# Arsenic and Nitrate Removal from Drinking Water by Ion Exchange U.S. EPA Demonstration Project at Vale, OR Final Performance Evaluation Report

by

Lili Wang<sup>§</sup> Abraham S.C. Chen<sup>§</sup> Anbo Wang<sup>‡</sup> Wendy E. Condit<sup>‡</sup>

<sup>‡</sup>Battelle, Columbus, OH 43201-2693 <sup>§</sup>ALSA Tech, LLC, Columbus, OH 43219-6093

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

> > for

Thomas J. Sorg Task Order Manager

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

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

### DISCLAIMER

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

#### FOREWORD

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

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

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

Sally Gutierrez, Director National Risk Management Research Laboratory

### ABSTRACT

As part of the EPA Arsenic Removal Technology Demonstration Program, a 540-gal/min (gpm) ion exchange (IX) system proposed by Kinetico was selected for demonstration at Vale, OR to remove arsenic and nitrate from a groundwater supply to meet their respective maximum contaminant level (MCL) of  $10-\mu g/L$  and 10-mg/L (as N). This report documents the activities performed and results obtained from a 3.5-year long demonstration study that evaluated the performance of IX technology for arsenic and nitrate removal, determined the required system operation and maintenance (O&M) and operator skills, characterized the residuals produced by the technology, and determined the capital and O&M cost of the technology.

This demonstration study was divided into three periods: Study Periods I and II and an interim period between the two. Study Period I (extending from September 19, 2006, through January 14, 2008) evaluated the originally proposed Purolite Arsenex II anion exchange (AIX) resin. Because of its deteriorating performance due to organic fouling and difficulties in restoring its exchange capacity after resin cleaning, a dual resin approach was identified and implemented in the interim period to address the relevant issues. In February 2009, Arsenex II resin was replaced with Purolite PFA300E resin, which was overlain with an organic scavenger, Purolite A850END. The performance of PFA300E/A850END was evaluated in Study Period II from February 10, 2009, through March 22, 2010.

### Summary of System Design

The IX treatment system consisted of two banks of sediment filters, two 63-in  $\times$  86-in pressure vessels configured in parallel, two 11-ton salt saturators, two 1,050-gal day tanks, two brine transfer pumps, one automatic system control panel, and associated valves, pressure gauges, flow totalizers, and sample ports. By design, each vessel was to be loaded with 110 ft<sup>3</sup> of AIX resin, treating 270 gpm of flow at a hydraulic loading rate of 12.5 gpm/ft<sup>2</sup> and an empty bed contact time (EBCT) of 3 min.

The amount of Arsenex II resin in each vessel was found to be less than the design value of  $110 \text{ ft}^3$ . During resin replacement in February 2009, it was discovered that the maximum amount of dual resin that could be loaded into each vessel was 98.5 ft<sup>3</sup>, which was 90% of the design value. The volume of Arsenex II resin in each vessel, based on the freeboard measurement, was estimated to be 93 ft<sup>3</sup>, which was 85% of the design value. The smaller resin bed resulted in a shorter EBCT, i.e., 2.6 min for Arsenex II and 2.8 min for dual resin (on average).

### Summary of System Operation

Routine operational data and sample collections were conducted in Study Periods I and II. The IX system operated for a total of 4,440 and 3,215 hr, treating approximately 128 and 93.6 million gal of water in Study Periods I and II, respectively. The average daily operating time was 9.5 hr in both periods. Average flowrates were 534 and 536 gpm in Study Periods I and II, respectively, very close to the design value of 540 gpm. Pressure losses across each IX vessel averaged 11 pounds per square inch (psi), as expected for a 5-ft deep resin bed. However, two 270-gpm flow restrictors installed at vessel outlets to prevent overrun during regeneration created additional headlosses (up to 30 psi) across the IX system.

The IX system was regenerated in a downflow, co-current mode using brine. Triggered automatically by a volume throughput setpoint in a programmable logic controller (PLC), the two IX vessels were regenerated sequentially, each cycling through the steps of spent brine draw, fresh brine draw, slow rinse, and fast rinse before returning to service. The spent brine draw step was designed to minimize wastewater production, but was discontinued in December 2007 due to concerns over possible resin

fouling caused by dissolved organic matter (DOM) accumulating in the spent brine solution. The regeneration waste stream was discharged to an evaporation pond outside of the treatment plant.

A total of 278 and 144 regeneration cycles took place in Study Periods I and II, respectively. Regeneration parameters, such as brine draw rate, brine volume, and specific gravity of diluted brine were monitored and adjusted, if needed. During the first six months of Study Period I, salt usage per regeneration cycle was much higher than the target level of 12 lb/ft<sup>3</sup> (up to 25.1 lb/ft<sup>3</sup>). After a brine injection pump had been installed to replace the Venturi eductor, the control of salt usage was greatly improved. In Study Period II, the average salt usage was 8.4 lb/ft<sup>3</sup>, 16% lower than the target value of 10 lb/ft<sup>3</sup>.

### Summary of System Performance

Based on analytical data from a total of 63 sampling events in both study periods, raw water contained 16.0 to 31.8  $\mu$ g/L of total arsenic (averaged 21.1  $\mu$ g/L, primarily as soluble As[V]) and 1.4 to 7.6 mg/L (as N) of nitrate (averaged 5.5 mg/L [as N]). Although arsenic and nitrate concentrations showed some variations (presumably due to fluctuations in individual wells), the water quality, in general, remained rather constant in both study periods. On average, raw water had a pH of 7.4, 319 mg/L of total alkalinity (as CaCO<sub>3</sub>), 78 mg/L of sulfate, 277  $\mu$ g/L of total phosphorus, 58 mg/L of silica (as SiO<sub>2</sub>), 506 mg/L of total dissolved solids (TDS), 1.9 mg/L of total organic carbon (TOC), 53  $\mu$ g/L of total vanadium, and 165 mg/L of total hardness (as CaCO<sub>3</sub>). Total iron was below its reporting limit of 25  $\mu$ g/L and total manganese was less than 1  $\mu$ g/L.

Weekly samples were collected from the treatment process during both study periods. Five run length studies also were conducted on Arsenex II and PFA300E/A850END to obtain breakthrough curves of arsenic, nitrate, and other competing anions. At system startup in September 2006, Arsenex II achieved a run length of 562,000 gal (or 404 bed volume [BV]) to 10-µg/L arsenic breakthrough, which was 59% of the vendor-projected run length of 680 BV. Since then, the system performance continued to deteriorate, as evidenced by more frequent exceedance of the arsenic MCL in system effluent and increasingly shortened useful run lengths (e.g., to 450,000 gal and then to 376,900 gal after four and seven months of operation, respectively). Analysis of a resin core sample revealed that the resin was severely fouled by organic matter. A cleaning procedure using a mixture of caustic/brine was developed in the laboratory by Purolite and implemented in the field in October 2007. Although the cleaning was able to restore the resin's capacities, such as volumetric capacity and strong base capacity, to 93% and 79% of the virgin resin level, respectively, the total organic content of the resin was reduced only by 24% and the useful run length improved only by 20% to 445,700 gal (320 BV). While organic matter continued to build up on the resin, the useful run length was shortened again to 323,500 gal (233 BV) about 10 months after the cleaning.

Shorter run lengths (i.e., only 34 to 47% of the vendor projection) would require more frequent resin regeneration and produce more wastewater, which potentially could overflow the evaporation pond. In seeking an alternative approach to address DOM in source water, the City of Vale expressed its desire to continue with the IX technology in case nitrate became an issue in the future, and to achieve a volume throughput of 600,000 gal to prevent the pond from overflowing. Thus, the option of replacing Arsenex II resin with other resin types was explored. Purolite proposed a dual resin approach, i.e., PFA300 top-dressed with A800END, which had been successfully implemented at the McCook Water Treatment Plant in McCook, NE for the removal of arsenic, nitrate, and uranium from water containing >3 mg/L of TOC. Following a site visit to McCook and a run length and elution study, it was confirmed that the dual resin approach could be an effective remedy to treat waters containing high levels of TOC.

After the IX system was rebedded with PFA300E/A850END in February 2009, weekly sampling data and run length study results revealed that the system could achieve a useful run length of approximately 454,400 gal (or 372 BV). This run length was calculated based on the actual PFA300E resin volume of 163.3  $\text{ft}^3$ . For a system containing 220  $\text{ft}^3$  of resin, it would treat 612,174 gal of water. Therefore, the smaller resin bed was the key reason for not meeting the treatment target of 600,000 gal desired by the City. TOC concentrations in treated water were consistently removed below the reporting limit of 1 mg/L, confirming the usefulness of the dual resin approach to address DOM issues throughout the desired service cycle.

Because the IX system was set to regenerate at 600,000 gal during most of the study, it was not surprising to detect high arsenic concentrations in system effluent when samples were collected past the resin's useful run lengths. Periodically, effluent concentrations exceeded raw water concentrations, a phenomenon referred to as chromatographic peaking or arsenic dumping. Arsenic dumping is caused by displacement of arsenic by more preferred anions such as sulfate, which often has a concentration three orders of magnitude higher than that of arsenic. Arsenic dumping is a major drawback of the IX technology and can be mitigated by properly controlling system run lengths and regeneration frequencies.

Nitrate chromatographic peaking also was observed in system effluent, but effluent nitrate concentrations never exceeded its MCL. Total phosphorus concentrations in system effluent were reduced to  $<10 \ \mu g/L$  most of the time but rose rapidly to exceed influent levels after reaching a throughput of approximately 415,000 gal in Study Period I and 488,000 gal in Study Period II. Sulfate was removed to less than 1 mg/L most of the time in both study periods and began to break after reaching a throughput of 376,940 gal in Study Period I and 487,940 gal in Study Period II. It reached 1/3 to 1/2 of its influent concentration at the end of the 600,000-gal service cycle. Because of its higher selectivity than arsenate and nitrate, sulfate continued to be removed to  $<5 \ \mu g/L$  in system effluent most of the time. Chromatographic peaking was not observed for vanadium in either period, suggesting that vanadium might have an equivalent or even higher selectivity than sulfate.

Slight reductions in treated water pH values were observed for a short period immediately after the system had just been regenerated. Although pH changes were small, i.e., no more than 0.3 pH unit, corresponding reductions in total alkalinity across the system were significant (up to 50%). The reduction in pH and alkalinity was attributed to removal of bicarbonate ions by the AIX resin. pH values of treated water returned to raw water levels afterwards due to complete breakthrough of bicarbonate ions, which had a lowest selectivity by the strong base AIX resin.

Distribution system water samples were collected only in Study Period I. Because treated water from the IX system was stored in a 200,000-gal reservoir before supplying the distribution system, the water quality of the distribution system water samples reflected the general quality of the plant effluent after being blended in the reservoir. After system startup, arsenic concentrations at all three sampling locations ranged from 7.1 to 24.0  $\mu$ g/L and averaged 12.6  $\mu$ g/L, which were significantly lower than the baseline levels, but not to the low level (i.e., <5  $\mu$ g/L) that would be expected from an IX treatment plant because the IX system had been operated beyond 10  $\mu$ g/L. Although occasionally, some low pH and low alkalinity were measured in treated water samples collected from the freshly regenerated vessels, the blending effect in the reservoir had mitigated any pH or alkalinity swing. Therefore, low pH and low alkalinity were measured in the distribution samples.

## **Residual Characterization**

Residuals produced by the IX system, including spent brine and rinse water, were discharged to the evaporation pond adjacent to the treatment building. Ferric chloride was added to the spent brine stream

in an attempt to precipitate arsenic and allow the iron sludge to settle in the evaporation pond. The design and construction of the evaporation pond and the ferric chloride treatment system were performed by the City's contractors.

The volume of wastewater produced was determined by regeneration frequency and the volume of wastewater produced per regeneration cycle. On average, each regeneration cycle produced 8,681 gal of wastewater per vessel in Study Period I and 7,244 gal per vessel in Study Period II, which is 17% less than that in Study Period I.

To characterize the quality of residuals, samples were collected from the waste stream from each regeneration step as well as the pond water. Total arsenic concentrations in spent brine, fresh brine, slow rinse, and fast rinse samples averaged 2,678, 2,221, 527, and 11.3  $\mu$ g/L, respectively, for Arsenex II, and averaged 2,203, 150, and 3.4  $\mu$ g/L, respectively for PFA300E/A850END (note that spent brine draw was not used). Similarly, nitrate concentrations averaged 122, 517, 194, and 3.6 mg/L (as N) for Arsenex II and 450, 68, and 2.6 mg/L (as N) for dual resins.

With a pH of 9.3 to 9.8 and a total alkalinity of 4,560 mg/L, the evaporation pond water contained 16 to 25.6 g/L of chloride, 13 to 30.2 g/L of sodium, and 38.2 to 60.1 g/L of TDS, indicating a highly alkaline and saline water. The pond water also contained up to 1.3 mg/L of total arsenic, 7.3 g/L of sulfate, 9.2 mg/L (as N) of nitrate, 13.3 mg/L of total phosphorus (as P), and 4.1 mg/L of vanadium. High arsenic concentrations in the pond water suggested ineffective ferric chloride treatment, presumably due to high TDS content and the presence of competing ions in the pond water.

A regeneration elution study performed on dual resins indicated that the percent recoveries were 112% for arsenic, 131% for nitrate, 113% for vanadium, and 98.5% for TOC.

## Cost of Technology

The capital cost of the IX system was \$395,434, which included \$260,194 for equipment, \$49,840 for site engineering, and \$85,400 for installation, accounting for 66%, 12%, and 22% of the total capital investment, respectively. This capital cost was normalized to the system's rated capacity of 540 gpm (or 777,600 gal/day [gpd]), which resulted in \$732 per gpm (or \$0.51 per gpd). The cost associated with design and construction of a new building, an evaporation pond, and a ferric chloride addition system (to treat the brine waste) was funded separately by the City of Vale, and not included in the cost of the system.

The O&M cost for the IX system included the incremental cost associated with the salt supply, electricity consumption, and labor, which was estimated to be \$0.35/1,000 gal of water treated. The cost of salt and caustic soda was the most significant add-on, approximately \$32,826 per year, or \$0.29/1,000 gal. Because the current salt saturators can only hold half truckload of salt, if more salt storage capacity is added to allow delivery of a full truckload, then the overall salt cost could be further reduced.

DIS	CLAI	MER	.ii
FOR	EWO	)RD	iii
ABS	TRAG	СТ	iv
APP	ENDI	ICES	ix
FIG	URES		ix
TAE	BLES .		. x
ABE	BREV	IATIONS AND ACRONYMS	xii
ACK	KNOW	VLEDGMENTSx	iv
1.0:	INTR	RODUCTION	.1
	1.1	Background	.1
	1.2	Treatment Technologies for Arsenic Removal	.2
	1.3	Project Objectives	.2
		·] · · · ·]·	
2.0	SUM	MARY AND CONCLUSIONS	.5
3.0:	MAT	ERIALS AND METHODS	.7
	3.1	General Project Approach	.7
	3.2	System O&M and Cost Data Collection	.8
	3.3	Sample Collection Procedures and Schedules	.9
		3.3.1 Source Water	.9
		3.3.2 Treatment Plant Water	.9
		333 Regeneration Wastewater	12
		3 3 4 Distribution System Water	12
	34	Real-Time Arsenic Monitoring with ArsenicGuard <sup>TM</sup>	12
	3 5	Run Length and Regeneration Elution Studies	13
	5.5	3.5.1 Run Length Studies	13
		3.5.2 Regeneration Flution Study	15
	36	IX Resin Cleaning	16
	37	Sampling Logistics	16
	5.7	3.7.1 Preparation of Arsenic Speciation Kits	16
		3.7.2 Preparation of Sampling Coolers	17
		3.7.3 Sample Shipping and Handling	17
	38	Analytical Procedures	17
	5.0	Analytical Flocedules	1/
1 0.	DEGI	TI TS AND DISCUSSION	10
4.0.	A 1	Eacility Description	10
	4.1	1 1 Source Weter Quelity	10
		4.1.1 Source water Quality	10
	1 2	4.1.2 Distribution System water Quality	23
	4.2	4.2.1 Jon Evolution Description	23
		4.2.1 IOII EXCHAIGE PIOCESS	23 77
	12	4.2.2 I realment Process	$\frac{21}{26}$
	4.3	System instantion.	20 26
		4.5.1 Permitting	)0 26
		4.5.2 Construction of Treatment Building and Evaporation Pond	30
	1 4	4.5.5 System Installation, Snakedown, and Startup	58 40
	4.4	System Operation	4U 4 1
		4.4.1 Operational Parameters	+1
		4.4.2 Kegeneration	+2

# CONTENTS

		4.4.2.1 Regeneration Set Points	.42
		4.4.2.2 Regeneration Monitoring	.44
		4.4.2.3 Salt Usage	.46
	4.4.3	IX Resin Fouling	.48
	4.4.4	Dual IX Resin Approach	.49
		4.4.4.1 Dual Resin Options	.50
		4.4.4.2 Concerns over Solids in IX Resin Beds	.50
		4.4.4.3 Special Study at McCook, NE	.51
		4.4.4.4 Dual Resin Installation	.54
	4.4.5	Residual Management	.54
	4.4.6	System Operation Requirement	.55
		4.4.6.1 Required System Operation and Operator Skills	.55
		4.4.6.2 Preventive Maintenance Activities	.56
		4.4.6.3 Chemical/Media Handling and Inventory Requirements	.56
4.5	System	Performance	.56
	4.5.1	Treatment Plant Sampling	.56
		4.5.1.1 Arsenic Speciation	.60
		4.5.1.2 Arsenic Removal	. 62
		4.5.1.3 Nitrate Removal	.65
		4.5.1.4 TOC, Sulfate, Phosphate, and Vanadium Removal	.67
		4.5.1.5 Other Water Quality Parameters	.67
	4.5.2	Real-Time Arsenic Monitoring by ArsenicGuard <sup>TM</sup>	.73
	4.5.3	Run Length Studies	.74
	4.5.4	Regeneration Elution Study	.79
	4.5.5	Regeneration Residual Sampling	.82
	4.5.6	Analysis of Evaporation Pond Water	.85
	4.5.7	Distribution System Water Sampling	.86
4.6	System	Cost	. 88
	4.6.1	Capital Cost	. 89
	4.6.2	Operation and Maintenance Cost	.90
5.0 REFI	ERENCE	S	.92

# APPENDICES

APPENDIX A:	Vale Arsenic System IX Resin Cleaning Procedure
APPENDIX B:	Vale, OR Project Chronology
APPENDIX C:	Operational Data

APPENDIX D: Analytical Data

# FIGURES

Figure 3-1.	Process Flow Diagram and Sampling Locations/Analyses for Vale IX System	11
Figure 3-2.	Real-Time Arsenic Analyzer – ArsenicGuard <sup>TM</sup>	13
Figure 3-3.	Regeneration Monitoring Setup	15
Figure 4-1.	Existing Well House in Vale, OR	19
Figure 4-2.	Existing Chlorination System in Vale, OR	19
Figure 4-3.	Historic Nitrate Data from Wells No. 1 Through No. 7	
Figure 4-4.	Simulation of Arsenex II Resin Run Length	
0	C C	

Figure 4-5.	Simulation of A850END/PFA300E Resin Run Length (June 2008)	26
Figure 4-6	Schematic of Kinetico's IX-263 As/N Removal System for Vale, OR	27
Figure 4-7.	System Inlet Piping and Booster Pump	29
Figure 4-8.	Photograph of Two Banks of Cartridge Filters	30
Figure 4-9.	Photographs of Arsenic/Nitrate Removal IX System at Vale, OR	31
Figure 4-10.	Skid-Mounted Piping/Valving Rack	31
Figure 4-11.	Photographs of IX Regeneration System at Vale, OR	33
Figure 4-12.	Salt Delivery to Fill Salt Saturators	34
Figure 4-13.	Wastewater Evaporation Pond	35
Figure 4-17.	Vale Treatment System Delivering and Offloading	38
Figure 4-18.	PLC Regeneration Setpoints Shown on OIP	43
Figure 4-19.	The McCook, NE Water Treatment Plant	51
Figure 4-20.	Sample Collection and pH/TDS Monitoring during Regeneration of AIX Vessel 5	
	at McCook, NE	52
Figure 4-21.	Results of McCook AIX Vessel 5	53
Figure 4-22.	Concentrations of Arsenic Species across Treatment System	61
Figure 4-23.	Total Arsenic Concentrations Measured During Study Period I	63
Figure 4-24.	Total Arsenic Concentrations Measured During Study Period II	64
Figure 4-25.	Reconstructed Breakthrough Curves for Nitrate	66
Figure 4-26.	Reconstructed Breakthrough Curves for Sulfate	68
Figure 4-27.	Reconstructed Breakthrough Curves for Total Phosphorus	69
Figure 4-28.	Reconstructed Breakthrough Curves for Total Vanadium	70
Figure 4-29.	pH Measured During Study Period I	71
Figure 4-30.	Reconstructed Breakthrough Curves for Total Alkalinity	72
Figure 4-31.	Examples of Real-Time Arsenic Monitoring by ArsenicGuard <sup>TM</sup>	73
Figure 4-32.	Vessel A Breakthrough Curves from Run Length Study 1	75
Figure 4-33.	Vessel A Breakthrough Curves from Run Length Study 2	75
Figure 4-34.	Vessel A Breakthrough Curves from Run Length Study 3	76
Figure 4-35.	Combined Effluent Breakthrough Curves from Run Length Study 4	77
Figure 4-36.	Breakthrough Curves from Run Length Study 5	78
Figure 4-37.	pH and Alkalinity Breakthrough Curves from Run Length Study 5	79
Figure 4-38.	Vessels A and B Elution Curves	80
Figure 4-39.	Vessels A and B Elution Curves for TDS and pH	81
Figure 4-40.	Results of Vale Pond Water Jar Tests	86

# TABLES

Table 1-1.	Summary of Round 1 and Round 2 Arsenic Removal Demonstration Locations,	
	Technologies, and Source Water Quality	3
Table 3-1.	Pre-Demonstration Study Activities and Completion Dates	7
Table 3-2.	Evaluation Objectives and Supporting Data Collection Activities	
Table 3-3.	Sampling and Analysis Schedule at Vale, OR	10
Table 3-4.	Sampling and Analysis Schedules for Run Length Studies	14
Table 3-5.	Sampling and Analysis Schedules for Resin Elution Study	16
Table 4-1.	Construction Details of Wells No. 1 to No. 7	
Table 4-2.	Vale, OR Source Water Data for Combined Wells No. 1 to No. 7	20
Table 4-3.	Wells No. 1 to No. 7 Water Quality Data from June 2000 to August 2000	
Table 4-4.	Wells No. 1 to No. 7 Water Quality Data from EPA (December 2004)	
Table 4-5.	Wells No. 1 to No. 7 Nitrate Concentrations (mg/L [as N]) from Source (February	
	2001 to October 2004)	

Table 4-6.	Physical and Chemical Properties of IX Resins	. 25
Table 4-7.	Design Specifications of IX System	. 28
Table 4-8.	System Punch List during Startup	. 39
Table 4-9.	Key Demonstration Study Activities/Events	.40
Table 4-10.	Summary of System Operational Data	.41
Table 4-11.	IX System Regeneration Setpoints at Vale, OR	. 44
Table 4-12.	IX System Regeneration Monitoring at Vale, OR	. 45
Table 4-13.	Vale, IX System Salt Loading Calculations	. 47
Table 4-14.	Resin Analyses After Laboratory or Field Cleaning	. 48
Table 4-15.	Freeboard Measurements During Rebedding at Vale, OR	. 54
Table 4-16.	Summary of Arsenic and Nitrate Analyses in Study Periods I and II	. 57
Table 4-17.	Summary of Other Water Quality Parameters in Study Period I	. 58
Table 4-18.	Summary of Other Water Quality Parameters in Study Period II	. 60
Table 4-19.	Mass Balance Calculations for Total Arsenic, Nitrate, Vanadium, and TOC	. 83
Table 4-20.	Regeneration Residual Sampling Results	. 84
Table 4-21.	Analytical Data for Pond Water at Vale, OR	. 85
Table 4-22.	Distribution System Sampling Results in Study Period I at Vale, OR	. 87
Table 4-23.	Cost Breakdowns of Capital Investment for Vale IX System	. 89
Table 4-24.	O&M Cost for Vale, OR Treatment System	. 90

# ABBREVIATIONS AND ACRONYMS

AAL	American Analytical Laboratories
AIX	anion exchange
Al	aluminum
AM	adsorptive media
As	arsenic
ASV	anodic stripping voltammetry
ATS	Aquatic Treatment Systems
bgs	below ground surface
BV	bed volume
C/F	coagulation/filtration
Ca	calcium
Cl	chlorine
Cu	copper
DHS DWP	(Oregon) Department of Human Service, Drinking Water Program
DO	dissolved oxygen
DOM	dissolved organic matter
DVB	divinylbenzene
EBCT	empty bed contact time
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
FRP	fiberglass reinforced plastic
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
HAA5	haloacetic acids
HDPE	high-density polyethylene
HIX	hybrid ion exchanger
hp	horsepower
ICP-MS ID IX	inductively coupled plasma-mass spectrometry identification ion exchange
LCR	Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MEI	Magnesium Elektron, Inc.
Mg	magnesium
MGD	million gallon per day

Mn	manganese
mV	millivolts
Na	sodium
NRMRL	National Risk Management Research Laboratory
NSF	NSF International
NTU	nephelometric turbidity units
O&M	operation and maintenance
OIP	operator interface panel
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
P&ID	piping and instrumentation diagram
PLC	programmable logic controller
POU	point of use
ppb	parts per billion
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
RO	reverse osmosis
SBA	strong-base anion
SDWA	Safe Drinking Water Act
STS	Severn Trent Services
TCLP	Toxicity Characteristic Leaching Procedure
TDH	total dynamic head
TDS	total dissolved solids
TOC	total organic carbon
TTHMs	trihalomethanes
V	vanadium
VFD	variable frequency drive
WTP	Water Treatment Plant

## ACKNOWLEDGMENTS

The authors wish to extend their sincere appreciation to the staff of the Department of Public Works at the City of Vale, OR. The primary operators, Mr. Les Bertalotto and Mr. Terry Harris, monitored the treatment system daily and collected water samples from the treatment and distribution systems on a regular schedule throughout the study period. This performance evaluation would not have been possible without their efforts.

### **1.0 INTRODUCTION**

### 1.1 Background

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

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

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

In 2003, EPA initiated Round 2 arsenic technology demonstration projects that were partially funded with Congressional add-on funding to the EPA budget. In June 2003, EPA selected 32 potential demonstration sites. The City of Vale, OR was one of those selected.

In September 2003, EPA again solicited proposals from engineering firms and vendors for arsenic removal technologies. EPA received 148 technical proposals for the 32 host sites, with each site receiving from two to eight proposals. In April 2004, another technical panel was convened by EPA to review the proposals and provide recommendations to EPA with the number of proposals per site ranging from none (for two sites) to a maximum of four. The final selection of the treatment technology at the sites that received at least one proposal was made, again, through a joint effort by EPA, the state regulators, and the host site. Since then, five sites have withdrawn from the demonstration program, reducing the number of sites to 27. An ion exchange (IX) system proposed by Kinetico was selected for demonstration at the Vale, OR, site for the removal of arsenic and nitrate from drinking water supplies.

As of February 2011, the performance evaluations of all 39 systems have been completed.

# 1.2 Treatment Technologies for Arsenic Removal

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

## **1.3 Project Objectives**

The objective of the Round 1 and Round 2 arsenic demonstration program was to conduct full-scale arsenic treatment technology demonstration studies on the removal of arsenic from drinking water supplies. The specific objectives were to:

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

This report documents the performance of the Kinetico IX system at the City of Vale, OR, from September 19, 2006, through March 22, 2010. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and preliminary O&M cost. Short-term special studies also were conducted to troubleshoot operational and performance issues and improve the overall effectiveness and efficiency of the treatment system.

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

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

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

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

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

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

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

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

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

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

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

(f) Including nine residential units.

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

## 2.0 SUMMARY AND CONCLUSIONS

Based on the data collected from this 3.5-year long demonstration study at Vale, OR, the following summary and 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:

- Arsenex II resin can remove arsenic and nitrate from water supplies to below their respective MCLs of 10-µg/L and 10-mg/L (as N), provided that the system is regenerated timely. The Vale, OR IX plant achieved an initial run length of 562,000 gal (or 404 bed volumes [BV]) at 10-µg/L arsenic breakthrough. However, due to organic fouling, the useful run length was reduced to up to 80% of the initial level after seven months of system operations.
- PFA300E top-dressed with A850END is effective at removing arsenic and nitrate and is less susceptible to organic fouling. The system can treat 454,400 gal (or 372 BV) of water before regeneration is required. Regenerating dual resins with an alkaline brine periodically (i.e., once every four months) can prevent PFA300E fouling.
- The smaller resin bed was the key reason for not meeting the treatment target of 600,000 gal desired by the City of Vale. To meet this treatment target, an additional 55 to 60 ft<sup>3</sup> of PFA300E resin would be required.
- Both Arsenex II and A850END/PFA300E consistently removed vanadium from an average of 52 μg/L in raw water to <5 μg/L in treated water for at least 600,000 gal (i.e., 431 BV).
- Arsenic and nitrate peaking can occur if the system was operated beyond exhaustion. To avoid peaking, the IX system must be regenerated timely.
- The presence of 1.4 to 2.2 mg/L of total organic carbon (TOC) in raw water can result in severe resin fouling. Cleaning the fouled IX resin with a mixture of caustic/brine can be effective in restoring resin's volumetric and strong base capacities and moisture content, but may not improve resin run length to the same extent.
- Simulation of the IX resin run length by computer software was found to over-estimate the resin performance by as high as 50%.

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

- Under normal operating conditions, the skill requirements to operate the system were minimal, with a typical daily demand on the operator of 40 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 onsite repairs.
- Monitoring salt usage during a regeneration cycle can ensure that the IX resin is properly regenerated.

• Salt unloading can generate excessive salt dust that is corrosive to the electrical and mechanical components of the treatment system. Placing the salt saturators in a separate room can minimize the salt dust and corrosion issues.

### Process residuals produced by the technology:

- Residuals produced by the IX system included spent brine and rinse water. The volume of wastewater produced was dependent upon regeneration frequency and settings.
- Design of residual (brine) disposal should consider that projections of wastewater production may be low because of lower than projected run lengths.
- Ferric chloride treatment was ineffective at removing arsenic in spent brine discharged to the evaporation pond, probably caused by high total dissolved solids (TDS).

## Cost of the technology:

- Using the system's rated capacity of 540 gal/min (gpm) (or 777,600 gal/day [gpd]), the capital cost was \$732/gpm (or \$0.51/gpd) of the design capacity.
- Cost of salt supply was the significant add-on to the previous plant operation. The cost for salt and caustic soda was \$0.29/1,000 gal of water treated.
- Design of the salt saturator should consider the storage capacity required for entire truckload delivery of salt to achieve maximum cost savings.

### 3.0 MATERIALS AND METHODS

### 3.1 General Project Approach

Table 3-1 summarizes all predemonstration activities and respective completion dates. The performance evaluation study of the IX system at Vale, OR began on September 19, 2006, and ended on March 22, 2010. Table 3-2 summarizes 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 their respective MCLs of 10  $\mu$ g/L and 10 mg/L (as N) through the collection of water samples across the treatment train, as described in a Performance Evaluation Study Plan (Battelle, 2006). The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of equipment repairs and replacement. The plant operator recorded unscheduled downtime and repair information on a Repair and Maintenance Log Sheet.

Activity	Date
Introductory Meeting Held	December 2, 2004
Letter of Understanding Issued	March 2, 2005
Request for Quotation Issued to Vendor	March 10, 2005
Vendor Quotation Received by Battelle	March 30, 2005
Purchase Order Completed and Signed	April 5, 2005
Engineering Package Submitted to Oregon DHS DWP	July 22, 2005
Treatment System Permit Issued	August 11, 2005
Building Construction Begun	December 5, 2005
Building Construction Completed	February 28, 2006
Letter Report Issued	March 30, 2006
Treatment System Shipped	May 8, 2006
Treatment System Arrived	May 12, 2006
System Installation Completed	June 5, 2006
System Shakedown Completed	July 23, 2006
Study Plan Issued	September 14, 2006
Performance Evaluation Begun	September 19, 2006

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

DHS DWP = Department of Human Service Drinking Water Program

The required system O&M and operator skill levels 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 preventive maintenance activities, frequency of chemical and/or media handling and inventory, and general knowledge needed for relevant chemical processes and health and safety practices. The staffing requirements for the system operation were recorded on an Operator Labor Hour Log Sheet.

The quantity of residuals generated was estimated by tracking 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. Spent regenerant samples were collected and analyzed for chemical characteristics.

The system cost 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 tracking the capital cost for equipment, site engineering, and installation, as well as the O&M cost for salt supply, electrical power use, and labor.

