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# Arsenic Removal from Drinking Water by Adsorptive Media U.S. EPA Demonstration Project at Chateau Estates Mobile Home Park in Springfield, OH Six-Month Evaluation Report

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Sally Gutierrez, Director
National Risk Management Research Laboratory

## ABSTRACT

This report documents the activities performed for and the results obtained from the first six months of the arsenic removal treatment technology demonstration project at the Chateau Estates Mobile Home Park at Springfield, OH. The objectives of the project are to evaluate the effectiveness of AdEdge Technologies' AD-33 media in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 μg/L. Additionally, this project evaluates the reliability of the treatment system (Arsenic Package Unit [APU]-250), the required system operation and maintenance (O&M) and operator skill levels, and the capital and O&M cost of the technology. The project also characterizes the water in the distribution system and process residuals produced by the treatment process.

The 250 gal/min (gpm) APU-250 treatment system consisted of two integrated units referred to as AD-26 oxidation/filtration and AD-33 adsorption systems. The AD-26 pretreatment system was for iron and manganese removal, followed in series by the AD-33 adsorption system for arsenic removal. Both the AD-26 oxidation/filtration and AD-33 adsorption systems were skid-mounted, each comprised of three carbon steel pressure vessels of similar construction and configuration but different sizes.

AD-26 media was a manganese dioxide mineral commonly used for oxidation and filtration of iron and manganese. Because chlorine was added prior to the AD-26 system, it helped precipitate soluble iron, oxidize As(III) to As(V), and form arsenic-laden solids, which were then filtered by the AD-26 media. The pre-treated water was subsequently polished by the AD-33 media, an iron-based adsorptive media developed by Bayer AG for arsenic removal.

The APU-250 system began regular operation on September 21, 2005. 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. Through the period from September 21, 2005, to March 26, 2006, the system treated approximately 8,184,000 gal (about 9,540 bed volumes) of water with the daily run time ranging from 3.7 to 15.1 hr/day and averaging 9.2 hr/day. For the most part, the AD-26 system operated at the well pump flowrates with water supplied by two alternating wells at 130 and 90 gpm. The AD-33 system operated based on demand from the distribution system, ranging from 9 to 56 gpm and averaging 33 gpm. Because of the low flowrates, long empty bed contact times (EBCT), averaged at 25.8 min, were experienced by the AD-33 system.

The system reduced total arsenic levels from between 9.5 and 31.3 μg/L (averaged 21.5 μg/L) in raw water to <10 μg/L in the treated water. As(III) was the predominating arsenic species in raw water, ranging from 5.6 to 24.7 μg/L and averaging 16.4 μg/L in both wells. The majority of arsenic was removed in the particulate form by the AD-26 media, leaving only 0.5 to 2.0 μg/L, existing mainly as As(V), to be further polished by the AD-33 media. The system also reduced total iron concentrations from an average of 1,000 μg/L to less than the method detection limit (MDL) of 25 μg/L, while the total manganese concentrations decreased from an average of 40.2 to 0.1 μg/L.

The AD-26 system was backwashed initially every two days for 15 min with a 2-min service-to-waste rinse, producing approximately 5,640 gal of wastewater per backwash event. During a power outage, the backwash settings were reset to default values, prompting the system to produce almost twice as much wastewater per backwash event. This problem was resolved by manually adjusting the backwash settings, which, after a short time, were further reduced to every three days for 9 min with a 90-sec rinse. Assuming that 82 mg/L of total suspended solid (TSS) was produced in 6,000 gal of backwash wastewater, approximately 4 lb of solids (including 0.02, 1.45, and 0.03 lb of arsenic, iron, and manganese, respectively) would be discharged during each backwash event. The AD-33 system was backwashed only once during the first six-months of operation.

Comparison of the distribution system sampling results before and after the system startup showed a significant decrease in arsenic concentration (from an average of 23.7 to 2.0 µg/L). The arsenic concentrations in the distribution system were similar to those in the system effluent. Iron and manganese also were significantly reduced in the distribution system. Neither lead nor copper concentrations appeared to have been affected by the operation of the system.

The most significant operational issue observed was related to the chlorine injection system. In spite of repeated efforts on fine-tuning the chlorine injection system and even reconfiguring the system piping to allow the injection to be controlled by well pump flowrates instead of on-demand flowrates, as much as 4 and 3.8 mg/L (as $Cl_2$) total and free chlorine, respectively, were measured in the treated water, which were significantly higher than the 1.5 and 1 mg/L (as $Cl_2$) of total and free residuals targeted for the treatment. The vendor continued to troubleshoot this problem.

The capital investment cost for the system was $292,252, including $212,826 for equipment, $27,527 for site engineering, and $51,899 for installation. This cost included the cost, paid for by the Park owner, to upgrade the system size from 150 to 250 gpm to meet the Ohio Environmental Protection Agency's (Ohio EPA's) redundancy requirement, upgrade the pressure vessel construction material from fiberglass reinforced plastic (FRP) to carbon steel, and add a chlorine injection and control system. Using the system's rated capacity of 250 gpm (360,000 gal/day [gpd]), the capital cost was $1,170 per gpm of design capacity ($0.81/gpd) and equipment-only cost was $851 per gpm of design capacity ($0.59/gpd).

The O&M cost included only incremental cost associated with the oxidation/filtration and adsorption system, such as media replacement and disposal, chemical supply, electricity consumption, and labor. Although media replacement did not occur during the first six months of system operation, the media replacement cost would represent the majority of the O&M cost and was estimated to be $34,230 and $13,140 to change out the AD-33 and AD-26 media, respectively.

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AAL | American Analytical Laboratories |
| Al | aluminum |
| AM | adsorptive media process |
| APU | arsenic package unit |
| As | arsenic |
| ATS | Aquativ Treatment Systems |
| | |
| BET | Brunauer, Emmett and Teller |
| bgs | below ground surface |
| BL | baseline sampling |
| BV | bed volume |
| | |
| Ca | calcium |
| Cl | chloride |
| C/F | coagulation/filtration process |
| CRF | capital recovery factor |
| | |
| DO | dissolved oxygen |
| | |
| EBCT | empty bed contact time |
| EPA | U.S. Environmental Protection Agency |
| | |
| F | fluoride |
| Fe | iron |
| FRP | fiberglass reinforced plastic |
| | |
| GFH | granular ferric hydroxide |
| gpd | gallons per day |
| gpm | gallons per minute |
| | |
| HIX | hybrid ion exchanger |
| | |
| ICP-MS | inductively coupled plasma-mass spectrometry |
| i.d. | inner diameter |
| ID | identification |
| IX | ion exchange |
| | |
| LCR | Lead and Copper Rule |
| | |
| MCL | maximum contaminant level |
| MDL | method detection limit |
| Mg | magnesium |
| Mn | manganese |
| mV | millivolts |
| | |
| Na | sodium |
| NaOCl | sodium hypochlorite |
| NRMRL | National Risk Management Research Laboratory |
| NS | not sampled |

## ABBREVIATIONS AND ACRONYMS (Continued)

| | |
|---|---|
| O&M | operation and maintenance |
| Ohio EPA | Ohio Environmental Protection Agency |
| OIT | Oregon Institute of Technology |
| ORD | Office of Research and Development |
| ORP | oxidation-reduction potential |
| | |
| psi | pounds per square inch |
| $PO_4$ | orthophosphate |
| PLC | programmable logic controller |
| POU | point-of-use |
| PVC | polyvinyl chloride |
| | |
| QA | quality assurance |
| QAPP | Quality Assurance Project Plan |
| QA/QC | quality assurance/quality control |
| | |
| RO | reverse osmosis |
| RPD | relative percent difference |
| | |
| Sb | antimony |
| SDWA | Safe Drinking Water Act |
| $SiO_2$ | silica |
| SM | system modification |
| SMCL | secondary maximum contaminant level |
| $SO4^{2-}$ | sulfate |
| SOC | synthetic organic compound |
| STMGID | South Truckee Meadows General Improvement District |
| STS | Severn Trent Services |
| | |
| TBD | to be determined |
| TCLP | toxicity characteristic leaching procedure |
| TDS | total dissolved solids |
| TOC | total organic carbon |
| TSS | total suspended solids |
| | |
| VOC | volatile organic compound |

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# 1.0 INTRODUCTION

## 1.1 Background

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

In October 2001, EPA announced an initiative for additional research and development of cost-effective technologies to help small community water systems (<10,000 customers) meet the new arsenic standard and to provide technical assistance to operators of small systems in order to reduce compliance costs. As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, on-site demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems. Shortly thereafter, an announcement was published in the *Federal Register* requesting water utilities interested in participating in 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 be the host sites for 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 from one to six proposals. In April 2003, an independent technical panel reviewed the proposals and provided its recommendations to EPA on the technologies that it determined were acceptable for the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration project. Using the information provided by the review panel, EPA, in cooperation with the host sites and the drinking water programs of the respective states, selected one technical proposal for each site. As of January 2007, 11 of the 12 systems have been operational and the performance evaluations of six systems have been completed.

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 Chateau Estates Mobile Home Park facility in Springfield, Ohio, 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, another technical panel was convened by EPA to review the proposals and provide recommendations to EPA with the number of proposals per site ranging from none (for two sites) to a maximum of four. The final selection of the treatment technology at the sites that received at least one proposal was made, again, through a joint effort by EPA, the state regulators, and the host site. Since then, four sites have withdrawn from the demonstration program, reducing the number of sites to 28. AdEdge Technologies (AdEdge), using the Bayoxide E33 media developed by Bayer AG, was selected for demonstration at the Chateau Estates site in September 2004.

## 1.2 Treatment Technologies for Arsenic Removal

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

## 1.3 Project Objectives

The objective of the arsenic demonstration program is to conduct 40 full-scale arsenic treatment technology demonstration studies on the removal of arsenic from drinking water supplies. The specific objectives are to:

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

This report summarizes the performance of the AdEdge system at the Chateau Estates Mobile Home Park in Springfield, OH, during the first six months from September 21, 2005, through March 26, 2006. The types of data collected included system operational, water quality (both across the treatment train and in the distribution system), residuals, and capital and preliminary O&M cost.

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

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

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

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

AM = adsorptive media process; C/F = coagulation/filtration; HIX = hybrid ion 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 being reconfigured from parallel to series operation.

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

(d) Replaced Village of Lyman, NE site which withdrew from program in June 2006.

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

(f) Including nine residential units.

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

## 2.0 SUMMARY AND CONCLUSIONS

Based on the information collected during the first six months of system operation, the following conclusions were made relating to the overall objectives of the treatment technology demonstration study.

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

- Chlorination effectively oxidized As(III) and Fe(II) and formed arsenic-laden particles filterable by the AD-26 media. Via filtration of particles, the AD-26 system alone was capable of reducing total arsenic concentrations to < 2 µg/L, far below the 10-µg/L MCL.
- Chlorination also was effective in precipitating Mn(II) without an extended contact time, converting 85 to 98% of $Mn^{2+}$ to $MnO_2$ in five of six speciation events. This observation was contrary to the findings of most researchers that due to slow oxidation kinetics upon chlorination, $Mn^{2+}$ would stay in the soluble form for an extended duration (Knocke et al., 1987 and 1990; Condit and Chen, 2006).
- The AD-33 system worked only as a polisher, reducing total arsenic concentrations from 2.0 to 0.5 µg/L (existing mainly as As(V) in the system effluent).
- In spite of repeated efforts, the automatic chlorine monitor/controller failed to control free and total chlorine residuals within the target level of 1.0 mg/L (as $Cl_2$), leaving as much as 3.8 mg/L (as $Cl_2$) of free chlorine and 4 mg/L (as $Cl_2$) of total chlorine at the entry point throughout the study period.

*Required system O&M and operator skill levels:*

- The daily demand on the operator was typically 20 min to visually inspect the system and record operational parameters.
- The most significant operational issue was related to the chlorine injection system. Many attempts of fine-tuning the system and even reconfiguring the system piping did not seem to resolve the significantly high levels of free and total chlorine measured in the treated water.

*Process residuals produced by the technology:*

- Residuals produced by the operation of the treatment system included backwash wastewater and spent media. Because the media was not replaced during the first six months of system operation, the only residual produced was backwash wastewater.
- The AD-26 system was capable of running up to three days, with an average run time of over 27 hrs, before it needed to be backwashed. The AD-33 system did not need backwashing during the six-month study period.
- Assuming an average of 82 mg/L of total suspended solids (TSS) in 6,000 gal of backwash wastewater, approximately 4 lb of solids would be discharged during each backwash event. The solids were comprised of 0.5%, 36.2%, and 0.8% of arsenic, iron, and manganese, respectively.

*Capital and O&M cost of the technology:*

- The unit capital cost is \$0.21/1,000 gal if the system operates at 100% utilization rate. The system's real unit cost is \$1.69/1,000 gal, based on 8,184,000 gal of water production in the first six months. The O&M cost is \$0.33/1,000 gal, based on labor, chemical usage, and electricity consumption.

# 3.0 MATERIALS AND METHODS

## 3.1 General Project Approach

Following the predemonstration activities summarized in Table 3-1, the performance evaluation study of the AdEdge treatment system began on September 21, 2005. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall system performance was determined based on its ability to consistently remove arsenic to the target MCL of 10 μg/L through the collection of biweekly water samples across the treatment train. The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

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

The quantity of aqueous and solid residuals generated was estimated by tracking the volume of backwash water produced during each backwash cycle. Backwash water was sampled and analyzed for chemical characteristics.

**Table 3-1. PreDemonstration Study Activities and Completion Dates**

| Activity | Date |
|---|---|
| Introductory Meeting Held | August 5, 2004 |
| Second Introductory Meeting Held | September 9, 2004 |
| Project Planning Meeting Held | October 8, 2004 |
| Draft Letter of Understanding Issued | October 15, 2004 |
| Final Letter of Understanding Issued | November 5, 2004 |
| Request for Quotation Issued to Vendor | November 16, 2004 |
| Vendor Quotation Received | November 29, 2004 |
| Purchase Order Completed and Signed | March 1, 2005 |
| Engineering Plans Submitted to Ohio EPA | June 1, 2005 |
| System Permit Issued by Ohio EPA | July 6, 2005 |
| Building Construction Began | July 15, 2005 |
| Final Letter Report Issued | July 19, 2005 |
| Building Construction Complete | August 15, 2005 |
| APU Unit Shipped and Arrived | August 19, 2005 |
| Final Study Plan Issued | August 30, 2005 |
| System Installation Completed | September 2, 2005 |
| System Shakedown Completed | September 9, 2005 |
| Performance Evaluation Began | September 21, 2005 |

Ohio EPA = Ohio Environmental Protection Agency

**Table 3-2. General Types of Data**

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

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, electrical 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 the vendor and Battelle. On a daily basis, the plant operator recorded system operational data, such as pressure, flowrate, totalizer, and hour meter readings on a Daily System Operation Log Sheet, checked the sodium hypochlorite (NaOCl) level, and conducted visual inspections to ensure normal system operations. If any problems occurred, the plant operator contacted the Battelle Study Lead, who determined if the vendor should be contacted for troubleshooting. The plant operator recorded all relevant information, including the problems encountered, course of actions taken, materials and supplies used, and associated cost and labor required, on a Repair and Maintenance Log Sheet. On a biweekly basis, the plant operator measured several water quality parameters on-site, including pH, temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP), and total and free chlorine, and recorded the data on a Water Quality Parameters Log Sheet. Backwash was set to be performed automatically for the oxidation/filtration vessels and manually for the adsorption vessels. Backwash was initially performed every two days for the pre-oxidation vessels, but was reduced to every three days. The adsorption vessels were backwashed only once during this operational period. The backwash data were recorded on a Backwash Log Sheet.

The capital cost for the arsenic removal system consisted of the cost for equipment, site engineering, and system installation. The O&M cost consisted of the cost for chemical usage, electricity consumption, and labor. Consumption of NaOCl was tracked on the Daily System Operation Log Sheet. Electricity consumption was determined from utility bills. Labor for various activities, such as routine system O&M, troubleshooting and repairs, and demonstration-related work, were tracked using an Operator Labor Hour Log Sheet. The routine system O&M included activities such as completing the field logs, replenishing the NaOCl solution, ordering supplies, performing system inspections, and others as recommended by the vendor. The labor 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, was recorded, but not used for the cost analysis.

### 3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected from the source, across the treatment system, from the distribution system, and during oxidation/filtration vessel backwash. Table 3-3 presents the sampling schedule and analytes measured during each sampling event. Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2004). The procedure for arsenic speciation is described in Appendix A of the QAPP.

**3.3.1 Source Water.** During the initial visit to the site, one set of source water samples from the West Well was collected and speciated using an arsenic specitation kit (see Section 3.4.1). A second introductory meeting was held to further discuss the technology selection for the site and a set of source water samples from the East Well was collected and speciated. The sample taps were flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Analytes for the source water samples are listed in Table 3-3.

**3.3.2 Treatment Plant Water.** During the system performance evaluation study, the plant operator collected samples on a biweekly basis. For the first biweekly event, samples were taken at the source (IN), after chlorination (AC), after the oxidation/filtration vessels (OT), and after the adsorption vessels (TT) and analyzed for the analytes listed in Table 3-3 for the monthly (without speciation) treatment plant water. For the second biweekly event, samples were collected and speciated on-site at the same four locations and analyzed for the analytes listed under the monthly (with speciation) treatment plant water list in Table 3-3.

**3.3.3 Backwash Water and Solids.** Backwash water samples were collected monthly by the plant operator from each oxidation/filtration vessel. Over the duration of backwash for each vessel, a side stream of backwash water was directed from the tap on the backwash water discharge line to a clean, 32-gal plastic container at approximately 1 gpm. After the content in the container was thoroughly mixed, one aliquot was collected as is and the other filtered with 0.45-µm disc filters. The samples were analyzed for analytes listed in Table 3-3.

Backwash solid samples were not collected in the initial six months of this demonstration. Two to three solid/sludge samples will be collected from the backwash water during the second half of the demonstration study. The solid/sludge samples will be collected in glass jars and analyzed for total metals and Toxicity Characteristic Leaching Procedure (TCLP) tests.

No backwash water or backwash solids samples were collected from the adsorption vessels during this study period. These samples will be collected during the second half of the demonstration study.

**3.3.4 Spent Media.** The media in the oxidation/filtration and adsorption vessels were not replaced during the first six months of the demonstration project. Therefore, no spent media were produced as residual solids.

**3.3.5 Distribution System Water.** Samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically, the arsenic, lead and copper levels. Prior to the system start-up from April to July 2005, four sets of baseline distribution water samples were collected at three Lead and Copper Rule (LCR) locations

**Table 3-3. Sampling Schedule and Analytes**

| Sample Type | Sampling Location(a) | No. of Samples | Frequency | Analyte | Sampling Date |
|---|---|---|---|---|---|
| Source Water | At Wellhead (IN) | 2 (East and West Wells) | Once at West Well during initial introductory visit and once at East Well during second introductory visit | On-site: pH, temperature, DO, and ORP<br><br>Off-site: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, $NH_3$, $NO_3$, $NO_2$, Cl, F, $SO_4$, $SiO_2$, $PO_4$, TDS, TOC, turbidity, and alkalinity | 08/05/04 and 09/09/04 |
| Treatment Plant Water | At Wellhead (IN), after Chlorination (AC), after Oxidation/ Filtration Vessels (OT), after Adsorption Vessels (TT) | 4 | Monthly (Without speciation) | On-site: pH, temperature, DO, ORP, and $Cl_2$ (free and total)(c)<br><br>Off-site: As (total), Fe (total), Mn (total), Ca, Mg, F, $NH_3$, $NO_3$, $SO_4$, $SiO_2$, P, turbidity, and alkalinity | 10/11/05, 11/08/05, 12/12/05, 01/16/06, 02/13/06, 03/13/06 |
| | | | Monthly (With speciation) | On-site: pH, temperature, DO, ORP, and $Cl_2$ (free and total)(c)<br><br>Off-site: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), Ca, Mg, F, $NH_3$, $NO_3$, $SO_4$, $SiO_2$, P, turbidity, and alkalinity | 09/28/05, 10/25/05, 12/05/05, 01/03/06, 02/01/06, 02/28/06 |
| Distribution Water | Two LCR Locations (including Park Clubhouse and Lot 76 Residence) and One Non-LCR Residence (Lot 16) | 3 | Monthly(b) | As (total), Fe (total), Mn (total), Cu (total), Pb (total), pH, and alkalinity, | Baseline sampling: 04/04/05, 05/03/05, 06/08/05, 07/07/05<br>Monthly sampling: 10/12/05, 11/15/05, 12/12/05, 01/16/06, 02/13/06, 03/13/06 |
| Backwash Water | Backwash Discharge Line from Each Oxidation/ Filtration Vessel | 3 | Monthly | As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, TDS, TSS, turbidity, | 10/13/05, 12/05/05, 01/12/06, 02/02/06, 02/27/06, 03/24/06 |

(a) Abbreviations in parentheses corresponding to sample locations shown in Figure 4-5.
(b) Four baseline sampling events performed from April to July 2005 before system became operational.
(c) Taken only at AC, OT, and TT locations.
LCR = lead and copper rule; TDS = total dissolved solids; TSS = total suspended solids

within the distribution system, including the Park Clubhouse and Lots 12 and 76 Residences. Following system startup, distribution system sampling continued on a monthly basis at the Park Clubhouse and Lot 76 Residence. Due to availability issues, the Lot 12 Residence was replaced by a non-LCR location at the Lot 16 Residence.

The homeowners of the two residences and the Park adminstrator collected samples following an instruction sheet developed according to the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The dates and times of last water usage before sampling and sample collection were recorded for calculation of the stagnation time. All samples were collected from a cold-water faucet that had not been used for at least 6 hr to ensure that stagnant water was sampled.

### 3.4 Sampling Logistics

**3.4.1 Preparation of Arsenic Speciation Kits.** The arsenic field speciation method used an anion exchange resin column to separate the soluble arsenic species, As(V) and As(III) (Edwards et al., 1998). Resin columns were prepared in batches at Battelle laboratories 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-printed, color-coded label consisting of sample identification (ID), date and time of sample collection, collector's name, site location, sample destination, analysis required, and preservative. The sample ID consisted of a two-letter code for a specific water facility, sampling date, a two-letter code for a specific sampling location, and a one-letter code designating the arsenic speciation bottle (if necessary). The sampling locations at the treatment plant were color-coded for easy identification. The labeled bottles for each sampling location were placed in separate ziplock™ bags and packed in a 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 off-site analyses were packed carefully in the original coolers with wet ice and shipped to Battelle. Upon receipt, the sample custodian verified that all samples indicated on the chain-of-custody forms were included and intact. Sample IDs were checked against the chain-of-custody forms, and the samples were logged into the laboratory sample receipt log. Discrepancies noted by the sample custodian were addressed with the plant operator by the Battelle Study Lead.

Samples for metals analyses were stored at Battelle's ICP-MS laboratory. Samples for other water quality analyses were packed in a cooler and picked up by a courier from American Analytical Laboratories (AAL) in Columbus, OH, which was under contract with Battelle for this demonstration study. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time, and disposed of properly thereafter.

### 3.5 Analytical Procedures

The analytical procedures described in detail in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2004) were followed by Battelle ICP-MS and AAL. Laboratory quality assurance/quality control (QA/QC) of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection limits (MDL), and completeness met the criteria established in the QAPP (i.e., relative percent difference [RPD] of 20%, percent recovery of 80 to 120%, and completeness of 80%). The quality assurance (QA) data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project.

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

# 4.0 RESULTS AND DISCUSSION

## 4.1 Facility Description and Pre-existing Treatment System Infrastructure

The water treatment system has a total of 226 connections and serves a population of approximately 600 in the Chateau Estates Mobile Home Park Community in Springfield, OH. Source water for the Park is groundwater supplied from two bedrock wells, the West Well and the East Well located near the pump house (Figure 4-1) at 3454 Folk Ream Road. As reported by the operator, the West Well produces about 150 gpm, and the East Well produces about 90 gpm. Before the installation of the treatment system, only the West Well was in operation. Both wells are 8-in in diameter and were originally installed to a depth of 100 ft below ground surface (bgs). In 2001, the East Well was extended to a depth of 220 ft bgs.


