after the installation/operation of the Isolux™ system to determine whether the treatment system had any impacts on the lead and copper levels and water chemistry in the distribution system. The samples were analyzed for pH, alkalinity, arsenic, iron, manganese, lead, and copper; results are presented in Table 4-7. Since system startup, arsenic concentrations in the distribution system decreased slightly from the baseline levels of 2.8, 6.0, and 5.2 µg/L (on average) to 2.0, 3.3, and 3.1 µg/L at the DS1, DS2, and DS3 sampling locations, respectively. These concentrations were somewhat lower than those of the plant effluent (Figure 4-19), presumably due to blending of the treated water with untreated water from wells that did not have elevated arsenic levels.

Lead and copper concentrations ranged from <0.1 to 8.7 µg/L and 19.9 to 885.1 µg/L, respectively. No samples exceeded the 15 µg/L-Pb or 1,300 µg/L-Cu action levels. Due to blending of water from 12 other wells, it was inconclusive whether these distribution system concentrations had been affected by the arsenic treatment system.

pH, alkalinity, and manganese concentrations remained fairly consistent, with average baseline levels at 7.6, 173 mg/L, and 0.6 µg/L, and after startup levels at 7.8, 173 mg/L, and 0.2 µg/L, respectively. Iron was not detected in any samples.

4.5.3 Spent Media Sampling. Samples of spent Isolux™-302M media samples from Media Run 1 were collected according to Section 3.3.4 for TCLP and total metals analyses. Figure 4-20 presents photographs taken during spent media sampling.

The TCLP results provided by MEI (Table 4-8) indicated that the Isolux™-302M media was non-hazardous and could be disposed of in a standard solid waste landfill. However, MEI opted to send the spent media cartridges to GemChem, Inc., an Environmental Management Company in Lititz, PA, for beneficial reuse. The spent media was combined with similar products for use as fill materials in applications such as quarry reclamation.
Table 4-7. Distribution System Sampling Results

<table>
<thead>
<tr>
<th>Sampling Event</th>
<th>DS1&lt;sup&gt;(a)&lt;/sup&gt; LCR Residence</th>
<th>DS2 Non-LCR Residence</th>
<th>DS3 Non-LCR Residence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st draw</td>
<td>1st draw</td>
<td>1st Draw</td>
</tr>
<tr>
<td>No.</td>
<td>Date</td>
<td>hrs</td>
<td>Stagnation Time</td>
</tr>
<tr>
<td>BL1</td>
<td>07/19/05</td>
<td>10.5</td>
<td>&lt;25</td>
</tr>
<tr>
<td>BL2</td>
<td>08/04/05</td>
<td>11.0</td>
<td>&lt;25</td>
</tr>
<tr>
<td>BL3</td>
<td>08/16/05</td>
<td>8.3</td>
<td>&lt;25</td>
</tr>
<tr>
<td>BL4</td>
<td>08/30/05</td>
<td>9.0</td>
<td>&lt;25</td>
</tr>
<tr>
<td>1</td>
<td>11/01/05</td>
<td>11.8</td>
<td>&lt;25</td>
</tr>
<tr>
<td>2</td>
<td>12/06/05</td>
<td>8.5</td>
<td>&lt;25</td>
</tr>
<tr>
<td>3</td>
<td>01/04/06</td>
<td>11.5</td>
<td>&lt;25</td>
</tr>
<tr>
<td>4</td>
<td>05/17/06&lt;sup&gt;(d)&lt;/sup&gt;</td>
<td>8.4</td>
<td>&lt;25</td>
</tr>
<tr>
<td>5</td>
<td>06/06/06</td>
<td>8.8</td>
<td>&lt;25</td>
</tr>
<tr>
<td>6</td>
<td>07/12/06&lt;sup&gt;(e)&lt;/sup&gt;</td>
<td>12.3</td>
<td>&lt;25</td>
</tr>
<tr>
<td>7</td>
<td>08/09/06</td>
<td>8.5</td>
<td>&lt;25</td>
</tr>
<tr>
<td>8</td>
<td>09/13/06</td>
<td>9.0</td>
<td>&lt;25</td>
</tr>
<tr>
<td>9</td>
<td>10/11/06&lt;sup&gt;(f)&lt;/sup&gt;</td>
<td>8.3</td>
<td>Homeowner not present for sample collection.</td>
</tr>
</tbody>
</table>

(a) BL1 and BL2 were collected from a non-LCR residence.
(b) DS3 sample collected on 05/18/06.
(c) DS3 sample collected on 07/13/06.
(d) Samples were past hold time.
BL = Baseline sampling; NA = data not available.
Figure 4-19. Total Arsenic Concentrations in Distribution System

Figure 4-20. Spent Media Sampling
(Clockwise from Top Left: Spent Media Surface with Outer Membrane Removed, Visual of Spent Media from Outer Surface to Inner Membrane [I] and [II], Sample Collection into Dishes, Mottled Appearance on Outer Surface)
Table 4-8. TCLP Results of Spent Media

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Isolux™-302M Leachate Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Ba</td>
<td>1.4</td>
</tr>
<tr>
<td>Cd</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Cr</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Pb</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Hg</td>
<td>&lt;0.003</td>
</tr>
<tr>
<td>Se</td>
<td>&lt;0.3</td>
</tr>
<tr>
<td>Ag</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

Provided by MEI.