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

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

### 3.2 System O&M and Cost Data Collection

The plant operator performed daily, weekly, and monthly system O&M and data collection according to instructions provided by Kinetico and Battelle. The plant operator recorded system operational data, such as pressure, flowrate, system throughput, hour meter, and regeneration counter readings on a Daily System Operation 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 then determine if Kinetico should be contacted for troubleshooting. The plant operator recorded all relevant information, including problem encountered, course of action taken, materials and supplies used, and associated cost and labor incurred, 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 pre-determined throughput setpoint. Occasionally, system regeneration was initiated by the operator for sampling purposes.

The capital cost for the arsenic-removal system consisted of the cost for equipment, site engineering, and system installation. The O&M cost consisted primarily of the cost for salt usage, electricity consumption, and labor. Salt was delivered to the treatment plant in bulk quantities by Handy Wholesale Products, Inc. in Burley, ID, on a monthly or as-needed basis. Salt usage was tracked through monthly invoices. Electricity consumption was obtained from utility bills for the study period. The labor for routine system O&M, system troubleshooting and repairs, and demonstration-related work, was recorded on an Operator Labor Hour Sheet. Routine O&M included activities such as completing field logs, 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 cost analysis.

## **3.3** Sample Collection Procedures and Schedules

System operation underwent three separate yet inter-related periods:

- Study Period I (from September 19, 2006 through January 14, 2008)
- Interim Period (from January 15, 2008 through February 9, 2009)
- Study Period II (from February 10, 2009 through March 22, 2010)

Sampling was performed only in Study Periods I and II with schedules noted in Section 3.3.2. The plant operator collected water samples from the treatment plant/distribution system and during regeneration either on a regular basis as summarized in Table 3-3, or through special run length/regeneration studies as described in Section 3.5. Table 3-3 provides sampling schedules and analytes measured during each regular sampling event. Figure 3-1 presents a process flow chart, along with applicable sampling/analysis schedules, for the IX system. Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2004).

**3.3.1 Source Water.** During the initial visit to the site on December 2, 2004, one set of source water samples was collected for detailed water quality analyses (Table 3-3). The source water also was speciated onsite for total and soluble As (including soluble As[III) and soluble As[V]), iron (Fe), manganese (Mn), uranium (U), and vanadium (V). Special care was taken to avoid agitation, which might cause unwanted oxidation.

**3.3.2** Treatment Plant Water. Routine treatment plant water samples were collected from September 20, 2006, through January 14, 2008 during Study Period I; and from March 25, 2009, through February 8, 2010 during Study Period II.

**Study Period I**: The plant operator collected water samples across the treatment train weekly on a fourweek cycle. For the first week of each four-week cycle, water samples were collected and speciated at four locations (i.e., at the wellhead [IN], after Vessel A [TA], after Vessel B [TB], and at the combined effluent from Vessels A and B [TT]) and analyzed for the analytes listed under the monthly treatment plant analyte list in Table 3-3. For the other three weeks, treatment plant samples were collected at three locations (i.e., IN, TA, and TB) and analyzed for the analytes listed under the weekly treatment plant analyte list in Table 3-3.

During Study Period I, several changes were made to the routine sampling schedule:

- Weekly sampling was not performed during the Thankgiving and Christmas holidays in 2006.
- One additional set of weekly samples was collected on February 6, 2007.
- The four-week-cycle treatment plant water sampling was discontinued on April 16, 2007, due to performance issue related to short run lengths (Section 4.4.3).
- From July 16, 2007 through January 14, 2008, limited weekly water sampling was conducted with samples collected at the TT location and analyzed for total As only.

**Study Period II**: Weekly sampling resumed on March 25, 2009, after dual resins had been installed. Water samples were collected at IN, TA, TB, and TT locations and analyzed for the same set of analytes done before plus TOC and V. Onsite water quality measurements and arsenic speciation were not performed during this study period. Treatment plant water sampling ended on February 8, 2010.

		No. of			a P
Sample Type	Sampling Locations <sup>(a)</sup>	Sampling Locations	Frequency	Analytes	Sampling Date
Source Water	IN	1	Once	Onsite: pH, temperature, DO, and ORP	12/02/04
				Offsite: As (total and soluble), As(III), As(V), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, Cl, F, NO <sub>2</sub> , NO <sub>3</sub> , NH <sub>3</sub> , SO <sub>4</sub> , SiO <sub>2</sub> , P, turbidity, alkalinity, TDS, and TOC	
Treatment Plant Water (Study Period I)	IN, TA, and TB	3	Weekly	Onsite: pH, temperature, DO, and ORP Offsite: As (total), Fe (total), Mn(total), NO <sub>3</sub> , SO <sub>4</sub> , SiO <sub>2</sub> , P, turbidity, alkalinity, and TDS	See Appendix D (09/20/06– 01/14/08)
	IN, TA, TB, and TT	4	Monthly	Same as those for weekly samples plus following: Offsite: As (soluble) As(III), As(V), Fe (soluble), Mn (soluble), V (total and soluble), F, Ca, and Mg	See Appendix D (09/20/06– 01/14/08)
Treatment Plant Water (Study Period II)	IN, TA, TB, and TT	4	Weekly	Offsite: As (total), Fe (total), Mn (total), V (total), NO <sub>3</sub> , SO <sub>4</sub> , SiO <sub>2</sub> , P, turbidity, alkalinity, TDS, and TOC	See Appendix D (03/25/09– 02/08/10)
Distribution System Water (Study Period I)	Two LCR and one Non- Residence Locations	3	Monthly	pH, alkalinity, As (total), Fe (total), Mn (total), Pb (total), and Cu (total)	Baseline: (06/15/05– 09/21/05) Monthly: (10/10/06– 04/10/07)
Residuals	Drain pipe off TA and TB	1 <sup>(b)</sup>	4 times	As (total), NO <sub>3</sub> , SO <sub>4</sub> , TDS, and pH	12/20/06, 01/31/07, 03/20/07, and 06/29/09

Table 3-3. Sampling and Analysis Schedule at Vale, OR

(a) Abbreviations in parentheses corresponding to sample locations in Figure 3-1: IN = at wellhead, TA = after Vessel A, TB = after Vessel B, and TT = conbined effluent.

(b) One composite sample from each regeneration step (i.e., reused brine draw, fresh brine draw, slow rinse, and fast rinse).

DO = dissolved oxygen; ORP = oxidation-reduction potential; TDS = total dissolved solids; TOC = total organic carbon



Figure 3-1. Process Flow Diagram and Sampling Locations/Analyses for Vale IX System

**3.3.3 Regeneration Wastewater.** Regeneration wastewater samples were collected three times in Study Period I and once in Study Period II. For each sampling event, one composite sample was collected from each of the four regeneration steps, i.e., spent brine draw, fresh brine draw, slow rinse, and fast rinse, during regeneration of one IX vessel. A portion of regeneration effluent was diverted to a 32-gal plastic container via a garden hose over the duration of each regeneration step. After the content in the container was thoroughly mixed, a portion of the liquid was transferred to a sample bottle and analyzed for the analytes listed under "Residuals" in Table 3-3. A total of four samples were collected during each sampling event. Arsenic speciation was not performed on these residual samples.

**3.3.4 Distribution System Water**. Water in the distribution system was sampled to assess the impact of the IX system on the water chemistry in the distribution system, specifically, the arsenic, nitrate, lead, and copper levels. Prior to the installation/operation of the treatment system, four sets of baseline distribution system water samples were collected on a monthly basis starting in June 2005. Three sampling locations were selected, including two residences within the city's sampling network under the Lead and Copper Rule (LCR) and one non-residential location. Following system startup, distribution system sampling continued on a monthly basis for seven months at the same three locations.

For the two LCR sampling locations, the plant operator delivered sample bottles to the residences and picked up sample bottles after sampling was complete. For the non-residential location, the plant operator collected samples directly from a spigot. Sampling followed 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 6 hr to ensure that stagnant water was sampled. The samplers recorded the date and time of last water use before sampling and the date and time of sample collection for calculation of stagnation time. Arsenic speciation was not performed on these samples. Analytes for the baseline and monthly distribution system water samples are listed in Table 3-3. Distribution system sampling discontinued after April 10, 2007.

# 3.4 Real-Time Arsenic Monitoring with ArsenicGuard<sup>TM</sup>

On November 19, 2008, an automated online arsenic analyzer, ArsenicGuard<sup>TM</sup> (Figure 3-2), was installed at the site to monitor total arsenic concentrations in the IX system influent (IN) and effluent (TT).

ArsenicGuard<sup>TM</sup> was developed by TraceDetect (Seattle, WA) to measure total inorganic arsenic in drinking and groundwater using anodic stripping voltammetry (ASV), a voltammetric method for quantitative determination of a specific ionic species. According to the vendor, the normal measurement range is 1 to 25  $\mu$ g/L. Because the analyzer also supports dilution up to 50:1, the measurement range can be extended upwards to 50 to 1,250  $\mu$ g/L. The accuracy in the normal range is 1  $\mu$ g/L or  $\pm 20\%$  (whichever is larger), and 50  $\mu$ g/L or  $\pm 20\%$  for the extended range. Because the sensor is only sensitive to arsenite, sample treatment is required prior to measurements. Each measurement begins with acidification of a sample to pH ~0.7 with 2M HCl, followed by reduction of arsenate to arsenite with 0.05N sodium thiosulfate. The analyzer then makes calibrated measurements by first scanning for arsenic in the treated sample, followed by adding a metered quantity of arsenite (the spike) and re-scanning. Upon completion of the measurements, the differences between the original peak and the spikes are used to calculate the concentration of the original sample. This method of standard additions is a way of calibrating the sensor for each sample matrix.

ArsenicGuard<sup>TM</sup> utilizes an electrochemical plating and stripping technique to measure part-per-billion (ppb) quantities of arsenic. The treated sample as mentioned above is drawn into a measurement cell, which houses a sensor along with a reference and an auxiliary electrode. The voltage of this electrochemical cell is manipulated so that arsenic is first plated onto the tip of the sensor during an



Figure 3-2. Real-Time Arsenic Analyzer – ArsenicGuard<sup>TM</sup>

accumulation phase, and then stripped off the sensor during a stripping phase. The duration of the accumulation phase is adjusted to ensure a good stripping signal, i.e., high concentrations are measured using a short accumulation time and low concentrations using a longer accumulation time. The sensing action occurs during the stripping phase of the measurement, during which the voltage of the electrochemical cell is ramped from the accumulation potential, due to the release of the stripping potential of arsenic. When arsenic is stripped off the sensor, it dissolves back into the test solution. This stripping process releases three electrons per arsenic atom and, therefore, the amount of arsenic accumulated on the tip of the sensor is proportional to the current measured during the stripping operation. This current is recorded for the treated sample as well as for the spiked sample in order to calculate the arsenic concentration in the original sample stream.

## 3.5 Run Length and Regeneration Elution Studies

**3.5.1 Run Length Studies**. Because routine weekly samples collected from the treatment plant represented only discrete data points on breakthrough of arsenic and nitrate from multiple service cycles, it was desirable to collect samples from complete service cycles to delineate breakthrough of arsenic, nitrate, and other competing anions and determine the appropriate run length of the IX system. The results of the studies were used to assess the system performance and to adjust the regeneration setpoint.

Table 3-4 summarizes sampling and analytical schedules of five run length studies (three in Study Period I and two in Study Period II), during which effluent samples were collected from either one or both IX vessels throughout five complete service cycles. The totalizer on the combined effluent ("TT") was used to track the volume of water treated since last regeneration. The totalizer was automatically reset to "zero" when Vessel A regeneration was completed, which signaled the beginning of a service cycle even

No.	Sampling Date	Study Period	Sampling Location	Regene- ration Setpoint (gal)	No. of Samples	Analytes
1	09/19/06– 09/22/06	Ι	ТА	905,300	10	As (total), $NO_3$ , $SO_4$ , V (total), P (total), and alkalinity
2	10/24/07– 10/26/07		ТА	600,000	7	As (total), NO <sub>3</sub> , SO <sub>4</sub> , and alkalinity
3	12/08/08- 12/10/08		IN <sup>(a)</sup> /TA	600,000	13	As (total), V (total), and silica
4	04/21/09- 04/22/09	II	TT	600,000	6	As (total), NO <sub>3</sub> , V (total), P (total), and TOC
5	06/29/09– 07/01/09		IN <sup>(a)</sup> /TA/ TB/TT <sup>(a)</sup>	600,000	26	As (total), NO <sub>3</sub> , SO <sub>4</sub> ,V (total), P (total), silica, alkalinity, pH, and TOC

Table 3-4. Sampling and Analysis Schedule for Run Length Studies

(a) Sample collected once during run length study.

though Vessel B regeneration was just started. The service cycle ended when the totalizer reached a set throughput value, which triggered the next regeneration cycle beginning with the Vessel A regeneration. Additional information for each of the studies is provided below.

*Run Length Study 1*: At system startup, a run length study was conducted by Battelle staff during September 19 through 22, 2006, to establish baseline performance of the IX system. Ten samples were collected from Vessel A effluent ("TA") during a service cycle. Sampling began shortly after the service cycle had started, and continued periodically, except during the night. Flow rates and throughput values were recorded at the time of sampling for run length calculations. Samples were analyzed for total As, V, and P, nitrate, sulfate, and total alkalinity.

*Run Length Study 2*: Following a caustic/brine cleaning on October 22, 2007, the operator performed a run length study from October 24 through 26, 2007, to determine the effectiveness of the cleaning. Seven samples were collected from Vessel A effluent ("TA") during a service cycle. Flow rates and throughput were recorded at the time of sampling. Samples were analyzed for total arsenic, nitrate, sulfate, and total alkalinity.

*Run Length Study 3*: Towards the end of Study Period I, the operator performed another run length study from December 8 through 10, 2008, to determine the extent of resin fouling. One raw water sample and 12 effluent samples from Vessel A ("TA") were collected during a service cycle. Flow rates and throughput values were recorded at the time of sampling. Samples were analyzed for total As, total V, and silica.

*Run Length Study 4*: At the startup of Study Period II, a run length study was conducted by the operator on April 21 through 22, 2009, to assess the performance of the dual resin IX system. Six samples were collected from the combined effluent from both vessels ("TT") during a service cycle. Flow rates and throughput values were recorded at the time of sampling. Samples were analyzed for total As, V, and P, nitrate, and TOC.

*Run Length Study 5*: To further confirm the performance of the dual resin system, Battelle staff conducted a run length study onsite from June 29 through July 1, 2009. Twelve effluent samples were collected from each vessel effluent during a service cycle. One influent (IN) and one combined effluent (TT) sample also were collected. Flow rates and throughput values were recorded at the time of

sampling. pH was monitored periodically onsite using a handheld pH probe. Samples were analyzed for total As, V, and P, nitrate, sulfate, total alkalinity, and TOC.

**3.5.2 Regeneration Elution Study**. In Study Period II, an elution study was conducted by Battelle staff members to evaluate the effectiveness of the regeneration process in removing arsenic, nitrate, and, especially, TOC from the dual IX resin beds and to explore the possibility of optimizing the regeneration process. Both the elution and follow-on run length studies were originally scheduled for March 2 through 4, 2009. However, all study activities had to be suspended due to an incident involving salt spills in the treatment plant building during a salt delivery/loading. The studies were rescheduled for June 29, 2009.

The IX resin vessels were set to regenerate for a volume throughput of 600,000 gal in a service cycle. Regeneration consisted of brine draw, slow rinse, and fast rinse with one vessel being taken offline for regeneration while the other remained in service. An 8% brine solution (specific gravity of 1.06) was used for brine draw. Raw water was used for slow and fast rinse. Figure 3-3 shows the experimental setup, including the use of a flow-through cell, for the elution study. A side stream of spent brine/rinse water was directed from the regeneration waste discharge line via a piece of <sup>3</sup>/<sub>8</sub>-in Tygon tubing to an 800-mL plastic beaker, or a flow-through cell, in which a Hanna HI 9635 conductivity/TDS probe (Hanna Instruments, Inc., Woonsockett, RI) and a VWR pH probe were placed (after calibration) for continuous measurements of TDS and pH. Because the flow-through cell was secured using a 3-in spring clamp just inside the rim of a 32-gal plastic container, the solution that overflowed the flow-through cell was collected into the plastic container. Upon completion of one regeneration step, the flow-through cell was immediately transferred to another 32-gal plastic container for continuing measurements. This process continued until all three regeneration steps were complete. A stopwatch was used to measure elapsed time. Table 3-5 lists the number of samples collected and analyzed during each regeneration step.



Figure 3-3. Regeneration Monitoring Setup

Regeneration Steps	Sampling Time (min)	Number of Grab Samples	Number of Composite Samples	Analytes
Brine Draw	0–21	Vessel A: 6 Vessel B: 6	Vessel A: 1 Vessel B: 1	Total As, V, and P, $NO_3$ , $SO_4$ ,
Slow Rinse	22–66	Vessel A: 7 Vessel B: 7	Vessel A: 1 Vessel B: 1	TDS, pH, temperature,
Fast Rinse	67–81	Vessel A: 3 Vessel B: 3	Vessel A: 1 Vessel B: 1	silica, TOC, and alkalinity

 Table 3-5. Sampling and Analysis Schedule for Resin Elution Study

Note that a caustic/brine cleaning was performed one week prior to the elution study. The cleaning was conducted to remove accumulated TOC, if any, from the dual IX resin beds. The caustic/brine cleaning followed the procedures presented in Appendix A.

# 3.6 IX Resin Cleaning

Due to deteriorating resin performance, resin core samples were collected from both IX vessels by Kinetico in March 2007 and shipped to Purolite for analyses. The resin samples were cleaned in Purolite's laboratory with either 10% brine or a mixture of 2% caustic and 10% brine and analyzed for moisture content, volumetric capacity, strong base capacity, and total organic fouling. The results are discussed in Section 4.4.3.

In light of positive laboratory results with the use of 2% caustic/10% brine in Purolite's laboratory and positive field results with 5% caustic/10% brine at another EPA arsenic removal demonstration site in Fruitland, ID (where similar fouling issues were experienced with its Purolite A300E resin and the Vale operators were invited to observe field cleaning in June 2007), a decision was made to perform resin cleaning at Vale, OR using similar procedures presented in Appendix A. Field cleaning was performed by Kinetico in late October 2007. The caustic/brine mixture was prepared by dispensing two 55-gal drums of 50% NaOH into the brine day tank using a drum pump, followed by filling the day tank with saturated brine up to 1,050 gal. The specific gravity of the mixture was about 1.042, corresponding to a 6% brine.

The caustic/brine mixture was drawn from the day tank downward through Vessel A or B for about 20 min. By the end of brine draw, a hand valve was closed manually to allow the resin to soak into the caustic/brine mixture for 30 min. Slow and then fast rinse were then followed for about 45 and 15 min, respectively. Upon completion of the field cleaning in October 2007, a resin core sample was taken from Vessel A using a piece of 2-in diameter and 4 ft long polyvinyl chloride (PVC) pipe and sent to Purolite for analyses. The top, middle, and bottom sections of the core sample were analyzed individually for the same set of analytes mentioned above.

# 3.7 Sampling Logistics

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

**3.7.1 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, 2004).

**3.7.2 Preparation of Sampling Coolers.** For each sampling event, a sample cooler was prepared with the appropriate number and type of sample bottles, disc filters, and/or speciation kits. All sample bottles were new and contained appropriate preservatives. Each sample bottle was taped with a preprinted, colored-coded, and waterproof label. The sample label consisted of sample identification (ID), date and time of sample collection, collector's name, site location, sample destination, analysis required, and preservative. The sample ID consisted of a two-letter code for a specific water facility, sampling date, a two-letter code for a specific sampling location, and a one-letter code 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 for each sampling location), which were then packed 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. In addition, a packet containing all sampling and shipping-related supplies such as latex gloves, sampling instructions, chain-of-custody forms, prepaid FedEx air bills, and bubble wrap also was placed in the cooler. Except for the operator's signature, the chain-of-custody forms and prepaid FedEx air bills had already been completed with the required information. The sample coolers were shipped via FedEx to the facility approximately 1 week prior to the scheduled sampling date.

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

Samples for metal analyses were stored at Battelle's inductively coupled plasma-mass spectrometry (ICP-MS) laboratory. Samples for other water quality analyses were packed in coolers and picked up by couriers from American Analytical Laboratories (AAL) in Columbus, OH, or TCCI Laboratories in New Lexington, OH, both of which were under contract with Battelle for this demonstration study. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposal. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

## 3.8 Analytical Procedures

The analytical procedures described in detail in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2004) were followed by Battelle ICP-MS, AAL, and TCCI Laboratories. Laboratory quality assurance/quality control (QA/QC) of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection 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.

Field measurements of pH, temperature, DO, and ORP were conducted by the plant operator using a WTW Multi 340i handheld meter, which was calibrated for pH and DO prior to use following the procedures provided in the user's manual. The ORP probe also was checked for accuracy by measuring the ORP of a standard solution and comparing it to the expected value. The plant operator collected a water sample in a clean, plastic beaker and placed the Multi 340i probe in the beaker until a stable value was obtained.

### 4.0 RESULTS AND DISCUSSION

### 4.1 Facility Description

The City of Vale, located in eastern Oregon, has a population of 1,976. In 2004, the average daily demand for water was 263,000 gpd, with the peak daily demand of 388,000 gpd occurring in July 2004. As shown in Table 4-1, the water demand was met by seven groundwater wells (Wells No. 1 through No. 7), operating on a rotating basis to achieve a combined flowrate of 525 gpm. This flowrate represents a hydraulic utilization of 35% based on the average daily demand and a corresponding run time of 8.3 hr/day. Water from the individual wells was blended and then chlorinated in a centralized treatment building. In 2004, Wells No. 1 through No. 5 each operated for approximately 3 to 8.5 hr/day, while Wells No. 6 and No. 7 were used only as backup wells. The City blended raw water from the various wells in order to minimize nitrate concentrations in water entering the distribution system. In addition to the seven wells, a 500-gpm groundwater well on Washington Street in downtown also serves as a backup well.

Well	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
Diameter (in)	8	8	8	8	8	8	8
Depth of Well (ft)	33	33	33	33	28.5	33	28.5
Screened Interval (ft bgs)	18-28	18-28	18-28	18–28	13.5-23.5	18-28	13.5-23.5
Static Water Level (ft bgs)	8 to 9	8 to 9	8 to 9	8 to 9	NA	NA	NA
Pump Capacity (gpm)	200	100	180	100	NA	NA	NA

Table 4-1. Construction Details of Wells No. 1 to No. 7

bgs = below ground surface; NA = not available

Wells No. 1 though No. 7 and the treatment building are located in the airfield of the county airport. The treatment building was 10 ft tall and built to the Federal Aviation Administration height limit (Figure 4-1). The Kinetico system was designed to incorporate lower-profile tanks so that the new building could be constructed near the airfield runway. Due to lack of sewer tie-ins at the airfield, a 1.8-acre evaporation basin along with a 0.2-acre drying bed both lined with a high-density polyethylene (HDPE) liner was constructed onsite to hold the regeneration waste.

A MIOX sytem was used to generate sodium hypochlorite onsite. As shown in Figure 4-2, the MIOX system consisted of a 78-gal salt drum, an electrolytic cell, an 8-gal/hr (gph) metering pump, and a 500-gal storage tank for the sodium hypochlorite solution. The target chlorine dosage was 0.2 mg/L (as  $Cl_2$ ) and the target residual level in treated water was 0.025 mg/L (as  $Cl_2$ ). Once chlorinated, the water flowed under pressure to a 200,000-gal atmospheric reservoir installed at the airport in 2001 and then was boosted by two booster pumps before entering the city's distribution system and two older reservoirs located on the hillside east of town. These reservoirs were built in 1917 and 1977 and had a capacity of 105,000 and 750,000 gal, respectively. Due to the additional pressure loss across the new arsenic and nitrate treatment system, a booster pump with a capacity of 600 gpm at 130 ft  $H_2O$  (56 psi) total dynamic head (TDH) was installed to raise the influent pressure and to supply water during system regeneration.

**4.1.1 Source Water Quality**. Analytical results from the raw source water sampling event held on December 2, 2004, are presented in Table 4-2 and compared to the data collected by the vendor and the city for the site selection of this demonstration study. When onsite, a Battelle staff member measured pH, temperature, DO, and ORP using a WTW 340i handheld meter. In addition, source water was filtered for



Figure 4-1. Existing Well House in Vale, OR



Figure 4-2. Existing Chlorination System in Vale, OR

	Facility		Kinetico	Battelle	
Parameter	Units	Data	Data	D	ata
			Not		
Date		Various	Specified	12/02/04	07/23/08
pH	S.U.	7.5	7.4	7.5	NA
Temperature	°C	NA	NA	13.1	NA
DO	mg/L	NA	NA	4.8	NA
ORP	mV	NA	NA	236	NA
Conductivity	umhos	NA	775	NA	NA
Total Alkalinity (as CaCO <sub>3</sub> )	mg/L	NA	284	158	278
Hardness (as CaCO <sub>3</sub> )	mg/L	NA	173	181	120
Turbidity	NTU	NA	NA	< 0.1	0.2
TDS	mg/L	NA	NA	446	458
TOC (as C)	mg/L	NA	NA	2.1	NA
Nitrate (as N)	mg/L	8 to 12	NA	4.1	3.5
Nitrite (as N)	mg/L	NA	NA	< 0.01	NA
Ammonia (as N)	mg/L	NA	NA	< 0.05	NA
Chloride	mg/L	NA	25.3	15.0	NA
Fluoride	mg/L	NA	0.6	0.5	NA
Sulfate	mg/L	83	84	75.0	63.9
Silica (as SiO <sub>2</sub> )	mg/L	NA	53.5	56.7	57.7
Phosphorus (as P)	mg/L	NA	< 0.5	0.3	0.3
As(total)	µg/L	20	18	16.7	20.5
As (total soluble)	μg/L	NA	NA	16.5	NA
As (particulate)	µg/L	NA	NA	0.2	NA
As(III)	µg/L	NA	NA	1.9	NA
As(V)	µg/L	NA	NA	14.6	NA
Fe (total)	μg/L	NA	<30	<25	<25
Fe (soluble)	μg/L	NA	NA	<25	NA
Mn (total)	μg/L	NA	<10	1.1	0.3
Mn (soluble)	ug/L	NA	NA	0.8	NA
U (total)	μg/L	NA	NA	6.1	NA
U (soluble)	µg/L	NA	NA	6.3	NA
V (total)	ug/L	NA	NA	46.8	51.2
V (soluble)	ug/L	NA	NA	50.4	NA
Na (total)	mg/L	164	114	110	NA
Ca (total)	mg/L	NA	46.5	51.1	30.0
Mg (total)	mg/L	NA	14	13.0	10.8

 Table 4-2.
 Vale, OR Source Water Data for Combined Wells No. 1 to No. 7

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

soluble arsenic, iron, manganese, uranium, and vanadium, and speciated for As(III) and As(V). Historical data from individual wells collected by EPA and the city are given in Tables 4-3, 4-4, and 4-5. Overall, Battelle's data are comparable to those provided by the other parties with the exception of the nitrate results that depend on the combination of wells as discussed previously. The analytical results of the source water sampling and implications for water treatment are briefly discussed below.

Parameter	Unit	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7
pH	S.U.	8.2	8.2	8.4	-	-	-	-
Conductivity	umhos	626	492	722	-	-	-	-
Alkalinity	mg/L	241	207	275	-	-	-	-
Hardness	mg/L	142	144	136	-	-	-	-
TDS	mg/L	343	390	833	-	-	-	-
Nitrate (as N)	mg/L	4.7	2.4	6.9	-	12.7	16.7	14.4
Nitrite (as N)	mg/L	< 0.01	< 0.01	0.01	-	< 0.01	< 0.01	< 0.01
Fluoride	mg/L	0.6	0.6	0.5	-	-	-	-
Sulfate	mg/L	77	51	91	-	-	-	-
As (total)	μg/L	23	22	16	-	10	20	25
Fe (total)	μg/L	820 <sup>(b)</sup>	480 <sup>(b)</sup>	5,760 <sup>(b)</sup>	-	-	-	-
Mn (total)	μg/L	50	70	280	-	-	-	-
Na (total)	mg/L	160	76	200	-	-	-	-

Table 4-3. Wells No. 1 to No. 7 Water Quality Data from June 2000 to August 2000<sup>(a)</sup>

(a) Samples analyzed by Analytical Laboratories, Inc. in Boise, ID.

(b) Iron levels elevated in these wells compared to other historical source water data.

Table 4-4. Wells No. 1 to No. 7 Water Quality Data from EPA (December 2004)

Parameter	unit	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7
As (total)	μg/L	16.0	12.0	10.0	14.0	13.0	28.0	28.0
Fe (total)	µg/L	43.8	5.2	10.5	11.8	14.5	23.7	66.5
Mn (total)	μg/L	ND	ND	0.9	0.7	ND	ND	1.8
P (total)	mg/L	0.27	0.29	0.28	0.21	0.28	0.36	0.40

ND = not detected

Table 4-5.	Wells No. 1 to No. 7 Nitrate Concentrations (mg/L [as N]) from Source
	(February 2001 to October 2004) <sup>(a)</sup>

Sampling Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7
02/28/01	5.46	5.06	7.10	11.50	14.70	12.50	13.30
07/03/01	5.78	2.14	6.03	11.70	13.70	12.20	10.60
08/14/01	5.38	4.15	6.08	12.00	13.60	11.70	5.52
08/21/01	5.54	4.84	6.02	-	-	11.00	5.42
02/12/02	6.24	5.39	6.26	13.70	-	-	-
02/19/02	-	-	-	-	13.60	11.30	16.90
05/08/02	7.12	5.60	10.70	14.30	13.80	14.50	18.00
08/14/02	6.40	5.36	10.70	13.50	12.10	12.20	9.14
11/13/02	4.99	4.09	7.83	8.86	8.36	9.21	10.70
05/13/03	5.54	4.24	8.47	10.50	9.85	14.50	18.90
09/09/03	3.21	2.14	3.00	9.57	7.48	10.50	10.80
11/04/03	2.86	2.81	3.12	6.82	6.63	10.30	10.50
02/10/04	4.10	3.03	5.34	5.17	7.43	12.70	13.70
05/11/04	2.70	1.88	3.12	5.24	4.80	12.60	14.30
10/12/04	2.37	1.75	3.42	5.82	4.81	7.38	8.14

(a) Samples analyzed by Magic Valley Labs in Twin Falls, ID.

*Arsenic*. Total arsenic concentrations in the blended source water ranged from 16.7 to 20  $\mu$ g/L (Table 4-2). Total arsenic concentrations in raw water from the individual wells ranged from 10 to 28  $\mu$ g/L (Tables 4-3 and 4-4). Based on the source water sampling results obtained by Battelle, out of 16.7  $\mu$ g/L of total arsenic, 14.6  $\mu$ g/L existed as soluble As(V). Therefore, As(V) was the predominating arsenic species. At raw water pH values of 7.4 to 7.5, As(V) is present primarily as HAsO<sub>4</sub><sup>2-</sup>, which can be removed electrostatically by anion exchange resin.

*Nitrate*. The City blended source water from various wells to minimize nitrate concentrations in the blended water to below the 10 mg/L MCL. As shown in Table 4-5 and Figure 4-3, nitrate concentrations in Wells No. 1 and No. 2 were less than 7.1 mg/L (as N) and exhibited a decreasing trend starting from 2002. Nitrate concentrations in Well No. 3 peaked at 10.7 mg/L (as N) and then decreased to just over 3.0 mg/L (as N) by 2004. Wells No. 4 to No. 7 had historical nitrate levels mostly over 10 mg/L and as high as 18.9 mg/L (as N). Concentrations in wells No. 4 and No. 5 also showed a significant decreasing trend with concentrations measured at 4.8 to 5.8 mg/L (as N) by October 2004. Concentrations in Wells No. 6 and No. 7 remained elevated from 2000 through 2004; the measurements made in October 2004 were less than 10 mg/L (as N) for both wells. Combined source water values were 8 to 12 mg/L (as N) from the facility and 4.1 mg/L (as N) from Battelle (Table 4-2). Similar to arsenic, the water treatment process relied upon the exchange of nitrate in source water with chloride on the resin.



Figure 4-3. Historic Nitrate Data from Wells No. 1 Through No. 7

*Sulfate*. Sulfate concentrations ranged from 51 to 91 mg/L in Wells No. 1 through No. 3 (Table 4-3) and from 75 to 84 mg/L in combined wells (Table 4-2). Because sulfate is preferred over arsenate and nitrate and because of its higher concentrations, sulfate competes strongly with arsenic and nitrate for exchange sites.
*Iron, Manganese, Silica, and TOC*. Iron and manganese concentrations in source water were less than 30 and 10  $\mu$ g/L, respectively, and, therefore, should not cause iron or manganese fouling to the IX resin. Silica concentrations averaged 56 mg/L (as SiO<sub>2</sub>); polymerization of silica on the resin surface could adversely impact the IX process. TOC measured at 2.1 mg/L; it is well known that AIX resins are susceptible to fouling by dissolved organic matter (DOM) (Boodoo, 2004).

