Arsenic Removal from Drinking Water by Ion Exchange
U.S. EPA Demonstration Project at Fruitland, ID
Six-Month Evaluation Report

by

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ABSTRACT

This report documents the activities performed during and the results obtained from the first six months of the performance evaluation of a Kinetico ion exchange (IX) system to remove arsenic (As) and nitrate from source water at the City of Fruitland in Idaho. The 250-gal/min (gpm) IX system consisted of a bank of five sediment filters and two 48-in-diameter by 72-in-tall pressure vessels configured in parallel. Each resin vessel contained 50 ft^3 of a strong base anionic exchange resin, i.e., A300E manufactured by Purolite. The system installation first began in March 2004; however, the commencement of the system operation was repeatedly delayed until June 2005 due to a series of problems encountered. The problems started with excessive sediment production from the original supply well, followed by the failure of a replacement well to pass bacterial testing even after repeated sanitation efforts. The problems were further compounded by the need to replace the resin that was erroneously installed in the resin vessels and a broken well pump that was salvaged from the original supply well into the replacement well.

During this reporting period from June 14 through December 16, 2005, the IX system operated for a total of 3,635 hr, averaging 20 hr/day. The system treated 35.9 million gal of water with an average daily production of 194,000 gal/day (gpd). The average flowrate was 165 gpm, which was equivalent to 66% of the 250-gpm design flowrate. This average flowrate yielded a 4.5-min empty bed contact time (EBCT) and a 6.6-gpm/ft^2 hydraulic loading rate to each resin vessel. The IX resin was regenerated in a downflow, co-current mode using a sodium chloride brine solution at a target salt level of 10 lb/ ft^3 of resin. Triggered automatically by a pre-set throughput in the programmable logic controller (PLC), the two IX vessels were regenerated sequentially, each cycling through the steps of brine draw, slow rinse, and fast rinse before returning to service. A total of 110 regeneration cycles took place during this reporting period, consuming approximately 172,390 lb (or 86 ton) of salt. Therefore, each regeneration cycle used an average of 1,567 lb of salt, or 15.7 lb/ft^3 of resin, which was 57% higher than the design value. Close examination of the regeneration steps revealed that this unexpectedly high salt usage was the result of a higher brine draw rate caused by improper flow control.

Total As concentrations in raw water ranged from 33.6 to 60.8 µg/L and averaged 42.1 µg/L, which existed primarily as As(V). Nitrate concentrations in raw water ranged from 6.9 to 11.2 mg/L (as N) and averaged 9.5 mg/L (as N). After treatment, total As and nitrate concentrations were reduced to below the respective maximum contaminant levels (MCLs), except when the system was freshly regenerated or experiencing mechanical problems. Removal of uranium, vanadium, and molybdenum by the IX system also was observed.

Sulfate, the most preferred anion by the resin, was removed from an average of 58 mg/L in raw water to less than 1 mg/L in the treated water, except when the system was experiencing mechanical problems. Raw water pH values ranged from 7.3 to 7.9. A significant reduction in pH in the treated water was observed immediately after resin regeneration, presumably due to the removal of bicarbonate ions by the freshly regenerated IX resin, as evidenced by the corresponding decrease in total alkalinity.

Resin run length studies were conducted over the course of three separate service runs. The purpose of the studies was to delineate the arsenic and nitrate breakthrough curves and determine the resin run length between two consecutive regeneration cycles. Based on the results of these studies, the resin run length was upwardly adjusted from the initial factory setting of 214,000 gal (or 286 bed volume [BV]) to 335,000 gal (or 448 BV), then downwardly adjusted to 316,000 gal (or 422 BV) to reach an optimal service run length. Effluent samples collected from the IX vessels indicated arsenic and nitrate leakage during the first 50,000 to 60,000 gal (or 67 to 80 BV) of throughput, which was consistent with the observations made during the treatment plant sampling in the six-month period. As expected, total alkalinity and pH values were significantly reduced during the early stage of all service runs.

During the first six months, the resin regeneration scheme was adjusted several times to improve regeneration efficiency and minimize residual production. Originally, the factory settings for the resin regeneration consisted of 64 min of brine draw with a 4% brine, 64 min of slow rinse, and 30 min of fast rinse. These settings were changed to 32 min of brine draw with an 8% brine (to achieve the same salt regeneration level), 40 min of slow rinse, and/or 6 or 15 min of fast rinse. The adjustments to the regeneration settings resulted in significant reductions in wastewater production. For example, the decrease in the brine draw time from 64 to 32 min reduced the spent brine volume by 50%, from 2,304 to 1,152 gal per regeneration cycle. The reduction in the slow rinse and fast rinse times also decreased the wastewater volume proportionally. Under a set of modified settings consisting of 25 min of brine draw with an 8% brine, 40 min of slow rinse, and 15 min of fast rinse, the amount of wastewater generated was 5,740 gal per cycle, accounting for 1.8% of the total volume treated (i.e., 316,000 gal). Because treated water was used for regeneration, the system production efficiency was 98.2%.

Two resin regeneration studies were conducted to evaluate the effectiveness of the resin regeneration process and characterize the residuals produced. Although the majority of arsenic and nitrate on the resin was eluted during the brine draw and slow rinse steps, arsenic concentrations as high as 35 µg/L were still measured towards the end of the fast rinse step. Therefore, it was not surprising to detect over 10 µg/L of arsenic during the early stage of the subsequent service run. Extending the fast rinse time from 6 to 15 min did not resolve the problem because the arsenic leakage was found to continue up to 52,000 gal (or 70 BV) of throughput, or approximately 3 to 4 hr into the service run. The waste stream discharged to the sewer contained an average of 1.2 to 2.4 mg/L of arsenic and 0.42 to 0.5 g/L of nitrate, equivalent to a mass loading of 31 to 56 g for arsenic and 8,615 to 12,649 g for nitrate per regeneration cycle. The percent recoveries were 114 and 63% for arsenic, 99 and 130% for nitrate, and 118 and 74% for sulfate, in the two regeneration studies, respectively.

The capital investment cost was $286,388, which included $173,195 for equipment, $35,619 for site engineering, and $77,574 for installation. This capital cost was normalized to the system's rated capacity of 250 gpm (360,000 gpd), which resulted in $1,146 per gpm ($0.80 per gpd). Funded separately by the City of Fruitland, the cost associated with the new building, sanitary sewer connection, and other discharge-related infrastructure was not included in the capital cost.

The operation and maintenance (O&M) cost for the IX system included the incremental cost associated with the salt supply, electricity consumption, and labor. Over the six-month operation period, the cost of the salt supply was $0.51/1,000 gal of water treated based on the average salt usage of 4.80 lb/1,000 gal. This salt cost could be reduced to $0.35/1,000 gal if the brine draw flow was controlled properly to reach a target salt usage of 3.16 lb/1,000 gal. Incremental electricity consumption associated with the IX system was not available, but assumed to be minimal. The actual power usage for operating the entire plant was approximately $0.08/1,000 gal of water treated. The routine, non-demonstration related labor activities consumed about 30 min/day, which corresponded to a labor cost of $0.04/1,000 gal. Therefore, the total O&M cost was approximately $0.63/1,000 gal (actual) or $0.47/1,000 gal (design), with the majority of the cost incurred by the salt supply.

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FIGURES

TABLES

ABBREVIATIONS AND ACRONYMS

AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media process
As	arsenic
bgs	below ground surface
Ca	calcium
Cl	chlorine
C/F	coagulation/filtration process
Cu	copper
DO	dissolved oxygen
EBCT	empty bed contact time
EMCT	equilibrium multicomponent chromatography theory
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
FRP	fiber reinforced plastic
GFH	granular ferric hydroxide
gpd	gallons per day
gpm	gallons per minute
HDPE	high-density polyethylene
hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IDEQ	Idaho Department of Environmental Quality
IX	ion exchange
LCR	Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MDWCA	Mutual Domestic Water Consumer's Association
Mg	magnesium
Mn	manganese
Mo	molybolenum
mV	millivolts
Na	sodium
NA	not applicable
NaOCl	sodium hypochlorite
NIST	National Institute of Standards and Technology

NRMRL	National Risk Management Research Laboratory
NSF	NSF International
NTU	nephelometric turbidity units
OIP	operator-interface-panel
O&M	operation and maintenance
ORD	Office of Research and Development
ORP	oxidation-reduction potential
PE	professional engineer
P&ID	piping and instrumentation diagrams
PLC	programmable logic controller
psi	pounds per square inch
PVC	polyvinyl chloride
QA	quality assurance
QAPP	quality assurance project plan
QA/QC	quality assurance/quality control
RPD	relative percent difference
SBA	strong-base anion exchange
SDWA	Safe Drinking Water Act
SM	system modification
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
U	uranium
UPS	uninterrupted power supply
UV	ultraviolet
V	vanadium
WRWC	White Rock Water Company

ACKNOWLEDGMENTS

1.0 INTRODUCTION

1.1　　　　Background

The Safe Drinking Water Act (SDWA) mandates that U.S. Environmental Protection Agency (EPA) identify and regulate drinking water contaminants that may have adverse human health effects and 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 the first round of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 sites from a list of 115 to be the host sites for the demonstration program. The facility at City of Fruitland in Idaho was selected to participate in this demonstration program.

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 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 Round 1 demonstration program. 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. An ion exchange (IX) system proposed by Kinetico was selected for demonstration at the Fruitland, Idaho site for the removal of arsenic and nitrate from drinking water supplies.

1.2　　　　Treatment Technologies for Arsenic Removal

The technologies selected for the 12 Round 1 EPA arsenic removal demonstration host sites include nine adsorptive media systems, one IX system, one coagulation/filtration system, and one process modification with iron addition. Table 1-1 summarizes the locations, technologies, vendors, and key source water quality parameters of the 12 demonstration sites. An overview of the technology selection and system design for the 12 demonstration sites and the associated capital cost is provided in two EPA reports (Wang et al., 2004; Chen et al., 2004), which are posted on the EPA website at http://www.epa.gov/ORD/NRMRL/wswrd/dw/arsenic/index.html. As of April 2007, 11 of the 12 systems have been operational and the performance evaluation of eight systems has been completed.

Table 1-1. Summary of Round 1 Arsenic Removal Demonstration Sites

Demonstration Site	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
				As (µg/L)	Fe (µg/L)	pH
WRWC (Bow), NH	AM (G2)	ADI	70[a]	39	<25	7.7
Rollinsford, NH	AM (E33)	AdEdge	100	36[b]	46	8.2
Queen Anne's County, MD	AM (E33)	STS	300	19[b]	270[c]	7.3
Brown City, MI	AM (E33)	STS	640	14[b]	127[c]	7.3
Climax, MN	C/F (Macrolite)	Kinetico	140	39[b]	546[c]	7.4
Lidgerwood, ND	Process Modification	Kinetico	250	146[b]	1,325[c]	7.2
Desert Sands MDWCA, NM	AM (E33)	STS	320	23[b]	39	7.7
Nambe Pueblo, NM	AM (E33)	AdEdge	145	33	<25	8.5
Rimrock, AZ	AM (E33)	AdEdge	90[a]	50	170	7.2
Valley Vista, AZ	AM (AAFS50 /ARM 200)	Kinetico	37	41	<25	7.8
Fruitland, ID	IX (A300E)	Kinetico	250	44	<25	7.4
STMGID, NV	AM (GFH)	Siemens	350	39	<25	7.4

AM = adsorptive media process; C/F = coagulation/filtration process; IX = ion exchange process;
MDWCA = Mutual Domestic Water Consumer's Association;
STMGID = South Truckee Meadows General Improvement District; WRWC = White Rock Water Company;
STS = Severn Trent Services
(a) Design flowrate reduced by 50% due to system reconfiguration from parallel to series operation.
(b) Arsenic existing mostly as As(III).
(c) Iron existing mostly as Fe(II).

1.3   Project Objectives

The objective of the Round 1 arsenic demonstration program is to conduct 12 full-scale arsenic removal 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 costs of the technologies.

This report summarizes the performance of a Kinetico IX system at Fruitland, Idaho during the first six months of operation from June 14 through December 16, 2005. The types of data collected include system operational, water quality (both across the treatment train and in the distribution system), residuals characterization, and capital and O&M costs.

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 IX arsenic/nitrate removal technology for use on small systems:

- The A300E IX technology is effective at removing arsenic and nitrate, provided that the system is regenerated properly. The system achieved a run length of 316,000 gal (422 BV) to the 10-mg/L nitrate (as N) breakthrough, which occurred before arsenic reached 10-µg/L breakthrough.

- The A300E IX technology is also effective at removing uranium, vanadium, and molybdenum.

- After the system was freshly regenerated, arsenic and nitrate leakage was detected in the treated water up to 50,000 to 60,000 gal (67 to 80 BV) of throughput (or 3 to 4 hr into the service run). This early leakage is indicative of the incomplete resin regeneration in the down-flow, co-current mode employed by the Fruitland system. Upflow counter-current regeneration will be tested for the later part of the study.

- Freshly regenerated IX resin removes bicarbonate ions, causing reduction in pH and total alkalinity during the initial 100 BV of a service run.

- Arsenic and nitrate peaking can occur if the system is allowed to operate beyond the planned run length. The proper regeneration frequency can be determined based on the arsenic and nitrate breakthrough curves during the service runs.

- Salt consumption by the Fruitland IX system was almost 50% higher than expected (i.e., 4.80 lb salt/1,000 gal of water treated) due to improper flow control of the brine draw. Consideration should be given to improve brine injection and the use of less dilute brine solution to save salt consumption.

- It is important to monitor the salt usage during a regeneration cycle to ensure the resin is regenerated properly.

Required system operation and maintenance and operator skill levels:

- Operational issues related to low flow and high pressure drop across the treatment system were experienced during system shakedown and startup. They were addressed through modifications to the flow restrictor on each resin vessel.

- Under normal operating conditions, the skill requirements to operate the system are minimal, with a typical daily demand on the operator of 30 min. Other skills needed for performing O&M activities include replacing filter bags periodically, using a hydrometer to check brine concentrations, monitoring salt inventory levels, scheduling salt delivery, and working with the vendor to troubleshoot and perform minor on-site repairs.

Process residuals produced by the technology:

- Residuals produced by the IX system include spent brine and rinse water. The volume of wastewater produced is dependent upon the regeneration frequency and settings.

- Regeneration wastewater can be disposed of to the sewer at the Fruitland, Idaho site.

Cost of the technology:

- Using the system's rated capacity of 250 gpm (or 201,600 gpd), the capital cost is $1,146/gpm (or $0.80/gpd) of the design capacity.

- Cost of salt supply is the most significant add-on to the previous plant operation. The actual salt supply during the six-month period cost $0.51/1,000 gal of water treated, which can be lowered to $0.35/1,000 gal if the designed salt usage (i.e., 3.16 lb/1,000 gal) is achieved.

3.0 MATERIALS AND METHODS

3.1 General Project Approach

Following the predemonstration activities summarized in Table 3-1, the performance evaluation of the IX system began on June 14, 2005. Table 3-2 summarizes the types of data collected and/or considered as part of the technology evaluation process. The overall system performance was evaluated based on its ability to consistently remove arsenic and nitrate to below the respective MCLs of 10-μg/L arsenic and 10-mg/L nitrate (as N) through collection of weekly and monthly water sampling across the treatment train. The reliability of the system was evaluated by tracking the unscheduled system downtime and the frequency and extent of repairs and replacement. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

Table 3-1. Pre-Demonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	08/21/03
Request for Quotation Issued to Vendor	08/26/03
Vendor Quotation Received by Battelle	09/19/03
Purchase Order Completed and Signed	10/16/03
Letter Report Issued	10/17/03
Draft Study Plan Issued	11/26/03
Engineering Package Submitted to IDEQ	01/25/04
Concrete Pad Poured	02/06/04
Building Construction Began	02/10/04
Final Study Plan Issued	02/25/04
IX-248-As/N System Shipped	03/03/04
Building Construction Completed	03/03/04
IX-248-As/N System Arrived	03/08/04
Excessive Sediment Production in Well No. 6 Occurred	03/25/04–03/26/04
Well Investigation on Sediment Production	04/01/04–04/13/04
Replacement Well No. 6-2004 Drilled	05/04/04–05/07/04
Temporary Treatment System Permit Issued	05/10/04
System Installation Completed	07/27/04
System Shakedown Halted due to Positive Coliform Tests	07/28/04
Well Sanitized Repetitively due to Positive Coliform Tests	07/04–04/05
Incorrect Resin Removed and Replaced with A300E Resin	04/21/05
Negative Coliform Tests Obtained and Submitted to IDEQ	05/04/05
New Pump Installed in Well No. 6-2004	05/19/05
Request for Discharging Treated Water to Distribution System Approved by IDEQ	06/07/05
System Shakedown Completed	06/13/05
Performance Evaluation Began	06/14/05

IDEQ = Idaho Department of Environmental Quality

The system 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 of relevant chemical processes and related health and safety practices. The staffing requirements for the system operation were recorded daily.

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

Evaluation Objectives	Data Collection
Performance	–Treated water quality, particularly arsenic and nitrate concentrations
Reliability	–Unscheduled downtime system –Frequency and extent of repairs including a description of problems, materials and supplies needed, and associated labor and cost
System O&M and Operator Skill Requirements	–Pre- and post-treatment requirements –Level of system automation for system operation and data collection –Staffing requirements including number of operators and laborers –Task analysis of preventive maintenance to include number, frequency, and complexity of tasks –Chemical handling and inventory requirements –General knowledge of relevant chemical processes and health and safety requirements practices
Residual Management	–Quantity and characteristics of spent brine and rinse water generated by process
System Cost	–Capital cost for equipment, engineering, and installation –O&M cost for chemical and/or media usage, electricity, and labor

The quantity of residuals generated was estimated by monitoring the flowrate and duration of each regeneration step (i.e., brine draw, slow rinse, and fast rinse) and the number of regeneration cycles during the study period. Regeneration wastewater was sampled and analyzed for chemical characteristics.

The cost of the system was evaluated based on the capital cost per gpm (or gpd) of design capacity and the O&M cost per 1,000 gal of water treated. This task required tracking of the capital cost for equipment, engineering, and installation, as well as the O&M cost for salt supply, electrical power use, and labor hours.

3.2   System O&M and Cost Data Collection

The plant operator performed daily, weekly, and monthly system O&M and data collection following the instructions provided by the vendor and Battelle. On a daily basis, the plant operator recorded system operational data, such as pressure, flowrate, system throughput, operating hours, and regeneration counter readings on a Daily System Operational Log Sheet, checked brine day tank and salt saturator levels, and conducted visual inspections for leaks or faults. If any problems occurred, the plant operator contacted the Battelle Study Lead, who would determine if the vendor should be contacted for troubleshooting. The plant operator recorded all relevant information on the Repair and Maintenance Log Sheet. On a weekly basis, the plant operator measured water quality parameters, including pH, temperature, dissolved oxygen (DO), and oxidation-reduction potential (ORP), and recorded the data on a Weekly Water Quality Parameters Log Sheet. During the study period, the system was regenerated automatically when triggered by a predetermined throughput setpoint. Occasionally, the system regeneration was initiated by the operator for sampling purposes.

The O&M cost consisted primarily of the cost for salt use, electricity consumption, and labor. Salt was delivered in bulk quantities by Western Step Saver, Inc., in Boise, Idaho, on a weekly or as needed basis to the treatment plant. The salt usage was tracked from the monthly invoices of the salt delivery. The electricity consumption was obtained from the utility bills for the reporting period. Labor for various activities, such as the routine system O&M, troubleshooting and repairs, and demonstration-related work, were recorded daily on an Operator Labor Hour sheet. The routine O&M included activities such as completing field logs, replenishing chemical solutions, 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, was recorded but not used for the cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected routinely by the operator from the wellhead, across the treatment plant, and from the distribution system. Table 3-3 summarizes the sampling schedule and analyses 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, 2003). The procedure for arsenic speciation is described in Appendix A of the QAPP.

3.3.1   Source Water. During the initial site visit on August 21, 2003, one set of source water samples was collected and speciated using an arsenic speciation kit described in Section 3.5.1. Because it had been taken offline due to elevated nitrate concentrations, Well No. 6 was purged for several hours before the samples were taken from a temporary tap on a hose discharging the water to a sump outside of the well house. Special care was taken to avoid agitation, which might cause unwanted oxidation. After installation of a replacement well, Well No. 6-2004, another set of source water was taken from this new well by the plant operator on July 13, 2004.

3.3.2   Treatment Plant Water. During the study period, water samples were collected by the operator weekly, on a four-week cycle, for on- and off-site analyses. For the first week of each four-week cycle, samples taken at the wellhead (IN) and after the two resin vessels combined (TT) were speciated on-site and analyzed for the anaytes listed in Table 3-3. For the next three weeks, samples were collected at three locations across the treatment train, including IN and after each resin vessel (i.e., TA and TB) and analyzed for the analytes listed in Table 3-3. On-site measurements for pH, temperature, DO, and ORP were performed during each sampling event. The sampling locations, frequency, and associated analytes are shown on a system flow diagram in Figure 4-8. Starting from May 2006, readings from a flow totalizer located on the combined effluent line were recorded at the time of sampling (instead of at the time of filling the Daily Log Sheet) in order to track the volume of water treated by the system (see discussions in Section 4.2.2). There were no individual totalizers available to track the volume of water treated by each vessel.

3.3.3   Regeneration Wastewater. Following Battelle's on-site regeneration study on September 22, 2005 (Section 3.4.2), six composite samples were collected monthly from the regeneration wastewater generated by both resin vessels, starting November 15, 2005. As shown in Figure 3-1, a garden hose was connected to the drain pipe underneath each tank to divert a portion of the wastewater produced from each of the three regeneration steps (i.e., brine draw, slow rinse, and fast rinse) into three separate 32-gal plastic containers over the entire duration of each step. At the end of Tank A regeneration, the content in each of the three containers was thoroughly mixed, and a portion of the water was transferred to sample bottles for total arsenic, nitrate, and sulfate analyses. The same procedure was repeated subsequently for the Tank B regeneration. Arsenic speciation was not performed on the wastewater samples. The operator used a Regeneration Log Sheet to record the time, duration, and flowrate of each regeneration step as well as the specific gravity of the brine (using a hydrometer) and the volume of saturated salt used for regenerating each tank.

3.3.4   Distribution System Water. Water in the distribution system was sampled to determine the impact of the IX system on the water chemistry in the distribution system, specifically, the arsenic, nitrate, lead, and copper levels. Since the City of Fruitland had 11 wells to supply the distribution system, sampling locations were selected from a small area of homes that received water primarily from Well No. 6-2004, including one residence (the operator's house) and two non-residential locations, even though none of them were part of the City's Lead and Copper Rule (LCR) sampling locations.

From December 2003 to March 2004 prior to the system startup, four monthly samples were collected from three locations within the distribution system to establish the baseline condition. Following the startup of the IX system in June 2005, distribution system sampling continued on a monthly basis at the same three locations. Analytes for the distribution system sampling are presented in Table 3-3.

Table 3-3. Sampling and Analysis Schedule at Fruitland, ID

Sample Type	Sampling Location(s)[a]	No. of Locations	Frequency	Analytes	Collection Date(s)
Source Water	At Wellhead (IN)	1	Once	Off-site: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), Al (total and soluble), V (total and soluble), Mo (total and soluble), Sb (total and soluble), Na, Ca, Mg, Cl, F, NO_3, S^{2-}, SO_4, SiO_2, PO_4, TOC, pH, and alkalinity	08/21/03 (Well No. 6), 07/13/04 (Well No. 6-2004)
Treatment Plant Water	At Wellhead (IN), after Tank A (TA), and after Tank B (TB)	3	Weekly	On-site: pH, temperature, DO, and ORP Off-site: As (total), Fe (total), Mn (total), U (total), V (total), Mo (total), F, NO_3, SO_4, SiO_2, PO_4, total P, alkalinity, and turbidity	06/23/05, 06/29/05, 07/06/05, 07/20/05, 08/03/05, 08/10/05, 08/24/05, 08/31/05, 09/07/05, 09/21/05, 09/28/05, 10/05/05, 10/26/05, 11/02/05, 11/16/05, 11/30/05
	At Wellhead (IN) and after Tanks A and B Combined (TT)	2	Monthly	On-site: pH, temperature, DO, and ORP 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), Mo (total and soluble), Ca, Mg, F, NO_3, SO_4, SiO_2, PO_4, total P, alkalinity, turbidity, and TDS	06/15/05, 07/13/05, 08/17/05, 09/14/05, 10/12/05, 11/09/05, 12/14/05
Distribution Water	One Non-LCR Residence and Two Non-Residential Locations	3	Monthly	Off-site: Total As, Fe, Mn, Pb, and Cu, pH, alkalinity, and NO_3	Baseline Sampling: 12/08/03, 01/06/04, 02/02/04, 03/02/04 Monthly Sampling: 06/29/05, 08/03/05, 08/24/05, 09/21/05, 10/26/05, 11/30/05, 12/15/05
Regeneration Wastewater	Drain Pipe off Tanks A and B	2[b]	Monthly	Off-site: Total As, NO_3, and SO_4	11/15/05

(a) Abbreviations in parentheses corresponding to sample locations in Figure 4-8.
(b) One composite sample collected from each of three regeneration steps during regeneration of each vessel.

The operator collected all of the samples following an instruction sheet developed according to the *Lead and Copper Rule Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). First-draw samples were collected from a cold-water faucet that had not been used for at least six hours to ensure that stagnant water was sampled. The sampler recorded the date and time of last water use before sampling and the date and time of sample collection for calculation of the stagnation time. Arsenic speciation was not performed on these samples.

Figure 3-1. Regeneration Wastewater Sampling

3.4 Resin Run Length and Spent Resin Regeneration Studies

3.4.1 Resin Run Length Studies. Because the routine weekly samples collected from the treatment plant only represented discrete data points from multiple service runs, it was necessary to collect samples from a few complete service runs to delineate arsenic and nitrate breakthrough curves and determine the appropriate run length of the IX system. The results of the studies were used to modify and optimize system performance. Table 3-4 summarizes the sampling and analytical schedules for three run length studies, during which the effluent from either one or both vessels was sampled throughout the entire service runs. The combined effluent totalizer was used to track the volume of water treated between two consecutive regeneration cycles. The totalizer was automatically reset to "zero" when regeneration of Tank A was complete and regeneration of Tank B just started. The reset of the totalizer also signaled the beginning of the service run. The service run ended when the totalizer reached a preset throughput, which triggered the next regeneration cycle. Additional information for each of the studies is provided below.

Run Length Study 1: During July 28 and 30, 2005, a vendor technician was on site to collect samples of the combined effluent from both resin vessels during one service run and perform field measurements for the analytes shown in Table 3-4. Sampling began when Tank A completed regeneration and went into service and when Tank B just began regeneration. Hourly samples were collected until 392,000 gal (524 BV) of water had been processed. In addition, operational parameters,

Table 3-4. Sampling and Analytical Schedules for Resin Run Length Studies

No.	Date	Run Length Setpoint (gal)	Run Length Setpoint (BV)	Sampling Location	No. of Samples	Analytes
1	07/28/05-07/30/05	214,000[a]	286	IN,[b] TT	30	As (total), NO_3, conductivity, pH, and temperature (on-site analysis only)
2	08/16/05-08/17/05	335,000	448	IN,[b] TA	11	As (total) and NO_3
3	12/07/05-12/08/05	316,000	422	IN,[b] TA, TB	22	As (total), U (total), V (total), Mo (total), NO_3, SO_4, alkalinity, and pH

(a) System not regenerated at setpoint. Samples collected up to 392,000 gal (524 BV) of throughput.
(b) Inlet sample collected once at beginning of test.

such as system inlet and outlet pressure, flowrate, and throughput were recorded every hour. Arsenic was analyzed on site using a Quick[TM] arsenic test kit (Industrial Test Systems) and a 28°C water bath to maintain the required sample temperature between 24 and 30°C. Nitrate was measured using a Hach nitrate test tube (CAT No. 14037-00). pH was measured using Macerey-Nagel pH 0-14 test strips. Conductivity was taken using a Myron-L, National Institute of Standards and Technology (NIST) certified meter. Because effluent arsenic and nitrate concentrations reached detectable levels of 2 μg/L and 5 mg/L, respectively, at approximately 400 BV (see Section 4.5.2), the regeneration throughput setpoint was upwardly adjusted from 214,000 gal (or 286 BV) to 335,000 gal (or 448 BV) on July 30, 2005.