**Figure 4-1. Pre-Existing Treatment Building at Chateau Estates Mobile Home Park**

The pre-existing water treatment system consisted of chlorination using a 12.5% NaOCl solution and addition of polyphosphate as a sequestering agent for corrosion and scale control. Figure 4-2 shows the chlorine and polyphosphate storage tanks and chemical metering pumps. Following chlorination and polyphosphate addition, extracted water was stored in a 2,000-gal hydropnuematic tank (Figure 4-3) prior to entering the distribution system.

Before the installation of the water treatment system, the West Well typically operated for approximately 5 hr/day, producing around 40,000 gal of water based on estimates provided by the facility. To help verify the flowrate of the West Well and the average flowrate to the distribution system from the existing hydropnuematic tank, a flow meter was installed downstream of the hydropnuematic tank in mid-November 2004. Readings from the flow meter and an hour meter (installed in early December 2004) on


**Figure 4-2. Pre-Existing Chlorine and Polyphosphate Addition Systems**

the West Well pump were collected until the end of February 2005. These readings confirmed that, on average, the West Well pump operated 5.6 hr/day and produced an average of 43,740 gal.

The average flowrate produced by the supply well was calculated based on the volume of water extracted and the hours of operation per day; the average flowrate from the supply well was calculated to be 131 gpm, less than the 150-gpm design flowrate assumed for the West Well. The average instantaneous flow reading collected from the hydropnuematic tank to the distribution system was 33 gpm. Figure 4-4 shows the instantaneous flow readings and calculated flowrate from the West Well.

**Source Water Quality.** Source water samples were collected on August 5, 2004, for the West Well and on September 9, 2004, for the East Well. Samples were analyzed for the analytes shown in Table 3-3. The analytical results from source water sampling events are presented in Table 4-1 and compared to data collected by the facility for the EPA demonstration site selection. Historic water quality data at the entry point and from the distribution system also were obtained from the Ohio Environmental Protection Agency (Ohio EPA) and the site owner, respectively, and are summarized in Table 4-1.

Total arsenic concentrations in source water (from both wells) ranged from 14.6 to 25.0 µg/L. Based on the sampling results obtained by Battelle, arsenic existed almost entirely as As(III) (24.7 µg/L) in the West Well. Arsenic in the East Well existed as As(III) (6.1 µg/L), As(V) (2.8 µg/L), and particulate As (5.7 µg/L). Total arsenic concentration in the West Well was much higher than that in the East Well (i.e., 24.6 versus 14.6 µg/L). The variations in concentration and species between these two wells were carefully monitored during the course of the demonstration study and are discussed in Section 4.5.1.

Total iron concentrations in source water ranged from 636 to 1,615 µg/L, which exceed the secondary maximum contaminant level (SMCL) of 300 µg/L. The most recent sampling results obtained by Battelle show iron concentrations in the West Well at 1,615 µg/L (existing almost entirely in the soluble form)


**Figure 4-3. Pre-Existing Storage Tank**

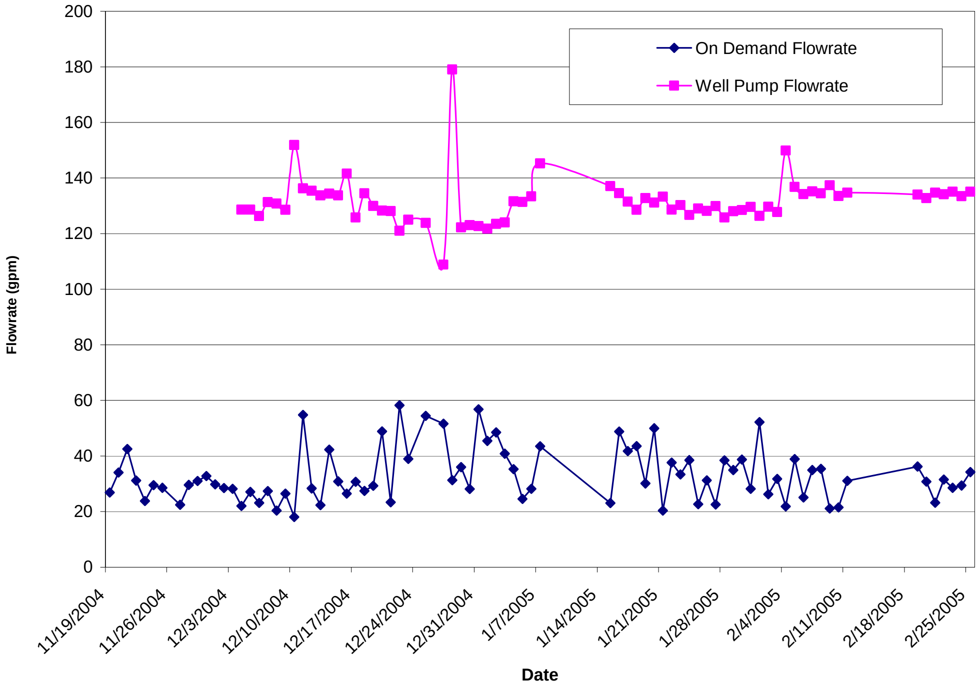


**Figure 4-4. West Well Pump Flowrate and On-Demand Flowrate**

**Table 4-1. Chateau Estates Mobile Home Park Water Quality Data**

| Parameter | Unit | Facility Data | Battelle Data | | Historical Data | |
|---|---|---|---|---|---|---|
| | | | West Well | East Well | Entry Point | Distribution |
| ***Date*** | | | 08/05/04 | 09/09/04 | 1995–2005 | 1998–2004 |
| pH | | NA | NA | 7.3 | 7.3 | NA |
| Conductivity | μmhos | NA | NA | NA | NA | NA |
| Temperature | °C | NA | 14.5 | 12.9 | NA | NA |
| DO | mg/L | NA | 0.8 | 3.4 | NA | NA |
| ORP | mV | NA | -88 | -25 | NA | NA |
| Total Alkalinity (as CaCO3) | mg/L | NA | 319 | 343 | 325 | NA |
| Hardness (as $CaCO_3$) | mg/L | 256 | 381 | 291 | NA | NA |
| Turbidity | NTU | NA | 23.0 | 6.5 | 1.07–1.4 | 0.3–17.3 |
| TDS | mg/L | NA | 418 | 372 | NA | NA |
| TOC | mg/L | NA | <1.0 | <0.7 | NA | NA |
| Nitrate | mg/L | NA | <0.04 | <0.04 | <0.05–0.33 | NA |
| Nitrite | mg/L | NA | <0.01 | <0.01 | <0.05 | NA |
| Ammonia | mg/L | NA | 0.24 | 0.17 | NA | NA |
| Chloride | mg/L | NA | 14 | 1.4 | 140 | NA |
| Fluoride | mg/L | NA | 1.5 | 0.8 | 0.85–1.64 | NA |
| Sulfate | mg/L | 19.3 | 27 | 15 | 20–33 | NA |
| Silica (as $SiO_2$) | mg/L | 11.3 | 19.4 | 17.5 | 16–18 | NA |
| Orthophosphate | mg/L | NA | <0.10 | <0.10 | NA | NA |
| As(total) | μg/L | 25.0 | 24.6 | 14.6 | 15–27.2 | 4.0–543 |
| As (total soluble) | μg/L | NA | 24.3 | 8.9 | NA | NA |
| As (particulate) | μg/L | NA | 0.3 | 5.7 | NA | NA |
| As(III) | μg/L | NA | 24.7 | 6.1 | NA | NA |
| As(V) | μg/L | NA | <0.1 | 2.8 | NA | NA |
| Fe (total) | μg/L | 1,078 | 1,615 | 636 | 738–2,570 | 40–44,800 |
| Fe (soluble) | μg/L | NA | 1,635 | 385 | NA | NA |
| Mn (total) | μg/L | 35.0 | 18.5 | 62.3 | <0.02–43 | NA |
| Mn (soluble) | μg/L | NA | 18.8 | 56 | NA | NA |
| U (total) | μg/L | NA | 0.9 | 1.45 | NA | NA |
| U (soluble) | μg/L | NA | 0.8 | 1.6 | NA | NA |
| V (total) | μg/L | NA | 0.2 | 0.41 | NA | NA |
| V (soluble) | μg/L | NA | 0.2 | 0.27 | NA | NA |
| Sb (total) | μg/L | NA | NA | 0.30 | <4 | NA |
| Na (total) | mg/L | 7 | 11.3 | 14.8 | 10–12 | NA |
| Ca (total) | mg/L | 68 | 89 | 67 | 68–73 | NA |
| Mg (total) | mg/L | 21 | 39 | 30 | 31–33 | NA |

N/A = not analyzed

and in the East Well at 636 μg/L (with 60% existing in the soluble form). The presence of particulate iron in the East Well water sample was consistent with the presence of particulate arsenic in the same water. The presence of particulate iron and arsenic in the East Well water, however, needed to be verified during the demonstration study to ensure that these results were not caused by inadvertent aeration of the sample during sampling. Note that the DO and ORP values of the East Well sample were significantly higher than those of the West Well sample.

Manganese concentrations in source water ranged from 18.5 to 62.3 µg/L. The sampling results obtained by Battelle show manganese concentrations in the West Well at 18.5 µg/L (existing entirely in the soluble form) and in the East Well at 62.3 µg/L (with 90% existing in the soluble form). Based on the relatively high iron and manganese concentrations in source water, the selected vendor proposed to include a pre-treatment step for iron and manganese removal prior to arsenic removal.

pH values of source water were consistently around 7.3. Typically, the target pH range for the use of adsorption with iron-based media for arsenic removal is 6.0 to 8.0. The pH value of 7.3 was well within this range; therefore, pH adjustment was not included for the arsenic treatment system.

Arsenic adsorption may be influenced by the presence of competing anions such as silica, sulfate, and phosphate. AD-33 was reported to be affected by silica at levels greater than 40 mg/L, sulfate at levels greater than 150 mg/L, and phosphate at levels greater than 1 mg/L (AdEdge, 2005). The silica levels ranged from 11.3 to 19.4 mg/L, the sulfate levels ranged from 15 to 27 mg/L, and the orthophosphate levels were less than the method detection limit; therefore, the presence of these anions should not have a significant impact on arsenic adsorption.

Other analyzed water quality parameters showed low concentrations or less than method detection limits of ammonia, nitrate, nitrite, fluoride, uranium, vanadium, antimony, and total organic carbon (TOC). The hardness levels ranged from 256 to 381 mg/L, which existed mainly as calcium hardness.

**4.1.2 Pre-Demonstration Treated Water Quality.** Results of the treated water samples collected at the entry point and from the distribution system from 1995 through 2005 were obtained from Ohio EPA and the facility and are summarized in Table 4-1. The concentrations of some constituents were considerably higher in the distribution system than those in raw water at the entry point. For example, arsenic concentrations in the distribution system ranged from 4.0 to 543 µg/L (versus 14.6 to 26.0 µg/L in raw water and 15 to 27.2 µg/L at the entry point). Iron concentrations in the distribution system ranged from 40 to 44,800 µg/L (versus 636 to 1,615 µg/L in raw water and 738 to 2,570 µg/L at the entry point). Elevated arsenic and iron concentrations in the distribution system might be caused by accumulation of particulate matter and/or corrosion products in the distribution system. The facility has been flushing the eleven fire hydrants located throughout the distribution system on a monthly basis.

**4.1.3 Distribution System.** Based on the information provided by the facility, the water mains within the distribution system are constructed primarily of polyvinyl chloride (PVC) and some copper piping. There also are a few sections of iron pipe installed at the wellhouse at the entry point to the distribution system. The laterals coming off the mains and leading to the individual mobile home units consist of copper and black polyethylene. The piping within the mobile home units is typically PVC, copper, or polybutylene. No lead pipe or lead solder was installed and/or used. Eleven fire hydrants are located throughout the distribution system. Fire hydrants are flushed once a month to remove sediment that builds up in the distribution system.

The LCR samples are collected at five locations every three years. Additional compliance samples include arsenic and iron collected monthly at locations throughout the distribution system and bacteria/total coliform collected monthly. The facility also samples for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), inorganics, nitrate, and radionuclides as directed by the Ohio EPA, typically once every two to three years.

## 4.2 Treatment Process Description

The treatment system consists of two integrated units referred to as an AD-26 pre-treatment system and an AD-33 arsenic package unit (APU) adsorption system. The AD-26 pretreatment system is for iron and manganese removal, followed in series by the APU adsorption system for arsenic removal. The treated water exiting the APU adsorption system is sent to distribution.

AD-26 media is a manganese dioxide mineral commonly used for oxidation and filtration of iron and manganese. The media has NSF Standard 61 approval for use in drinking water applications. Table 4-2 provides physical and chemical properties of the AD-26 media.

Raw water was first treated with chlorine to provide oxidation prior to the AD-26 media. The use of chlorine helped precipitate soluble iron and convert As(III) to As(V). The As(V) formed was adsorbed onto the precipitated iron solids, which in turn, were filtered out by the AD-26 media. Thereby, the media acted primarily as a filter.

Following the oxidation/filtration system, the pre-treated water was sent to the APU system as a polishing step. AdEdge's APU arsenic removal system is designed for small systems in the flow range of 10-300 gpm. The APU is a fixed bed adsorption system that uses Bayoxide E33 media, an iron-based adsorptive media developed by Bayer AG and branded and referred to as AD-33 by AdEdge, for removal of arsenic in small drinking water systems. Table 4-3 presents physical and chemical properties of the AD-33 media. AD-33 is delivered in a dry crystalline form and has NSF Standard 61 approval for use in drinking water applications. Once reaching capacity, the spent media may be removed and disposed of after being subjected to EPA's TCLP test.

Both the AD-26 oxidation/filtration and the APU systems are skid-mounted, each comprised of three carbon steel pressure vessels of similar construction and configuration but of different sizes. Table 4-4 presents the key system design parameters. Figure 4-5 shows the generalized process flow for the system including sampling locations and parameters to be analyzed. Six key process components are discussed as follows:

- **Intake.** Raw water was pumped from the supply wells, i.e., the West and East Wells, alternating every cycle, and fed to the AD-26 oxidation/filtration system.

- **Chlorination.** Prior to the AD-26 oxidation/filtration system, water was chlorinated using a 12.5% liquid NaOCl solution injected to the 4-in PVC line. Chlorine oxidized arsenic and iron and maintained chlorine residual for disinfection. The automatic chlorine injection system was composed of a solenoid driven diaphragm metering pump with a maximum capacity of 2 gal/hr, an in-line chlorine probe, a chlorine monitor/control module equipped with a flow sensor, and a 75-gal polyethylene chemical feed tank with secondary containment. A side-stream of water was directed, via 0.188-in inner diameter (i.d.) polyethylene tubing, from a valve located approximately 12-ft downstream of the chlorine injection point and an inline mixer to the chlorine monitor/controller module. The chlorine injection pump was turned on and off initially by the flow sensor (so that chlorine was injected only when there was on-demand flow flowing through the treatment system and, therefore, the chlorine monitor/controller module), but later by the well pumps (so that chlorine was injected only when a well was on). Further, the feedback from the inline probe to the monitor/controller module relative to a free chlorine set point automatically adjusted the injection rate (in terms of pulses per minute) of the chlorine metering pump. The proper operation of the NaOCl feed system was tracked by the operator through measurements of free and total chlorine across the treatment train and at the entry point. Figure 4-6 is a composite of photographs of the chlorine feed system and its components.

- **Iron/Manganese Removal.** When a well was on, prechlorinated water entered the AD-26 oxidation/filtration system at an average flowrate of 130 gpm (Table 4-4) and exited the

**Table 4-2. Physical and Chemical Properties of AD-26 Media[(a)]**

| Parameter | Value |
|---|---|
| Matrix | Manganese Dioxide Mineral (>80% active ingredient) |
| Physical Form | Dry Granular Media |
| Color | Black |
| Bulk Density (lbs/ft$^3$) | 120 |
| Moisture Content (%) | <10 (by weight) |
| Particle Size Distribution (U.S. Standard Mesh) | 20 × 40 |
| Oxidant | 12.5% NaOCl |

(a) Provided by AdEdge.

**Table 4-3. Physical and Chemical Properties of AD-33 Media[(a)]**

| ***Physical Properties*** | |
|---|---|
| **Parameter** | **Value** |
| Matrix | Iron Oxide Composite |
| Physical Form | Dry Pellets |
| Color | Amber |
| Bulk Density (lb/ft$^3$) | 35 |
| BET Area (m$^2$/g) | 142 |
| Attrition (%) | 0.3 |
| Moisture Content (%) | <15 (by weight) |
| Particle Size Distribution (U.S. Standard Mesh) | 10 × 35 |
| Crystal Size (Å) | 70 |
| Crystal Phase | $\alpha$ – FeOOH |
| ***Chemical Analysis*** | |
| **Constituents** | **Weight (%)** |
| FeOOH | 90.1 |
| CaO | 0.27 |
| MgO | 1.00 |
| MnO | 0.11 |
| $SO_3$ | 0.13 |
| $Na_2O$ | 0.12 |
| $TiO_2$ | 0.11 |
| $SiO_2$ | 0.06 |
| $Al_2O_3$ | 0.05 |
| $P_2O_5$ | 0.02 |
| Cl | 0.01 |

(a) Provided by Bayer AG.
BET = Brunauer, Emmett, and Teller.

system to the three new hydropnuematic tanks. The AD-26 oxidation/filtration system consisted of three 36-in-diameter, 60-in-sidewall height carbon steel pressure vessels configured in parallel. Each vessel was filled with 31 in (19 ft$^3$) of AD-26 media, which was underlain by 7 in (5 ft$^3$) of fine underbedding. The AD-26 system was controlled by electrically actuated butterfly valves and a centralized programmable logic controller (PLC) unit. Figure 4-7 is a photograph of the AD-26 system.

**Table 4-4. Design Features of AdEdge Treatment System**

| Parameter | Value | Remarks |
|---|---|---|
| ***Influent Specifications*** | | |
| Peak Design Flowrate (gpm) | 250 | System upsized from 150 gpm at Park Owner's request |
| West Well Flowrate (gpm) | 130 | Average flowrate based on totalizer and well pump hour meter readings |
| East Well Flowrate (gpm) | 90 | Based on information received from facility |
| Average Throughput to System (gpd) | 40,000 | – |
| Arsenic Concentration (μg/L) | 24.6 | – |
| Iron Concentration (μg/L) | 1,615 | – |
| ***Prechlorination*** | | |
| Chlorine Dosage (mg/L [as $Cl_2$]) | 2.5 | 1.0 mg/L residual chlorine within distribution system |
| ***AD-26 – Oxidation/Filtration*** | | |
| No. of Vessels | 3 | – |
| Configuration | Parallel | – |
| Vessel Size (in) | 36 D × 60 H | – |
| Type of Media | AD-26 | – |
| Quantity of Media ($ft^3$/vessel) | 19 | 57 $ft^3$ total |
| Flowrate through Each Vessel (gpm) | 43 | Total flowrate of 130 gpm through AD-26 system |
| Backwash Flowrate through Each Vessel (gpm) | 130 | 18.4 gpm/$ft^2$ |
| Backwash Duration (min) | 15 | Per Vessel |
| Expected Backwash Frequency (times/week) | 3 | Actual backwash frequency to be determined during system operation |
| Estimated AD26 Media Life (yr) | 4 | Vendor provided estimate |
| ***AD-33 Adsorption*** | | |
| No. of Vessels | 3 | – |
| Configuration | Parallel | – |
| Vessel Size (in) | 48 D × 60 H | – |
| Type of Media | AD-33 | Bayoxide E33 |
| Quantity of Media ($ft^3$/vessel) | 38 | 114 $ft^3$ total |
| Flowrate through Each Vessel (gpm) | on-demand | |
| EBCT (min/vessel) | 25.8 | Based on average on-demand flowrate of 33 gpm measured prior to demonstration study (Figure 4-4). |
| Backwash Flowrate (gpm) | 127 | 10 gpm/$ft^2$ |
| Backwash Duration (min) | 15 | Per Vessel |
| Expected Backwash Frequency (times/60 days) | 1 | Actual backwash frequency to be determined during system operation |
| Bed Volumes (BV)/Day | 47 | Based on throughput of 40,000 gpd, 1 BV = 114 $ft^3$ |
| Estimated Working Capacity (BV) | 83,500 | Bed volumes to breakthrough at 10 μg/L based on vendor estimate |
| Estimated Volume to Breakthrough (gal) | 71,200,000 | Vendor provided estimate |
| Estimated AD33 Media Life (yr) | 4.9 | Estimated frequency of media change-out based on estimated media working capacity of 83,500 BVs and average throughput of 40,000 gpd to system |

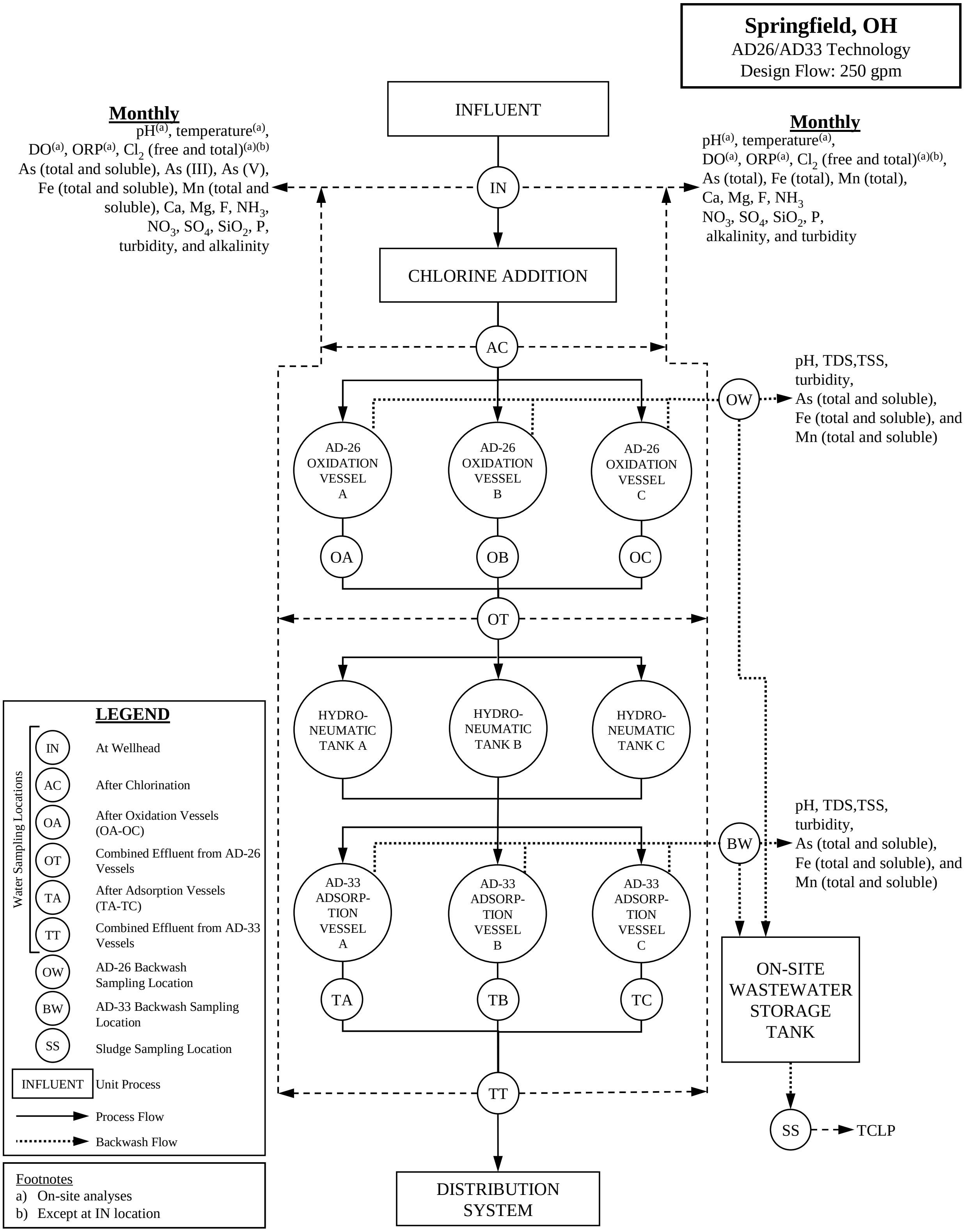


**Figure 4-5. Process Flow Diagram and Sampling Location**


**Figure 4-6. Chlorine Injection System**
*(Clockwise from Top: Chlorine Injection Point; Chlorine Monitor/Control Module; Chlorine Injection System; Metering Pump; Chlorine Sensor; Chlorine Monitor/Controller)*

**Figure 4-7. AD-26 Treatment System**

- **Hydropnuematic Tanks.** The filtered water from the AD-26 system entered the three hydropnuematic tanks for storage until needed to meet demand. Each tank had a storage capacity of 528 gal for a total capacity of 1,584 gal. Figure 4-8 is a photograph of the three hydropnuematic tanks.