*Other Water Quality Parameters.* Total dissolved solids (TDS) measured at 446 mg/L, a level which may impact the performance of the IX resin. Total phosphorus concentrations in the individual wells ranged from 0.2 to 0.4 mg/L (as P) (Table 4-4), which could affect the exchange of arsenic and nitrate anions. Concentrations of uranium and vanadium were measured at 6.1 and 46.8  $\mu$ g/L, respectively, which could compete with arsenic and nitrate for exchange sites.

Total alkalinity in source water ranged from 158 to 284 mg/L (as CaCO<sub>3</sub>); bicarbonate anions also compete for exchange sites, especially immediately after resin regeneration. Removal of bicarbonate causes the treated water pH to decrease, making the treated water corrosive as it enters the distribution system. The pH value of raw water was 7.4 or 7.5. Unlike adsorptive media, IX resins are not sensitive to water pH.

**4.1.2 Distribution System Water Quality.** The distribution system sampling for the EPA demonstration study included three residences (i.e., 629 15th Street North, 780 15th Street North, and 252 B Street West) supplied by the combination of Wells No. 1 through No. 7. These locations are a good representation of the distribution system and the first two also are part of the City's sampling network for the LCR. The distribution system consisted of PVC mains with HDPE or copper service lines to individual homes.

Water in the distribution system was sampled once a year for haloacetic acids (HAA5) and trihalomethanes (TTHMs) under EPA's Disinfection Byproducts Rule. In 2004, the HAA5 level was 0.009 mg/L, compared to the MCL of 0.06 mg/L. The TTHMs level was 0.03 mg/L, compared to the MCL of 0.08 mg/L. The treated water also was sampled once every three years at 10 residences under EPA's LCR. During the latest sampling round in 2002, the lead concentration was 0.004 mg/L, compared to the action level of 0.015 mg/L, and the copper concentration was 0.865 mg/L, compared to the action level of 1.3 mg/L.

## 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; and 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 an AIX resin. Once its capacity is exhausted, the resin is regenerated with a brine solution containing high concentrations of chloride to displace the arsenate and nitrate on the resin. Strong-base anionic (SBA) IX resins are commonly used for arsenate and nitrate removal. Resin capacity typically is not sensitive to water pH (in the range of 6.5 to 9.0). An SBA IX resin tends to have a higher affinity for more highly charged anions, resulting in a general hierarchy of selectivity as follows:

$$SO_4^{2-} > HAsO_4^{2-} > NO_3^{-} > NO_2^{-} > CI^{-} > H_2AsO_4^{-}, HCO_3^{-} >> Si(OH)_4; H_3AsO_4^{-}$$

Because sulfate is preferred over arsenate and nitrate and because its concentration is at least three orders of magnitude higher than those of arsenic, it is a major competing anion to arsenate 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 >500 mg/L of TDS and

>150 mg/L of sulfate. Also, particulates in feed water can potentially foul the SBA IX resin, and, therefore, must be removed prior to IX process.

Most nitrate removal plants use either a nitrate selective resin or an SBA Type II or Type I resin. Nitrate selective resins typically have triethylamine functional groups, which show higher selectivity for hydrophobic anions (such as nitrate and perchlorate) over hydrophilic divalent anions (such as sulfate and arsenate). Therefore, sulfate and arsenate will break before nitrate. Since arsenate is less selective than sulfate, it will break before sulfate. Operating to arsenic breakthrough using a nitrate selective resin has two major issues: (1) the operating cost is higher because of a shorter run length to arsenic breakthrough than nitrate breakthrough and (2) it is more expensive to monitor arsenic breakthrough than nitrate breakthrough in real time. Therefore, a nitrate selective resin would not be a good choice for removing both arsenic and nitrate (Boodoo, 2004). When sulfate is relatively low, Type II and Type I SBA resins are preferred due to their lower prices. For drinking water applications, Type II is preferred over Type I because of a fishy odor associated with Type I resins.

Two types of SBA IX resins were evaluated during the demonstration study at Vale. Purolite Arsenex II was used in Study Period I. However, due to organic fouling, the resin had to be replaced with PFA300E top-dressed with A850END, in Study Period II. These resins are NSF International (NSF) Standard 61 approved for use in drinking water treatment. Their physical and chemical properties are presented in Table 4-6 and highlighted as follows:

**Arsenex II** was claimed by the vendor as a proprietary, arsenic selective IX resin, specifically designed for arsenic removal in the presence of high sulfate. However, it was not clear whether the term "arsenic selective" actually meant higher affinity for arsenic than sulfate (like the term "nitrate selective" for higher affinity for nitrate than sulfate). No literature was available for this resin, which was posted on Purolite's Web site.

**PFA300** is a gel-Type II SBA resin, which has a high operating capacity at a low regeneration level because of its uniform particle size distribution (i.e., uniformity coefficient is 1.2). It is less susceptible to organic fouling than standard gel-type SBA resins. Except for its narrower size distribution, PFA300 is very similar to A300E, which was evaluated for arsenic and nitrate removal at another EPA demonstration site in Fruitland, ID (Wang et al., 2010). The physical and chemical properties of A300E also are listed in Table 4-6 for reference.

**A850END** is specially produced from A850 with a narrower size grading of 300- to 600-µm diameter. A850 is a gel-Type I SBA resin with an acrylic matrix. This gel or highly macroporous acrylic-based SBA Type I resin can remove most naturally occurring DOM, such as humic and fulvic acids, to at least 50 to 80%. A850END can be regenerated with lower levels of sodium hydroxide than those required for a polystyrene-based Type I resin.

Resin run lengths for arsenic and nitrate removal at Vale were estimated by Purolite using its computerized simulator. Figure 4-4 shows the simulation for ArseneX II based on a modeling run with 20  $\mu$ g/L of arsenic, 53 mg/L of nitrate (as N), and 83 mg/L of sulfate in water. The results indicate that bicarbonate breaks first, followed by nitrate, arsenic, and sulfate. Nonetheless, breakthrough of arsenic at 10  $\mu$ g/L would occur first at 680 BV followed by nitrate breakthrough at 9 mg/L (as N) at 740 BV (1 BV = 220 ft<sup>3</sup>). These run lengths, however, were significantly over-predicted than the actual run lengths (generally less than 431 BV or 600,000 gal) as discussed in Section 4.4.3.

	Study Period I	Study ]	Period II	Reference
Parameters	Arsenex II	<b>A850</b> <sup>(a)</sup>	PFA300	A300E
Polymer Structure	Gel polystyrene	Gel polyacrylic	Gel polystyrene	Gel polystyrene
	crosslinked with	crosslinked with	crosslinked with	crosslinked with
	DVB	DVB	DVB	DVB
Functional Group	Dimethyl ethanol	Trimethylamine	Dimethyl ethanol	Dimethyl ethanol
	amine		amine	amine
Physical Form/Appearance	Opaque spherical	Clear spherical	Amber spherical	Clear spherical
	beads	beads	beads	beads
Whole Bead Count	95% minimum	-	95% minimum	-
Resin Type	SBA Type II	SBA Type I	SBA Type II	SBA Type II
Ionic Form, as Shipped	Cl	Cl	Cl	Cl
Shipping Weight (lbs/ft <sup>3</sup> or g/L)	43	42.5–45.6 or	43 or 690	43–45 or
		680–730		690-720
Specific Gravity (g/mL)	-	1.09	1.10	1.09
Mesh Size (U.S. Standard) (Wet)	$16 \times 50$	-	25  imes 40	$16 \times 50$
Bead Size Range (mm)	0.3–1.2	0.60-0.85	+0.710 mm <1%;	0.3-1.2
_			-0.425 mm <1%	
Uniformity Coefficient	-	1.70	1.20	1.70
Moisture Retention (%)	42–54	57-62	40–45	40–45
Reversible Swelling	$\text{Cl}^{-}$ to $\text{SO}_4^{2^-}/\text{NO}_3^{-^-}$	Cl <sup>-</sup> to OH <sup>-</sup>	Cl <sup>-</sup> to OH <sup>-</sup>	Cl <sup>-</sup> to OH <sup>-</sup>
	Negligible	15% (max)	10% (max)	10% (max)
Total Exchange Capacity, Cl <sup>-</sup>	1.0	1.25	1.4	1.4
Form (eq/L) (wet, volumetric)				
pH Range	0-14	1–10	No limit	No limit
Maximum Temperature Limit	100/212	85/185	85/185	85/185
(°C/°F)				

Table 4-6. Physical and Chemical Properties of IX Resins

Source: Purolite

DVB = divinylbenzene; SBA = strong base anion

(a) A850END specially produced from A850 with a narrower size grading of 300- to 600-µm diameter. Some properties, such as bead size range and uniformity coefficient expect to vary from those of A850.

Figure 4-5 presents results of a simulation for PFA300E done in June 2008. Similar to the simulation for Arsenex II, nitrate breaks first, followed by arsenic and sulfate. But unlike Arsenex II, nitrate breakthrough at 10 mg/L (as N) would occur first at approximately 650 BV followed by arsenic breakthrough to 10  $\mu$ g/L at approximately 700 BV. The vendor recommended regenerating at 523 BV with 10 lb/ft<sup>3</sup> of salt. In January 2009, Purolite updated the run length simulation after receiving additional source water quality data for Vale. The updated run length to 10-mg/L nitrate (as N) breakthrough was 604 BV, corresponding to 993,940 gal of throughput (1 BV = 220 ft<sup>3</sup>).



Figure 4-4. Simulation of Arsenex II Resin Run Length



Figure 4-5. Simulation of A850END/PFA300E Resin Run Length (June 2008)

**4.2.2 Treatment Process**. The Vale IX system utilized the packed-bed anionic IX technology to remove arsenic and nitrate from source water. Figure 4-6 is a process schematic of the treatment system. The process equipment included two banks of five skid-mounted bag filters, two skid-mounted resin vessels, two salt saturators, two brine day tanks, three pre-wired brine transfer/injection pumps, one air compressor, one post-chlorination system, as well as associated valves, sample ports, pressure gauges, and flow elements/controls. The IX system was fully automated and controlled by a central control panel consisting of a programmable logic control (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, and check the status of alarms. The modem allowed the vendor to remotely dial in for monitoring and troubleshooting. All pneumatic valves were constructed of PVC and all plumbing was Schedule 80 PVC solvent bonded. Table 4-7 summarizes the design specifications of the IX system.



Figure 4-6. Schematic of Kinetico's IX-263 As/N Removal System for Vale, OR

System Component/Parameter	Study Period I	Study Period II							
	Pre-treatment								
Bag Filter Assembly	Two banks of five 20-µm	5-µm filter bags							
	bag filters in parallel								
IX Vessels and Media Beds									
Vessel Size (in)	63 D × 86 H	Same							
Cross-Sectional Area (ft <sup>2</sup> /vessel)	21.6	Same							
Number of Resin Vessels	2	Same							
Configuration	Parallel	Same							
Resin Type(s)	Purolite Arsenex II	Purolite A850END/PFA300E							
IX Resin Quantity (ft <sup>3</sup> /vessel) <sup>(a)</sup>	110	15 and 95 ft <sup>3</sup> , respectively							
Flint Gravel Support Media (ft <sup>3</sup> /vessel)	4	Same							
	Service								
Design Flowrate (gpm)	540	Same							
Hydraulic Loading Rate (gpm/ft <sup>2</sup> )	12.5	Same							
Specific Flowrate (gpm/ft <sup>3</sup> )	2.45	Same							
EBCT (min)	3.0	Same							
Estimated Working Capacity (BV)	550-680	523-604							
Volume Throughput (gal)	905,300-1,119,280	860,650–993,940							
	Regeneration								
Regeneration Mode	Co-current downflow	Same							
Regeneration Level (lb salt/ft <sup>3</sup> resin)	12	10							
Brine Concentration (%)	10	8							
Reused Brine Draw Duration, Flowrate,	15 min, 50 gpm, 750 gal	Discontinued							
and Volume <sup>(b)</sup>									
Fresh Brine Draw Duration, Flowrate,	17 min, 50 gpm, 850 gal	21 min, 64 gpm, 1,344 gal							
and Volume <sup>(b)</sup>									
Slow Rinse Duration, Flowrate, and	40 min, 50 gpm, 2,000 gal	45 min, 44 gpm, 1,980 gal							
Volume <sup>(b)</sup>									
Fast Rinse Duration, Flowrate, and	20 min, 220 gpm, 4,400	15 min, 260 gpm, 3,900 gal							
Volume <sup>(b)</sup>	gal								
Wastewater Volume per Regeneration	7,250 (per vessel),	7,224 (per vessel),							
Event (gal) <sup>(6)</sup>	14,500 (total)	14,448 (total)							
Salt Consumption per Regeneration	760 (per vessel),	760 (per vessel),							
Event (lb)	1,520 (total)	1,520 (total)							
	Brine System								
Brine Day Tank Size (in)	61 D × 97 H (two)	Use one tank only							
Brine Day Tank Material	HDPE	Same							
Fresh Brine Transfer Pump	1.5 hp, max. 90 gpm @ 25 ft H <sub>2</sub> O TDH	Same							
Fresh Brine Venturi Eductor	2 in (draw factor 0.75 to $1.0$ )	Discontinued							
Reused Brine Injection Pump	5 hp, max. 200 gpm @ 45 ft H <sub>2</sub> O TDH	Discontinued							
Salt Saturator Size (ton)	11 (two)	Same							
Salt Saturator Material	Fiberglass	Same							
	Post-treatment	<del></del>							
Target Chlorine Residual (mg/L [as Cl <sub>2</sub> ])	0.025	Same							

Tuble + 7. Design opermentions of 12 bysten	Table 4-7.	Design	<b>Specifications</b>	of IX S	ystem
---	------------	--------	-----------------------	---------	-------

(a) Actual amounts were 93 ft<sup>3</sup> for Arsenex II and 16.7 and 81.7 ft<sup>3</sup> for A850END and of PFA300E, respectively.

(b) Source: Kinetico "Brine Waste Minimization Memo for Vale, OR" dated April 4, 2006.

Major process steps and system components are presented as follows:

• Intake. Raw water from Wells No. 1 through 7 was pumped to the treatment building and then combined at a common header. To overcome the anticipated headloss from the treatment system, the incoming water was boosted by a 25-horsepower (hp) booster pump to meet the minimum influent pressure requirement of the IX system. Two booster pumps (one on standby), each rated for 600 gpm at 130 ft H<sub>2</sub>O head (or 56 psi), and a three-phase Danfoss VLT8000 series variable frequency drive (VFD) were installed at the common header. System inlet piping and a booster pump is shown in Figure 4-7.



Figure 4-7. System Inlet Piping and Booster Pump

• Sediment Filtration. Prior to entering the IX resin vessels, raw water was filtered through two parallel, skid-mounted bag filter assemblies to remove sediment. Each assembly consisted of five parallel FSI X100 polypropylene housing units, each lined with a 20- $\mu$ m (in Study Period I) or 5- $\mu$ m filter bag (in Study Period II). Each filter was rated at 65 gpm, giving a total capacity of 325 gpm per assembly or 650 gpm for both. Filter bags in the two assemblies were cleaned or replaced when headlosses across each assembly had reached 10-to 15-lb/in<sup>2</sup> (psi) levels. Figure 4-8 presents a photograph of the bag filter assemblies. This filtration step was used to prevent the resin beds from being clogged and/or fouled by particulates.



Figure 4-8. Photograph of Two Banks of Cartridge Filters

• Ion Exchange. After passing through the bag filters, water flowed downward through two 63 in × 86 in pressure vessels configured in parallel (Figures 4-9 and 4-10). Mounted on a polyurethane-coated, welded steel frame, the pressure vessels were of fiber reinforced plastic (FRP) construction and rated for 150 psi working pressure. Each vessel had a 6-in top and bottom flanges, and was equipped with a diffuser-style upper distributor and a hub and laterals-style underdrain. All pneumatic valves were PVC, and all plumbing was Schedule 80 PVC solvent bond. By design, each vessel was to be loaded with 4 ft<sup>3</sup> of flint gravel support on the bottom, 110 ft<sup>3</sup> of resin in the middle (about 61 in deep), and 4 ft<sup>3</sup> of polyethylene filler beads on the top. The filler material was intended to prevent resin from being washed away in an upflow, counter-current regeneration. Filler beads were not added because they were not needed for co-current regeneration.

The IX system was designed for 540 gpm, yielding a hydraulic loading rate of 12.5 gpm/ft<sup>2</sup> and an empty bed contact time (EBCT) of 3 min. Each vessel was equipped with a 270-gpm flow restrictor on the effluent piping to help balance the flow between the two vessels and prevent overrun during regeneration. An insertion-type paddle wheel flow element was installed on the combined effluent line to register flowrate and throughput of the product water since last regeneration. When a pre-determined throughput setpoint was reached, Vessel A was automatically taken out of service for regeneration, whereas Vessel B remained online for treatment. Once Vessel A regeneration was complete, the totalizer was automatically reset to zero and began to register the water treated by Vessel A. Meanwhile, Vessel B was taken out of service for regeneration. After Vessel B regeneration was complete, the totalizer registered the amount of water treated by both vessels.



Figure 4-9. Photographs of Arsenic/Nitrate Removal IX System at Vale, OR



Figure 4-10. Skid-Mounted Piping/Valving Rack

For the study purposes, two additional insertion-type paddle wheel flow elements were installed on the individual vessel outlet to accurately track the throughput from each vessel. These flow elements were not wired to the PLC and did not reset to zero after each regeneration.

• **Resin Regeneration.** The purpose of resin regeneration is to restore exhausted resin back to its chloride form for service. The regeneration process can either be co-current (i.e., in the same direction of the process flow) or counter-current (i.e., in the opposite direction of the process flow). A counter-current regeneration maximizes the chemical's ability to regenerate the resin and minimize the volume of waste. The vendor decided to use downflow, co-current regeneration, which was thought to be superior to upflow, counter-current regeneration for arsenic and nitrate because the counter-current regeneration would force the contaminants concentrated at the bottom of the resin bed back through the entire bed, thus leaving more contaminants in the bed (Clifford et al., 1987, 2003). In addition, co-current regeneration was easier to implement. One drawback of co-current regeneration is arsenic/nitrate leakage, which may occur in the early stage of a service cycle, as observed at Fruitland (Wang et al., 2010).

The Vale system was retrofitted in July 2006 by Kinetico to be capable of counter-current regeneration, if desired. However, due to a series of mechanical problems that occurred to the Fruitland system after similar retrofitting (from co-current to counter-current to curb arsenic/nitrate leakage), the Vale system remained co-current throughout the entire study period.

Regeneration could be initiated either automatically based on a throughput setpoint or manually by pressing a push-button on the PLC. Once regeneration was initiated, it followed a sequence of four pre-set steps, including spent brine draw, fresh brine draw, slow rinse, and fast rinse. There was no backwash step in the original design and it could not be added later due to lack of freeboard in the vessels. During the demonstration study, the regeneration scheme was adjusted several times to optimize the regeneration efficiency and reduce waste production (Section 4.4.2.1). In doing so, the duration of each regeneration step was reset on the PLC and the brine concentration was adjusted by changing the brine draw rate using a hand valve located upstream of an eductor or a brine injection pump. The brine concentration was confirmed by measuring the specific gravity of the adjusted solution using a hydrometer.

Unlike most of the IX systems, including the Fruitland system where treated water is used for preparing the brine solution and rinsing the beds, raw water was used at Vale due to insufficient head in the 200,000-gal atmospheric reservoir at the airfield. Figure 4-11 shows photographs of major regeneration system components. Table 4-7 presents relevant regeneration settings. The four regeneration steps are discussed below.

**Step 1. Spent Brine Draw** – The treatment system was originally designed with a brine reclaim feature to minimize salt usage and brine waste. During the first half of brine draw, a spent brine solution with a concentration of 9 to 10% was pumped from a 1,050-gal day tank at approximately 50 gpm for 15 min using a 5-hp centrifugal pump. The entire volume of waste produced during spent brine draw was discharged to an evaporation pond. The volume of spent brine was tracked by a 2-in mechanical totalizer installed on a brine feed line. The use of spent brine could reduce the brine waste volume by 137 gal/vessel and the corresponding salt consumption by 885 to 758 lb/vessel, or 14%. The brine reclaim, however, was discontinued on December 10, 2007, due to concerns that DOM might accumulate in spent brine and would increase the resin fouling (Section 4.4.3).



Figure 4-11. Photographs of IX Regeneration System at Vale, OR

**Step 2. Fresh Brine Draw** – Fresh brine was used for the second half of brine draw. Saturated brine was drawn from a second 1,050-gal day tank and mixed with make-up water (i.e., raw water) via a Venturi educator (later changed to a chemical injection pump) before entering a resin vessel. The day tank was equipped with a high- and a low-level sensor interlocked with a 1.5-hp brine transfer pump to fill the tank with saturated brine (about 23 to 26%) from two salt saturators. Each salt saturator was 8-ft in diameter, 10-ft tall with an 11-ton salt storage capacity. This was modified from the initial design of one 22-ton saturator due to the height restriction on the building near the airport runway. The salt saturators were sized to hold 30 days of salt supply for daily regeneration and were re-filled by a salt delivery truck (Figure 4-12) on a monthly or as-needed basis. A 2-in mechanical totalizer was installed on the brine line to track the volume of saturated brine used.

By design, 336 gal of saturated brine would be drawn from the fresh brine day tank and mixed with approximately 530 gal of make-up water to produce 866 gal of a 10% brine solution. As the fresh brine was drawn into a resin vessel, approximately 750 gal of spent brine was first directed to the spent brine day tank until reaching a high-level setpoint. The remainder of spent brine (~100 gal) was discharged directly to the evaporation pond.

**Step 3. Slow Rinse** – At the end of brine draw, a valve on the saturated brine feed line was shut, and only the make-up water (i.e., raw water) was introduced to the resin vessel at 50 gpm for 40 min to rinse off the brine from the resin bed. This step produced approximately 2,000 gal of wastewater to be discharged directly to the evaporation pond. The resin manufacturer recommended 2.5 BV (1 BV =  $110 \text{ ft}^3 = 823 \text{ gal}$ ), or 2,057 gal, of water for slow rinse.



Figure 4-12. Salt Delivery to Fill Salt Saturators

**Step 4. Fast Rinse** – Fast rinse was performed at the service flowrate of approximately 220 gpm to further remove/flush out residual brine from resin beads and blind spots in the IX vessels. This step was set to last for 20 min and would produce 4,400 gal of wastewater to be discharged directly to the evaporation pond. The resin manufacturer recommended 5 BV (or 4,114 gal) for fast rinse.

- **Post Chlorination.** The target chlorine dosage was 0.2 mg/L (as Cl<sub>2</sub>) and the target residual level for disinfection of treated water was 0.025 mg/L (as Cl<sub>2</sub>). Once chlorinated, the water flowed to the 200,000-gal atmospheric reservoir near the airport, from which it was sent by two booster pumps to the city's distribution system and two older reservoirs located on the other side of the town.
- **Residual Disposal.** Due to lack of connection to the City sewer, an evaporation pond was constructed adjacent to the treatment building for disposal of spent brine and rinse water from the regeneration process (Figure 4-13). The evaporation pond consisted of a 368 ft (length) × 214 ft (width) × 13 ft (depth) evaporation basin and a 200 ft (length) × 55 ft (width) × 16 ft (depth) drying bed. The evaporation basin had a surface area of 1.8 acre and a storage capacity of 7,657,844 gal (or 23.5 acre-ft).

As part of the pond design, ferric chloride (FeCl<sub>3</sub>) was added to spent brine prior to being discharged to the pond (see Figure 4-14). Specifically, 0.25 gal of a commercial grade FeCl<sub>3</sub> solution (40% with specific gravity of 1.4) was fed to the waste brine stream at a rate of 1.0 gph for 15 min. Based on the design brine draw rate of 50 gpm, the iron dosage would be approximately 63 mg/L (as Fe). Because FeCl<sub>3</sub> was fed in a batch mode into a total waste volume of 7,250 gal (per vessel), the average iron dosage was only 6.65



Figure 4-13. Wastewater Evaporation Pond



Figure 4-14. Ferric Chloride Addition to Treat Spent Brine

mg/L. The wastewater traveled via a 4-in underground PVC pipe to a wet well, then was pumped to the evaporation basin via a 6-in PVC pipe. By design, the FeCl<sub>3</sub>-treated water was expected to precipitate and settle to the bottom of the evaporation basin. Over a period of time, the sludge would accumulate in a 1-ft wide, 16-ft deep depressed area (with an 8:1 sloped bottom) at one end of the basin, and then be pumped to the adjacent drying basin periodically. However, due to the presence of high TDS in the wastewater, the FeCl<sub>3</sub> treatment was not effective at removing arsenic from the brine waste (see Section 4.5.6).

# 4.3 System Installation

**4.3.1 Permitting.** Engineering plans for the system permit application were prepared by Holladay Engineering (Payette, ID), a subcontractor to Kinetico (the firm also provided engineering services to the City). The plans included general arrangement diagrams, specifications of the IX system, and drawings detailing connections between the treatment system and the building. After incorporating comments from the vendor and Battelle, the City submitted the plans on July 22, 2005, to the Oregon DHS DWP for review. On August 11, 2005, the permit packages were approved by Oregon DHS DWP.

**4.3.2 Construction of Treatment Building and Evaporation Pond.** The City issued an Advertisement for Bid on August 10, 2005, for the earthwork necessary to construct and complete a 1.8-acre evaporation basin and a 0.2-acre drying bed, a HDPE liner, fencing, a wet well lift station, a new building, a walkway, a ferric chloride shed, and chemical equipment, etc. Only one bidder submitted a bid for a total amount of \$498,844.00 on September 1, 2005, which was significantly higher than the city's budget of \$325,000.00. The high bid might have been affected by rebuilding efforts following the aftermath of hurricane Katrina in the Gulf of Mexico region, which created a high demand for materials, equipment, and contractors in that area. Therefore, the city council voted to re-advertise for bid on October 13 through November 13, 2005, with a new construction schedule and a final completion date of May 16, 2006. Four bids ranging from \$388,960.00 to \$436,070.00 were received and opened on November 14, 2005, with all exceeding the city's budget again. The city negotiated a contract with the low bidder – Holcomb Construction, and signed the Notice of Award and Notice to Proceed in early December 2005.

The building construction began on December 5, 2005, and was completed ahead of schedule on February 28, 2006. The 20 ft-tall addition covered 1,025  $\text{ft}^2$  of floor space (41-ft long and 25-ft wide) and had a wood frame, steel siding and roofing, and a 12-ft wide roll-up door. Figure 4-15 shows photographs of the new structure, adjacent to the existing pump house.

Construction of the evaporation pond didn't begin until the ground dried out for earthwork, was interrupted by the weather in April, and was completed in late May 2005, just before system startup. The pond consisted of an evaporation basin and a drying bed. A 40-mil textured HDPE liner was installed in the evaporation basin and drying bed to prevent any leakage to groundwater. An 8-ft tall exterior fence consisting of steel posts, wire mesh, and an access gate was installed surrounding the pond. Figure 4-16 is a photograph of the evaporation pond under construction; photographs of the completed pond are presented in Figure 4-13.

Based on the cost breakdowns from the construction contractor, the cost for mobilization/demobilization and clearing/grubbing the entire construction site was \$36,140.00. The cost for earthwork, HDPE liner, and fencing was \$81,809.00. The cost for the new building, walkway, and ferric chloride shed was \$111,018.00. The cost for the chemical equipment for ferric chloride addition was \$11,353.00, including a hand truck for hauling chemical barrels, a wall-mounted chemical metering pump, and a wall-mounted first aid kit, and a combination shower/eyewash station.



Figure 4-15. Vale Treatment Plant Building Construction



Figure 4-16. Installation of HDPE Liner in Evaporation Pond

**4.3.3 System Installation, Shakedown, and Startup**. The IX system was delivered to Vale, OR on two flatbeds on May 12, 2006. Upon arrival, system components were offloaded (Figure 4-17) and installation activities began immediately thereafter. A Kinetico technician was onsite from May 22 through May 26, 2006, to perform resin loading and system startup and then returned on June 1, 2006, to complete system startup and shakedown. The technician provided operator's training on June 6, 2006. The system was placed online in a fully automatic mode on June 21, 2006, after relevant control issues had been addressed by the city to synchronize the operation of the wells and booster pumps with the PLC of the treatment system. However, automatic regeneration of the system was found to cut short and did not complete the full cycle as designed. This problem was resolved by programming changes made by Kinetico on June 30, 2006.





Figure 4-17. Vale Treatment System Delivering and Offloading

During the first week of July 2006, when the system was first brought online, an unusually low system flowrate (i.e., 300 gpm at 60 psi inlet pressure) and an unusually high pressure drop across the IX beds (i.e., 35 to 40 psi) were experienced, which prompted a recommendation by the vendor to backwash the IX beds. Because the system was not designed/equipped for resin backwashing, the vendor proposed to retrofit the piping in the field to allow for backwashing as well as counter-current regeneration, if desired. Revised piping drawings were provided to Battelle on July 17, 2006.

A Kinetico technician returned to the site on July 20, 2006, to complete the retrofit and system shakedown. Four, 4-in PVC butterfly valves were added to the system piping to re-direct the flow for IX vessel backwashing, which, however, could be performed only manually by physically operating the valves. After backwashing, the system flowrate and headloss across each IX vessel became normal at 577 gpm and 13 psi, respectively. Although the vender attributed the low system flowrate and excessive pressure drop to sediment buildup in bag filters, it was apparent that the IX resin beds had to be backwashed to remove fines upon loading. Factory settings in the PLC also were adjusted in the field as needed. One of the changes made was to shorten the spent brine draw time from 15 to 10 min to avoid draining of the spent brine tank. The system was placed online in a co-current mode on July 23, 2006.

Battelle performed system inspections and operator training from September 19 through 21, 2006. Training included calibration and use of the water quality meter, collection and recording of operational data, proper sample collection techniques, arsenic speciation, and sample handling and shipping procedures. The first set of samples was collected from the IX system on September 20, 2006, signifying the official start of the performance evaluation study at Vale, OR. Table 4-8 summarizes punch list items identified during the system start-up and inspection as well as corrective actions taken.

			Resolution
	Punch List/Operational Issues	Corrective Action(s) Taken	Date
1	Fresh brine draw rate about twice	Actions taken from October 2006	03/05/07
	the design value	through March 2007 to reduce salt	
		usage to target level of 12 lb/ft <sup>3</sup>	
2	Flow totalizers after Vessels A	Kinetico verified meters; flow through	10/19/06
	and B appeared to be out of	Vessel B continued to be higher than	
	calibration; meter for Vessel B	that through Vessel A in Study Period	
	appeared to be off by 36%,	Ι	
	yielding higher readings than		
	those for Vessel A over same		
	time period		
3	Flow element displayed only	Cumulative volume of water	10/25/06
	throughput since last regeneration	processed added to PLC display	
4	Pressure gauge PI-5 had a wide	Old gauge replaced; new gauge	10/20/06
	span, causing inaccurate readings	worked well	
5	Excessive salt dust generated	Kinetico installed a water line to	10/20/06
	from salt delivery	alleviate salt dust	
6	Reused brine pump failed	Pump functional after being taken	10/19/06
		apart and cleaned	

Table 4-8. System Punch List during Startup

## 4.4 System Operation

Table 4-9 presents key demonstration study activities and events taking place during the three study periods. Study Period I, extending from September 19, 2006, through January 14, 2008, focused on evaluation of Purolite Arsenex II resin that was originally selected for the demonstration. At the end of this period, the system was taken offline for 4.5 months for well rehabilitation. Due to deteriorating performance of Arsenex II resin and unsuccessful attempts to clean the resin, the focus of the Interim Period was to identify an alternative approach to address the resin fouling issue. Study Period II, extending from February 10, 2009, through March 22, 2010, focused on evaluation of dual resins - Purolite<sup>®</sup> A850END/PFA300E. Table 4-9 highlights key demonstration activities under each study period, which will be discussed in this section. A more complete site chronology is presented in Appendix B for reference.