Visual observations of the spent media cartridge indicated sediment accumulation on the outer membrane of the cartridge and on the outer surface of the annular space immediately under the outer membrane. Figure 4-21 shows dark to light brown colors of the outer membrane of a typical cartridge removed from the system. Once the outer membrane was cut away, the outer surface of the media displayed a mottled appearance (Figure 4-22), which may be indicative of the actual distribution of the incoming flow. Iron concentrations of the spent media taken across the annular space of the cartridge averaged 800, 30, <0.5, and 128 µg/g for the outer surface, subsurface, mid-portion, and inner portion, respectively, thus confirming the visual observations of sediment accumulation on the media. The iron concentration measured at the inner portion was higher than at the mid-portion; this suggests channeling of the incoming flow, which might have contributed, in part, to the short run length observed during Media Run 1.

Figure 4-21. Spent Media Cartridge Removed from Isolux™ System (Provided by MEI)
Table 4-9 presents the results of metals analyses. Arsenic concentrations across the annular space of the media cartridge were relatively consistent, averaging 271, 285, 321, and 249 µg/g from the outer surface to the inner portion. These values were lower than the loading (i.e., 814 µg/g or about 0.08%) based on the system throughput and the arsenic concentrations before and after the treatment system. The differences observed most likely were caused by the relatively small quantities of the samples taken for the metal analyses. Also, the results of Al, Si, P, Mn, and Cu analyses further support the speculation of channeling, which resulted in metal concentrations measured at the inner portion being higher than those of the mid-portion of the media cartridge.

4.6 System Cost

The system cost was evaluated based on the capital cost per gpm (or gpd) of the design capacity and the O&M cost per 1,000 gal of water treated. The capital cost included the cost for equipment, site engineering, and installation. The O&M cost included cost for media cartridges, bag filters, electricity, and labor.

4.6.1 Capital Cost. The capital investment for equipment, site engineering, and installation of the Isolux™ treatment system was $76,840 (see Table 4-10). The equipment cost was $58,500 (or 76% of the total capital investment), which included $48,000 for two 75-gpm Isolux™ Modules, $8,000 for 36 Isolux™ technology media cartridges (18 media cartridges per module), and $2,500 for shipping.

The engineering cost included the cost for preparing the required permit application submittal, including system specifications, P&IDs, electrical diagrams, interconnection of piping layouts, and obtaining the required permit approval from CDPH. The engineering cost was $8,500, or 11% of the total capital investment.
The installation, shakedown, and startup cost covered the labor and materials required to unload, install, and test the system for proper operation. All installation activities were performed by MEI and GHCSD; startup and shakedown activities were performed by MEI with the operator’s assistance. The installation, startup, and shakedown costs, were $9,840, or 13% of the total capital investment.

### Table 4-9. Spent Media Analysis

<table>
<thead>
<tr>
<th>Sample Description</th>
<th>Analyte</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>P</th>
<th>Ca</th>
<th>Mn</th>
<th>Fe</th>
<th>Ni</th>
<th>Cu</th>
<th>Zn</th>
<th>As</th>
<th>Cd</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer surface</td>
<td>A</td>
<td>576</td>
<td>535</td>
<td>410</td>
<td>722</td>
<td>5,925</td>
<td>790</td>
<td>847</td>
<td>0.7</td>
<td>38.2</td>
<td>724</td>
<td>258</td>
<td>1.9</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>541</td>
<td>485</td>
<td>380</td>
<td>734</td>
<td>6,030</td>
<td>748</td>
<td>755</td>
<td>0.6</td>
<td>37.7</td>
<td>723</td>
<td>279</td>
<td>1.8</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>602</td>
<td>512</td>
<td>375</td>
<td>736</td>
<td>6,083</td>
<td>776</td>
<td>799</td>
<td>0.6</td>
<td>39.4</td>
<td>749</td>
<td>275</td>
<td>1.9</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td>573</td>
<td>511</td>
<td>389</td>
<td>731</td>
<td>6,013</td>
<td>771</td>
<td>800</td>
<td>0.7</td>
<td>38.4</td>
<td>732</td>
<td>271</td>
<td>1.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Subsurface</td>
<td>A</td>
<td>551</td>
<td>187</td>
<td>353</td>
<td>636</td>
<td>5,620</td>
<td>&lt;125</td>
<td>&lt;0.5</td>
<td>0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>5.8</td>
<td>304</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>551</td>
<td>186</td>
<td>379</td>
<td>626</td>
<td>5,645</td>
<td>&lt;125</td>
<td>33.8</td>
<td>&lt;0.5</td>
<td>5.6</td>
<td>752</td>
<td>290</td>
<td>2.1</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>500</td>
<td>169</td>
<td>248</td>
<td>627</td>
<td>5,486</td>
<td>&lt;125</td>
<td>26.0</td>
<td>&lt;0.5</td>
<td>5.4</td>
<td>755</td>
<td>262</td>
<td>2.0</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td>534</td>
<td>181</td>
<td>327</td>
<td>629</td>
<td>5,584</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.6</td>
<td>765</td>
<td>285</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td>Mid-portion</td>
<td>A</td>
<td>500</td>
<td>78.2</td>
<td>400</td>
<td>309</td>
<td>5,617</td>
<td>&lt;125</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>587</td>
<td>334</td>
<td>2.0</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>481</td>
<td>47.6</td>
<td>284</td>
<td>280</td>
<td>5,258</td>
<td>&lt;125</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>574</td>
<td>307</td>
<td>2.1</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>519</td>
<td>66.8</td>
<td>417</td>
<td>303</td>
<td>5,592</td>
<td>&lt;125</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>572</td>
<td>322</td>
<td>1.9</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td>500</td>
<td>64.2</td>
<td>367</td>
<td>297</td>
<td>5,489</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.7</td>
<td>777</td>
<td>321</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td>Inner portion</td>
<td>A</td>
<td>481</td>
<td>116</td>
<td>455</td>
<td>383</td>
<td>5,458</td>
<td>156</td>
<td>118</td>
<td>&lt;0.5</td>
<td>5.0</td>
<td>578</td>
<td>234</td>
<td>2.0</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>525</td>
<td>144</td>
<td>441</td>
<td>380</td>
<td>5,686</td>
<td>154</td>
<td>133</td>
<td>&lt;0.5</td>
<td>5.2</td>
<td>584</td>
<td>268</td>
<td>1.9</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>517</td>
<td>122</td>
<td>426</td>
<td>372</td>
<td>5,554</td>
<td>162</td>
<td>134</td>
<td>&lt;0.5</td>
<td>5.2</td>
<td>587</td>
<td>246</td>
<td>2.1</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td>508</td>
<td>127</td>
<td>441</td>
<td>378</td>
<td>5,566</td>
<td>157</td>
<td>128</td>
<td>-</td>
<td>5.1</td>
<td>583</td>
<td>249</td>
<td>2.0</td>
<td>-</td>
</tr>
</tbody>
</table>