**Figure 4-8. Hydropnuematic Tanks**

- **Arsenic Adsorption.** Upon demand, water stored in the hydropnuematic tanks flowed through the APU arsenic adsorption system at a varying flowrate. As discussed in Section 4.1, flowrates ranging from 18.1 to 58.2 gpm and averaging 33.0 gpm (Figure 4-4) were recorded flowing from the existing hydropnuematic tank to the distribution system during a pre-demonstration water demand study. The APU system consisted of three 48-in-diameter, 60-in-sidewall height carbon steel pressure vessels also configured in parallel. Each of the APU vessels contained approximately 38 $ft^3$ (114 $ft^3$ total) of AD-33 media. Assuming a flowrate of 33.0 gpm (or 11.0 gpm/vessel), the media empty bed contact time (EBCT) in each vessel would be 25.8 min, which is at least 5 times higher than that recommended by the vendor. Figure 4-9 is a photograph of the APU system. Similar to the AD-26 system, the APU system was controlled by a series of electrically actuated butterfly valves and the PLC unit. Figure 4-10 presents a photograph of the APU control panel.

- **Backwash.** Both the AD-26 and APU systems required backwashing to remove particulates and solids that build up in the media beds. Both systems could be set to initiate backwash automatically based on differential pressure (Δp) measured across the individual pressure vessels, system run time, or volume of water treated. Each vessel was backwashed one at a time using water stored in the hydropnuematic tanks.

**Figure 4-9. AD-33 Treatment System**

**Figure 4-10. System Control Panel**

For the AD-26 system that filtered arsenic laden-iron solids and manganese solids, backwash was performed every two to three days. Backwash was adjusted on February 9, 2006, from once every 2 days for 15 min per vessel to once every 3 days for 9 min per vessel, with a 2- or 1.5-min filter-to-waste rinse at a flowrate of 130 gpm. After the adjustment, the amount of wastewater produced should have been reduced from approximately 6,630 to 4,100 gal for the three vessels.

For the APU system, backwash was set initially for manual control. The backwash duration was 15 min and the backwash flowrate was at 127 gpm. The backwash water produced from the three vessels was approximately 5,850 gal. Due to a power outage at the end of November 2005, which reverted settings back to default, the APU vessels were backwashed automatically once every 60 days. The backwash water was collected in two 6,000-gal onsite storage tanks. A vacuum truck picked up the backwash water weekly and disposed of it off-site at the Village of North Hampton sewer system.

- **Media replacement.** When AD-26 and AD-33 media exhaust their capacities, the spent media will be removed from the vessels and disposed of. Virgin media will be loaded into the vessels. Media replacement was not performed during the first six-months of operation.

## 4.3 System Installation

The installation of the treatment system was completed by LBJ Inc., a subcontractor to AdEdge, on September 2, 2005. The following briefly summarizes some of the system/building installation activities, including permitting, building preparation, system offloading, installation, shake-down, and start-up.

**4.3.1 Permitting.** Design drawings and a process description of the proposed treatment system were submitted to the Ohio EPA by LBJ, Inc., on May 27, 2005. Ohio EPA's review comments were received on June 21, 2005. The comments were related to redundancy, sampling requirements, disinfection practice, and minimum empty bed contact time. After incorporating the responses to the comments, the plans were resubmitted to Ohio EPA on June 30, 2005. Ohio EPA granted the treatment system permit on July 6, 2005.

**4.3.2 Building Preparation.** The existing building housing the pre-existing treatment system needed modifications for the planned arsenic treatment system. The necessary additional preparation included removing the ceiling joists, cutting into the floor to install sub-floor piping, removing the 2,000-gal pre-existing hydropnuematic tank, and pouring a pad for the three new hydropnuematic tanks. The building construction began on July 15, 2005, and was completed on August 15, 2005.

**4.3.3 Installation, Shakedown, and Startup.** The treatment system arrived at the site on August 10, 2005. The installation activities, which lasted about two weeks, included removing the existing hydropnuematic tank, offloading and placing the AD-26 oxidation/filtration and AD-33 APU systems and the three new hydropnuematic tanks within the building, connecting system piping at the tie-in points, completing electrical wiring and connections, and assembling the chlorine injection system.

Upon completion of system installation, the media vessels were tested hydraulically before media loading on September 1, 2005. For the APU system, six 100-lb bags of coarse gravel (for a total of 600 lb [or 6 $ft^3$]), three 100-lb bags of fine gravel (for a total of 300 lb [or 3 $ft^3$]), and one and one fifth 1,100-lb supersacks of the AD-33 media (for a total of 1,330 lb [or 38 $ft^3$]) were loaded sequentially into each vessel containing approximately half a tank of water. Figure 4-11 shows a photograph of loading the AD-33 media from a supersack through a hatch on the roof of the building. Each AD-26 vessel was loaded with five 100-lb bags of fine gravel (for a total of 500 lb [or 5 $ft^3$]) and then approximately 41 55-lb bags


**Figure 4-11. AD-33 Media Loading**

of the AD-26 media (for a total of 2,255 lb [or 19 $ft^3$]) with the vessel containing about half a tank of water. Figure 4-12 is a composite of pictures showing the media bags and media loading into one of the AD-33 vessels.

After media loading, the vessels were backwashed one at a time to remove media fines. Backwashing continued until the backwash water ran clear. Freeboard measurements were then taken from where the straight side of the tank starts to the top of media. For the AD-26 oxidation/filtration vessels, the freeboard to the top of the media was measured at 24 to 25 in, which, based on the 55-in freeboard to the top of the underbedding gravel, would yield a bed depth of 30 to 31 in (compared to the design value of 32 in). For the AD-33 adsorption vessels, the freeboard measurements to the top of the media ranged from 24 to 26 in, which, based on the freeboard measurement of 58 in to the top of gravel, would result in a bed depth of 32 to 34 in (compared to the design value of 36 in).

After the media was loaded and backwashed, the vendor and plant operator performed system shakedown and startup work, which included checking system control and interlocking, testing for balanced flows among individual vessels, and adjusting chlorine injection and control. The system was then sanitized with a 12.5% NaClO according to the Ohio EPA procedure. A water sample was collected for bacteria analysis and the system was bypassed until the results of the bacteria analysis were received.

After the satisfactory results of the bacteria analysis had been forwarded to Ohio EPA, the system was officially put online on September 21, 2005. Battelle conducted a system inspection and provided operator training on data and sample collection on September 28, 2005.

The configuration of the system as it was initially installed allowed water to flow from one of the wells into the three hydropnuematic tanks until demand in the distribution system forced water, after chlorination, to flow through the AD-26 oxidation/filtration and AD-33 adsorption systems. Due to difficulties encountered when attempting to maintain a stable chlorine residual level in the treated water (see discussion in Section 4.4.2), the system was reconfigured on October 26, 2005, to allow the chlorine addition system and the AD-26 oxidation/filtration vessels to locate prior to the hydropnuematic tanks. As such, the chlorine injection pump and the AD-26 system could operate based on the well flowrate of either 130 or 90 gpm (depending on the operating well). Downstream from the hydropnuematic tanks, the AD-33 adsorption system operated on-demand as before. This configuration improved the chlorine feed system for a more steady feed into the head of the treatment system.


**Figure 4-12. AD-33 Media Supersack, AD-26 Media Bags and Loading of Underbedding**

## 4.4 System Operation

**4.4.1 Operational Parameters.** The operational parameters for the first six months of the system operation were tabulated and are attached as Appendix A. Key parameters are summarized in Table 4-5. As discussed in Section 4.3.3, the AdEdge treatment system operated on-demand from the system startup on September 21, 2005, through October 25, 2005. Since then, the system piping was retrofitted so that the chlorine injection system and AD-26 oxidation/filtration system would operate at pump flowrates and the AD-33 adsorption system would operate on-demand as before. During the first six months of system operation from September 21, 2005, through March 26, 2006, the West Well pump ran for a total of 974 hr with a daily average of 5.4 hr/day (Note: 5.4 hr/day was used to calculate cumulative hours from September 28 through October 21, 2005, during which an hour meter was not available at the well pump), and the East Well pump ran for a total of 686 hr with a daily average of 3.8 hr/day (Note: East Well stopped running during October 27 through 31 due to replacement of the old well piping). The combined

**Table 4-5. Summary of APU-250 System Operation**

| Operational Parameter | Value/Condition | | | |
|---|---|---|---|---|
| Duration | 09/21/05 -03/26/06 | | | |
| ***Well Pumps*** | | | | |
| Daily Run Time (hr/day) | Well | Range | Average | |
| | West | 0.7 – 10.4 | 5.4 | |
| | East | 0.2 – 7.8 | 3.8 | |
| | Combined | 3.7 – 15.1 | 9.2 | |
| ***AD-26 Oxidation/Filtration System*** | | | | |
| Time Operated (hr) | 1,421[a] | | | |
| Throughput (gal) | Vessel | 09/21/05 – 11/28/05 | 11/28/05 – 03/26/06 | |
| | A | 514,502 | 1,664,484 | |
| | B | 1,330,884 | 2,039,922 | |
| | C | 1,095,615 | 2,131,453 | |
| | Combined | 2,941,001 | 5,835,859 | |
| | Total | 8,776,860 | | |
| Flowrate before Retrofit (gpm)[b] | Vessel | Range | Average | |
| | A | 0 | NA | |
| | B | 11 – 28 | 17 | |
| | C | 6 – 24 | 12 | |
| | Combined | 17 – 52 | 29 | |
| Flowrate after Retrofit (gpm) [b] | Vessel | Range | Average | |
| | A | 14 – 40 | 29 | |
| | B | 17 – 49 | 36 | |
| | C | 18 – 51 | 37 | |
| | Combined | 49 – 140 | 102 | |
| | Cal. Combined[c] | 30 – 128 | 89 | |
| Vessel/System Pressure and ΔP (psi) | Vessel | Inlet | Outlet | ΔP |
| | A | 49 (36 – 60) | 45 (33 – 58) | NA |
| | B | 46 (36 – 58) | 46 (36 – 58) | NA |
| | C | 47 (28 – 58) | 48 (28 – 58) | NA |
| | System | 48 (16 – 60) | 46 (33 – 55) | 3 (0 – 9) |
| ***AD-33 Adsorption System*** | | | | |
| Throughput (gal) | Vessel | 09/21/05 – 11/28/05 | 11/28/05 – 03/26/06 | |
| | D | 884,259 | 1,728,900 | |
| | E | 1,067,843 | 2,152,272 | |
| | F | 740,679 | 1,560,330 | |
| | Combined | 2,742,781 | 5,441,502 | |
| | Total | 8,184,283 | | |
| Bed Volume (BV) | 9,540 | | | |
| Flowrate (gpm) | Vessel | Range | Average | |
| | D | 5 – 17 | 11 | |
| | E | 5 – 22 | 13 | |
| | F | 3 – 17 | 9 | |
| | Combined | 9 – 56 | 33 | |
| EBCT (min)[d] | Vessel | Range | Average | |
| | D | 16.7 – 56.9 | 25.8 | |
| | E | 12.9 – 56.9 | 21.9 | |
| | F | 16.7 – 94.8 | 31.6 | |
| | Combined | 5.1 – 31.6 | 25.8 | |
| Vessel/System Pressure and ΔP (psi) | Vessel | Inlet | Outlet | ΔP |
| | D | 48 (36 – 60) | 51 (31 – 60) | NA |
| | E | 48 (36 – 58) | 48 (36 – 58) | NA |
| | F | 47 (32 – 56) | 47 (36 – 56) | NA |
| | System | 47 (35 – 56) | 48 (35 – 58) | 0 |

(a) From October 26, 2005, through March 26, 2006.
(b) System piping retrofitted on October 26, 2005.
(c) Totalizer readings divided by sum of West Well and East Well hours.
(d) Calculated based on 114 $ft^3$ of media in adsorption system.

daily run times for both wells ranged from 3.7 to 15.1 hr/day and averaged 9.2 hr/day. The operating time of the APU vessels could not be determined due to the on-demand use of the system; however, since October 26, 2005 (after the system piping retrofit), the AD-26 system operated for 1,421 hr based on the hour meters at the well pumps. The system was bypassed for five days from November 29 through December 3, 2005, due to a power outage that caused problems with the control panel. This issue is discussed further in Section 4.4.5.

During the first six months, the system treated approximately 8,776,000 gal of water based on the totalizer readings for each of three AD-26 oxidation/filtration vessels or 8,184,000 gal for the three AD-33 adsorption vessels. The combined throughput for the AD-26 system was 7.2% higher than that for the AD-33 system. Significantly imbalanced flow was observed among the three AD-26 (Vessels A, B, and C) and three AD-33 vessels (Vessels D, E, and F). Before the totalizers were reset on November 28, 2005, due to a power outage, 17.5, 45.3, and 37.3% of the flow passed through Vessels A, B, and C, respectively. The exceptionally low flow through Vessel A was caused mainly by close to zero throughput through that vessel before October 26, 2005, when the AD-26 system operated on-demand. After the totalizer was reset and when the system was operating primarily at pump flowrates, a more even flow was observed, accounting for 28.5, 35.0, and 36.5% through Vessels A, B, and C, respectively. For the AD-33 vessels, 32.3, 38.9, and 28.8% of the flow passed through Vessels D, E, and F, respectively, before the totalizers were reset and 31.8, 39.6, and 28.7% after the totalizer rest.

Using the 8,184,000 gal throughput for calculations, 9,540 bed volumes (BV) of water were treated by the AD-33 system during the first six months of system operation. BV calculations were performed based on 114 $ft^3$ of media in the adsorption system. The instantaneous on-demand flowrates to the individual adsorption vessels ranged from 3 to 22 gpm with combined flowrates ranging from 9 to 56 gpm and averaging 33 gpm (Figure 4-13). This average on-demand flowrate is identical to that obtained just before the demonstration study.

Flowrates through the three AD-26 vessels were monitored using individual totalizers/flowmeters installed at the exit side of the vessels. Before the system piping retrofit, instantaneous on-demand flowrate readings taken from the meters ranged from 6 to 28 gpm for Vessels B and C, with combined flowrates ranging from 17 to 52 gpm and averaging 29 gpm (Table 4-5 and Figure 4-14). As noted above, little or no flow passed through Vessel A during this time period. After the system piping retrofit, the system operated at the well pump flowrates. The instantaneous flowrate readings taken from the meters ranged from 14 to 51 gpm for the three vessels with combined flowrates ranging from 49 to 140 gpm and averaging 102 gpm. The combined flowrates from the meter readings are compared in Figure 4-14 with the calculated flowrates derived by dividing the combined throughput values by the corresponding operating hours. As expected, the calculated flowrates were much less scattered than the instantaneous readings (i.e., 30 to 128 gpm [averaged 89] versus 49 to 140 gpm). The average flowrate obtained from the meter readings was closer to the operating time-weighted average (i.e., 117 gpm) of the West and East Wells flowrates (i.e., 130 and 90 gpm, respectively).

Based on the flowrates to the individual vessels and system, the EBCTs for the individual adsorption vessels varied from 12.9 to 94.8 min and averaged 26.4; the EBCTs for the system varied from 5.1 to 31.6 min and averaged 25.8 min. This EBCT is at least 5 times higher than what normally would be recommended by the vendor for iron-based adsorptive media.

The pressure loss across each AD-26 oxidation/filtration vessel ranged from 0-10 psi and averaged 2 psi. The inlet pressure of the AD-26 system ranged from 16-60 psi and averaged 48 psi, while the outlet pressure of the AD-26 system ranged from 33-55 psi and averaged 46 psi. The average differential pressure for the AD-26 system was 3 psi. The pressure loss across each AD-33 oxidation/filtration vessel

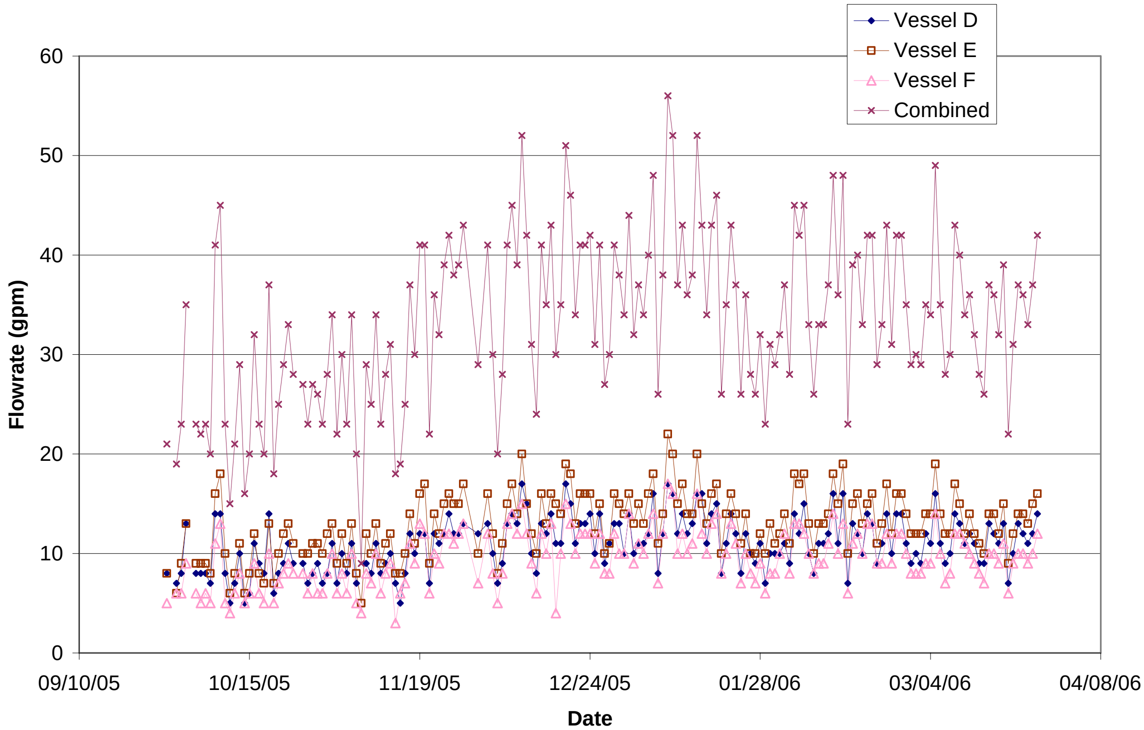


**Figure 4-13. AD-33 Adsorption System Flowrates**

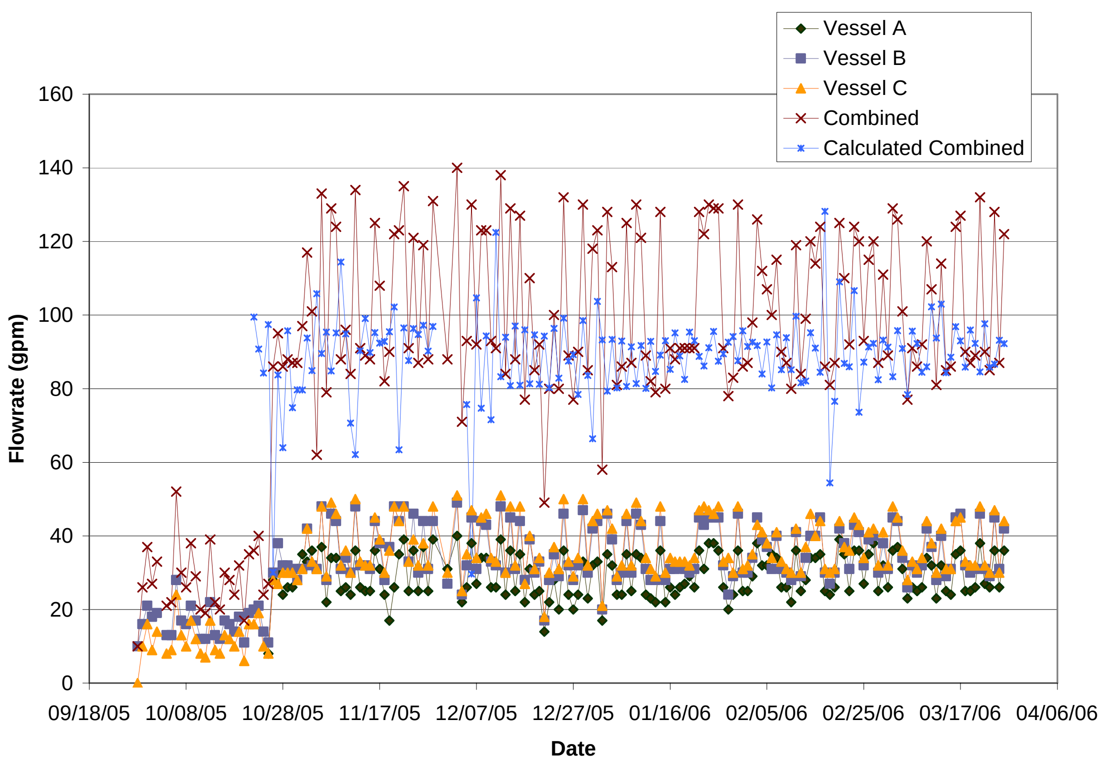


**Figure 4-14. AD-26 Oxidation/Filtration System Flowrates**

ranged from 0 to 7 psi and averaged 1 psi. The inlet pressure of the AD-33 system ranged from 35 to 56 psi and averaged 47 psi, while the outlet pressure of the AD-33 system ranged from 35 to 58 and averaged 48 psi. The average differential pressure for the AD-33 system was 0 psi.

**4.4.2 Chlorine Injection.** As described in Section 4.2, chlorine was added as an oxidant to oxidize As(III) and Fe(II) using a 12.5% NaOCl solution. The chlorine injection system experienced operational irregularities during the first six months of system operation, as reflected by a variation of free and total chlorine residuals measured at the entry point shown in Figure 4-15. After system startup, with a free chlorine set point of 2.5 mg/L (as $Cl_2$), free and total chlorine residuals varied considerably from 0.34 to 3.49 mg/L and from 0.43 to 3.91 mg/L (as $Cl_2$), respectively, which, at the time, were thought to have been caused by the fluctuating on-demand flow flowing through the treatment system. The system was, therefore, reconfigured on October 26, 2005, so that the chlorine addition system and the AD-26 system were located before the hydropnuematic tanks and operated based on the well flowrate of either 130 or 90 gpm. Table 4-6 summarizes timelines of the settings and activities associated with the chlorine injection system.