Demonstration Study Activities/Events	Date
Study Period I. Evaluating Arsenex II Resin	09/19/06-01/14/08
Run Length Study 1 performed	09/19/06-09/22/06
Site visit by Kinetico to address punch-list items	10/20/06-10/23/06
• Meeting with Kinetico and EPA at Battelle to discuss performance issues	02/21/07
• Site visit by Kinetico to install brine injection pump in place of educator and to collect resin samples	02/28/07-03/07/07
Regular weekly sampling discontinued	04/16/07
Limited weekly sampling at TT location	07/16/07-01/14/08
• Site visit by Kinetico to conduct resin cleaning; reused brine draw discontinued; resin samples collected	10/22/07
Run Length Study 2 performed	10/24/07-10/26/07
Interim Period. Identifying Alternative Approaches	01/14/08-02/09/09
• IX system shutdown due to well rehabilitation	01/14/08-05/01/08
System operation resumed	05/02/08
• Meeting with Vale, EPA, and consultants at Battelle to discuss available options	07/15/08
• Site visit by Battelle to inspect resin and vessels	08/15/08
Special study on dual resin system at McCook, NE	08/25/08
ArsenicGuard installed to provide online arsenic monitoring	11/19/08
Run Length Study 3 performed	12/08/08-12/10/08
New resins procured and arrived at site	12/26/08
Study Period II. Evaluating A850END/PFA300E Dual Resins	02/10/09 to 03/22/10
Dual resins installed	02/10/09-02/13/09
Arsenic in system effluent monitored with ArsenicGuard	02/13/09-03/02/09
Special study aborted due to salt loading incident	03/02/09-03/04/09
Weekly sampling resumed	03/25/09-12/16/09
Run Length Study 4 performed	04/21/09-04/22/09
Resin cleaning performed	06/24/09
Run Length Study 5 performed	06/29/09-07/01/09
Elution study performed	06/29/09-07/01/09
Resin cleaning performed	10/16/09
System bypassed due to faulty flow sensor	12/22/09-01/15/10
Weekly sampling resumed	02/02/10-02/08/10

 Table 4-9. Key Demonstration Study Activities/Events

**4.4.1 Operational Parameters.** Operational data were collected for a total of 70 weeks in Study Period I and 52 weeks in Study Period II. Table 4-10 summarizes key operational parameters collected from each study period. The complete set of operational data is presented in Appendix C after tabulation.

In Study Period I, the IX system operated for a total of 4,440 hr based on readings of an hour meter installed at the wellhead. Excluding October 19, 2006, and a week in November 2007, the system operated for 466 days, resulting in an average daily run time of 9.5 hr. The system processed approximately 128,000,000 gal of water based on readings of a wellhead Mag meter (excluding the amount of water used for regeneration). Due to the lack of Mag meter readings between September 27 through October 25, 2006, the throughput for that period was estimated based on the average daily demand of 274,473 gpd. The peak daily demand was 497,751 gpd, which occurred on May 31. 2007.

In Study Period II, the IX system operated for a total of 3,215 hr in 337 days (excluding 24 days from December 22, 2009, through January 15, 2010, when the system was not in operation). The average daily run time also was 9.5 hr. The system processed approximately 93,600,000 gal of water with an average daily demand of 277,653 gpd. The 524,463-gpd peak daily demand occurred on July 31, 2009.

Parameter	Study Period I	Study Period II
Data Collection Period	09/27/06-01/14/08	02/16/09-02/12/10
Total Operating Time (hr)	4,440	3,215
Total Operating Days (day)	466	337
Average Daily Run Time (hr/day)	9.5	9.5
Throughput to Distribution <sup>(a)</sup> (gal)	127,904,500 <sup>(b)</sup>	93,569,200
Average Daily Use (gpd)	274,473	277,653
Peak Daily Use (gpd)	497,751	524,463
Number of Regeneration Cycles	278	144
Regeneration Frequency (day/regeneration)	1.7	2.3
System Service Flowrate <sup>(c)</sup> (gpm)	490–576 (534)	542–557 (536)
Empty Bed Contact Time (min)	2.4–2.8 (2.6) <sup>(d)</sup>	2.6–3.3 (2.8) <sup>(e)</sup>
Hydraulic Loading (gpm/ft <sup>2</sup> )	11.3–13.3 (12.3)	10.4–12.9 (12.4)
Pressure Loss Across IX Vessel (psi)	Vessel A 6–15 (11)	Vessel A 7–13 (10)
	Vessel B 6–17 (11)	Vessel B 7–24 (11)
Pressure Loss Across System (psi)	30-47 (40)	33–42 (40)

 Table 4-10.
 Summary of System Operational Data

(a) Based on wellhead totalizer readings, excluding water used for regeneration.

(b) Throughput from 09/27/06 to 10/25/06 estimated due to lack of totalizer readings.

(c) Based on flowmeter on system effluent; excluding lower flowrate during system regeneration.

(d) Based on 186 ft<sup>3</sup> of Arsenex II in two IX vessels.

(e) Based on 197  $ft^3$  of dual resins in two IX vessels.

Figures in parentheses representing average values.

Key operational parameters, including product water flowrate, EBCT, hydraulic loading rate, and pressure loss across each IX vessel and across the system, are similar between the two study periods and comparable to the respective design values, as discussed below.

• System service flowrates ranged from 490 to 576 gpm and averaged 534 gpm in Study Period I, and ranged from 542 to 557 gpm and averaged 536 gpm in Study Period II. These values compared well with the system design flow of 540 gpm. When one vessel was being regenerated, water continued to be treated by the other vessel at 251 to 298 gpm in Study Period I and 260 to 288 gpm in Study Period II.

- Average EBCTs were 2.6 min and 2.8 min for Study Periods I and II, respectively; comparable to the design value of 3 min.
- Average hydraulic loading rates were 12.3 and 12.4 gpm/ft<sup>2</sup> for Study Periods I and II, respectively, close to the design value of 12.5 gpm/ft<sup>2</sup>.
- The pressure loss across each IX vessel ranged from 6 to 17 psi and averaged 11 psi in Study Period I, and ranged from 7 to 24 psi and averaged 11 psi in Study Period II. Such headloss was expected for a 5-ft deep resin bed because 1 foot of resin normally causes 1 to 2 psi of pressure loss.
- The pressure loss across the IX system averaged 40 psi in both study periods. Based on observations made for other EPA demonstration systems, including the IX system at Fruitland, ID, high pressure losses across the IX system was caused primarily by the 270-gpm flow restrictor installed on each vessel outlet. Similar flow restrictors had been found to overly restrict the flow and had to be removed for the Fruitland system. The flow restrictors were not removed at Vale because the wellhead booster pump was capable of overcoming the high pressure losses experienced, supply the water to the IX system at the design flowrate, and maintain the effluent pressure at 10 to 12 psi in the 200,000-gal atmospheric storage tank.

**4.4.2 Regeneration**. The system PLC initiated an automatic regeneration cycle based on a throughput setpoint. The duration of each regeneration step, e.g., brine draw, slow rinse, and fast rinse, was controlled by a timer in the PLC. In Study Period I, a total of 278 regeneration cycles took place, corresponding to a regeneration frequency of once every 1.7 days. In Study Period II, a total of 144 regeneration cycles took place, corresponding to a frequency of once every 2.3 days. The regeneration setpoints, monitoring parameters, and salt usage during the entire study period are discussed as follows.

**4.4.2.1 Regeneration Setpoints**. The PLC OIP contains a screen of regeneration setpoints as shown in Figure 4-18. A summary of regeneration setpoints for both study periods is presented in Table 4-11. During the initial system startup in July 2006, the system was set to regenerate every 600,000 gal of volume throughput. The regeneration cycle consisted of a 10-min spent brine draw and a 17-min fresh brine draw with an 11% brine (to achieve a salt level [*a.k.a* salt loading or regeneration level] of 12 lb/ft<sup>3</sup> of resin), followed by a 30-min slow rinse and a 15-min fast rinse. Changes were made several times to the volume throughput, spent and fresh brine draw time, and brine concentration in Study Period I to ensure good effluent water quality and proper salt loading. The adjustments were made based on results of two run length studies performed during September 19 through 22, 2006, and October 24 through 26, 2007, and observations/measurements made during regeneration.

- On September 13, 2006, just one week before Run Length Study 1, the volume throughput setpoint was extended to 905,300 gal to be closer to Purolite's simulation of 1,119,280 gal.
- Based on Run Length Study 1 results (Section 4.5.3), the volume throughput setpoint was reduced to 600,000 gal on October 5, 2006. When a Kinetico technician returned to the site on October 20, 2006, to address a high salt usage issue, spent and fresh brine draw times were reduced to 7 and 8 min, respectively, and the brine concentration was reduced to 6%. These changes, however, overly adjusted the salt usage, causing the salt loading to drop to 5.9 lb/ft<sup>3</sup> based on the data obtained on November 21, 2006. Low salt loadings apparently had impacted the performance of the IX system.
- On December 5, 2006, the brine concentration was adjusted back to 11% and the fresh brine draw time increased to 13 min. These changes increased the salt loading back up to 25 lb/ft<sup>3</sup> as measured on January 31, 2007.

	10	FIRST BRINE TO WASTE T	DRAW (REU TME (MIN.)	SED)					
	17	SECOND BRI TO WASTE T	NE DRAW (N IME (MIN.)	EW)					
	30	SLOW RINSE TIME (MIN.)							
	15	FAST RINSE TIME (MIN.)							
	600000	TOTAL VOLU REGEN TRIG							
	5.0	BRINE SATURATOR A HIGH ALARM LEVEL (FT)							
	2.0	BRINE SATU LOW ALARM	RATOR A LEVEL (FT)						
	5.0	BRINE SATU HIGH ALARN	RATOR B I LEVEL (FT)						
	2.0	BRINE SATU	RATOR B						
FILTER	CONTROL	DATA	BRINE	BOOSTER	ALARM				
	and the second se								
	2404 (0) -1 - 5								
FILTER SETPOINTS - /MMI1	249// (Display)								
FILTER SETPOINTS - IMMI1	249// (Display)	BRINE DRAV	W (NEW)						
S FILTER SETPOINTS - //MMI1	249// (Display)	BRINE DRAV TO WASTE 1 SLOW RINSI	N (NEW) IME (MIN.) E						
EILTER SETPOINTS - //MMI1	249// (Display) 21 45 15	BRINE DRAV TO WASTE 1 SLOW RINSI TIME (MIN.) FAST RINSE	N (NEW) TME (MIN.) E						
E FILTER SETPOINTS - /MMI1	249// (Display) 21 45 15 800000	BRINE DRAM TO WASTE 1 SLOW RINSI TIME (MIN.) FAST RINSE TIME (MIN.) TOTAL VOLU	N (NEW) TME (MIN.) E JME						
FILTER SETPOINTS - ///MI	249// (Display) 21 45 15 600000	BRINE DRAV TO WASTE 1 SLOW RINSI TIME (MIN.) FAST RINSE TIME (MIN.) TOTAL VOLL REGEN TRIG	N (NEW) TIME (MIN.) E JME GER (GAL.) PATOR A						
FILTER SETPOINTS - /MMI1	249// (Display) 21 45 15 600000 5.0	BRINE DRAN TO WASTE T SLOW RINSI TIME (MIN.) FAST RINSE TIME (MIN.) TOTAL VOLU REGEN TRIG BRINE SATU HIGH ALARM	W (NEW) TME (MIN.) E JME GER (GAL.) RATOR A L LEVEL (FT) RATOR A						
E FILTER SETPOINTS - //MM11	249// (Display) 21 45 15 600000 5.0 2 0	BRINE DRAY TO WASTE 1 SLOW RINSI TIME (MIN.) FAST RINSE TIME (MIN.) TOTAL VOLU REGEN TRIG BRINE SATU HIGH ALARM BRINE SATU LOW ALARM	N (NEW) TME (MIN.) E JME GER (GAL.) RATOR A I LEVEL (FT) RATOR B						
FILTER SETPOINTS - ///MI1	249// (Display) 21 21 45 15 600000 5.0 2.0 5.0	BRINE DRAV TO WASTE 1 SLOW RINSI TIME (MIN.) FAST RINSE TIME (MIN.) TOTAL VOLU REGEN TRIG BRINE SATU HIGH ALARM BRINE SATU BRINE SATU	N (NEW) TIME (MIN.) E GER (GAL.) RATOR A I LEVEL (FT) RATOR B I LEVEL (FT) RATOR B						
FILTER SETPOINTS - ////	249// (Display) 21 45 50 5.0 2.0 5.0 2.0	BRINE DRAN TO WASTE T SLOW RINSI TIME (MIN.) FAST RINSE TIME (MIN.) TOTAL VOLU REGEN TRIG BRINE SATU HIGH ALARN BRINE SATU HIGH ALARN BRINE SATU LOW ALARN	N (NEW) TME (MIN.) E GER (GAL.) RATOR A I LEVEL (FT) RATOR B I LEVEL (FT) RATOR B I LEVEL (FT)						



- To better control fresh brine injection, Kinetico installed a brine injection pump to replace the Venturi eductor during a site visit by the end of February 2007. Meanwhile, the technician inadvertently reset the system for counter-current regeneration. The mistake was corrected later during another site visit on March 5, 2007. The fresh brine draw time was increased to 15 min while the brine concentration was reduced to 6%. A salt loading close to the target of 12 lb/ft<sup>3</sup> was achieved based on the data collected in March 2007.
- On April 13, 2007, the volume throughput setpoint was reduced to 370,000 gal based on the arsenic breakthrough data to ensure that arsenic concentrations in system effluent were below its MCL.

Setting	Date of	Regen. Trigger gal	Run Length BV <sup>(a)</sup>	Spent Brine Draw Min	Fresh Brine Draw min	Slow Rinse min	Fast Rinse min	Brine	Brine Conc.	
Startup	07/23/06	600,000	431	10	17	30	15	1.08	11	
1		/		Study Period	Ι					
1	09/13/06	905,300	651	10	17	30	15	1.08	11	
	10/05/06;									
2	10/20/06	600,000	431	7	8	30	15	1.042	6	
3	12/05/06	600,000	431	7	13	30	15	1.08	11	
4 <sup>(b)</sup>	03/05/07	600,000	431	7	15	30	15	1.042	6	
5	04/13/07	370,000	266	7	15	30	15	1.042	6	
6	10/22/07	600,000	431	0 <sup>(c)</sup>	23	30	15	1.042	6	
	Study Period II									
7	02/13/09	600,000	491	Discont'd	21	45	15	1.06	8	

Table 4-11. IX System Regeneration Setpoints at Vale, OR

(a) Based on 186 and 163.3 ft<sup>3</sup> of IX resin(s) in Study Periods I and II, respectively.

(b) After a brine injection pump installed to replace eductor.

(c) Spent brine draw discontinued due to concern over resin fouling caused by DOM in spent brine.

sp. gr. = specific gravity

• On October 22, 2007, after resin cleaning, the volume throughput setpoint was returned to 600,000 gal, spent brine draw was discontinued, and the fresh brine draw time was increased to 23 min to compensate for the spent brine.

In Study Period II, the regeneration setpoints for the dual IX resin system were established by Battelle according to resin specifications and the experience gained through system operations at Fruitland, ID. The target salt loading was  $10 \text{ lb/ft}^3$ . To achieve this level, brine draw was set at 60 gpm for 21 min using an 8% brine. The brine draw rate used in Study Period I ranged from 73 to 145 gpm, which exceeded the recommended draw rate of 0.2 to 0.8 gpm/ft<sup>3</sup> according to the resin specification sheet. Since slow rinse used the same flow as the brine makeup water, its duration was increased to 45 min to compensate for the lower flowrate. The regeneration setpoints remained unchanged throughout Study Period II.

**4.4.2.2 Regeneration Monitoring**. Regeneration of Vessels A and B were monitored and recorded on log sheets nine times in Study Period I and twice in Study Period II. Since data recorded for both vessels were rather similar, averages between the two vessels are presented in Table 4-12 for all regeneration steps. The volume of water used for each regeneration step was recorded from a totalizer located upstream of the eductor. Volumes of spent and fresh brines were recorded from individual brine totalizers on the outlet of both brine tanks. The volume of fresh brine draw (i.e., diluted brine) was calculated using Equation 1:

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

where:

 $V_{brine, d}$  = volume of diluted brine (gal)  $V_{brine, s}$  = volume of saturated brine (gal)  $V_{water}$  = volume of brine make-up water (gal)  $\gamma_{brine, s}$  = specific gravity of saturated brine, e.g. 1.176 for 23% brine  $\gamma_{brine, d}$  = specific gravity of diluted brine, e.g. 1.074 for 10% brine

				Step 1 Step 2						Step 3			Step 4		Total		
			Spe	nt Brine Dr	aw		Fre	esh Brine Dra	W		Slow Rinse			Fast Rinse		Waste	
							Makeup	Saturated	Dilute								Production
			Draw	Draw	Flow	Draw	Water	Brine	Brine	Flow	Rinse	Rinse	Flow	Rinse	Rinse	Flow	Per Regen
Study		Setting	Time	Volume	Rate	Time	Volume	Volume	Volume	Rate	Time	Volume	Rate	Time	Volume	Rate	Cycle
Period	Date	ID	min	gal	gpm	min	gal	gal	gal	gpm	min	gal	gpm	min	gal	gpm	gal
	Desi	gn Value	15	750	50	17	518	336	850	50	40	2,000	50	20	4,400	220	7,250
	09/21/06	1	10	760	76	17	1,239	648	1,853	109	30	2,267	76	15	3,527	235	7,646
	11/21/06	2	7	579	83	8	636	123	749	94	30	2,400	80	15	3,900	260	7,048
	01/31/07	3	7	515	74	13	1,027	856	1,883	145	30	2,385	80	15	3,893	260	8,160
т	03/05/07	4	7	525	75	15	856	301	1,161	73	30	2,637	88	15	3,296	220	7,093
1	03/07/07	4	7	530	77	15	1,111	286	1,389	93	30	2,303	77	15	3,384	226	7,075
	03/20/07	4	7	528	75	15	1,230	324	1,534	102	30	2,475	83	15	3,378	225	7,387
	11/27/07	6	Ε	Discontinued	1	23	1,932	525	2,457	107	30	2,520	84	15	3,720	248	8,697
	12/13/07	6	Ε	Discontinued	1	23	1,730	530	2,260	113	30	2,565	86	15	3,900	260	8,725
	08/15/08	6	Ε	Discontinued	1	23	2,000	629	2,592	113	30	2,497	83	15	3,533	236	8,622
	Desi	gn Value	Γ	Discontinued	1	21	924	420	1,334	64	45	1,980	44	15	3,900	260	7,214
II	02/13/09	7	E	Discontinued	1	21	924	400	1,324	63	45	1,980	44	15	3,945	264	7,257
	06/29/09	7	Ε	Discontinued	1	21	924	329	1,253	60	45	1,980	44	15	3,998	267	7,230

 Table 4-12. IX System Regeneration Monitoring at Vale, OR

Note: All values refer to one IX vessel using averages of Vessel A and B.

In Study Period I, as shown in Table 4-12, spent brine draw rates ranged from 74 to 83 gpm and averaged 77 gpm, which was over 50% higher than the design value of 50 gpm. Shortening the draw duration from the design value of 15 min to 10 min, then to 7 min, helped to correct for the high draw rate issue.

The fresh brine draw step was problematic during the early part of the study. Fresh brine draw rates ranged from 73 to 145 gpm, which was two to three times the design value of 50 gpm and exceeded the upper limit of the suggested regeneration rate of 0.8 gpm/ft<sup>3</sup>. A higher brine draw rate would mean more salt consumption. To maintain a lower salt level, a shorter brine draw time may be used but not desirable because it may not provide enough time for exchange reactions to occur throughout the resin bed. As such, the brine draw rate was purposely reduced to 64 gpm in Study Period II.

At the beginning of the study, the saturated brine volume drawn during the fresh brine draw step was 648 gal, which almost doubled the design value of 336 gal. Follow-on adjustments performed either under- or over-corrected the problem, resulting in 123 and 856 gal of saturated brine under Settings 2 and 3, respectively. The vendor suggested that the problem might have been caused by an incorrectly sized Venturi eductor (oversized in this case) and that it would be better off to replace the eductor with a brine injection pump. Since the installation of a brine injection pump in late February 2007, the saturated brine volume was better controlled to just below or above the target value at 286 to 324 gal (under Setting 4), as monitored on March 5, 7, and 20, 2007. Under Setting 6, saturated brine volumes were higher, ranging from 525 to 629 gal due to the use of an extended draw time (i.e., 23 min) to make up the loss due to discontinuation of spent brine draw.

In Study Period I, slow rinse rates ranged from 76 to 88 gpm and averaged 82 gpm, which was over 60% higher than the design value of 50 gpm. Fast rinse rates ranged 220 to 260 gpm and averaged 241 gpm, which is close to the design value of 220 gpm. Regeneration of each IX vessel produced 7,048 to 8,725 gal of wastewater during Study Period I, but averaged at 8,681 gal under Setting 6.

In Study Period II, all regeneration parameters monitored were similar to the design values and appeared to be adequate based on results of the elution study (see Section 4.5.5). Regeneration of each IX vessel generated an average of 7,244 gal of wastewater, which is 20% less than that under Setting 6 in Study Period I.

**4.4.2.3** Salt Usage. The amount of salt used by each regeneration cycle was calculated based on concentrations and volumes of spent and/or fresh brines according to Equation 2. The salt loading was then calculated by dividing the weight of salt by the volume of resin. The results of the calculations are presented in Table 4-13.

$$W_{salt} = V_{brine} \times \gamma_{brine} \times d_{water} \times C_{salt}$$
<sup>(2)</sup>

where:

 $W_{salt}$  = weight of salt (lb)  $V_{brine}$  = volume of brine used (gal)  $\gamma_{brine}$  = specific gravity of brine  $d_{water}$  = density of water, e.g., 8.34 (lb/gal)  $C_{salt}$  = percent of salt (%)

The specific gravity of saturated brine at 23% was 1.176. Specific gravities of spent brines measured by a hydrometer ranged from 1.039 (5.4%) to 1.066 (8.9%), which were affected by concentrations of diluted fresh brines used for previous regeneration cycles. Specific gravities of diluted brine measured in Study Period I ranged from 1.042 (6%) to 1.080 (11%), depending on regeneration settings. The specific gravity of diluted brine measured in Study Period II was 1.060 (8.1%), close to the target of 8%.

				Spent l	Brine			Fresh	Brine		Total	
Study Period	Date	Setting ID	Spent Brine Volume gal	sp. gr. of Spent Brine	Spent Brine Conc.	Weight of Salt lb	Saturated Brine Volume gal	sp. gr. of Diluted Brine	Diluted Brine Conc. %	Weight <sup>(a)</sup> of Salt Ib	Total Salt Weight <sup>(b)</sup> Ib	Total Salt Loading <sup>(c)</sup> lb/ft <sup>3</sup>
	Design	Value	750	1.067	9.0	600	336	1.074	10.0	760	1,346	12
	09/21/06	1	760	1.047	6.5	429	648	1.080	10.8	1,462	1,891	20.3
	11/21/06	2	579	1.039	5.4	272	123	1.042	5.9	276	548	5.9
	01/31/07	3	515	1.066	8.9	406	856	1.080	10.8	1,931	2,337	25.1
т	03/05/07	4	525	1.060	8.1	377	301	1.042	5.9	678	1,055	11.3
1	03/07/07	4	360	1.045	6.2	195	286	1.042	5.9	645	840	9.0
	03/20/07	4	528	1.050	6.9	318	324	1.050	6.9	731	1,049	11.3
	11/27/07	6		Discont	inued		525	1.051	7.0	1,184	1,184	12.7
	12/13/07	6	Discontinued				530	1.042	5.9	1,196	1,196	12.9
	08/15/08	6	Discontinued			629	1.057	7.8	1,419	1,419	15.3	
	Design	Value	Discontinued			420	1.059	8	945	945	10	
II	02/13/09	7		Discont	inued		400	1.060	8.1	902	902	9.3
	06/29/09	7		Discont	inued		329	1.060	8.1	741	741	7.6

 Table 4-13.
 Vale, IX System Salt Loading Calculations

(a) Based on saturated brine.
(b) Sum of spent brine and fresh brine.
(c) Based on actual resin volume in each vessel, i.e., 93 ft<sup>3</sup> of Arsenex II and 97.5 ft<sup>3</sup> of dual resin.

sp. gr. = specific gravity

As shown in Table 4-13, the salt loading was  $20.3 \text{ lb/ft}^3$  on September 21, 2006, approximately 70% higher than the design value of 12 lb/ft<sup>3</sup>. This higher loading was mainly caused by the higher brine volume used in regeneration. The salt loading was reduced to 5.9 lb/ft<sup>3</sup>, then increased back to  $25.1 \text{ lb/ft}^3$  following the adjustments made in October and December 2006, respectively. After the installation of the brine injection pump, salt loadings ranged from 9.0 to  $11.3 \text{ lb/ft}^3$  (under Setting 4) from 12.7 to  $15.3 \text{ lb/ft}^3$  (under Setting 6), indicating a better control of the salt use. In Study Period II, the average salt loading was  $8.5 \text{ lb/ft}^3$ , about 15% lower than the design value of 10 lb/ft<sup>3</sup>.

**4.4.3 IX Resin Fouling.** Deteriorating resin performance was observed over the course of Study Period I, as evidenced by a decreasing trend in resin run length. For example, shortly after system startup in September 2006, the system treated approximately 600,000 gal of water before arsenic in system effluent reached 10  $\mu$ g/L. The amount of water treated was reduced to 450,000 gal in early January 2007 based on weekly water sampling data (Section 4.5.1.2). After seven months into system operation, the useful run length was further reduced to 376,940 gal in April 2007 (Section 4.5.1.2), which was 63% of the initial value.

To determine the causes for the shortened run lengths, resin core samples were collected from both IX vessels in March 2007 and sent to Purolite for analyses (along with resin samples collected from the Fruitland IX system). Purolite reported that some resin beads were visibly fouled by particulates and likely DOM when viewed under a microscope. These samples were cleaned in Purolite's laboratory with a 10% brine and a mixture of 2% caustic/10% brine, respectively, and analyzed after each cleaning. The results are presented in Table 4-14 and compared with the specifications of virgin Arsenex II resin.

			Percent	Percent Strong	TOC (mg of			
		Volumetric	Volumetric	Base	<b>C</b> /	Iron	Silica	
Resin	Moisture	Capacity	Capacity	Capacity	g of	Content	Content	
Sample	(%)	(eq/L)	(%) <sup>(a)</sup>	(%)	resin)	(mg/g)	(mg/g)	
Arsenex II-virgin	40–45	1.2	100	100	NA	NA	NA	
	10% Bri	ine Cleaning ir	n Purolite Lab	oratory (Mar	ch 2007)			
Vessel A	35.5	0.83	69	92	12.0	26	129	
Vessel B	35.0	0.94	78	81	15.4	13	204	
29	% Caustic/10	0% Brine Clear	ning in Purolit	e Laboratory	(March 20	007)		
Vessel A	38.0	1.13	94	93	9.6	NA	NA	
Vessel B	38.9	1.16	97	87	6.0	NA	NA	
5%	Caustic/10%	% Brine Clean	ing at Vale Tre	atment Plan	t (October 2	2007)		
Vessel A-top	43.2	1.05	88	81	10.7	157	NA	
Vessel A-middle	39.9	1.14	95	77	8.0	122	NA	
Vessel A-bottom	38.7	1.15	96	79	8.6	14	NA	
Average	40.6	1.11	93	79	9.1	98	NA	
Six Months after Field Cleaning (August 2008)								
Vessel A	38.7	0.96	80	NA	61.0	120	NA	
Vessel B	37.7	1.08	90	NA	46.0	100	NA	

Table 4-14. Resin Analyses After Laboratory or Field Cleaning

(a)% = actual volumetric capacity/virgin volumetric capacity.

After cleaning with 10% brine, samples collected from Vessels A and B contained 12.0 and 15.4 mg of C/g of resin, respectively, indicating organic built-up. The extent of TOC fouling was considered severe by Purolite and the primary cause for the deteriorating performance and shortened run lengths observed.

Organic fouling resulted in significant losses (i.e., 22 to 31%) in volumetric capacity. The reduction in resin capacity also was reflected by a lower moisture content and a lower strong base capacity. It was suspected that some SBA exchange sites were converted to a weak base type, which would not be as useful for removing arsenic or nitrate. Iron and silica levels also increased, suggesting that they also acted as foulants.

The laboratory cleaning with a mixture of 2% caustic/10% brine was able to remove a significant amount of foulants, achieving a noticeable recovery of the resin's capacities. For example, the volumetric capacity was restored to 94 to 97% of the virgin resin level and the strong base capacity restored to 87 to 93%. Increases in moisture content and strong base capacities reflected the recovery of exchange sites blocked by organic matter before resin cleaning. The TOC content on the resin was reduced to 6.0 to 9.6 mg of C/g of resin (although lower than what would be expected considering the significant gain in overall capacities), suggesting reduction in TOC fouling by caustic/brine cleaning.

Prompted by the promising results of the laboratory cleaning at Purolite and the field cleaning at Fruitland, ID, the IX system at Vale underwent a similar cleaning process using a mixture of 5% caustic/10% brine in October 2007 (Section 3.6). After cleaning, a core resin sample was collected from Vessel A and shipped to Purolite for analyses. Meanwhile, Run Length Study 2 was conducted from October 24 through 26, 2007, to determine cleaning effectiveness. Results of the laboratory analyses showed the highest levels of TOC and iron and the lowest volumetric capacity in the top section (see Table 4-14), suggesting that the resin was the most severely fouled by DOM and iron at the top. The resin in the middle and bottom sections contained, on average, 22% less TOC and 57% less iron, thus having 9% more volumetric capacity. The strong base capacity at the middle and the bottom was similar to that at the top. Based on the results of Run Length Study 2, the resin run length was improved by approximately 20% to 445,700 gal.

In August 2008, resin samples after field cleaning were collected from both vessels and sent to Purolite for analyses. The data showed that TOC had continued to accumulate on the resin at levels up to 61 mg of C/g of resin, approximately six times the TOC level right after the field cleaning in October 2007. In December 2008, about 10 months after the October 2007 cleaning (not including the five month well rehabilitation extending from January through May 2008), the useful run length was further reduced to 323,530 gal (Section 4.5.3, Run Length Study 3), which was 27% lower than that observed right after the caustic/brine cleaning in October 2007.

**4.4.4 Dual IX Resin Approach.** Since the caustic/brine cleaning failed to effectively strip off all TOC from Arsenex II resin and restore its run length back to 600,000 gal, the possibilities of either converting the system into an AM or C/F system or replacing Arsenex II with other types of resin were contemplated. Because the IX system could not be easily converted to an AM or C/F system according to the equipment vendor and because the City of Vale preferred an IX system due to concerns over possible increases in nitrate concentration in the future, the investigation was focused on the search of other types of resin. In May 2008, Professor Dennis Clifford of the University of Houston recommended the use of an acrylic IX resin, such as Purolite A850, as a TOC scavenger. Meanwhile, Purolite recommended the use of dual IX resins such as PFA300E (for arsenic/nitrate removal) overlain by a layer of A850END (for TOC removal). The volume ratio between PFA300E and A850END would be 85:15. For a total of 110 ft<sup>3</sup> of resin, one vessel would contain approximately 95 ft<sup>3</sup> of PFA300E and 15 ft<sup>3</sup> of A850END. Purolite's simulation software generated an estimated run length of 523 BV in June 2008 or 604 BV in January 2009 based on additional source water quality data (see Figure 4-5). The revised projection corresponded to a throughput of 993,940 gal (1 BV = 220 ft<sup>3</sup>).

Due to the high silica and TOC levels in source water, it was recommended that a 5% caustic/10% brine wash be performed every four months as a precautionary measure.

**4.4.4.1 Dual Resin Options.** On July 15, 2008, a meeting was held at Battelle with EPA, the City of Vale, and two technical consultants - Professor Dennis Clifford and Mr. Glen Latimer, to discuss options for implementing the dual resin approach. Because the City expressed its desire to continue with the IX technology for any future issues with nitrate, alternative treatment technologies were not further pursued. Three options regarding system configuration were explored, which are summarized as follows:

- The first option was to remove the old resin and replace it with 15 ft<sup>3</sup> (8-in depth) of A850END underlain by 95 ft<sup>3</sup> (~52-in depth) of PFA300E in each vessel. No changes to system configuration would be needed and each vessel would retain the EBCT of 3 min. The estimated cost of the media would be approximately \$50,000. This option was considered the most acceptable and most time- and cost-effective option.
- The second option was to add a third vessel in front of the two existing vessels. The additional vessel would be of 72-in diameter and contain 113 ft<sup>3</sup> (48-in depth) of A850END for TOC scavenging. The existing 63-in vessels would each be rebedded with 110ft<sup>3</sup> of PFA300E for arsenic/nitrate removal. The EBCT of the 72-in vessel would be approximately 1.5 min while the EBCT of the 63-in vessel would remain at 3 min. Significant changes to the system would have to be made to accommodate the additional vessel. The cost of media for this option was estimated to be approximately \$81,765. This option could be costly and would require significant engineering support and perhaps approval by the state drinking water program.
- The third option was to change the configuration of the two existing 63-in vessels from parallel to series. Under this configuration, the first vessel would contain 110 ft<sup>3</sup> of A850END for TOC removal followed by the second vessel containing 110 ft<sup>3</sup> of A300E for arsenic/nitrate removal. The change in configuration would require cutting back the system flow to maintain an acceptable loading rate and pressure drop. The system would be regenerated by running a 10% brine solution through the PFA300E vessel followed by the A850END vessel, then discharging the wastewater to the evaporation pond. The cost of media for this option would be approximately \$57,200. This option might also have required regulatory approval.

The meeting concluded that the first option of replacing the old resin from the existing vessels with dual IX resins was acceptable to all parties involved and should be pursued immediately.