### Table 4-10. Capital Investment for MEI’s Isolux™ Treatment System

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Cost</th>
<th>% of Capital Investment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equipment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isolux™ 75 gpm module</td>
<td>2</td>
<td>$48,000</td>
<td></td>
</tr>
<tr>
<td>Isolux™ technology media cartridges</td>
<td>36</td>
<td>$8,000</td>
<td></td>
</tr>
<tr>
<td>Freight</td>
<td>-</td>
<td>$2,500</td>
<td></td>
</tr>
<tr>
<td><strong>Equipment Total</strong></td>
<td></td>
<td>$58,500</td>
<td>76%</td>
</tr>
<tr>
<td><strong>Engineering</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vendor material</td>
<td>-</td>
<td>$1,500</td>
<td></td>
</tr>
<tr>
<td>Vendor labor</td>
<td>-</td>
<td>$2,000</td>
<td></td>
</tr>
<tr>
<td>Subcontractor material</td>
<td>-</td>
<td>$2,000</td>
<td></td>
</tr>
<tr>
<td>Subcontractor labor</td>
<td>-</td>
<td>$3,000</td>
<td></td>
</tr>
<tr>
<td><strong>Engineering Total</strong></td>
<td></td>
<td>$8,500</td>
<td>11%</td>
</tr>
<tr>
<td><strong>Installation, Shakedown, and Startup</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material (mechanical)</td>
<td>-</td>
<td>$500</td>
<td></td>
</tr>
<tr>
<td>Material (electrical)</td>
<td>-</td>
<td>$300</td>
<td></td>
</tr>
<tr>
<td>Vendor labor (mechanical)</td>
<td>-</td>
<td>$6,480</td>
<td></td>
</tr>
<tr>
<td>Vendor travel</td>
<td>-</td>
<td>$2,560</td>
<td></td>
</tr>
<tr>
<td><strong>Installation, Shakedown, and Startup</strong></td>
<td></td>
<td>$9,840</td>
<td>13%</td>
</tr>
<tr>
<td><strong>Total Capital Investment</strong></td>
<td></td>
<td>$76,840</td>
<td>100%</td>
</tr>
</tbody>
</table>
The total capital cost of $76,840 was normalized to $512/gpm ($0.36/gpd) of design capacity using the system’s rated capacity of 150 gpm (or 216,000 gpd). The total capital cost also was converted to an annualized cost of $7,253/year, using a capital recovery factor of 0.09439 based on a 7% interest rate and a 20-year return. Assuming that the system was operated 24 hours a day, 7 days a week at the design flow rate of 150 gpm to produce 78,840,000 gal of water per year, the unit capital cost would be $0.09/1,000 gal. This calculation assumed that the system operated 24 hr/day at its rated capacity. The system operated 19.6 hr/day (on average) at approximately 79.3 gpm (on average) (see Table 4-4). Based on this reduced use rate, the system would produce only 34,038,700 gal of water in one year (assuming 365 days per year), and the unit capital cost would increase to $0.21/1,000 gal.