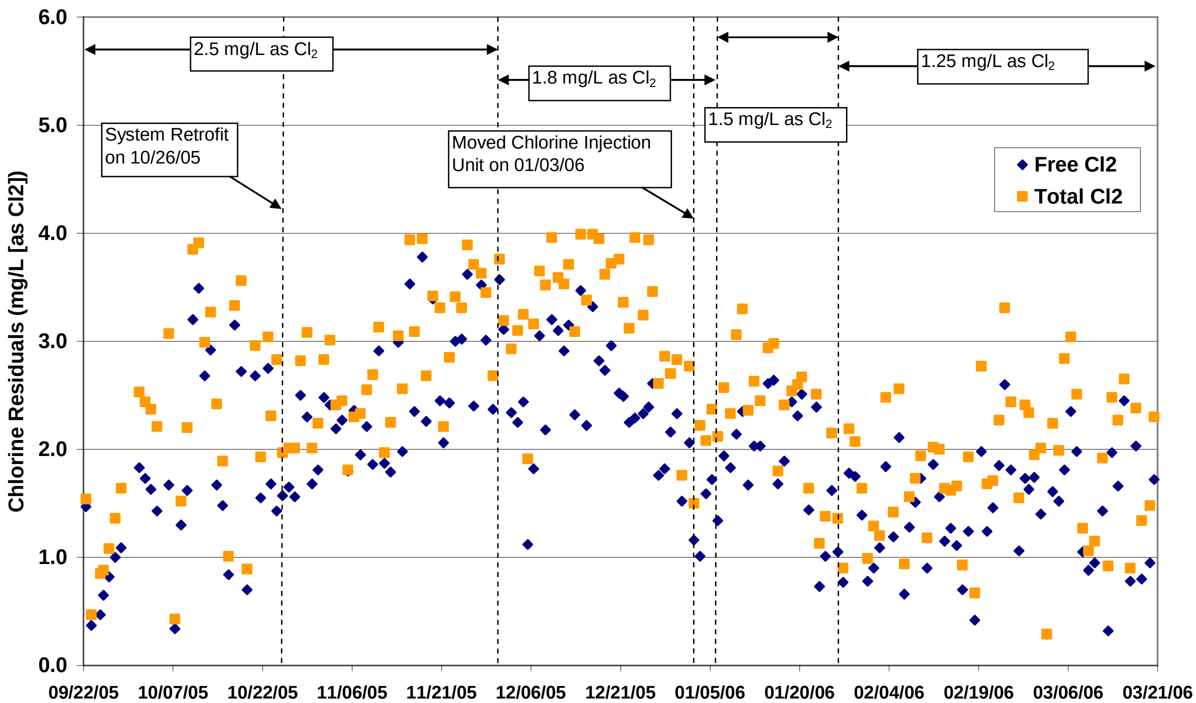


**Figure 4-15. Free and Total Chlorine Residuals at Entry Point**

After system reconfiguration, the free chlorine set point was maintained at 2.5 mg/L (as $Cl_2$). Although somewhat improved, the free and total chlorine residuals measured at the entry point continued to scatter, with concentrations ranging from 1.56 to 3.78 mg/L and from 1.81 to 3.95 mg/L (as $Cl_2$), respectively. On November 30, 2005, the free chlorine set point was decreased from 2.5 to 1.8 mg/L (as $Cl_2$), but the scattering of free and total chlorine residuals continued without significant improvement. On December 20, 2005, modification was made to the setting of pump stroke length in an attempt to reduce chlorine residuals. On January 3, 2006, in an attempt to shorten the response time of the chlorine controller, the chlorine injection system was relocated from the east wall of the wellhouse to approximately 20 ft to the west wall next to the AD-26 vessels and the chlorine injection point so that the length of the poly tubing was reduced from 25 to 30 ft to 5 to 10 ft. On January 6, 2006, the chlorine metering pump was interlocked to the well pumps so that it would operate only when one of the well pumps was on. In addition, on January 6 and 26, 2006, the free chlorine set point was further reduced from 1.8 to 1.5 and then, 1.25 mg/L (as $Cl_2$). The combination of these efforts caused a somewhat decreasing trend for the chlorine residuals at the entry point but the residuals continued to scatter significantly between 0.29 and 2.60 mg/L (as $Cl_2$) for free chlorine and between 0.29 and 3.31 mg/L (as $Cl_2$) for total chlorine.

In addition to the problems related to elevated free and total chlorine residuals, the presence of iron particles after chlorination caused the inline chlorine probe and tubing leading from the inline mixer to the chlorine probe to clog. As a result, erratic readings were taken by the chlorine monitor, causing a wide variation of chlorine levels in water. The operator has included the cleaning of the relevant system components as part of the routine system O&M. The vendor has been informed of the problems and continued to monitor and troubleshoot the problems.

**Table 4-6. Settings/Activities Associated with Chlorine Injection System**

| Operating Period | | Free Chlorine Setting[a] (mg/L [as $Cl_2$]) | Chlorine Metering Pump on/off Controlled by | Chlorine Metering Pump Stoke Length (%) | Poly Tubing Length[b] (ft) | Remarks |
|---|---|---|---|---|---|---|
| From | To | | | | | |
| 09/21/05 | 10/26/05 | 2.5 | Flow Sensor[c] | 50 | 25–30 | System piping retrofitted on 10/26/05. |
| 10/26/05 | 11/30/05 | 2.5 | Flow Sensor | 50 | 25–30 | |
| 11/30/05 | 12/20/05 | 1.8 | Flow Sensor | 50 | 25–30 | |
| 12/20/05 | 01/03/06 | 1.8 | Flow Sensor | 45 | 25–30 | Stroke length reduced to 45% on 12/20/05. |
| 01/03/06 | 01/06/06 | 1.8 | Flow Sensor | 45 | 5–10 | Chlorine injection system relocated on 01/03/06 to help reduce distance of poly tubing and response time of chlorine controller. |
| 01/06/06 | 01/26/06 | 1.5 | Well Pumps | 45 | 5–10 | Relay rewired from electrical panel to pumps on 01/06/06. |
| 01/26/06 | 03/26/06 | 1.25 | Well Pumps | 45 | 5–10 | |

(a) Feedback from chlorine probe to controller that automatically adjusted injection rate (pulse/min) of chlorine metering pump.
(b) Poly tubing that offshoot from main water line approximately 12 ft downstream from in-line mixer to the chlorine monitor/controller.
(c) Chlorine monitor/controller assembly.

**4.4.3 Backwash.** Table 4-7 summarizes the backwash settings and volume of wastewater produced from the three AD-26 oxidation/filtration vessels during the first six months of system operation. Figure 4-16 plotted the volume of wastewater produced over time. Under the initial settings (i.e., 15 min backwash and 2 min service-to-waste rinse), an average of 5,640 gal, or 85% of the expected volume, were produced from the three vessels during a backwash event. When the Park experienced the

**Table 4-7. AD-26 Backwash Settings and Volume of Wastewater Produced**

| Operating Period | | Backwash Settings | | | Average Volume of Wastewater Produced per Backwash Event | | |
|---|---|---|---|---|---|---|---|
| From | To | Backwash Duration (min) | Fast Rinse Duration (min) | Backwash Frequency (times/wk) | Expected Based on Settings (gal) | Actual (gal) | Remarks |
| 10/26/05 | 11/28/05 | 15 | 2 | 3 | 6,630 | 5,640[(a)] | Piping retrofit completed on 10/26/05; power outage occurred on 11/28/05 |
| 12/03/05 | 01/12/06 | 20 | 25 | 3 | 17,550 | 13,100 | System operation resumed on 12/03/05; PLC fixed on 01/12/06 |
| 01/12/06 | 02/09/06 | 15 | 1.5 | 3 | 6,435 | 5,890 | Backwash settings adjusted on 02/09/06 |
| 02/09/06 | 03/26/06 | 9 | 1.5 | 2 | 4,095 | 6,180 | First six months of operation ended 03/26/06 |

(a) Excluding data from October 28, 2005, October 30, 2005, and November 19, 2005, when abnormally low volumes of wastewater were recorded.

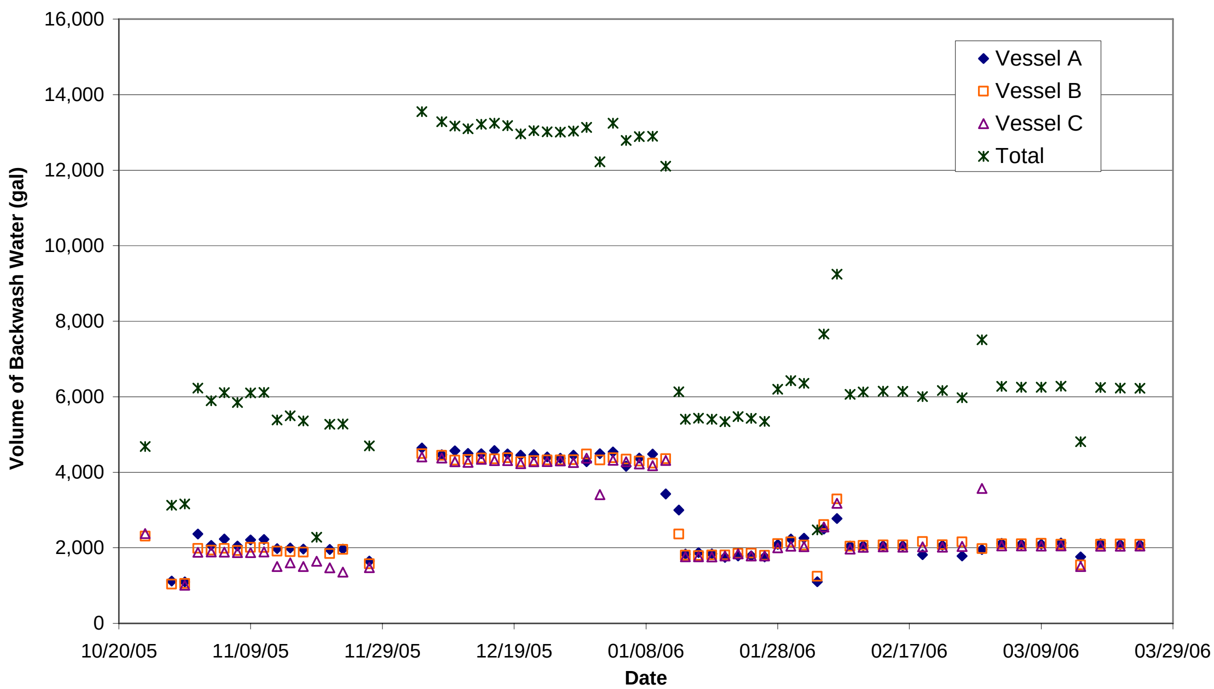


**Figure 4-16. Volume of Wastewater Produced When Backwashing AD-26 Vessels**

power outage on November 28, 2005, the backwash controls apparently were reset so that each vessel would be backwashed for 20 min and rinsed for an extended duration (the vendor reported 25 min but was not sure if it was correct). Consequently, more than twice as much wastewater, i.e., 13,100 gal on average, was produced from each backwash event. Upon request, the backwash settings were adjusted back to 15 min and 90 sec service-to-waste rinse on January 12, 2006, and the volume of wastewater produced was restored to an average of 5,890 gal per backwash event. Since the backwash water cleared up fairly quickly, it was decided on February 9, 2006, to reduce the backwash duration from 15 to 9 min while the rinse duration remained unchanged. This reduced backwash setting, however, did not result in the expected reduction in wastewater production per backwash event, with the average volume staying at 6,180 gal. Nonetheless, because the backwash frequency also was reduced from once every two days to once every three days on February 9, 2006, the overall wastewater production was reduced by 30%. The vendor was informed of this observation and was expected to look into the PLC for the discrepancies.

The vendor recommended to backwash the AD-33 adsorption vessels approximately once every 60 days. Automatic backwash could be initiated either by timer or by differential pressure across the vessels. However, due to the steady pressure in the vessels and the effective arsenic and particulate removal by the oxidation/filtration vessels, the AD-33 vessels were backwashed only once on February 1, 2006, during this six-month operational period.

**4.4.4 Residual Management.** Residuals produced by the operation of the system would include backwash water and spent media. The media was not replaced during the first six months of system operation; therefore, the only residual produced was backwash wastewater. Backwash wastewater was stored in two 6,000-gal storage tanks on-site and a vacuum truck hauled the backwash wastewater for off-site disposal at the Village of North Hampton sewer system on a weekly basis.

On February 27, 2006, during the system backwash and sample collection, one of the backwash wastewater storage tanks overflowed, due to the fact that there was already water in the storage tank before the backwash was manually initiated. The incident was reported to Ohio EPA, which requested a copy of the latest analytical data. After reviewing the analytical data, the Ohio EPA deemed that the spill would not adversely affect the environment. The quality of the backwash wastewater is discussed in Section 4.5.2.

**4.4.5 System/Operation Reliability and Simplicity.** The operational issues related to the chlorine injection system as discussed Section 4.4.2 were the primary factors affecting system/operation reliability and simplicity.

Unscheduled downtime during the first six months of system operation was caused by a power outage on November 28, 2005; a power surge was created, causing the master and slave chips within the control panel to malfunction. The system was shut down and bypassed from November 28 through December 3, 2005, while the vendor and plant operator tried to troubleshoot and fix the problems. On November 30, 2005, a new set of chips was installed and the system was rebooted. The control panel malfunctioned again and a new set of chips had to be shipped to the Park. On December 1, 2005, the new chips were installed and the system was rebooted. All totalizer readings were reset and the system became operational. However, on December 2, 2005, the control panel malfunctioned in the middle of the night, causing all three vessels to backwash at once. Meanwhile, the system stopped sending water to the distribution system. The vendor went through the steps to correct the problems to no avail, so on December 3, 2005, a new master and slave chips were installed and the control panel became operational.

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

***Pre- and Post-Treatment Requirements***. The pre-treatment included chlorinating source water to oxidize arsenic, iron, and manganese, while maintaining chlorine residuals for disinfection. In addition, the AD-26 media was used to filter arsenic-ladened iron solids and, perhaps, manganese solids and oxidize any remaining reduced metals, such as Mn(II). Post-treatment was not needed for this system.

***System Automation***. The APU-250 system included automated controls, which interlocked the well pump alternating on/off controls. The system also was equipped with an automated chlorine feed and control unit, which processed the signal from a chlorine sensor and activated a solenoid that drove the metering pump. In addition, the system was fitted with automated controls to allow for automatic backwash for both the AD-26 and AD-33 vessels. The backwash wastewater storage tanks did not have automation associated with them. Because there were no level sensors installed in the tanks, there could be a potential for the tanks to overflow as observed on February 27, 2006.

***Operator Skill Requirements***. The skills required to operate the APU-250 system were relatively complex due to the problems associated with the chlorine injection and the power outage that occurred at the site. The operator needed to adjust the dosage of the chlorine, adjust the metering pump, clean the chlorine probe and associated tubing (which would get clogged with iron particulates), and change out the master chip within the control panel.

Under normal operating conditions, the operator spent approximately 20 min daily to perform visual inspection and record the system operating parameters on the Daily Field Log Sheets. The operator also performed routine weekly and monthly maintenance according to the users' manual to ensure proper system operation. Normal operation of the system did not appear to require additional skills beyond those necessary to operate the existing water supply equipment.

All Ohio public water systems, both community and nontransient, serving more than 250 people must have a certified operator. Operator certifications are granted by the State of Ohio after passing an exam and maintaining a minimum amount of continuing education hours at professional training events on a biannual basis. Operator certifications are classified by Class I through IV water system operator, Class I and II water distribution operator, Class I through IV wastewater works operator, and Class I and II wastewater collection system operator. Class I is the lowest classification with Class IV being the highest. Chateau Estates has a Class III water system operator.

***Preventive Maintenance Activities***. Preventive maintenance tasks included such items as periodic checks of flow meters and pressure gauges and inspection of system piping and valves. The chlorine feed/control unit tended to build up iron residue which needed to be cleaned out periodically. Typically, the operator performed these duties only when he was onsite for routine activities.

***Chemical/Media Handling and Inventory Requirements***. The only chemical required for the system operation was the NaOCl solution used for chlorination, which was already in use at the site. Every week, approximately 15 gal of the 12.5% chlorine solution was added to the 75-gal chlorine tank.

## 4.5 System Performance

The performance of the APU-250 system was evaluated based on analyses of water samples collected from the treatment plant, the media backwash, and distribution system.

**4.5.1 Treatment Plant Sampling.** Table 4-8 summarizes the analytical results of arsenic, iron, and manganese measured at the four sampling locations across the treatment train. Table 4-9 summarizes the results of other water quality parameters. Appendix B contains a complete set of analytical results

**Table 4-8. Summary of Arsenic, Iron, and Manganese Analytical Results**

| Parameter | Sampling Location | Sample Count | Concentration (μg/L) | | | Standard Deviation |
|---|---|---|---|---|---|---|
| | | | Minimum | Maximum | Average | |
| As (total) | IN | 13 | 9.5 | 31.3 | 21.5 | 6.0 |
| | AC | 13 | 9.4 | 29.8 | 22.4 | 5.5 |
| | OT | 13 | 0.5 | 2.0 | - [(a)] | |
| | TT | 13 | <0.1 | 0.5 | - [(a)] | |
| As (soluble) | IN | 6 | 8.4 | 25.6 | 17.5 | 5.8 |
| | AC | 6 | 1.9 | 4.8 | 3.3 | 0.9 |
| | OT | 6 | 0.5 | 1.8 | - [(a)] | |
| | TT | 6 | <0.1 | 0.4 | - [(a)] | |
| As (particulate) | IN | 6 | 0.7 | 5.7 | 2.1 | 2.0 |
| | AC | 6 | 6.2 | 20.5 | 15.4 | 4.9 |
| | OT | 6 | <0.1 | 0.3 | - [(a)] | |
| | TT | 6 | <0.1 | 0.2 | - [(a)] | |
| As (III) | IN | 6 | 5.6 | 24.7 | 16.4 | 6.6 |
| | AC | 6 | 0.3 | 0.7 | 0.5 | 0.2 |
| | OT | 6 | <0.1 | 0.7 | - [(a)] | |
| | TT | 6 | <0.1 | 0.8 | - [(a)] | |
| As (V) | IN | 6 | <0.1 | 2.8 | 1.2 | 0.9 |
| | AC | 6 | 1.5 | 4.3 | 2.9 | 0.9 |
| | OT | 6 | 0.1 | 1.2 | - [(a)] | |
| | TT | 6 | <0.1 | <0.1 | - [(a)] | |
| Fe (total) | IN | 13 | 521 | 1,595 | 1,000 | 431 |
| | AC | 13 | 535 | 1,595 | 1,131 | 424 |
| | OT | 13 | <25 | 25.3 | 13.5 | 3.5 |
| | TT | 13 | <25 | <25 | <25 | - |
| Fe (soluble) | IN | 6 | 390 | 1,463 | 754 | 392 |
| | AC | 6 | <25 | <25 | <25 | - |
| | OT | 6 | <25 | <25 | <25 | - |
| | TT | 6 | <25 | <25 | <25 | - |
| Mn (total) | IN | 13 | 17.9 | 82.1 | 40.2 | 22.3 |
| | AC | 13 | 17.3 | 77.3 | 31.7 | 17.1 |
| | OT | 13 | <0.1 | 0.4 | 0.2 | 0.1 |
| | TT | 13 | <0.1 | 0.1 | 0.1 | 0.0 |
| Mn (soluble) | IN | 6 | 18.8 | 81.6 | 44.0 | 23.3 |
| | AC | 6 | 0.4 | 39.6 | 9.4 | 14.9 |
| | OT | 6 | <0.1 | 0.4 | 0.2 | 0.2 |
| | TT | 6 | <0.1 | 0.5 | 0.1 | 0.2 |

One-half of detection limit used for samples with concentrations less than detection limit for calculations.
Duplicate samples included in calculations.
(a) Statistics not provided; see Figure 4-17 for arsenic breakthrough curves.

**Table 4-9. Summary of Other Water Quality Parameter Results**

| Parameter | Sampling Location | Unit | Sample Count | Concentration/Unit | | | Standard Deviation |
|---|---|---|---|---|---|---|---|
| | | | | Minimum | Maximum | Average | |
| Alkalinity (as $CaCO_3$) | IN | mg/L | 13 | 329 | 361 | 344 | 8.6 |
| | AC | mg/L | 13 | 330 | 370 | 344 | 11.2 |
| | OT | mg/L | 13 | 331 | 365 | 343 | 9.9 |
| | TT | mg/L | 13 | 334 | 365 | 343 | 7.8 |
| Fluoride | IN | mg/L | 13 | 0.8 | 1.5 | 1.2 | 0.2 |
| | AC | mg/L | 13 | 1.1 | 1.6 | 1.3 | 0.2 |
| | OT | mg/L | 13 | 1.1 | 1.5 | 1.3 | 0.1 |
| | TT | mg/L | 13 | 1.2 | 1.5 | 1.3 | 0.1 |
| Sulfate | IN | mg/L | 13 | 14.0 | 33.0 | 23.0 | 5.6 |
| | AC | mg/L | 13 | 12.0 | 33.1 | 24.1 | 6.8 |
| | OT | mg/L | 13 | 13.7 | 30.7 | 24.6 | 4.1 |
| | TT | mg/L | 13 | 22.8 | 27.6 | 25.3 | 1.7 |
| Ammonia (as N) | IN | mg/L | 13 | <0.05 | 0.26 | 0.18 | 0.08 |
| | AC | mg/L | 13 | <0.05 | 0.24 | 0.08 | 0.09 |
| | OT | mg/L | 13 | <0.05 | <0.05 | - | - |
| | TT | mg/L | 13 | <0.05 | <0.05 | - | - |
| Nitrate (as N) | IN | mg/L | 13 | <0.05 | <0.05 | - | - |
| | AC | mg/L | 13 | <0.05 | <0.05 | - | - |
| | OT | mg/L | 13 | <0.05 | 0.2 | 0.04 | 0.05 |
| | TT | mg/L | 13 | <0.05 | <0.05 | - | - |
| Total P (as $PO_4$) | IN | mg/L | 12 | <0.01 | <0.03 | - | - |
| | AC | mg/L | 12 | <0.01 | <0.03 | - | - |
| | OT | mg/L | 12 | <0.01 | <0.03 | - | - |
| | TT | mg/L | 12 | <0.01 | <0.03 | - | - |
| Silica (as $SiO_2$) | IN | mg/L | 13 | 17.0 | 19.9 | 18.3 | 1.0 |
| | AC | mg/L | 13 | 17.1 | 19.7 | 18.3 | 0.8 |
| | OT | mg/L | 13 | 16.9 | 19.2 | 18.1 | 0.7 |
| | TT | mg/L | 13 | 16.2 | 18.9 | 17.8 | 0.8 |
| Turbidity | IN | NTU | 13 | 5.9 | 25.0 | 13.5 | 7.8 |
| | AC | NTU | 13 | 0.7 | 14.0 | 2.4 | 3.6 |
| | OT | NTU | 13 | <0.1 | 0.8 | 0.4 | 0.3 |
| | TT | NTU | 13 | <0.1 | 1.4 | 0.4 | 0.4 |
| pH | IN | S.U. | 11 | 7.1 | 7.5 | 7.3 | 0.1 |
| | AC | S.U. | 11 | 7.0 | 7.4 | 7.3 | 0.1 |
| | OT | S.U. | 11 | 7.1 | 7.5 | 7.3 | 0.1 |
| | TT | S.U. | 11 | 7.1 | 7.4 | 7.2 | 0.1 |
| Temperature | IN | ºC | 11 | 10.2 | 25.0 | 17.3 | 4.3 |
| | AC | ºC | 11 | 10.2 | 25.0 | 16.7 | 3.9 |
| | OT | ºC | 11 | 10.2 | 25.0 | 16.6 | 3.8 |
| | TT | ºC | 11 | 10.2 | 25.0 | 16.6 | 3.8 |
| DO | IN | mg/L | 9 | 1.1 | 2.7 | 1.7 | 0.6 |
| | AC | mg/L | 10 | 0.9 | 2.7 | 1.9 | 0.6 |
| | OT | mg/L | 10 | 1.2 | 3.0 | 2.0 | 0.6 |
| | TT | mg/L | 10 | 1.0 | 2.7 | 2.0 | 0.6 |

Table 4-9. Summary of Water Quality Parameter Sampling Results (Continued)

| Parameter | Sampling Location | Unit | Sample Count | Concentration/Unit | | | Standard Deviation |
|---|---|---|---|---|---|---|---|
| | | | | Minimum | Maximum | Average | |
| ORP | IN | mV | 11 | -131 | 232 | 76.2 | 131 |
| | AC | mV | 11 | -77.6 | 746 | 464 | 293 |
| | OT | mV | 11 | 270 | 728 | 525 | 175 |
| | TT | mV | 10 | 281 | 718 | 561 | 151 |
| Free Chlorine (as $Cl_2$) | AC | mg/L | 6 | 0.3 | 2.5 | 1.8 | 0.9 |
| | OT | mg/L | 9 | 0.3 | 3.1 | 1.3 | 0.9 |
| | TT | mg/L | 10 | 0.7 | 3.2 | 1.7 | 0.7 |
| Total Chlorine (as $Cl_2$) | AC | mg/L | 4 | 0.7 | 3.2 | 2.2 | 1.1 |
| | OT | mg/L | 8 | 0.6 | 3.5 | 1.9 | 0.9 |
| | TT | mg/L | 10 | 0.8 | 3.8 | 2.2 | 0.9 |
| Total Hardness (as $CaCO_3$) | IN | mg/L | 13 | 285 | 365 | 336 | 20.5 |
| | AC | mg/L | 13 | 282 | 349 | 335 | 18.4 |
| | OT | mg/L | 13 | 240 | 357 | 333 | 33.3 |
| | TT | mg/L | 13 | 297 | 360 | 339 | 19.7 |
| Ca Hardness (as $CaCO_3$) | IN | mg/L | 13 | 170 | 215 | 204 | 11.7 |
| | AC | mg/L | 13 | 170 | 215 | 202 | 11.8 |
| | OT | mg/L | 13 | 140 | 215 | 199 | 21.6 |
| | TT | mg/L | 13 | 166 | 222 | 203 | 14.6 |
| Mg Hardness (as $CaCO_3$) | IN | mg/L | 13 | 115 | 152 | 131 | 11.3 |
| | AC | mg/L | 13 | 112 | 141 | 133 | 8.1 |
| | OT | mg/L | 13 | 101 | 153 | 134 | 14 |
| | TT | mg/L | 13 | 115 | 153 | 136 | 10.3 |

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

through the first six months of system operation. The results of the water samples collected throughout the treatment plant are discussed below.