**4.4.4.2 Concerns over Solids in IX Resin Beds.** Since the beginning of the resin fouling discussion, Purolite had expressed concerns over the lack of backwashing in the Vale system operation and suspected that iron/organic complex in source water could have contributed to the resin fouling. It recommended that either a pre-filter be added ahead of the IX vessels or a backwashing step be incorporated into the regeneration cycle. Since the iron levels in raw water were consistently below the reporting limit of 25  $\mu$ g/L and manganese levels were below 1  $\mu$ g/L, the existing sediment filtration using 5- $\mu$ m bag filters should be sufficient as long as the bag filters were changed out whenever needed. During a trip to Vale on August 15, 2008, Battelle staff performed a visual inspection of the inside of each IX vessel and saw no signs of solids accumulation on the bed surface. Therefore, the pre-filter option was deemed unnecessary.

When onsite, a measurement taken on Vessel A from the top of the flange to the top of the resin bed and showed 19.75 in of freeboard in each IX vessel. This freeboard measurement indicated that there was not enough freeboard in the vessels to support IX resin backwashing. This, in conjunction with the fact that little or no iron was present in source water, led to the decision not to include a backwashing step into the IX resin regeneration cycle. The freeboard measurement was later used to estimate the actual resin volume in the vessel.

**4.4.3 Special Study at McCook, NE.** A dual IX resin system was installed by the McCook Water Treatment Plant (WTP) in McCook, NE for the removal of arsenic, nitrate, and uranium from water containing high TOC (Boodoo et al., 2008). To learn more about McCook's experience with the dual IX resin approach, Battelle staff members visited the McCook WTP on August 26 and 27, 2008, and conducted an elution study on the effectiveness of the regeneration process and a run length study on the dual IX resin system. Results of the special study along with a description of the facility water quality, water treatment process, and major activities conducted onsite were documented in a technical memorandum. A brief summary is provided herein.

The McCook water treatment plant, rated at a 7 million gallon per day (MGD) production capacity, began operation in February 2006. Source water quality varied depending on which groundwater wells were supplying water. Typical water quality is profiled as: pH 7.2, 382 mg/L of alkalinity, 226 mg/L of sulfate, 525 mg/L of hardness (as CaCO<sub>3</sub>), 100 µg/L of phosphorus, 850 mg/L of TDS, 12.5 µg/L of arsenic (soluble As[V] as predominating species), 13 µg/L of nitrate, 31.1 µg/L of uranium, and 3.5 mg/L of TOC. The treatment process consists of six 10-ft × 15-ft (straight-side-height) cation vessels and six 9.5-ft × 15-ft (straight-side-height) anion vessels. Each anion vessel contained 66 in of A300E (392 ft<sup>3</sup>) resin top-dressed with 12 in of A850END (69 ft<sup>3</sup>) resin for simultaneous removal of multiple contaminants (see Figure 4-19). Approximately 50% of raw water bypassed the entire treatment system and only 50% of softened water was treated by the AIX vessels. Most of the time, only two or three anion vessels were placed online; each anion vessel was set to regenerate every 579,000 gal (168 BV) of water treated for nitrate control. Co-current regeneration with a salt dosage of 10 lb/ft<sup>3</sup> was conducted in four steps: 10-min backwash, 52-min brine draw, 45-min slow rinse, and 40-min fast rinse.



Figure 4-19. McCook, NE Water Treatment Plant

A complete regeneration and service cycle of one anion vessel (i.e., Vessel 5) was monitored in a two-day period. Grab and composite samples were collected from each step of the regeneration cycle (see Figure 4-20). Following regeneration, time-series influent and effluent samples were collected during the Vessel 5 service cycle. In addition, a resin core sample was collected from a freshly regenerated Vessel 6 for visual inspection and analysis.



Figure 4-20. Sample Collection and pH/TDS Monitoring during Regeneration of AIX Vessel 5 at McCook, NE

Figure 4-21a plots elution curves of arsenic, uranium, nitrate, sulfate, TOC, TDS, and bicarbonate versus time during the regeneration cycle. The percent recovery of each contaminant (i.e., arsenic, uranium, nitrate, and TOC) from the regeneration cycle was calculated by dividing the amount of contaminant in the spent brine and rinse water by the amount removed from raw water. Figure 4-21b presents the exhaustion breakthrough curves for arsenic and nitrate. The main observations and findings from the McCook study are briefly summarized as follows:

- Due to the long freeboard over the resin bed (i.e., 8 to 9 ft), it took over 40 min for brine to emerge from the vessel to the discharge line, as indicated by TDS reading. TDS readings reached the maximum level of 117 g/L approximately 10 min before the end of the slow rinse.
- Resin regeneration achieved 99% recovery for TOC, 86% for arsenic, 130% for uranium, and 55% for nitrate. The spent brine had a distinctive yellowish or tea color, indicating the presence of DOM.
- TOC levels in the effluent water were below detection during the run length study (576,000 gal). Arsenic and nitrate breakthrough at their respective MCLs occurred at 445,000 gal (129 BV) and 550,000 gal (161 BV), respectively. Uranium was almost completed removed.



(b) Exhaustion Curves Figure 4-21. Results of McCook AIX Vessel 5

• The resin core sample did not show two distinctive layers; A850END and A300E resins appeared to be mixed. Purolite's laboratory could not find enough A850END sample for separate resin analyses. Per Purolite, resin capacities were "acceptable" after 2.5 years of service.

Findings at McCook suggest that A850END can be effective at removing TOC from raw water, thus preventing the underlying resin from being fouled. Based upon these findings, a decision was made to replace Arsenex II with A850END/PFA300E at Vale.

**4.4.4 Dual Resin Installation.** Rebedding of the two IX vessels was performed during February 10 and 13, 2009, by Accurate Water Solutions, a subcontractor to Battelle. Arsenex II resin was removed from the vessels using a vacuum truck, but the gravel underbedding remained in the vessels to be reused. Freeboard measurements were then made from the top of the flange to the top of the gravel. Purolite PFA300E and A850END IX resins were then loaded sequentially into each vessel with freeboard measurements taken immediately after loading of each IX resin. It was noted that the top of the A850END layer had already reached the bottom of the top diffuser, indicating maximum loading in the two resin vessels. Calculations of resin volumes based on the freeboard measurements and resin volumes are presented in Table 4-15.

			Total Resin
Freeboard			Volume
Measurement	Vessel A	Vessel B	( <b>ft</b> <sup>3</sup> )
To top of Gravel (in)	70.75	71.25	-
To top of PFA300E (in)	25.5	26.0	-
To top of A850END (in)	16.0	17.0	-
Depth of PFA300E (in)	45.25	45.25	-
Depth of A850END (in)	9.5	9.0	-
Volume of PFA300E (ft <sup>3</sup> )	81.6	81.7	163.3
Volume of A850END (ft <sup>3</sup> )	17.1	16.2	33.3
Total Resin Volume (ft <sup>3</sup> )	98.7	97.9	196.6

Table 4-15. Freeboard Measurements during Dual Resin Rebedding

Once the IX resins had been loaded, each vessel underwent a regeneration cycle. Based on the results from the first regeneration of each vessel, the regeneration settings were adjusted to achieve the target salt loading of  $10 \text{ lb/ft}^3$ .

**4.4.5 Residual Management.** Residuals produced by the IX system included spent brine and rinse water, which were discharged to the evaporation pond adjacent to the treatment building. FeCl<sub>3</sub> was added to spent brine in an attempt to precipitate arsenic and allow the iron sludge to settle in the evaporation pond. The design and construction of the evaporation pond and the FeCl<sub>3</sub> treatment system were performed by the City's contractors and described in Sections 4.2.2 and 4.3.2.

The volume of wastewater produced was determined by the regeneration frequency and the volume of wastewater generated per regeneration cycle. Table 4-12 presents relevant calculations of wastewater production under different regeneration settings. Reclaiming spent brine could save salt use and reduce wastewater production. Comparing amounts of wastewater produced under Regeneration Setting 6 (without brine reclaim) and Regeneration Setting 4 (with brine reclaim), 17% less wastewater was

produced (reduced from an average of 8,622 to 7,185 gal) when spent brine was reused per vessel when reused brine was applied. The use of spent brine, however, was discontinued on December 10, 2007 due to concerns over resin fouling by TOC.

The evaporation pond was designed based on the Purolite-projected resin run length and regeneration frequency. Shorter run lengths and higher regeneration frequencies experienced caused the pond to fill faster than originally designed. In April 2008, the City obtained one-time approval from the Oregon DHS to use the pond water as a dust suppressant in the nearby area. This helped to lower the water level in the pond.

To characterize the water quality of the residuals, samples were collected from the waste stream from each regeneration step as well as the pond water. The results are provided in Sections 4.5.5 and 4.5.6.

Prior to dual resin installation, a sample of the old Arsenex II resin was collected on August 15, 2008, and sent to Belmont Labs for the Toxicity Characteristic Leaching Procedure (TCLP) test. The results showed less than MDL of arsenic, cadmium, chromium, selenium, mercury and silver, 0.25 mg/L of barium, and 0.058 mg/L of lead. After passing the TCLP, the spent Arsenex II resin was disposed of as a non-hazardous waste.

# 4.4.6 System Operation Requirement

**4.4.6.1 Required System Operation and Operator Skills.** 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

**Pre-** and Post-Treatment Requirements. Pretreatment included filtration with two banks of bag filters (each containing five) to remove sediment from source water. Filter bags were replaced when differential pressure ( $\Delta p$ ) readings across the bag filter assembly were greater than 12 to 15 psi. Filter bags were replaced five times from September 27, 2006 to January 14, 2008 in Study Period I; and twice from February 16, 2009 to March 22, 2010 in Study Period II. It took approximately two hours each time to replace all 10 filter bags. The only post-treatment was post-chlorination for disinfection.

*System Automation.* The IX system was fully automatic and controlled by the PLC in the central control panel. The control panel 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 alarm status. Setpoint screens were password-protected so that changes could be made only by authorized 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 regeneration sampling events when regeneration was initiated manually to record log sheets and capture spent regenerant and rinse samples. It is a good practice to periodically check on relevant parameters during a complete regeneration cycle, including specific gravity of dilute brine and volumes of spent and/or fresh brines used, to ensure adequate salt loadings and identify operational issues, if any, at an early stage.

*Operator Skill Requirements.* Operating and maintaining an 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.

Oregon state law requires owners of public and private drinking water and wastewater systems to have their systems under the responsible control and direction of certified operators. Oregon DHS DWP administers the certification program for drinking water system operators. DHS DWP classifies water distribution systems and treatment plants according to their complexity and size:

- Water systems with 149 and fewer connections and utilizing groundwater as their only source or purchasing all their water from another public water system without adding any additional treatment require a small water system "S" certification.
- Water systems with 150 or more connections require certification at Levels 1 to 4 in either treatment and/or distribution. Distribution systems are classified as Levels 1 to 4 according to the population served by the system. Treatment plants are classified as Levels 1 to 4, depending on factors such as system complexity, size, and source water.

The plant operator at Vale, OR had a treatment plant Level 1 license. After receiving proper training from the vendor during system startup, the operator understood the PLC, knew how to use the OIP, and worked with the vendor and Battelle to troubleshoot and perform minor on-site repairs.

**4.4.6.2 Preventive Maintenance Activities.** Preventive maintenance tasks recommended by the vendor included daily to monthly visual inspection of the piping, valves, vessels, 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. During the demonstration study, maintenance activities performed by the operator included replacing filter bags periodically, checking the brine concentration using a hydrometer, and adjusting regeneration frequency and setpoints as instructed by the vendor or Battelle.

**4.4.6.3** Chemical/Media Handling and Inventory Requirements. Routine regeneration requires sodium chloride and periodically, caustic soda for resin cleaning. The IX system has fully automated controls with IX resin regeneration triggered by volume throughput. A salt truck delivered salt on a monthly or as-needed basis with the operator's presence. The salt saturators were sized to hold 22 tons of salt supply. Assuming that the system regenerated 13 times per month (based on regeneration frequency in Study Period II, Table 4-10) and used 1,633 lb of salt per event (as designed for Study Period II), it would require 21,229 lb or 9.5 tons of salt per month. Therefore, the salt saturators held about two months of salt supply.

Because the salt saturators were situated in the same room as the treatment system, excessive salt dust was generated during salt delivery. The salt is corrosive to the electrical/mechanical components of the treatment system. Placing the salt saturators in a separate room would minimize the salt dust and corrosion issues.

## 4.5 System Performance

The performance of the IX system was evaluated based on analyses of water samples collected across the treatment train, during regeneration, and from the distribution system. In addition, special run length studies and an elution study were conducted to provide additional insight into system performance.

**4.5.1 Treatment Plant Sampling.** In Study Period I, Arsenex II performance was evaluated through sampling across the treatment train on 31 occasions, including two duplicate sampling events and

eight speciation events. Regular weekly sampling was discontinued after April 16, 2007; only TT samples were collected for total arsenic and nitrate analyses between July 16, 2007 and January 14, 2008. In Study Period II, A850END/PFA300E were evaluated through sampling across the treatment train on 32 occasions. No duplicate sampling or speciation sampling took place in Study Period II. Table 4-16 summarizes arsenic and nitrate analytical results in both study periods. Tables 4-17 and 4-18 summarize results of other water quality parameters in Study Periods I and II, respectively. Appendix D contains a complete set of analytical results. The results obtained are discussed in the following subsections.

		Sampling					Standard					
Parameter	Unit	Location <sup>(a)</sup>	Count	Minimum	Maximum	Average	Deviation					
Study Period I												
As (total)	μg/L	IN	31	18.3	31.8	22.6	3.1					
		TA	30	0.5	45.8	- <sup>(b)</sup>	- <sup>(b)</sup>					
		TB	29	0.4	33.8	- <sup>(b)</sup>	- <sup>(b)</sup>					
		TT	30	0.7	48.7	- <sup>(b)</sup>	- <sup>(b)</sup>					
As	μg/L	IN	8	19.2	22.9	21.0	1.1					
(soluble)		TA	8	1.6	42.1	- <sup>(b)</sup>	- <sup>(b)</sup>					
		TB	7	1.8	29.8	- <sup>(b)</sup>	- <sup>(b)</sup>					
		TT	8	1.6	35.9	- <sup>(b)</sup>	- <sup>(b)</sup>					
As	μg/L	IN	8	< 0.1	3.7	1.9	1.3					
(particulate)		TA	8	< 0.1	3.6	0.7	1.2					
		TB	7	< 0.1	3.0	1.2	1.3					
		TT	8	< 0.1	3.4	1.0	1.2					
As (III)	μg/L	IN	8	0.4	2.3	1.0	0.6					
		TA	8	0.4	2.5	0.9	0.7					
		TB	7	0.3	2.8	0.9	0.9					
		TT	8	0.3	2.7	0.9	0.8					
As (V)	μg/L	IN	8	17.8	22.5	20.0	1.5					
		TA	8	0.8	39.6	- <sup>(b)</sup>	- <sup>(b)</sup>					
		TB	7	1.0	27.0	- <sup>(b)</sup>	- <sup>(b)</sup>					
		TT	8	0.9	33.1	- <sup>(b)</sup>	- <sup>(b)</sup>					
Nitrate	mg/L	IN	31	1.4	7.6	5.4	1.5					
(as N)	_	TA	30	< 0.05	9.9	- <sup>(b)</sup>	- <sup>(b)</sup>					
		TB	29	< 0.05	8.9	- <sup>(b)</sup>	- <sup>(b)</sup>					
		TT	30	0.4	7.1	- <sup>(b)</sup>	- <sup>(b)</sup>					
Study Period II												
As (total)	μg/L	IN	32	16.0	23.3	19.6	1.8					
		TA	31	0.1	34.7	- <sup>(b)</sup>	- <sup>(b)</sup>					
		TB	31	< 0.1	31.1	- <sup>(b)</sup>	- <sup>(b)</sup>					
		TT	32	< 0.1	31.4	- <sup>(b)</sup>	- <sup>(b)</sup>					
Nitrate	mg/L	IN	32	4.0	7.5	5.6	0.7					
(as N)	-	ТА	31	0.1	9.9	- <sup>(b)</sup>	_ <sup>(b)</sup>					
		TB	31	0.6	9.9	- <sup>(b)</sup>	_ <sup>(b)</sup>					
		TT	32	0.1	9.3	_ <sup>(b)</sup>	_(b)					

Table 4-16. Summary of Arsenic and Nitrate Analyses in Study Periods I and II

(a) See Figure 3-1 for sampling locations.

(b) Not meaningful for concentrations related to breakthrough, see Figures 4-23 through 4-25 and Appendix D for results.

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

Duplicate samples included in calculations.

		Sampling					Standard
Parameter	Unit	Location <sup>(a)</sup>	Count	Minimum	Maximum	Average	Deviation
Alkalinity	mg/L	IN	31	254	358	329	23.8
		TA	30	171	432	_ <sup>(c)</sup>	_ <sup>(c)</sup>
		TB	29	143	427	- <sup>(c)</sup>	_ <sup>(c)</sup>
		TT	8	194	400	- <sup>(c)</sup>	_ <sup>(c)</sup>
Fluoride	mg/L	IN	8	0.5	1.1	0.7	0.2
		TA	8	0.5	1.1	0.7	0.3
		TB	7	0.5	1.4	0.8	0.3
		TT	8	0.5	1.3	0.7	0.3
Sulfate	mg/L	IN	30 <sup>(b)</sup>	63.9	97.0	81.8	7.7
		TA	30	<1	38.0	- <sup>(c)</sup>	_ <sup>(c)</sup>
		TB	29	<1	38.0	- <sup>(c)</sup>	- <sup>(c)</sup>
		TT	8	<1	40.0	_ <sup>(C)</sup>	_ <sup>(C)</sup>
Phosphorus	μg/L	IN	31	212	337	278	33.4
(as P)		TA	30	<10	664	_ <sup>(c)</sup>	_(c)
		TB	29	<10	458	- <sup>(c)</sup>	_ <sup>(C)</sup>
		TT	8	<10	559	-(0)	_(C)
Silica	mg/L	IN	31	46.1	59.2	55.6	2.1
(as $SiO_2$ )		TA	30	53.6	60.0	56.1	1.4
		TB	29	10.3	59.8	54.2	8.6
		TT	8	54.6	59.9	56.4	1.9
Turbidity	NTU	IN	31	0.2	0.9	0.5	0.2
		TA	30	0.1	1.2	0.5	0.2
		TB	29	0.1	1.6	0.6	0.3
		TT	8	0.4	1.1	0.6	0.2
TOC	mg/L	IN	1	2.0	2.0	2.0	-
TDS	mg/L	IN	31	434	766	514	61.7
		TA	30	412	606	485	40.8
		TB	29	432	550	486	32.1
		TT	8	430	554	483	42.5
pН	S.U.	IN	22	7.2	8.0	7.4	0.2
		TA	22	7.1	8.3	7.5	0.3
		TB	22	7.0	8.2	7.5	0.3
	. ~	TT	22	7.0	8.2	7.4	0.3
Temperature	°C	IN	22	14.6	17.5	15.5	0.8
		TA	22	14.4	17.9	15.4	0.8
		TB	22	14.3	18.2	15.4	0.9
<b>D</b> 0	~		22	14.0	16.8	15.3	0.7
DO	mg/L	IN	22	1.6	6.3	3.7	1.4
		TA	22	2.0	6.5	4.0	1.5
		TB	22	1.8	6.9	3.9	1.6
000	× 7		22	2.0	6.5	4.1	1.5
ORP	mV		22	127	295	253	33.1
		TA	22	126	262	222	32.1
		TB	22	120	252	214	33.2
<b>T</b> ( 1	~		22	118	252	216	36.3
Total	mg/L		9	120	251	165	36.0
Hardness			8	140	240	1/1	30.4
			/	142	241	1/3	<u> </u>
		11	8	137	229	1/1	28.7

Table 4-17. Summary of Other Water Quality Parameters in Study Period I
Parameter	Unit	Sampling Location <sup>(a)</sup>	Count	Minimum	Maximum	Average	Standard Deviation
Ca Hardness	mg/L	IN	9	75.0	187	115	30.5
	0	TA	8	96.2	178	120	25.4
		TB	7	98.0	179	121	28.0
		TT	8	92.8	169	120	24.0
Mg	mg/L	IN	9	44.0	63.9	50.1	6.5
Hardness		TA	8	43.9	61.8	50.9	6.2
		TB	7	43.6	61.6	51.7	6.2
		TT	8	43.7	59.8	51.0	5.9
Fe (total)	μg/L	IN	31	<25	<25	<25	0.0
		TA	30	<25	<25	<25	0.0
		TB	29	<25	<25	<25	0.0
		TT	8	<25	<25	<25	0.0
Fe (soluble)	μg/L	IN	8	<25	<25	<25	0.0
		TA	8	<25	<25	<25	0.0
		TB	7	<25	<25	<25	0.0
		TT	8	<25	<25	<25	0.0
Mn (total)	μg/L	IN	31	< 0.01	2.1	0.4	0.4
		TA	30	< 0.01	2.3	0.5	0.4
		TB	29	< 0.01	1.4	0.4	0.3
		TT	8	< 0.01	0.6	0.4	0.2
Mn	μg/L	IN	8	< 0.01	0.5	0.4	0.1
(soluble)		TA	8	0.2	0.6	0.4	0.1
		TB	7	< 0.01	0.5	0.3	0.2
		TT	8	< 0.01	0.6	0.4	0.2
V (total)	μg/L	IN	9	46.5	60.5	54.1	5.5
		TA	8	0.6	3.6	2.0	1.0
		TB	7	0.7	4.5	2.2	1.3
		TT	9	0.6	3.9	2.1	1.0
V (soluble)	μg/L	IN	8	48.5	61.2	54.2	5.1
		TA	8	0.5	3.5	2.0	1.0
		TB	7	0.6	4.5	2.1	1.3
		TT	8	0.7	3.5	2.1	0.9

Table 4-17. Summary of Other Water Quality Parameters in Study Period I (Continued)

(a) See Figure 3-1 for sampling locations.(b) Excluding an outlier on 10/02/2006.

(c) Not meaningful for concentrations related to breakthrough, see Figures 4-26 and 4-27; and Appendix D for results.

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

		Sampling					Standard
Parameter	Unit	Location <sup>(a)</sup>	Count	Minimum	Maximum	Average	Deviation
Alkalinity	mg/L	IN	32	279	346	309	15.1
		ТА	31	76.0	402	_ <sup>(b)</sup>	_ <sup>(b)</sup>
		TB	31	26.4	390	_ <sup>(b)</sup>	- <sup>(b)</sup>
		TT	32	52.8	400	_ <sup>(b)</sup>	_ <sup>(b)</sup>
Sulfate	mg/L	IN	32	63.6	83.2	74.0	4.4
		TA	31	< 0.1	61.7	_(b)	- <sup>(b)</sup>
		TB	31	< 0.1	16.0	_ <sup>(b)</sup>	- <sup>(b)</sup>
		TT	32	< 0.1	21.3	_ <sup>(b)</sup>	- <sup>(b)</sup>
Phosphorus	μg/L	IN	31	249	345	275	19.7
(as P)		TA	30	<10	452	_ <sup>(b)</sup>	- <sup>(b)</sup>
		TB	30	<10	447	_ <sup>(b)</sup>	- <sup>(b)</sup>
		TT	31	<10	457	_ <sup>(b)</sup>	- <sup>(b)</sup>
Silica	mg/L	IN	32	54.5	66.2	59.4	2.6
(as SiO <sub>2</sub> )		TA	31	54.9	65.2	59.8	2.3
		TB	31	54.4	67.2	60.1	2.8
		TT	32	53.6	64.6	59.8	2.5
Turbidity	NTU	IN	32	< 0.1	2.6	0.3	0.5
		TA	31	< 0.1	1.3	0.4	0.4
		TB	31	< 0.1	4.2	0.5	0.7
		TT	32	< 0.1	2.1	0.4	0.4
TOC	mg/L	IN	32	1.4	2.2	1.8	0.2
		TA	31	<1	<1	<1	0.0
		TB	31	<1	<1	<1	0.0
		TT	32	<1	<1	<1	0.0
TDS	mg/L	IN	32	434	588	498	32.1
		ТА	31	416	606	476	41.6
		TB	31	420	724	484	62.4
		TT	32	368	650	478	51.7
Fe (total)	μg/L	IN	32	<25	<25	<25	0.0
		ТА	31	<25	<25	<25	0.0
		TB	31	<25	<25	<25	0.0
		TT	32	<25	<25	<25	0.0
Mn (total)	μg/L	IN	32	0.2	5.3	0.7	1.1
		ТА	31	0.1	3.2	0.5	0.6
		TB	31	0.2	3.3	0.5	0.6
		TT	32	0.2	3.0	0.5	0.6
V (total)	μg/L	IN	32	46.9	59.4	51.3	3.1
		ТА	31	< 0.1	7.3	2.3	2.0
		TB	31	< 0.1	14.5	2.9	3.5
		TT	32	< 0.1	11.5	2.7	2.7

Table 4-18. Summary of Other Water Quality Parameters in Study Period II

(a) See Figure 3-1 for sampling locations.

(b) Not meaningful for concentrations related to breakthrough, see Appendix D for results. One-half of detection limit used for nondetect samples for calculations.

**4.5.1.1** Arsenic Speciation. Eight speciation sampling events were conducted in Study Period I. Figure 4-22 presents arsenic speciation results at the IN, TA, TB, and TT sampling locations. Soluble As(V) was the predominant species in raw water, ranging from 17.8 to 22.5  $\mu$ g/L and averaging 20.0  $\mu$ g/L (Table 4-16). Trace amounts of particulate As and soluble As(III) also existed with concentrations









Figure 4-22. Concentrations of Arsenic Species across Treatment System

averaging 1.9 and 1.0  $\mu$ g/L, respectively. After the IX treatment, a small amount of particulate As (0.9  $\mu$ g/L [on average]) was removed by either the bag filters or the IX resin beds. Soluble As(III) concentrations, however, remained essentially unchanged at 0.9  $\mu$ g/L. This was as expected because the IX process does not remove neutral species such as arsenite. Speciation sampling was not conducted in Study Period II.

For each sampling event, the volume throughput at the time of sampling is marked on Figure 4-22 to relate treatment results with the run length. As shown on the figure, arsenic was removed to below the  $10-\mu g/L$  MCL during the early stage of service cycles. Elevated arsenic concentrations (i.e., >10  $\mu g/L$ ) were measured in IX vessel effluent on September 20, 2006, and January 10, February 12, and March 12, 2007, when samples were collected at a throughput of 653,391, 451,996, 475,337, and 543,862 gal, respectively, indicating that the IX system needed to be regenerated before reaching 450,000 gal.

**4.5.1.2 Arsenic Removal.** Arsenic and nitrate were the two primary contaminants of concern in source water; thus, their removal was key to assessing the performance of the IX system. Figures 4-23 and 4-24 present total arsenic concentrations across the treatment train for Study Periods I and II, respectively. Figure 4-23 plots the concentration data against either sampling dates ("temporal plot") or volume throughputs at the time of sampling ("reconstructed breakthrough curves"). Because the temporal plot does not explain why arsenic exceeds the MCL, the reconstructed breakthrough curves provide more insight into system performance. Typically, a breakthrough curve is constructed with data collected from one complete service cycle. Because the IX system was regenerated once every two to three days, routine weekly treatment plant water samples were collected from different service cycles. Collectively, these data, after being sorted by volume throughput (from low to high), can exhibit breakthrough behaviors similar to those one would expect in a service cycle. Therefore, "reconstructed breakthrough curves" were used to discuss nitrate, sulfate, and other parameters in the following sections (Note that the September 25 and October 31, 2006 data were not plotted due to lack of throughput data).

*Study Period I*. As shown in Table 4-16, total arsenic concentrations in source water varied from 18.3 to  $31.8 \ \mu g/L$  and averaged 22.6  $\mu g/L$  in Study Period I. These concentrations were slightly higher than those (i.e., 16.7 and 20  $\mu g/L$  [see Table 4-2]) sampled previously during the initial site visit on December 2, 2004.

The temporal plot in Figure 4-23a can be divided into three sub-periods: from startup to April 13, 2007; from April 13, 2007, to October 22, 2007; and after October 22, 2007. The volume throughput setpoint was 600,000 gal for the first sub-period, shortened to 370,000 gal for the second sub-period, and returned to 600,000 gal for the sub-third period (after resin cleaning). Arsenic had been consistently removed to below the MCL in the second sub-period, but its concentrations were erratic in the first and third sub-periods. The "reconstructed breakthrough curves" in Figure 4-23b showed that, except for three TT samples collected on November 14, November 19, and December 3, 2007, all other TA, TB, and TT samples collected prior to a volume throughput 370,000 gal contained <10  $\mu$ g/L of arsenic. In contrast, all but one sample collected after 370,000 gal had arsenic concentrations exceeding the MCL. In addition to sampling time, operational issues such as low salt loadings (between October 20 and December 5, 2006) and counter-current regeneration (set by mistake in late February 2007) also had contributed to the high effluent concentrations observed (such as those collected on November 6, 14, and 28, 2006, and on March 5 and 12, 2007).

The IX system performance was deteriorating with time as evidenced by the weekly arsenic monitoring data and special run length study results. The run length to  $10-\mu$ g/L arsenic breakthrough was reduced from 562,300 gal at startup in September 2006 to 449,702 gal in early January 2007, and then to 376,940



Figure 4-23. Total Arsenic Concentrations Measured During Study Period I (a) Temporal Plot; (b) Reconstructed Breakthrough Curves



Figure 4-24. Total Arsenic Concentrations Measured During Study Period II

gal in early April 2007. As discussed in Section 4.4.3, shortened run lengths most likely were caused by organic matter buildup, which could block exchange sites and reduce resin capacities.

Immediately after resin cleaning on October 22, 2007, A TT sample collected at a volume throughput of 377,889 gal contained 2.1  $\mu$ g/L, which was significantly lower than the 11.1  $\mu$ g/L measured in another TT sample collected at 376,940 gal on April 2, 2007 (see data in Appendix D). However, all of the six subsequent TT samples collected between October 29 and December 10, 2007 exceeded the arsenic MCL. Three of the samples were collected at high volume throughputs of 595,337, 533,870, and 530,622 gal, with arsenic concentrations of 33.5, 33.8, and 48.7  $\mu$ g/L, respectively. The other three were collected at low volume throughputs of 131,979, 50,196, and 51,996 gal, with lower arsenic concentrations of 11.8, 10.2, and 11.9  $\mu$ g/L, respectively, all of which were over the MCL. According to Run Length Study 2 conducted on October 24 to 26, 2007, throughput to 10- $\mu$ g/L arsenic breakthrough was approximately 445,700 gal, which explained why the high-throughput samples contained high arsenic concentrations.

Puzzled by the low-throughput sample results, the operator observed a regeneration cycle on November 27, 2007, and noticed that while in the automatic mode, Vessel A skipped regeneration and only Vessel B was regenerated. During troubleshooting, Kinetico discovered that because the spent brine draw time was set to zero after the caustic wash on October 22, 2007, the PLC did not work properly as the software could not accept zero as a setpoint. Once the draw time was temporarily set to 1 min on December 10, 2007, the PLC worked correctly to regenerate both vessels. (Note that the spent brine draw step was removed from the PLC in February 2009 after installation of dual resins.) The subsequent two TT samples collected at 200,373 gal on December 17, 2007, and at 195,150 gal on January 7, 2008, contained

1.3 and 2.2  $\mu$ g/L of arsenic, respectively. However, the TT sample collected at 418,136 gal on January 14, 2008 contained 20.6  $\mu$ g/L of arsenic, indicating that the run length to 10  $\mu$ g/L was shortened again, compared with the 445,700 gal established right after resin cleaning in October 2007. Because the IX system was shut down for well rehabilitation during January 14 and May 1, 2008, another resin cleaning was not performed.

As the IX system was allowed to operate beyond the  $10-\mu g/L$  breakthrough, effluent arsenic concentrations became significantly higher than influent arsenic concentrations, a phenomenon commonly known as chromatographic peaking or dumping. This arsenic dumping was caused by more preferred anions such as sulfate, which displaced previously exchanged arsenic from the resin. In addition, because sulfate concentrations were more than three orders of magnitude higher than those of arsenic, these concentration effects further accelerated displacement. Arsenic dumping is a major drawback of the IX technology, but can be mitigated by controlling the timing of regeneration to prevent overrun.

**Study Period II**. Total arsenic concentrations in raw water ranged from 16.0 to 23.3  $\mu$ g/L and averaged 19.6  $\mu$ g/L in Study Period II. Run Length Study 4 performed in April 2009 indicated a useful run length of approximately 436,350 gal. Based on the "reconstructed breakthrough curves" in Figure 4-24, arsenic breakthrough at 10  $\mu$ g/L occurred at TT between 444,200 gal (3.2  $\mu$ g/L on July 20, 2009) and 487,900 gal (13.7  $\mu$ g/L on September 2, 2009) and was estimated to be 472,500 gal. The average of the two values (i.e., 436,350 and 472,500 gal) was 454,400 gal, which was 51% of the projected run length by the Purolite simulation. The run length for Vessel B was slightly longer than that of Vessel A, i.e., by approximately 20,000 to 40,000 gal. Arsenic dumping also was observed in Study Period II as samples were collected at a throughput higher than 487,900 gal.