4.6.2 Operation and Maintenance Cost. The O&M cost included media cartridge replacement and disposal, electricity consumption, and labor. Table 4-11 summarizes the O&M cost.

The cost to replace and dispose of the spent media cartridges represented the majority of the O&M cost (i.e., $7,080 for 36 cartridges in two modules). By averaging this cost over the useful life of the media, the unit cost per 1,000 gal of water treated was plotted as a function of the media life (i.e., run length in BV), as shown in Figure 4-23. The media run length (in BV) was calculated by dividing the system throughput (in gal) by the quantity of media in both modules (i.e., 11.4 ft³ [or 85.3 gal]). The Isolux™ system processed an average of 61,600, 92,800, and 85,100 BV prior to reaching the 10 µg/L arsenic breakthrough during Media Runs 1, 2, and 3, respectively. Based on these volumes, the unit media replacement cost was $1.35, $0.89, and $0.98/1,000 gal, respectively.

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Media Cartridge Replacement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isolux™ media cartridges ($/changeout)</td>
<td>$6,480</td>
<td>36 cartridges (18 cartridges/module)</td>
</tr>
<tr>
<td>Transportation</td>
<td>$600</td>
<td>36 cartridges (18 cartridges/module)</td>
</tr>
<tr>
<td>Media cartridge replacement ($/1,000 gal)</td>
<td>See Figure 4-23</td>
<td></td>
</tr>
<tr>
<td><strong>Electricity Consumption</strong></td>
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<td>Electricity Cost ($/1,000 gal)</td>
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<td>Labor Cost ($/1,000 gal)</td>
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<td>Labor rate = $37.5/hr²al</td>
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<td><strong>Total O&amp;M Cost ($/1,000 gal)</strong></td>
<td>See Figure 4-23</td>
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(a) O/M labor would be higher if a contract operator was required.

The Isolux™ treatment modules contained booster pumps that required electricity; however, the booster pumps were not used during the study. Therefore, additional electrical cost incurred by the Isolux™ system operation was assumed to be negligible.

Under normal operating conditions, routine labor activities to operate and maintain the system consumed 2.5 per week as noted in Section 4.4.2. Assuming that the system operates at an average flowrate of 79.3 gpm for 19.6 hr/day and 7 day/week to produce 653,000 gal of water per week, the estimated labor cost would be $0.14/1,000 gal of water treated.
Note: 1 BV = media volume in both modules

Figure 4-23. Total O&M Cost, Including Media Replacement
5.0 REFERENCES


APPENDIX A

OPERATIONAL DATA
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<td>73</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

1 BV = 5.793 = 42.82 gal for each module; 2 BV = 11.46 = 85.3 gal for two modules.
APPENDIX B

ANALYTICAL DATA
Table B-1. Analytical Results from Long-Term Sampling At Tehachapi, CA

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th>10/26/05&lt;sup&gt;(c)&lt;/sup&gt;</th>
<th>11/01/05</th>
<th>11/08/05</th>
<th>11/15/05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling Location Parameter</td>
<td>Unit</td>
<td>IN</td>
<td>AC</td>
<td>TM</td>
</tr>
<tr>
<td>Bed Volume BV</td>
<td>-</td>
<td>1.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Alkalinity mg/L&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>176</td>
<td>185</td>
<td>185</td>
<td>185</td>
</tr>
<tr>
<td>Fluoride mg/L</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>-</td>
</tr>
<tr>
<td>Sulfate mg/L</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>-</td>
</tr>
<tr>
<td>Nitrate (as N) mg/L</td>
<td>0.47</td>
<td>0.48</td>
<td>0.47</td>
<td>-</td>
</tr>
<tr>
<td>Total P µg/L&lt;sup&gt;(b)&lt;/sup&gt;</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Silica (as SiO₂) mg/L</td>
<td>27.8</td>
<td>28.0</td>
<td>21.0</td>
<td>27.7</td>
</tr>
<tr>
<td>Turbidity NTU</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>pH S.U.</td>
<td>7.5</td>
<td>7.6</td>
<td>7.5</td>
<td>7.4</td>
</tr>
<tr>
<td>Temperature °C</td>
<td>18.2</td>
<td>17.2</td>
<td>17.9</td>
<td>20.3</td>
</tr>
<tr>
<td>DO mg/L</td>
<td>NA&lt;sup&gt;(d)&lt;/sup&gt;</td>
<td>NA&lt;sup&gt;(d)&lt;/sup&gt;</td>
<td>NA&lt;sup&gt;(d)&lt;/sup&gt;</td>
<td>1.8</td>
</tr>
<tr>
<td>ORP mV</td>
<td>444</td>
<td>616</td>
<td>589</td>
<td>449</td>
</tr>
<tr>
<td>Total Chlorine mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total Hardness mg/L&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>177</td>
<td>176</td>
<td>178</td>
<td>181</td>
</tr>
<tr>
<td>Ca Hardness mg/L&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>130</td>
<td>128</td>
<td>131</td>
<td>133</td>
</tr>
<tr>
<td>Mg Hardness mg/L&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>47.9</td>
<td>47.9</td>
<td>47.3</td>
<td>47.7</td>
</tr>
<tr>
<td>As (total) µg/L</td>
<td>14.0</td>
<td>12.7</td>
<td>0.4</td>
<td>12.7</td>
</tr>
<tr>
<td>As (soluble) µg/L</td>
<td>13.1</td>
<td>12.4</td>
<td>0.4</td>
<td>-</td>
</tr>
<tr>
<td>As (particulate) µg/L</td>
<td>0.9</td>
<td>0.3</td>
<td>&lt;0.1</td>
<td>-</td>
</tr>
<tr>
<td>As (Ill) µg/L</td>
<td>2.0</td>
<td>0.6</td>
<td>0.6</td>
<td>-</td>
</tr>
<tr>
<td>As (V) µg/L</td>
<td>11.1</td>
<td>11.8</td>
<td>&lt;0.1</td>
<td>-</td>
</tr>
<tr>
<td>Fe (soluble) µg/L</td>
<td>&lt;25</td>
<td>&lt;25</td>
<td>&lt;25</td>
<td>-</td>
</tr>
<tr>
<td>Mn (total) µg/L</td>
<td>3.5</td>
<td>3.7</td>
<td>0.1</td>
<td>3.6</td>
</tr>
<tr>
<td>Mn (soluble) µg/L</td>
<td>3.4</td>
<td>3.2</td>
<td>0.2</td>
<td>-</td>
</tr>
<tr>
<td>Zr (total) µg/L</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Zr (soluble) µg/L</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>-</td>
</tr>
</tbody>
</table>