***Arsenic***. The key parameter for evaluating the effectiveness of the arsenic removal system was the concentration of arsenic in the treated water. Water samples were collected on 13 occasions, including one duplicate, with field speciation performed during six of the 13 occasions from the four sampling locations at IN, AC, OT, and TT.

Figure 4-17 contains four bar charts showing the concentrations of total arsenic, particulate arsenic, As(III), and As(V) at the IN, AC, OT, and TT locations for each speciation event. Total arsenic concentrations in raw water ranged from 9.5 to 31.3 µg/L and averaged 21.5 µg/L (Table 4-8). As(III) was the predominating species, ranging from 5.6 to 24.7 µg/L and averaging 16.4 µg/L. As(V) and particulate arsenic concentrations were low, averaging 1.2 and 2.1 µg/L, respectively. The presence of As(III) as the predominating arsenic species was consistent with the low DO concentrations (averaging 1.7 mg/L) measured (Table 4-9). The ORP readings, however, were high, averaging 76.2 mV. Recall that the ORP readings obtained during the August 5 and September 9, 2004, source water sampling events

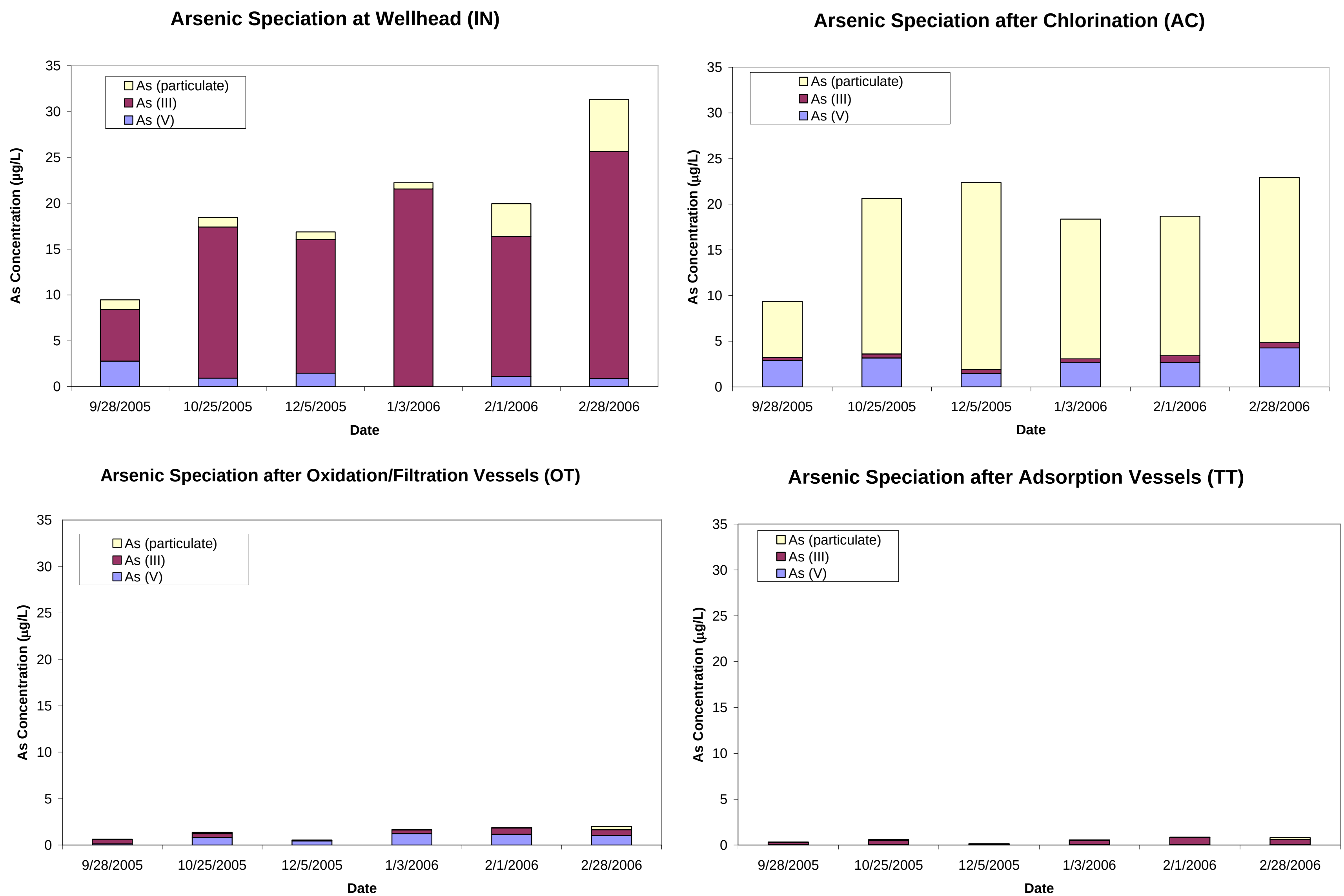


**Figure 4-17. Concentrations of Various Arsenic Species at IN, AC, OT and TT Sampling Locations**

were -88 mV for the West Well and -25 mV for the East Well. The higher than expected ORP readings might have been caused by aeration of water during sampling.

Similar to the samples collected during the August 5 and September 9, 2004, source water sampling events, total arsenic concentrations were higher in the West Well than the East Well (28.4 versus 18.0 µg/L on average). Unlike what was observed during these source water sampling events, As(III) was the predominating species in both wells. The West Well measured only 2.9 and 18% of As(V) and particulate arsenic, respectively, (based on one set of speciation results) with the East Well measuring 9.8 and 8.8% on average (based on five sets of speciation results). There was no evidence to suggest that there were significant differences in arsenic speciation between the two wells. The presence of elevated particulate arsenic and particulate iron during some of these speciation events and the September 9, 2004, the East Well source water sampling (as discussed in Section 4.1.1), most likely was caused by inadvertent aeration of the samples during sampling.

Chlorination oxidized As(III) to As(V) which, in turn, was attached effectively, at an average pH value of 7.3 (see Table 4-9), to iron solids and form particulate arsenic. The samples collected downstream of the chlorine injection point at the AC location showed a decrease in soluble arsenic concentration from an average of 17.5 µg/L in source water to an average of 3.3 µg/L after chlorination. Particulate arsenic increased in concentration from an average of 2.1 µg/L in source water to an average of 15.4 µg/L after chlorination. The majority of particulate arsenic was filtered by the AD-26 oxidation/filtration media, leaving only 0.5 to 2.0 µg/L of total arsenic, existing mainly as As(V), to be further removed by the AD-33 adsorption vessels. By the end of the first six months of system operation, total arsenic concentrations in the treated water after the AD-33 adsorption vessels were reduced to less than 0.5 µg/L. Figure 4-18 presents arsenic breakthrough curves from the AD-26 oxidation/filtration and AD-33 adsorption systems.

Free and total chlorine were monitored at the AC, OT, and TT sampling locations to ensure that the target chlorine residual levels were properly maintained. Free chlorine levels at the AC location ranged from 0.3 to 2.5 mg/L (as $Cl_2$) and averaged 1.8 mg/L (as $Cl_2$); total chlorine levels ranged from 0.7 to 3.2 mg/L (as $Cl_2$) and averaged 2.2 mg/L (as $Cl_2$) (Table 4-9). The residual chlorine levels measured at the OT and TT locations were similar to those measured at the AC location, indicating little or no chlorine consumption through the AD-26 and AD-33 vessels. Repeated attempts had been made to reduce the levels of free and total chlorine residuals to the target levels of 1.5 and 1 mg/L (as $Cl_2$). However, as of the end of the first six months of system operation, the chlorine injection system appeared to have not been able to consistently control the chlorine levels in the treated water.

Comparison of the free and total chlorine levels at the AC location indicated that total chlorine was on average 0.4 mg/L (as $Cl_2$) higher than free chlorine. The 0.2 mg/L (as N) of ammonia in source water apparently had reacted with $OCl^-$ to form $NH_2Cl$, causing the total chlorine levels to be consistently higher than those of free chlorine throughout the study period.

After chlorination, as expected, DO concentrations remained essentially unchanged; however, ORP readings increased significantly to 464, 525, and 561 mV, on average, at the AC, OT, and TT locations, respectively. The high ORP readings were consistent with the presence of high free chlorine levels, which averaged 1.8 mg/L (as $Cl_2$) at the AC location, and 1.3 and 1.7 mg/L (as $Cl_2$) at the OT and TT locations, respectively.

***Iron.*** Total iron concentrations at the wellhead ranged from 521 to 1,595 µg/L and averaged 1,000 µg/L. Iron concentrations following the prechlorination step at the AC location were similar to those at the wellhead, with concentrations ranging from 535 µg/l to 1,595 µg/L. Iron was removed from the treatment train by the AD-26 media with concentrations at the OT sampling point ranging from less than the method detection limit of 25 µg/L to 25.3 µg/L and averaged <25µg/L at the TT sample point. Dissolved iron levels ranged from 390 to 1,463 µg/L in the wellhead and were always less than the method detection limit at the AC, OT, and TT sampling locations. The data indicated that chlorine effectively oxidized soluble iron to form iron solids, which were then effectively filtered by the AD-26 oxidation/filtration media. The current backwash frequency of once every 3 days appears to be adequate without having any iron leakage between backwash cycles.

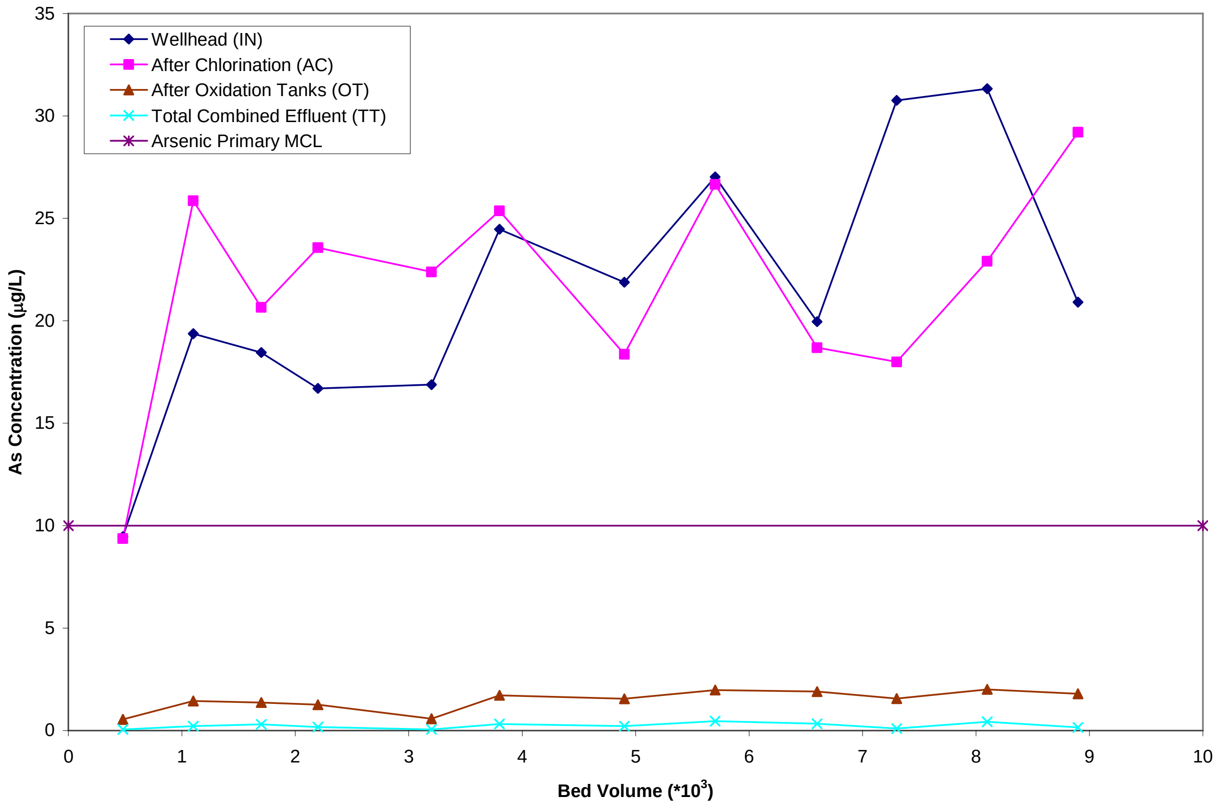


**Figure 4-18. Total Arsenic Breakthrough Curves for AD-26 Oxidation/Filtration and AD-33 Adsorption System**

***Manganese.*** The treatment plant water samples were analyzed for total manganese at each sampling event and soluble manganese during speciation sampling. Total manganese levels existing almost entirely in the soluble form ranged from 17.9 to 82.1 µg/L and averaged 40.2 µg/L for the source water samples (IN). After prechlorination, over 70% on average, of soluble manganese was precipated, presumably, to form $MnO_2$ solids, which, along with unoxidized $Mn^{2+}$, were removed by the AD-26 media to <0.4 µg/L. Total manganese concentrations were further reduced to 0.1 µg/L after the AD-33 adsorptive media. Note that 0.45 µm disk filters were used to separate solids from the soluble fraction.

It is interesting to note that the amount of $Mn^{2+}$ that precipitated upon chlorination varied during the 6 speciation events, with five events ranging from 85.0 to 98% precipitation rates and the remaining one at 48.8%. The 85 to 98% precipitation rates observed during the five speciation events reflected rapid oxidation kinetics by chlorine, which were contrary to the findings by most researchers who investigated the oxidation of $Mn^{2+}$ even with some lengths of contact time (Knocke et al., 1987 and 1990; Condit and Chen, 2006).

***Other Water Quality Parameters***. pH values of raw water measured at the IN location varied from 7.1 to 7.5. This near neutral pH is desirable for iron removal and adsorption processes which, in general, have a greater arsenic removal capacity at near or lower than neutral pH values. The pH values remained essentially unchanged after the AD-26 and AD-33 vessels. Alkalinity, reported as $CaCO_3$, ranged from 329 to 370 mg/L across the treatment train. The results indicate that the adsorptive media did not affect the amount of alkalinity in water after treatment. The treatment plant samples were analyzed for hardness only when arsenic speciation was performed. Total hardness, existing primarily as calcium hardness (about 60%), ranged from 240 to 365 mg/L (as $CaCO_3$), and also remained constant throughout the treatment train. Sulfate concentrations ranged from 12.0 to 33.1 mg/L, and remained constant throughout the treatment train. Silica (as $SiO_2$) concentration ranged from 16.2 to 19.9 mg/L, and appeared unaffected by the chlorine injection and the AD-26 and AD-33 media. Fluoride results ranged from 0.8 to 1.6 mg/L in all samples. Fluoride did not appear to be affected by the AD-33 media. Total phosphorous was below the detection limit of 0.01 mg/L (as $PO_4$) for all samples

**4.5.2 Backwash Water Sampling.** Backwash was performed using the AD-26-treated water stored in the hydropnuematic tanks. The unfiltered samples were analyzed for pH, TDS, TSS, and total arsenic, iron, and manganese. Samples filtered with 0.45-µm disc filters were analyzed for soluble arsenic, iron, and manganese. As shown in Table 4-10, OW1, the first oxidation vessel, was sampled every month, while OW2, the second oxidation vessel, was sampled five times and OW3, the third oxidation vessel, was only sampled the last two times. The pH of the backwash water was similar to that of the treated water ranging from 7.3 to 7.7. TDS concentrations ranged from 360 to 424 mg/L and averaged 405 mg/L; TSS concentrations ranged from 18 to 156 mg/L and averaged 82 mg/L. The unusually low TSS values measured on February 2 and March 24, 2006, for Vessel 2 and on March 24, 2006, for Vessel 3 were thought to be the results of sampling errors caused by insufficient mixing of the solids/water mixtures in the backwash water collection containers immediately before sampling. Note that lower TSS values also had lower particulate arsenic, iron, and manganese concentrations. As such, these three sets of data were not used for further data analyses.

The majority of the total arsenic, iron and manganese were from particulates. Total arsenic concentrations averaged 405 µg/L while soluble arsenic concentrations averaged only 4.7 µg/L. Total iron levels ranged from 13,545 to 57,464 µg/L in all three vessels with soluble iron levels ranging from <25 to 279 µg/L. Total manganese levels ranged from 342 to 1,357 µg/L, while soluble manganese levels ranged from 1.6 to 7.5 µg/L.

Assuming that 82 mg/L of TSS (average of TSS values for the three oxidation/filtration vessels except for the three outliers) was produced in 6,000 gal of backwash wastewater, approximately 4 lb of solids would be discharged during each AD-33 backwash event. The solids discharged would be composed of 0.02, 1.45, and 0.03 lb of arsenic, iron, and manganese, respectively, assuming 400 µg/L of particulate arsenic, 28,900 µg/L of particulate iron, and 600 µg/L of particulate manganese in the backwash wastewater.

During the first six months of system operation, the AD-33 adsorption vessels were backwashed only once in the 20th week, generating approximately 5,800 gal of wastewater. Initially the vendor recommended that the AD-33 vessels be backwashed once every 60 days. After reviewing the system operation, it was determined that the media would not need to be backwashed on a regular basis and that it would be determined based on system pressures. After the power outage at the end of November 2005, the default setting (which was once every 60 days) was restored causing a backwash on February 1, 2006. No backwash samples were taken because it was not known that the backwash was going to take place.

**4.5.3 Distribution System Water Sampling.** Prior to the installation/operation of the treatment system, first draw baseline distribution system water samples were collected at three locations (2

**Table 4-10. Backwash Sampling Results**

| Sampling Event | pH | TDS | TSS | Total As | Soluble As | Particulate As | Total Fe | Soluble Fe | Total Mn | Soluble Mn |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | S.U. | mg/L | mg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L |
| ***Oxidation/Filtration Vessel 1 (OW1)*** | | | | | | | | | | |
| 10/13/05 | 7.7 | 414 | NS | NS | 2.7 | NS | NS | <25 | NS | 1.8 |
| 12/05/05 | 7.6 | 420 | 156 | 296 | 3.2 | 293 | 21,366 | 54 | 724 | 3.1 |
| 01/12/06 | 7.7 | 408 | 46 | 238 | 5.6 | 232 | 13,545 | 161 | 527 | 5.0 |
| 02/02/06 | 7.6 | 412 | 96 | 634 | 4.3 | 630 | 57,464 | 133 | 1,357 | 5.2 |
| 02/27/06 | 7.6 | 384 | 64 | 536 | 4.7 | 532 | 30,997 | 116 | 486 | 1.6 |
| 03/24/06 | 7.4 | 400 | 92 | 487 | 5.6 | 482 | 24,432 | 279 | 443 | 4.5 |
| ***Oxidation/Filtration Vessel 2 (OW2)*** | | | | | | | | | | |
| 12/05/05 | 7.6 | 378 | 54 | 231 | 3.9 | 227 | 15,282 | 65 | 342 | 3.3 |
| 01/12/06 | 7.5 | 360 | 42 | 269 | 4.6 | 265 | 15,216 | 102 | 556 | 3.3 |
| 02/02/06 | 7.7 | 416 | 22 | 114 | 3.2 | 111 | 8,226 | 73 | 183 | 2.9 |
| 02/27/06 | 7.5 | 424 | 64 | 501 | 5.3 | 496 | 30,131 | 160 | 481 | 2.2 |
| 03/24/06 | 7.3 | 424 | 18 | 133 | 4.0 | 129 | 6,577 | 170 | 213 | 3.0 |
| ***Oxidation/Filtration Vessel 3 (OW3)*** | | | | | | | | | | |
| 02/27/06 | 7.5 | 414 | 120 | 853 | 7.2 | 846 | 51,450 | 226 | 414 | 7.5 |
| 03/24/06 | 7.4 | 408 | 28 | 184 | 4.3 | 179 | 9,869 | 245 | 408 | 7.4 |

NS = Not Sampled; TDS = Total Dissolved Solids; TSS = Total Suspended Solids
OW2 not sampled on 10/13/05.
OW3 not sampled 10/13/05, 12/05/05, 01/12/06, or 02/02/06.

residences and the mobile park clubhouse) on April 4, May 5, June 8, and July 7, 2005. Following the installation of the treatment system, distribution water sampling continued on a monthly basis. Two of the three locations, i.e., the clubhouse and one residence, remained the same as the baseline, but the residence for the third location was changed on October 12, 2005, by a new residence due to availability. The samples were collected on October 12, 2005, November 15, 2005, December 12, 2005, January 16, 2006, February 13, 2006, and March 13, 2006. The results of the distribution system sampling are summarized in Table 4-11.

The most noticeable change in the distribution samples since system startup was a decrease in arsenic, iron, and manganese concentrations. Baseline arsenic concentrations ranged from 9.2 to 68.8 µg/L and averaged 23.7 µg/L for all three locations. After the performance evaluation began, arsenic concentrations reduced to <0.1 to 4.5 µg/L (averaged 2.0 µg/L). The baseline iron concentrations ranged from 113 to 5,504 µg/L (averaging 1,359) with the highest concentrations observed in the clubhouse water samples (ranging from 1,423 to 5,504 µg/L). After the treatment system became operational, iron concentrations decreased to less than the method detection limit of 25 µg/L in all samples except for one at 28.1 µg/L. Manganese had a similar trend with baseline concentrations averaging 15.2 µg/L and after startup samples averaging 0.1 µg/L.