Unlike the Fruitland IX system where elevated arsenic concentrations were measured in effluent up to 50,000 to 60,000 gal (67 to 80 BV) after the system had just been regenerated, arsenic leakage was not noticeable at Vale, OR. Because co-current regeneration was employed at both Fruitland and Vale, it was not clear what had caused the difference between the two sites.

**4.5.1.3** *Nitrate Removal.* As shown in Table 4-16, nitrate concentrations in source water ranged from 1.4 to 7.6 mg/L (as N) and averaged 5.4 mg/L (as N) in Study Period I; and ranged from 4.0 to 7.5 mg/L (as N) and averaged 5.6 mg/L (as N) in Study Period II. Figures 4-25a and 4-25b present "reconstructed breakthrough curves" of nitrate for Study Periods I and II, respectively. While consistently below the nitrate MCL of 10 mg/L (as N) in both study periods, effluent nitrate concentrations exhibited an increasing trend and approached or even exceeded influent nitrate concentrations towards the end of a service cycle. For example, effluent nitrate concentrations reached or exceeded coresponding influent concentrations at a volume throughput of approximately 380,000 gal in Study Period I and 480,000 gal in Study Period II. Because these volume throughput values were longer than those to the 10- $\mu$ g/L arsenic breakthrough, useful run lengths for both the ArseneX II and dual resin systems were controlled by arsenic breakthrough, not nitrate breakthrough.

The original intent of system design was to control system operations based on nitrate breakthrough because it was easier and cheaper to monitor nitrate using a Hach test kit and because the regular resin is cheaper than the nitrate selective resin. The facility reported a higher nitrate concentration of 8 to 12 mg/L (as N) for technology selection and computer simulation. The facility also indicated that it preferred the IX system over other technologies because of its ability to remove both arsenic and nitrate.



Figure 4-25. Reconstructed Breakthrough Curves for Nitrate (a) Study Period I; (b) Study Period II

### 4.5.1.4 TOC, Sulfate, Phosphate, and Vanadium Removal.

*TOC.* In Study Period I, TOC was measured only once on April 16, 2007, at a concentration of 2.0 mg/L in raw water. After it was identified as a foulant, TOC concentrations were monitored across the dual resin system in 32 sampling events throughout Study Period II. Raw water TOC concentrations ranged from 1.4 to 2.2 and averaged 1.8 mg/L, which were consistent with the 2.1 mg/L measured on December 2, 2004 during the initial source water sampling. At the TA, TB, and TT locations, TOC concentrations were consistently reduced to below the MDL of 1 mg/L, suggesting effective removal by the dual resin system throughout the entire service cycle of 600,000 gal.

*Sulfate*. Figure 4-26 presents "reconstructed breakthrough curves" for sulfate in Study Periods I and II. Sulfate concentrations in raw water averaged 82 mg/L in Study Period I and 74 mg/L in Study Period II. Sulfate was removed to less than 1 mg/L most of the time in both periods until reaching a volume throughput of 376,940 gal in Study Period I and 487,940 gal in Study Period II. Afterwards, sulfate concentrations began to rise as more water was treated and reached 1/3 to 1/2 of its influent concentration by the end of the 600,000-gal service cycle. Because of its higher selectivity than arsenate and nitrate, sulfate continued to be removed even when arsenate and nitrate had reached their respective MCL in the effluent. Displacement of arsenate and nitrate by sulfate would result in higher effluent arsenate and nitrate 4.5.1.2 and 4.5.1.3.

Deteriorating resin performance also was reflected by sulfate concentrations in system effluent. For example, in Study Period I at system startup on September 20, 2006, the sulfate concentration at TT was 9 mg/L at a volume throughput of 653,391 gal. After six months into system operation on March 19, 2007, the average of sulfate concentrations at TA and TB was 9 mg/L at a volume throughput of only 415,021 gal, indicating a 36% reduction in run length for sulfate.

**Phosphate.** Figures 4-27 presents "reconstructed breakthrough curves" for total phosphorus. Raw water contained 212 to 345  $\mu$ g/L of total phosphorus, which averaged 278  $\mu$ g/L in Study Period I and 275  $\mu$ g/L in Study Period II. Total phosphorus concentrations in effluents were reduced to less than 10  $\mu$ g/L most of the time, but rose rapidly and exceeded influent levels after reaching a volume throughput of approximately 415,000 gal in Study Period I and 488,000 gal in Study Period II. The pre-adsorbed phosphate was displaced by more preferred sulfate.

*Vanadium*. Total vanadium concentrations in raw water measured in both study periods were similar, ranging from 46.5 to 60.5  $\mu$ g/L. Figure 4-28 presents "reconstructed breakthrough curves" of total vanadium in Study Period I and II. Arsenex II reduced vanadium concentrations to <5  $\mu$ g/L throughout Study Period I. PFA300E/A850END also reduced vanadium concentrations to <5  $\mu$ g/L on all but four occasions on March 25, April 2, September 30, and December 10, 2009, when TT samples collected at 59,084, 551,090, 56,986, and 27,963 gal of volume throughput contained total vanadium concentrations of 11.5, 6.0, 7.4, and 9.8  $\mu$ g/L, respectively. Chromatographic peaking was not observed for vanadium in either period, suggesting that vanadium ions, such as VO<sub>4</sub><sup>3-</sup>, HVO<sub>4</sub><sup>2-</sup> and/or H<sub>2</sub>VO<sub>4</sub><sup>-</sup>, may have an equivalent or even higher selectivity than sulfate and/or uranium ions.

**4.5.1.5** *Other Water Quality Parameters*. Figures 4-29 and 4-30 present a "reconstructed pH plot" and "reconstructed breakthrough curves" for pH and total alkalinity, respectively. Raw water pH values ranged from 7.2 to 8.0 and averaged 7.4 in Study Period I. pH was not measured in Study Period II. Total alkalinity concentration in raw water ranged from 254 to 358 and averaged 329 mg/L (as CaCO<sub>3</sub>) in Study Period I; and ranged from 279 to 346 and averaged 309 mg/L (as CaCO<sub>3</sub>) in Study Period II.



Figure 4-26. Reconstructed Breakthrough Curves for Sulfate (a) Study Period I; (b) Study Period II



Figure 4-27. Reconstructed Breakthrough Curves for Total Phosphorus (a) Study Period I; (b) Study Period II



Figure 4-28. Reconstructed Breakthrough Curves for Total Vanadium (a) Study Period I; (b) Study Period II



Figure 4-29. pH Measured During Study Period I

Slight reductions in pH values were observed for a short period immediately after the IX system had been freshly regenerated. For example, pH values at the IN, TA, TB, and TT locations were 7.3, 7.2, 7.1, and 7.2, respectively, on October 18, 2006, after 125,800 gal of water had been treated; and 7.3, 7.1, 7.0, and 7.1, respectively, on April 10, 2007 after 114,200 gal of water had been treated. Although pH changes were small, i.e., no more than 0.3 pH unit, corresponding reductions in total alkalinity across the IX system were quite significant, i.e., 306, 209, 190, and 194 mg/L (as CaCO<sub>3</sub>), respectively, on October 18, 2006; and 357, 286, 251, and 282 mg/L (as CaCO<sub>3</sub>), respectively, on April 10, 2007. The most significant decrease in total alkalinity was observed on December 4, 2006 after 69,595 gal of water had been treated: i.e., 326, 171, and 145 mg/L at the IN, TA, and TB locations, respectively. This 50% reduction in total alkalinity could not be verified by corresponding pH values because they were measured the next day. Reductions in total alkalinity also were observed in Study Period II in samples collected immediately after regeneration up to 173,000 gal of volume throughput. For example, over 90% of reduction in total alkalinity was observed on March 25 and September 30, 2009, after 59,084 and 56,986 gal of water had been treated, respectively.

The reduction in pH and alkalinity immediately after regeneration was attributed to the removal of bicarbonate ions by the AIX resin. As reported in the literature, one disadvantage of the IX process is the production of low pH and corrosive water during the initial 50 to 100 BV of a service cycle (Clifford, 1999). Afterwards, the pH value of treated water returned to the raw water level due to the complete breakthrough of bicarbonate ions, which had a lowest selectivity by the SBA AIX resin.



Figure 4-30. Reconstructed Breakthrough Curves for Total Alkalinity (a) Study Period I; (b) Study Period II

4.5.2 **Real-Time Arsenic Monitoring by ArsenicGuard<sup>TM</sup>.** The ArsenicGuard<sup>TM</sup> analyzer was installed on November 19, 2008, to provide real-time monitoring of arsenic in raw and treated water. ArsenicGuard<sup>TM</sup> took one measurement every 45 min (even when the well pump was off and the system was not in operation) with data displayed as strip charts, which can be downloaded from the computer for further processing. Figure 4-31 shows two examples of real-time total arsenic plots using data downloaded from ArsenicGuard<sup>TM</sup>. The top graph plotted data from January 16 through February 9, 2009, right before Arsenex II replacement in February 2009. The bottom graph plotted data from August 6 through 30, 2009, after dual resins installation. The plots clearly showed reoccuring service/ regeneration cycles as arsenic concentrations in system effluent cycled between a few  $\mu$ g/L and higher than corresponding influent concentrations. As shown in Table 4-11, system regeneration was set at a volume throughput of 600,000 gal during applicable operating periods shown in Figure 4-31 (under Setting 6 in Study Period I and Setting 7 in Study Period 7). Arsenic breakthrough to 10 µg/L occurred before reaching 600,000 gal for both Arsenex II and PFA300E/A850END and continuing operations resulted in arsenic dumping in every regeneration cyle. Because ArsenicGuard<sup>™</sup> continued analyzing "samples" even when the system was not in operation, the plots shown in Figure 4-31 do not represent actual arsenic breakthrough curves or reflect actual run lengths.



Figure 4-31. Examples of Real-Time Arsenic Monitoring by ArsenicGuard<sup>TM</sup>

For comparison purposes, Figure 4-31 also plotted three sets of influent/effluent weekly arsenic data measured by ICP-MS during the period from August 6 through August 30, 2009. The ArsenicGuard<sup>TM</sup> and ICP-MS data appeared to be consistent with each other both at low ppb and around 20  $\mu$ g/L levels.

In addition to arsenic monitoring, the ArsenicGuard<sup>TM</sup> was equipped with a nitrate sensor for real-time nitrate monitoring. However, the nitrate sensor failed about one week after installation. Inspections of the unit revealed coating and/or clogging of the sample chamber, all Teflon<sup>®</sup> lines, and other assoicated parts with a white powdery film/deposit. After cleaning and/or replacing of all affected parts, the nitrate sensor resumed functioning normally, but this normalcy could not be sustained. The salty, corrosive environment was thought to have affected the nitrate measurements. The nitrate monitoring was abandoned afterwards.

**4.5.3 Run Length Studies.** Three run length studies (1 to 3) were conducted on Arsenex II in Study Period I and two (4 and 5) on A850END/PFA300E in Study Period II. Results of these studies are discussed below. Note that all throughput readings were taken from the totalizer on the combined effluent even though samples were collected from individual vessel effluent or combined effluent.

*Run Length Study 1 (September 19 to 22, 2006)*. Run Length Study 1 was conducted on Vessel A shortly after system startup in September 2006 to establish baseline system performance. Raw water samples collected on September 20, 2006 contained 24.8  $\mu$ g/L of total arsenic, 3.5 mg/L of nitrate (as N), 73 mg/L of sulfate, 325  $\mu$ g/L of total phosphorus, 60  $\mu$ g/L of total vanadium, and 301 mg/L (as CaCO<sub>3</sub>) of alkalinity (See Appendix D). Figure 4-32 presents total arsenic, nitrate, sulfate, total vanadium, total phosphorus, and total alkalinity breakthrough curves from Vessel A. The first sample collected at 10,700 gal contained slightly elevated total arsenic, total phosphorus, and total arsenic concentration generated resin bed. Total arsenic concentrations decreased to <1  $\mu$ g/L, stayed at this low level through 500,000 gal, and then peaked at 10  $\mu$ g/L between 550,000 and 600,000 gal (approximately 562,300 gal based on linear interpolation). Afterwards, the effluent arsenic concentration reached the influent level at approximately 650,000 gal, then continued to increase to 60.8  $\mu$ g/L in the last sample collected at 904,350 gal. Arsenic dumping resulted in an effluent concentration almost 2.5 times the influent level, the highest level ever detected at this plant throughout the entire study. Therefore, the regeneration setpoint was reduced to 600,000 gal on October 5, 2006 as soon as the sample results became available.

Nitrate was below detection before reaching 550,000 gal and gradually increased to 5.2 mg/L (as N) at 904,350 gal by the end of this special study period. This effluent nitrate level exceeded the influent level but was lower than the 10-mg/L (as N) MCL. Sulfate stayed below 1 mg/L until 550,000 gal, and then increased sharply to 42.8 mg/L (or 60% of the influent level) at 904,350 gal. Total phosphorus also rose sharply after 550,000 gal and reached 766  $\mu$ g/L (or 2.4 times the influent level) at 904,350 gal. Total vanadium was below 3  $\mu$ g/L throughout the entire cycle (except for the initial spike mentioned above), suggesting that it might have a higher selectivity than sulfate. Total alkalinity concentrations started off low at 10 mg/L (as CaCO<sub>3</sub>) at 10,700 gal, rose steadily to its influent level at 323,700 gal, and then leveled off between 312 and 368 mg/L (as CaCO<sub>3</sub>) through the end of this special study period.

*Run Length Study 2 (October 24 to 26, 2007)*. Run Length Study 2 was conducted on Vessel A two days after resin cleaning using a mixture of 5% caustic/10% brine in October 2007 to assess the effectiveness of the cleaning. Figure 4-33 presents total arsenic, nitrate, sulfate, and total alkalinity breakthrough curves, which are similar to those shown in Figure 4-32, except that the first breakthrough point for total As, nitrate, and sulfate occurred at approximately 400,000 gal, shorter than the 550,000 gal observed in Run Length Study 1. The run length to  $10-\mu g/L$  of arsenic breakthrough was approximately 445,720 gal, which was 20% more than the pre-cleaning level, but only 80% of the baseline level. The highest arsenic



Figure 4-32. Vessel A Breakthrough Curves from Run Length Study 1



Figure 4-33. Vessel A Breakthrough Curves from Run Length Study 2

concentration was 35.7  $\mu$ g/L in the last sample collected at 565,000 gal. Nitrate concentrations were below 10 mg/L (as N) throughout this run length study. Sulfate concentrations stayed below 1 mg/L until 400,000 gal, and then increased sharply to 23 mg/L at the end of this special study. Total vanadium concentrations were <3  $\mu$ g/L throughout this run length study (data not shown in the graph). Total alkalinity concentrations started off at 24 mg/L (as CaCO<sub>3</sub>) at 5,000 gal, increased rapidly to 345 mg/L (as CaCO<sub>3</sub>) at 300,000 gal, and then leveled off between 335 and 364 mg/L (as CaCO<sub>3</sub>) thereafter.

*Run Length Study 3 (December 8 to 10, 2008)*. Run Length Study 3 was conducted on Vessel A to assess the condition of the resin following nine months of system operation after the October 2007 caustic/brine cleaning. Raw water samples collected at the beginning of the study contained 24.0 µg/L of total arsenic, 53.3 µg/L of total vanadium, and 57.7 mg/L (as SiO<sub>2</sub>) of silica. As shown in Figure 4-34, the run length to 10-µg/L of arsenic breakthrough was shortened significantly from the previous 445,720 gal to approximately 323,530 gal. The deteriorating performance also was reflected by the total vanadium breakthrough curve, which showed a concentration of 11.3 µg/L at 600,000 gal, compared to <1 µg/L in both Run Length Studies 1 and 2. Silica concentrations stayed constant throughout this special study, ranging from 58.0 to 59.3 mg/L (as SiO<sub>2</sub>).



Figure 4-34. Vessel A Breakthrough Curves from Run Length Study 3

*Run Length Study 4 (April 21 to 22, 2009)*. To establish baseline performance of the dual resins at the beginning of Study Period II, combined effluent samples were collected mostly between 400,000- and 600,000-gal volume throughput. Raw water samples collected on April 22, 2009 at 162,061 gal of water

treated contained 23.3  $\mu$ g/L of total arsenic, 308  $\mu$ g/L of total phosphorus, 59.4  $\mu$ g/L of total vanadium, 6.8 mg/L of nitrate (as N), and 2.0 mg/L of TOC (See Appendix D).

As shown in Figure 4-35, arsenic breakthrough at 10  $\mu$ g/L occurred between 403,000 and 450,000 gal and estimated to be 436,350 gal using linear interpolation, which was consistent with the results of weekly sampling discussed in Section 4.5.1.2 (Figure 4-24). Arsenic peaking occurred after 500,000 gal with the highest concentration measured at 30  $\mu$ g/L. Similarly, total phosphorus began to exceed its influent level around 500,000 gal with the highest concentration measured at 438  $\mu$ g/L. Total vanadium was removed to <5  $\mu$ g/L in all but the first sample. Nitrate was below its MCL for the entire study period, reaching its influent concentration by the end of the study. TOC was removed to below the reporting limit of 1 mg/L consistently throughout, suggesting that A850END had worked well as a TOC scavenger.



Figure 4-35. Combined Effluent Breakthrough Curves from Run Length Study 4

*Run Length Study 5 (June 29 to July 1, 2009)*. Resin cleaning was performed one week prior to this run length study. Figures 4-36a and 4-36b show breakthrough curves of arsenic, nitrate, sulfate, total phosphorus, and total vanadium for Vessels A and B, respectively. pH and alkalinity data were plotted for both vessels on Figure 4-37. TOC and silica data were not plotted.

As shown in Figure 4-36, effluent from Vessels A and B reached  $10-\mu g/L$  arsenic breakthrough at approximately 443,000 and 493,000 gal, respectively, or 468,000 gal (on average). Nitrate did not reach the 10 mg/L MCL in either vessel. TOC stayed below the MDL of 1 mg/L throughout the study, indicating good removal by the TOC scavenger. Total phosphorus rose sharply around 400,000 gal for both vessels. Sulfate and total vanadium remained low throughout the study period while silica concentrations in the treated water were similar to the raw water level (i.e., 58.7 mg/L [as SiO<sub>2</sub>]).



Figure 4-36. Breakthrough Curves from Run Length Study 5



Figure 4-37. pH and Alkalinity Breakthrough Curves from Run Length Study 5

Similar to the re-constructed plot (Figure 4-29) based on weekly samples, decreases in pH values were observed at the beginning of the run length study after the IX system had been freshly regenerated. pH values were at 6.2 at throughput up to 70,000 gal, and increased to 7.1 and 7.0 at 178,360 and 175,240 gal for Vessels A and B, respectively. The decreases in pH corresponded to the decreases in total alkalinity, i.e., from 26.7 mg/L initially to 283 mg/L at 178,360 gal for Vessel A; and from 29 mg/L initially to 216 mg/L at 175,240 gal for Vessel B. Alkalinity for both vessels remained steady at 370 mg/L after 300,000 gal of water treated.

**4.5.4 Regeneration Elution Study.** The results of the elution study conducted on June 29, 2009 are discussed as follows.

**Elution Curves.** Figure 4-38 presents elution curves of arsenic, nitrate, total phosphorus, alkalinity, sulfate, vanadium, silica, and TOC for Vessels A and B. Figure 4-39 shows similar curves for TDS and pH. All figures have a primary and a secondary y-axis to accommodate all intended analytes on the same graphs. TDS concentration reflects salt concentration in the eluent. As the brine solution entered an IX vessel, arsenic, nitrate, sulfate, TOC, and other analytes of concern on the exhausted resin were displaced into the eluent by highly concentrated chloride ions. The highest concentrations of arsenic, sulfate, and TOC from Vessel A were measured at 6,963 µg/L, 33,560 mg/L, and 327 mg/L, respectively, approximately 11 min into the brine draw step. Nitrate did not peak until 18 min into brine draw at 942 mg/L (as N). Peak concentrations of arsenic, nitrate, sulfate, and TOC from Vessel B occurred between 5 min and 15 min into the brine draw step and were measured at  $6,882 \mu g/L$ , 900 mg/L (as N), 40,000 mg/L, and 308 mg/L, respectively. Maximum TDS concentrations for each vessel occurred approximately 6 min into the slow rinse step. After 41 min into the 45 min slow rinse step, arsenic and nitrate concentrations decreased to below their respective MCLs while TOC was below its detection limit. Sulfate concentrations fell below its secondary MCL (250 mg/L) at 36 and 28 min into the slow rinse step for Vessels A and B, respectively. TDS concentrations for both vessels exceeded its secondary MCL (500 mg/L) during the entire regeneration cycle.





Figure 4-38. Vessels A and B Elution Curves





Figure 4-39. Vessels A and B Elution Curves for TDS and pH

As shown on Figure 4-39, starting pH values were approximately neutral, i.e., 7.1 for TA and 7.0 for TB. During brine draw, pH values continued to rise until peaking at 8.4 after 16 min into the slow rinse step for Vessel A and 8.6 after 13 min into the slow rinse step for Vessel B. By the end of the fast rinse, pH values in each vessel had decreased to approximately 6.2.

**Regeneration Flowrate and Wastewater Volume.** As part of the June 29, 2009 elution study, regeneration flowrates were monitored during the regeneration of each vessel. Flowrates for Vessel A were 44 gpm for brine draw, 42 to 44 gpm for slow rinse, and 260 to 261 for fast rinse, compared to the target values of 64, 44, and 260 gpm. Flowrates for Vessel B varied from 40 to 43 for brine draw, 43 to 44 gpm for slow rinse, and 263 to 277 gpm for fast rinse. The average flowrate for brine draw was 43 gpm, which was about 33% lower than the target value of 64 gpm. The lower brine draw flowrate resulted in lower salt usage and lower salt loading as discussed below under "Saturated Brine Usage."

The volume of wastewater produced was 6,363 gal by Vessel A and 6,491 gal by Vessel B and 12,900 gal by both vessels. The wastewater produce was discharged to the evaporation pond.

**Saturated Brine Usage.** The amount of 23% saturated brine used was tracked by the brine totalizer. Regeneration Vessels A and B used 338 and 319 gal of saturated brine, respectively, equivalent to 760 and 718 lb of salt, respectively. Salt loadings for Vessels A and B were 7.7 and 7.33 lb/ft<sup>3</sup>, which were 23% and 27% lower than the target loading of 10 lb/ft<sup>3</sup>.

**Mass Recovered During Regeneration.** Concentrations of arsenic, nitrate, vanadium, and TOC were measured in composite samples collected at the conclusion of each of the three regeneration steps and the respective volumes of the waste stream were used to calculate the mass of each contaminate recovered from regeneration. The amount of each contaminant removed from influent water was calculated based on concentrations of influent and effluent samples collected prior to the regeneration and a volume throughput of 403,000 gal. Because only one set of influent and effluent samples were collected prior to regeneration, the amounts of contaminants removed from influent water could be erroneous. The percent recovery of arsenic, nitrate, vanadium, and TOC from regeneration was calculated using Equation 3:

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

where:

 $\ensuremath{\%R}$  = percent recovery  $M_{recovered}$  = mass of contaminate in regenerant waste (mg or g)  $M_{removed}$  = mass of contaminate removed from influent water (mg or g)

As shown in Table 4-19, the regeneration waste stream contained 17.3 g of arsenic, 4.2 kg of nitrate, 50.1 g of vanadium, and 1.1 kg of TOC per regeneration cycle. The percent recoveries were 112% for arsenic, 131% for nitrate, 113% for vanadium, and 98.5% for TOC. The majority of arsenic, nitrate, vanadium, and TOC were removed during the brine draw step and the early stage of the slow rinse step. A rather small amount was removed during the fast rinse step.

**4.5.5 Regeneration Residual Sampling.** During regeneration of Vessels A and B in Study Period I, the operator collected composite samples from the waste stream from each regeneration step on December 20, 2006; January 31, 2007; and March 20, 2007. Composite samples also were collected on June 29, 2009, as part of the elution study on the dual resin system. Table 4-20 summarizes analytical results of the four residual sampling events. As expected, the majority of arsenic and nitrate was eluted during the brine draw step (both reused and fresh brine) for both Arsenex II and PFA300E/A850END. For Arsenex II, total arsenic concentrations in the reused brine, fresh brine, slow rinse, and fast rinse samples averaged 2,678, 2,221, 527, and 11.3  $\mu$ g/L, respectively; the corresponding concentrations for

Parameter	Unit	Values								
Volume of Water Treated	gal			403,	000					
		Arsen	ic Mass B	Balance	Vanadium Mass Balance					
Vessel		А	В	Total	А	В	Total			
Concentration in Composite Brine Draw Waste	μg/L	1,471	2,935	2,203 <sup>(a)</sup>	5,981	4,705	5,343 <sup>(a)</sup>			
Concentration in Composite Slow Rinse Waste	μg/L	152	148	150 <sup>(a)</sup>	918	829	873 <sup>(a)</sup>			
Concentration in Composite Fast Rinse Waste	μg/L	3.0	3.8	3.4 <sup>(a)</sup>	12.8	14.6	13.7 <sup>(a)</sup>			
Brine Draw Volume	gal	924	882	1,806	924	882	1,806			
Slow Rinse Volume	gal	1,980	1,980	3,960	1,980	1,980	3,960			
Fast Rinse Volume	gal	3,900	4,080	7,980	3,900	4,080	7,980			
Mass Recovered from Brine Draw Step	mg	5,144	9,798	14,941	20,917	15,706	36,623			
Mass Recovered from Slow Rinse Step	mg	1,140	1,106	2,246	6,876	6,216	13,092			
Mass Recovered from Fast Rinse Step	mg	43.8	59.0	103	188	225	413			
Total Mass Recovered	mg	6,328	10,963	17,291	27,981	22,147	50,128			
Mass Removed from Influent Water <sup>(b)</sup>	mg			15,482			44,388			
Percent Recovery	%		112%							
		Nitrat	te Mass B	alance	TOC	<sup>c</sup> Mass Ba	alance			
Concentration in Composite Brine Draw Waste	mg/L	498	401	450 <sup>(a)</sup>	83.8	158	121 <sup>(a)</sup>			
Concentration in Composite Slow Rinse Waste	mg/L	84.7	51.9	68 <sup>(a)</sup>	20.8	18.0	19.4 <sup>(a)</sup>			
Concentration in Composite Fast Rinse Waste	mg/L	2.6	2.6	$2.6^{(a)}$	<1.0	<1.0	<1.0 <sup>(a)</sup>			
Brine Draw Volume	gal	1,980	1,980	3,960	1,980	1,980	3,960			
Slow Rinse Volume	gal	3,900	4,080	7,980	3,900	4,080	7,980			
Fast Rinse Volume	gal	8,279	10,387	18,665	8,279	10,387	18,665			
Mass Recovered from Brine Draw Step	g	1,742	1,339	3,080	293	527	821			
Mass Recovered from Slow Rinse Step	g	635	389	1,024	156	135	291			
Mass Recovered from Fast Rinse Step	g	38.1	39.5	78	7.4	7.7	15			
Total Mass Recovered	g	2,415	1,767	4,182	456	670	1,126			
Mass Removed from Influent Water <sup>(b)</sup>	g			3,203			1,144			
Percent Recovery	%			131%			98.5%			

 Table 4-19. Mass Balance Calculations for Total Arsenic, Nitrate, Vanadium, and TOC

(a) Average concentrations from both vessels used for calculations.

(b) Calculated using concentrations in raw and treated water.

Note: One-half the detection limit used in calculations.

PFA300E/A850END were 2,203, 150, and 3.4  $\mu$ g/L. Similarly, nitrate concentrations averaged 122, 517, 194, and 3.6 mg/L (as N) for Arsenex II and 450, 68, and 2.6 mg/L (as N) for PFA300E/A850END.

Comparing the data of spent and fresh brine samples, the TDS of spent brine was 36% of that of fresh brine, indicating dilution of spent brine during the previous regeneration cycle. Therefore, spent brine had a lower strength than fresh brine. Because it was difficult to estimate carryovers of arsenic and nitrate from the previous regeneration cycle, percent recoveries of arsenic and nitrate were not calculated for Arsenex II to assess the regeneration efficiency.

Fast rinse samples contained low levels of arsenic, nitrate, sulfate, and TDS, indicating that resin beds had been rinsed thoroughly and were ready to be put online for a service cycle. This also explained why there was little or no arsenic/nitrate leakage at the beginning of a service cycle following regeneration. The lower pH value of the fast rinse water, i.e., ranging from 6.4 to 6.9, was caused by bicarbonate removal by the freshly regenerated resin, which continued through the beginning of the service cycle.

	Reused Brine Draw							Fresh	n Brine Di	raw			S	low Rins	e			Fast Rinse			
Sampling	g Event	As (total)	Nitrate	Sulfate	SQT	Hq	As (total)	Nitrate	Sulfate	SQT	Hq	As (total)	Nitrate	Sulfate	SQT	Hq	As (total)	Nitrate	Sulfate	SQT	рН
_			mg/L				-	mg/L		~	~ ~ ~	~	mg/L	~	-		-	mg/L	-		
Date	Vessel	μg/L	(as N)	mg/L	mg/L	S.U.	μg/L	(as N)	mg/L	mg/L	S.U.	μg/L	(as N)	mg/L	mg/L	S.U.	μg/L	(as N)	mg/L	mg/L	S.U.
Study Period I																					
12/20/06	Α	43.8 <sup>(a)</sup>	26.2 <sup>(a)</sup>	3,800 <sup>(a)</sup>	22,800 <sup>(a)</sup>	8.7 <sup>(a)</sup>	3,208	631	13,000	89,900	8.2	942	122	974	20,800	8.4	10.7	3.5	<1	738	6.6
	В	32.5 <sup>(a)</sup>	134	19,000	29,800	8.7	2,934	333	6,200	96,400	8.2	688	264	1,900	42,700	8.4	4.9	2.9	2.0	678	6.4
01/31/07	Α	2,962	109	14,000	26,800	8.6	1,532	808	9,700	95,500	8.3	447	201	1,600	41,900	8.4	13.7	2.1	43	744	6.5
	В	2,393	124	30,000	29,100	8.6	1,775	838	13,000	91,900	8.3	115	47.3	346	10,200	8.4	10.6	3.4	1.0	728	6.5
03/20/07	Α	(b)	(b)	(b)	(b)	(b)	1,372	248	23,000	54,100	8.4	404	5.2	3,900	74,100	8.3	15.8	5.4	295	1,000	6.8
	В	(b)	(b)	(b)	(b)	(b)	2,507	245	26,000	55,200	8.4	568	523	2,800	73,300	8.3	12.4	4.1	4.0	1,050	6.9
	Average	2,678	122	21,000	28,600	8.6	2,221	517	15,150	80,500	8.3	527	194	1,920	43,833	8.3	11.3	3.6	69.0	823	6.6
									Study	Period II											
06/29/09	Α		N	ot Applicab	ole		1,471	498	7,080	59,165	7.6	152	84.7	710	34,800	7.8	3.0	2.6	1.2	753	6.4
	В	Not Applicable					2,935	401	14,000	70,500	7.7	148	51.9	671	25,900	8.0	3.8	2.6	8.9	760	6.3
	Average		No	ot Applicab	le		2,203	450	10,540	64,833	7.7	150	68	691	30,350	7.9	3.4	2.6	5.1	757	6.4

# Table 4-20. Regeneration Residual Sampling Results

(a) Data not included in calculating averages.(b) Data not presented due to abnormal results.

**4.5.6 Analysis of Evaporation Pond Water.** Table 4-21 presents analytical results of the pond water samples. With a pH of 9.3 to 9.8, the pond water contained 4,560 mg/L of total alkalinity, 16 to 25.6 g/L of chloride, 13 to 30.2 g/L of sodium, and 38.2 to 60.1 g/L of TDS, indicating a highly alkaline and saline water. The pond water also contained as high as 1.3 mg/L of total arsenic, 7.3 g/L of sulfate, 9.2 mg/L (as N) of nitrate, 13.3 mg/L of total phosphorus (as P), and 4.1 mg/L of vanadium.

Sample		Pond Water									
Parameter	Unit	07/16/07	09/17/07	03/15/08 <sup>(a)</sup>	02/09/09	04/09/09 <sup>(b)</sup>					
рН	S.U.	NA	NA	NA	9.8	9.3-9.7					
Total Alkalinity	mg/L	NA	NA	NA	4,560	NA					
Sulfate (as SO <sub>4</sub> )	mg/L	7,380	NA	NA	7,300	NA					
Nitrate (as N)	mg/L	NA	NA	4.1	9.2	NA					
Total P (as P)	mg/L	NA	NA	NA	NA	13.3					
Phosphate (as PO <sub>4</sub> )	mg/L	37.3	58.4	NA	44.1	NA					
Silica (SiO <sub>2</sub> )	μg/L	34.6	18.8	NA	60.7	NA					
Chloride	mg/L	16,000	NA	25,600	22,300	NA					
Turbidity	NTU	NA	NA	NA	65.0	NA					
TDS	mg/L	38,200	NA	NA	60,100	NA					
TSS	mg/L	NA	NA	NA	122	NA					
As (total)	μg/L	1,070	1,330	788	1,234	1,315					
As (soluble)	μg/L	NA	1,320	NA	1,226	NA					
Fe (total)	μg/L	574	<1,500	NA	523	271					
Fe (soluble)	μg/L	NA	NA	NA	567	NA					
Mn (total)	μg/L	NA	NA	NA	NA	14.1					
Mn (soluble)	μg/L	NA	NA	NA	NA	NA					
V (total)	μg/L	3,730	4,100	NA	1,477	1,405					
V (soluble)	μg/L	NA	4,070	NA	1,309	NA					
Na (total)	mg/L	16,550	15,410	13,000	16,032	30,167					
Na (soluble)	mg/L	NA	15,712	NA	15,575	NA					

Table 4-21. Analytical Data for Pond Water at Vale, OR

(a) Data provided by City of Vale.