Run Length Study 2: On August 16 and 17, 2005, the plant operator collected a series of samples from Tank A to help construct the arsenic and nitrate breakthrough curves. Sampling at TA began approximately 30 min after regeneration of Tank A had been completed, and continued by intervals of 1 to 3 hr except during the night. The flowrate and throughput were recorded at the time of sampling for calculation of the resin run length. The samples collected were sent to Battelle for arsenic and nitrate analyses.

Run Length Study 3: Following another adjustment to the throughput setpoint from 335,000 gal (or 448 BV) to 316,000 gal (or 422 BV) on September 19, 2005, 10 samples were collected by Battelle staff and the plant operator from each resin vessel during September 22 through 23, 2005, to further examine the arsenic and nitrate breakthrough from the IX system. Sampling from each vessel was repeated on December 7 and 8, 2005, because, for unknown reasons, the arsenic and nitrate concentrations in all TA and TB samples collected on September 22 and 23, 2005, were similar to those in raw water. The first TA and TB samples were collected approximately 30 min after regeneration of Tanks A and B had been completed. Subsequent samples were taken every 1 to 3 hr thereafter (except during the night). The last sample was collected at 288,000 gal, before reaching the 316,000-gal setpoint. The samples collected were sent to Battelle for total As, U, V, Mo, NO_3^-, SO_4^{2-}, pH, and alkalinity analyses.

3.4.2   Spent Resin Regeneration Studies. During the first six months, the regeneration scheme was adjusted a few times to improve the brine regeneration efficiency and minimize waste production. Two studies were performed to evaluate the effectiveness of the resin regeneration process and determine the quantity and chemical characteristics of the residuals. Table 3-5 summarizes the sampling schedules, analytes measured, and corresponding regeneration settings.

Regeneration Study 1. During the late July 2005 trip to Fruitland, the vendor technician changed the brine concentration from 4 to 8% and the brine draw time from 64 to 32 min in an attempt to maintain a

Table 3-5. Sampling and Analysis Schedule for Spent Resin Regeneration Studies

No.	Date	Throughput of Previous Run (gal)	Regeneration Step	Duration (min)	No. of Grab Samples	No. of Composite Samples	Analytes
1	07/30/05	392,000	Brine Draw	32	31	Not collected	specific gravity and conductivity
			Slow Rinse	64	61		
			Fast Rinse	30	28		
2	09/22/05	316,000	Brine Draw	32	8	1	TDS, pH, alkalinity, total As, U, V, Mo, NO_3, and SO_4
			Slow Rinse	64	6	1	
			Fast Rinse	6	2	1	

target regeneration level of 10 lb NaCl/ft^3 resin. Upon completion of the Run Length Study 1 as described above, the technician continued to perform the regeneration study by monitoring the conductivity and specific gravity of the regeneration wastewater using a Myron-L NIST-certified meter and a hydrometer every minute. Regenerant and rinse samples were not taken for arsenic and nitrate analyses.

Regeneration Study 2. To further characterize the residuals, a regeneration study was conducted on both resin vessels by Battelle staff on September 22, 2005. The test apparatus was similar to that described in Section 3.3.3 except that a flow-through cell attached to the inner rim of a 32-gal plastic container was used to receive water continuously from each vessel during each of the three regeneration steps (see Figure 3-1). A Hanna HI 9635 conductivity/TDS meter (Hanna Instruments, Inc., Woonsockett, RI) and a WTW Multi 340i handheld meter (VWR) were placed in the flow-through cell for continuous measurements of conductivity/TDS, pH, and temperature during regeneration. In addition, the time elapsed and flow totalizer readings also were recorded every 1 to 2 min. Grab samples were collected every 4 to 6 min by filling up sample bottles with the overflow from the flow-through cell. At the end of the regeneration cycle, the content in each 32-gal container was thoroughly mixed, and a composite sample was collected from each container. The samples were shipped to Battelle for analyses.

3.5   Sampling Logistics

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

3.5.1   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). Arsenic speciation kits were prepared in batches at Battelle laboratories according to the procedures detailed in Appendix A of the EPA-endorsed QAPP (Battelle, 2003).

3.5.2   Preparation of Sampling Coolers. All sample bottles were new and contained appropriate preservatives. Each sample bottle was taped with a pre-printed, colored-coded, and waterproof label. The sample label consisted of sample identification (ID), date and time of sample collection, sampler initials, location, where the sample was being sent to, analysis required, and preservative. The sample ID consisted of a two-letter code for a specific water facility, the sampling date, a two-letter code for a specific sampling location, and a one-letter code for the specific analysis to be performed. The sampling locations were color-coded for easy identification. For example, red, yellow, green, and blue were used for IN, TA, TB, and TT sampling locations. Pre-labeled bottles were placed in one of the plastic bags (each corresponding to a specific sampling location) in a sample cooler. When arsenic speciation samples were to be collected, arsenic speciation kits also were included in the cooler.

When appropriate, the sample cooler was packed with bottles for the three distribution system sampling locations and/or the two backwash sampling locations (one for each tank). In addition, a packet containing all sampling and shipping-related supplies, such as latex gloves, sampling instructions, chain-of-custody forms, prepaid Federal Express air bills, ice packs, and bubble wrap, also was placed in the cooler. Except for the operator's signature, the chain-of-custody forms and prepaid Federal Express air bills had already been completed with the required information. The sample coolers were shipped via Federal Express to the facility approximately one week prior to the scheduled sampling date.

3.5.3   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, sample custodians verified that all samples indicated on the chain-of-custody forms were included and intact. Sample label identifications were checked against the chain-of-custody forms and the samples were logged into the laboratory sample receipt log. Any discrepancies were addressed with the field sample custodian, and the Battelle Study Lead was notified.

Samples for water quality analyses by Battelle's subcontract laboratories were packed in coolers at Battelle and picked up by a courier from either AAL (Columbus, OH) or TCCI Laboratories (New Lexington, OH). The samples for arsenic speciation analyses were stored at Battelle's Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) Laboratory. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposal. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

3.6   Analytical Procedures

Analytical procedures are described in detail in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2003). Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a WTW Multi 340i handheld meter, which was calibrated prior to use following the procedures provided in the user's manual. The plant operator collected a water sample in a 400-mL plastic beaker and placed the Multi 340i probe in the beaker until a stable measured value was reached.

Laboratory quality assurance/quality control (QA/QC) of all methods followed the guidelines provided in the QAPP (Battelle, 2003). Data quality in terms of precision, accuracy, method detection limit (MDL), and completeness met the criteria established in the QAPP, i.e., relative percent difference (RPD) of 20%, percent recovery of 80% to 120%, and completeness of 80%. The QA data associated with each analyte will be presented and evaluated in a QA/QC summary report to be prepared under separate cover and to be shared with the other 11 demonstration sites included in the Round 1 arsenic study.

4.0 RESULTS AND DISCUSSION

4.1　　　Facility Description

Fruitland is located in southwest Idaho, approximately 50 miles northwest of Boise on Highway I-95. The City of Fruitland has multiple production wells (Wells No. 1, 5, 6, 9, 10, 11, 12, 14, 15, 16, and 20) that supply water to approximately 4,000 residents. Well No. 6, originally selected for this demonstration project, is located on South Utah Street between Southwest 4th and 7th Streets. Drilled in 1973 to replace old Well No. 3, the well was installed to a total depth of 199 ft below ground surface (bgs) in a 24-in-diameter by 204-ft-deep borehole, using a rotary drilling method. The well was lined with a 12-in-diameter steel casing extending from 3 ft above ground to 109 ft bgs and a 10-in-diameter steel casing extending from 109 ft to 199 ft bgs. The well had four screened sections: 44 to 54 ft bgs, 58 to 68 ft bgs, 109 to 119 ft bgs, and 179 to 189 ft bgs. The static water level was 36.4 ft bgs. A submersible pump placed at 105 ft bgs was rated at 250 gpm. A downhole camera survey on October 29, 1998, indicated that 90% of the third screen (109-119 ft bgs) was plugged and that the fourth screened section was completely buried in sediment. Well No. 6 was taken offline since January 2000 due to higher-than-MCL levels of nitrate in the well water. There was no water treatment in place prior to the installation of the IX system.

Problems with sediment production were encountered with Well No. 6 during the shakedown of the IX system in March 2004. A replacement well, Well No. 6-2004, was installed in June 2004 to a total depth of 125 ft bgs in a 20-in-diameter by 140-ft-deep borehole using a cable tool drilling method at a location approximately 25 ft from the existing well (see more details in Section 4.3). The well was constructed of a 12-in-diameter steel casing with three screened sections: 50 to 70 ft bgs, 95 to 105 ft bgs, and 110 to 120 ft bgs. The submersible pump from the old Well No. 6 was placed into the new well at 105 ft bgs. The well pumping tests indicated that this well could produce about 200 gpm of water while maintaining a similar static water level at 36.3 ft bgs (aggressive pumping was not desired by the City due to its concern over potential subsidence of the ground).

4.1.1　　　Source Water Quality. Source water samples were collected from the old Well No. 6 on August 21, 2003, and from the replacement well, Well No. 6-2004, on July 13, 2004. The analytical results of both wells are presented in Table 4-1 and compared to the data provided by the City to EPA for the demonstration site selection and the data independently collected by EPA and Kinetico. Figure 4-1 plotted the historic nitrate data for Well No. 6 obtained from IDEQ. Tables 4-2 and 4-3 summarize the historic data of several heavy metals, fluoride, and radiological analytes for Well No. 6. Based on the July 13, 2004 data, water quality of the new well was very similar to that of the old well.

Arsenic Species. The total As concentration in Well No. 6-2004 was 49.7 µg/L, including 39.9 µg/L of soluble As and 9.8 µg/L of particulate As. Although the total As concentration was somewhat higher than that in the old well, which ranged from 32 to 46 µg/L (Tables 4-1 and 4-2), the soluble As concentration was very similar to that in the old well (i.e., 39.9 vs. 40.1 µg/L). The higher particulate concentration (i.e., 9.8 vs. 3.4 µg/L) might be caused by insufficient well purging or sample tap flushing. Depending on the particle size, particulate As might be removed by the pre-filters located upstream of the IX resin vessels. Removal of particulates and sediments can help alleviate adverse effects on the resin beds. Similar to the old well, most soluble As was present as As(V) or arsenate (i.e., $H_2AsO_4^-$, 39.0 µg/L) with only a small amount existing as As(III) or arsenite (i.e., H_3AsO_3, 1.0 µg/L). Because IX resin is effective at removing arsenate, pre-oxidation of the water upstream of the IX process would not be required.

Table 4-1. Source Water Quality Data of Old and Replacement Wells

Parameter	Unit	Facility Data	EPA Data	Kinetico Data	Battelle Data	Battelle Data
Well ID		No. 6	No. 6	No. 6	No. 6	No. 6-2004
Sampling Date		NA	08/28/02	NA	08/21/03	07/13/04
pH	S.U.	7.4	NS	7.6	7.4	7.4
Total Alkalinity (as $CaCO_3$)	mg/L	357	NS	388	381	379
Hardness (as $CaCO_3$)	mg/L	252	251	271	233	240
Chloride	mg/L	14.0	NS	17.8	16.0	12.0
Fluoride	mg/L	NS	NS	0.72	1.0	0.6
Nitrate (as N)	mg/L	5.2-13.9	NS	8.7	NS	14.0
Sulfide	mg/L	NS	NS	NS	NS	NS
Sulfate	mg/L	60.0	57.3	64.0	58.0	53.0
Silica (as SiO_2)	mg/L	57.8	54.3	57.8	55.1	57.4
Orthophosphate (as PO_4)	mg/L	0.12	NS	0.3 (as P)	<0.10	<0.10
TOC	mg/L	0.1	NS	NS	<1.0[a]	2.2
As (total)	μg/L	37.0	41.0	44.0	43.5	49.7
As (soluble)	μg/L	NS	NS	NS	40.1	39.9
As (particulate)	μg/L	NS	NS	NS	3.4	9.8
As (III)	μg/L	8.0	NS	NS	0.8	1.0
As (V)	μg/L	34.0	NS	NS	39.3	39.0
Fe (total)	μg/L	10-190	744	450	<30	268
Fe (soluble)	μg/L	NS	NS	NS	<30	<25
Al (total)	μg/L	NS	120	NS	21	151
Al (soluble)	μg/L	NS	NS	NS	<10	<10
Mn (total)	μg/L	50.0	32.0	50	1.6	28.3
Mn (soluble)	μg/L	NS	NS	NS	0.5	18.0
V (total)	μg/L	NS	NS	NS	36.2	34.0
V (soluble)	μg/L	NS	NS	NS	35.1	33.7
Mo (total)	μg/L	NS	NS	NS	9.7	6.2
Mo (soluble)	μg/L	NS	NS	NS	9.2	6.6
Sb (total)	μg/L	NS	<25	NS	<0.1	<0.1
Sb (soluble)	μg/L	NS	NS	NS	<0.1	<0.1
Na (total)	mg/L	107	104	118	97	114
Ca (total)	mg/L	60.5	60.0	66.0	55.0	51.3
Mg (total)	mg/L	25.4	24.6	26.0	23.1	27.2

(a) Sample collected on October 14, 2003.
NS = Not sampled

Nitrate. Nitrate concentration in the new well was 14.0 mg/L (as N), which was comparable to the highest level of detection in the old well. Figure 4-1 showed an increasing nitrate concentration in the old well from 5.2 mg/L in July 1986 to 13.90 mg/L in November 2001. According to the vendor, the A300E IX resin selected for Fruitland had a similar run length to reach the respective MCLs for arsenate and nitrate, thus maximizing the efficiency of the system.

Fruitland Nitrate Concentrations Over Time
(July 1986 through November 2001)
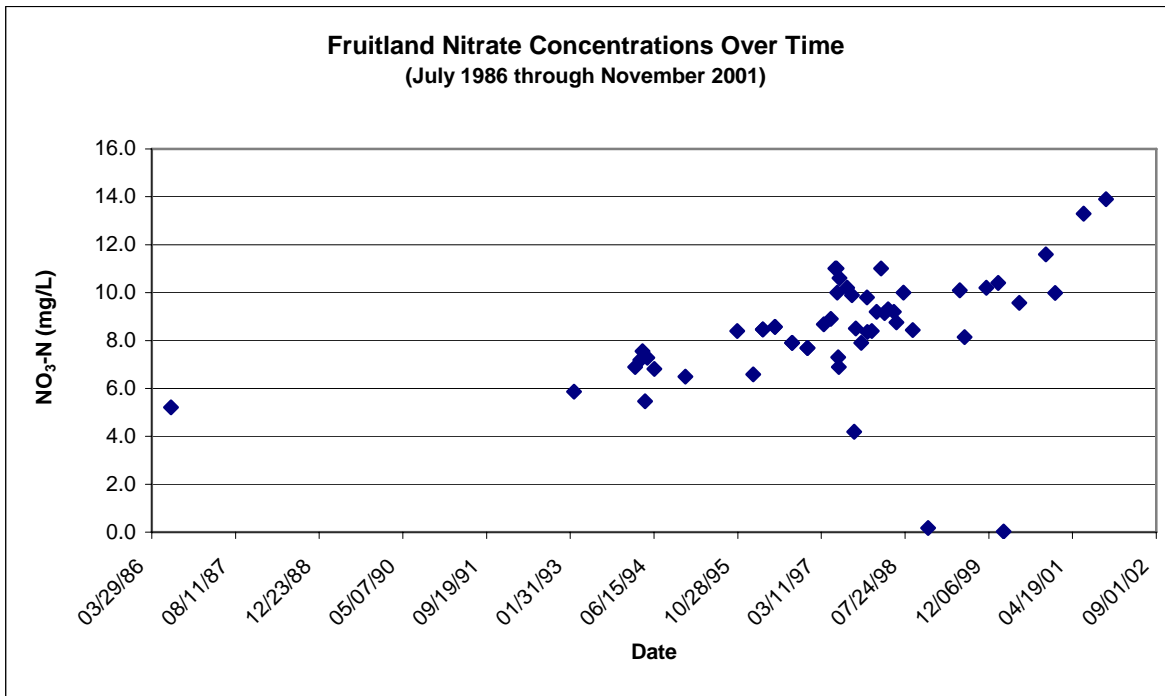
Source: Idaho Department of Environmental Quality

Figure 4-1. Historic Nitrate Concentrations Over Time in Well No. 6

Table 4-2. Historic Water Quality Results for Well No. 6

Analyte	10/24/95	07/28/98	03/30/00	6/26/00	11/05/01
	Concentration (mg/L)				
Arsenic	0.046	0.043	0.034	0.032	0.039
Antimony	<0.005	<0.005	NS	NS	<0.005
Barium	0.05	0.06	NS	NS	0.06
Beryllium	<0.0005	<0.0005	NS	NS	<0.0005
Cadmium	<0.0005	<0.0005	NS	NS	<0.0005
Chromium	0.002	0.002	NS	NS	0.002
Mercury	<0.0005	<0.0002	NS	NS	<0.0002
Nickel	<0.02	<0.02	NS	NS	<0.02
Selenium	<0.005	<0.005	NS	NS	<0.005
Sodium	85.8	67.7	NS	NS	110
Thallium	<0.002	<0.002	NS	NS	<0.002
Fluoride	0.68	0.68	NS	NS	0.65

Source: Idaho Department of Environmental Quality
NS = Not sampled

Table 4-3. Radiological Sampling Results for Well No. 6

Sampling Date	Radium 226 (pCi/L)	Uranium (µg/L)	Gross Alpha Activity (pCi/L)	Gross Beta Activity (pCi/L)
10/24/95	NS	NS	12.8±4.3	6.3
12/06/95	0.0±0.2	NS	NS	NS
03/04/96	0.0±0.1	NS	NS	NS
06/06/96	0.0±0.2	NS	NS	NS
09/17/96	0.1±0.2	NS	NS	NS
06/08/00	NS	NS	19.7	6.6
09/29/00	NS	NS	23.2	13.9
12/06/00	NS	22.4	21.7	13.4
06/25/01	NS	NS	11.2	14.3
11/05/01	NS	NS	17.5	15.1
03/08/02	<0.2	NS	NS	NS

Source: Idaho Department of Environmental Quality
NS = Not sampled
pCi/L = picoCuries per liter

Sulfate. The sulfate concentration in the new well was 53.0 mg/L, slightly lower than that (ranging from 57.3 to 64.0 mg/L) in the old well (see Table 4-1). Because sulfate is more preferred by the A300E IX resin than arsenate and nitrate and because of its higher concentration, sulfate is a strong competing anion for arsenic and nitrate removal.

Other Water Quality Parameters. Total dissolved solid (TDS) concentration in source water was not measured, but estimated to be 560 mg/L based on 114 mg/L sodium, 51.3 mg/L of calcium, 27.2 mg/L of magnesium, 379 mg/L of bicarbonate, 12.0 mg/L of chloride, 0.6 mg/L of fluoride, 14.0 mg/L of nitrate, 53.0 mg/L of sulfate, and 57.4 mg/L silica after taking into account the loss of CO_2 and H_2O upon evaporation of $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$. This estimated TDS value agreed with the average TDS of 571 mg/L measured during the study period (see Table 4-13 on page 38). Other dissolved ions present included 33.7 µg/L of vanadium and 6.6 µg/L of molybdenum. The uranium concentration measured on December 6, 2002 was 22.4 µg/L (Table 4-3), lower than its MCL of 30 µg/L. Iron and aluminum were present primarily as particulates; the dissolved species were below the respective detection limits. The pH value of raw water was 7.4. Unlike adsorptive media, IX resins are not sensitive to the water pH.

4.1.2   Distribution System and Treated Water Quality. The City of Fruitland employs a looped drinking water distribution system, with water from multiple production wells entering the distribution system at various locations. Water produced from Wells No. 5, 9, and 10 is pumped into a reservoir, which is then connected to the distribution network. Water from Wells No. 14 and 20 is blended prior to entering the distribution system. The distribution system is constructed of asbestos cement pipe in the area of Well No. 6, but some sections in other areas of the town are constructed of polyvinyl chloride (PVC) pipe. During periods in which production exceeds demand, the excess water is stored in one one-million-gal ground level tank and one 200,000-gal elevated tank. The well pumps are controlled by level sensors in the water tanks.

Process water from the IX treatment system enters the distribution system via an existing 6-in-diameter line, which includes a branch line to a small area of homes receiving water primarily from Well No. 6-2004. The service lines to individual homes in this area are mainly copper, while the lines within these

homes are constructed of galvanized iron, copper, and polyethylene pipes. Three sampling locations were selected from this area for the distribution system sampling (Section 3.3.4).

The City of Fruitland samples water from the distribution system for several analytes. Four monthly samples are collected from a group of six locations for fecal coliform analysis. Samples also are taken for asbestos analysis every three years. Under the EPA LCR, samples are collected from customer taps at 10 locations every three years.

4.2   Treatment Process Description

4.2.1   Ion Exchange Process. Ion exchange is a proven technology for removing arsenic and nitrate from drinking water supplies (Clifford, 1999; Ghurye et al., 1999; Wang et al., 2002). It is a physical/chemical process that removes dissolved arsenate and nitrate ions from water by exchanging them with chloride ions on anion exchange resins. Once its capacity is exhausted, the resin is regenerated with a brine solution containing a high concentration of chloride ions to displace the arsenate and nitrate ions on the resin. Strong-base anion exchange (SBA) resins are commonly used for arsenate and nitrate removal. Resin capacity typically is not sensitive to the pH values (in the range of 6.5 to 9.0) of the water treated.

An SBA resin tends to have a higher affinity for more highly charged anions, resulting in a general hierarchy of selectivity as follows:

$$SO_4^{2-} > HAsO_4^{2-} > NO_3^- > NO_2^- > Cl^- > H_2AsO_4^-, HCO_3^- \gg Si(OH)_4; H_3AsO_4$$
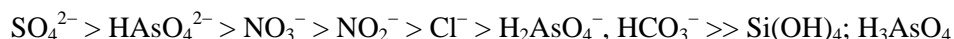
Because sulfate is more preferred by the resin over arsenic and nitrate and because its concentration is about three orders of magnitude higher than that of arsenic, it is a major competing anion to arsenic and nitrate removal by the IX process. High TDS levels also can significantly reduce arsenic and nitrate removal efficiencies. In general, the IX process is not economically attractive if source water contains high TDS (>500 mg/L) and sulfate (>150 mg/L). Also, particulates in feed water can potentially foul the resin, and must be removed by bag filters upstream of an IX vessel.

The Fruitland IX system used Purolite A300E, a Type II SBA resin in chloride form, to remove arsenic and nitrate from source water. The resin is NSF International (NSF) Standard 61 approved for use in drinking water treatment and its typical physical and chemical properties are presented in Table 4-4. According to Purolite's computerized simulation on the Fruitland water, the A300E resin has a relatively higher capacity for arsenic and nitrate removal than A520E, a nitrate-selective resin. As shown in Figure 4-2, A300E reaches the 10-mg/L nitrate (as N) and 10-µg/L arsenic breakthrough at approximately 700 and 880 BV, respectively (note that this simulation significantly over-predicts the actual resin run length, which was 422 BV as discussed in Sections 4.4 and 4.5). Because nitrate breaks through before arsenate, nitrate will determine the resin run length (Ghurye et al., 1999). Using Clifford's equilibrium multi-component chromatography theory (EMCT) model, the run length to the 10-mg/L nitrate (as N) breakthrough was estimated to   be about 580 BV when using a type II SBA resin (like A300E) for the Fruitland Well No. 6-2004 water. The estimated run length was further refined to about 450 BV after taking considerations of mass transfer (Clifford, 2006). This run length was very close to the 422 BV actually experienced at the Fruitland, Idaho site.

4.2.2   Treatment Process. The IX system for the Fruitland, Idaho site utilized the packed-bed anion exchange technology to remove arsenic and nitrate from source water. Figure 4-3 is a process schematic of the system. The process equipment included one bank of five skid-mounted bag filters, two skid-mounted resin tanks, one skid-mounted central control panel, one floor-mounted salt saturator

Table 4-4. Typical Physical and Chemical Properties of Purolite A300E Resin

Property	Values
Polymer Structure	Macroporous styrene-divinylbenzene
Functional Groups	Quaternary ammonium: $R(CH_3)_2(C_2H_4OH)N^+$
Physical Appearance	Clear spherical beads
Ionic Form	Chloride
Mesh Size Range (U.S. Standard Mesh) (Wet)	16×50 (+16 mesh < 5%; -50 mesh < 1%)
Uniformity Coefficient	1.7 maximum
Water Retention	40-45%
Swelling	Salt –OH, 10%
pH Limitations	None
Temperature Limitations	185 ºF maximum
Chemical Resistance	Unaffected by dilute acids, alkalis, and most solvents
Whole Clear Beads	92% minimum
Shipping Weight	44 lb/ft^3 (705 g/L)
Total Capacity	1.45-1.6 meq/mL minimum volumetric (wet);

Source: Kinetico
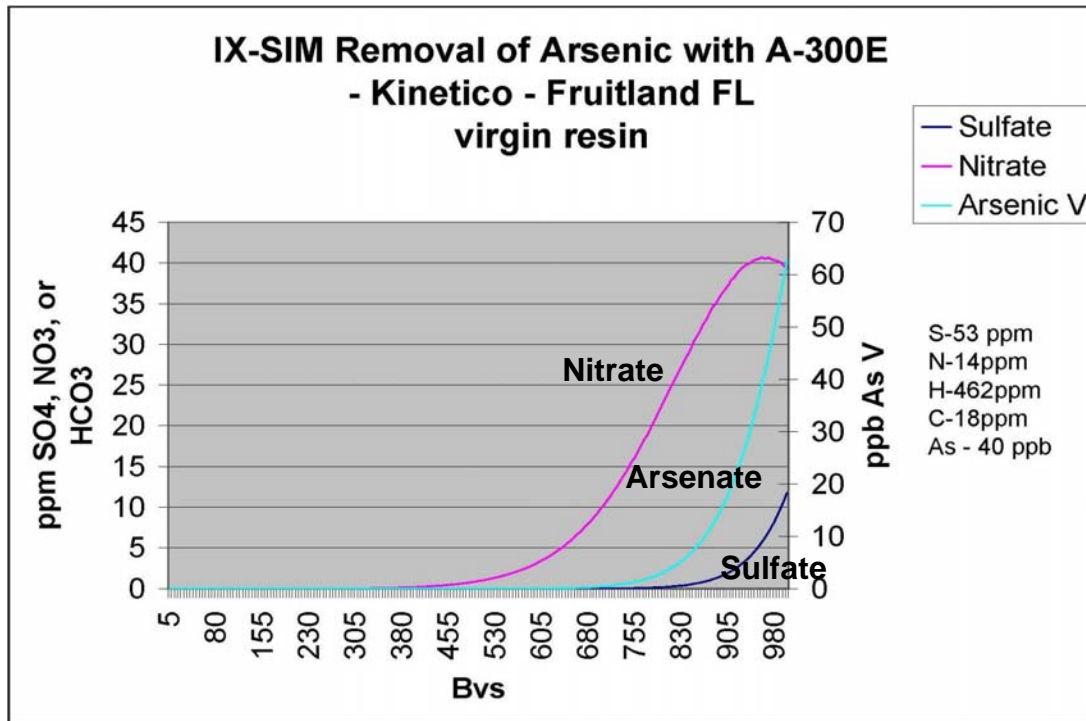
Source: Kinetico

Figure 4-2. Purolite A300E Simulation
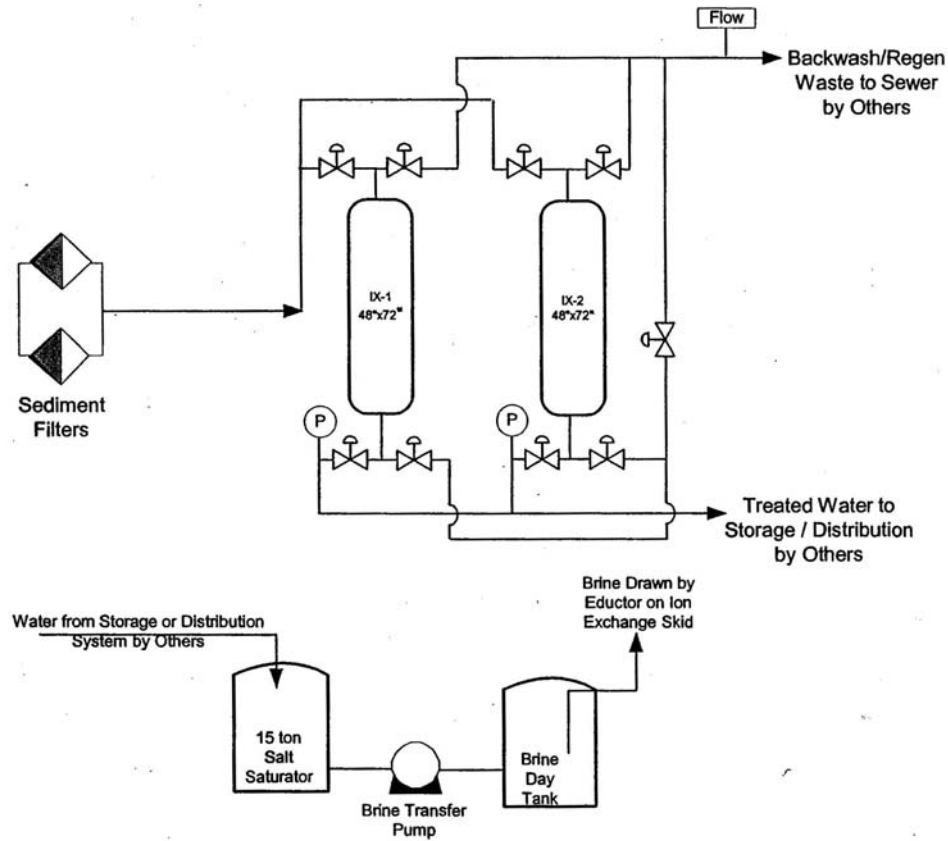
Source: Kinetico

Figure 4-3. Process Schematic of Kinetico's IX-248-As/N Removal System

system, one skid-mounted pre-wired brine transfer pump, one brine tank, one floor-mounted air compressor, as well as associated valves, sample ports, pressure gauges, and flow elements/controls. Figures 4-4 through 4-6 are photographs of the system and its components being installed at Fruitland. The IX system was fully automated and controlled by a central control panel that consisted of a PLC, a touch screen operator-interface-panel (OIP), and a data communication modem. The OIP allowed the operator to monitor system flowrate and volume throughput since last regeneration, change system setpoints as needed, and check the status of alarms. The modem allowed the vendor to remotely dial in for monitoring and troubleshooting purposes. All pneumatic valves were constructed of PVC and all plumbing was Schedule 80 PVC solvent bonded. Table 4-5 summarizes the design specifications of the IX system.