## Table 4-11. Distribution System Sampling Results

| Sampling Event | | DS1 | | | | | | | | DS2 | | | | | | | | DS3[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stagnation Time | pH | Alkalinity | As | Fe | Mn | Pb | Cu | Stagnation Time | pH | Alkalinity | As | Fe | Mn | Pb | Cu | Stagnation Time | pH | Alkalinity | As | Fe | Mn | Pb | Cu |
| **No.** | **Date** | **hr** | **S.U.** | **mg/L** | **μg/L** | **μg/L** | **μg/L** | **μg/L** | **μg/L** | **hr** | **S.U.** | **mg/L** | **μg/L** | **μg/L** | **μg/L** | **μg/L** | **μg/L** | **hr** | **S.U.** | **mg/L** | **μg/L** | **μg/L** | **μg/L** | **μg/L** | **μg/L** |
| BL1[b] | 04/04/05 | 25.3 | 7.4 | 339 | 68.8 | 5,504 | 54.9 | 0.3 | 445 | 8.7 | 7.4 | 334 | 14.8 | 592 | 6.6 | 1.4 | 48.4 | 8.3 | 7.5 | 334 | 12.6 | 257 | 3.5 | 3.6 | 714 |
| BL2 | 05/03/05 | 6.1 | 7.4 | 355 | 43.9 | 3,190 | 35.2 | 0.2 | 191 | 7.8 | 7.4 | 355 | 13.7 | 563 | 7.0 | 2.2 | 39.0 | 10.9 | 7.3 | 364 | 9.2 | 113 | 3.0 | 1.7 | 1,045 |
| BL3[c] | 06/08/05 | 6.0 | 7.4 | 343 | 33.2 | 2,232 | 26.2 | 0.1 | 83.3 | 8.8 | 7.4 | 339 | 10.6 | 237 | 3.1 | 0.1 | 10.4 | NA | 7.5 | 343 | 12.0 | 238 | 4.0 | 1.2 | 1,353 |
| BL4 | 07/07/05 | 6.2 | 7.3 | 352 | 25.9 | 1,423 | 16.4 | <0.1 | 55.4 | 8.0 | 7.3 | 352 | 27.6 | 1,769 | 19.3 | 5.2 | 64.9 | 12.0 | 7.4 | 352 | 12.1 | 200 | 3.1 | 0.7 | 764 |
| 1 | 10/12/05 | 7.8 | 7.4 | 343 | 3.6 | <25 | <0.1 | <0.1 | 9.0 | 7.8 | 7.5 | 352 | 1.0 | <25 | <0.1 | 0.2 | 5.8 | 8.3 | 7.5 | 352 | 2.8 | <25 | 0.1 | 0.3 | 5.2 |
| 2 | 11/15/05 | 9.0 | 7.8 | 330 | 4.5 | <25 | <0.1 | <0.1 | 78.9 | 7.5 | 7.5 | 339 | <0.1 | <25 | <0.1 | 0.3 | 28.4 | 6.5 | 8.0 | 198 | 2.3 | <25 | <0.1 | 0.1 | 95.0 |
| 3 | 12/12/05 | 6.1 | 7.5 | 352 | 2.1 | <25 | <0.1 | <0.1 | 29.5 | 10.9 | 7.6 | 343 | 1.1 | <25 | <0.1 | 0.3 | 39.0 | 9.0 | 7.5 | 348 | 3.6 | <25 | 0.1 | 0.3 | 125 |
| 4 | 01/16/06 | 6.3 | 7.3 | 348 | 3.6 | 28.1 | 0.5 | 0.3 | 123 | 7.3 | 7.5 | 356 | 1.0 | <25 | 0.3 | 1.6 | 38.8 | 6.9 | 7.5 | 356 | 2.2 | <25 | 0.2 | 1.1 | 159 |
| 5 | 02/13/06 | 6.0 | 7.4 | 338 | 2.0 | <25 | <0.1 | 0.1 | 52.5 | 7.5 | 7.5 | 333 | 0.4 | <25 | <0.1 | 0.1 | 14.9 | 7.3 | 7.4 | 317 | 2.5 | <25 | 0.1 | 0.2 | 45.9 |
| 6 | 03/13/06 | 7.2 | 7.5 | 331 | 0.8 | <25 | 0.1 | 0.2 | 50.3 | 8.3 | 7.6 | 331 | 0.2 | <25 | <0.1 | 0.4 | 22.9 | 8.0 | 7.7 | 360 | 2.0 | <25 | 0.2 | 1.4 | 123 |

BL = Baseline Sampling; NA = Not Available
Lead action level = 15 μg/L; copper action level = 1.3 mg/L
(a) DS3 samples collected from Lot 12 until 10/12/05.
(b) DS1 collected on 04/03/05.
(c) DS2 collected on 06/09/05.

Lead concentrations ranged from <0.1 to 5.2 µg/L, with none of the samples exceeding the action level of 15 µg/L. Copper concentrations ranged from 5.2 to 1,353 µg/L across all sampling locations, with one sample exceeding the 1,300 µg/L action level during baseline sampling. The arsenic treatment system does not seem to have an affect on the Pb or Cu concentrations in the distribution system.

Measured pH values ranged from 7.3 to 8.0 and averaged 7.5. Alkalinity levels ranged from 198 to 364 mg/L (as $CaCO_3$). The arsenic treatment system does not seem to affect these water quality parameters in the distribution system.

### 4.6 System Cost

The cost of the system 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. This required the tracking of the capital cost for the equipment, site engineering, and installation and the O&M cost for media replacement and disposal, chemical supply, electricity consumption, and labor. The park owner decided to upgrade the system from 150 gpm to 250 gpm in response to the Ohio EPA's redundancy requirement and to build additional capacity for future growth of the Park. The additional cost incurred was funded by the park owner and is listed as system upgrades on Table 4-12.

**4.6.1 Capital Cost.** The capital investment for equipment, site engineering, and installation for the 250-gpm treatment system was $292,252. The equipment cost was $212,826 (or 73% of the total capital investment), including $144,136 for the 150-gpm system (funded by EPA) and $68,690 for the system upgrades (funded by the facility). The vendor provided cost breakdowns for the 150-gpm system, which included $87,270 for the skid-mounted APU-150 unit, $54,331 for the skid-mounted AD-26 unit, and $2,535 for freight (as shown in Table 4-12). The APU-150 system included $35,586 for the skid-mounted fiberglass vessels, $21,254 for the AD-33 media ($280/ft$^3$ or $5.33/lb), $12,600 for process valves and piping, $12,075 for instrumentation and controls, and $5,753 for other materials. The AD-26 system included $23,400 for the skid-mounted AD-26 unit, $7,866 for the AD-26 media ($218.50/ft$^3$ or $1.75/lb), $10,800 for process valves and piping, $10,600 for instrumentation and controls, and $1,665 for other materials. The $68,690 of equipment upgrades covered the cost of upgrading three 42-in diameter FRP vessels to three 48-in diameter steel epoxy vessels for the APU unit and three 30-in diameter FRP vessels to three 36-in diameter steel epoxy vessels for the AD-26 unit, adding 38 ft$^3$ of AD-33 and 21 ft$^3$ of AD-26 media, adding three new hydropnuematic tanks, and adding a chlorine injection system including a chlorine monitor/controller module.

The engineering cost included the cost for the preparation of a process flow diagram of the treatment system, mechanical drawings of the treatment equipment, and a schematic of the building footprint and equipment layout to be used as part of the permit application submittal (see Section 4.3.1). The engineering cost was $27,527, which was 9% of the total capital investment.

The installation cost included the equipment and labor to unload and install the skid-mounted units, perform piping tie-ins and electrical work, and load and backwash the media (see Section 4.3.3). The installation was performed by AdEdge and LBJ, Inc., a local contractor subcontracted by AdEdge. The installation cost was $51,899, or 18% of the total capital investment.

The capital cost of $292,252 was normalized to $1,170/gpm ($0.81 gpd) of design capacity using the system's rated capacity of 250 gpm (or 360,000 gpd). The capital cost also was converted to an annualized cost of $27,590/yr using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-yr return period. Assuming that the system operated 24 hr/day, 7 day/wk at the design flowrate of 250 gpm to produce 360,000 gal/day, the unit capital cost would be $0.21/1,000 gal. During

**Table 4-12. Capital Investment Cost for AdEdge Treatment System**

| Description | Quantity | Cost | % of Capital Investment Cost |
|---|---|---|---|
| ***Equipment Costs*** | | | |
| Three 42-in Diameter Fiberglass Vessels on Skid (for APU-150) | 1 unit | $35,586 | – |
| AD-33 Media | 76 $ft^3$ | $21,254 | – |
| Gravel Underbedding | 1 | $1,125 | – |
| Process Valves and Piping | 1 | $12,600 | – |
| Instrumentation and Controls | 1 | $12,075 | – |
| Totalizer for Backwash Line | 1 | $990 | – |
| O&M Manuals | | $720 | – |
| One-Year O&M Support | | $2,920 | – |
| *Subtotal* | | *$87,270* | – |
| Three 30-in Diameter Fiberglass Vessels on Skid (for AD26) | 1 unit | $23,400 | – |
| AD26 Media | 36 $ft^3$ | $7,866 | – |
| Gravel Underbedding | 1 | $990 | – |
| Process Valves and Piping | 1 | $10,800 | – |
| Instrumentation and Controls | 1 | $10,600 | – |
| Additional Sample Taps | 1 | $675 | – |
| *Subtotal* | | *$54,331* | – |
| Freight-AD33 Media | 2,430 lb | $600 | – |
| Freight-AD26 Media | 4,470 lb | $525 | – |
| Freight-System | 12,000 lb | $1,410 | – |
| *Subtotal* | | *$2,535* | – |
| Upgrades to APU-250 System (Paid by Owner) | | | – |
| Additional AD-33 Media | 38 $ft^3$ | $10,627 | – |
| Additional AD-26 Media | 21 $ft^3$ | $4,588 | – |
| Other Upgrades (Vessels, Hydro Tanks, etc) | 1 | $53,475 | – |
| *Subtotal* | | *$68,690* | – |
| **Equipment Total** | – | **$212,826** | **73%** |
| ***Engineering Cost*** | | | |
| Vendor Labor | – | $4,534 | – |
| Vendor Travel | – | $2,480 | – |
| Vendor Material | – | $98 | – |
| Subcontractor Labor | – | $14,375 | – |
| Subcontractor Travel | | $403 | – |
| Subcontractor Material | – | $564 | – |
| System Upgrade (Paid by Owner) | – | $5,074 | – |
| **Engineering Total** | – | **$27,527** | **9%** |
| ***Installation Cost*** | | | |
| Vendor Labor | – | $7,920 | – |
| Vendor Travel | – | $4,200 | – |
| Vendor Material | – | $925 | – |
| Subcontractor Mechanical | – | $9,000 | – |
| Subcontractor Electrical | – | $780 | – |
| Subcontractor Other Labor | – | $4,200 | – |
| System Upgrade (Paid by Owner) | – | $24,874 | – |
| **Installation Total** | – | **$51,899** | **18%** |
| **Total Capital Investment** | – | **$292,252** | **100%** |

**Table 4-13. Operation and Maintenance Cost for AdEdge Treatment System**

| Cost Category | Value | Assumptions |
|---|---|---|
| Volume Processed (gal) | 8,184,000 | Through March 26, 2006 |
| ***Media Replacement and Disposal*** | | |
| AD26 Media Unit Cost ($/ft$^3$) | 150 | Vendor quote |
| AD26 Media Volume (ft$^3$) | 57 | To fill three 36-in diameter vessels |
| Underbedding Gravel ($) | 1,040 | Vendor quote |
| Subcontractor Labor Cost ($) | 1,950 | Vendor quote |
| Freight ($) | 705 | Vendor quote |
| Waste Disposal ($) | 650 | Vendor quote |
| Waste Analysis ($) | 245 | Vendor quote |
| Subtotal ($) | 13,140 | |
| AD26 Media Replacement and Disposal cost ($/1,000 gal) | 0.08 | Assume 10-year media life, treating 164 million gal of water |
| AD33 Media Unit Cost ($/ft$^3$) | 260 | Vendor quote |
| AD33 Media Volume (ft$^3$) | 114 | To fill three 48-in diameter vessels |
| Underbedding Gravel ($) | 1,040 | Vendor quote |
| Subcontractor Labor Cost ($) | 1,950 | Vendor quote |
| Freight ($) | 705 | Vendor quote |
| Waste Disposal ($) | 650 | Vendor quote |
| Waste Analysis ($) | 245 | One TCLP test |
| Subtotal ($) | 34,230 | |
| AD-33 Media Replacement and Disposal cost ($/1,000 gal) | See Figure 4-19 | |
| ***Chemical Usage*** | | |
| Chemical Cost ($/1,000) | 0.17 | Approximately $1,400 for six months |
| ***Electricity*** | | |
| Electricity Cost ($/1,000 gal) | 0.001 | Electrical costs assumed negligible |
| ***Labor*** | | |
| Average Weekly Labor (hr) | 2.33 | 20 min/day |
| Labor cost ($/1,000 gal) | 0.16 | Labor rate = $21/hr |
| **Total O&M Cost/1,000 gal** | See Figure 4-19 | Total O&M cost = adsorptive media replacement cost + 0.08 + 0.17 + 0.16 |

the first six months, the system produced 8,184,000 gal of water (see Table 4-5); at this reduced rate of usage, the unit capital cost increased to $1.69/1,000 gal.

**4.6.2 Operation and Maintenance Cost.** The O&M cost included such items as media replacement and disposal, chemical supply, electricity, and labor, as summarized in Table 4-13. Although not incurred during the first six months of system operation, the media replacement cost would represent the majority of the O&M cost. The vendor initially estimated that the AD-26 media would have a 4-yr life expectancy, but after reviewing the performance of the media, the vendor revised its estimate to a 10-yr life expectancy before replacement. It is estimated to cost $13,140 for replacement of 57 ft$^3$ media in three AD-26 vessels. At the current water use rate (i.e., 8,184,000 gal for six month), the system would treat 164 million gal of water in a 10-yr period. Therefore, the AD-26 media replacement cost would be equivalent to $0.08/1,000 gal of water treated.

The vendor estimated that the AD-33 media would have a 4.9-yr life expectancy before replacement. It was estimated to cost $34,230 to change out the adsorptive vessels with 114 $ft^3$ of AD-33 media; that estimate included the cost for media, freight, labor, travel expenses, and media disposal fee. This cost was used to estimate the media replacement cost per 1,000 gal of water treated as a function of the projected media run length to the 10-µg/L arsenic breakthrough (Figure 4-19).

A 12.5% NaOCl solution was used for chlorination. The cost associated with chlorination was approximately $1,400 during this period, which translated into a chemical cost of $0.17/1,000 gal of water treated.

Comparison of electrical bills provided by the park prior to system installation and since startup did not indicate any noticeable increase in power consumption by the treatment system. Therefore, electrical cost associated with operation of the APU-250 system was assumed to be negligible. Under normal operating conditions, routine labor activities to operate and maintain the system consumed 20 min per day, which translates into 2.33 hr per week, as noted in Section 4.4.6. Therefore, the estimated labor cost is $0.16/1,000 gal of water treated.

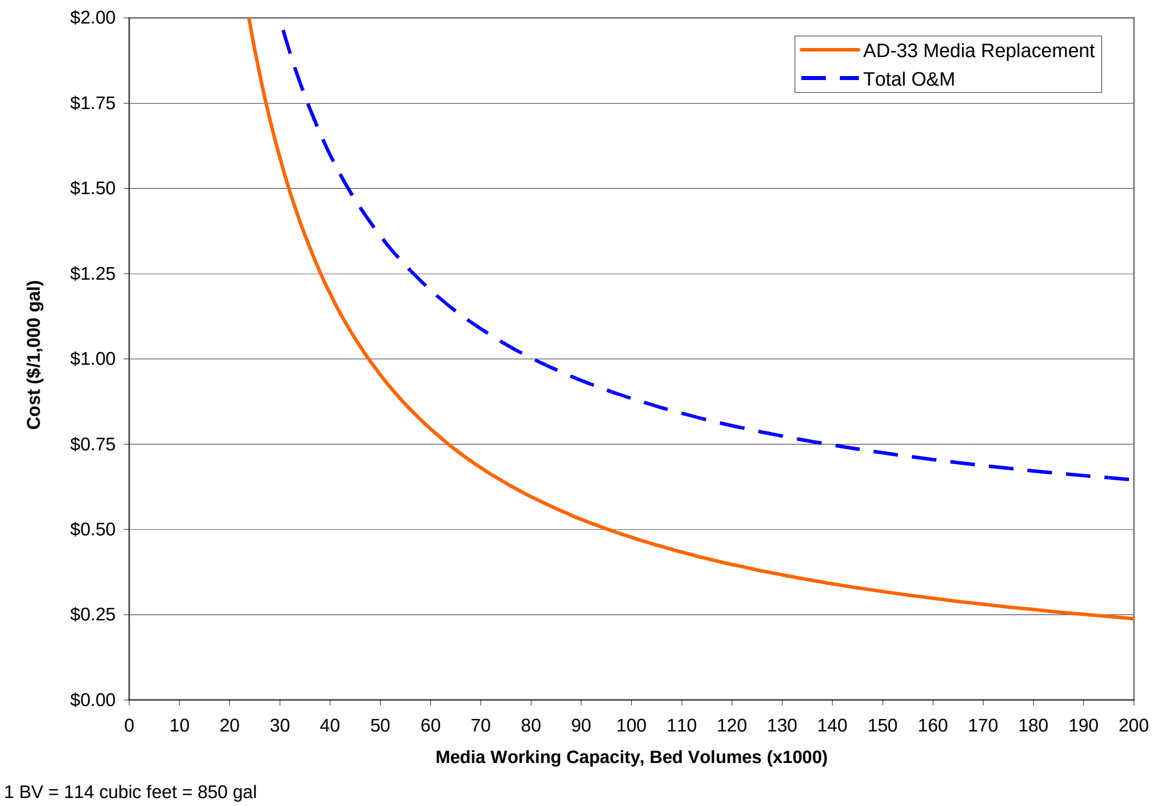


**Figure 4-19. Media Replacement Cost Curves for Springfield System**

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# APPENDIX A

# OPERATIONAL DATA

# Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 1 of 4)

| | | Hour Meter | | | | Service | | | Backwash | | System Pressure | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | West Well | | East Well | | AD-26 | | AD-33 | AD-26 | AD-33 | AD-26 | | AD-33 | |
| Week No. | Date | Daily Op Hours | Cumulative Hours[(a)] | Daily Op Hours | Cumulative Hours[(a)] | Combined Flowrate[(b)(c)] | Calculated Combined Flowrate[(d)] | Combined Flowrate [(e)] | Backwash Water Produced | Backwash Water Produced | Inlet Pressure | Outlet Pressure | Inlet Pressure | Outlet Pressure |
| | | hrs | hrs | hrs | hrs | gpm | gpm | gpm | gal | gal | psi | psi | psi | psi |
| 2 | 09/28/05 | NA | 5.4 | NA | 3.8 | 10 | NA | 21 | NA | NA | 38 | 38 | 55 | 55 |
| | 09/29/05 | NA | 10.8 | 0.2 | 4.0 | 26 | NA | NA | NA | NA | 52 | 51 | NA | NA |
| | 09/30/05 | NA | 16.2 | 3.0 | 7.0 | 37 | NA | 19 | NA | NA | 39 | 38 | 42 | 42 |
| | 10/01/05 | NA | 21.6 | 2.7 | 9.7 | 27 | NA | 23 | NA | NA | 54 | 52 | 38 | 38 |
| | 10/02/05 | NA | 27.0 | 3.1 | 12.8 | 33 | NA | 35 | NA | NA | 48 | 48 | 50 | 50 |
| 3 | 10/03/05 | NA | 32.4 | 6.6 | 19.4 | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | 10/04/05 | NA | 37.8 | 0.1 | 19.5 | 21 | NA | 23 | NA | NA | 44 | 44 | 38 | 40 |
| | 10/05/05 | NA | 43.2 | 2.4 | 21.9 | 22 | NA | 22 | NA | NA | 40 | 40 | 46 | 48 |
| | 10/06/05 | NA | 48.6 | 6.9 | 28.8 | 52 | NA | 23 | NA | NA | 44 | 46 | 40 | 40 |
| | 10/07/05 | NA | 54.0 | 1.1 | 29.9 | 30 | NA | 20 | NA | NA | 42 | 52 | 44 | 44 |
| | 10/08/05 | NA | 59.4 | 1.2 | 31.1 | 26 | NA | 41 | NA | NA | 42 | 42 | 54 | 54 |
| | 10/09/05 | NA | 64.8 | 4.3 | 35.4 | 38 | NA | 45 | NA | NA | 42 | 38 | 54 | 54 |
| 4 | 10/10/05 | NA | 70.2 | 4.6 | 40.0 | 29 | NA | 23 | NA | NA | 42 | 42 | 48 | 50 |
| | 10/11/05 | NA | 75.6 | 2.9 | 42.9 | 20 | NA | 15 | NA | NA | 44 | 44 | 40 | 40 |
| | 10/12/05 | NA | 81.0 | 2.8 | 45.7 | 19 | NA | 21 | NA | NA | 44 | 46 | 44 | 44 |
| | 10/13/05 | NA | 86.4 | 2.8 | 48.5 | 39 | NA | 29 | NA | NA | 54 | 52 | 44 | 44 |
| | 10/14/05 | NA | 91.8 | 4.2 | 52.7 | 22 | NA | 16 | NA | NA | 40 | 40 | 40 | 40 |
| | 10/15/05 | NA | 97.2 | 2.0 | 54.7 | 20 | NA | 20 | NA | NA | 42 | 40 | 40 | 40 |
| | 10/16/05 | NA | 102.6 | 3.3 | 58.0 | 30 | NA | 32 | NA | NA | 42 | 44 | 43 | 43 |
| 5 | 10/17/05 | NA | 108.0 | 3.6 | 61.6 | 28 | NA | 23 | NA | NA | 40 | 40 | 50 | 50 |
| | 10/18/05 | NA | 113.4 | 3.2 | 64.8 | 24 | NA | 20 | NA | NA | 44 | 46 | 46 | 46 |
| | 10/19/05 | NA | 118.8 | 2.7 | 67.5 | 32 | NA | 37 | NA | NA | 54 | 52 | 52 | 52 |
| | 10/20/05 | NA | 124.2 | 5.7 | 73.2 | 17 | NA | 18 | 4,533 | NA | 48 | 46 | 42 | 44 |
| | 10/21/05[(f)] | NA | 129.6 | 3.3 | 77.0 | 35 | NA | 25 | NA | NA | 54 | 52 | 44 | 44 |
| | 10/22/05 | 6.5 | 136.1 | 4.5 | 81.5 | 36 | 99 | 29 | 4,671 | NA | 52 | 50 | 46 | 46 |
| | 10/23/05 | 4.6 | 140.7 | 3.2 | 84.7 | 40 | 91 | 33 | NA | NA | 54 | 52 | 46 | 46 |
| 6 | 10/24/05 | 3.3 | 144.0 | 2.5 | 87.2 | 24 | 84 | 28 | 4,683 | NA | 42 | 44 | 50 | 50 |
| | 10/25/05 | 4.7 | 148.7 | 3.2 | 90.4 | 27 | 97 | NA | NA | NA | 48 | 48 | 54 | 54 |
| | 10/26/05[(g)] | 2.5 | 151.2 | 5.6 | 96.0 | 86 | 30 | 27 | 337 | NA | 52 | 52 | 52 | 52 |
| | 10/27/05 | 6.2 | 157.4 | 0.0 | 96.0 | 95 | 84 | 23 | NA | NA | 40 | 40 | 40 | 42 |
| | 10/28/05 | 8.5 | 165.9 | 0.0 | 96.0 | 86 | 64 | 27 | 3,127 | NA | 50 | 50 | 52 | 52 |
| | 10/29/05 | 7.5 | 173.4 | 0.0 | 96.0 | 88 | 96 | 26 | NA | NA | 46 | 46 | 48 | 48 |
| | 10/30/05 | 7.1 | 180.5 | 0.0 | 96.0 | 87 | 75 | 23 | 3,161 | NA | 52 | 54 | 50 | 48 |
| 7 | 10/31/05 | 10.1 | 190.6 | 0.5 | 96.5 | 87 | 80 | 28 | 653 | NA | 54 | 54 | 52 | 52 |
| | 11/01/05 | 2.8 | 193.4 | 2.6 | 99.1 | 97 | 80 | 34 | 6,228 | NA | 50 | 50 | 55 | 55 |
| | 11/02/05 | 4.0 | 197.4 | 2.5 | 101.6 | 117 | 94 | 22 | NA | NA | 47 | 47 | 48 | 48 |
| | 11/03/05 | 3.9 | 201.3 | 3.3 | 104.9 | 101 | 85 | 30 | 5,888 | NA | 45 | 45 | 50 | 50 |
| | 11/04/05 | 3.9 | 205.2 | 2.7 | 107.6 | 62 | 106 | 23 | NA | NA | 53 | 53 | 47 | 47 |
| | 11/05/05 | 3.8 | 209.0 | 3.3 | 110.9 | 133 | 90 | 34 | 6,106 | NA | 53 | 53 | 45 | 45 |
| | 11/06/05 | 4.4 | 213.4 | 3.0 | 113.9 | 79 | 95 | 20 | NA | NA | 47 | 48 | NA | NA |
| 8 | 11/07/05 | 4.6 | 218.0 | 3.8 | 117.7 | 129 | 85 | 9 | 5,846 | NA | 40 | 42 | 40 | 42 |
| | 11/08/05 | 4.3 | 222.3 | 2.8 | 120.5 | 124 | 95 | 29 | NA | NA | 54 | 52 | 50 | 52 |
| | 11/09/05 | 4.1 | 226.4 | 3.3 | 123.8 | 88 | 114 | 25 | 6,100 | NA | 44 | 44 | 44 | 46 |
| | 11/10/05 | 3.9 | 230.3 | 2.5 | 126.3 | 96 | 95 | 34 | NA | NA | 52 | 50 | 50 | 52 |
| | 11/11/05 | 4.8 | 235.1 | 4.1 | 130.4 | 84 | 71 | 23 | 6,116 | NA | 50 | 50 | 52 | 52 |
| | 11/12/05 | 3.8 | 238.9 | 2.7 | 133.1 | 134 | 62 | 28 | NA | NA | 50 | 48 | 50 | 50 |
| | 11/13/05 | 5.8 | 244.7 | 4.0 | 137.1 | 91 | 90 | 31 | 5,389 | NA | 44 | 44 | 48 | 48 |

## Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 2 of 4)

| Week No. | Date | Hour Meter | | | | Service | | | Backwash | | System Pressure | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | West Well | | East Well | | AD-26 | | AD-33 | AD-26 | AD-33 | AD-26 | | AD-33 | |
| | | Daily Op Hours | Cumulative Hours[(a)] | Daily Op Hours | Cumulative Hours[(a)] | Combined Flowrate[(b)(c)] | Calculated Combined Flowrate[(d)] | Combined Flowrate [(e)] | Backwash Water Produced | Backwash Water Produced | Inlet Pressure | Outlet Pressure | Inlet Pressure | Outlet Pressure |
| | | hrs | hrs | hrs | hrs | gpm | gpm | gpm | gal | gal | psi | psi | psi | psi |
| | 11/14/05 | 3.1 | 247.8 | 1.8 | 138.9 | 89 | 99 | 18 | NA | NA | 38 | 38 | 40 | 42 |
| | 11/15/05 | 5.3 | 253.1 | 3.7 | 142.6 | 88 | 90 | 19 | 5,494 | NA | 52 | 50 | 50 | 50 |
| | 11/16/05 | 3.3 | 256.4 | 1.7 | 144.3 | 125 | 95 | 25 | NA | NA | 54 | 50 | 38 | 38 |
| 9 | 11/17/05 | 8.0 | 264.4 | 7.1 | 151.4 | 108 | 92 | 37 | 5,256 | NA | 38 | 38 | 48 | 50 |
| | 11/18/05 | 3.2 | 267.6 | 1.7 | 153.1 | 82 | 93 | 30 | NA | NA | 52 | 48 | 52 | 52 |
| | 11/19/05 | 5.5 | 273.1 | 3.3 | 156.4 | 90 | 95 | 41 | 2,277 | NA | 40 | 48 | 48 | 50 |
| | 11/20/05 | 7.0 | 280.1 | 3.7 | 160.1 | 122 | 102 | 41 | NA | NA | 50 | 48 | 50 | 50 |
| | 11/21/05 | 2.3 | 282.4 | 2.0 | 162.1 | 123 | 63 | 22 | 5,272 | NA | 48 | 48 | 43 | 43 |
| | 11/22/05 | 4.5 | 286.9 | 2.5 | 164.6 | 135 | 97 | 36 | NA | NA | 51 | 49 | 44 | 44 |
| | 11/23/05 | 5.2 | 292.1 | 3.2 | 167.8 | 91 | 88 | 32 | 5,276 | NA | 46 | 45 | 47 | 47 |
| 10 | 11/24/05 | 5.3 | 297.4 | 2.8 | 170.6 | 121 | 96 | 39 | NA | NA | 51 | 49 | 43 | 43 |
| | 11/25/05 | 5.1 | 302.5 | 2.8 | 173.4 | 87 | 95 | 42 | 219 | NA | 46 | 43 | 48 | 48 |
| | 11/26/05 | 5.8 | 308.3 | 3.1 | 176.5 | 119 | 97 | 38 | NA | NA | 51 | 46 | 36 | 36 |
| | 11/27/05 | 6.7 | 315.0 | 4.3 | 180.8 | 88 | 90 | 39 | 4,700 | NA | 43 | 41 | 48 | 48 |
| | 11/28/05[(h)] | 7.4 | 322.4 | 3.4 | 184.2 | 131 | 97 | 43 | NA | NA | 46 | 42 | 42 | 44 |
| | 11/29/05 | 2.8 | 325.2 | 5.8 | 190.0 | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | 11/30/05 | 0.7 | 325.9 | 7.4 | 197.4 | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 11 | 12/01/05 | 3.7 | 329.6 | 2.1 | 199.5 | 88 | NA | 29 | NA | NA | 41 | 38 | 42 | 42 |
| | 12/02/05 | NA | 335.0 | NA | 203.3 | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | 12/03/05 | 12.5 | 347.5 | 11.9 | 215.2 | 140 | NA | 41 | NA | NA | 46 | 44 | 54 | 54 |
| | 12/04/05 | 5.1 | 352.6 | 2.9 | 218.1 | 71 | NA | 30 | NA | NA | 46 | 44 | 44 | 46 |
| | 12/05/05 | 3.1 | 355.7 | 4.1 | 222.2 | 93 | 76 | 20 | 13,547 | NA | 42 | 40 | 42 | 42 |
| | 12/06/05 | 5.5 | 361.2 | 3.4 | 225.6 | 130 | 30 | 28 | 1,227 | NA | 48 | 46 | 42 | 42 |
| | 12/07/05 | 5.7 | 366.9 | 3.2 | 228.8 | 92 | 105 | 41 | NA | NA | 42 | 33 | 52 | 54 |
| 12 | 12/08/05 | 5.8 | 372.7 | 4.9 | 233.7 | 123 | 75 | 45 | 13,284 | NA | 52 | 48 | 40 | 40 |
| | 12/09/05 | 6.4 | 379.1 | 3.6 | 237.3 | 123 | 94 | 39 | NA | NA | 52 | 48 | 52 | 52 |
| | 12/10/05 | 8.2 | 387.3 | 5.7 | 243.0 | 93 | 72 | 52 | 13,166 | NA | 44 | 42 | 42 | 47 |
| | 12/11/05 | 4.0 | 391.3 | 3.2 | 246.2 | 91 | 122 | 42 | NA | NA | 44 | 40 | 40 | 40 |
| | 12/12/05 | 7.2 | 398.5 | 5.9 | 252.1 | 138 | 83 | 31 | 13,097 | NA | 44 | 40 | 48 | 48 |
| | 12/13/05 | 4.3 | 402.8 | 2.4 | 254.5 | 84 | 94 | 24 | NA | NA | 40 | 40 | 35 | 35 |
| | 12/14/05 | 5.6 | 408.4 | 5.0 | 259.5 | 129 | 81 | 41 | 13,217 | NA | 50 | 47 | 49 | 49 |
| 13 | 12/15/05 | 5.5 | 413.9 | 3.3 | 262.8 | 88 | 97 | 35 | NA | NA | 43 | 39 | 48 | 48 |
| | 12/16/05 | 5.5 | 419.4 | 5.2 | 268.0 | 127 | 81 | 43 | 13,241 | NA | 50 | 49 | 45 | 45 |
| | 12/17/05 | 6.0 | 425.4 | 3.4 | 271.4 | 77 | 96 | 30 | NA | NA | 42 | 40 | 43 | 43 |
| | 12/18/05 | 5.3 | 430.7 | 5.2 | 276.6 | 110 | 81 | 35 | 13,181 | NA | 57 | 54 | 42 | 42 |
| | 12/19/05 | 6.8 | 437.5 | 3.7 | 280.3 | 85 | 95 | 51 | NA | NA | 48 | 44 | 46 | 48 |
| | 12/20/05 | 6.5 | 444.0 | 5.5 | 285.8 | 92 | 81 | 46 | 12,959 | NA | 40 | 38 | 42 | 42 |
| | 12/21/05 | 8.0 | 452.0 | 4.0 | 289.8 | 49 | 94 | 34 | NA | NA | 44 | 40 | 44 | 44 |
| 14 | 12/22/05 | 5.6 | 457.6 | 5.3 | 295.1 | 80 | 80 | 41 | 13,048 | NA | 50 | 48 | 52 | 52 |
| | 12/23/05 | 5.5 | 463.1 | 3.2 | 298.3 | 100 | 96 | 41 | NA | NA | 42 | 38 | 42 | 42 |
| | 12/24/05 | 9.1 | 472.2 | 6.6 | 304.9 | 80 | 83 | 42 | 13,019 | NA | 52 | 50 | 52 | 52 |
| | 12/25/05 | 5.4 | 477.6 | 3.0 | 307.9 | 132 | 99 | 31 | NA | NA | 48 | 44 | 50 | 50 |
| | 12/26/05 | 3.7 | 481.3 | 3.8 | 311.7 | 89 | 88 | 41 | 13,004 | NA | 42 | 40 | 40 | 40 |
| | 12/27/05 | 5.5 | 486.8 | 3.1 | 314.8 | 77 | 89 | 27 | NA | NA | 48 | 48 | 36 | 36 |
| | 12/28/05 | 6.1 | 492.9 | 5.3 | 320.1 | 90 | 78 | 30 | 13,035 | NA | 42 | 40 | 44 | 46 |
| 15 | 12/29/05 | 5.6 | 498.5 | 3.0 | 323.1 | 130 | 98 | 41 | NA | NA | 44 | 38 | 44 | 44 |
| | 12/30/05 | 7.4 | 505.9 | 4.8 | 327.9 | 85 | 84 | 38 | 13,135 | NA | 46 | 44 | 44 | 44 |
| | 12/31/05 | 9.5 | 515.4 | 2.6 | 330.5 | 118 | 66 | 34 | NA | NA | 52 | 46 | 48 | 50 |
| | 01/01/06 | 4.2 | 519.6 | 7.8 | 338.3 | 123 | 104 | 44 | 12,221 | NA | 50 | 46 | 46 | 48 |

# Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 3 of 4)

| | | Hour Meter | | | | Service | | | Backwash | | System Pressure | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | West Well | | East Well | | AD-26 | | AD-33 | AD-26 | AD-33 | AD-26 | | AD-33 | |
| Week No. | Date | Daily Op Hours hrs | Cumulative Hours[a] hrs | Daily Op Hours hrs | Cumulative Hours[a] hrs | Combined Flowrate[b][c] gpm | Calculated Combined Flowrate[d] gpm | Combined Flowrate [e] gpm | Backwash Water Produced gal | Backwash Water Produced gal | Inlet Pressure psi | Outlet Pressure psi | Inlet Pressure psi | Outlet Pressure psi |
| 16 | 01/02/06 | 5.3 | 524.9 | 3.1 | 341.4 | 58 | 93 | 32 | 900 | NA | 52 | 47 | 39 | 39 |
| | 01/03/06 | 6.0 | 530.9 | 6.0 | 347.4 | 128 | 79 | 37 | 13,241 | NA | 39 | 38 | 41 | 41 |
| | 01/04/06 | 6.2 | 537.1 | 3.8 | 351.2 | 113 | 93 | 34 | NA | NA | 56 | 55 | 47 | 47 |
| | 01/05/06 | 6.3 | 543.4 | 6.0 | 357.2 | 81 | 80 | 40 | 12,788 | NA | 56 | 54 | 43 | 43 |
| | 01/06/06 | 6.7 | 550.1 | 4.0 | 361.2 | 86 | 93 | 48 | NA | NA | 53 | 49 | 53 | 53 |
| | 01/07/06 | 6.0 | 556.1 | 6.0 | 367.2 | 125 | 81 | 26 | 12,894 | NA | 43 | 43 | 39 | 39 |
| | 01/08/06 | 7.7 | 563.8 | 4.9 | 372.1 | 87 | 91 | 38 | NA | NA | 45 | 42 | 48 | 48 |
| 17 | 01/09/06 | 7.3 | 571.1 | 6.6 | 378.7 | 130 | 81 | 56 | 12,898 | NA | 50 | 48 | 52 | 52 |
| | 01/10/06 | 7.2 | 578.3 | 5.1 | 383.8 | 121 | 92 | 52 | NA | NA | 52 | 46 | 50 | 50 |
| | 01/11/06 | 4.7 | 583.0 | 5.6 | 389.4 | 89 | 80 | 37 | 12,106 | NA | 44 | 42 | 48 | 48 |
| | 01/12/06 | 6.0 | 589.0 | 3.9 | 393.3 | 82 | 93 | 43 | NA | NA | 54 | 50 | 52 | 52 |
| | 01/13/06 | 5.5 | 594.5 | 4.5 | 397.8 | 79 | 85 | 36 | 6,133 | NA | 58 | 54 | 52 | 52 |
| | 01/14/06 | 7.5 | 602.0 | 5.5 | 403.3 | 128 | 89 | 38 | 5,402 | NA | 54 | 50 | 54 | 54 |
| | 01/15/06 | 5.5 | 607.5 | 3.6 | 406.9 | 80 | 93 | 52 | NA | NA | 56 | 52 | 52 | 52 |
| 18 | 01/16/06 | 3.7 | 611.2 | 3.3 | 410.2 | 91 | 85 | 43 | 5,434 | NA | 42 | 42 | 40 | 40 |
| | 01/17/06 | 6.2 | 617.4 | 4.3 | 414.5 | 88 | 95 | 34 | NA | NA | 48 | 44 | 46 | 48 |
| | 01/18/06 | 6.5 | 623.9 | 5.8 | 420.3 | 91 | 89 | 43 | 5,406 | NA | 48 | 42 | 50 | 50 |
| | 01/19/06 | 4.0 | 627.9 | 3.3 | 423.6 | 91 | 83 | 46 | NA | NA | 54 | 52 | 48 | 48 |
| | 01/20/06 | 4.5 | 632.4 | 4.0 | 427.6 | 91 | 95 | 26 | 5,343 | NA | 44 | 42 | 48 | 48 |
| | 01/21/06 | 5.9 | 638.3 | 3.8 | 431.4 | 91 | 93 | 35 | NA | NA | 58 | 54 | 50 | 50 |
| | 01/22/06 | 7.5 | 645.8 | 5.6 | 437.0 | 128 | 89 | 43 | 5,476 | NA | 48 | 44 | 40 | 40 |
| 19 | 01/23/06 | 3.5 | 649.3 | 2.2 | 439.2 | 122 | 86 | 37 | NA | NA | 48 | 42 | 44 | 44 |
| | 01/24/06 | 4.0 | 653.3 | 3.9 | 443.1 | 130 | 91 | 26 | 5,427 | NA | 42 | 41 | 55 | 58 |
| | 01/25/06 | 5.5 | 658.8 | 4.0 | 447.1 | 129 | 96 | 36 | NA | NA | 16 | 42 | 50 | 50 |
| | 01/26/06 | 5.1 | 663.9 | 4.7 | 451.8 | 129 | 87 | 28 | 5,348 | NA | 52 | 48 | 54 | 56 |
| | 01/27/06 | 4.4 | 668.3 | 3.4 | 455.2 | 91 | 89 | 26 | NA | NA | 43 | 41 | 47 | 48 |
| | 01/28/06 | 3.8 | 672.1 | 3.9 | 459.1 | 78 | 93 | 32 | 6,202 | NA | 46 | 44 | 50 | 50 |
| | 01/29/06 | 5.3 | 677.4 | 3.4 | 462.5 | 83 | 94 | 23 | NA | NA | 49 | 47 | 43 | 44 |
| 20 | 01/30/06 | 6.1 | 683.5 | 5.3 | 467.8 | 130 | 88 | 31 | 6,426 | NA | 52 | 48 | 54 | 56 |
| | 01/31/06 | 4.5 | 688.0 | 3.8 | 471.6 | 86 | 96 | 29 | NA | NA | 50 | 48 | 48 | 48 |
| | 02/01/06 | 4.6 | 692.6 | 5.5 | 477.1 | 87 | 91 | 32 | 6,355 | 5,752 | 46 | 44 | 48 | 46 |
| | 02/02/06 | 5.5 | 698.1 | 3.3 | 480.4 | 98 | 93 | 37 | NA | NA | 50 | 46 | 50 | 52 |
| | 02/03/06 | 5.3 | 703.4 | 3.6 | 484.0 | 126 | 92 | 28 | 2,473 | NA | 52 | 48 | 54 | 54 |
| | 02/04/06 | 7.4 | 710.8 | 5.1 | 489.1 | 112 | 84 | 45 | 7,661 | NA | 54 | 52 | 54 | 54 |
| | 02/05/06 | 5.3 | 716.1 | 3.9 | 493.0 | 107 | 93 | 42 | NA | NA | 52 | 46 | 50 | 50 |
| 21 | 02/06/06 | 6.3 | 722.4 | 3.8 | 496.8 | 100 | 80 | 45 | 9,244 | NA | 44 | 42 | 44 | 44 |
| | 02/07/06 | 4.7 | 727.1 | 2.9 | 499.7 | 115 | 95 | 33 | NA | NA | 54 | 50 | 54 | 54 |
| | 02/08/06 | 6.2 | 733.3 | 4.3 | 504.0 | 90 | 85 | 26 | 6,060 | NA | 44 | 42 | 42 | 42 |
| | 02/09/06 | 4.9 | 738.2 | 3.4 | 507.4 | 87 | 94 | 33 | NA | NA | 46 | 43 | 48 | 48 |
| | 02/10/06 | 5.4 | 743.6 | 4.7 | 512.1 | 80 | 85 | 33 | 6,125 | NA | 56 | 54 | 54 | 54 |
| | 02/11/06 | 6.8 | 750.4 | 4.6 | 516.7 | 119 | 100 | 37 | NA | NA | 50 | 44 | 50 | 50 |
| | 02/12/06 | 4.3 | 754.7 | 3.3 | 520.0 | 84 | 82 | 48 | NA | NA | 48 | 42 | 48 | 48 |
| 22 | 02/13/06 | 5.7 | 760.4 | 4.3 | 524.3 | 99 | 82 | 36 | 6,150 | NA | 44 | 43 | 44 | 45 |
| | 02/14/06 | 5.3 | 765.7 | 3.8 | 528.1 | 120 | 95 | 48 | NA | NA | 50 | 47 | 56 | 56 |
| | 02/15/06 | 5.3 | 771.0 | 3.9 | 532.0 | 114 | 91 | 23 | NA | NA | 56 | 50 | 39 | 39 |
| | 02/16/06 | 5.3 | 776.3 | 4.6 | 536.6 | 124 | 84 | 39 | 6,144 | NA | 42 | 41 | 50 | 50 |
| | 02/17/06 | 5.7 | 782.0 | 3.7 | 540.3 | 86 | 128 | 40 | NA | NA | 45 | 42 | 53 | 54 |
| | 02/18/06 | 4.9 | 786.9 | 3.6 | 543.9 | 81 | 54 | 33 | NA | NA | 55 | 53 | 44 | 44 |
| | 02/19/06 | 6.5 | 793.4 | 4.9 | 548.8 | 87 | 77 | 42 | 6,003 | NA | 47 | 46 | 51 | 51 |

## Table A-1. EPA Arsenic Demonstration Project at Springfield, OH - Daily System Operation Log Sheet (Page 4 of 4)

| | | Hour Meter | | | | Service | | | Backwash | | System Pressure | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | West Well | | East Well | | AD-26 | | AD-33 | AD-26 | AD-33 | AD-26 | | AD-33 | |
| Week No. | Date | Daily Op Hours | Cumulative Hours[(a)] | Daily Op Hours | Cumulative Hours[(a)] | Combined Flowrate[(b)(c)] | Calculated Combined Flowrate[(d)] | Combined Flowrate [(e)] | Backwash Water Produced | Backwash Water Produced | Inlet Pressure | Outlet Pressure | Inlet Pressure | Outlet Pressure |
| | | hrs | hrs | hrs | hrs | gpm | gpm | gpm | gal | gal | psi | psi | psi | psi |
| 23 | 02/20/06 | 5.3 | 798.7 | 3.9 | 552.7 | 125 | 109 | 42 | NA | NA | 52 | 48 | 52 | 54 |
| | 02/21/06 | 5.8 | 804.5 | 5.1 | 557.8 | 110 | 87 | 29 | NA | NA | 54 | 48 | 54 | 54 |
| | 02/22/06 | 5.6 | 810.1 | 4.5 | 562.3 | 92 | 86 | 33 | 6,167 | NA | 46 | 44 | 48 | 48 |
| | 02/23/06 | 6.6 | 816.7 | 4.8 | 567.1 | 124 | 107 | 43 | NA | NA | 52 | 48 | 50 | 50 |
| | 02/24/06 | 5.4 | 822.1 | 3.7 | 570.8 | 120 | 74 | 31 | 0 | NA | 54 | 48 | 54 | 54 |
| | 02/25/06 | 7.7 | 829.8 | 5.3 | 576.1 | 93 | 87 | 42 | 5,976 | NA | 44 | 42 | 46 | 44 |
| | 02/26/06 | 6.2 | 836.0 | 4.1 | 580.2 | 115 | 91 | 42 | NA | NA | 56 | 52 | 52 | 52 |
| 24 | 02/27/06 | 3.6 | 839.6 | 2.4 | 582.6 | 120 | 92 | 35 | NA | NA | 52 | 46 | 52 | 52 |
| | 02/28/06 | 5.6 | 845.2 | 3.8 | 586.4 | 87 | 82 | 29 | 7,507 | NA | 48 | 46 | 48 | 48 |
| | 03/01/06 | 5.7 | 850.9 | 3.8 | 590.2 | 111 | 93 | 30 | NA | NA | 58 | 54 | 54 | 54 |
| | 03/02/06 | 4.6 | 855.5 | 3.9 | 594.1 | 89 | 91 | 29 | NA | NA | 48 | 46 | 48 | 48 |
| | 03/03/06 | 5.1 | 860.6 | 4.0 | 598.1 | 129 | 83 | 35 | 6,278 | NA | 50 | 48 | 52 | 52 |
| | 03/04/06 | 5.1 | 865.7 | 3.3 | 601.4 | 126 | 96 | 34 | NA | NA | 48 | 44 | 52 | 52 |
| | 03/05/06 | 8.1 | 873.8 | 5.9 | 607.3 | 101 | 91 | 49 | NA | NA | 56 | 50 | 52 | 54 |
| 25 | 03/06/06 | 2.9 | 876.7 | 2.3 | 609.6 | 77 | 78 | 35 | 6,250 | NA | 46 | 44 | 46 | 46 |
| | 03/07/06 | 4.4 | 881.1 | 3.7 | 613.3 | 91 | 96 | 28 | NA | NA | 46 | 44 | 48 | 48 |
| | 03/08/06 | 4.9 | 886.0 | 3.6 | 616.9 | 86 | 92 | 30 | NA | NA | 50 | 48 | 48 | 48 |
| | 03/09/06 | 4.3 | 890.3 | 4.6 | 621.5 | 92 | 84 | 43 | 6,254 | NA | 46 | 44 | 44 | 44 |
| | 03/10/06 | 6.0 | 896.3 | 3.5 | 625.0 | 120 | 86 | 40 | NA | NA | 52 | 48 | 52 | 50 |
| | 03/11/06 | 4.8 | 901.1 | 5.1 | 630.1 | 107 | 102 | 34 | NA | NA | 60 | 46 | 48 | 48 |
| | 03/12/06 | 4.9 | 906.0 | 3.8 | 633.9 | 81 | 94 | 36 | 6,283 | NA | 54 | 50 | 54 | 54 |
| 26 | 03/13/06 | 1.4 | 907.4 | 2.3 | 636.2 | 114 | 103 | 32 | NA | NA | 56 | 52 | 56 | 54 |
| | 03/14/06 | 6.3 | 913.7 | 3.9 | 640.1 | 85 | 84 | 28 | NA | NA | 48 | 44 | 48 | 48 |
| | 03/15/06 | 4.5 | 918.2 | 4.1 | 644.2 | 86 | 89 | 26 | 4,808 | NA | 46 | 44 | 44 | 44 |
| | 03/16/06 | 4.6 | 922.8 | 3.3 | 647.5 | 124 | 97 | 37 | NA | NA | 50 | 48 | 48 | 48 |
| | 03/17/06 | 4.4 | 927.2 | 3.1 | 650.6 | 127 | 93 | 36 | NA | NA | 56 | 52 | 52 | 52 |
| | 03/18/06 | 4.6 | 931.8 | 4.2 | 654.8 | 90 | 86 | 32 | 6,246 | NA | 44 | 40 | 48 | 48 |
| | 03/19/06 | 6.7 | 938.5 | 5.6 | 660.4 | 87 | 96 | 39 | NA | NA | 46 | 42 | 44 | 44 |
| 27 | 03/20/06 | 3.6 | 942.1 | 2.4 | 662.8 | 89 | 92 | 22 | NA | NA | 48 | 44 | 48 | 48 |
| | 03/21/06 | 5.1 | 947.2 | 4.0 | 666.8 | 132 | 85 | 31 | 6,232 | NA | 52 | 50 | 52 | 54 |
| | 03/22/06 | 5.7 | 952.9 | 4.6 | 671.4 | 90 | 98 | 37 | NA | NA | 48 | 44 | 46 | 46 |
| | 03/23/06 | 3.6 | 956.5 | 2.8 | 674.2 | 85 | 86 | 36 | NA | NA | 48 | 46 | 46 | 46 |
| | 03/24/06 | 5.8 | 962.3 | 4.2 | 678.4 | 128 | 87 | 33 | 6,222 | NA | 54 | 52 | 50 | 50 |
| | 03/25/06 | 6.2 | 968.5 | 4.3 | 682.7 | 87 | 93 | 37 | NA | NA | 48 | 44 | 46 | 46 |
| | 03/26/06 | 5.1 | 973.6 | 3.7 | 686.4 | 122 | 92 | 42 | NA | NA | 52 | 46 | 50 | 50 |

Note: System started on September 21, 2005, at 5:00 pm, but operational readings not taken until September 28, 2005.