(a) As CaCO₃.
(b) As P.
(c) Water quality parameters measured on 10/25/05.
(d) Water quality parameter not measured.

IN – influent; MA = after module A; MB = after module B; TM = after combined module effluent. NA = not available.
Table B-1. Analytical Results from Long-Term Sampling At Tehachapi, CA (Continued)

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th>11/29/05</th>
<th>12/06/05</th>
<th>12/13/05</th>
<th>01/04/06</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling Location</td>
<td>Parameter</td>
<td>IN</td>
<td>AC</td>
<td>TM</td>
</tr>
<tr>
<td>Bed Volume</td>
<td>BV</td>
<td>-</td>
<td>-</td>
<td>32.4</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>mg/L</td>
<td>176</td>
<td>189</td>
<td>189</td>
</tr>
<tr>
<td>Fluoride</td>
<td>mg/L</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Sulfate</td>
<td>mg/L</td>
<td>39</td>
<td>41</td>
<td>44</td>
</tr>
<tr>
<td>Nitrate (as N)</td>
<td>mg/L</td>
<td>0.48</td>
<td>0.47</td>
<td>0.50</td>
</tr>
<tr>
<td>Total P</td>
<td>µg/L</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Silica (as SiO₂)</td>
<td>mg/L</td>
<td>27.2</td>
<td>27.2</td>
<td>27.5</td>
</tr>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>0.3</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>pH</td>
<td>S.U.</td>
<td>7.6</td>
<td>7.6</td>
<td>7.3</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>15.7</td>
<td>16.0</td>
<td>14.8</td>
</tr>
<tr>
<td>DO</td>
<td>mg/L</td>
<td>2.7</td>
<td>2.2</td>
<td>2.3</td>
</tr>
<tr>
<td>ORP</td>
<td>mV</td>
<td>472</td>
<td>578</td>
<td>534</td>
</tr>
<tr>
<td>Total Chlorine</td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total Hardness</td>
<td>mg/L</td>
<td>184</td>
<td>184</td>
<td>184</td>
</tr>
<tr>
<td>Ca Hardness</td>
<td>mg/L</td>
<td>137</td>
<td>138</td>
<td>136</td>
</tr>
<tr>
<td>Mg Hardness</td>
<td>mg/L</td>
<td>46.3</td>
<td>48.2</td>
<td>47.4</td>
</tr>
<tr>
<td>As (total)</td>
<td>µg/L</td>
<td>11.4</td>
<td>11.5</td>
<td>3.3</td>
</tr>
<tr>
<td>As (soluble)</td>
<td>µg/L</td>
<td>11.8</td>
<td>12.1</td>
<td>3.2</td>
</tr>
<tr>
<td>As (particulate)</td>
<td>µg/L</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>As (III)</td>
<td>µg/L</td>
<td>2.4</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>As (V)</td>
<td>µg/L</td>
<td>9.4</td>
<td>11.4</td>
<td>2.2</td>
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<tr>
<td>Fe (soluble)</td>
<td>µg/L</td>
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<td>&lt;25</td>
<td>&lt;25</td>
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<tr>
<td>Mn (total)</td>
<td>µg/L</td>
<td>3.6</td>
<td>3.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Mn (soluble)</td>
<td>µg/L</td>
<td>3.5</td>
<td>3.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Zr (total)</td>
<td>µg/L</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Zr (soluble)</td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(a) As CaCO₃.  
(b) As P.