Figure 4-7 presents a process flow chart, along with the sampling/analysis schedule, for the IX-248-As/N system. The major process steps and system components are presented as follows:

- **Sediment Filtration.** Prior to entering the resin tanks, raw water was filtered through a skid-mounted bag filter assembly to remove sediment, if any. The bag filter assembly consisted of five FSI X100 polypropylene housing units in parallel, each lined with a 20-μm filter bag. The filter bags were replaced when the pressure gauges on the inlet and outlet of the bag filter assembly indicated a head loss of over 6 pounds per square inch (psi).

Figure 4-4. Photograph of Bank of Five Bag Filters

Figure 4-5. Photograph of IX-248-As/N System at Fruitland, ID
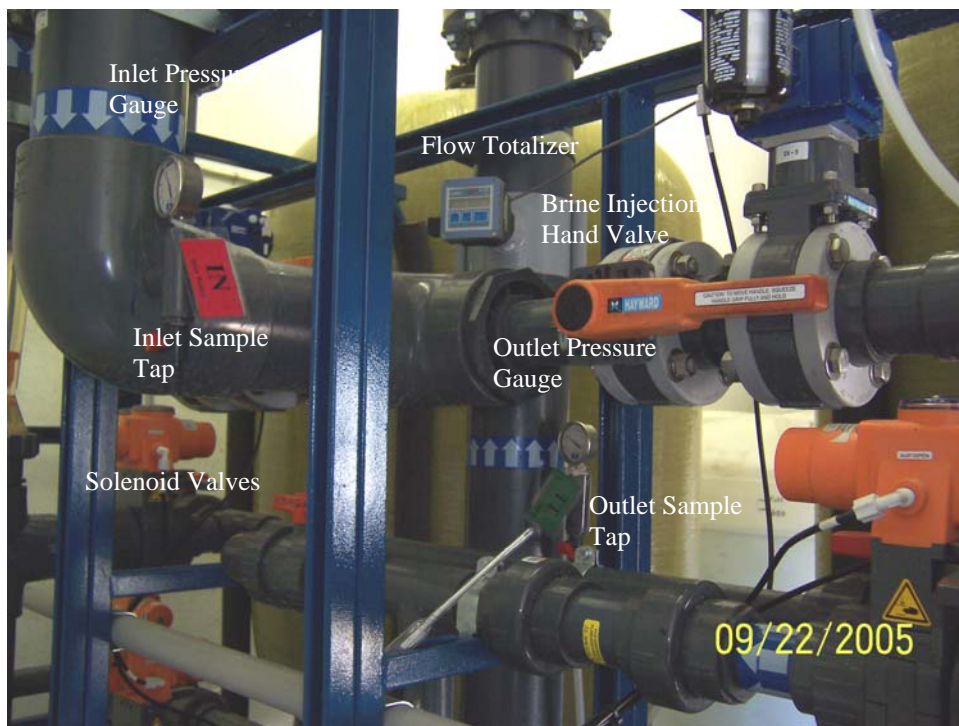
Figure 4-6. Sampling Taps, Pressure Gauges, and Valves

Figure 4-7. Photograph of Brine System

Table 4-5. Design Specifications of IX System

Parameter	Value	Remarks
IX Vessels		
Tank Size (in)	48 D × 72 H	–
Cross-Sectional Area (ft^2/tank)	12.6	
No. of Tanks	2	
Configuration	Parallel	
Media		
IX Resin Quantity (ft^3)	50 (per tank); 100 (total)	Bed depth = 48 in
Resin Type	Purolite A300E	
Flint Gravel Support Media (ft^3)	3 (per tank); 6 (total)	Approximately 12 in deep
Polypropylene Filler Beads (ft^3)	3 (per tank); 6 (total)	Approximately 12 in deep
Pre-treatment (Bag Filter Assembly)		
No. Bag Filters	5	
Configuration	Parallel	
Filter Pore Size (μm)	20	
IX Service		
Design Flowrate (gpm)	250	
Hydraulic Loading (gpm/ft^2)	10	
EBCT (min)	3.0	Based on flowrate of 250 gpm for two tanks in parallel
Estimated Working Capacity (BV)	400-500	1 BV = 100 ft^3 = 748 gal
Volume Throughput (gal)	299,200-374,000	
Resin Regeneration		
Regeneration Mode	Co-current, downflow	
Regeneration Level (lb of salt/ft^3 of resin)	10	
Brine Draw Duration (min)	64	Based on 4% brine solution
Brine Draw Flowrate (gpm)	23	
Slow Rinse Duration (min)	64	
Slow Rinse Flowrate (gpm)	23	
Fast Rinse Duration (min)	30	
Fast Rinse Flowrate (gpm)	75	
Wastewater Production (gal)	5,200 (per tank); 10,400 (total)	
Salt Consumption (lb/regeneration)	500 (per tank);1,000 (total)	
Brine System		
Brine Day Tank Size (in)	61 D × 64 H	Capacity = 685 gal
Brine Day Tank Material	HDPE	
Brine Transfer Pump Size (hp)	½	
Salt Saturator Size (in)	96 D × 180 H (original) 96 D × 148 H (shortened)	Saturator shortened by 32 in (straight height) to fit building height; corresponding capacity reduced from 15 to 12.3 tons
Salt Saturator Material	Fiberglass	

INFLUENT
(WELL No. 6-2004)

Fruitland, ID
Ion Exchange Technology
Design Flow: 250 gpm

Monthly

$pH^{(a)}$, temperature$^{(a)}$, $DO^{(a)}$, $ORP^{(a)}$,
As (total and soluble), As(III), As(V),
Fe (total and soluble), Mn (total and soluble),
U (total and soluble), V (total and soluble),
Mo (total and soluble), Ca, Mg, F, NO_3, SO_4,
SiO_2, PO_4, TDS, turbidity, alkalinity

Weekly

$pH^{(a)}$, temperature$^{(a)}$, $DO^{(a)}$, $ORP^{(a)}$,
As (total), Fe (total), Mn (total), U (total),
V (total), Mo (total), NO_3, SO_4, PO_4,
turbidity, alkalinity

IN

CARTRIDGE
FILTRATION

SEWER

TDS, As (total),
NO_3, SO_4

RG

MEDIA
VESSEL
#1

MEDIA
VESSEL
#2

TA

TB

$pH^{(a)}$, temperature$^{(a)}$, $DO^{(a)}$, $ORP^{(a)}$,
As (total), Fe (total), Mn (total), U (total),
V (total), Mo (total), NO_3, SO_4, PO_4,
turbidity, alkalinity

$pH^{(a)}$, temperature$^{(a)}$, $DO^{(a)}$, $ORP^{(a)}$,
As (total and soluble), As(III), As(V),
Fe (total and soluble), Mn (total and soluble),
U (total and soluble), V (total and soluble),
Mo (total and soluble), Ca, Mg, F, NO_3, SO_4,
SiO_2, PO_4, TDS, turbidity, alkalinity

TT

LEGEND

Water Sampling Locations

IN	At Wellhead
TA	After Tank A
TB	After Tank B
TT	At Combined Effluent
RG	Regeneration Sampling Location

CARTRIDGE FILTRATION — Unit Process

→ Process Flow

······► Backwash Flow

Footnote
(a) On-site analyses

DISTRIBUTION
SYSTEM

Note: A flow totalizer located on combined effluent line near TT used to register volume throughput since
last regeneration and trigger automatic IX resin regeneration once reaching a pre-set throughput setpoint.

**Figure 4-8. Process Flow Diagram and Sampling Locations/Analyses for
Fruitland IX System**

- **IX Resin Filtration.** After passing through the bag filters, water flowed downward through two 48-in-diameter by 72-in-height pressure tanks configured in parallel. The pressure tanks were of fiber reinforced plastic (FRP) construction, rated for 150 psi working pressure, and mounted on a polyurethane coated, welded steel frame. Each tank had a 6-in top and bottom flange and two 4-in side flanges, and was equipped with a diffuser-style upper distributor and a hub and lateral-style lower distributor. Each tank was filled with 3 ft^3 of flint gravel support media, 50 ft^3 of A300E resin, and 3 ft^3 of polypropylene filler beads on the top (to prevent resin from being washed away in an upflow, counter-current regeneration). The system was designed to treat 250 gpm, with a hydraulic loading of 10 gpm/ ft^2 and an EBCT of 3 min. Each resin tank was equipped with a 125-gpm flow-limiting device to prevent filter overrun and possible damage to the system. The flow-limiting devices, however, overly restricted the flow and were removed later to maximize the water production. The system treated less than 200 gpm of flow during the study period.

  An insertion-type paddle wheel flow element was installed on the combined effluent line to register the flowrate and volume throughput of the system since last regeneration. When a pre-determined throughput setpoint was reached, Tank A was automatically taken out of service for regeneration first, whereas Tank B remained in service to treat water, which would not be registered on the totalizer during Tank A regeneration. Once Tank A regeneration was complete, the totalizer was automatically reset to zero and began to register the amount of water treated by Tank A. Meanwhile, Tank B was taken out of service for regeneration. After Tank B regeneration was complete, the totalizer registered the amount of water treated by both tanks.

- **Resin Regeneration.** Regeneration can be initiated automatically based on a throughput setpoint or manually by pressing a push-button on the PLC. Once regeneration was initiated, the PLC controlled the sequence of three regeneration steps, i.e., brine draw, slow rinse, and fast rinse. To achieve a regeneration level of 10 lb $NaCl/ft^3$ of resin, the original design called for 64 min of brine draw at 23 gpm using a 4% brine solution. During the study, the regeneration scheme was adjusted several times to optimize the regeneration efficiency, reduce waste production, and minimize arsenic and nitrate leakage (Section 4.4.2). The duration of each regeneration step can be reset on the PLC. The brine concentration was adjusted using a hand valve located upstream of the eductor to change the brine draw rate and a hydrometer was used to measure the specific gravity of the brine solution to confirm its concentration. Brine was drawn from a brine day tank into the resin tanks via a Venturi eductor. The brine day tank was equipped with high/low level sensors interlocked with a brine transfer pump to fill the tank with saturated brine (about 23 to 26%) from a 15-ton salt saturator. The saturator was sized to hold 30 days of salt supply for daily regeneration and was re-filled by a salt delivery truck on a weekly or as needed basis (see Figure 4-9). Treated water was used to make the brine solution and rinse the beds. The wastewater produced was discharged to a floor drain connecting via a 6-in drain line to a lift station outside of the building, where the water was pumped to the existing city sewer.

  The system was designed to regenerate in either a co-current or a counter-current mode. The vendor decided to use downflow, co-current regeneration, which was thought to be superior to upflow, counter-current regeneration for arsenic and nitrate. Upflow regeneration would force the contaminants concentrated at the bottom of the resin beds back through the entire resin beds, which tended to leave relatively more contaminants in the resin. Clifford et al. (1987, 2003) recommended the co-current downflow regeneration for arsenic removal because it was easier to implement. For nitrate removal, co-current "complete" regeneration (i.e., removing over 95% of exchanged nitrate) is recommended only when bypass blending

is allowed, which was not the case in Fruitland. Due to the arsenic/nitrate leakage problems detected at Fruitland, the co-current regeneration was converted to counter-current regeneration during the later part of the study.

Figure 4-9. Salt Delivery to Fill Salt Saturator

4.3 System Installation

Since the system installation first began in March 2004, a series of events had taken place that seriously delayed the commencement of the demonstration study until June 2005. The events taking place included the production of excessive sediment from the old well, installation of a replacement well, repeated failures of bacterial testing, replacement of resin, and replacement of a well pump. These events are discussed in detail in the following sections.

4.3.1 Building Construction. The City of Fruitland constructed an addition to the existing pump house for the IX system. The 17 ft-tall addition covered 360 ft^2 of floor space and was with a wood frame, steel siding and roofing, and a roll-up door. The total cost was approximately $18,000. The building construction began on February 6, 2004, when the concrete pad was poured. Construction of the wood frame began on February 10, 2004, and the building was completed (with the exception of the electrical and the final siding) on March 3, 2004. A photograph of the new structure, adjacent to the existing well house, is shown in Figure 4-10.

4.3.2 Installation of Replacement Well. After the IX-248-As/N system was delivered to the newly completed building on March 8, 2004, the system installation began immediately. The installation was nearly complete when excessive sediment accumulation was noted in the bag filters and the empty resin vessels (as much as 3 in) during a hydraulic test performed on March 25 and 26, 2004. Completion of the system installation, including loading the resin in the tanks, was put off to allow the facility to investigate the sand production problem. The City performed an investigation of the well from April 1 through 13, 2004, including an initial video surveying, cleaning, bailing, and pumping, and final video

25

surveying. The investigation revealed the presence of two holes in the well casing, with each hole having an associated void in the adjacent sand pack. On April 13, 2004, the City Council voted to replace Well No. 6 with a new well on the same lot, located approximately 25 ft from the existing well.

Figure 4-10. New Addition to Old Well House

The initial design for Well No. 6-2004 called for a 12-in-diameter steel casing completed to 95 ft bgs, with a screened interval from 50 to 70 ft bgs. Installation of the replacement well commenced on May 5, 2004, after the well location was approved by IDEQ and a well drilling permit was issued by the Idaho Department of Water Resources. Well installation continued through May 26, when well development and pump testing indicated that the well was unable to produce an adequate supply of water, presumably caused by the shorter screen interval installed. On May 28, the City Council voted to increase well depth to 120 bgs with two additional screened sections extending from 95 to 105 ft bgs and from 110 to 120 ft bgs (see Section 4.1). The modifications to Well No. 6-2004 were completed in July 2004, and water samples were collected for coliform tests. The first water sample was tested positive for coliform, requiring another chlorine shock and a second round of coliform sampling. Following the second chlorine shock and a negative coliform test result, the vendor proceeded with the loading of the IX resin in the vessels on July 23, 2004 and the shakedown/startup and operator training activities were scheduled to begin on July 28.

4.3.3   **Permitting**. Engineering plans for the system permit application were prepared by Holladay Engineering, a Kinetico subcontractor (also serving as the engineer for the City of Fruitland) located in Payette, Idaho. The plans included general arrangement diagrams, specifications of the IX-248-As/N system, and drawings detailing the connections of the new unit to the existing facility and new building. After incorporating comments from the vendor and Battelle, the plans were submitted on January 25, 2004, by the City to IDEQ for review and approval. Review comments provided by IDEQ on February 25, 2004, were addressed by the City and Holladay Engineering within a week. On May 10, 2004, IDEQ sent an e-mail stating that the submittal for the demonstration was generally acceptable, and that the project was approved to proceed once the new well was installed.

4.3.4   **System Installation, Shakedown, and Startup**. The IX-248-As/N system was delivered to the site on March 8, 2004. Mechanical Installation, Inc., a subcontractor to Kinetico, performed the off-

loading and installation of the system, including connections to the existing entry and distribution piping (Figure 4-11). Because the salt saturator had the same height, i.e., 17 ft, as the building, it had to be shortened before it could be brought into the building. As such, the top section of the fiberglass vessel was cut off and then a 32-in long section of the straight shell was removed. After the shortened vessel was brought into the building, the top section was placed back and soldered on March 18, 2004 (Figure 4-12).

Figure 4-11. Equipment Off-Loading

Following the installation of the replacement well, the vendor proceeded with the loading of the IX resin in the tanks on July 23, 2004. Battelle personnel arrived at Fruitland on July 28, 2004, to provide data and sample collection training to the operator. The vendor engineer also was on-site to install a new touch screen on the control panel. However, the City learned on the same day that the latest bacterial sample taken from the system had failed and that the system would require further sanitation. This was complicated by the fact that the IX resin had already been loaded into the vessels and that the resin could not be exposed to the chlorine treatment. The City re-shocked the well with chlorine and bypassed the IX system by pumping water to waste. Battelle and Kinetico proceeded with the operator training as scheduled and left the site on July 29, 2004.

The City began a series of chlorine shocking, pumping, and sampling activities for Well No 6-2004 immediately following the completion of operator training. The City administered multiple cycles of treatment, but the samples continued to test positive for coliform. The well driller remobilized to the site in December 2004 to redevelop the well, clean the screens, and disinfect the pump and the well. However, intermittent positive coliform results continued after the redevelopment effort. In light of the coliform data, IDEQ agreed to a post-chlorination system at Well No. 6-2004 for the period of the

Figure 4-12. Cutting and Soldering Salt Saturator

demonstration. However, chlorination was not desired by the City due to concerns regarding taste and odor and resistance from a local beverage bottling facility.

The City continued to shock the well with chlorine from December 2004 through April 2005 following a pattern of shocking, pumping to waste, sampling, and analyzing for coliform and residual chlorine. Intermittent positive results for coliform persisted during this period. The City considered potential treatments to allow water to enter the distribution system, including prechlorination (upstream of the IX system), postchlorination (prior to entering the distribution system), and ultraviolet (UV) treatment. The City also collected samples from the outlet of the resin tanks in March 2005; the results for these samples were negative for coliform. The vendor, therefore, determined that a special sanitization method most likely would not be needed to treat the resin that might have been exposed to the coliform-contaminated water because the regeneration brine was deemed sufficiently toxic to kill coliform, if any, in the IX system.

In April 2005, samples collected at the IX system effluent during a short test run (while the treated water was discharging to waste) indicated that arsenic breakthrough had already occurred. The vendor determined that a nitrate-specific resin, A-520E (also manufactured by Purolite), had been erroneously delivered to the site and loaded into the IX vessels. A vendor technician arrived on-site on April 20, 2005, to remove A-520E resin from and load A300E resin into the vessels. After resin replacement and upon IDEQ's request, water samples were collected from the wellhead and the system effluent for the bacterial test, which showed negative coliform results. The sample results were submitted to IDEQ on May 4, 2005. Meanwhile, it was discovered that the pump in Well No. 6-2004, which had been salvaged from the original well, Well No. 6, was broken and required replacement. The new pump was installed on May 19, 2005, and was disinfected and began pumping to waste on May 20, 2005. Samples collected

on May 23 and 24, 2005, indicated the absence of coliform. Holladay Engineering sent a letter to IDEQ on June 1, 2005, reporting the negative coliform results and requesting permission to send the treated water to distribution. IDEQ provided an approval in an e-mail dated June 7, 2005. As such, the performance evaluation study officially began on June 14, 2005. After Battelle reviewed the data and sample collection procedures with the operator via telephone, the first set of samples was collected from the IX system on June 15, 2005.

4.4 System Operation

4.4.1   Operational Parameters. The plant operational data collected from June 14 through December 16, 2005 is tabulated and attached as Appendix A and key parameters are summarized in Table 4-6. During the first six months, the IX system operated for 3,635 hr based on the well pump hour meter, with an average daily operating time of 20 hr. Well No. 6-2004 operated longer in the summer, 22 hr/day between June and September compared to 16 hr/day between October and December. The six-month throughput was 35.9 million gal based on the wellhead totalizer. The average daily demand was 194,300 gpd; the peak daily demand was 255,000 gpd, which occurred on September 14, 2005.

The IX system was equipped with an insertion paddle wheel flow meter/totalizer on the product water discharge line to monitor the combined flow from both resin vessels. During the first week of operation, the product water flowrates through both vessels ranged from 130 to 144 gpm (except for 73 gpm on June 16, 2005, when one vessel was regenerating), which was 28 to 35% lower than the 200-gpm well capacity and 42 to 48% lower than the 250-gpm design flowrate. The pressure drop (ΔP) across the system also was elevated, with values ranging from 20 to 30 psi. It was speculated that the 100-gpm flow restrictor on the outlet of each vessel might have caused the lower-than-expected flowrate. As such, each flow restrictor was modified with a wider opening on June 21, 2005, which resulted in a higher flowrate of 170 gpm and a lower ΔP of 6 psi. The flow restrictors were later replaced with blank pipe sections on July 7, 2005, which did not seem to further increase the system flowrate.

Since then, the product water flowrates ranged from 138 to 179 gpm and averaged 165 gpm and the ΔP ranged from 8 to 18 psi (excluding those recorded during resin regeneration). Thus, the corresponding hydraulic loading to each tank ranged from 5.5 to 7.1 gpm/ft^2 and averaged 6.6 gpm/ft^2, which was 34% lower than the design value of 10 gpm/ft^2. The corresponding EBCT ranged from 5.4 to 4.2 min and averaged 4.5 min, which was 50% higher than the design value of 3 min. When one vessel was being regenerated, the second tank was still in service, providing treated water at a flowrate of 122 to 145 gpm. The flowrates exceeded the 125-gpm limit, at times, due to the removal of the flow restrictors. This flow range represents a hydraulic loading of 9.7 to 11.5 gpm/ft^2 and an EBCT of 3.1 to 2.6 min. The pressure drop across each tank was 8 to 10 psi most of the time during normal operation but could increase to 20 psi during regeneration.

4.4.2   Regeneration. The system PLC automatically initiated a regeneration cycle based on a throughput setpoint. The duration of each of the three regeneration steps, i.e., brine draw, slow rinse, and fast rinse, was controlled by the PLC. During the six-month operation, a total of 110 regeneration cycles took place, including 33 at the factory setpoint of 214,000 gal, 33 at a field-modified setpoint of 335,000 gal, and 44 at yet another field-modified setpoint of 316,000 gal (see Table 4-7).

4.4.2.1   Regeneration Settings. Table 4-7 presents the initial and modified regeneration settings for the IX system during the six-month period. From June 14 through July 26, 2005, regeneration was triggered by a factory throughput setpoint of 214,000 gal. A 4% brine solution was used to regenerate the resin at 23 gpm for 64 min to achieve the designed regeneration level of 10 lb of salt/ft^3 resin. Based on the results of the arsenic/nitrate run length and regeneration studies discussed in Sections 4.5.2 and 4.5.3,

Table 4-6. Summary of IX-248-As/N System Operation at Fruitland, ID

Parameter	Value
Operational Period	June 14, 2005–December 16, 2005
Total Operating Time (hr)	3,635
Average Daily Operating Time (hr/day)	22 (from June to September)
	16 (from October to December)
Throughput to Distribution (gal)	35,946,000[a]
Average Daily Use (gpd)	194,300
Peak Daily Use (gpd)	255,000
Number of Regeneration Cycles	110[b]
Service Flowrate (gpm)	138[c]–179 (average 165)
Empty Bed Contact Time (min)	5.4–4.2 (average 4.5)
Hydraulic Loading to Each Resin Tank (gpm/ft^2)	5.5–7.1 (average 6.6)
Pressure Loss across Each Resin Tank (psi)	8–10[d]
Pressure Loss across Entire System (psi)	8–18[e]

(a) Based on existing wellhead totalizer readings.
(b) Including 33, 33, and 44 regeneration cycles at a throughput setpoint of 214,000, 335,000, and 316,000 gal, respectively.
(c) Excluding lower flowrates during regeneration.
(d) As high as 20 psi pressure loss recorded during regeneration of other resin vessel.
(e) As high as 26 psi pressure loss recorded during regeneration of other resin vessel.

Table 4-7. IX System Regeneration Settings at Fruitland, ID

Parameter	Initial Setting	Modified Setting 1	Modified Setting 2	Modified Setting 3
Operational Period	06/14/05–07/26/05	07/27/05–09/19/05	09/20/05–12/05/05	12/06/05–12/16/05
Run Length Setting (gal)	214,000	335,000	316,000	316,000
Run Length Setting (BV)	286	448	422	422
Regeneration Interval (hr)[a]	22	34	32	32
Brine Concentration (%)	4	8	8	8
Brine Draw Time (min)	64	32	32	25
Slow Rinse Time (min)	64	64	64	40
Fast Rinse Time (min)	30	30	6	15
Total Regeneration Time (min/vessel)	158	126	102	80
No. of Regeneration Cycles	33	33	39	5
Salt Delivered (lb)	37,260	55,295	67,705	12,110
Average Salt Usage (lb/cycle)[a]	1,129	1,675	1,736	NA
Average Regeneration Level (lb/ft^3)[b]	11.3	16.7	17.4	NA

(a) Calculated by dividing amount of salt delivered by number of regeneration cycles, assuming same salt storage levels in saturator at beginning and end of each operational period.
(b) Calculated based on 100 ft^3 of resin in two tanks. Design value was 10 lb/ft^3.
NA = not available due to insufficient data

the regeneration settings were modified three times during the six-month period, including: 1) on July 26, 2005, a vendor technician was on site to increase the brine concentration from 4 to 8%, reduce the brine draw time from 64 to 32 min, and increase the throughput setpoint to from 214,000 to 335,000 gal based on his field arsenic/nitrate measurements; 2) on September 19, 2005, the operator was instructed by the vendor to reduce the throughput setpoint from 335,000 to 316,000 gal and the fast rinse time from 30 to 6

min based on the results of an arsenic/nitrate breakthrough study conducted on August 16 and 17, 2005; and 3) on December 5, 2005, the operator was instructed again to decrease the brine draw time from 32 to 25 min and slow rinse time from 64 to 40 min, and increase the fast rinse time from 6 to 15 min. Rationales of these modifications are discussed in Sections 4.5.2 and 4.5.3.