(a) In instances where readings not taken for hour meter, average was used to calculate cumulative hours (5.4 hrs for West Well and 3.8 for East Well)

(b) Oxidation Vessel A not in service between September 28, 2005 through October 23, 2005.

(c) Sum of flowrate readings on each of three AD-26 vessels.

(d) Totalizer readings divided by sum of West and East Wells operating hours.

(e) Sum of flowrate readings of each of three AD-33 vessels.

(f) Hour meter on East Well switched to West Well and a new hour meter installed on East Well on October 21, 2005.

(g) Since October 26, 2005, AD-26 system operated at pump flowrates and AD-33 system continued to operate on-demand.

(h) System by-passed between November 28 (8 a.m.) and 29, 2005, due to power outage/surge. System back online on November 30, 2005.

NA = Not Available

# APPENDIX B

# ANALYTICAL DATA

## Table B-1. Analytical Results from Long-Term Sampling at Springfield, OH (Page 1 of 4)

| Sampling Date | | 09/28/05 | | | | 10/11/05[a] | | | | 10/25/05 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sampling Location | | IN - East | AC | OT | TT | IN - East | AC | OT | TT | IN - East | AC | OT | TT |
| Parameter | Unit | | | | | | | | | | | | |
| Bed Volume | BV | - | - | - | 0.5 | - | - | - | 1.1 | - | - | - | 1.7 |
| Alkalinity (as $CaCO_3$) | mg/L | 361 | 370 | 365 | 365 | 352 | 356 | 352 | 348 | 343 | 330 | 339 | 334 |
| Ammonia (as N) | mg/L | 0.3 | 0.2 | <0.05 | <0.05 | 0.2 | <0.05 | <0.05 | <0.05 | 0.2 | <0.05 | <0.05 | <0.05 |
| Fluoride | mg/L | 1.2 | 1.2 | 1.3 | 1.5 | 1.3 | 1.3 | 1.4 | 1.4 | 1.1 | 1.4 | 1.2 | 1.2 |
| Sulfate | mg/L | 14.0 | 13.8 | 13.7 | 23.0 | 17.9 | 20.1 | 23.0 | 23.0 | 20.0 | 12.0 | 25.0 | 26.0 |
| Nitrate (as N) | mg/L | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Orthophosphate (as $PO_4$) | mg/L | <0.05 | <0.05 | <0.05 | <0.05 | - | - | - | - | - | - | - | - |
| Total P (as $PO_4$) | mg/L | - | - | - | - | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 |
| Silica (as $SiO_2$) | mg/L | 18.3 | 18.8 | 19.2 | 17.3 | 17.5 | 17.1 | 16.9 | 16.2 | 17.1 | 17.2 | 17.2 | 16.7 |
| Turbidity | NTU | 5.9 | 1.4 | <0.1 | <0.1 | 6.6 | 0.7 | <0.1 | 0.1 | 7.6 | 1.0 | <0.1 | 0.1 |
| pH | S.U. | 7.4 | 7.4 | 7.3 | 7.4 | 7.2 | 7.2 | 7.1 | 7.1 | 7.3 | 7.4 | 7.4 | 7.3 |
| Temperature | °C | 23.1 | 17.6 | 17.1 | 18.0 | 21.4 | 21.1 | 20.8 | 20.4 | 25.0 | 25.0 | 25.0 | 25.0 |
| DO | mg/L | 1.1 | 1.8 | 1.4 | 1.6 | 1.3 | 1.4 | 1.6 | 1.6 | 1.9 | 1.5 | 1.5 | 1.2 |
| ORP | mV | 107 | 746 | 728 | 718 | 232 | 624 | 627 | 566 | 102 | 734 | 712 | 713 |
| Free Chlorine | mg/L | - | NA[b] | NA[b] | 1.1 | - | 1.4 | 1.1 | 3.2 | - | NA[b] | 2.1 | 1.3 |
| Total Chlorine | mg/L | - | NA[b] | NA[b] | 1.6 | - | 1.8 | NA[c] | 3.3 | - | NA[b] | 2.2 | 1.9 |
| Total Hardness (as $CaCO_3$) | mg/L | 285 | 282 | 287 | 297 | 339 | 343 | 334 | 340 | 344 | 337 | 353 | 343 |
| Ca Hardness (as $CaCO_3$) | mg/L | 170 | 170 | 171 | 166 | 205 | 202 | 198 | 203 | 210 | 205 | 214 | 208 |
| Mg Hardness (as $CaCO_3$) | mg/L | 115 | 112 | 116 | 131 | 134 | 141 | 135 | 137 | 134 | 131 | 139 | 135 |
| As (total) | µg/L | 9.5 | 9.4 | 0.5 | <0.1 | 19.4 | 25.9 | 1.4 | 0.2 | 18.5 | 20.6 | 1.4 | 0.3 |
| As (soluble) | µg/L | 8.4 | 3.2 | 0.6 | <0.1 | - | - | - | - | 17.4 | 3.6 | 1.2 | 0.2 |
| As (particulate) | µg/L | 1.1 | 6.2 | <0.1 | <0.1 | - | - | - | - | 1.1 | 17.0 | 0.1 | 0.1 |
| As (III) | µg/L | 5.6 | 0.3 | 0.5 | 0.2 | - | - | - | - | 16.5 | 0.4 | 0.4 | 0.4 |
| As (V) | µg/L | 2.8 | 2.9 | 0.1 | <0.1 | - | - | - | - | 0.9 | 3.2 | 0.8 | <0.1 |
| Fe (total) | µg/L | 549 | 535 | <25 | <25 | 521 | 1,283 | <25 | <25 | 614 | 800 | <25 | <25 |
| Fe (soluble) | µg/L | 390 | <25 | <25 | <25 | - | - | - | - | 519 | <25 | <25 | <25 |
| Mn (total) | µg/L | 77.0 | 77.3 | <0.1 | <0.1 | 82.1 | 32.7 | <0.1 | <0.1 | 62.1 | 47.3 | 0.2 | 0.1 |
| Mn (soluble) | µg/L | 81.6 | 39.6 | <0.1 | <0.1 | - | - | - | - | 58.8 | 7.1 | 0.4 | 0.5 |

(a) Water quality measurements taken on 11/18/05. (b) Water quality measurements not recorded.
IN = at Wellhead; AC = after chlorination; OT after oxidation vessels; TT = after adsorption vessels

## Table B-1. Analytical Results from Long-Term Sampling at Springfield, OH (Page 2 of 4)

| Sampling Date | | 11/08/05 | | | | 12/05/05 | | | | 12/12/05[a] | | | | 01/03/06 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sampling Location | | IN - East | AC | OT | TT | IN - East | AC | OT | TT | IN - West | AC | OT | TT | IN - East | AC | OT | TT |
| Parameter | Unit | | | | | | | | | | | | | | | | |
| Bed Volume | BV | - | - | - | 2.2 | - | - | - | 3.2 | - | - | - | 3.6 | - | - | - | 4.9 |
| Alkalinity (as $CaCO_3$) | mg/L | 352 | 343 | 352 | 343 | 343 | 339 | 339 | 339 | 338 | 343 | 348 | 339 | 339 | 339 | 334 | 339 |
| Ammonia (as N) | mg/L | 0.2 | <0.05 | <0.05 | <0.05 | 0.2 | 0.2 | <0.05 | <0.05 | 0.2 | <0.05 | <0.05 | <0.05 | 0.2 | <0.05 | <0.05 | <0.05 |
| Fluoride | mg/L | 1.3 | 1.5 | 1.4 | 1.4 | 0.8 | 1.1 | 1.1 | 1.2 | 1.4 | 1.4 | 1.3 | 1.3 | 1.2 | 1.2 | 1.3 | 1.3 |
| Sulfate | mg/L | 20.8 | 29.9 | 25.0 | 25.9 | 17.1 | 24.5 | 21.6 | 22.8 | 30.1 | 30.3 | 25.0 | 25.7 | 22.0 | 22.0 | 27.0 | 27.0 |
| Nitrate (as N) | mg/L | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.20 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Orthophosphate (as $PO_4$) | mg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Total P (as $PO_4$) | mg/L | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 |
| Silica (as $SiO_2$) | mg/L | 17.6 | 18.1 | 17.6 | 17.0 | 18.1 | 19.0 | 18.3 | 18.3 | 19.7 | 19.7 | 18.9 | 18.7 | 18.8 | 17.9 | 18.0 | 18.2 |
| Turbidity | NTU | 7.9 | 0.9 | <0.1 | <0.1 | 7.0 | 1.1 | <0.1 | 0.1 | 24.0 | 1.5 | 0.8 | 0.4 | 9.2 | 1.0 | 0.5 | 0.7 |
| pH | S.U. | NA[b] | NA[b] | NA[b] | NA[b] | 7.5 | 7.4 | 7.4 | 7.3 | 7.4 | 7.4 | 7.4 | 7.4 | 7.2 | 7.2 | 7.2 | 7.2 |
| Temperature | °C | NA[b] | NA[b] | NA[b] | NA[b] | 10.2 | 10.2 | 10.2 | 10.2 | 14.4 | 14.2 | 14.2 | 14.1 | 15.7 | 15.7 | 15.7 | 15.6 |
| DO | mg/L | NA[b] | NA[b] | NA[b] | NA[b] | NA | 0.9 | 1.2 | 1.0 | 1.5 | 1.9 | 1.9 | 2.3 | 1.3 | 2.5 | 2.1 | 2.6 |
| ORP | mV | NA[b] | NA[b] | NA[b] | NA[b] | 145 | 148 | 394 | 468 | 132 | 689 | 681 | 684 | 5 | 691 | 679 | 689 |
| Free Chlorine | mg/L | - | NA[b] | NA[b] | NA[b] | - | NA[c] | 3.1 | 1.5 | - | NA[c] | NA[c] | 2.7 | - | 2.3 | 1.1 | 1.8 |
| Total Chlorine | mg/L | - | NA[b] | NA[b] | NA[b] | - | NA[c] | 3.5 | 2.0 | - | NA[c] | NA[c] | 3.8 | - | 2.8 | 1.6 | 2.2 |
| Total Hardness (as $CaCO_3$) | mg/L | 333 | 349 | 345 | 359 | 322 | 325 | 240 | 347 | 331 | 326 | 323 | 320 | 357 | 345 | 348 | 354 |
| Ca Hardness (as $CaCO_3$) | mg/L | 212 | 212 | 215 | 222 | 195 | 189 | 140 | 194 | 202 | 202 | 203 | 205 | 214 | 215 | 202 | 207 |
| Mg Hardness (as $CaCO_3$) | mg/L | 121 | 137 | 130 | 138 | 126 | 136 | 101 | 153 | 129 | 124 | 120 | 115 | 143 | 131 | 146 | 147 |
| As (total) | µg/L | 16.7 | 23.6 | 1.3 | 0.2 | 16.9 | 22.4 | 0.6 | <0.1 | 24.5 | 25.4 | 1.7 | 0.3 | 21.9 | 18.4 | 1.6 | 0.2 |
| As (soluble) | µg/L | - | - | - | - | 16.0 | 1.9 | 0.5 | <0.1 | - | - | - | - | 21.2 | 3.1 | 1.6 | 0.2 |
| As (particulate) | µg/L | - | - | - | - | 0.8 | 20.5 | <0.1 | <0.1 | - | - | - | - | 0.7 | 15.3 | <0.1 | <0.1 |
| As (III) | µg/L | - | - | - | - | 14.6 | 0.4 | <0.1 | <0.1 | - | - | - | - | 21.5 | 0.4 | 0.4 | 0.5 |
| As (V) | µg/L | - | - | - | - | 1.5 | 1.5 | 0.4 | <0.1 | - | - | - | - | <0.1 | 2.7 | 1.2 | <0.1 |
| Fe (total) | µg/L | 671 | 1,595 | <25 | <25 | 773 | 1,386 | 25 | <25 | 1,587 | 1,546 | <25 | <25 | 1,260 | 802 | <25 | <25 |
| Fe (soluble) | µg/L | - | - | - | - | 658 | <25 | <25 | <25 | - | - | - | - | 933 | <25 | <25 | <25 |
| Mn (total) | µg/L | 54.3 | 18.3 | 0.4 | <0.1 | 42.8 | 20.0 | <0.1 | <0.1 | 19.6 | 19.6 | 0.4 | <0.1 | 24.7 | 36.3 | <0.1 | <0.1 |
| Mn (soluble) | µg/L | - | - | - | - | 43.5 | 0.4 | <0.1 | <0.1 | - | - | - | - | 24.4 | 3.8 | 0.3 | 0.2 |

(a) Water quality measurements performed on 12/16/05. (b) Water quality measurements not recorded. (c) Operator saw error message while taking readings.
IN = at Wellhead; AC = after chlorination; OT after oxidation vessels; TT = after adsorption vessels

## Table B-1. Analytical Results from Long-Term Sampling at Springfield, OH (Page 3 of 4)

| Sampling Date | | 01/16/06 | | | | 02/01/06 [(a)] | | | | 02/13/06 | | | | 02/28/06[(b)] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sampling Location | | IN - West | AC | OT | TT | IN - East | AC | OT | TT | IN - West | AC | OT | TT | IN - West | AC | OT | TT |
| Parameter | Unit | | | | | | | | | | | | | | | | |
| Bed Volume | BV | - | - | - | 5.7 | - | - | - | 6.6 | - | - | - | 7.3 | - | - | - | 8.1 |
| Alkalinity (as $CaCO_3$) | mg/L | 343 | 352 | 352 | 348 | 348 | 343 | 335 | 343 | 338 | 342 | 338 | 338 | 329 | 350 | 338 | 338 |
| Ammonia (as N) | mg/L | 0.2 | <0.05 | <0.05 | <0.05 | 0.2 | 0.2 | <0.05 | <0.05 | 0.1 | 0.2 | <0.05 | <0.05 | 0.2 | <0.05 | <0.05 | <0.05 |
| Fluoride | mg/L | 1.4 | 1.4 | 1.2 | 1.2 | 1.1 | 1.1 | 1.3 | 1.3 | 1.3 | 1.1 | 1.2 | 1.2 | 1.5 | 1.3 | 1.5 | 1.4 |
| Sulfate | mg/L | 29.5 | 29.6 | 25.2 | 23.9 | 22.0 | 22.0 | 24.0 | 25.0 | 28.0 | 20.0 | 23.0 | 25.0 | 33.0 | 23.0 | 27.0 | 26.0 |
| Nitrate (as N) | mg/L | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Orthophosphate (as $PO_4$) | mg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Total P (as $PO_4$) | mg/L | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 |
| Silica (as $SiO_2$) | mg/L | 19.4 | 19.2 | 18.2 | 18.9 | 18.5 | 18.3 | 18.5 | 18.5 | 19.1 | 17.6 | 18.5 | 18.1 | 19.9 | 17.9 | 18.5 | 17.7 |
| Turbidity | NTU | 24.0 | 1.1 | 0.1 | 0.2 | 11.0 | 1.2 | 0.3 | 0.2 | 25.0 | 2.0 | 0.6 | 0.6 | 25.0 | 1.2 | 0.5 | 0.6 |
| pH | S.U. | 7.2 | 7.2 | 7.2 | 7.1 | 7.2 | 7.3 | 7.2 | 7.2 | 7.1 | 7.0 | 7.1 | 7.1 | 7.2 | 7.2 | 7.2 | 7.1 |
| Temperature | °C | 17.1 | 16.7 | 16.5 | 16.3 | 17.8 | 17.6 | 17.4 | 17.3 | 16.6 | 16.0 | 15.8 | 15.7 | 13.6 | 13.9 | 14.0 | 14.1 |
| DO | mg/L | 2.7 | 2.7 | 2.8 | 2.7 | 1.7 | 1.5 | 2.0 | 2.6 | 1.8 | 2.1 | 2.7 | 2.3 | 2.6 | 2.6 | 3.0 | 2.4 |
| ORP | mV | -131 | 110 | 395 | 475 | 228 | 653 | 341 | 393 | -90 | -78 | 600 | 619 | -84 | 304 | 270 | 281 |
| Free Chlorine | mg/L | - | 2.1 | 0.4 | 1.7 | - | - | 0.6 | 1.4 | - | 2.4 | 1.7 | 1.2 | - | 2.5 | 0.3 | 0.7 |
| Total Chlorine | mg/L | - | 3.2 | 1.8 | 1.8 | - | - | 0.6 | 1.6 | - | NA | 2.3 | 1.7 | - | NA | 0.9 | 0.8 |
| Total Hardness (as $CaCO_3$) | mg/L | 344 | 349 | 351 | 349 | 321 | 323 | 347 | 305 | 360 | 349 | 357 | 360 | 365 | 341 | 349 | 348 |
| Ca Hardness (as $CaCO_3$) | mg/L | 209 | 211 | 214 | 214 | 201 | 197 | 194 | 183 | 208 | 210 | 213 | 212 | 215 | 208 | 207 | 209 |
| Mg Hardness (as $CaCO_3$) | mg/L | 134 | 139 | 137 | 135 | 120 | 126 | 153 | 121 | 152 | 139 | 144 | 148 | 150 | 134 | 141 | 139 |
| As (total) | µg/L | 27.0 | 26.7 | 2.0 | 0.5 | 20.0 | 18.7 | 1.9 | 0.3 | 30.8 | 18.0 | 1.6 | 0.1 | 31.3 | 22.9 | 2.0 | 0.4 |
| As (soluble) | µg/L | - | - | - | - | 16.4 | 3.4 | 1.8 | 0.4 | - | - | - | - | 25.6 | 4.8 | 1.7 | 0.2 |
| As (particulate) | µg/L | - | - | - | - | 3.6 | 15.3 | <0.1 | <0.1 | - | - | - | - | 5.7 | 18.1 | 0.3 | 0.2 |
| As (III) | µg/L | - | - | - | - | 15.3 | 0.7 | 0.7 | 0.8 | - | - | - | - | 24.7 | 0.6 | 0.6 | 0.6 |
| As (V) | µg/L | - | - | - | - | 1.1 | 2.7 | 1.2 | <0.1 | - | - | - | - | 0.9 | 4.3 | 1.0 | <0.1 |
| Fe (total) | µg/L | 1,595 | 1,538 | <25 | <25 | 650 | 660 | <25 | <25 | 1,573 | 728 | <25 | <25 | 1,484 | 703 | <25 | <25 |
| Fe (soluble) | µg/L | - | - | - | - | 563 | <25 | <25 | <25 | - | - | - | - | 1463 | <25 | <25 | <25 |
| Mn (total) | µg/L | 17.9 | 17.4 | 0.2 | <0.1 | 34.4 | 34.2 | 0.2 | <0.1 | 18.9 | 39.0 | 0.2 | <0.1 | 18.2 | 34.9 | <0.1 | <0.1 |
| Mn (soluble) | µg/L | - | - | - | - | 36.6 | 2.2 | <0.1 | <0.1 | - | - | - | - | 18.8 | 3.2 | <0.1 | <0.1 |

(a) Water quality measurements taken on 01/30/06. (b) Water quality measurements taken on 02/27/06.
IN = at Wellhead; AC = after chlorination; OT after oxidation vessels; TT = after adsorption vessels

**Table B-1. Analytical Results from Long-Term Sampling at Springfield, OH (Page 4 of 4)**

| Sampling Date | | 03/13/06[a] | | | |
|---|---|---|---|---|---|
| Sampling Location | | IN - East | AC | OT | TT |
| Parameter | Unit | | | | |
| Bed Volume | BV | - | - | - | 8.9 |
| Alkalinity (as $CaCO_3$) | mg/L | 351/335 | 331/331 | 331/335 | 339/343 |
| Ammonia (as N) | mg/L | <0.05/<0.05 | <0.05/<0.05 | <0.05/<0.05 | <0.05/<0.05 |
| Fluoride | mg/L | 1.3/1.3 | 1.5/1.6 | 1.5/1.6 | 1.4/1.4 |
| Sulfate | mg/L | 22.8/22.4 | 32.5/33.1 | 30.7/29.2 | 27.5/27.6 |
| Nitrate (as N) | mg/L | <0.05/<0.05 | <0.05/<0.05 | <0.05/<0.05 | <0.05/<0.05 |
| Total P (as $PO_4$) | mg/L | <0.01/<0.01 | <0.01/<0.01 | <0.01/<0.01 | <0.01/<0.01 |
| Silica (as $SiO_2$) | mg/L | 17.3/17.0 | 18.8/18.7 | 17.8/17.4 | 17.8/17.4 |
| Turbidity | NTU | 11.0/11.0 | 4.3/14.0 | 0.8/0.7 | 1.4/1.1 |
| pH | S.U. | 7.3 | 7.4 | 7.5 | 7.2 |
| Temperature | °C | 15.7 | 15.4 | 15.4 | 15.5 |
| DO | mg/L | - | - | - | - |
| ORP | mV | 193 | 489 | 347 | - |
| Free Chlorine | mg/L | - | 0.3 | 1.6 | 2.0 |
| Total Chlorine | mg/L | - | 0.7 | 2.5 | 2.5 |
| Total Hardness (as $CaCO_3$) | mg/L | 329/336 | 342/346 | 349/344 | 345/339 |
| Ca Hardness (as $CaCO_3$) | mg/L | 206/210 | 204/208 | 210/211 | 211/209 |
| Mg Hardness (as $CaCO_3$) | mg/L | 123/126 | 138/138 | 139/133 | 134/130 |
| As (total) | µg/L | 20.9/21.8 | 29.2/29.8 | 1.8/1.8 | 0.2/0.2 |
| As (soluble) | µg/L | - | - | - | - |
| As (particulate) | µg/L | - | - | - | - |
| As (III) | µg/L | - | - | - | - |
| As (V) | µg/L | - | - | - | - |
| Fe (total) | µg/L | 829/896 | 1,561/1,564 | <25/<25 | <25/<25 |
| Fe (soluble) | µg/L | - | - | - | - |
| Mn (total) | µg/L | 35.4/34.7 | 17.6/17.3 | 0.2/0.2 | <0.1/<0.1 |
| Mn (soluble) | µg/L | | | | |

(a) Duplicate samples taken on 03/13/06
IN = at Wellhead; AC = after chlorination; OT after oxidation vessels; TT = after adsorption vessels