(b) Samples collected on 02/09/09 re-analyzed on 04/09/09.

NA = not available

Based on results of the regeneration residual sampling in Table 4-20 and the volume of the waste stream produced by each regeneration step, the average arsenic concentration in the waste stream was estimated to be 834  $\mu$ g/L. Although evaporation of the pond water could concentrate the contaminants in the pond, the high arsenic concentrations measured in the pond water suggested that the FeCl<sub>3</sub> treatment was not effective in treating arsenic, due presumably to the presence of high TDS in the pond water.

As described in Section 4.2.2, 0.25 gal of a 40% ferric chloride solution was fed to the waste stream in a batch mode for 15 min during each vessel regeneration. The iron dosage was calculated to be 6.6 mg/L (as Fe) assuming 7,250 gal of wastewater would be produced during regeneration of each vessel. Based on the average arsenic concentration of 834  $\mu$ g/L in the waste stream, the mass ratio of Fe to As was approximately 8:1, which was significantly lower than the generally recommended 20:1 ratio for effective arsenic removal in drinking water treatment.

A series of jar tests were performed in Battelle's Treatability Laboratory on the pond water containing  $1,315 \mu g/L$  of total arsenic. Iron dosages were 20, 60, 80, 120, 320, 800, and 1,600 mg/L (as Fe),

corresponding to Fe to As mass ratios of 15:1 to 1,216:1 at a pH value of 6.9 to 7.2. Analytical results showed that final arsenic concentrations in the supernatant ranged from 106 to 904  $\mu$ g/L and generally decreased with increasing iron dosages, as shown in Figure 4-40. However, the concentration reduction leveled off after the first 320 mg/L of iron addition. Even with the 320 mg/L of iron addition, arsenic in supernatant remained high at 200  $\mu$ g/L, indicating ineffective treatment by FeCl<sub>3</sub>. In contrast, the spent regenerant from an AM system containing up to 200 mg/L of arsenic (but no salt) was effectively treated to below 10  $\mu$ g/L with FeCl<sub>3</sub> at a mere 30:1 Fe/As mass ratio under a neutral pH condition. As shown in Figure 4-40, total phosphorus and total vanadium also were removed, suggesting that these anions might contents along with the presence of competing anions rendered the FeCl<sub>3</sub> treatment of the pond water ineffective.



Figure 4-40. Results of Vale Pond Water Jar Tests

**4.5.7 Distribution System Water Sampling**. Table 4-22 summarizes results of the distribution system sampling. Prior to system startup, four monthly baseline distribution water samples were collected from June through September 2005 at three locations within the distribution system. These three locations included two LCR residences and one non-residence. Following system startup, distribution system sampling continued on a monthly basis at the same locations until April 2007. No distribution water samples were collected during Study Period II. All stagnation time for the first draw samples met the minimum 6 hr requirement, except for one occasion at DS2 on August 23, 2005 (4.8 hr).

	Location		DS1							DS2						DS3									
	Address		629 15th St North							780 15th Street North						252 B Street West									
	Sample																								
	Туре		LCR							LCR						Non-Residence									
	Flushed/1s																								
	t Draw				1st I	Draw					1st Draw									1st E	Draw				
No.	Sampling Date	Stagnation Time (hr)	рН	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time (hr)	Hq	Alkalinity	As	Fe	Mn	4D	Си	Stagnation Time (hr)	Hq	Alkalinity	As	Fe	Mn	Pb	Си
BL1	06/15/05	8.5	7.4	484	21.4	<25	0.2	1.1	337	9.3	7.3	484	20.7	<25	1.4	1.4	154	7.2	7.3	431	22.4	<25	0.7	1.7	381
BL2	07/13/05	6.6	7.5	308	17.5	<25	0.9	1.2	194	7.4	7.4	308	16.2	<25	0.1	1.9	390	9.8	7.5	308	16.1	<25	0.8	0.7	96.1
BL3	08/23/05	7.5	7.4	308	25.6	<25	0.6	0.2	83.7	4.8	7.4	308	26.2	<25	0.1	0.3	341	14.5	7.3	308	24.9	<25	0.6	0.5	85.8
BL4	09/21/05	7.0	7.6	299	14.7	<25	0.6	1.0	210	6.2	7.5	308	14.0	<25	0.2	2.2	492	15.3	7.6	308	14.7	<25	0.7	1.8	106
1	10/10/06	6.5	7.6	280	9.7	<25	< 0.1	0.5	156	7.6	7.6	288	11.1	<25	0.4	1.6	501	11.1	7.5	291	9.8	193	12.8	2.5	75.3
2	11/14/06	14.8	7.5	325	10.3	<25	< 0.1	12.9	248	7.9	7.4	347	8.7	<25	0.2	2.8	891	14.9	7.4	296	7.1	34	13.7	5.1	66.9
3	12/05/06	15.0	7.5	321	11.8	<25	< 0.1	21.9	277	7.3	7.5	323	10.6	<25	< 0.1	0.9	223	12.0	7.4	323	12.4	<25	0.4	0.2	84.4
4	01/10/07	15.3	7.7	334	10.6	<25	< 0.1	2.6	53.9	7.3	7.7	338	10.4	<25	0.1	0.5	134	14.0	7.6	326	9.7	<25	1.0	0.3	141
5	02/08/07	14.8	7.7	327	11.7	<25	0.1	7.6	157	7.3	7.7	335	14.2	<25	1.0	0.6	234	NA	7.6	318	10.9	<25	1.3	0.4	100
6	03/07/07 <sup>(a)</sup>	14.8	7.8	329	18.6 <sup>(a)</sup>	<25	< 0.1	4.7	149	6.7	7.6	342	24.0 <sup>(a)</sup>	<25	< 0.1	1.0	381	15.0	7.7	327	16.9 <sup>(a)</sup>	<25	1.1	0.4	141
7	04/10/07	15.0	7.7	344	17.0	<25	< 0.1	8.3	100	7.5	7.6	334	16.5	<25	0.3	0.8	479	14.5	7.6	365	12.8	<25	1.6	0.3	108

### Table 4-22. Distribution System Sampling Results in Study Period I at Vale, OR

BL = baseline sampling.; Lead action level = 15 μg/L; copper action level = 1.3 mg/L μg/L as unit for all analytes except for pH and alkalinity (mg/L [as CaCO<sub>3</sub>]).
(a) System not functioning properly due to inadvertent switching to counter-current regeneration.

Because treated water from the IX plant was stored in the 200,000-gal reservoir before supplying the distribution system, the water quality of the distribution samples would reflect the general quality of the plant effluent after being blended in the reservoir.

Arsenic concentrations of the four baseline sampling events were comparable among all three locations, ranging from 14.0 to 26.2  $\mu$ g/L and averaged 19.5  $\mu$ g/L. After system startup, arsenic concentrations at all three locations ranged from 7.1 to 24.0  $\mu$ g/L and averaging 12.6  $\mu$ g/L. Arsenic concentrations were reduced significantly, but not to the low level (i.e., < 5  $\mu$ g/L) that would be expected from an IX treatment plant because the IX system was allowed to operate beyond 10  $\mu$ g/L. In five of seven sampling events, arsenic concentrations in distribution water were close to or slightly higher than the MCL of 10  $\mu$ g/L. For the sampling event on March 7, 2007, the arsenic concentration in distribution water increased to as high as 24.0  $\mu$ g/L, corresponding to the high levels in the plant effluent on March 5, 12, and 19, 2007, caused by the inadvertent switching to counter-current regeneration. For the sampling event on April 10, 2007, arsenic concentrations were 17.0, 16.5, and 12.8  $\mu$ g/L at the DS1, DS2, and DS3 locations, respectively, significantly higher than the 1.6  $\mu$ g/L in the plant effluent. Examination of the sampling logs revealed that plant effluent samples were collected in the middle of the day after the system had just been regenerated while distribution "first draw" samples were collected early in the morning when the reservoir was filled with water containing high levels of arsenic before regeneration.

There was no obvious change to the pH value before and after system startup: the values ranged from 7.3 to 7.6 and averaged 7.5 before startup and ranged from 7.4 to 7.8 and averaged 7.6 after system startup. Alkalinity also stayed essentially the same, with concentrations ranging from 299 to 484 mg/L (as  $CaCO_3$ ) before startup and from 280 to 365 mg/L (as  $CaCO_3$ ) after startup. Although occasionally, some low pH and low alkalinity were measured in treated water samples collected from freshly regenerated vessels (see Section 4.5.2), the blending effect in the reservoir had mitigated any potential pH or alkalinity swing. Therefore, low pH and low alkalinity were never measured in distribution system water samples.

Lead levels at DS2 and DS3 were similar to those in baseline samples. The average concentrations were 1.4  $\mu$ g/L at DS2 and 1.2  $\mu$ g/L at DS3 before system startup; and were 1.2  $\mu$ g/L at DS2 and 1.3  $\mu$ g/L at DS3 after system startup. Lead level at DS1, however, increased after system startup to an average of 8.3  $\mu$ g/L, compared to 1.2  $\mu$ g/L in baseline samples. On December 5, 2006, lead concentrations at DS1 reached 21.9  $\mu$ g/L, exceeding the action level of 15  $\mu$ g/L. The reason for the elevated lead concentrations at DS1 is unknown since the pH and alkalinity appeared normal. Baseline copper concentrations varied from 83.7 to 492  $\mu$ g/L and averaged 239  $\mu$ g/L. After system startup, copper concentrations decreased slightly to an average of 224  $\mu$ g/L, with no samples exceeding the 1,300  $\mu$ g/L action level.

Total iron concentrations in all samples were  $<25 \ \mu g/L$  and total manganese  $<2 \ \mu g/L$ , as expected, except for two occasions at DS3 on October 10 and November 14, 2006 when total iron concentrations were measured at 193 and 34  $\mu g/L$ , respectively, and total manganese concentrations measured at 12.8 and 13.7  $\mu g/L$ , respectively.

## 4.6 System Cost

The cost of the IX 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 tracking of the capital cost for the treatment equipment, site engineering, and installation and the O&M cost for salt supply, electricity consumption, and labor. The cost associated with the design and construction of the evaporation pond, the new building, and FeCl<sub>3</sub> addition system 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 Vale. Information on the construction cost is included in Section 4.3.2 at the courtesy of the City of Vale.

**4.6.1 Capital Cost.** The capital investment for the Vale IX system was \$395,434, which included \$260,194 for equipment, \$49,840 for site engineering, and \$85,400 for installation. Table 4-23 presents breakdowns of the capital cost provided by Kinetico. The equipment cost included the cost for the IX resin, filter skid, vessels, brine system, pre-filters, air compressor, instrumentation and controls, shipping, and labor. The equipment cost was 66% of the total capital investment.

			% of Capital
Description	Quantity	Cost	<b>Investment</b> Cost
Equ	ipment Cos	t	
Welded Stainless Steel Frame	1	\$8,030	_
Fiberglass IX Vessels	2	\$16,134	_
Distributors	2	\$2,718	_
Arsenex II Resin	$220 \text{ ft}^3$	\$64,400	_
Brine System	_	\$43,784	_
Process Valves and Piping	_	\$24,868	_
Air Compressor	_	\$1,500	_
Pre-treatment Filters	_	\$8,800	_
Instrumentation & Controls	_	\$13,090	_
Initial Salt	22 Tons	\$5,808	_
Sample Taps and Totalizer/meters	_	\$1,728	_
Shipping	_	\$17,000	_
Labor	_	\$52,334	_
Equipment Total	—	\$260,194	66%
Eng	ineering Co	st	
Vendor Labor	_	\$42,840	—
Subcontractor Labor	_	\$7,000	—
Engineering Total	-	\$49,840	12%
Inst	allation Cos	t	
Vendor Labor	_	\$15,400	-
Subcontractor Labor	-	\$65,750	—
Travel	-	\$4,250	-
Installation Total	-	\$85,400	22%
Total Capital Investment		\$395,434	100%

Table 4-23. Cost Breakdowns of Capital Investment for Vale IX System

The site engineering cost included the cost for preparing a process design report and the required engineering plans and obtaining the required permit approval from Oregon DHS DWP. The engineering plans included a general arrangement drawing, piping and instrumentation diagrams (P&IDs), interconnecting piping layouts, vessel fill details, a schematic of the PLC panel, an electrical on-line diagram, and other associated drawings. The engineering cost of \$49,840 was 12% of the total capital investment.

The installation cost included the cost for travel and labor to perform system unloading and anchoring, plumbing, mechanical and electrical connections, resin loading, system shakedown and startup, and operator's training. The installation cost was 22% of the total capital investment.

The total capital cost of \$395,434 was normalized to the system's rated capacity of 540 gpm (777,600 gpd), which resulted in \$732 per gpm (\$0.51 per gpd). The capital cost also was converted to an annualized cost of \$37,325/yr using a capital recovery factor of 0.09439 based on a 7% interest rate and a 20-year return. Assuming that the system operates 24 hr/day, 7 day/wk at the design flowrate of 540 gpm

to produce 283.8 million gal of water per year, the unit capital cost would be \$0.13/1,000 gal. In reality, the system operated an average of 9.5 hr/day at 534 gpm (in Study Period I, see Table 4-10), producing 111.1 million gal of water per year. At this reduced rate of operation, the unit capital cost increased to \$0.34/1,000 gal.

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 4-24. Salt supply was a major operating cost. Coarse solar salt manufactured at the North American Salt's Ogden, Utah facility, was used for the resin regeneration. This salt is NSF-certified for drinking water treatment. Over the first year of demonstration study, a total of 397,100 lb of salt was consumed. The salt delivery charge totaled \$30,180 for the same period. Based on an annual water production of 111.1 million gal, the average salt use was 3.6 lb/1,000 gal, corresponding to a salt cost of \$0.27/1,000 gal. This salt cost was almost 50% lower than that (\$0.49/1,000 gal) at Fruitland, ID. The lower salt use rate and the cheaper salt unit price are the two factors contributing to the lower salt cost at Vale. The average salt use rate was 3.6 lb/1,000 gal at Vale vs 4.4 lb/1,000 gal at Fruitland (due to an improper flow control of brine draw at Fruitland). The unit salt price was \$0.076/lb at Vale vs \$0.11/lb at Fruitland because Vale purchased salt in bulk quantities (i.e., half a truck load for two 11-ton saturators), which was cheaper than smaller quantities. If more storage capacity is added to allow delivery of a full truck load, then the overall salt cost can be further reduced. In addition, the Vale IX system adopted a caustic cleaning procedure every four months to prevent resin fouling. Each cleaning consumed two 55-gal drums of caustic soda (each 700 lb), which cost \$882. Based on three cleanings in a year, the cost of the caustic soda is \$2,646 or \$0.02/1,000 gal. Therefore, the sum of salt and caustic cost is \$0.29/1,000 gal.

Cost Category	Value	Assumptions								
Volume Processed (1000 gal/year)	111,100	Based on 9.5 hr/day and 534 gpm flowrate								
Salt Usage										
Salt Unit Price (\$/lb)	0.076	_								
Total Salt Usage (lb/year)	397,100	Quantity delivered								
Salt Use (lb/1,000 gal)	3.6	_								
Total Salt cost (\$/year)	30,180	_								
Unit Salt Use Cost (\$/1,000 gal)	0.27	_								
Caustic Soda Unit Price (\$/lb)	0.63	Delivery charge included								
Total Caustic Usage (lb/year)	4,200	Three cleanings, each using 1,400 lb of caustic								
Total Caustic cost (\$/year)	2,646	_								
Unit Caustic Cost (\$/1,000 gal)	0.02	_								
Sum of Salt and Caustic Cost (\$/1,000 gal)	0.29	_								
	Electricity Consum	ption								
Power Use (\$/1,000 gal)	0.028	Monthly electric bill increased by \$250								
	Labor									
Average Weekly Labor (hr/wk)	3.33	40 min/day; 5 day/wk								
Total Labor Hours (hr/year)	173.33	52 week a year								
Total Labor Cost (\$/year)	3,640	Labor rate $=$ \$21/hr								
Labor Cost (\$/1,000 gal)	0.034	_								
Total O&M Cost/1,000 gal	0.35	_								

Incremental electricity consumption associated with the IX system was estimated based on the monthly electricity bill before and after the system startup. For example, the electricity bill at the treatment plant

was approximately \$850 a month in 2006 and increased by 29% to \$1,100 a month in 2007. Thus, the annual increase was \$3,000, or \$0.028/1,000 gal.

The routine, non-demonstration related labor activities consumed about 40 min/day, five days a week. Based on this time commitment and a labor rate of \$21/hr, the annual labor cost was \$3,640, or \$0.034/1,000 gal. In sum, the total O&M cost was approximately \$0.35/1,000 gal.

#### **5.0 REFERENCES**

- Battelle. 2004. *Revised Quality Assurance Project Plan for Evaluation of Arsenic Removal Technology*. Prepared under Contract No. 68-C-00-185, Task Order No. 0029, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Battelle. 2006. Study Plan for Evaluation of Arsenic Removal Technology at Vale, OR. Prepared under Contract No. 68-C-00-185, Task Order No. 0029, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Boodoo, F. 2004. "Multi-Contaminant Control with Ion Exchange." *Water Technology Magazine*, *5*(27).
- Boodoo, F., G. Schreiber, T. Satchell, L. Benton, B. Szczesny, E. Woo, D. Mielke. 2008. "Simultaneous Ion Exchange Removal of Arsenic, Nitrate, Uranium, and TOC at City of McCook, NE." AWWA Inorganic Contaminants Workshop, Albuquerque, NM.
- Chen, A.S.C., L. Wang, J.L. Oxenham, and W.E. Condit. 2004. Capital Costs of Arsenic Removal Technologies: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1. EPA/600/R-04/201. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Clifford, D.A. 1999. "Ion Exchange and Inorganic Adsorption." Chapter 9 in R. Letterman (ed.), *Water Quality and Treatment Fifth Edition*. McGraw Hill, Inc., New York, NY.
- Clifford, D.A., C.C. Lin, L.L. Horng, and J.V. Boegel. 1987. Nitrate Removal from Drinking Water in Glendale, Arizona. EPA/600/52-86/107, U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Clifford, D.A, G. Ghurye, and A.R. Tripp. 2003. "Arsenic Removal from Drinking Water Using Ion-Exchange with Spent Brine Recycling." *JAWWA*, *95(6)*: 119-130.
- Edwards, M., S. Patel, L. McNeill, H. Chen, M. Frey, A.D. Eaton, R.C. Antweiler, and H.E. Taylor. 1998. "Considerations in As Analysis and Speciation." *JAWWA*, *90*(*3*): 103-113.
- Ghurye, G.L., D.A. Clifford, and A.R. Tripp. 1999. "Combined Arsenic and Nitrate Removal by Ion Exchange." *JAWWA*, *91(10)*: 85-96.
- Kinetico, 2006. Operation and Maintenance Manual, IX-263-As/N Arsenic/Nitrate Removal System, Kinetico.
- EPA. 2001. National Primary Drinking Water Regulations: Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring. *Federal Register*, 40 CFR Parts 9, 141, and 142.
- EPA. 2002. Lead and Copper Monitoring and Reporting Guidance for Public Water Systems. EPA/816/R-02/009. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.
- EPA. 2003. Minor Clarification of the National Primary Drinking Water Regulation for Arsenic. *Federal Register*, 40 CFR Part 141.

- Wang, L., W.E. Condit, and A.S.C. Chen. 2004. Technology Selection and System Design: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1. EPA/600/R-05/001. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Wang , L., A.S.C. Chen, T.J. Sorg, and K.A. Fields. 2002. "Field Evaluation of As Removal by IX and AA". *JAWWA*, *94*(4):161-173.
- Wang, L., and A.S.C. Chen. 2010. U.S. EPA Arsenic/Nitrate Removal Technology Demonstration at Fruitland, ID. EPA/600/R-10/152. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.

APPENDIX A

Vale Arsenic System IX Resin Cleaning Procedure
#### VALE ARSENIC SYSTEM IX RESIN CLEANING PROCEDURE

Original (Revision 2) provided by Kinetico on September 21, 2007 Revision 3 provided by Battelle in June 2009 Revision 4 provided by Battelle in February 2010

- Step 1: Add sodium hydroxide (NaOH) to brine day tank
  - a. Make sure that brine day tank level is between low and low-low float so that there is enough room for adding NaOH.
  - b. Using a drum pump to add two 55-gal drums of 50% NaOH to the day tank. Be sure to add all 110 gal of NaOH to the tank. To assist in mixing, turn on brine refill valve and pump while NaOH is being added. Slow down brine refill as needed to ensure that all NaOH is used.
  - c. After brine day tank is full, close brine refill valve and turn off brine transfer pump.
- Step 2: Verify flow configuration
  - a. Verify that valves and the PLC are set to co-current regeneration (valve #HV9 is open and valve #HV 10 is closed).
- Step 3: Update/change slow rinse setpoint
  - a. Change slow rinse time from 45 to 75 min using touch screen. The extra 30 min is provided for resin soak in Step 5. Go to setpoint screen, touch the box next to slow rinse time, type in 75, and press enter key.
- Step 4: Begin cleaning Vessel (A or B)
  - a. Start a regeneration using pushbutton for the selected vessel
- Step 5: Soak resin bed
  - a. When brine draw on the selected vessel is finished (21 min), manually close valve #HV9.
  - b. Using slow rinse timer on the screen as the clock, allow resin to soak in caustic/brine solution for 30 min.
- Step 6: Rinse resin bed
  - a. After 30 min have elapsed, 45 min will be showing on slow rinse timer, manually open valve #HV9 to allow slow rinse and fast rinse to proceed automatically.
- Step 7: Repeat for other vessel
  - a. When the selected vessel regeneration is finished, repeat steps 4 to 6 for the other vessel.
- Step 8: Reset slow rinse setpoint
  - a. When both vessels have been regenerated, change slow rinse time back to 45 min. Using touch screen to go to setpoint screen and touch box next to slow rinse time. Another box will appear, type in 45 and press enter key.
- Step 9: Check brine draw setpoint, (fresh brine only, no brine recycle)
  - a. While in setpoint screen, make sure that second (fresh) brine draw time is set at 21 min. This will provide approximately 500 gal of fresh brine during regeneration.

Step 10: Reset total volume setpoint

a. Go to filter setpoint screen, press box next to total volume regen button and type in desired setpoint (e.g., 600,000 gal) and press enter key.

Step 11: Perform back to back regeneration

a. Repeat regeneration using pushbutton for each vessel; let both vessels regenerate automatically.

Step 12: Return system to service.

Step 13: Continue sampling

a. Sample effluent for arsenic and nitrate from each vessel during first 30,000 to 80,000 gal and again at 400,000 to 480,000 gal.

## APPENDIX B

Vale, OR Project Chronology

### VALE, OR PROJECT CHRONOLOGY

- 09/19/06: Study data collection begun.
- 09/19/06 09/22/06: Run length special study showed significantly lower than designed run length to As 10-µg/L breakthrough at **600,000 gal** and higher than designed salt usage during regeneration events.
- 09/27/06: Punch list items issued to Kinetico for resolution.
- 02/21/07: Meeting with Kinetico and EPA at Battelle to discuss performance issues and punch list items.
- 02/28/07 03/07/07: Kinetico was onsite to collect ion exchange resin samples for Purolite's analysis, install a fresh brine pump in place of the eductor system, and address punch list items. Ion exchange system was unexpectedly changed to counter-current mode by technician (not planned).
- 03/09/07: Kinetico indicated no record of vessel fill with polymer beads, which was required for counter-current mode and agreed to change back to co-current mode. Action items resolved were fresh brine pump installation and fresh brine totalizer replacement.
- 03/12/07: System was returned to co-current operation and continued to exhibit short run lengths to  $10 \mu g/L$  breakthrough after this visit even though design salt loading had been achieved.
- 04/16/07: Regular weekly sampling was discontinued until performance issues resolved. Battelle requested reduced regeneration frequency from 600,000 gal to 370,000 gal on April 16, 2007 to maintain ion exchange performance to below 10 μg/L MCL.
- 05/18/07: Kinetico and Purolite discussed that tests on Vale and Fruitland resin indicated organic matter buildup on the IX resin, which might have affected the IX resin performance. Kinetico and Purolite tested a caustic/brine cleaning procedure in the laboratory and recommended implementing the procedure in the field at Fruitland and then at Vale.
- 06/19/07: Fruitland caustic wash was conducted, Vale operators invited to attend for observation purposes, decision was made to wait on results of Fruitland wash before moving forward at Vale.
- 07/10/07: Operator replaced fresh brine pump that failed.
- 07/16/07: Limited weekly sampling (at TT location only) resumed at Vale per EPA request.
- 10/22/07: Caustic wash was performed at Vale by Kinetico, post-caustic wash resin samples were collected, and reused brine was turned off
- 10/24/07 to 10/26/07: Post-caustic wash run length special study was conducted immediately on first run after caustic wash. Run length at **445,722 gal.**
- 12/10/07: PLC updates were made to allow for reused brine regeneration to be turned off.
- 12/14/07: Post-caustic wash resin sample results were received from Purolite.
- 01/14/08: Ion exchange system was shut down for well rehabilitation and weekly limited sampling efforts were discontinued.
- 02/14/08: After reviewing Purolite's resin analyses and run length study results, Kinetico recommended further caustic washing to reduce fouling of the IX resin and suggested that the reused brine system components be used for a periodic, manual cleaning cycle.

- 04/11/08: Battelle held a conference call with Kinetico and requested that it look into alternate IX resin selection (including TOC scavenging resin) and the feasibility of converting the system to adsorption and/or coagulation filtration.
- 04/22/08: The City of Vale initiated pumping from lagoon after one-time approval from the State of Oregon to pump the wastewater in the lagoon to the airport grounds in order to lower the water level in the pond.
- 05/01/08: The City of Vale informed Battelle that the treatment system would be restarted on May 1, 2008 at the 600,000-gal regeneration interval.
- 05/07/08: Kinetico responded that they would not be able to provide services to reconfigure the treatment system to another process per EPA request and that they were willing to provide a credit in lieu of one more trip to the site for a caustic wash.
- 05/09/08: Battelle contacted Purolite to provide a run length simulation for the Purolite resin A850 suggested by Dennis Clifford of University of Houston.
- 05/15/08: Francis Boodoo of Purolite responded with an alternate suggestion for replacing the resin bed with new PFA300E and a top protective layer of a special grading of A850 known as A850END.
- 06/04/08: Battelle received a revised run length simulation and cost quote from Purolite for its proposed new resin design configuration of \$50,000 including 95 ft<sup>3</sup> of PFA300E (for arsenic/nitrate removal) and 15 ft<sup>3</sup> of A850End (for TOC scavenging) in one vessel. The estimated run length was equivalent to 639,000 gal (523 BV adjusted based on 163.3 ft<sup>3</sup> of A300E resin).
- 07/15/08: Battelle held a meeting with EPA, Kinetico, and the City in Columbus, OH to discuss next steps for the project and to troubleshoot IX treatment system performance. Dennis Clifford and Glen Latimer were in attendance to provide consultation support.
- 07/23/08: The city collected additional source water samples on July 23, 2008, from the combined inlet and each of the individual seven wells for analysis of key parameters. These results were later provided to Purolite to update the IX simulation.
- 08/15/08: Battelle visited Vale and worked with the operator to view the inside of the IX vessels and collect IX resin samples and spent filter samples. Battelle also observed a regeneration cycle and recorded salt usage parameters.
- 08/25/08: Battelle visited McCook to collect IX resin samples from the dual resin vessels and perform an elution study on both service and regeneration cycles for arsenic, nitrate, and more.
- 11/07/08: Purolite provided a quote for the new IX resin resins on November 7, 2008 and Battelle coordinated with Purolite to set up the purchase order.
- 11/19/08: TraceDetect installed the ArsenicGuard system.
- 11/19/08: Purolite reported that the Vale IX resin samples had moderate fouling by silica with Vessel A at 1,375 ppm SiO<sub>2</sub> and Vessel B at 2,500 ppm SiO<sub>2</sub>.
- 11/20/08: A Purolite local rep, Steve Soldatek, visited Vale on November 20, 2008, to inspect the system and investigate optimizing salt usage and wastewater regeneration. However, Steve Soldatek indicated that he did not have a chance to run any elution tests because the city was having some issues with the wellhead pumps.
- 12/08/08: A special run length study was performed on the fouled IX resin from December 8 to 10, 2008. The results of this study indicated that 10-µg/L arsenic breakthrough continued to

occur at a relatively low bed volume (**323,531 gal**), which is 27% lower than the post-caustic wash run length of **445,722 gal** in October 2007. The operator continued to operate the treatment system through 600,000 gal due to wastewater generation issues.

- 02/19/08: Purolite shipped A300E and A850END IX resins to Vale, which arrived on December 26, 2008.
- 01/14/09: Purolite issued an updated run length simulation for the dual IX resin beds based on the water quality samples collected in July 2008. The simulation results were comparable to the simulation results provided based on previous water quality samples in June 2008. Purolite run length estimate was **738,000 gal (604 BV adjusted based on 163.3 ft<sup>3</sup> of A300E resin).**
- 02/10/09 to 02/13/09: Tom Jadach of Accurate Water Solutions was onsite to remove original IX resin, load new resins, and restart the system. Tom Jadach reported lower-than-designed IX resin volumes.
- 02/13/09 to 03/02/09: Monitored effluent arsenic levels via ArsenicGuard system.
- 03/2/09 to 03/4/09: Battelle was onsite to conduct an elution study and a run length study. Due to an incident that occurred during the salt loading, the studies were compromised and had to be postponed until later.
- 03/25/09: Weekly sampling resumed.
- 04/21/09: The run length study was conducted by the operator starting on this date.
- 04/23/09: The operator informed Battelle that the City was switching salt suppliers from Handy Wholesale to Western Step Savers.
- 06/24/09: One week prior to a scheduled visit by Battelle, the operator performed a caustic wash on the dual IX resin beds.
- 06/28/09 to 06/30/09: Battelle was onsite to conduct the elution and run length studies originally scheduled for March 2009.
- 07/13/09: Eight drums of A300E (including two off-color drums) were picked-up by Smith's Pack & Ship to be returned to Pulrolite's warehouse in Santa Fe Springs, CA, for refund.
- 07/21/09: Drums arrived at Purolite warehouse in Santa Fe Springs, CA
- 08/12/09: Battelle received notification from Steve Soldatek that the refund payment for the returned resin would be issued that week.
- 10/16/09: The operator performed a caustic wash on the dual IX resin beds.
- 12/22/09: The operator informed Battelle that the treatment system was bypassed because of a faulty flow sensor. The operator was in contact with Tom Jadach of Accurate Water Solutions to place an order for the new sensor.
- 01/15/10: The operator replaced the main flow sensor and put the system back online.