4.4.2.2 ***Regeneration Monitoring***. Regeneration parameters were monitored on September 22, November 10, and November 15, 2005, as summarized in Table 4-8. The volume of the treated water used for each regeneration step was recorded from a totalizer installed upstream of the Venturi eductor and used to calculate the average flowrate of each step. Brine usage was recorded from the 685-gal brine day tank with 50-gal graduations. The volume of brine draw (i.e., diluted brine) was calculated using Equation (1).

$$V_{brine,d} = (\gamma_{brine,s} \times V_{brine,s} + V_{water}) / \gamma_{brine,d} \qquad (1)$$

where:

$V_{brine,d}$ = volume of diluted brine (gal)
$V_{brine,s}$ = volume of saturated brine (gal)
V_{water} = volume of water used (gal)
$\gamma_{brine,s}$ = specific gravity of saturated brine, i.e., 1.176 for 23% brine
$\gamma_{brine,d}$ = specific gravity of diluted brine, i.e., 1.061 for 8% brine.

About 350 to 375 gal of saturated brine was used to regenerate each tank. The average flowrate of brine draw was 36 gpm, about 56% higher than the design value of 23 gpm. This higher flowrate resulted in the higher salt consumption as discussed in Section 4.4.2.3. The slow rinse flowrate ranged from 24 to 27 gpm, close to the design value. The fast rinse flowrate ranged from 58 to 67 gpm, lower than the design value of 75 gpm. Regeneration produced 6,127 to 6,650 gal of wastewater per vessel, equivalent to 16 to 18 BV. At a regeneration setpoint of 316,000 gal (422 BV), the water production efficiency was 96%.

Table 4-8. IX System Regeneration Parameters

Date of Regeneration	09/22/05			11/10/05			11/15/05		
Vessel Regenerated	A	B	Total	A	B	Total	A	B	Total
Brine Draw									
Brine Used in Day Tank (gal)	360	NA	720[b]	350	350	700	375	375	750
Treated Water Used (gal)	802	1,340[a]	1,604[b]	800	800	1,600	900	700	1,600
Brine Draw Volume (gal)[c]	1,149	NA	2,299[b]	1,137	1,137	2,274	1,258	1,070	2,328
Brine Draw Time (min)	32	32	64	32	32	64	32	32	64
Brine Draw Flowrate (gpm)	36	NA	36[b]	36	36	36	40	34	37
Slow Rinse									
Slow Rinse Volume (gal)	1,519	1,542	3,061	1,900	1,600	3,500	1,900	1,600	3,500
Slow Rinse Time (min)	64	64	128	64	64	128	64	64	128
Slow Rinse Flowrate (gpm)	24	24	24	30	25	27	30	25	27
Fast Rinse									
Fast Rinse Volume (gal)	383	359	742	300	400	700	400	400	800
Fast Rinse Time (min)	6	6	12	6	6	12	6	6	12
Fast Rinse Flowrate (gpm)	64	60	62	50	67	58	67	67	67
Total Waste Production per Regeneration Cycle									
Wastewater Produced (gal/cycle)	6,100			6,500			6,650		
Wastewater Produced (BV/cycle)	16			17			18		

(a) Including an unknown amount of water that went into salt saturator.
(b) Assuming TB consumed same amount of brine and water as TA.
(c) Calculated using Equation 1.

4.4.2.3   ***Salt Usage***. The amount of salt used by each regeneration cycle was calculated based on the concentrations and volumes of saturated and diluted brine solutions, respectively, according to Equation (2). The results are presented in Table 4-9.

$$W_{salt} = V_{brine} \times \gamma_{brine} \times d_{water} \times C_{salt} \qquad\qquad (2)$$

       where:

              W_{salt} = weight of salt (lb)
              V_{brine} = volume of brine (gal)
              γ_{brine} = specific gravity of brine
              d_{water} = density of water, i.e., 8.34 (lb/gal)
              C_{salt} = percent of salt (%).

Table 4-9. IX System Salt Usage Calculations

	Saturated Brine				Diluted Brine			
Date	Volume (gal)[a]	Specific Gravity[b]	Percent of Salt (%)	Salt Usage (lb)	Volume (gal)[a]	Specific Gravity[c]	Percent of Salt (%)	Salt Usage (lb)
09/22/05	720	1.176	23	1,624	2,299	1.061	8	1,627
10/25/05	750	1.176	23	1,692	NA	NA	NA	NA
11/10/05	700	1.176	23	1,579	2,274	1.061	8	1,609
11/15/05	750	1.176	23	1,692	2,328	1.061	8	1,648
			Average	1,647			*Average*	1,628

(a) Data from Table 4-8 except for that on 10/25/05.
(b) Ideal salt saturation level used for calculation.
(c) Measured using a field hydrometer.

The specific gravity of the saturated brine measured with a hydrometer on September 22, 2005, was 1.16, corresponding to 21% of NaCl, which was lower than the ideal salt saturation level of 23 to 25%. The specific gravity of the diluted brine measured was 1.061, corresponding to 8% of NaCl as expected. Using the ideal salt saturation level for calculation, it yielded the amount of salt usage (by weight) similar to that based on the diluted brine, as shown in Table 4-9. The average salt usage per cycle was 1,647 and 1,628 lb based on the saturated and 8% brine, respectively, which was over 60% higher than the design value of 1,000 lb (derived from 10 lb of salt/ft^3 of resin for 100 ft^3 of resin in both vessels).

The salt usage also was estimated based on the amount of salt delivered and the number of regeneration cycles taking place over a period of time, assuming the same level of salt in the salt saturator at the beginning and end of the period. During the 27 weeks of operation, a total of 172,390 lb (or 86 tons) of salt was delivered in 28 shipments with quantities varying from 3,205 to 9,035 lb per shipment. Because the system was regenerated 110 times during this 27-week period, regeneration of both vessels used, on average, 1,567 lb of salt. Table 4-7 presents the average salt usage under different regeneration settings, i.e., 1,129 lb for the period from June 14 through July 26, 1,675 lb from July 27 to September 19, and 1,736 lb from September 20 to December 5, 2005. Divided by 100 ft^3 of resin in both vessels, these salt usage values corresponded to a regeneration level of 11.3, 16.7 and 17.4 lb/ft^3 of resin, respectively. The salt regeneration level was only 13% higher than the design value of 10 lb/ft^3 initially, but became 67 and 74% higher since July 26, 2005.

As noted above, the higher-than-expected salt usage was caused by the higher brine draw rate (i.e., 36 gpm versus the design value of 23 gpm). It was suspected that, when the 4% brine solution was changed to 8% on July 26, 2005, a hand valve located upstream of the Venturi eductor might have been overly adjusted, resulting in the higher brine draw rate. For the same period of time from September 20 to December 5, 2005, the salt usage rates based on the salt delivery data were consistent with those calculated based on the saturated and diluted brine consumption rates as shown in Table 4-9 (i.e., 1,736 lb versus 1,647 lb and 1,628 lb, respectively).

After being notified of the higher brine draw rate issue, the vendor instructed the operator to shorten the brine draw time from 32 to 25 min on the PLC on December 5, 2005. Shortening the brine draw time on the PLC was recommended because it was easy to do (versus manipulating the hand valve upstream of the Venturi eductor to try to reach target brine draw flowrate). Reduction of the brine draw time from 32 to 25 min, however, would decrease the salt usage by only 22%. Further decrease in the brine draw time was not recommended by the vendor because of the concern over incomplete regeneration. The actual salt usage after the December 5, 2005 change will be evaluated in the final report after sufficient data are collected.

The salt usage in terms of 1,000 gal of water treated was calculated to be: 1) 4.80 lb/1,000 gal based on the amount of salt consumed, i.e., 172,390 lb, and the amount of water treated, i.e., 35,946,000 gal, over the six-month period, and 2) 3.16 lb/1,000 gal based on the design value of 1,000 lb of salt and the actual run length of 316,000 gal (because the higher brine draw rate was due to the improper flow control and was not intended). The second salt usage value was consistent with the 3.19 lb/1,000 gal stated in the vendor's proposal and those reported in the literature (Clifford et al., 1987 and 2003). For example, in a nitrate study conducted at Glendale, Arizona, where similar run length to nitrate breakthrough (~400 BV) was obtained from a type II resin, Clifford et al. (1987) reported a salt usage of 3.25 lb/1,000 gal for complete regeneration and 2.36 lb/1,000 gal for partial regeneration. Guter's work on nitrate removal in McFarland, California (1981) produced an even lower salt consumption than experienced in Glendale, Arizona.

4.4.3   Residual Management. Residuals produced by the IX system included spent brine and rinse water, which was discharged to a floor drain. The wastewater was then transported via a 6-in underground drain pipe to a lift station outside of the building before being pumped to a nearby sanitary sewer for disposal. The volume of wastewater produced was determined by the regeneration frequency and the volume of wastewater generated per regeneration cycle. Table 4-10 presents the calculations of wastewater production under different regeneration settings using the flowrates derived from Table 4-8, i.e., 36 gpm for brine draw, 26 gpm for slow rinse, and 62 gpm for fast rinse. The adjustments to the regeneration settings resulted in significant reductions in the wastewater production. For example, the increase of the brine concentration from 4% to 8% reduced the spent brine volume by 50%, from 2,304 to 1,152 gal per regeneration cycle. The reduction in slow rinse and fast rinse time also decreased the wastewater volume proportionally. Under Modified Setting 3, the total wastewater volume per cycle was reduced to 5,740 gal, which was 50% of that under the initial setting. The monthly wastewater production was estimated for the different regeneration settings (assuming an average daily demand of 194,300 gpd) and also presented in Table 4-10. Depending on the settings, the system would regenerate 17, 18, or 27 times each month and produce 105,900 to 293,400 gal of wastewater per month, corresponding to 94.6% to 98.2% of production efficiencies. Based on the number of regeneration cycles performed under each setting, approximately 949,000 gal of wastewater was produced during the first six months of operation.

4.4.4   System/Operation Reliability and Simplicity. Table 4-11 summarizes the operational problems encountered and corrective actions taken during the first six months of system operation. A power outage occurred over the weekend of June 18 and 19, 2005, causing several operational problems. First, the product water totalizer read 341,000 gal on June 20, 2005, exceeding the regeneration setpoint

Table 4-10. Comparison of Wastewater Production Under Different IX Regeneration Settings

Parameter	Initial Settings	Modified Settings 1	Modified Settings 2	Modified Settings 3
Run Length Setting (gal)	214,000	335,000	316,000	316,000
Brine Draw				
Brine Concentration (%)	4	8	8	8
Brine Draw Time (min)	64	32	32	25
Brine Draw Rate (gpm)[a]	36	36	36	36
Brine Draw Volume (gal)	2,304	1,152	1,152	900
Slow Rinse				
Slow Rinse Time (min)	64	64	64	40
Slow Rinse Flowrate (gpm)[a]	26	26	26	26
Slow Rinse Volume (gal)	1,664	1,664	1,664	1,040
Fast Rinse				
Fast Rinse (min)	30	30	6	15
Fast Rinse Flowrate (gpm)[a]	62	62	62	62
Fast Rinse Volume (gal)	1,860	1,860	372	930
Total Waste Production				
Wastewater Produced per Vessel (gal)	5,828	4,676	3,188	2,870
Wastewater Produced per Regeneration Cycle (gal)[b]	11,656	9,352	6,376	5,740
Average Monthly Production (gal/month)[c]	5,829,000	5,829,000	5,829,000	5,829,000
Monthly Regeneration Cycles (times/month)	27	17	18	18
Monthly Wastewater Production (gal/month)	293,400	162,700	117,600	105,900
Water Production Efficiency (%)	94.6	97.2	98.0	98.2

(a) Flowrates measured under Modified Setting 3 used for calculations under other settings.
(b) Regeneration of both vessels in one regeneration cycle.
(c) Based on an average daily demand of 194,300 gpd in Table 4-6.

of 214,000 gal. An examination of the system revealed that the brine transfer pump had been reset to "off", thus, preventing the scheduled regeneration from taking place. Second, due to the power outage, the PLC regeneration setting was returned from "co-current" to the factory default "counter-current". Although the system was designed with flexibilities to support both regeneration modes, the plumbing and valving was configured in the field only to support the "co-current" regeneration. Therefore, it was suspected that the system had not been properly regenerated for about 10 days, as indicated by the higher-

Table 4-11. Summary of IX System Operational Problems

Date	Problem Encountered	Corrective Actions Taken
06/14/05– 06/21/05	System experienced low flow and elevated pressure loss	Flow restrictors modified and subsequently removed on 07/07/05
06/15/05	Brine transfer pump malfunctioned	Pump fixed on same day by operator
06/18/05– 06/29/05	After a power outage, IX system restarted but failed to initiate regeneration because brine transfer pump had been reset to "off"; PLC returned to default "counter-current" regeneration instead of "co-current"	PLC setting changed back to "co-current" on 06/29/05; an uninterrupted power supply (UPS) installed on 07/26/05 to provide back-up power
08/03/05	Regeneration failed to occur after treating 534,000 gal of water due to a broken low level sensor in brine day tank	Level sensor fixed on same day by operator

than-expected arsenic and nitrate concentrations in the treated water samples on June 23 and 29, 2005 (Sections 4.5). The PLC setting was changed back to "co-current" on June 29, 2005, after sample collection. In addition, an uninterrupted power supply (UPS) was installed by the vendor on July 26, 2005 to provide a backup power to the PLC. The system failed to regenerate again on August 3, 2005, due to a broken level sensor in the brine day tank. The product water totalizer read 534,000 gal on that day, far exceeding the setpoint of 335,000 gal. The prolonged service run resulted in higher-than-influent-levels of arsenic and nitrate in the treated water, known as "chromatographic effect" (see Sections 4.5). The level sensor was repaired by the operator on the same day.

The required system operation and operator skills are further discussed below according 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.

4.4.4.1   Pre- and Post-Treatment Requirements. Pretreatment included filtration with a bank of five bag filters to remove sediment from source water. The bag filters were replaced when the ΔP across the bag filters was greater than 6 psi. The bag filters were replaced four or five times during the six-month operation and it took approximately one hour each time to replace all five filter bags. There was no post-treatment employed, except for the provision of post-chlorination in case of any bacterial outbreak.

4.4.4.2   System Automation. The IX system was fully automatic and controlled by the PLC in the central control panel. The control panel also contained a touch screen OIP that allowed the operator to monitor system flowrate and throughput since last regeneration. The OIP also allowed the operator to change system setpoints, as needed, and check the status of alarms. Setpoint screens were password-protected so that changes could only be made by unauthorized personnel. Typical alarms were for no flow, storage tank high/low, and regeneration failure. The IX system was regenerated automatically based on a throughput setpoint, except during the regeneration sampling events when the system was regenerated manually in order to capture spent regenerant and rinse samples. Although the system would require minimal operator oversight and intervention if all functions were operating as intended, a number of operational issues did arise with the automated resin vessel regeneration and associated equipment, as noted in Section 4.4.4.

4.4.4.3   Operator Skill Requirements. The O&M of the IX system required minimal additional operator skills beyond those required for small system operators, such as solid work ethic, basic mathematical skills, abilities to understand chemical properties, familiarities with electronic and mechanical components, and abilities to follow written and verbal instructions. Understanding of and compliance with all occupational and chemical safety rules and regulations also were required. Since all major system operations were automated and controlled by the PLC, the operator was required to understand and learn how to use the PLC and OIP to perform tasks after receiving training from the vendor.

The level of operator certification is determined by the type and class of the public drinking water systems. IDEQ's drinking water rules require all community and non-transient non-community public drinking water and distribution systems to be classified based on potential health risks. Classifications range from "Class I" (lowest) to "Class IV" (highest) for treatment systems and from "Very Small" to "Class IV" for distribution systems, depending on factors such as the system complexity, size, and source water. There are 11 different types and classes of individual drinking water operator classes for which licenses are issued. The City of Fruitland Public Water System is classified as a "Class II" distribution system and the plant operator has a matching "Class II" license. After receiving proper training by the vendor during the system startup, the operator understood the PLC, knew how to use the OIP, and worked with the vendor to troubleshoot and perform minor on-site repairs.

4.4.4.4 Preventive Maintenance Activities. Preventive maintenance tasks recommended by the vendor included daily to monthly visual inspection of the piping, valves, tanks, flow meters, and other system components. Routine maintenance also may be required on an as needed basis for the air compressor motor and the replacement of o-ring seals or gaskets on automated or manual valves and the brine transfer pump (Kinetico, 2004). During this reporting period, maintenance activities performed by the operator included replacing filter bags periodically, checking the brine concentration using a hydrometer, adjusting regeneration frequency and setpoints as instructed by the vendor, and conducting troubleshooting activities as described in Section 4.4.2 related to the malfunction of automated regeneration operations.

4.4.4.5 Chemical/Media Handling and Inventory Requirements. The chemicals required for the IX system included sodium chloride for regeneration. The system has fully automated controls with the regeneration being triggered by volume throughput. The salt truck delivered salt on a weekly or as needed basis with or without the operator's presence. The salt saturator was sized to hold 15 tons of salt supply; this capacity, however, was reduced by 18% to 12.3 ton due to shortening of the tank height to fit the building. Assuming that the system regenerates 18 times per month (see Table 4-10) and uses 1,000 lb of salt per event (as designed), it would require 18,000 lb or 9 tons of salt per month. Therefore, the salt saturator holds about six weeks of salt supply.

4.5 System Performance

The performance of the IX-248-As/N system was evaluated based on analyses of water samples routinely collected from the treatment train, regeneration cycles, and the distribution system. Since the IX system was regenerated several times a week, the routine weekly samples collected from the treatment plant only represented discrete data points from multiple service runs. Therefore, the resin run length and regeneration studies were conducted to provide additional insights into the system performance.

4.5.1 Treatment Plant Sampling. The treatment plant water was sampled on 24 occasions (including one duplicate sampling event) and speciated on seven occasions during the six months of operation. Table 4-12 summarizes the arsenic and nitrate analytical results. Table 4-13 summarizes the results of other water quality parameters. Appendix B contains a complete set of analytical results through the six-month period. The results of the water samples collected throughout the treatment plant are discussed as follows.

4.5.1.1 Arsenic and Nitrate Removal. Arsenic and nitrate were the two primary contaminants of concern in source water; thus, their removal was crucial to assessing the performance of the IX system. Figures 4-13 and 4-14 show total As and nitrate concentrations across the treatment train, respectively, over the six-month period. Each figure consists of two plots: the first plots total As or nitrate concentrations against the sampling dates and the second plots the same set of concentration data against the system throughput at the time of sample collection. Because the system was regenerated two to three times a week, the weekly treatment plant samples were collected from multiple service runs. Typically, a breakthrough curve is constructed with data from the same service run. To better understand the IX system performance with data collected from multiple service runs, the concentration data were plotted against the system throughput (from low to high) when samples were collected. These "reconstructed" breakthrough curves are presented in Figures 4-13b for total arsenic and 4-14b for nitrate.

Table 4-12. Summary of Arsenic and Nitrate Data

Parameter	Sampling Location[a]	Unit	Number of Samples	Concentration			
				Minimum	Maximum	Average	Standard Deviation
As (total)	IN	µg/L	24	33.6	60.8	42.1	7.8
	TA	µg/L	14[b]	0.7	25.6	4.6	7.5
	TB	µg/L	14[b]	0.5	15.1	4.5	4.9
	TT	µg/L	7	0.7	2.8	1.4	0.9
As (soluble)	IN	µg/L	7	37.3	59.9	42.6	8.1
	TT	µg/L	7	0.7	3.2	1.4	1.1
As (particulate)	IN	µg/L	7	<0.1	8.9	2.1	3.2
	TT	µg/L	7	<0.1	0.2	0.1	0.0
As(III)	IN	µg/L	7	0.9	2.4	1.6	0.6
	TT	µg/L	7	0.8	2.4	1.5	0.6
As(V)	IN	µg/L	7	35.9	58.7	41.0	8.3
	TT	µg/L	7	<0.1	0.8	0.2	0.3
Nitrate (as N)	IN	mg/L	24	6.89	11.20	9.46	0.88
	TA	mg/L	13[b]	0.41	9.70	2.32	2.49
	TB	mg/L	14[b]	0.33	9.83	1.92	1.98
	TT	mg/L	7	0.40	4.34	1.29	1.43

One-half of detection limit used for non-detect samples for calculations.

Duplicate samples included calculations.

(a) See Figure 4-8 for sampling locations.

(b) Excluding data collected on June 23 and 29 and August 3, 2005, when system was not regenerated properly.

Total As concentrations in raw water ranged from 33.6 to 60.8 µg/L and averaged 42.1 µg/L (Table 4-12). Nitrate concentrations in raw water ranged from 6.89 to 11.20 mg/L (as N) and averaged 9.46 mg/L (as N). After the IX treatment, total As and nitrate concentrations were reduced to below the respective MCLs at the TT location for all seven sampling events when the samples were collected at a system throughput between 37,000 (first data point) and 224,000 gal (7th data point), as shown on Figures 4-13b and 4-14b. However, samples collected after individual resin vessels at the TA and TB sampling locations exceeded the MCLs on several occasions, due to either mechanical failure (i.e., June 23 and 29 and August 3, 2005) or leakage from the freshly regenerated resin beds (i.e., August 10 and 31, 2005). These results are further discussed below:

Samples Taken on June 23 and 29, 2005. TA and TB samples collected on June 23 and 29, 2005 after 212,000 gal (or 283 BV) and 147,000 gal (or 197 BV) of water had been treated, respectively, showed almost no arsenic or nitrate removal (data not shown on the "reconstructed" breakthrough curves). It was discovered later that, after a power outage on June 17, 2005, the system PLC was reset automatically to the default "counter-current" regeneration (see Sections 4.4.4). As a result, the system was not properly regenerated during this period. The effluent water quality returned to normal after the problem was corrected on June 29, 2005.

Samples Taken on August 3, 2005. TA and TB samples showed higher-than-raw-water-levels of arsenic and nitrate (i.e., 41.4 and 46.3 µg/L vs. 34.2 µg/L for total As and 9.7 and 9.7 mg/L vs. 9.3 mg/L (as N) for nitrate) because the system had failed to regenerate at the setpoint of 335,000 gal (448 BV) and continue to operate up to 534,000 gal (714 BV) due to a broken brine tank level sensor. The prolonged

Table 4-13. Summary of Other Water Quality Parameters

Parameter	Sampling Location[a]	Unit	No. of Samples	Concentration			
				Minimum	Maximum	Average	Standard Deviation
Alkalinity (as CaCO$_3$)	IN	mg/L	24	365	484	386	22.9
	TA	mg/L	16	3.0	462	338	140
	TB	mg/L	17	3.0	462	299	186
	TT	mg/L	7	286	484	421	74.6
Fluoride	IN	mg/L	8	0.5	0.7	0.5	0.1
	TA	mg/L	1	0.7	0.7	0.7	-
	TB	mg/L	1	0.7	0.7	0.7	-
	TT	mg/L	7	0.5	0.5	0.5	0.0
Sulfate	IN	mg/L	24	40.8	76.0	58.5	7.8
	TA	mg/L	16	<1	94.0	13.3	28.6
	TB	mg/L	17	<1	63.0	10.7	22.8
	TT	mg/L	7	<1	<1	<1	0.0
Orthophosphate (as PO$_4$)	IN	mg/L	24	<0.05	0.56	0.12	0.12
	TA	mg/L	16	<0.05	0.23	0.05	0.07
	TB	mg/L	17	<0.05	0.25	0.05	0.07
	TT	mg/L	7	<0.05	0.85	0.14	0.31
Total P (as PO$_4$)	IN	mg/L	6	<0.03	0.40	0.29	0.14
	TA	mg/L	4	<0.03	<0.03	<0.03	0.00
	TB	mg/L	4	<0.03	<0.03	<0.03	0.00
	TT	mg/L	2	<0.03	0.35	0.18	0.24
Silica (as SiO$_2$)	IN	mg/L	22	46.6	63.4	56.4	3.4
	TA	mg/L	17	53.8	61.6	57.3	1.7
	TB	mg/L	17	54.5	63.2	57.5	1.9
	TT	mg/L	7	45.9	57.2	53.6	4.7
Turbidity	IN	NTU	24	<0.1	1.4	0.3	0.4
	TA	NTU	16	<0.1	0.7	0.2	0.2
	TB	NTU	17	<0.1	0.6	0.2	0.2
	TT	NTU	7	<0.1	1.6	0.3	0.6
TDS	IN	mg/L	7	550	598	571	14.6
	TT	mg/L	7	498	558	535	20.1
pH	IN	S.U.	22	7.3[b]	7.9	7.6	0.1
	TA	S.U.	15	6.8	7.9	7.6	0.3
	TB	S.U.	16	6.0	7.9	7.4	0.4
	TT	S.U.	7	7.2	7.7	7.4	0.2
Temperature	IN	℃	23	14.6	15.4	15.1	0.2
	TA	℃	15	14.6	15.9	15.0	0.4
	TB	℃	16	14.6	15.4	14.9	0.2
	TT	℃	7	14.8	15.2	15.0	0.2
Dissolved Oxygen	IN	mg/L	22	1.9	4.3	2.8	0.7
	TA	mg/L	15	1.8	3.4	2.5	0.4
	TB	mg/L	16	2.1	3.5	2.6	0.4
	TT	mg/L	6	1.7	3.0	2.5	0.5

Table 4-13. Summary of Other Water Quality Parameters (Continued)

Parameter	Sampling Location[a]	Unit	Number of Samples	Concentration			
				Minimum	Maximum	Average	Standard Deviation
ORP	IN	mV	23	191	276	235	23.8
	TA	mV	15	180	297	229	31.0
	TB	mV	16	3.0	260	214	60.5
	TT	mV	7	172	260	231	30.6
Total Hardness (as $CaCO_3$)	IN	mg/L	7	227	303	251	25.1
	TT	mg/L	7	229	252	244	7.9
Ca Hardness (as $CaCO_3$)	IN	mg/L	8	134	180	150	13.8
	TT	mg/L	7	140	155	146	5.2
Mg Hardness (as $CaCO_3$)	IN	mg/L	7	86.2	123	101	11.2
	TT	mg/L	7	89.3	104	98	4.6
Fe (total)	IN	µg/L	24	<25	211	24.5	43.8
	TA	µg/L	17	<25	<25	<25	0.0
	TB	µg/L	17	<25	<25	<25	0.0
	TT	µg/L	7	<25	<25	<25	0.0
Fe (soluble)	IN	µg/L	7	<25	<25	<25	0.0
	TT	µg/L	7	<25	<25	<25	0.0
Mn (total)	IN	µg/L	24	11.8	30.8	22.9	4.9
	TA	µg/L	17	13.9	33.7	22.9	4.5
	TB	µg/L	17	14.3	28.0	22.4	4.0
	TT	µg/L	7	9.9	26.5	20.4	6.2
Mn (soluble)	IN	µg/L	7	10.0	30.4	21.1	7.2
	TT	µg/L	7	10.4	28.7	21.1	6.7
U (total)	IN	µg/L	24	16.6	22.6	18.9	1.4
	TA	µg/L	17	<0.1	0.3	0.1	0.1
	TB	µg/L	17	<0.1	2.5	0.2	0.6
	TT	µg/L	7	<0.1	<0.1	<0.1	0.0
U (soluble)	IN	µg/L	7	16.2	19.7	18.5	1.2
	TT	µg/L	7	<0.1	<0.1	<0.1	0.0
V (total)	IN	µg/L	24	30.6	53.0	39.2	4.0
	TA	µg/L	17	0.3	16.6	3.3	4.1
	TB	µg/L	17	0.3	36.1	6.2	8.9
	TT	µg/L	7	<0.1	4.2	1.5	1.6
V (soluble)	IN	µg/L	7	36.6	45.2	40.2	2.6
	TT	µg/L	7	<0.1	5.7	1.8	2.1
Mo (total)	IN	µg/L	22	12.0	14.6	12.8	0.8
	TA	µg/L	15	<0.1	13.0	1.7	3.7
	TB	µg/L	15	<0.1	13.3	1.8	4.2
	TT	µg/L	7	<0.1	0.5	0.2	0.1
Mo (soluble)	IN	µg/L	7	11.8	14.0	12.8	0.8
	TT	µg/L	7	<0.1	0.4	0.2	0.1