IN – influent; MA = after module A; MB = after module B; TM = after combined module effluent.  
NA = not available.
Table B-1. Analytical Results from Long-Term Sampling At Tehachapi, CA (Continued)

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th>01/10/06</th>
<th>05/02/06</th>
<th>05/10/06</th>
<th>05/16/06</th>
<th>05/24/06</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling Location Parameter</td>
<td>Unit</td>
<td>IN</td>
<td>AC</td>
<td>MA</td>
<td>MB</td>
</tr>
<tr>
<td>Bed Volume</td>
<td>BV</td>
<td>-</td>
<td>-</td>
<td>71.2</td>
<td>67.7</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>mg/L</td>
<td>194</td>
<td>194</td>
<td>194</td>
<td>189</td>
</tr>
<tr>
<td>Fluoride</td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sulfate</td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nitrate (as N)</td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total P</td>
<td>µg/L</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Silica (as SiO₂)</td>
<td>mg/L</td>
<td>27.9</td>
<td>28.2</td>
<td>28.3</td>
<td>27.9</td>
</tr>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>0.2</td>
<td>0.1</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>pH</td>
<td>S.U.</td>
<td>7.7</td>
<td>7.8</td>
<td>7.7</td>
<td>7.7</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>18.2</td>
<td>19.0</td>
<td>14.0</td>
<td>19.0</td>
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<tr>
<td>DO</td>
<td>mg/L</td>
<td>2.2</td>
<td>1.8</td>
<td>2.0</td>
<td>2.3</td>
</tr>
<tr>
<td>ORP</td>
<td>mV</td>
<td>413</td>
<td>609</td>
<td>675</td>
<td>676</td>
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<tr>
<td>Total Chlorine</td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total Hardness</td>
<td>mg/L</td>
<td>171</td>
<td>176</td>
<td>170</td>
<td>173</td>
</tr>
<tr>
<td>Ca Hardness</td>
<td>mg/L</td>
<td>123</td>
<td>127</td>
<td>122</td>
<td>121</td>
</tr>
<tr>
<td>Mg Hardness</td>
<td>mg/L</td>
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<td>48.8</td>
<td>48.3</td>
<td>51.6</td>
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<tr>
<td>As (total)</td>
<td>µg/L</td>
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<td>12.4</td>
<td>12.4</td>
<td>11.9</td>
</tr>
<tr>
<td>As (soluble)</td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>As (particulate)</td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>As (III)</td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>As (V)</td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mn (total)</td>
<td>µg/L</td>
<td>3.4</td>
<td>3.3</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
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<tr>
<td>Mn (soluble)</td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zr (total)</td>
<td>µg/L</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Zr (soluble)</td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(a) As CaCO₃.  
(b) As P.  
(c) Media replacement took place on February 20, 2006.

IN – influent; MA = after module A; MB = after module B; TM = after combined module effluent.  
NA = not available.
Table B-1. Analytical Results from Long-Term Sampling At Tehachapi, CA (Continued)

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th>05/30/06</th>
<th>06/06/06</th>
<th>06/13/06</th>
<th>06/21/06</th>
<th>6/28/2006&lt;sup&gt;(c)&lt;/sup&gt;</th>
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<tbody>
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<td></td>
<td>IN</td>
<td>AC</td>
<td>MA</td>
<td>MB</td>
<td>IN</td>
</tr>
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<td><strong>Parameter</strong></td>
<td><strong>Unit</strong></td>
<td><strong>Value</strong></td>
<td><strong>Unit</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td></td>
<td>Bed Volume</td>
<td>BV</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Alkalinity</td>
<td>mg/L&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>192</td>
<td>192</td>
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<td></td>
<td>Fluoride</td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Sulfate</td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Nitrate (as N)</td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Total P</td>
<td>µg/L&lt;sup&gt;(b)&lt;/sup&gt;</td>
<td>10.2</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td></td>
<td>Silica (as SiO₂)</td>
<td>mg/L</td>
<td>27.2</td>
<td>26.9</td>
<td>25.8</td>
</tr>
<tr>
<td></td>
<td>Turbidity</td>
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<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>S.U.</td>
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<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
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<td>°C</td>
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<td>20.3</td>
<td>20.3</td>
</tr>
<tr>
<td></td>
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<td>2.6</td>
<td>2.2</td>
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<tr>
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<td>280</td>
<td>285</td>
</tr>
<tr>
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<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Total Hardness</td>
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<td>158</td>
<td>156</td>
<td>163</td>
</tr>
<tr>
<td></td>
<td>Ca Hardness</td>
<td>mg/L&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>117</td>
<td>116</td>
<td>122</td>
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<tr>
<td></td>
<td>Mg Hardness</td>
<td>mg/L&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>41.0</td>
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</tr>
<tr>
<td></td>
<td>As (total)</td>
<td>µg/L</td>
<td>10.1</td>
<td>10.0</td>
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</tr>
<tr>
<td></td>
<td>As (soluble)</td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>As (particulate)</td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>As (III)</td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>As (V)</td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Fe (soluble)</td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
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<td>Mn (total)</td>
<td>µg/L</td>
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<tr>
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<td>Mn (soluble)</td>
<td>µg/L</td>
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<td>-</td>
<td>-</td>
</tr>
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<td>Zr (total)</td>
<td>µg/L</td>
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<td>0.7</td>
<td>&lt;0.1</td>
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<tr>
<td></td>
<td>Zr (soluble)</td>
<td>µg/L</td>
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</table>

(a) As CaCO₃.
(b) As P.
(c) Water quality parameters measured on 06/27/06.