One-half of detection limit used for non-detect samples for calculations.
Duplicate samples included for calculations.
(a) See Figure 4-8 for sampling locations.
(b) Excluding an outlier on 07/06/05.
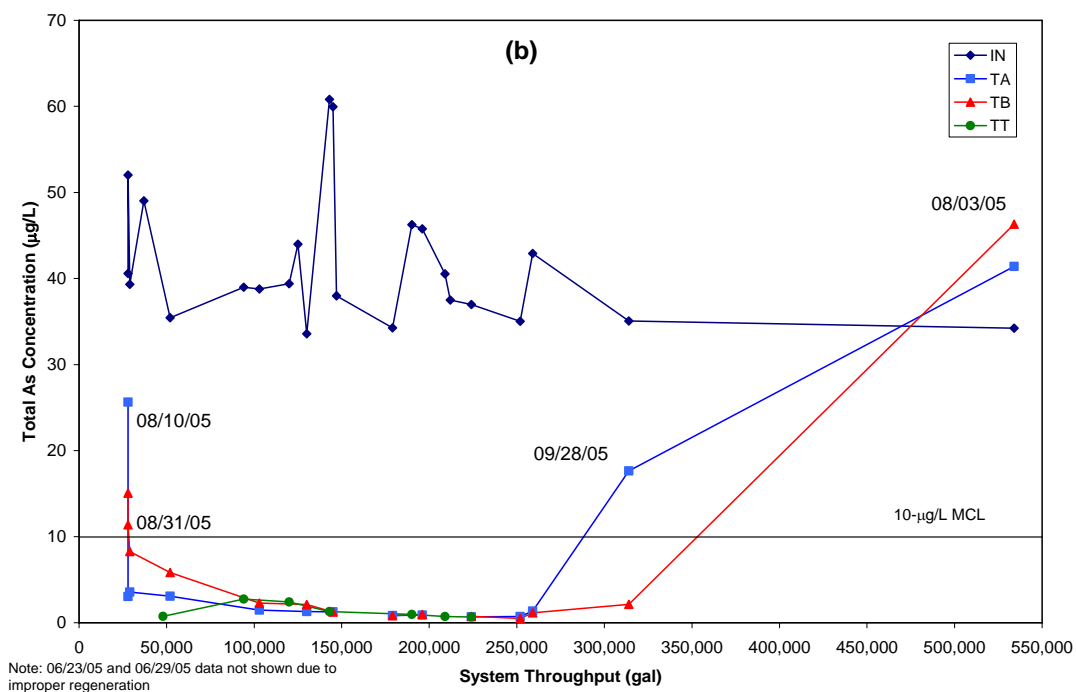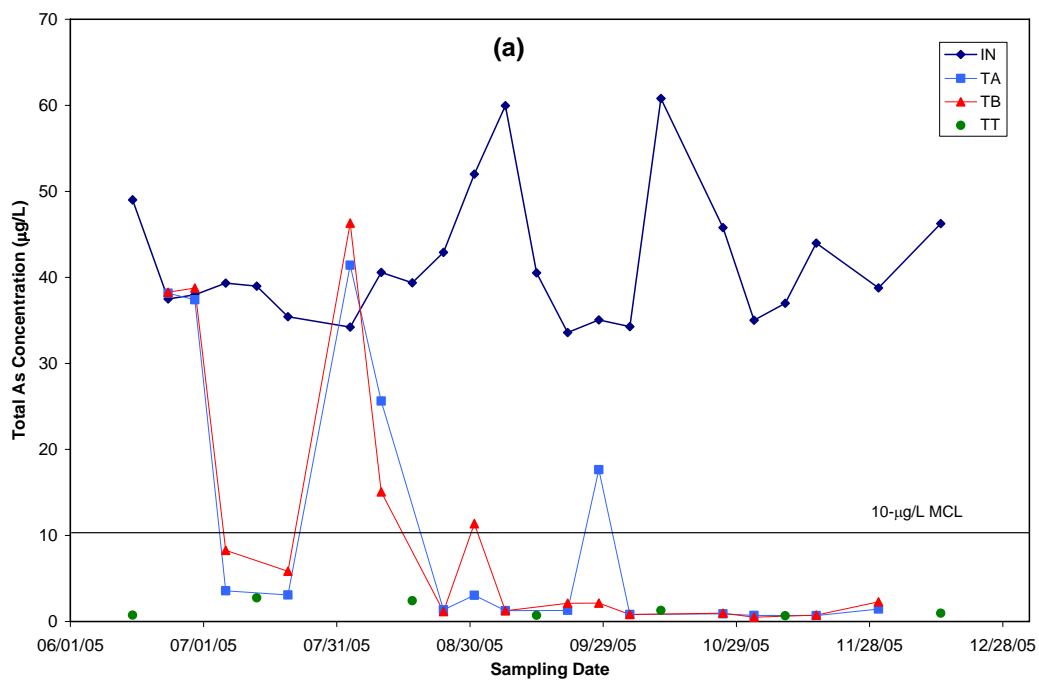
**Figure 4-13. Total Arsenic Concentrations Measured over Six-Month Period
(a) Temporal Plot; (b) Reconstructed Breakthrough Curves**
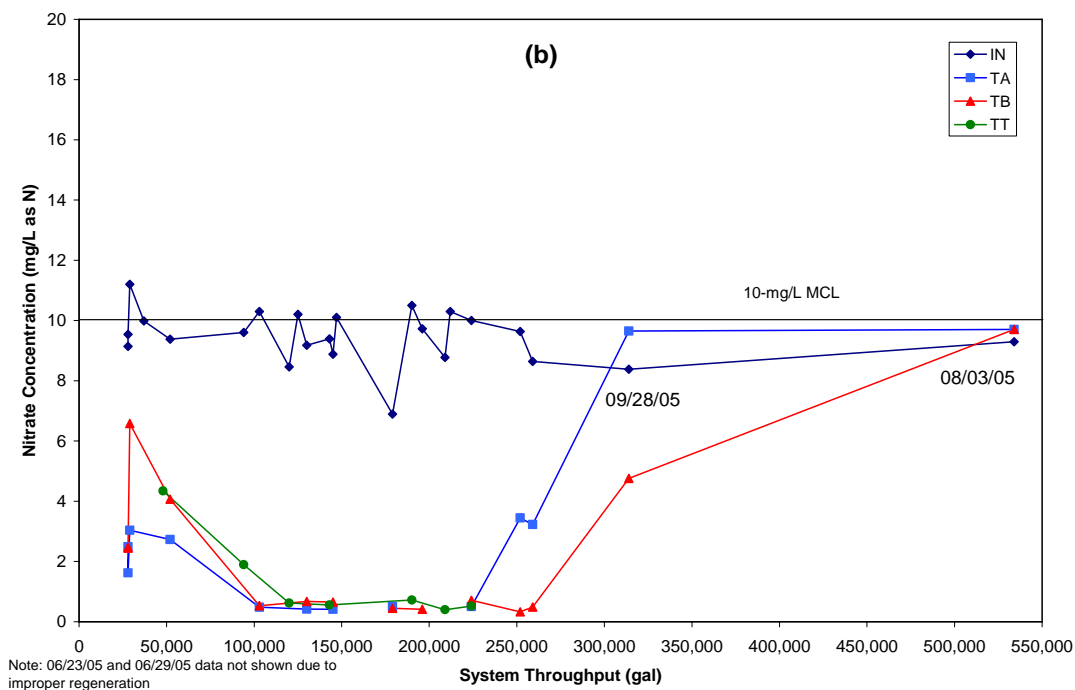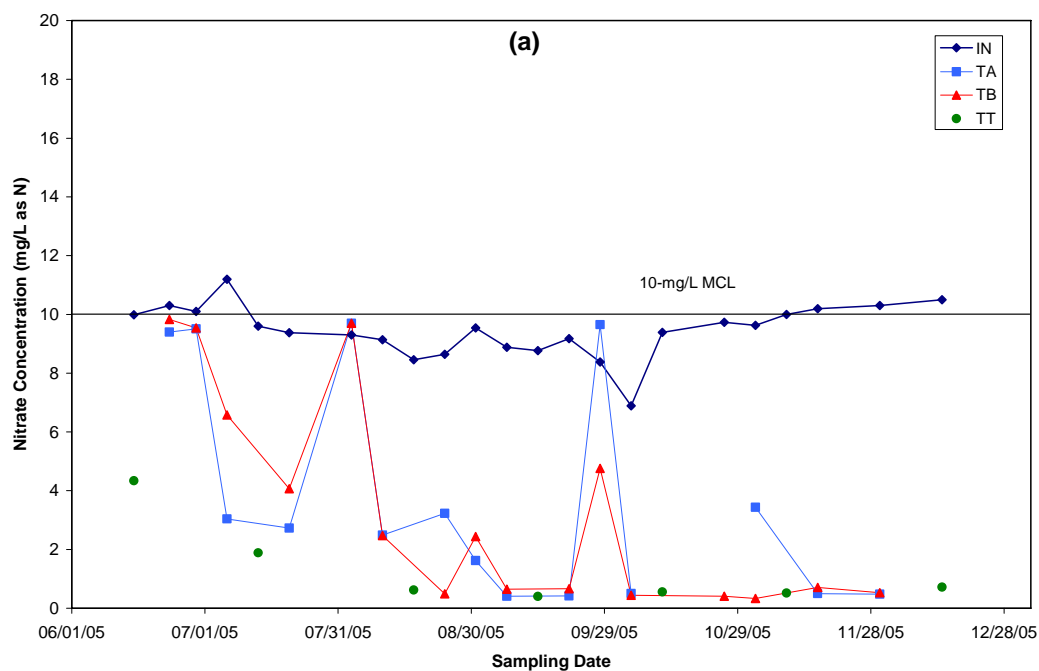
**Figure 4-14. Nitrate Concentrations Measured over Six-Month Period
(a) Temporal Plot; (b) Reconstructed Breakthrough Curves**

service run forced previously exchanged arsenic and nitrate to be displaced, presumably, by more preferred anions, such as sulfate, in raw water, resulting in the "chromatographic peaking" observed. According to the selectivity sequence discussed in Sections 4.2.1, an SBA resin like A300E prefers sulfate over $HAsO_4^{2-}$, nitrate, and $H_2AsO_4^-$; the HCO_3^- ion is less preferred than $HAsO_4^{2-}$ but has a similar affinity to the resin as $H_2AsO_4^-$.

Samples Taken on August 10 and 31, 2005. TA and TB samples collected at 28,000 gal (37 BV) of throughput contained 25.6 and 15.1 µg/L of total As, respectively, exceeding the 10- µg/L MCL. This early arsenic leakage reoccurred on August 31, 2005, when 11.4 µg/L of total As was measured in the TB sample at 28,000 gal (37 BV). The arsenic leakage problem was further investigated in the resin run length studies.

Samples Taken on September 28, 2005. The TA sample contained 17.6 µg/L of total As and 9.7 mg/L of nitrate (as N), exceeding the arsenic MCL and approaching the nitrate MCL. The samples were collected after 314,000 gal (420 BV) of water had been treated, which was close to the regeneration setpoint of 316,000 gal (422 BV). However, since the TB sample contained only 2.1 µg/L of total As, the combined effluent from both tanks, if equally blended, would have been just under the arsenic MCL.

4.5.1.2 Arsenic Speciation. Figure 4-15 shows the arsenic speciation results of samples collected at the wellhead and combined effluent. As(V) was the predominant species in raw water, ranging from 35.9 to 58.7 µg/L and averaging 41.0 µg/L. Only trace amounts of particulate As and As(III) existed, with concentrations averaging 2.1 and 1.6 µg/L, respectively. After treatment, As(III) concentrations remained essentially unchanged, averaging 1.5 µg/L. As expected, the IX process did not remove the neutral species of arsenite.

4.5.1.3 Uranium, Vanadium, and Molybdenum Removal. Figure 4-16 presents the reconstructed breakthrough curves of total U, V, and Mo during the six-month period. Total U concentrations ranged from 16.6 to 22.6 µg/L in raw water, which was removed to less than 1 µg/L in treated water except for July 6, 2005 at 2.5 µg/L (TB). Total V concentrations ranged from 30.6 to 53.0 µg/L and averaged 39.2 µg/L in raw water. After treatment, total V was removed to less than 10 µg/L except for a few occasions with samples collected at 50,000 gal or less of throughput . The highest detection of total V was 36.1 µg/L (TB) on July 6, 2005. Total Mo in raw water was less than 15 µg/L, which was removed to less than 1 µg/L in treated water except for June 23 and 29, 2005.

4.5.1.4 Other Water Quality Parameters. Figure 4-17 presents the "reconstructed" breakthrough curves for sulfate, pH, and total alkalinity during the six-month period. Sulfate concentrations ranged from 41 to 76 mg/L in raw water, which was removed to less than 1 mg/L after treatment except for June 23 and 29 and August 3, 2005, when the system experienced mechanical problems (see section 4.4.4). Raw water pH values ranged from 7.3 to 7.9 and averaged 7.6 (except for an outlier of 6.7 on July 6, 2005). Treated water pH values remained in the similar range, but lower pH values were observed for a short duration after the system had been freshly regenerated. For example, the pH values at IN, TA, and TB locations were 7.8, 7.0, and 7.3, respectively, on August 10 and 7.7, 7.5, and 6.8, respectively, on August 31, 2005, after 28,000 gal of water treated. This pH reduction corresponded to the significant reduction in total alkalinity, i.e., from 383 to 3 and 3 mg/L (as $CaCO_3$) on August 10, 2005, and from 374 to 158 and 7 mg/L (as $CaCO_3$) on August 31, 2005. The pH measurement on July 6, 2005, at 29,000 gal was questionable (i.e., 6.7, 6.8 and 6.0 at the IN, TA, and TB locations); however, the total alkalinity values were measured at 396, 176, and 6 mg/L (as $CaCO_3$), very similar to the August 31, 2005 data. The reduction in pH and alkalinity was attributed to the removal of bicarbonate ions by the IX resin. As well documented in the literature, one disadvantage of the IX process is the production of low pH and corrosive water by the freshly regenerated resin during the initial 100 BV of an service run (Clifford, 1999). Afterwards, rapid bicarbonate elution from the resin vessels raises the pH values to above neutral.

Arsenic Species at Inlet (IN)

Arsenic Species after Tanks A and B Combined (TT)
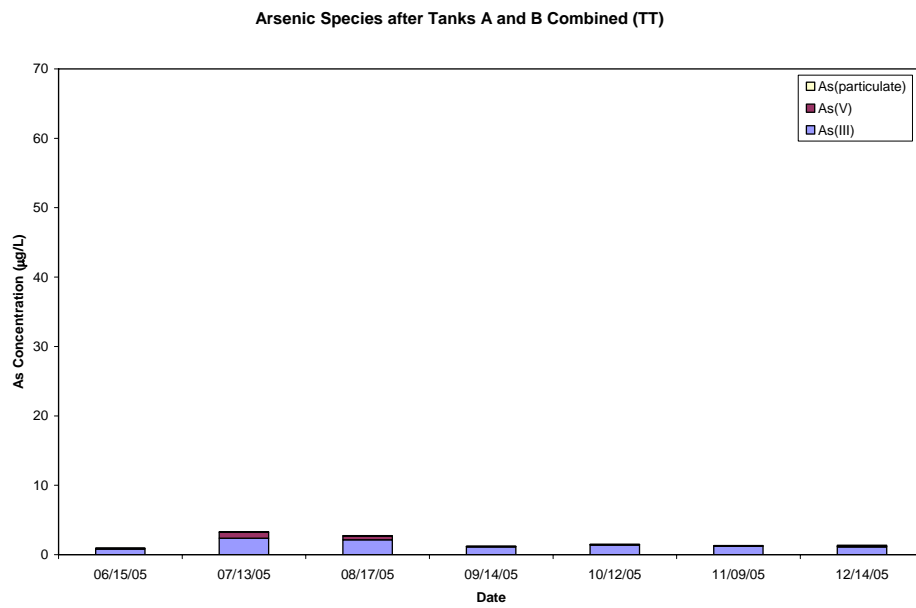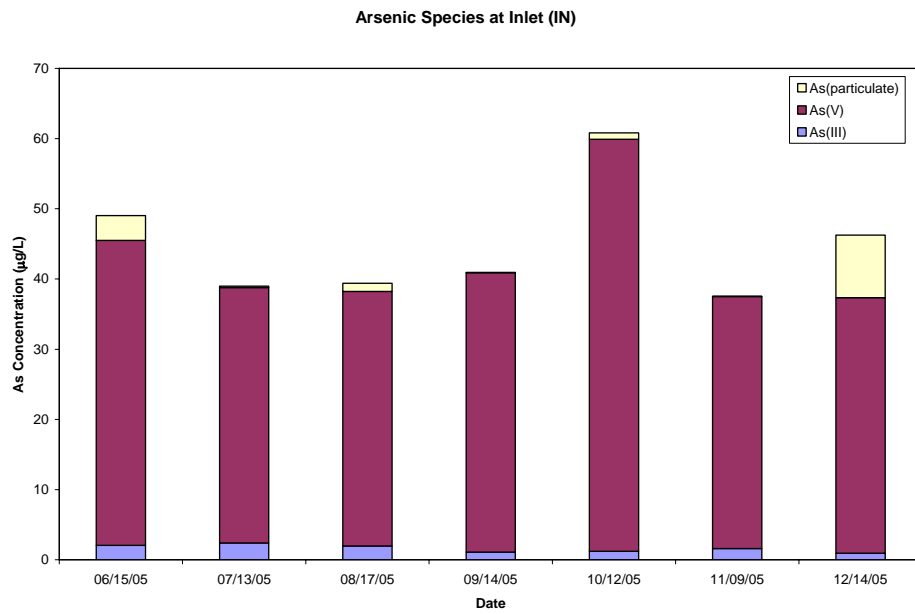
Figure 4-15. Concentrations of Arsenic Species at Wellhead and Combined Effluent
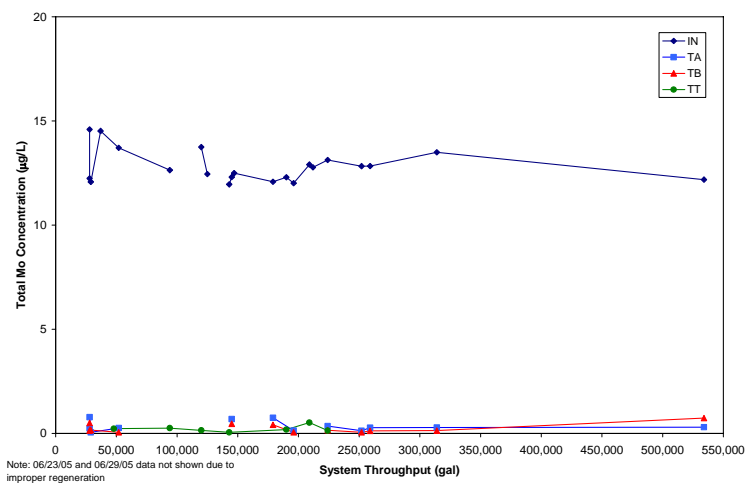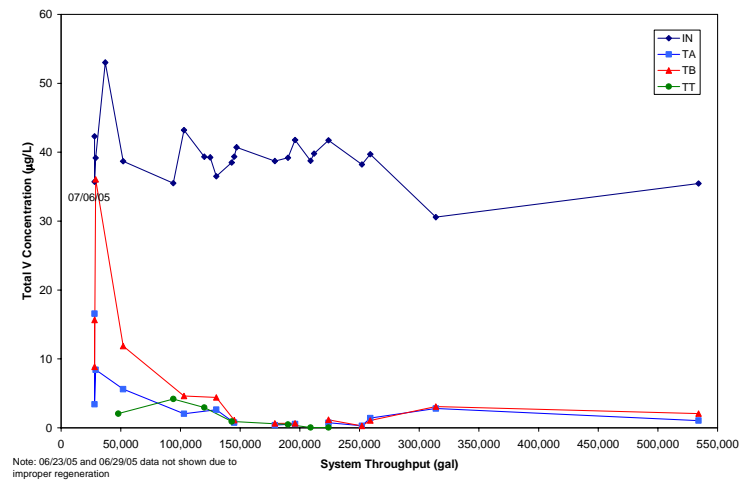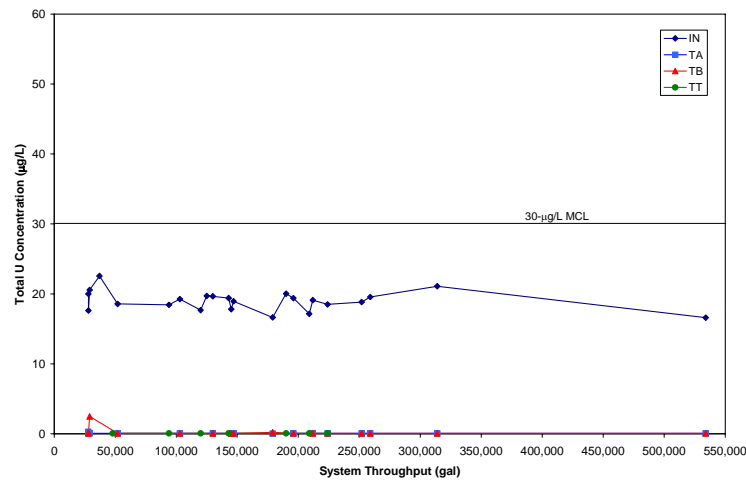
Figure 4-16. Reconstructed Breakthrough Curves for Total U, V, and Mo Over Six-Month Period
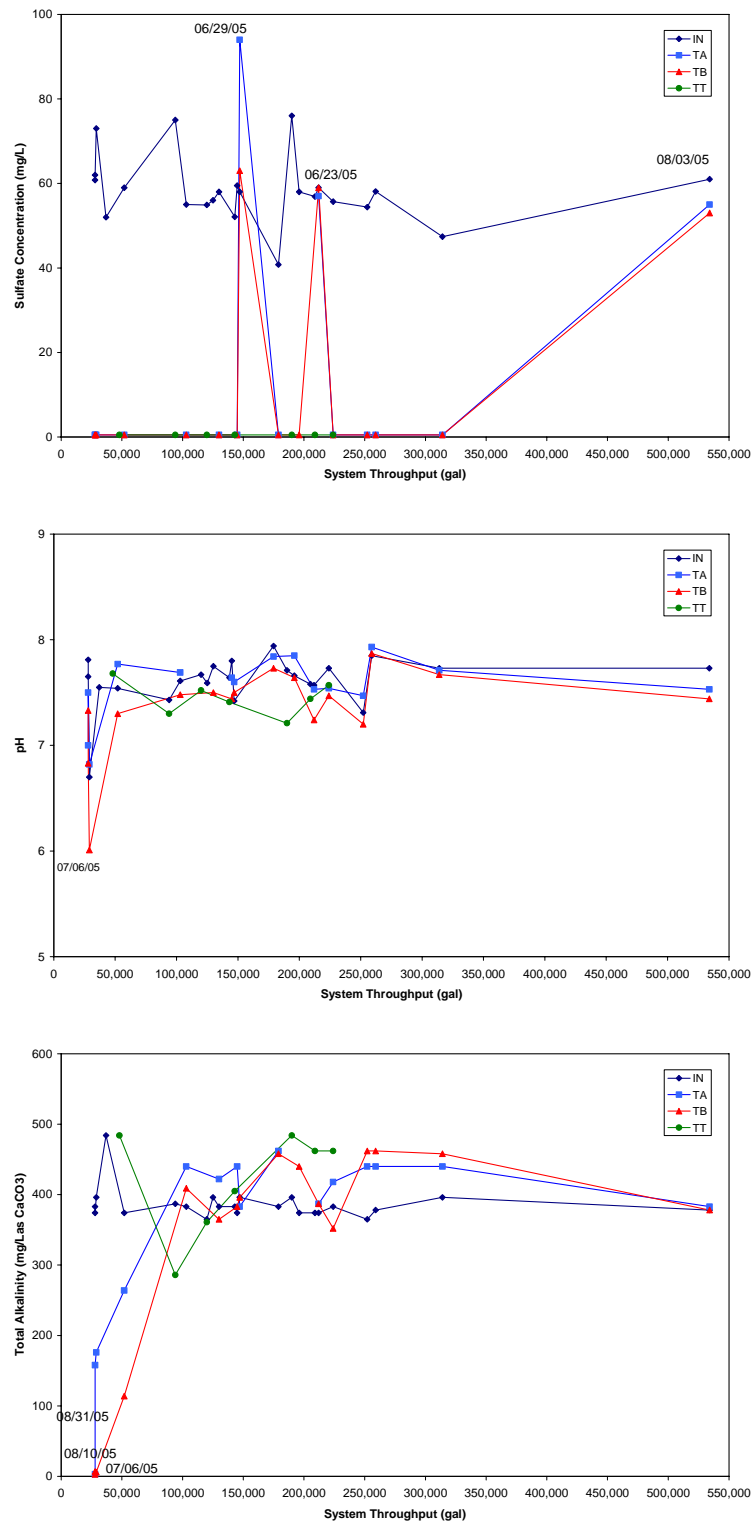
Figure 4-17. Reconstructed Breakthrough Curves for Sulfate, pH, and Total Alkalinity over Six-Month Period

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4.5.2   Resin Run Length Studies. Figure 4-18 presents the total arsenic and nitrate breakthrough curves from three service runs that started on July 28, August 16, and December 7, 2005, respectively. Total alkalinity, pH, sulfate, and total V also were measured during the December 7, 2005 service run and their breakthrough curves are presented in Figure 4-19.

Run Length Study 1 (July 28-30, 2005): Combined effluent samples were collected and analyzed for total As and nitrate using field test kits (Section 3.4.1). Arsenic and nitrate reached the respective detectable concentrations of 2 µg/L and 5 mg/L after 303,000 gal (~ 400 BV) of water had been treated. Samples collected at 366,000 gal (489 BV) showed arsenic and nitrate breakthrough at 20 µg/L and 10 mg/L, respectively. Subsequent samples were collected from individual vessels to confirm the results. Total As concentrations were measured at > 50 µg/L in Tank A effluent and 10 µg/L in Tank B effluent. The higher arsenic breakthrough from Tank A was expected because it had been in service longer than Tank B. Nitrate concentrations were measured at 10 mg/L for both vessels. As a result of this study, the regeneration setpoint was adjusted from 214,000 gal (286 BV) to 335,000 gal (448 BV) on July 30, 2005 (Section 3.4.1).

Run Length Study 2 (August 16-17, 2005): The first sample was collected from Tank A at 86,000 gal (115 BV) and contained 5 µg/L of total arsenic and 1.5 mg/L of nitrate (as N). Total arsenic concentrations then decreased to as low as 1.2 µg/L at 302,000 gal before rising again to as high as 5.4 µg/L before approaching the 335,000-gal setpoint. Nitrate concentrations decreased to 0.1 mg/L (as N) at 250,000 gal, and then increased steadily to 10 mg/L (as N) at 302,000 gal. Therefore, nitrate reached its MCL earlier than arsenic did, which was consistent with the hierarchy of selectivity of an SBA resin (i.e., the divalent arsenate ion is more preferred than nitrate) as discussed in Section 4.2.1. The results of the study prompted the regeneration setpoint to be reduced to 316,000 gal (422 BV) on September 19, 2005 (Section 3.4.1).

Run Length Study 3 (December 7-8, 2005): In this study, samples were collected from each tank with more samples taken during the first 60,000 gal (or 80 BV) of throughput. The sampling results clearly indicated the initial arsenic and nitrate leakage from both resin vessels. Tank A arsenic and nitrate breakthrough curves were very similar to those of the second run length study. The initial arsenic leakage from Tank B was as high as 18.7 µg/L at 24,000 gal (or 32 BV). The initial nitrate leakage from either tank was similarly elevated, but below the MCL. The nitrate concentration after Tank A reached 10 mg/L (as N) at 288,000 gal (or 385 BV).

As shown on Figure 4-19, total alkalinity and pH values were significantly reduced to as low as 11 mg/L (as $CaCO_3$) and a pH unit of 6 for the first 24,000 gal, consistent with the six-month monitoring data (Figure 4-17). Total alkalinity and pH values gradually approached the raw water levels and leveled off after approximately 250 BV. Sulfate concentrations were below the detectable level throughout the service run.   The total V breakthrough curves also showed initial leakage, with more severe leakage observed at Tank B. Total U and Mo levels were below the respective method detection limits throughout the service run.

4.5.3   Regeneration Studies and Residual Sampling

4.5.3.1   Regeneration Study 1 (July 30, 2005). Figure 4-20 presents the specific gravity and conductivity of the discharge water during the Tank B regeneration on July 30, 2005. Specific gravity of the eluent from Tank B increased rapidly as the brine solution was drawn into the vessel, leveled off, and then decreased rapidly a few minutes after the commencement of the slow rinse step. Specific gravity measured the percent concentration of salt in the brine solution. It was verified that the brine solution entering Tank B had a specific gravity of 1.06, corresponding to 8% of salt. Because neither the brine draw flow nor the day tank usage was monitored during this study, the salt consumption could not be
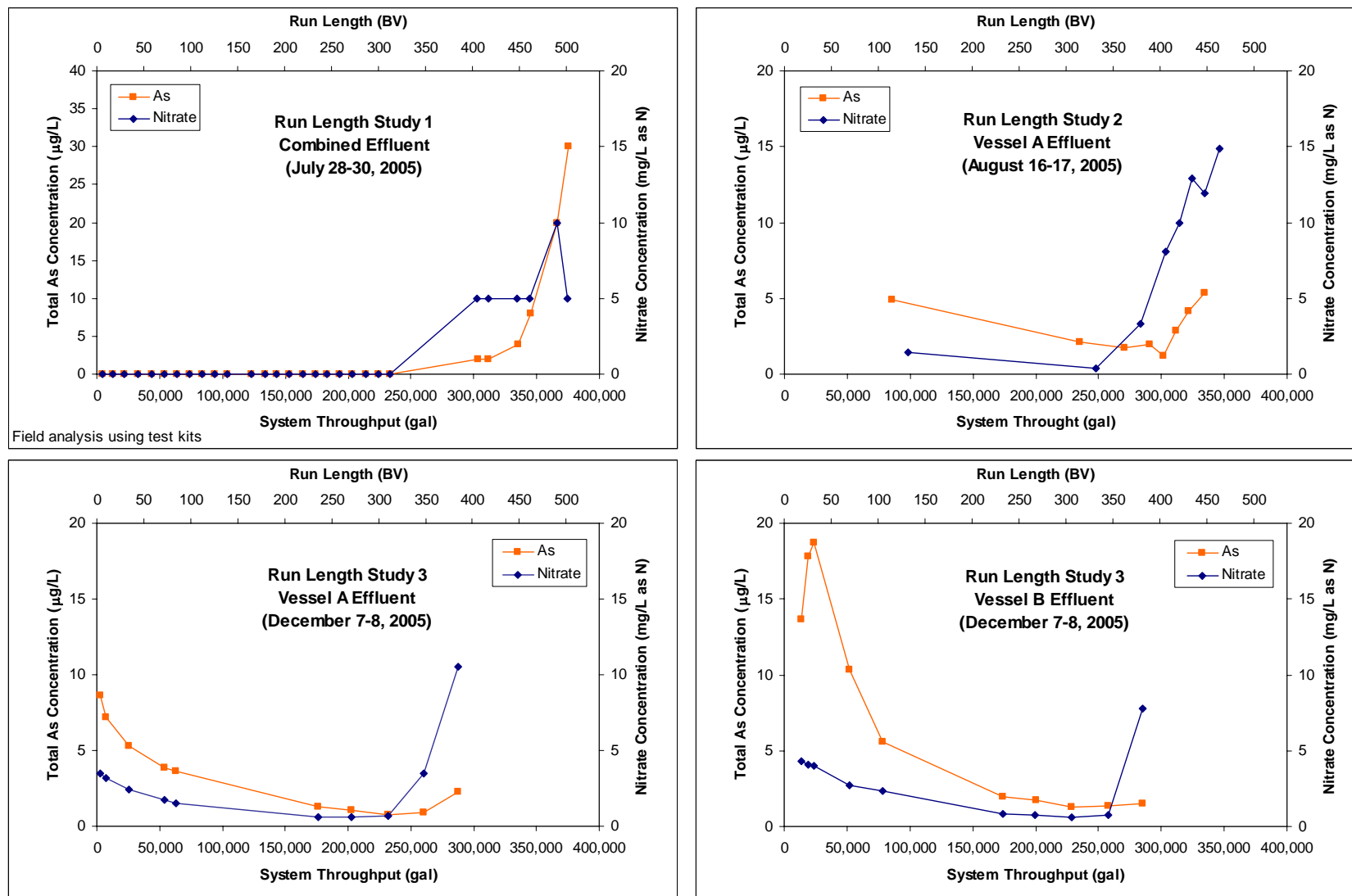
Figure 4-18. Total Arsenic and Nitrate Breakthrough Curves from Run Length Studies
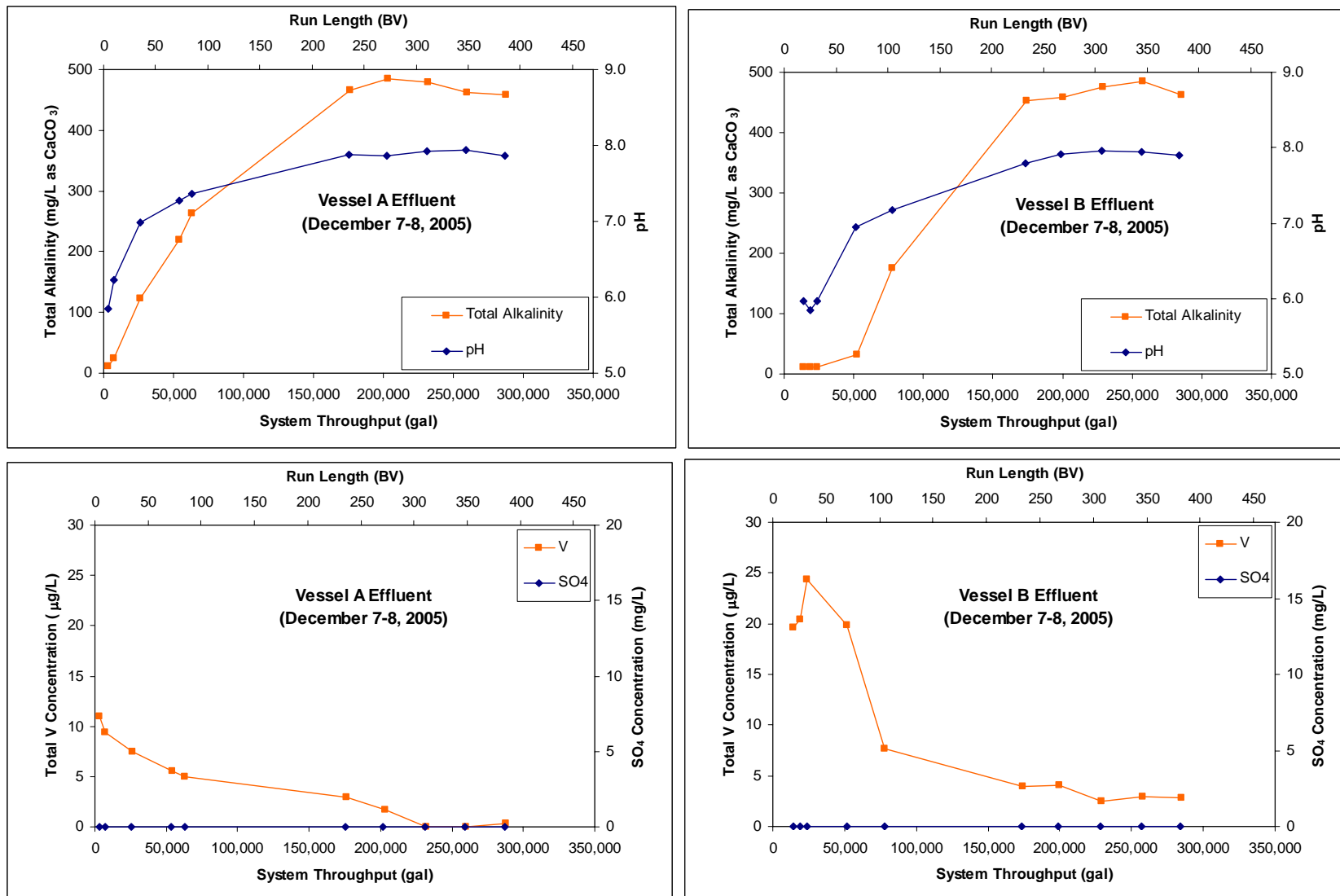
Figure 4-19. Total Alkalinity, pH, Sulfate, and Vanadium Breakthrough Curves from Run Length Study 3 (December 7 through 8, 2005)

Vessel B Regeneration (07/30/05)
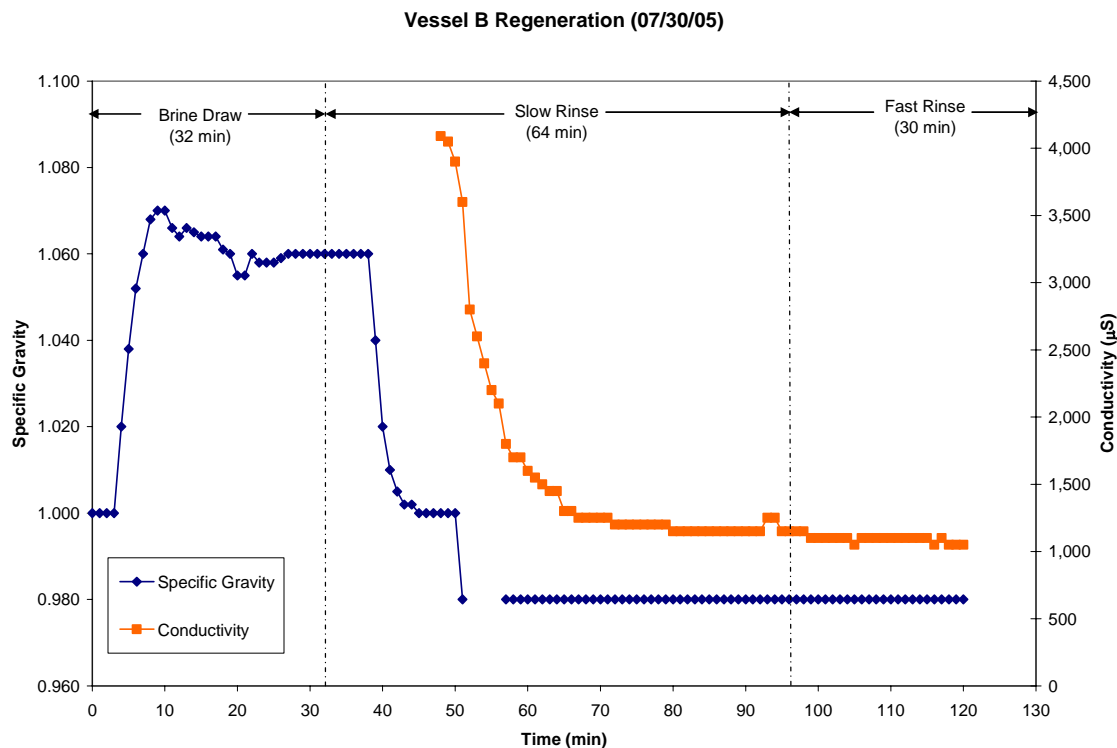
Source: Kinetico

Figure 4-20. Tank B Regeneration Curve

verified. Conductivity of the eluent exceeded the meter range during the brine draw, dropped rapidly during the slow rinse, and then leveled off at about 1,200 µs after about 65 min into the regeneration. The data suggested that the slow rinse and fast rinse time could be significantly reduced to minimize the volume of water used and wastewater generated. While the slow rinse time was unchanged, the fast rinse time was adjusted to 6 min on September 19, 2005.

4.5.3.2   *Regeneration Study 2 (September 22, 2005)*

Regeneration Curves. Figures 4-21 and 4-22 present the concentrations of total arsenic, nitrate, sulfate, TDS, and pH in the eluent from the regeneration of both Tanks A and B on September 22, 2005. These regeneration curves were typical of an IX system and similar to those observed previously (Wang et al., 2002). The TDS concentration was indicative of the salt concentration in the eluent. As the 8% of salt solution was drawn into the tank, the arsenic, nitrate, and sulfate on the exhausted resin were displaced by the highly concentrated chloride ions into the eluent. The highest concentrations of arsenic and sulfate were detected after 8 to 12 min into the regeneration, slightly earlier than nitrate. The highest concentrations measured were 14.9 mg/L of arsenic, 2.3 g/L of nitrate (as N), and 51 g/L of sulfate for Tank A, and 18.9 mg/L of arsenic, 2.2 g/L of nitrate (as N), and 49 g/L of sulfate for Tank B. While the nitrate concentration dropped to below 10 mg/L towards the end of fast rinse, the arsenic concentration was still around 35 µg/L. Therefore, it was not surprising to detect over 10-µg/L arsenic leakage during the early stage of the subsequent service run. Extending the fast rinse time to 15 min on December 5, 2005, did not appear to resolve the problem because the arsenic leakage continued as much as 52,000 gal (or 70 BV), approximately 3 to 4 hr into the service run.

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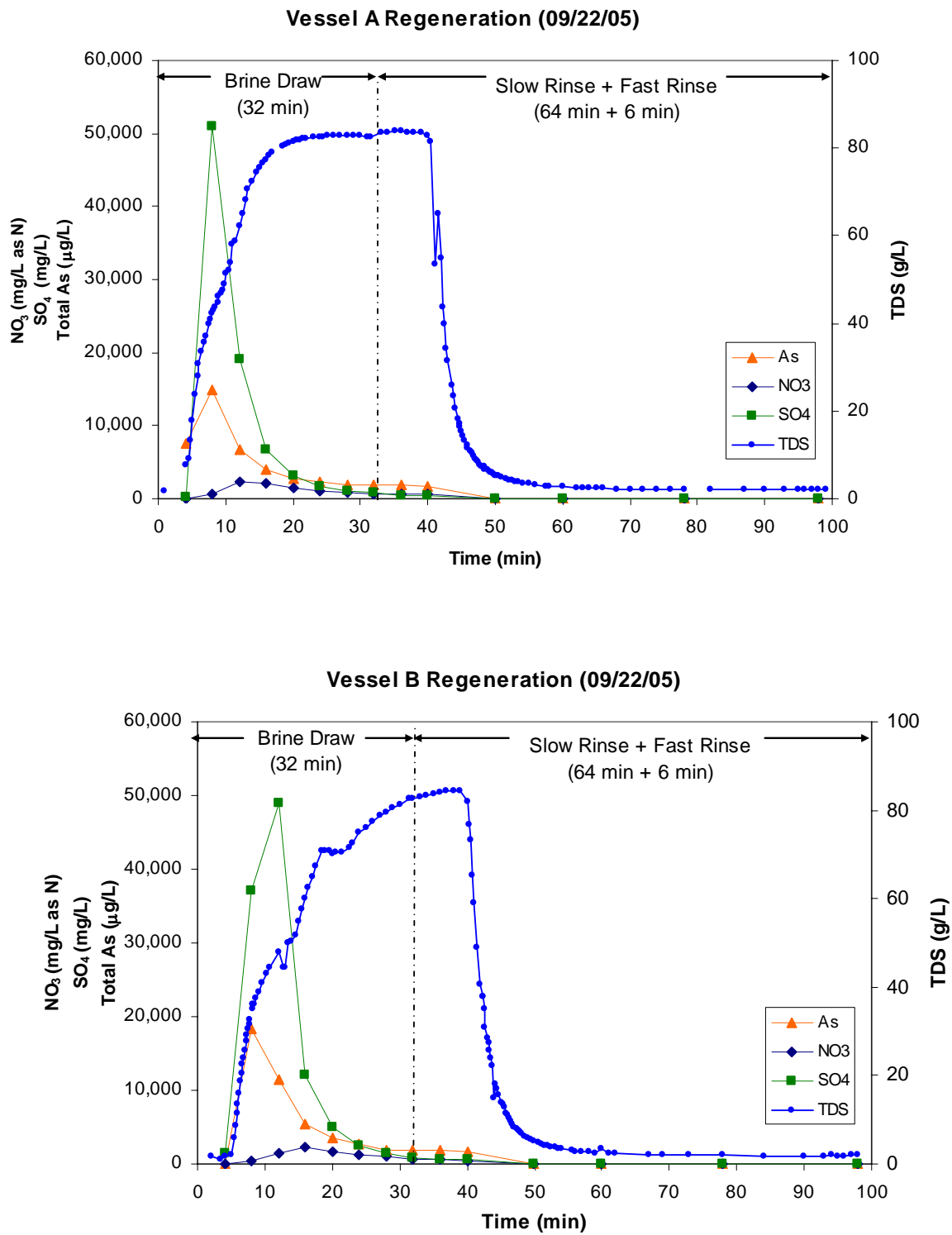
Figure 4-21. Tanks A and B Regeneration Curves of Arsenic, Nitrate, and Sulfate
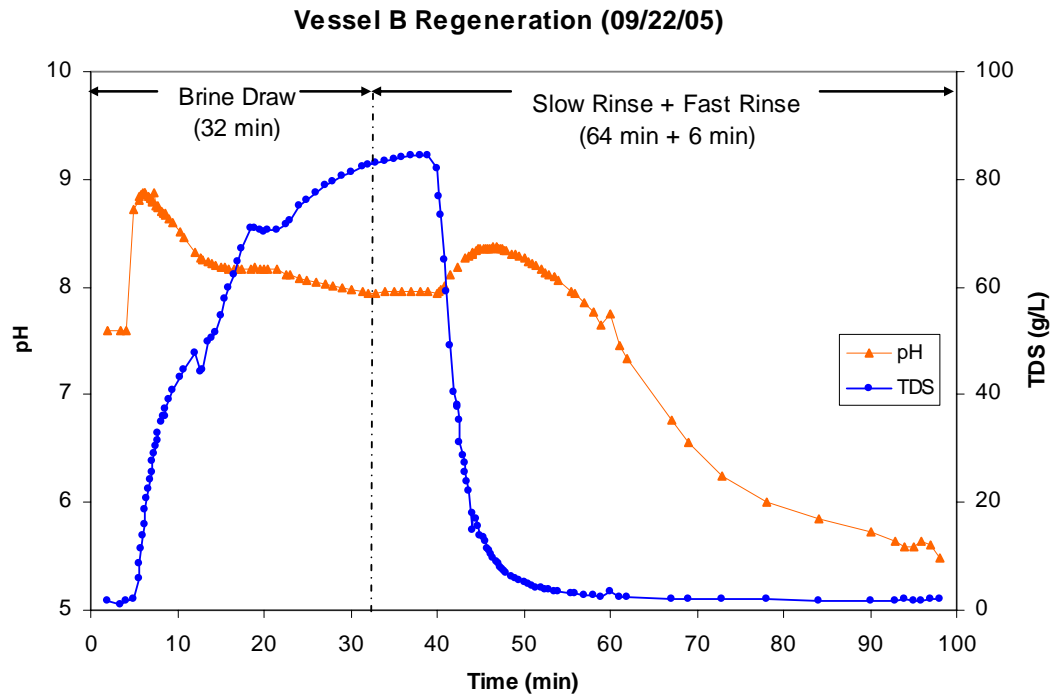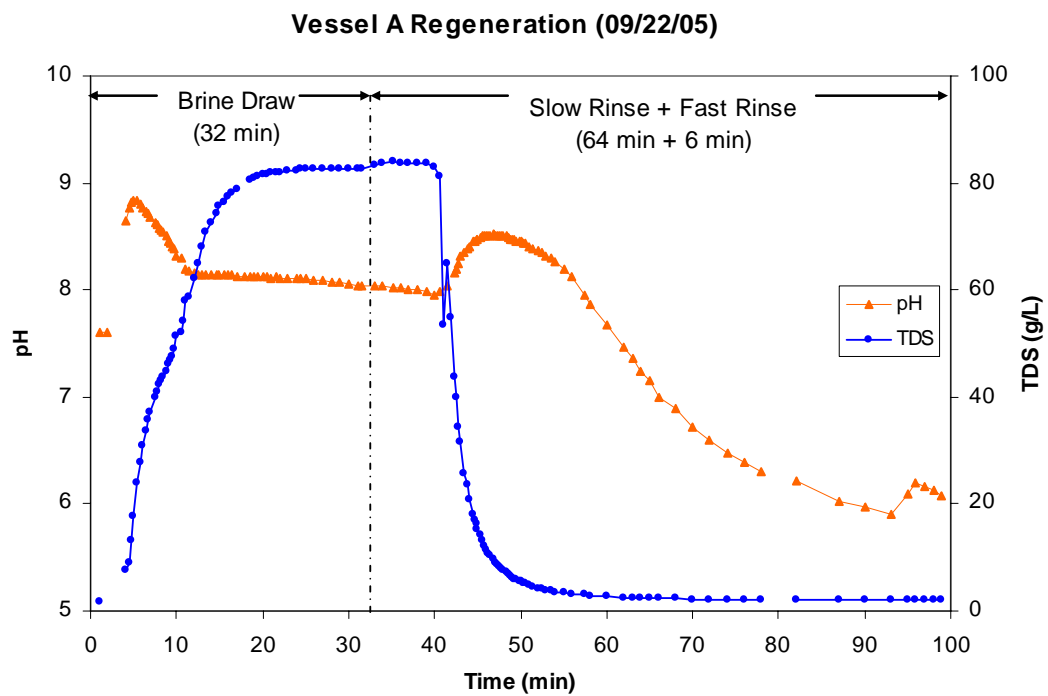
Figure 4-22. Tanks A and B Regeneration Curves of TDS and pH

As shown in Figure 4-22, the pH value of the eluent was close to neutral (i.e., 7.5) at the beginning of the regeneration cycle but rapidly rose to close to 9.0 during the brine draw, presumably due to the release of bicarbonate ions from the resin. The pH value dropped to between 5.5 to 6.0 by the end of fast rinse due to removal of bicarbonates by the freshly regenerated resin. This is consistent with that observed in the above-mentioned run length studies and the treatment plant sampling during the six-month operation period.

Regeneration Flowrate. As part of the September 22, 2005 regeneration study, regeneration flowrates were monitored during the regeneration of each tank and plotted in Figure 4-23. Due to concerns over the accuracy of the flowrate readings from a floater-type rotameter installed on the waste discharge line, readings of the totalizer located upstream of the Venturi eductor also were recorded every 1 to 2 min for flowrate calculations. Because the totalizer did not register the volume of the saturated brine drawn by the eductor, the brine draw flowrates shown in Figure 4-23 were lower than the actual values. For Tank A, flowrates varied from 22 to 29 gpm for brine draw, 22 to 28 gpm for slow rinse, and 56 to 75 gpm for fast rinse. As a result, a total of 802, 1,519, and 383 gal of wastewater was produced from each step, corresponding to an average flowrate of 25, 24, and 64 gpm, respectively. Adding the volume of the saturated brine (i.e., 360 gal), the average flowrate for brine draw would be 36 gpm, about 56% higher than the design value of 23 gpm.
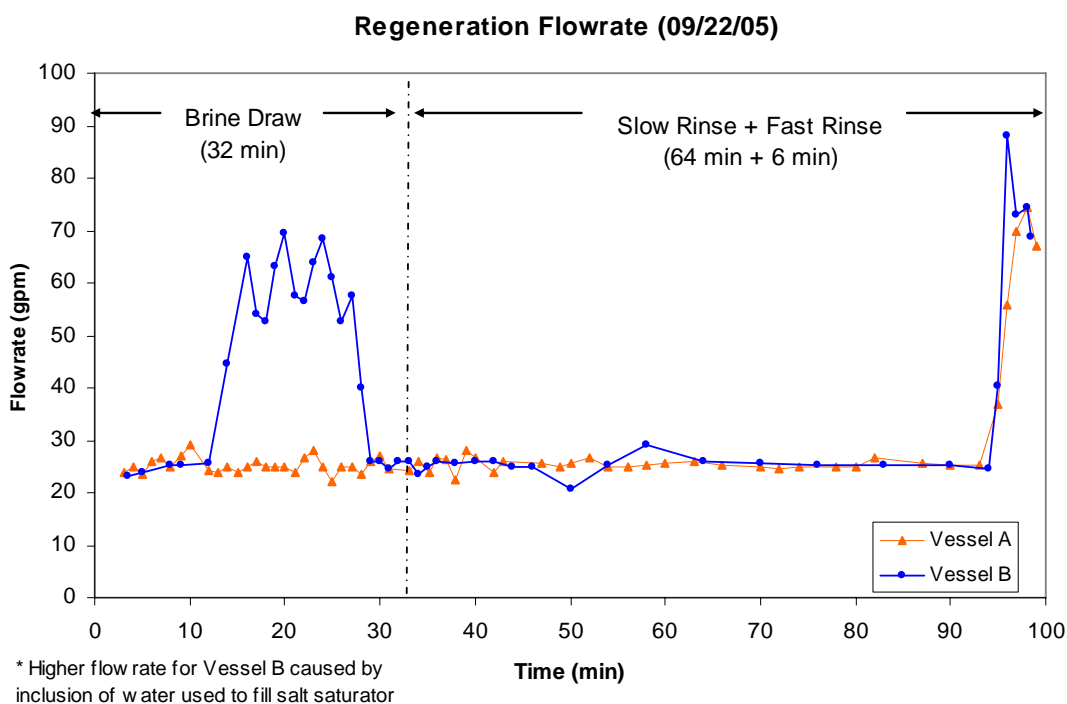
Figure 4-23. Regeneration Flowrate

For Tank B, the flowrates were similar to those of Tank A except for the brine draw. A total of 1,340, 1,542, and 359 gal of water was used, corresponding to an average flowrate of 42, 24, and 60 gpm, respectively. The higher brine draw flowrates for Tank B were caused inadvertently by the chain of events described below. The low-level sensor in the brine day tank was triggered during the Tank B regeneration so that the brine transfer pump was turned on to transfer brine from the salt saturator to refill the day tank. Meanwhile, the level sensor in the salt saturator also reached a low level so that it called for water to make up more brine solution. The water filling the salt saturator was registered on the same

totalizer used for flowrate measurements, causing the seemly higher water usage and flowrates during the Tank B regeneration.

Saturated Brine Usage. As shown in Table 4-8, approximately 360 gal of saturated brine (i.e., 730 lb of salt) was used for Tank A regeneration, equivalent to 14.6 lb of salt/ft^3 of resin. This regeneration level was 46% higher than the designed value of 10 lb of salt/ft^3 of resin. For a throughput setpoint of 316,000 gal, the salt use is 4.6 lb/1,000 gal of water treated. The brine usage was not recorded for Tank B because the day tank was refilled automatically in the middle of the brine draw. Although the 600-gal day tank was sized to supply 500 gal of brine for regeneration of both tanks, it had to be refilled in the middle of the brine draw due to the higher usage. To track the brine usage by each tank, the day tank was refilled manually prior to the regeneration of each tank and the data are discussed in Section 4.4.2.3. To reduce the salt usage to close to the design level of 10 lb/ft^3, the brine draw time was shortened from 32 min to 25 min with the brine draw flowrate remaining unchanged on December 5, 2005. This modification would achieve a 22% reduction in salt usage as discussed in Section 4.4.2.

4.5.3.3   *Residual Sampling.* Composite samples were collected from both tanks from each regeneration step (i.e., brine draw, slow rinse, and fast rinse) on September 22 and November 15, 2005. Analytical results of total arsenic, nitrate, and sulfate are included in Table 4-14. As expected, the majority of arsenic, nitrate, and sulfate was eluted from the tanks during brine draw, with average concentrations from both tanks at 6,048 μg/L, 990 mg/L, and 9,150 mg/L, respectively, for the September 22, 2005 event; and 3,480 μg/L, 1,420 mg/L, and 5,900 mg/L, respectively, for the November 15, 2005 event. These concentrations and the respective volumes of the waste stream were used to calculate the mass of arsenic, nitrate, and sulfate recovered from the regeneration, as shown in Table 4-14. It was estimated that 56.0 g of total arsenic, 9.7 kg of nitrate, and 81.9 kg of sulfate were recovered and discharged to the sewer in the September 22, 2005 event and 31.0 g of total arsenic, 12.6 kg of nitrate, and 51.1 kg of sulfate in the November 15, 2005 event. Assuming 6,100 and 6,650 gal of wastewater were produced for the two events (see Table 4-8), the average concentrations of arsenic, nitrate, and sulfate in the waste stream would be 2.4 mg/L, 0.42 g/L, and 3.55 g/L, respectively, for the September 22, 2005 event, and 1.2 mg/L, 0.5 g/L, and 2.03 g/L, respectively, for the November 15, 2005 event.