IN – influent; MA = after module A; MB = after module B; TM = after combined module effluent.
NA = not available.
<table>
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<th>Sampling Date</th>
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<th>07/11/06</th>
<th>07/18/06</th>
<th>07/26/06&lt;sup&gt;(c)&lt;/sup&gt;</th>
<th>08/02/06&lt;sup&gt;(d)&lt;/sup&gt;</th>
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<td><strong>Unit</strong></td>
<td><strong>IN</strong></td>
<td><strong>AC</strong></td>
<td><strong>MA</strong></td>
</tr>
<tr>
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<td>-</td>
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<td>193</td>
<td>197</td>
<td>188</td>
<td>193</td>
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<tr>
<td><strong>Fluoride mg/L</strong></td>
<td>-</td>
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<td>-</td>
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</tr>
<tr>
<td><strong>Sulfate mg/L</strong></td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Nitrate (as N) mg/L</strong></td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td><strong>Total P µg/L</strong></td>
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<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
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<tr>
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<td>27.6</td>
<td>28</td>
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<td>350</td>
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<td>1.27</td>
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<td>181</td>
<td>186</td>
<td>185</td>
<td>183</td>
<td>181</td>
</tr>
<tr>
<td><strong>Ca Hardness mg/L</strong></td>
<td>132</td>
<td>135</td>
<td>134</td>
<td>133</td>
<td>135</td>
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<tr>
<td><strong>Mg Hardness mg/L</strong></td>
<td>49.7</td>
<td>50.6</td>
<td>50.7</td>
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<td>10.4</td>
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<tr>
<td><strong>As (soluble) µg/L</strong></td>
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<td>-</td>
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<tr>
<td><strong>As (particulate) µg/L</strong></td>
<td>-</td>
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<td><strong>As (III) µg/L</strong></td>
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<td><strong>As (V) µg/L</strong></td>
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<td><strong>Fe (soluble) µg/L</strong></td>
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<td><strong>Mn (total) µg/L</strong></td>
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<tr>
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<td><strong>Zr (soluble) µg/L</strong></td>
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</table>

(a) As CaCO₃.<br>(b) As P.<br>(c) Water quality parameters measured on 07/25/06.<br>(d) Water quality parameters measured on 08/01/06.

IN – influent; MA = after module A; MB = after module B; TM = after combined module effluent.
NA = not available.
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<th>08/22/06</th>
<th>08/29/06</th>
<th>09/05/06</th>
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<tbody>
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<td><strong>Sampling Location</strong></td>
<td><strong>IN</strong></td>
<td><strong>AC</strong></td>
<td><strong>MA</strong></td>
<td><strong>MB</strong></td>
<td><strong>IN</strong></td>
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<td><strong>Parameter</strong></td>
<td><strong>Unit</strong></td>
<td><strong>Bed Volume BV</strong></td>
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<td><strong>Alkalinity</strong></td>
<td>mg/L(a)</td>
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<td>189</td>
<td>189</td>
<td>189</td>
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<tr>
<td><strong>Fluoride</strong></td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Sulfate</strong></td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Nitrate (as N)</strong></td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total P</strong></td>
<td>µg/L(b)</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
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<tr>
<td><strong>Silica (as SiO2)</strong></td>
<td>mg/L</td>
<td>27.9</td>
<td>27.7</td>
<td>28.1</td>
<td>28.3</td>
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<tr>
<td><strong>Turbidity</strong></td>
<td>NTU</td>
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<td>0.6</td>
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<td>0.3</td>
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<td>7.5</td>
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<td>20.5</td>
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<td>20.5</td>
</tr>
<tr>
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<td>mg/L</td>
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<td>2.0</td>
<td>1.9</td>
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<td>634</td>
<td>651</td>
<td>663</td>
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<td><strong>Total Chlorine</strong></td>
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<td><strong>Total Hardness</strong></td>
<td>mg/L(a)</td>
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<td>182</td>
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<tr>
<td><strong>Ca Hardness</strong></td>
<td>mg/L(a)</td>
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<td>133</td>
<td>136</td>
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<td><strong>Mg Hardness</strong></td>
<td>mg/L(a)</td>
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<td>48.8</td>
<td>49.3</td>
<td>51.1</td>
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<td>µg/L</td>
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<td>12.2</td>
<td>9.3</td>
<td>12.2</td>
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<tr>
<td><strong>As (soluble)</strong></td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>As (particulate)</strong></td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>As (III)</strong></td>
<td>µg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>As (V)</strong></td>
<td>µg/L</td>
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<td>-</td>
<td>-</td>
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<tr>
<td><strong>Mn (total)</strong></td>
<td>µg/L</td>
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<td><strong>Mn (soluble)</strong></td>
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<td>&lt;0.1</td>
<td>&lt;0.1</td>
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<tr>
<td><strong>Zr (soluble)</strong></td>
<td>µg/L</td>
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<td>-</td>
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</tbody>
</table>

(a) As CaCO₃.
(b) As P.