The percent recovery of arsenic, nitrate, and sulfate from regeneration was calculated using Equation (3):

$$\%R = M_{recovered} / M_{removed} \times 100\% \qquad\qquad (3)$$

> where:
> $\%R = percent\ recovery$
> $M_{recovered} = mass\ of\ arsenic,\ nitrate,\ or\ sulfate\ in\ regenerant\ waste\ (mg\ or\ g)$
> $M_{removed} = mass\ of\ arsenic,\ nitrate,\ or\ sulfate\ removed\ from\ raw\ water\ (mg\ or\ g)$

As shown in Table 4-14, the percent recoveries were 114 and 63% for arsenic, 99 and 130% for nitrate, and 118 and 74% for sulfate, for the two sampling events, respectively. The percent recovery for an IX system was reported to be 85% to100% in the literature (Clifford, 1999). More data are being collected at Fruitland to further evaluate the regeneration efficiency of the IX system.

4.5.4   **Distribution System Water Sampling**. The results of the distribution system sampling are summarized in Table 4-15. The stagnation times for the first draw samples ranged from 5.8 to 12.5 hr, which met the requirements by the EPA LCR sampling protocol (EPA, 2002).

During the baseline sampling period from December 2003 to March 2004, the old Well No. 6 was not in service due to its higher-than-MCL nitrate concentration and the distribution system was supplied by other wells. Well No. 6-2004 was drilled in May 2004 and put online with the IX treatment system in

Table 4-14. Mass Balance Calculations for Total Arsenic, Nitrate, and Sulfate

Parameter	Unit	09/22/05			11/15/05		
Volume of Water Treated	gal	316,000			314,000		
		Tank A	Tank B	Total	Tank A	Tank B	Total
		Arsenic Mass Balance					
Concentration in Composite Brine Draw	µg/L	6,014	6,082	6,048[a]	2,602	4,358	3,480[a]
Concentration in Composite Slow Rinse	µg/L	293	271	282[a]	62.3	61.1	61.7[a]
Concentration in Composite Fast Rinse	µg/L	35.0	35.7	35.4[a]	32.9	35.0	33.9[a]
Brine Draw Volume	gal	1,149	1,149	2,298	1,258	1,070	2,328
Slow Rinse Volume	gal	1,519	1,542	3,061	1,900	1,600	3,500
Fast Rinse Volume	gal	383	359	742	400	400	800
Mass Recovered from Brine Draw	mg	26,155	26,450	52,605	12,390	17,650	30,039
Mass Recovered from Slow Rinse	mg	1,685	1,582	3,266	448	370	818
Mass Recovered from Fast Rinse	mg	51	49	99	50	53	103
Total Mass Recovered in Regeneration Waste	mg	27,890	28,081	55,971	12,887	18,073	30,960
Mass Removed from Raw Water[b]	mg			49,278			48,966
Percent Recovery	**%**			**114**			**63**
		Nitrate Mass Balance					
Concentration in Composite Brine Draw	mg/L	1,020	961	990[a]	1,230	1,610	1,420[a]
Concentration in Composite Slow Rinse	mg/L	80.4	99.8	90.1[a]	22	16.8	19.4[a]
Concentration in Composite Fast Rinse	mg/L	2.9	3.2	3.1[a]	4.4	3.4	3.9[a]
Brine Draw Volume	gal	1,149	1,149	2,298	1,258	1,070	2,328
Slow Rinse Volume	gal	1,519	1,542	3,061	1,900	1,600	3,500
Fast Rinse Volume	gal	383	359	742	400	400	800
Mass Recovered from Brine Draw	g	4,436	4,179	8,615	5,857	6,520	12,377
Mass Recovered from Slow Rinse	g	462	582	1,045	158	102	260
Mass Recovered from Fast Rinse	g	4	4	9	7	5	12
Total Mass Recovered in Regeneration Waste	g	4,902	4,766	9,669	6,022	6,627	12,649
Mass Removed from Raw Water[b]	g			9,772			9,710
Percent Recovery	**%**			**99**			**130**
		Sulfate Mass Balance					
Concentration in Composite Brine Draw	mg/L	9,200	9,100	9,150[a]	4,300	7,500	5,900[a]
Concentration in Composite Slow Rinse	mg/L	318	81	199[a]	26	12.7	19.4[a]
Concentration in Composite Fast Rinse	mg/L	3.6	1.1	2.4[a]	4.7	<1	2.6[a]
Brine Draw Volume	gal	1,149	1,149	2,298	1,258	1,070	2,328
Slow Rinse Volume	gal	1,519	1,542	3,061	1,900	1,600	3,500
Fast Rinse Volume	gal	383	359	742	400	400	800
Mass Recovered from Brine Draw	g	40,010	39,576	79,586	20,475	30,375	50,849
Mass Recovered from Slow Rinse	g	1,828	473	2,301	187	77	264
Mass Recovered from Fast Rinse	g	5	1	7	7	1	8
Total Mass Recovered in Regeneration Waste	g	41,844	40,050	81,894	20,669	30,452	51,121
Mass Removed from Raw Water[b]	g			69,371			68,932
Percent Recovery	**%**			**118**			**74**

(a) Average of two tanks.
(b) Calculated using average concentrations in raw and treated water.

Table 4-15. Summary of Distribution System Sampling Results for City of Fruitland

ID		DS1 Non-Residence — 1st Draw									DS1 Flushed(a)								DS2 Non-Residence — 1st Draw									DS2 Flushed(a)								DS3 Non-LCR Residence — 1st Draw								
No. Events	Sampling Date	Stag. Time (hr)	pH	Alkalinity	As	Fe	Mn	Pb	Cu	NO3	pH	Alkalinity	As	Fe	Mn	Pb	Cu	NO3	Stag. Time (hr)	pH	Alkalinity	As	Fe	Mn	Pb	Cu	NO3	pH	Alkalinity	As	Fe	Mn	Pb	Cu	NO3	Stag. Time (hr)	pH	Alkalinity	As	Fe	Mn	Pb	Cu	NO3
BL1	12/08/03	NA	7.7	264	46.1	<25	1.1	9.5	159	6.9	NS	NS	NS	NS	NS	NS	NS	NS	NA	7.7	252	52.3	<25	0.9	2.3	90.9	5.5	NS	NS	NS	NS	NS	NS	NS	NS	7.5	7.8	246	45.9	<25	<0.1	0.3	86.2	4.6
BL2	01/06/04	NA	7.3	292	55.8	<25	1.0	10.4	148	7.4	7.6	304	58.4	<25	0.2	5.6	101	7.9	NA	7.7	280	59.1	<25	2.7	25.5	330	7.4	7.7	292	58.4	<25	0.1	1.1	75.1	7.8	8.0	7.8	280	58.5	<25	0.6	0.7	178	7.4
BL3	02/02/04	NA	7.4	258	61.0	198	0.5	10.9	44.9	7.9	7.7	242	63.9	<25	0.2	4.1	86.0	7.7	8.0	7.7	248	59.0	54	0.6	2.4	299	7.9	7.7	256	56.6	41	0.3	0.3	22.0	7.7	7.0	7.7	200	43.9	26	0.5	0.8	122	5.7
BL4	03/02/04	10.3	7.6	279	66.2	<25	1.1	6.7	108	8.9	7.6	288	75.4	<25	0.2	2.9	71.2	6.7	11.5	7.6	283	66.8	<25	6.2	2.8	203	9.9	7.6	288	75.4	<25	0.3	0.7	46.7	6.9	5.8	7.6	288	73.7	<25	0.2	0.2	237	7.9
Average				273	57.3		0.9	9.4	115	7.8		278	65.9		0.2	4.2	85.9	7.4			266	59.3		2.6	8.3	231	7.7		279	63.5		0.2	0.7	47.9	7.5			254	55.5		0.4	0.5	156	6.4
1	06/29/05	10.8	7.6	383	39.9	<25	13.2	0.8	21.3	NA	7.5	387	40.0	<25	11.5	2.6	10.7	NA	10.3	7.5	361	37.6	<25	7.8	2.8	330	NA	7.5	396	41.6	<25	9.4	0.4	22.1	NA	9.0	7.5	387	42.6	<25	11.6	0.5	188	NA
2	08/03/05	9.7	7.4	374	44.0	<25	22.4	1.0	22.5	NA	7.4	440	25.3	<25	21.1	2.9	36.9	NA	10.3	7.6	378	43.5	<25	14.5	0.6	15.6	NA	7.6	396	45.8	<25	15.0	1.2	22.9	NA	9.5	7.5	378	42.9	<25	20.9	0.4	25.5	NA
3	08/24/05	NA	7.5	427	2.7	<25	19.1	0.6	9.7	NA	7.7	458	2.1	<25	19.7	0.4	8.1	NA	10.0	7.7	422	11.8	<25	11.8	0.3	6.9	NA	7.6	449	9.4	<25	13.2	0.4	7.7	NA	NA	7.7	427	2.0	<25	19.7	0.2	24.4	NA
4	09/21/05	NA	7.6	396	1.1	<25	22.8	0.3	11.5	NA	7.4	392	2.4	<25	25.3	1.2	44.0	NA	10.0	7.4	396	2.7	<25	12.9	0.7	20.9	NA	7.4	374	3.0	<25	11.0	0.9	44.3	NA	NA	7.4	392	2.7	<25	22.1	0.6	86.3	NA
5	10/26/05	NA	7.7	440	4.0	<25	19.1	1.5	22.0	NA	7.7	431	2.4	<25	17.6	0.8	16.6	NA	12.5	7.6	462	3.6	<25	11.6	0.6	14.0	NA	7.7	444	3.7	<25	11.4	0.5	8.2	NA	NA	7.7	264	17.7	<25	2.3	0.1	37.6	NA
6	11/30/05	12.5	7.9	431	2.8	<25	17.8	0.5	33.1	NA	7.6	440	4.9	<25	18.5	0.6	31.3	NA	12.0	7.6	308	16.3	<25	7.2	0.68	119	NA	7.7	308	18.7	<25	6.4	0.3	148	NA	12.3	7.7	427	3.3	<25	15.6	0.1	24.1	NA
7	12/15/05	NA	7.8	462	5.6	<25	23.0	0.5	15.6	<0.05	7.4	330	5.9	<25	17.8	0.7	40.8	1.5	NA	7.4	290	6.4	<25	10.3	0.1	10.6	1.7	7.5	180	6.7	<25	6.4	2.4	143	4.0	NA	7.4	312	4.7	<25	16.9	<0.1	41.2	1.6
Average				416	3.2		19.6	0.8	19.4			411	3.5			1.3	26.9	1.5			374	8.1		10.9	0.8	73.9			364	8.3		10.4	0.9	56.6				370	6.1		15.6	0.3	61.0	

(a) Stagnation times not available for flushed samples.

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

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

µg/L as unit for all analytical parameters except for pH (S.U.) and alkalinity (mg/L as $CaCO_3$).

June 2005. Since then, the monthly distribution sampling resumed at the same locations to evalute any impacts of the treatment system on the distribution water quality. However, due to the use of a new well, different water quality of the supply wells also could be a contributing factor. For example, the average concentrations of nitrate, alkanility, and total Mn were lower in the baseline samples than those measured at inlet to the IX system (Tables 4-12 and 13), i.e., 7.4 mg/L (as N), 278 mg/L (as $CaCO_3$), and 0.2 μg/L in the baseline flushed samples vs. 9.5 mg/L (as N), 386 mg/L (as $CaCO_3$), and 23 μg/L in the well samples. In addition, the average concentration of total As was higher (i.e., 65 μg/L) in the baseline samples vs. 42 μg/L in the well samples.

During the six-month operation period, the arsenic levels in the distribution sytem were significantly reduced to below the MCL when the IX system operated normally. Higher-than-MCL concentrations were measured during the first two sampling events (June 29 and August 3, 2005) when the system experienced operational problems. The November 30, 2005, arsenic data were below 10 μg/L at DS1 and DS3 locations, reflecting the low arsenic concentration in the plant effluent. However, the DS2 samples contained 16.3 and 18.7 μg/L of arsenic in the first draw and flushed samples, respectively. It was unclear if it was due to a sampling error or if the DS2 location received water from other sources at the time of sampling. Nitrate was only analyzed on the Decemer 15, 2005, samples, which showed <0.05 to 4.0 mg/L of nitrate (as N).

No significant changes in the pH values were observed in the distribution samples. The pH values ranged from 7.3 to 7.7 in the baseline samples and 7.4 to 7.9 after the system was placed online. On two occasions when the plant effluent had a pH value below 7 (i.e., pH 6.0 on July 6 and pH 6.8 on August 31, 2005), distribution samples were not collected. Therefore, there was lack of evidence on whether the low pH water produced by the freshly regenerated resin would impact the the pH in the distribution system. Alkalinity levels ranged from 200 to 304 mg/L and averaged 270 mg/L (as $CaCO_3$) in the baseline samples. After the system was in place, they ranged from 264 to 462 mg/L (as $CaCO_3$) with an average of 387 mg/L (as $CaCO_3$). This higher alkalinity was likely attibuted to the different water quality of the supply wells as discussed above. The freshly regenerated IX system would reduce the alkalinity for a short period of time due to exchange of bicarbonates onto the resin. Unfortunately, no distribution samples were taken at the time when the abnormally low alkalinity occurred in the plant effluent on July 6, August 10, and August 31, 2005.

Reduction in lead and copper levels was observed in the first draw samples at DS1 and DS2 locations. For example, previously, the average lead concentrations were 9.4, 8.3, and 0.5 μg/L in the first draw samples at DS1, DS2, and DS3, respectively; they were reduced to 0.8, 0.8, and 0.3 μg/L afterwards. The average copper concentrations were 115, 231, and 156 μg/L in the baseline samples and reduced to 19, 74, and 61 μg/L afterwards. Therefore, the lead and copper levels in the distribution system appeared to be lowered by the operation of the IX system.

4.6   System Cost

The cost of the system was evaluated based on the capital cost per gpm (or gpd) of design capacity and the O&M cost per 1,000 gal of water treated. This required the tracking of the capital cost for the treatment equipment, engineering, and installation and the O&M cost for salt supply, electricity consumption, and labor. The cost associated with the new building, sanitary sewer connection, and other discharge-related infrastructure was not included in the capital cost because it was out of the scope of the demonstration project, and was funded separately by the City of Fruitland.

4.6.1   Capital Cost. The capital investment for the Fruitland IX system was $286,388, which included $173,195 for equipment, $35,619 for site engineering, and $77,574 for installation. Table 4-16

presents the cost breakdowns of the capital cost provided by the vendor. The equipment cost included the cost for the IX resin, filter skid, tanks, brine system, pre-filters, air compressor, instrumentation and controls, engineering subcontractor, labor, and system warranty. The system warranty covered repairs and/or replacement of any equipment or installation workmanship for a period of 12 months after system startup. The equipment cost was 61% of the total capital investment.

Table 4-16. Cost Breakdowns of Capital Investment for Fruitland IX System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Cost			
IX Resin, Filter Skid, and Vessels	1	$63,673	–
Brine System	1	$35,388	
Pre-treatment Filters	1	$3,540	
Air Compressor	1	$1,295	–
Instrumentation & Controls	1	$11,524	–
Engineering Subcontractor	1	$8,000	–
Labor	–	$32,870	–
Warranty	–	$16,905	–
Equipment Total	–	**$173,195**	**61%**
Engineering Cost			
Labor	–	$35,619	–
Engineering Total	–	**$35,619**	**12%**
Installation Cost			
Labor	–	$11,524	–
Travel	–	$4,095	–
Subcontractor	–	$61,955	–
Installation Total	–	**$77,574**	**27%**
Total Capital Investment	–	**$286,388**	**100%**

The site engineering cost included the cost for preparing a process design report and the required engineering plans, including a general arrangement drawing, P&IDs, inter-connecting piping layouts, tank fill details, a schematic of the PLC panel, an electrical on-line diagram, and other associated drawings. After being certified and stamped by an Idaho-registered professional engineer (PE), the plans were submitted to IDEQ for permit review and approval. The engineering cost was 12% of the total capital investment.

The installation cost included the cost for labor and materials for system unloading and anchoring, plumbing, and mechanical and electrical connections (see Section 4.3). The installation cost was 27% of the total capital investment.

The total capital cost of $286,388 was normalized to the system's rated capacity of 250 gpm (360,000 gpd), which resulted in $1,146 per gpm ($0.80 per gpd). The capital cost also was converted to an annualized cost of $27,032/yr using a capital recovery factor of 0.09439 based on a 7% interest rate and a 20-year return. Assuming that the system operated 24 hr/day, 7 day/wk at the design flowrate of 250 gpm to produce 131 million gal of water per year, the unit capital cost would be $0.21/1,000 gal. In fact, the system operated an average of 22 hr/day at 165 gpm (see Table 4-6), producing 35.9 million gal of water during the six-month period. At this reduced rate of operation, the unit capital cost increased to $0.38/1,000 gal.

The City of Fruitland constructed an addition to their existing pump house to house the IX system. The 17-ft tall addition covered 360 ft^2 of floor space with a wood frame and steel siding and roofing, and a roll-up door. The total cost for the material and electrical was approximately $18,000.

4.6.2   Operation and Maintenance Cost. The O&M cost included primarily the cost associated with salt supply, electricity consumption, and labor, as summarized in Table 4-17. Morton solar salt was used to prepare brine solution for the resin regeneration. Over the six-month period, a total of 172,390 lb of salt was consumed to treat 35,946,000 gal of water. The salt delivery charge totaled $18,313 for the same period which included fuel surcharges of $50 per delivery starting October 2005. The average salt use was 4.80 lb/1,000 gal, which corresponded to a salt cost of $0.51/1,000 gal (Table 4-17). However, this higher-than-expected salt usage was caused by improper flow control of the brine draw as discussed in Section 4.4.2. If the target salt usage of 3.16 lb/1,000 gal were achieved, the salt cost would have been reduced to $0.35/1,000 gal. Incremental electricity consumption associated with the IX system was not available, but assumed to be minimal. The actual power usage for operating the entire plant was obtained from utility bills and used to estimate the electricity cost at $0.08/1,000 gal of water treated. The routine, non-demonstration related labor activities consumed about 30 min/day, as noted in Section 4.4.4. Based on this time commitment and a labor rate of $21/hr, the labor cost was estimated at $0.04/1,000 gal of water treated. In sum, the total O&M cost was approximately $0.63/1,000 gal based on the actual salt usage and $0.47/1,000 gal based on the target salt usage.

Table 4-17. O&M Cost for Fruitland, ID Treatment System

Cost Category	Value	Assumptions
Volume Processed (1,000 gal)	35,946	From June 14 through December 16, 2005
Salt Usage		
Salt Unit Price ($/lb)	0.11	Unit price increased progressively from $0.095 to $0.10 and $0.11 per pound
Total Salt Usage (lb)	172,390	Quantity delivered and invoiced
Salt Use (lb/1,000 gal)	4.80	Based on actual salt usage
Total Salt Cost ($)	18,313	Based on total invoiced amounts, including fuel surcharges.
Unit Salt Use Cost ($/1,000 gal)	0.51	Based on target salt usage of 3.16 lb/1,000 gal, the salt cost would be $0.35/1,000 gal
Electricity Consumption		
Power Use ($/1,000 gal)	0.08	Based on utility bills for entire treatment plant.
Labor		
Average Weekly Labor Hours (hr)	2.5	30 min/day; 5 day/wk
Total Labor Hours (hr)	72	Including 1 hr for replacing bag filters each time for 5 times
Total Labor Cost ($)	1,512	Labor rate = $21/hr
Labor Cost ($/1,000 gal)	0.04	
Total O&M Cost ($/1,000 gal)	**0.63**	

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APPENDIX A

OPERATIONAL DATA

US EPA Arsenic Demonstration Project at Fruitland, ID – Daily System Operation and Operation Labor Log Sheet

		Pump House				Product Water Flow Meter			System Pressures				Regeneration		
	Date	Opt. Hours	Cum. Hours	Master Flow Meter	Treated Volume	Product Water Flowrate	Product Water Flow Totalizer	BV Treated	Combined System Inlet Pressure (IN)	Tank A Outlet Pressure (TA)	Tank B Outlet Pressure (TB)	Product Water Pressure (TT)	Regen. Counter	Salt Delivered	Cumulative Salt Delivered
		hr	hr	kgal	kgal	gpm	kgal	BV	psig	psig	psig	psig		lb	lb
1	06/14/05	NA	NA	80,712	NA	130	111	0	74	65	62	44	NA		
	06/15/05	22.4	22.4	80,866	154	144	37	0	72	64	62	44	NA		
	06/16/05	24.2	46.6	81,067	201	73	NA	NA	84	78	In Regen	42	NA	3,945	3,945
	06/17/05	15.5	62.1	81,197	130	142	122	0	73	68	65	46	NA		
2	06/20/05	56.4	118.5	81,666	469	142	341	0	64	62	70	44	NA		
	06/21/05	22.0	140.5	81,838	172	142	100	0	65	62	70	44	NA		
	06/22/05	21.1	161.6	82,031	193	170	58	0	52	52	62	46	NA		
	06/23/05	16.2	177.8	82,195	164	171	212	0	62	58	58	46	NA	3,950	7,895
3	06/27/05	88.1	265.9	83,028	833	167	98	0	63	55	56	45	NA		
	06/28/05	22.0	287.9	83,237	209	155	72	0	62	58	58	50	NA		
	06/29/05	8.4	296.3	83,315	78	156	147	0	64	56	58	48	NA		
	06/30/05	20.6	316.9	83,516	201	160	127	0	62	56	56	46	NA	5,000	12,895
	07/01/05	21.4	338.3	83,704	188	150	77	0	60	54	52	44	NA		
4	07/05/05	93.2	431.5	84,620	916	167	34	0	62	56	54	46	13		
	07/06/05	25.0	456.5	84,851	231	165	24	0	60	54	54	46	14		
	07/07/05	24.0	480.5	85,085	234	122	18	0	70	60	In Regen	40	15	8,860	21,755
	07/08/05	20.4	500.9	85,288	203	164	211	0	60	52	52	44	15		
5	07/11/05	66.0	566.9	85,908	620	163	109	0	60	54	54	46	18		
	07/12/05	23.9	590.8	86,144	236	168	99	0	60	50	50	46	19		
	07/13/05	23.1	613.9	86,386	242	170	94	0	60	48	48	45	20		
	07/14/05	24.3	638.2	86,632	246	170	94	0	60	48	48	44	21	6,470	28,225
	07/15/05	24.0	662.2	86,869	237	168	85	0	60	50	50	48	22		
6	07/18/05	72.0	734.2	87,594	725	164	70	0	60	50	48	42	25		
	07/19/05	23.5	757.7	87,830	236	167	62	0	60	50	48	44	26		
	07/20/05	23.5	781.2	88,067	237	169	52	0	60	50	50	48	27		
	07/21/05	23.7	804.9	88,307	240	167	47	0	60	50	50	48	28		
	07/22/05	23.7	828.6	88,545	238	167	43	0	58	50	50	48	29		

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	Date	Pump House				Product Water Flow Meter			System Pressures				Regeneration		
		Opt. Hours	Cum. Hours	Master Flow Meter	Treated Volume	Product Water Flowrate	Product Water Flow Totalizer	BV Treated	Combined System Inlet Pressure (IN)	Tank A Outlet Pressure (TA)	Tank B Outlet Pressure (TB)	Product Water Pressure (TT)	Regen. Counter	Salt Delivered	Cumulative Salt Delivered
		hr	hr	kgal	kgal	gpm	kgal	BV	psig	psig	psig	psig		lb	lb
7	07/25/05	69.5	898.1	89,225	680	129	2	0	66	50	In Regen	44	32	9,035	37,260
	07/26/05	23.2	921.3	89,454	229	127	218	0	66	In Regen	48	44	33		
	07/27/05	23.6	944.9	89,678	224	154	197	0	60	50	50	46	33		
	07/28/05	24.0	968.9	89,901	223	160	175	0	58	50	48	42	34	8,970	46,230
	07/29/05	49.9	1018.8	90,139	238	165	168	0	62	52	52	46	35		
8	08/01/05	42.8	1061.6	90,842	703	161	90	0	58	50	50	48	37		
	08/02/05	23.3	1084.9	91,077	235	159	314	0	58	50	50	46	37		
	08/03/05	23.2	1108.1	NM	NA	161	534	1	58	50	50	46	37		
	08/04/05	24.4	1132.5	91,543	466	163	124	0	58	50	50	46	38	3,985	50,215
	08/05/05	21.0	1153.5	91,760	217	155	332	0	58	50	50	46	38		
9	08/08/05	72.0	1225.5	92,387	627	138	232	0	52	50	50	42	40		
	08/09/05	23.8	1249.3	92,631	244	178	115	0	58	50	50	44	41		
	08/10/05	23.9	1273.2	92,882	251	138	4	0	68	50	In Regen	46	42		
	08/11/05	22.0	1295.2	93,111	229	168	223	0	58	50	50	46	42	5,485	55,700
	08/12/05	23.8	1319.0	93,349	238	163	103	0	58	50	50	46	43		
10	08/15/05	69.5	1388.5	93,984	635	109	7	0	62	50	In Regen	46	45		
	08/16/05	23.5	1412.0	94,223	239	175	234	0	60	50	50	46	45		
	08/17/05	24.4	1436.4	94,477	254	173	120	0	58	50	50	46	46		
	08/18/05	21.8	1458.2	94,699	222	133	336	0	70	In Regen	50	46	47	6,010	61,710
	08/19/05	23.7	1481.9	94,939	240	167	215	0	60	60	50	46	47		
11	08/22/05	68.9	1550.8	95,626	687	161	169	0	60	50	50	46	49		
	08/23/05	22.8	1573.6	95,846	220	161	37	0	60	50	50	46	50		
	08/24/05	23.3	1596.9	96,078	232	158	259	0	60	50	50	48	50		
	08/25/05	22.7	1619.6	96,294	216	162	117	0	60	50	50	46	51	3,205	64,915
	08/26/05	23.2	1642.8	96,520	226	158	332	0	58	50	50	48	51		
12	08/29/05	70.5	1713.3	97,179	659	147	258	0	58	50	50	46	53		
	08/30/05	22.7	1736.0	97,411	232	170	128	0	58	50	50	46	54		
	08/31/05	23.3	1759.3	97,652	241	139	5	0	70	50	In Regen	44	55		
	09/01/05	23.0	1782.3	97,893	241	170	237	0	58	50	50	46	55	8,425	73,340
	09/02/05	23.3	1805.6	98,131	238	169	114	0	58	50	50	46	56		
13	09/06/05	87.4	1893.0	99,035	904	170	274	0	58	50	50	48	58		
	09/07/05	23.1	1916.1	99,267	232	161	145	0	59	50	50	48	59		
	09/08/05	22.1	1938.2	99,487	220	130	3	0	68	50	In Regen	48	60	8,025	81,365
	09/09/05	21.5	1959.7	99,696	209	157	265	0	58	50	50	48	60	5,860	87,225

US EPA Arsenic Demonstration Project at Fruitland, ID – Daily System Operation and Operation Labor Log Sheet (Continued)

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	Date	Pump House				Product Water Flow Meter			System Pressures				Regeneration		
		Opt. Hours	Cum. Hours	Master Flow Meter	Treated Volume	Product Water Flowrate	Product Water Flow Totalizer	BV Treated	Combined System Inlet Pressure (IN)	Tank A Outlet Pressure (TA)	Tank B Outlet Pressure (TB)	Product Water Pressure (TT)	Regen. Counter	Salt Delivered	Cumulative Salt Delivered
		hr	hr	kgal	kgal	gpm	kgal	BV	psig	psig	psig	psig		lb	lb
	09/12/05	65.9	2025.6	100,303	607	140	81	0	54	50	50	46	62		
	09/13/05	22.9	2048.5	100,547	244	175	314	0	58	50	50	48	62		
14	09/14/05	18.7	2067.2	100,802	255	171	209	0	58	50	50	48	63	5,330	92,555
	09/15/05	27.8	2095.0	101,025	223	168	73	0	58	50	50	48	64		
	09/16/05	21.7	2116.7	101,255	230	165	294	0	58	50	50	48	64		
	09/19/05	61.9	2178.6	101,904	649	175	216	0	58	50	50	48	66		
	09/20/05	21.8	2200.4	102,129	225	170	106	0	58	50	50	48	67		
15	09/21/05	22.2	2222.6	102,356	227	170	130	0	58	50	50	48	68	6,050	98,605
	09/22/05	16.8	2239.4	102,534	178	170	300	0	58	50	50	48	68		
	09/23/05	22.3	2261.7	102,760	226	164	187	0	58	50	50	48	69		
	09/26/05	73.9	2335.6	103,511	751	170	264	0	58	50	50	48	71		
	09/27/05	24.3	2359.9	103,757	246	170	172	0	58	50	50	48	72		
16	09/28/05	14.3	2374.2	103,906	149	170	314	0	58	50	50	48	72		
	09/29/05	11.9	2386.1	104,018	112	170	94	0	58	50	50	48	73	7,240	105,845
	09/30/05	16.5	2402.6	104,193	175	174	261	0	58	49	49	46	73		
	10/03/05	51.4	2454.0	104,753	560	167	127	0	58	50	50	48	75		
	10/04/05	20.9	2474.9	104,943	190	125	NA	In Regen	68	In Regen	50	48	76		
17	10/05/05	18.8	2493.7	105,133	190	165	179	0	58	50	50	48	76	6,510	112,355
	10/06/05	24.1	2517.8	105,367	234	165	74	0	58	50	50	48	77		
	10/07/05	20.6	2538.4	105,566	199	147	262	0	58	50	50	48	77		
	10/11/05	69.7	2608.1	106,296	730	167	302	0	58	50	50	48	79		
	10/12/05	17.1	2625.2	106,475	179	173	143	0	58	50	50	48	80	6,020	118,375
18	10/13/05	14.0	2639.2	106,624	149	173	286	0	59	50	50	48	80		
	10/14/05	5.3	2644.5	106,678	54	179	11	0	58	48	48	48	80		
	10/17/05	39.3	2683.8	107,094	416	170	80	0	58	50	50	48	82		
	10/18/05	16.2	2700.0	107,264	170	169	244	0	59	50	50	48	82	6,040	124,415
19	10/19/05	14.8	2714.8	107,415	151	170	59	0	59	50	50	48	83		
	10/20/05	17.7	2732.5	107,630	215	170	239	0	59	50	50	48	83		
	10/21/05	4.0	2736.5	107,640	10	170	280	0	59	50	50	50	83		
	10/24/05	38.7	2775.2	108,050	410	145	108	0	68	50	In Regen	44	85	5,965	130,380
	10/25/05	18.4	2793.6	108,243	193	170	192	0	58	50	50	46	85		
20	10/26/05	21.3	2814.9	108,463	220	164	196	0	59	50	50	46	86		
	10/27/05	18.9	2833.8	108,661	198	173	58	0	60	50	50	46	87		
	10/28/05	18.2	2852.0	108,846	185	168	235	0	59	50	50	44	87		

US EPA Arsenic Demonstration Project at Fruitland, ID – Daily System Operation and Operation Labor Log Sheet (Continued)

A-4

	Date	Pump House Opt. Hours hr	Cum. Hours hr	Master Flow Meter kgal	Treated Volume kgal	Product Water Flowrate gpm	Product Water Flow Totalizer kgal	BV Treated BV	Combined System Inlet Pressure (IN) psig	Tank A Outlet Pressure (TA) psig	Tank B Outlet Pressure (TB) psig	Product Water Pressure (TT) psig	Regen. Counter	Salt Delivered lb	Cumulative Salt Delivered lb
	10/31/05	58.1	2910.1	109,445	599	165	148	0	58	50	50	44	89		
	11/01/05	22.2	2932.3	109,669	224	168	33	0	58	50	50	44	90		
21	11/02/05	22.0	2954.3	109,898	229	165	252	0	58	50	50	46	90	6,000	136,380
	11/03/05	20.4	2974.7	110,102	204	166	118	0	58	50	50	46	91		
	11/04/05	22.0	2996.7	110,323	221	138	NA	In Regen	68	In Regen	50	46	92		
	11/07/05	54.7	3051.4	110,881	558	168	203	0	67	50	50	49	93		
	11/08/05	18.8	3070.2	111,069	188	161	54	0	59	50	50	49	94		
22	11/09/05	17.7	3087.9	111,248	179	161	224	0	59	50	50	49	94	5,955	142,335
	11/10/05	7.8	3095.7	111,342	94	171	314	0	59	50	50	44	94		
	11/11/05	20.5	3116.2	111,537	195	170	178	0	58	50	50	46	95		
	11/14/05	37.5	3153.7	111,916	379	160	212	0	49	50	50	49	96		
	11/15/05	10.5	3164.2	112,024	108	161	314	0	49	50	50	44	96		
23	11/16/05	15.0	3179.2	112,169	145	160	125	0	49	50	50	46	97	5,975	148,310
	11/17/05	18.5	3197.7	112,350	181	163	302	0	58	50	50	48	97		
	11/18/05	15.7	3213.4	112,509	159	169	168	0	58	50	50	44	98		
	11/21/05	42.7	3256.1	112,935	426	160	199	0	58	50	50	49	99		
24	11/22/05	12.0	3268.1	113,102	167	160	30	0	58	50	50	49	100		
	11/23/05	21.8	3289.9	113,270	168	160	190	0	58	50	50	49	100	6,005	154,315
	11/28/05	62.1	3352.0	113,890	620	170	135	0	58	50	50	49	102		
25	11/29/05	17.3	3369.3	114,062	172	159	299	0	58	50	50	49	102		
	11/30/05	18.5	3387.8	114,241	179	158	103	0	58	50	50	49	103	5,965	160,280
	12/01/05	15.0	3402.8	114,388	147	159	283	0	58	50	50	49	103		
	12/05/05	64.1	3466.9	115,021	633	158	233	0	58	50	50	48	105		
	12/06/05	13.6	3480.5	115,151	130	168	32	0	58	50	50	49	106		
26	12/07/05	13.8	3494.3	115,287	136	167	102	0	58	50	50	48	107		
	12/08/05	23.3	3517.6	115,512	225	151	193	0	59	50	50	49	107	5,975	166,255
	12/09/05	22.9	3540.5	115,735	223	151	83	0	59	50	50	49	108		
	12/12/05	26.2	3566.7	115,989	254	128	NA	In Regen	59	In Regen	50	49	109		
	12/13/05	9.1	3575.8	116,078	89	158	85	0	59	50	50	49	109		
27	12/14/05	11.1	3586.9	116,188	110	160	190	0	59	50	50	49	109	6,135	172,390
	12/15/05	23.8	3610.7	116,418	230	150	86	0	59	50	50	49	110		
	12/16/05	24.7	3635.4	116,658	240	152	294	0	59	50	50	49	110		

System regenerates every 316,000 gallons.
NM = Not measured
NA = Not available

APPENDIX B

ANALYTICAL DATA

Analytical Results from Long-Term Sampling at Fruitland, ID

Sampling Date		06/15/05		06/23/05[a,b]			06/29/05[b]			07/06/05			07/13/05		07/20/05			08/03/05[c]		
Sampling Location Parameter	Unit	IN	TT	IN	TA	TB	IN	TA	TB	IN	TA	TB	IN	TT	IN	TA	TB	IN	TA	TB
Water Treated	Kgal	-	37	-	212		-	147		-	29		-	94	-	52		-	534	
Bed Volume	BV	-	49	-	283		-	197		-	39		-	126	-	70		-	714[d]	
Alkalinity (as CaCO₃)	mg/L	484	484	374	387	387	396	383	396	396	176	6	387	286	374	264	114	378	383	378
Fluoride	mg/L	0.5	0.5	-	-	-	0.7	0.7	0.7	-	-	-	0.5	0.5	-	-	-	-	-	-
Sulfate	mg/L	52	<1	59	57	59	58	94	63	73	<1	<1	75	<1	59	<1	<1	61	55	53
Nitrate (as N)	mg/L	10.0	4.3	10.3	9.4	9.8	10.1	9.5	9.5	11.2	3.0	6.6	9.6	1.9	9.4	2.7	4.1	9.3	9.7	9.7
Orthophosphate (as PO₄)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	0.2	0.2	0.3	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.1	0.2	0.2
Total P (as PO₄)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO2)	mg/L	57.8	57.2	57.7	57.3	58.0	59.3	58.6	57.5	58.6	58.4	59.0	46.6	48.1	55.8	56.6	55.5	56.2	56.1	55.5
Turbidity	NTU	0.1	<0.1	1.4	0.1	0.4	0.7	0.7	0.5	0.2	0.2	0.6	0.2	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
TDS	mg/L	568	542	-	-	-	-	-	-	-	-	-	578	558	-	-	-	-	-	-
pH	S.U.	7.6	7.7	7.6	7.5	7.2	7.4	7.6	7.5	6.7	6.8	6.0	7.4	7.3	7.5	7.8	7.3	7.7	7.5	7.4
Temperature	⁰C	15.2	15.1	15.0	15.2	15.3	14.9	14.9	14.8	15.2	15.8	15.1	15.2	15.2	15.4	15.3	15.3	15.4	15.1	14.8
DO	mg/L	2.6	3.0	4.0	3.4	3.5	2.4	2.4	2.1	3.6	2.2	3.3	2.1	1.9	1.9	2.2	2.5	3.1	1.8	2.5
ORP	mV	212	172	192	204	199	225	191	225	209	180	260	206	217	191	209	198	199	227	186
Total Hardness (as CaCO₃)	mg/L	303	252	-	-	-	-	-	-	-	-	-	242	242	-	-	-	-	-	-
Ca Hardness	mg/L	180	150	-	-	-	-	-	-	-	-	-	143	145	-	-	-	-	-	-
Mg Hardness	mg/L	123	101	-	-	-	-	-	-	-	-	-	98.8	97.0	-	-	-	-	-	-
As (total)	µg/L	49.0	0.7	37.5	38.2	38.3	38.0	37.4	38.8	39.3	3.6	8.3	39.0	2.8	35.4	3.1	5.8	34.2	41.4	46.3
As (soluble)	µg/L	45.5	0.9	-	-	-	-	-	-	-	-	-	38.8	3.2	-	-	-	-	-	-
As (particulate)	µg/L	3.5	<0.1	-	-	-	-	-	-	-	-	-	0.2	<0.1	-	-	-	-	-	-
As (III)	µg/L	2.1	0.8	-	-	-	-	-	-	-	-	-	2.4	2.4	-	-	-	-	-	-
As (V)	µg/L	43.4	<0.1	-	-	-	-	-	-	-	-	-	36.4	0.8	-	-	-	-	-	-
Fe (total)	µg/L	<25	<25	211	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Fe (soluble)	µg/L	<25	<25	-	-	-	-	-	-	-	-	-	<25	<25	-	-	-	-	-	-
Mn (total)	µg/L	11.8	9.9	15.4	13.9	14.3	15.7	14.5	15.1	19.4	20.3	20.9	18.4	19.8	25.4	20.8	23.3	23.3	23.1	24.7
Mn (soluble)	µg/L	10.0	10.4	-	-	-	-	-	-	-	-	-	20.2	20.2	-	-	-	-	-	-
U (total)	µg/L	22.6	<0.1	19.1	<0.1	<0.1	19.0	<0.1	<0.1	20.6	<0.1	2.5	18.4	<0.1	18.6	<0.1	<0.1	16.6	<0.1	<0.1
U (soluble)	µg/L	19.5	<0.1	-	-	-	-	-	-	-	-	-	18.8	<0.1	-	-	-	-	-	-
V (total)	µg/L	53.0	2.1	39.8	0.9	1.1	40.7	5.0	4.5	39.2	8.4	36.1	35.5	4.2	38.7	5.6	11.9	35.4	1.1	2.1
V (soluble)	µg/L	45.2	2.1	-	-	-	-	-	-	-	-	-	36.6	5.7	-	-	-	-	-	-
Mo (total)	µg/L	14.5	0.2	12.8	8.2	10.7	12.5	13.0	13.3	12.1	<0.1	0.2	12.6	0.3	13.7	0.3	<0.1	12.2	0.3	0.7
Mo (soluble)	µg/L	14.0	0.2	-	-	-	-	-	-	-	-	-	12.0	0.2	-	-	-	-	-	-

(a) Nitrate, turbidity, and orthophosphate analyzed outside of holding time.
(b) Vessels not properly regenerated due to wrong settings caused by power outage on 06/17/05. Problem fixed on 06/29/05 after sampling.
(c) Vendor technician on site from 7/26/05 through 7/30/05 conducting an arsenic and nitrate breakthrough study and regeneration study. Regeneration setpoint changed from 214,000 to 335,000 gal of water treated. Brine draw time reduced from 64 to 32 min.
(d) Regeneration not started until 199,000 gal past the set point of 355,000 gal due to problem with level sensor in brine day tank.

Analytical Results from Long-Term Sampling at Fruitland, ID (Continued)

Sampling Date		08/10/05			08/17/05		08/24/05			08/31/05			09/07/05			09/14/05		09/21/05		
Sampling Location Parameter	Unit	IN	TA	TB	IN	TT	IN	TA	TB	IN	TA	TB	IN	TA	TB	IN	TT	IN	TA	TB
Water Treated	Kgal	-	28		-	120	-	259		-	28		-	145		-	209	-	130	
Bed Volume	BV	-	37		-	160	-	346		-	37		-	194		-	279	-	174	
Alkalinity (as CaCO$_3$)	mg/L[a]	383 -	3 -	3 -	365 -	361 -	378 -	440 -	462 -	374 378	158 158	7 8	374 -	440 -	383 -	374 -	462 -	383 -	422 -	365 -
Fluoride	mg/L	-	-	-	0.5	0.5	-	-	-	-	-	-	-	-	-	0.5	0.5	-	-	-
Sulfate	mg/L	61 -	<1 -	<1 -	55 -	<1 -	58 -	<1 -	<1 -	62 61	<1 <1	<1 <1	60 -	<1 -	<1 -	57 -	<1 -	58 -	<1 -	<1 -
Nitrate (as N)	mg/L	9.1 -	2.5 -	2.5 -	8.5 -	0.6 -	8.6 -	3.2 -	0.5 -	9.5 9.5	1.6 1.7	2.4 2.3	8.9 -	0.4 -	0.7 -	8.8 -	0.4 -	9.2 -	0.4 -	0.7 -
Orthophosphate (as PO$_4$)	mg/L[b]	0.1 -	0.1 -	<0.05 -	0.1 -	<0.05 -	0.2 -	<0.05 -	<0.05 -	0.2 0.2	<0.05 <0.05	<0.05 <0.05	0.3 -	<0.05 -	<0.05 -	0.3 -	<0.05 -	0.1 -	<0.05 -	<0.05 -
Total P (as PO$_4$)	mg/L[b]	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
Silica (as SiO2)	mg/L	58.7 -	58.4 -	58.6 -	48.3 -	45.9 -	63.4 -	61.6 -	63.2 -	58.7 57.1	57.6 57.3	58.3 57.7	57.5 -	57.0 -	57.1 -	58.7 -	54.0 -	55.7 -	55.3 -	55.8 -
Turbidity	NTU	<0.1 -	<0.1 -	<0.1 -	0.1 -	<0.1 -	0.1 -	0.1 -	0.1 -	0.2 0.3	0.3 0.2	0.1 0.4	0.2 -	0.3 -	0.3 -	0.1 -	0.1 -	0.2 -	0.5 -	0.1 -
TDS	mg/L	-	-	-	598	552	-	-	-	-	-	-	-	-	-	574	542	-	-	-
pH	S.U.	7.8	7.0	7.3	7.7	7.5	7.9	7.9	7.9	7.7	7.5	6.8	7.8	7.6	7.4	7.6	7.4	7.8	NA[a]	7.5
Temperature	°C	15.4	15.0	14.8	15.3	15.2	15.1	14.7	14.9	14.9	15.0	14.7	15.1	14.8	14.8	15.1	14.8	15.1	NA[a]	14.8
DO	mg/L	3.0	2.2	3.1	-	-	2.4	2.6	2.6	3.7	2.1	2.8	3.8	2.9	2.4	2.7	2.6	3.0	NA[a]	2.3
ORP	mV	216	297	3.0	240	244	242	235	244	265	207	246	247	260	252	241	240	276	NA[a]	253
Total Hardness (as CaCO$_3$)	mg/L	-	-	-	247	249	-	-	-	-	-	-	-	-	-	247	247	-	-	-
Ca Hardness	mg/L	-	-	-	145	145	-	-	-	-	-	-	-	-	-	150	148	-	-	-
Mg Hardness	mg/L	-	-	-	102	104	-	-	-	-	-	-	-	-	-	97.7	98.9	-	-	-
As (total)	µg/L	40.6 -	25.6 -	15.1 -	39.4 -	2.4 -	42.9 -	1.4 -	1.1 -	52.0 51.5	3.0 2.9	11.4 10.8	60.0 -	1.3 -	1.2 -	40.5 -	0.7 -	33.6 -	1.3 -	2.1 -
As (soluble)	µg/L	-	-	-	38.2	2.7	-	-	-	-	-	-	-	-	-	40.9	0.7	-	-	-
As (particulate)	µg/L	-	-	-	1.1	<0.1	-	-	-	-	-	-	-	-	-	<0.1	<0.1	-	-	-
As (III)	µg/L	-	-	-	2.0	2.1	-	-	-	-	-	-	-	-	-	1.1	1.1	-	-	-
As (V)	µg/L	-	-	-	36.3	0.5	-	-	-	-	-	-	-	-	-	39.8	<0.1	-	-	-
Fe (total)	µg/L	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 <25	<25 <25	<25 <25	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -	<25 -
Fe (soluble)	µg/L	-	-	-	<25	<25	-	-	-	-	-	-	-	-	-	<25	<25	-	-	-
Mn (total)	µg/L	30.0 -	25.8 -	26.4 -	28.0 -	26.4 -	26.5 -	25.5 -	24.6 -	25.2 25.1	25.7 25.2	25.5 25.7	26.4 -	26.2 -	28.0 -	30.8 -	26.5 -	27.4 -	24.4 -	24.2 -
Mn (soluble)	µg/L	-	-	-	29.0	27.2	-	-	-	-	-	-	-	-	-	30.4	28.7	-	-	-
U (total)	µg/L	20.0 -	0.3 -	0.2 -	17.7 -	<0.1 -	19.5 -	<0.1 -	<0.1 -	17.6 17.5	<0.1 <0.1	<0.1 <0.1	17.8 -	<0.1 -	<0.1 -	17.2 -	<0.1 -	19.7 -	<0.1 -	<0.1 -
U (soluble)	µg/L	-	-	-	17.9	<0.1	-	-	-	-	-	-	-	-	-	16.2	<0.1	-	-	-
V (total)	µg/L	42.3 -	16.6 -	15.7 -	39.3 -	3.0 -	39.7 -	1.4 -	1.1 -	35.7 36.5	3.4 3.2	8.9 8.4	39.4 -	0.8 -	1.1 -	38.7 -	<0.1 -	36.5 -	2.6 -	4.4 -
V (soluble)	µg/L	-	-	-	40.0	3.4	-	-	-	-	-	-	-	-	-	38.4	<0.1	-	-	-
Mo (total)	µg/L	14.6 -	0.2 -	0.1 -	13.7 -	0.1 -	12.8 -	0.3 -	0.1 -	12.2 12.7	0.8 0.7	0.5 0.5	12.3 -	0.7 -	0.5 -	12.9 -	0.5 -	- -	- -	- -
Mo (soluble)	µg/L	-	-	-	13.2	0.1	-	-	-	-	-	-	-	-	-	12.4	0.4	-	-	-

(a) Operator not recorded water quality measurement.

Analytical Results from Long Term Sampling at Fruitland, ID (Continued)

Sampling Date		09/28/05			10/05/05			10/12/05		10/26/05			11/02/05			11/09/05	
Sampling Location Parameter	Unit	IN	TA	TB	IN	TA	TB	IN	TT	IN	TA	TB	IN	TA	TB	IN	TT
Water Treated	Kgal	-	314		-	179		-	143	-	196		-	252		-	224
Bed Volume	BV	-	420		-	239		-	191	-	262		-	337		-	299
Alkalinity (as $CaCO_3$)	mg/L	396	440	458	383	462	458	383	405	374	NA[a]	440	365	440	462	383	462
Fluoride	mg/L	-	-	-	-	-	-	0.5	0.5	-	-	-	-	-	-	0.5	0.5
Sulfate	mg/L	47	<1	<1	41	<1	<1	52	<1	58	NA[a]	<1	54	<1	<1	55.7	<1
Nitrate (as N)	mg/L	8.4	9.7	4.8	6.9	0.5	0.4	9.4	0.6	9.7	NA[a]	0.4	9.6	3.4	0.3	10.0	0.5
Orthophosphate (as PO_4)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.6	0.9	0.1	NA[a]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total P (as PO_4)	mg/L	-	-	-	-	-	-	0.4	<0.03	0.4	<0.03	<0.03	0.3	<0.03	<0.03	0.4	<0.03
Silica (as SiO2)	mg/L	56.1	57.4	58.0	53.8	53.8	54.5	56.7	57.2	NA[a]	57.0	58.5	57.1	58.3	57.3	56.2	56.1
Turbidity	NTU	1.0	0.2	0.1	<0.1	0.5	0.1	0.2	<0.1	<0.1	NA[a]	<0.1	<0.1	0.2	<0.1	<0.1	<0.1
TDS	mg/L	-	-	-	-	-	-	566	524	-	-	-	-	-	-	566	498
pH	S.U.	7.7	7.7	7.7	7.9	7.8	7.7	7.6	7.4	7.7	7.9	7.6	7.3	7.5	7.2	7.7	7.6
Temperature	°C	15.0	15.0	15.0	14.6	14.6	14.6	14.9	15.0	14.8	14.8	14.8	14.8	14.8	14.8	14.7	14.8
DO	mg/L	4.3	2.5	2.7	2.3	2.4	2.8	3.2	2.9	1.9	3.1	2.2	2.1	2.9	2.4	2.6	1.7
ORP	mV	248	214	219	249	242	216	242	260	252	251	237	248	260	220	257	259
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	232	241	-	-	-	-	-	-	257	251
Ca Hardness	mg/L	-	-	-	-	-	-	134	142	-	-	-	-	-	-	157	155
Mg Hardness	mg/L	-	-	-	-	-	-	97.1	99.2	-	-	-	-	-	-	99.2	96.5
As (total)	µg/L	35.1	17.6	2.1	34.3	0.8	0.8	60.8	1.3	45.8	0.9	1.0	35.0	0.7	0.5	37.0	0.7
As (soluble)	µg/L	-	-	-	-	-	-	59.9	1.2	-	-	-	-	-	-	37.5	0.7
As (particulate)	µg/L	-	-	-	-	-	-	0.9	<0.1	-	-	-	-	-	-	<0.1	<0.1
As (III)	µg/L	-	-	-	-	-	-	1.2	1.4	-	-	-	-	-	-	1.6	1.2
As (V)	µg/L	-	-	-	-	-	-	58.7	<0.1	-	-	-	-	-	-	35.9	<0.1
Fe (total)	µg/L	102	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Fe (soluble)	µg/L	-	-	-	-	-	-	<25	<25	-	-	-	-	-	-	<25	<25
Mn (total)	µg/L	25.5	33.7	15.6	24.8	23.4	23.1	23.2	23.0	22.9	22.2	22.9	24.9	23.3	23.1	21.8	23.0
Mn (soluble)	µg/L	-	-	-	-	-	-	21.8	24.0	-	-	-	-	-	-	21.7	23.1
U (total)	µg/L	21.1	<0.1	<0.1	16.6	0.0	0.2	19.4	<0.1	19.4	<0.1	<0.1	18.8	<0.1	<0.1	18.5	<0.1
U (soluble)	µg/L	-	-	-	-	-	-	19.7	<0.1	-	-	-	-	-	-	18.3	<0.1
V (total)	µg/L	30.6	2.8	3.1	38.7	0.4	0.7	38.5	0.9	41.8	0.6	0.7	38.2	0.3	0.3	41.7	<0.1
V (soluble)	µg/L	-	-	-	-	-	-	40.0	0.9	-	-	-	-	-	-	40.7	<0.1
Mo (total)	µg/L	13.5	0.3	0.1	12.1	0.8	0.4	12.0	<0.1	12.0	0.1	<0.1	12.8	0.1	<0.1	13.1	0.1
Mo (soluble)	µg/L	-	-	-	-	-	-	13.3	<0.1	-	-	-	-	-	-	13.0	<0.1

(a) Sampling error.

Analytical Results from Long Term Sampling at Fruitland, ID (Continued)

Sampling Date		11/16/05			11/30/05			12/14/05	
Sampling Location Parameter	Unit	IN	TA	TB	IN	TA	TB	IN	TT
Water Treated	Kgal	-	125		-	103		-	190
Bed Volume	BV	-	167		-	138		-	254
Alkalinity (as CaCO$_3$)	mg/L	396	418	352	383	440	409	396	484
Fluoride	mg/L	-	-	-	-	-	-	0.5	0.5
Sulfate	mg/L	56	<1	<1	55	<1	<1	76	<1
Nitrate (as N)	mg/L	10.2	0.5	0.7	10.3	0.5	0.5	10.5	0.7
Orthophosphate (as PO$_4$)	mg/L	0.1	<0.05	<0.05	0.1	<0.05	<0.05	0.1	<0.05
Total P (as PO$_4$)	mg/L	0.3	<0.03	<0.03	0.3	<0.03	<0.03	-	-
Silica (as SiO2)	mg/L	56.1	56	55.9	57.0	57.5	57.6	56.8	56.6
Turbidity	NTU	<0.1	<0.1	0.2	<0.1	0.2	0.1	0.8	1.6
TDS	mg/L	-	-	-	-	-	-	-	-
pH	S.U.	7.6	7.5	7.5	7.6	7.7	7.5	7.7	7.2
Temperature	^{0}C	15.2	14.8	14.8	15.4	15.9	15.4	15.1	14.9
DO	mg/L	2.2	2.1	2.8	3.3	2.5	2.4	2.3	2.5
ORP	mV	252	248	250	249	213	221	248	224
Total Hardness (as CaCO$_3$)	mg/L	-	-	-	-	-	-	227	229
Ca Hardness	mg/L	-	-	-	-	-	-	141	140
Mg Hardness	mg/L	-	-	-	-	-	-	86.2	89.3
As (total)	µg/L	44.0	0.7	0.7	38.8	1.5	2.3	46.3	1.0
As (soluble)	µg/L	-	-	-	-	-	-	37.3	0.8
As (particulate)	µg/L	-	-	-	-	-	-	8.9	0.2
As (III)	µg/L	-	-	-	-	-	-	0.9	1.1
As (V)	µg/L	-	-	-	-	-	-	36.4	<0.1
Fe (total)	µg/L	<25	<25	<25	<25	<25	<25	<25	<25
Fe (soluble)	µg/L	-	-	-	-	-	-	<25	<25
Mn (total)	µg/L	19.9	20.3	21.2	21.9	21.4	22.1	15.0	14.6
Mn (soluble)	µg/L	-	-	-	-	-	-	14.8	14.1
U (total)	µg/L	19.7	<0.1	<0.1	19.2	<0.1	<0.1	20.0	<0.1
U (soluble)	µg/L	-	-	-	-	-	-	19.1	<0.1
V (total)	µg/L	39.2	0.7	1.2	43.2	2.0	4.6	39.2	0.5
V (soluble)	µg/L	-	-	-	-	-	-	40.4	0.3
Mo (total)	µg/L	12.5	0.4	0.2	12.6	20.1	20.1	12.3	0.2
Mo (soluble)	µg/L	-	-	-	-	-	-	11.8	0.1