IN = influent; MA = after module A; MB = after module B; TM = after combined module effluent.
NA = not available.
### Table B-1. Analytical Results from Long-Term Sampling At Tehachapi, CA (Continued)

<table>
<thead>
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<th>09/26/06</th>
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<td><strong>Sampling Location</strong></td>
<td><strong>Parameter</strong></td>
<td><strong>IN</strong></td>
<td><strong>AC</strong></td>
<td><strong>MA</strong></td>
</tr>
<tr>
<td><strong>Bed Volume</strong></td>
<td>BV</td>
<td>-</td>
<td>-</td>
<td>21.8</td>
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<tr>
<td><strong>Alkalinity</strong></td>
<td>mg/L</td>
<td>190</td>
<td>192</td>
<td>190</td>
</tr>
<tr>
<td><strong>Fluoride</strong></td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Sulfate</strong></td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Nitrate (as N)</strong></td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total P</strong></td>
<td>µg/L</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
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<td>mg/L</td>
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<td>27.1</td>
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<td>0.1</td>
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<td>655</td>
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<td><strong>Total Hardness</strong></td>
<td>mg/L</td>
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<td>192</td>
<td>190</td>
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<td>µg/L</td>
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<td><strong>As (soluble)</strong></td>
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<td><strong>As (particulate)</strong></td>
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<td><strong>Fe (soluble)</strong></td>
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<td><strong>Mn (total)</strong></td>
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<td><strong>Zr (total)</strong></td>
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<td>&lt;0.1</td>
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<td><strong>Zr (soluble)</strong></td>
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(a) As CaCO₃.  
(b) As P.
Table B-1. Analytical Results from Long-Term Sampling At Tehachapi, CA (Continued)

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th>10/10/06</th>
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<td>MA</td>
<td>MB</td>
<td>IN</td>
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<td>Bed Volume BV</td>
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<td>654</td>
<td>671</td>
<td>679</td>
<td>327</td>
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<td>Total Chlorine mg/L</td>
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<td>-</td>
<td>-</td>
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<td>As (total) µg/L</td>
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<td>MA</td>
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<td>IN</td>
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<tr>
<td>As (total) µg/L</td>
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<td>01/10/07</td>
<td>01/23/07</td>
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<td>MB</td>
<td>IN</td>
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<tr>
<td>Bed Volume BV</td>
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<td>46.9</td>
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</tr>
<tr>
<td>pH S.U.</td>
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<td>7.7</td>
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<td>17.9</td>
<td>18.0</td>
<td>16.3</td>
</tr>
<tr>
<td>DO mg/L</td>
<td>3.6</td>
<td>3.2</td>
<td>3.2</td>
<td>3.3</td>
<td>3.1</td>
</tr>
<tr>
<td>ORP mV</td>
<td>313</td>
<td>505</td>
<td>536</td>
<td>551</td>
<td>320</td>
</tr>
<tr>
<td>Total Chlorine mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>As (total) µg/L</td>
<td>14.2</td>
<td>13.9</td>
<td>10.1</td>
<td>3.8</td>
<td>13.3</td>
</tr>
</tbody>
</table>
Table B-1.  Analytical Results from Long-Term Sampling At Tehachapi, CA (Continued)

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th>02/13/07</th>
<th>02/20/07</th>
<th>02/27/07</th>
<th>03/06/07</th>
<th>03/13/07</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling Location</td>
<td>IN</td>
<td>AC</td>
<td>MA</td>
<td>MB</td>
<td>IN</td>
</tr>
<tr>
<td>Bed Volume</td>
<td>BV</td>
<td>-</td>
<td>-</td>
<td>67.7</td>
<td>63.0</td>
</tr>
<tr>
<td>pH</td>
<td>S.U.</td>
<td>7.5</td>
<td>7.6</td>
<td>7.6</td>
<td>7.6</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>15.1</td>
<td>16.0</td>
<td>16.4</td>
<td>16.9</td>
</tr>
<tr>
<td>DO</td>
<td>mg/L</td>
<td>3.9</td>
<td>2.8</td>
<td>2.9</td>
<td>2.8</td>
</tr>
<tr>
<td>Total Chlorine</td>
<td>mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.4</td>
</tr>
<tr>
<td>As (total)</td>
<td>µg/L</td>
<td>10.5</td>
<td>10.7</td>
<td>6.8</td>
<td>6.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th>03/20/07</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling Location</td>
<td>IN</td>
</tr>
<tr>
<td>Bed Volume</td>
<td>BV</td>
</tr>
<tr>
<td>pH</td>
<td>S.U.</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
</tr>
<tr>
<td>DO</td>
<td>mg/L</td>
</tr>
<tr>
<td>ORP</td>
<td>mV</td>
</tr>
<tr>
<td>Total Chlorine</td>
<td>mg/L</td>
</tr>
<tr>
<td>As (total)</td>
<td>µg/L</td>
</tr>
</tbody>
</table>

IN – influent; MA = after module A; MB = after module B; TM = after combined module effluent. NA = not available.