APPENDIX C

**OPERATIONAL DATA** 

# US EPA Arsenic Demonstration Project at Vale, OR – Daily System Operation Log Sheet (Study Period I)

I	arameters	Pump Hour Meter	Daily Hour	Master Totalizer	Daily Volume	Booster Pump Pressure (PT4)	System Inlet Pressure (PT1)	Tank A Outlet Pressure	Tank B Outlet Pressure	Product Water Pressure	Finished Water Flowrate	Finished Water Volume Since Last Regen	BV Treated Since Last Regen.	Regen. Counter	Regen Water Totalizer (Per Event)	Fresh Brine Day Tank Totalizer	Reused Brine Day Tank Totalizer
	Unit	hr	hr/day	kgal	gpd	psig	psig	psig	psig	psig	gpm	gal	BV		gal	gal	gal
	09/18/06	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	09/19/06	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
1	09/20/06	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	09/21/06	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	09/22/06	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	09/25/06	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	09/26/06	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
2	09/27/06	1 467	NR	562	NR	53	52	43	42	14.0	NR	NR	NR	1	14 056	54 229	86 084
	09/28/06	1,107	73	562	NR	NR	NR	NR	NR	NR	551	72 934	52.4	2	14 042	55.018	87.617
	10/02/06	1,470	11.1	NR	NR	60	53	40	38	10.0	563	14 150	10.2	3	400.672	56,800	89,000
	10/02/00	1,510	0.0	NR	NR	60	52	40		10.0	560	86 162	61.0	3	14.025	58,000	00,500
3	10/04/00	1,540	7.7	ND	ND	60	53	40	40	10.0	555	270,996	272.0	4	14,025	38,000 ND	90,500 ND
	10/03/06	1,550	11.5	INK	NR	60	10	40	40	10.0	333	379,880	275.0	4	14,023	INK 50.200	02.000
	10/06/06	1,560	9.9	NR	NK	10	10	NR 40	NR 10	INK 10.0	INK	23,393	17.0	5	14,023	59,300	92,000
	10/09/06	1,585	8.6	NR	NK	60	53	40	40	10.0	560	132,197	95.0	6	14,139	60,600	93,600
	10/10/06	1,599	15.4	NK	NK	60 ND	- 33 ND	42 ND	42 ND	10.0	542	551,907	396.7	0	14,139	NR (1.024	NK 05.149
4	10/11/06	1,007	8.5	NK	NK	NR	NR	NR	NK	NK	INK	158,555	2(7.2	7	14,013	61,924	95,148
	10/12/06	1,015	/.0	NK ND	NK	NR	NR	NR	NK	NK	NR	3/1,/11	207.2	/	14,013	NR 62 200	NK
	10/15/06	1,028	15.0	INK	NR	INR	52	12	10	14.0	INK	155,259	97.2	0	14,005	63,200	90,080
	10/16/06	1,055	8.9	NR	NR	60	53	42	42	14.0	554	303,084	217.8	9	12,529	63,733	97,165
5	10/17/06	1,661	5.9	NR	NR	60	53	42	42	14.0	561	480,521	345.4	9	12,529	63,/33	97,165
	10/18/06	1,671	10.6	NR	NR	60	53	42	42	14.0	550	125,750	90.4	10	12,475	64,235	97,165
	10/20/06	1,675	2.1	NR	NR	60	53	42	41	11.5	550	254,901	183.2	10	12,475	64,235	97,165
	10/23/06	1,704	10.0	NR	NR	60	53	40	40	12.0	547	181,240	130.3	12	12,620	64,918	99,300
6	10/25/06	1,723	8.3	450	NR	60	53	40	40	12.0	547	110,143	79.2	13	12,605	65,238	100,310
	10/26/06	1,731	8.7	721	292,315	60	53	40	40	12.0	561	352,840	253.6	13	NR	NR	NR
	10/27/06	1,739	7.8	1,063	349,277	60	53	42	42	12.0	527	581,176	417.7	13	12,605	65,250	100,310
	10/30/06	1,768	9.5	1,789	234,667	60	53	40	39	11.5	560	112,126	80.6	15	66	71,265	102,390
7	11/01/06	1,783	8.1	NR	NR	NR	NR	NR	NR	NR	NR	546,698	392.9	15	66	71,265	102,390
	11/02/06	1,792	8.6	2,520	NR	60	53	42	41	12.0	555	169,900	122.1	16	78	71,590	103,441
	11/03/06	1,803	11.8	2,904	384,000	60	53	41	40	12.0	550	525,750	377.9	16	78	71,590	103,441
	11/06/06	1,822	6.3	3,478	193,121	60	52	40	39	11.5	550	443,420	318.7	17	12,546	71,912	104,482
8	11/07/06	1,831	8.8	3,734	256,000	60	52	40	39	11.5	552	63,142	45.4	18	12,540	72,234	105,528
Ŭ	11/08/06	1,844	11.7	4,163	380,160	60	52	41	41	11.5	538	460,960	331.3	18	12,540	72,234	105,528
	11/09/06	1,852	7.0	4,383	198,621	60	52	41	41	11.5	551	50,212	36.1	19	12,517	72,549	106,587
7	11/13/06	1,879	7.0	5,248	220,851	60	52	40	38	11.5	522	235,410	169.2	20	12,516	72,868	107,630
	11/14/06	1,885	7.5	5,435	242,595	60	52	40	38	11.5	522	407,330	292.8	20	12,516	72,868	107,630
9	11/15/06	1,889	3.5	5,580	121,749	60	52	40	39	11.5	548	543,182	390.4	20	12,516	72,868	107,630
	11/16/06	1,898	10.8	5,838	313,519	10	10	2	3	10.0	NR	167,266	120.2	21	12,516	73,145	108,635
	11/17/06	1,908	8.7	6,166	279,479	60	52	41	40	11.5	550	472,401	339.5	21	12,519	NR	NR
10	11/20/06	1,932	8.0	6,887	248,502	60	54	41	40	11.5	551	526,727	378.6	22	12,606	73,396	109,695
10	11/21/06	1,934	1.9	6,962	66,380	60	52	40	39	11.0	550	595,910	428.3	22	12,606	73,400	109,695
7	11/27/06	1,987	9.1	8,588	276,766	60	52	40	40	11.5	542	263,888	189.7	25	12,434	74,149	112,810
11	11/28/06	1,997	9.5	8,895	308,070	60	52	41	40	11.5	549	547,771	393.7	25	NR	NR	NR
	11/29/06	2,008	10.7	9,237	317,729	60	51	40	40	12.0	536	250,659	180.2	26	12,424	74,442	113,860
7	12/04/06	2,045	7.6	10,362	230,277	60	52	38	42	12.0	525	69,595	50.0	28	12,411	74,910	115,922
	12/05/06	2,053	8.0	10,627	259,592	60	52	39	40	12.0	530	315,840	227.0	28	12,411	NR	NR
12	12/06/06	2,062	8.5	10,873	246,857	60	51	40	40	12.0	550	120,650	86.7	29	12,328	75,338	117,901
	12/07/06	2,066	4.3	11,016	139,607	60	51	NR	NR	NR	550	251,583	180.8	29	12,328	NR	NR
	12/08/06	2,078	11.5	11,363	339,918	60	51	41	42	11.5	540	292,407	210.2	30	13,120	75,538	11,854
	12/11/06	2,102	7.9	12,119	244,913	60	51	40	40	12.0	545	376,161	270.4	31	13,080	75,540	119,110
13	12/12/06	2,115	13.8	12,492	413,169	10	10	4	4	10.5	NR	105,469	75.8	32	13,061	NR	NR
	12/13/06	2.118	4.0	12,611	132.837	60	51	41	41	11.5	NR	216.079	155.3	32	13.061	75.540	120.120

<b>US EPA Arsenic Demonstration Pro</b>	oiect at Vale. OR -	- Daily System O	peration Log She	et (Study Peri	od I) (Continued)

1	Parameters	Pump Hour Meter	Daily Hour	Master Totalizer	Daily Volume	Booster Pump Pressure (PT4)	System Inlet Pressure (PT1)	Tank A Outlet Pressure	Tank B Outlet Pressure	Product Water Pressure	Finished Water Flowrate	Finished Water Volume Since Last Regen	BV Treated Since Last Regen.	Regen. Counter	Regen Water Totalizer (Per Event)	Fresh Brine Day Tank Totalizer	Reused Brine Day Tank Totalizer
	Unit	hr	hr/day	kgal	gpd	psig	psig	psig	psig	psig	gpm	gal	BV		gal	gal	gal
	12/14/06	2,126	7.7	12,880	249,910	60	51	41	41	11.5	544	466,119	335.0	32	13,061	75,540	120,122
	12/15/06	2,134	7.1	13,084	197,154	59	54	41	41	11.5	550	40,752	29.3	33	13,310	75,540	121,130
	12/18/06	2,161	9.0	13,901	273,282	59	54	41	40	11.5	550	115,597	83.1	35	13,321	75,540	123,230
	12/19/06	2,170	7.9	14,212	259,617	59	54	43	44	11.5	540	402,769	289.5	35	13,321	NR	NR
14	12/20/06	2,176	8.0	14,402	263.077	59	54	43	44	12.0	545	576.250	414.2	35	13.321	NR	NR
	12/21/06	2.185	7.6	14 673	221 727	59	54	43	44	12.0	545	217 873	156.6	36	13 308	NR	124 230
	12/26/06	2,100	87	15.968	272 234	3	2	0	0	2.5	NP	179.036	128.7	38	13,302	75 540	126 310
15	12/27/06	2,227	6.6	16 222	212,254	2	2	0	0	2.5	ND	414,177	207.7	29	15,502 ND	75,540 ND	126,310
15	12/27/00	2,235	7.1	16,223	215,507	50	54	42	42	12.0	551	414,177	126.4	38	12 207	75.542	120,310
	12/29/00	2,240	7.1	10,033	213,808	59	54	43	43	12.0	542	175,878	120.4	39	12,407	75,542	127,303
16	01/02/07	2,279	/.0	17,599	240,249	59	54	43	43	11.5	542	449,702	323.2	40	13,407	75,540	128,384
16	01/03/07	2,290	10.3	17,930	303,592	60	54	40	40	11.5	540	141,462	101.7	41	13,300	/5,540	129,415
	01/05/07	2,304	7.5	18,403	245,892	59	54	43	44	11.5	541	576,326	414.2	41	13,300	NR	129,416
	01/08/07	2,328	7.9	19,115	240,394	59	54	40	0	11.0	281	616,000	442.8	43	6,377	75,540	130,945
17	01/10/07	2,343	8.1	19,605	255,190	59	54	43	43	11.5	542	451,996	324.9	43	13,310	75,547	131,473
	01/11/07	2,354	9.0	19,923	266,233	NR	NR	NR	NR	NR	548	128,699	92.5	44	13,297	NR	132,530
	01/12/07	2,361	6.3	20,098	158,690	59	53	43	43	11.5	545	290,201	208.6	44	13,297	NR	132,530
	01/16/07	2,395	9.0	21,140	278,279	0	0	0	0	2.5	NR	13,149	9.5	46	476	75,547	134,582
18	01/17/07	2,401	5.6	21,326	183,452	59	54	40	40	12.0	554	189,175	136.0	46	13,522	75,547	134,582
10	01/18/07	2,412	9.8	21,698	318,478	59	54	43	43	12.0	544	532,119	382.5	46	13,522	NR	134,582
	01/19/07	2,421	8.9	21,972	259,068	59	54	43	43	12.0	545	170,210	122.3	47	13,450	NR	NR
	01/22/07	2,450	10.2	22,857	322,470	59	54	40	40	12.0	561	371,180	266.8	48	13,293	75,548	136,634
19	01/23/07	2,461	9.6	23,187	284,041	59	54	43	43	12.0	542	61,367	44.1	49	13,484	NR	137,629
	01/24/07	2,468	9.7	23,439	312,828	59	54	43	43	12.0	547	294,135	211.4	49	13,484	NR	NR
	01/30/07	2,516	8.0	24,940	250,167	59	54	40	40	12.0	550	443,388	318.7	51	13,286	75,550	139,680
20	01/31/07	2,524	6.8	25,148	193,114	59	54	40	40	12.0	548	18,456	13.3	52	13,282	NR	140,710
	02/02/07	2,544	9.3	25,799	301,719	60	57	1	46	11.0	280	910,940	654.7	53	2.698	NR	141.840
	02/06/07	2.575	8.2	26.786	257,152	59	54	43	43	11.5	562	278.676	200.3	54	585	75.548	142,755
	02/07/07	2,584	10.1	27.099	335,108	59	54	43	43	11.0	552	562,856	404.6	54	13.284	NR	NR
21	02/08/07	2,593	6.4	27,337	182,784	10	10	12	12	10.5	NR	164.220	118.0	55	13.272	NR	143,800
	02/09/07	2,601	9.5	27,622	315,692	59	54	43	43	11.5	560	424,369	305.0	55	13,272	NR	NR
	02/12/07	2.625	8.1	28,353	253,343	59	53	43	43	11.5	559	475,337	341.7	56	13.284	75,548	144.826
	02/13/07	2.635	11.3	28,666	342,753	10	10	5	5	4.0	NR	144,490	103.9	57	13.397	NR	145,840
22	02/14/07	2,642	5.9	28 898	194 233	59	53	43	43	11.5	539	NR	NR	57	13 397	NR	145 840
	02/15/07	2,651	10.5	29.186	320.247	60	56	43	43	11.0	285	4 775	3.4	58	764	NR	146 372
	02/16/07	2,658	6.0	29,180	249.035	59	56	42	42	11.5	546	207 772	149.3	58	6 5 1 4	NR	146 372
	02/10/07	2,650	8.3	30,138	235,409	59	53	42	42	11.5	555	251.951	181.1	50	13 267	75 546	140,372
1	02/20/07	2,002	8.6	30 453	283 500	50	53	43	43	11.5	576	546 795	393.0	50	13 267	NP	147 /3/
23	02/20/07	2,091	0.0	20,768	285,500	50	52	43	43	11.5	540	218 240	156.0	59	13,207	ND	147,434
	02/22/07	2,702	7.4	21 202	242 326	50	54	43	43	11.0	267	614 474	441.7	61	4 002	ND	148,455
	02/25/07	2,713	7.0	21.005	242,320	50	52	12	43	11.0	520	108 210	77.0	62	4,992	75.547	148,903
	02/20/07	2,741	6.9	31,993	2/3,121	59	53	43	42	11.5	544	106,519	206.8	62	12 242	75,547 ND	130,462 ND
24	02/27/07	2,747	0.0	32,191	200,170	59	55	42	43	11.5	284	287,095	200.8	62	15,245	INK	150.482
24	02/28/07	2,756	0.0	22,550	240,078	50	52	42	43	11.5	547	225 515	455.0	62	12 200	ND	151.019
	03/01/07	2,700	7.6	32,193	251 174	50	52	45	43	11.5	555	452.050	226.2	63	13,200	NR	151,018
	03/06/07	2,774	8.5	3/ 122	263 727	0	<i>JJ</i> 9	1	0	0.0	NP	214 272	154.0	65	13,200	820	153 690
25	02/08/07	2,007	0.5	24,155	205,757	50	52	1	42	9.0	527	214,272	197.2	60	12,504	1.002	153,000
23	03/06/07	2,027	0.4	24,004	243,803	59	52	43	42	11.5	557	200,300	107.5	60	13,394	1,992	154,962
<u> </u>	03/09/07	2,835	8.2	34,920	270,000	59	52	43	42	11.5	530	495,180	355.9	09	13,394	1,992	154,982
26	03/12/07	2,858	8.0	35,648	249,600	59	52	45	42	11.5	548	543,862	390.9	70	13,622	2,558	156,042
20	03/14/07	2,675	0.0	26 750	200,007	59	52	43	42	11.5	541	409,301	294.4	/1	13,021	3,102	157,055
<u> </u>	03/10/07	2,894	9.5	30,739	292,290	59	52	44	43	11.5	541	332,918	239.3	12	13,802	3,770	158,050
27	03/19/07	2,919	8.4	37,514	260,220	39	>5 ND	41 ND	40	12.0	536	415,021	298.3	/3	14,038	4,420	159,065
1	03/20/07	2.925	5.0	37.709	181./48	I NK	NK	NK	NK	NK	560	595.140	427.8	/3	NK	4.420	159.065

#### Finished Booster вv System Water Regen Reused Pump Pump Inlet Tank A Tank B Product Finished Volume Treated Water Fresh Brine Brine Day Daily Master Daily Pressure Pressure Outlet Outlet Water Water Since Last Since Last Regen. Totalizer Dav Tank Tank Hour Totalizer (PT4) Parameters Meter Hour Volume (PT1) Pressure Pressure Pressure Flowrate Regen Regen. Counter (Per Event) Totalizer Totalizer Unit hr/day BV hr kgal gpd psig psig psig psig psig gpm gal gal gal gal 322.244 317,445 228.2 74 03/21/07 2.937 10.8 38.076 59 53 44 43 11.5 527 14,016 5,074 160,121 273,546 03/23/07 2.954 9.0 38,587 59 53 44 43 11.5 549 174.150 125.2 75 14,071 5.727 161,168 03/26/07 2,981 9.2 39,441 288,270 59 52 43 43 11.5 536 346,850 249.3 76 14,022 162,180 6,375 2,992 10.1 39,761 294,629 59 52 43 43 532 26,348 18.9 77 7.035 163,240 03/27/07 11.5 13 963 28 537 332.8 03/29/07 3,007 7.8 40,231 252 537 59 52 42 42 11.5 463,076 77 13,963 7,035 163,240 03/30/07 3,020 10.4 40,621 308,571 58 50 41 40 11.5 525 210,119 151.0 78 13,836 7,682 164,284 04/02/07 9.8 301,270 58 56 40 538 376,943 270.9 79 13,735 8,324 165,283 3.047 41.461 41 11.5 04/03/07 3,056 9.2 41,722 272,348 56 41 11.0 276 3,065 2.2 7,172 8,720 166,348 60 1 80 29 04/05/07 3.079 10.2 42.393 303.849 60 56 46 11.0 280 12,778 9.2 81 10,171 9,621 167,366 04/06/07 12.6 42.786 395.748 57 49 39 39 11.5 524 378,643 272.2 167.866 3,091 81 13,776 9,631 04/09/07 3.119 9.3 43.648 285.286 10 10 12 12 10.5 NR 565,850 406.7 82 13,782 10.288 168.366 04/10/07 3,126 8.5 43,824 226,488 58 50 40 38 11.5 547 114,230 82.1 83 13,785 10,950 169,410 30 04/11/07 3,135 8.2 44,096 263,758 58 50 40 39 11.5 547 367,940 264.5 83 13,785 10,950 169,412 10 12 12 10.5 NR 59.387 42.7 13,777 11.612 04/12/07 3 146 9.0 44,427 260 459 10 84 170,426 04/13/07 3,153 9.4 44,656 294,429 57 48 39 38 11.5 521 274,003 196.9 84 13,777 11,612 170,426 40 39 537 371,129 13,780 171,488 04/16/07 3,178 8.5 45,422 259,539 58 49 11.5 266.8 85 12,275 10.7 306,383 40 39 545 262.587 188.7 172,490 04/17/07 3.189 45.722 58 49 11.5 86 13.781 12,940 31 04/18/07 3.199 9.7 45.997 275.000 58 49 40 39 11.5 538 132,727 95.4 87 13.796 13.610 173,492 8.7 174.533 04/19/07 3.209 9.3 46.282 266,494 60 55 45 1 11.0 275 12.064 88 9.991 14.288 04/20/07 3.217 8.9 46.544 278,435 58 49 39 39 11.5 542 256,340 184.2 88 13.802 14.288 174.533 04/23/07 3.248 10.4 47,472 305.096 58 49 40 37 12.0 530 347.130 249.5 90 13.804 15.648 176.644 04/24/07 3 2 5 9 10.5 47,755 293,180 58 49 39 39 11.5 505 223,305 160.5 91 13,807 16,328 177,682 32 04/26/07 3,283 12.2 48,456 351,110 10 10 12 12 10.5 NR 102,190 73.5 93 13,824 17,693 179,725 255,452 12 12 245.7 17,693 3,291 48,715 10 10.5 NR 341,774 179,725 04/27/07 8.1 10 93 13,824 50,223 10 12 12 10.0 NR 197,948 142.3 97 13,812 183,793 05/01/07 3,343 12.2 352,519 10 20,424 3,354 13.3 50,521 376,421 58 48 38 38 11.5 513 87,897 63.2 98 13,819 21,111 184,788 05/02/07 33 58 39 38 253.5 05/03/07 3,363 9.3 50,806 291,064 48 11.5 516 352,636 98 13,819 21,111 184,788 05/04/07 3,374 9.1 51,118 256,731 10 10 12 12 10.5 NR 253,914 182.5 99 13,852 21,795 185,850 52,038 58 37 509 3,405 11.2 327,111 48 38 11.5 335,786 241.4 13,814 23,165 187,920 05/07/07 101 05/08/07 3,421 14.2 52,490 421,282 10 9 11 11 10.0 NR 369,427 265.5 102 14,112 23,851 188,910 34 05/09/07 3.430 10.9 52,744 308.658 58 53 38 37 11.5 535 220,929 158.8 103 14.193 24,538 189,960 05/10/07 3.446 14.7 53.218 437.538 56 52 42 41 11.5 512 276.815 199.0 104 14,104 25.215 191.020 05/11/07 3,459 13.5 53,627 400,653 56 52 42 41 11.5 526 271,212 194.9 104 14,187 25.957 192,000 57 545 05/14/07 3,497 12.6 54,734 369,000 53 40 40 12.0 144,125 103.6 108 14,256 27,990 195,145 35 05/16/07 3,526 14.9 55,575 438,783 57 53 40 40 12.0 540 155,497 111.8 110 14,157 29,390 197,220 3,556 05/18/07 15.0 56,450 439,791 57 52 42 42 12.0 529 199,287 143.2 112 14,170 30,800 199,252 188.1 05/21/07 3,600 13.4 57,761 397,022 57 52 42 42 11.5 524 261,712 115 14,170 32,914 202,297 432,000 57 52 42 529 142.1 13,977 05/22/07 3,612 14.8 58,106 42 11.5 197,650 116 33.600 205,205 36 58 53 42 547 05/24/07 3.639 14.1 58,899 413,739 42 11.5 163,510 117.5 118 14,167 35,010 205,342 05/25/07 3.653 14.4 59,320 423,944 57 52 42 42 11.5 540 170.056 119 14.175 35.718 206.360 05/29/07 3.710 13.3 60,985 389.854 NM NM NM NM NM NR 126.115 90.6 123 14.176 38.555 210,490 37 05/30/07 3.719 11.9 61.259 350,720 58 53 40 40 12.0 525 47,125 33.9 124 14.177 39.265 211.525 05/31/07 3.735 16.8 61,717 497.751 58 52 42 42 12.0 526 87,834 63.1 14,147 39.977 212.517 125 06/04/07 3,797 15.6 63,553 460,599 58 52 40 40 10.5 530 252,860 181.7 129 14,141 42,810 216,580 217,880 06/05/07 3,812 15.1 64,015 455,671 60 58 41 47 11.0 257 373,790 268.7 131 0 43,520 38 06/06/07 3,825 12.9 365,652 58 52 40 40 10.5 545 331,505 238.3 131 14,129 44,230 218,620 64.387 58 337,618 52 42 41 11.5 515 237,575 170.8 44,933 06/07/07 3,836 11.8 64,700 132 14,087 219,674 58 42 537 201,225 06/08/07 3 8 4 9 11.8 65.076 340 528 52 41 11.5 144 6 133 14,129 45 640 220 727 06/11/07 3.884 11.6 66.103 342.333 58 52 6 41 11.5 251 384,127 276.1 136 14,630 47.422 223.312 06/12/07 3,893 9.8 289,055 58 52 42 41 12.0 517 253,790 182.4 136 47,773 223,836 66,377 14,120 39 06/14/07 NR NR 67,197 391,642 10 10 12 12 10.5 NR 243,032 174.7 138 14,100 49,199 225,882 06/15/07 NR NR 67,569 326,634 10 10 11 11 10.0 NR 203,743 146.4 139 14,086 49,910 226,950

#### US EPA Arsenic Demonstration Project at Vale, OR – Daily System Operation Log Sheet (Study Period I) (Continued)

<b>US EPA Arsenic Demonstration Pro</b>	oiect at Vale. OR -	- Daily System O	peration Log She	et (Study Peri	od I) (Continued)

F	arameters	Pump Hour Meter	Daily Hour	Master Totalizer	Daily Volume	Booster Pump Pressure (PT4)	System Inlet Pressure (PT1)	Tank A Outlet Pressure	Tank B Outlet Pressure	Product Water Pressure	Finished Water Flowrate	Finished Water Volume Since Last Regen	BV Treated Since Last Regen.	Regen. Counter	Regen Water Totalizer (Per Event)	Fresh Brine Day Tank Totalizer	Reused Brine Day Tank Totalizer
	Unit	hr	hr/day	kgal	gpd	psig	psig	psig	psig	psig	gpm	gal	BV		gal	gal	gal
	06/18/07	3,974	12.9	68,722	379,502	58	51	41	40	11.5	520	11,904	8.6	142	14,025	52,050	230,015
	06/19/07	3,989	15.1	69,155	437,558	58	51	41	40	11.5	515	132,038	94.9	143	14,005	52,759	231,044
40	06/20/07	4,005	16.5	69,646	491,000	58	51	40	40	11.0	512	201,487	144.8	144	14,022	53,472	232,034
	06/21/07	4,019	14.6	70,036	420,674	58	51	40	40	11.5	524	176,651	127.0	145	14,015	54,122	233,061
	06/22/07	4,031	14.5	70,370	412,841	58	51	40	40	11.5	520	100,460	72.2	146	14,006	54,895	234,190
	06/25/07	4,067	11.8	71,458	348,160	58	50	40	39	12.0	517	337,432	242.5	148	13,985	56,380	236,165
4.1	06/27/07	4,101	15.6	72,410	440,797	58	49	39	39	12.0	512	60,061	43.2	151	13,955	58,446	239,242
41	06/28/07	4,112	12.3	72,758	373,970	60	55	1	43	11.0	270	378,895	272.3	152	2,363	58,870	239,715
	06/29/07	4,125	15.1	73,136	438,968	58	49	39	38	11.5	515	343,410	246.8	152	13,959	59,159	240,239
	07/02/07	4.170	13.9	74.425	403.075	49	36	14	33	11.0	260	370.762	266.5	156	0	60.680	243,380
	07/03/07	4.182	13.3	74,759	377.224	58	48	38	38	11.5	512	292.509	210.2	156	13.930	60.690	244.328
42	07/05/07	4.212	16.1	NR	NR	58	48	38	37	11.5	512	332,328	238.9	158	13.877	60.690	246,349
	07/06/07	4.228	16.7	76.095	NR	58	47	38	37	11.5	509	362.331	260.4	158	13,760	60.690	247.366
	07/09/07	4 269	13.4	77 267	382 694	58	46	38	32	11.5	520	277 140	199.2	162	13 661	60,690	250 425
	07/10/07	4 287	15.4	77,267	416 283	3	3	0	0	1.0	NR	40 305	29.0	164	13,442	61.058	252,490
13	07/11/07	4,207	14.6	78 175	410,203	58	53	44	43	11.5	536	46,305	32.6	165	14 813	61,655	252,490
-15	07/12/07	4,301	14.0	78,552	429,943	50	59	44	45	11.0	208	10.401	7.5	165	0.858	62 205	253,401
	07/12/07	4,314	14.7	78,555	438,908	60	59	44	44	11.0	540	245.067	248.0	166	14 211	02,295 ND	234,493 ND
	07/15/07	4,520	12.1	/8,917	364,000	60	50	44	44	11.0	540	343,007	246.0	160	14,511	INK (1.200	INK 257.524
	07/16/07	4,365	12.7	80,035	366,307	58	52	40	40	11.0	535	242,110	1/4.0	169	14,342	64,298	257,534
44	07/18/07	4,391	12.9	80,806	381,526	58	53	40	40	11.0	535	179,240	128.8	1/1	14,353	65,650	259,568
	07/19/07	4,404	13.9	81,204	406,468	58	53	40	40	11.0	537	163,285	117.4	172	14,359	66,330	260,565
	07/20/07	4,418	13.4	81,597	393,000	58	53	40	40	11.0	510	143,135	102.9	173	14,360	67,010	261,555
	07/23/07	4,452	11.0	82,623	326,146	10	9	11	11	10.0	NR	327,278	235.2	175	14,361	68,300	263,500
45	07/25/07	4,471	10.5	83,153	295,814	58	52	42	42	11.5	529	50,201	36.1	177	14,368	69,760	265,600
	07/26/07	4,483	11.2	83,522	337,371	60	57	47	40	11.0	275	6,949	5.0	178	8,761	70,388	266,690
	07/30/07	4,530	11.4	84,899	335,229	58	53	43	42	11.5	541	131,433	94.5	181	14,251	72,429	269,820
46	08/01/07	4,550	11.1	85,494	332,738	58	53	43	42	11.5	530	300,162	215.7	182	14,301	73,100	270,340
.0	08/02/07	4,562	9.6	85,994	396,694	60	57	0	42	11.0	260	380,170	273.3	184	2,766	74,130	272,315
	08/03/07	4,576	18.2	86,270	348,632	50	52	42	42	11.5	523	251,367	180.7	184	14,332	74,467	272,838
	08/06/07	4,608	10.7	87,204	315,718	58	52	42	42	12.0	504	348,955	250.8	186	14,262	75,830	274,840
	08/07/07	4,623	11.7	87,641	343,869	58	52	42	42	12.0	520	369,901	265.9	187	14,264	76,510	275,890
47	08/08/07	4,632	12.2	87,886	336,000	58	52	42	42	12.0	535	21,930	15.8	188	14,293	77,190	276,925
	08/09/07	4,644	9.4	88,238	276,984	58	52	42	42	12.0	550	153,813	110.6	189	14,343	77,870	277,935
	08/10/07	4,649	7.6	88,409	241,412	5	5	6	7	6.0	NR	312,975	225.0	189	14,343	77,873	277,935
	08/14/07	NR	NR	89,581	294,534	51	45	35	35	11.5	511	243,014	174.7	192	14,072	79,920	281,038
48	08/15/07	4,704	10.6	89,999	345,931	52	44	35	34	11.5	508	239,783	172.3	193	13,778	80,650	282,044
	08/17/07	4,722	8.8	90,520	256,932	59	50	41	40	11.0	518	342,527	246.2	194	13,937	81,242	283,024
	08/21/07	4,754	8.5	91,430	243,388	59	50	40	40	12.0	533	26,825	19.3	197	14,104	83,248	286,122
49	08/24/07	4 786	10.5	92 359	307 107	59	49	40	39	11.5	511	115 436	83.0	199	14 023	84 060	288 220
	08/28/07	4 823	93	93 456	272 829	59	49	40	39	11.5	531	359 292	258.2	201	13,930	85 954	290,220
50	08/29/07	4 835	10.1	93,807	289.319	10	10	12	12	10.5	NR	297 923	214.1	201	13,931	86 634	291,350
50	08/30/07	4 845	8.8	94.067	245 831	10	10	0	0	10.0	NR	153 020	110.0	202	13,951	87 305	292 330
51	00/04/07	4,045	7.6	05 161	245,851	60	52	42	0	11.0	275	7 722	5.6	205	8 717	80.261	205 224
51	09/04/07	4,005	0.0	95,101	217,257	50	17	42	37	12.0	400	04.070	67.6	200	13 726	07,201	275,524
50	00/12/07	4,943	9.2	07 074	201,099	10	+/		12	12.0	470 ND	74,079	206.1	210	13,720	02 575	277,420
32	09/12/07	4,937	8.6	97,270	202,173	10	10	12	12	10.0	521	246 292	200.1	211	13,723	92,373	201.420
52	09/14/07	4,9/4	0.0	97,700	245,408	59	40	37	30	11.5	501	340,283	248.9	212	13,///	93,243	301,439
53	09/17/07	4,997	8.1	98,398	226,565	59	46	36	56	11.5	501	163,149	117.3	214	15,674	94,563	303,492
54	09/24/07	5,048	7.3	99,858	208,882	59	45	36	35	12.0	509	346,796	249.3	217	13,618	96,580	306,500
	09/26/07	5,065	7.5	100,324	202,731	60	45	36	0	11.0	262	14,640	10.5	219	11,373	97,910	308,580
55	10/01/07	5,100	7.4	101,328	209,835	60	43	34	30	12.0	505	167,558	120.4	221	13,316	99,240	130,620
55	10/04/07	5,126	8.1	102,063	229,091	10	10	2	2	10.0	NR	72,808	52.3	223	13,803	100,507	312,660
56	10/08/07	5 161	93	103 087	270 810	10	9	2	2	10.0	NR	243 918	175.3	225	13 821	101 915	314 765

# US EPA Arsenic Demonstration Project at Vale, OR – Daily System Operation Log Sheet (Study Period I) (Continued)

I	Parameters	Pump Hour Meter	Daily Hour	Master Totalizer	Daily Volume	Booster Pump Pressure (PT4)	System Inlet Pressure (PT1)	Tank A Outlet Pressure	Tank B Outlet Pressure	Product Water Pressure	Finished Water Flowrate	Finished Water Volume Since Last Regen	BV Treated Since Last Regen.	Regen. Counter	Regen Water Totalizer (Per Event)	Fresh Brine Day Tank Totalizer	Reused Brine Day Tank Totalizer
	Unit	hr	hr/day	kgal	gpd	psig	psig	psig	psig	psig	gpm	gal	BV		gal	gal	gal
	10/09/07	5.172	11.1	103,377	310.253	59	47	37	37	11.5	518	192,807	138.6	226	13,735	102,580	315,762
	10/11/07	5,195	10.7	104,032	300,478	0	0	3	3	2.0	NR	22,197	16.0	228	13,687	103,924	317,818
	10/17/07	5,257	10.5	105,798	300,596	58	53	42	42	11.5	549	313,849	225.6	232	13,656	106,622	321,460
57	10/18/07	5.266	9.6	106.060	273,391	58	53	42	42	12.0	513	170.643	122.7	233	14.298	107,295	322,505
	10/19/07	5.277	9.4	106,390	273,103	58	53	42	42	11.5	543	90,330	64.9	234	14.296	107,974	323,541
	10/22/07	5,301	8.4	107.113	258,985	2	2	1	4	0.0	NR	377.889	271.6	236	707	108,835	325.081
58	10/26/07	5,329	6.9	107,853	181,688	58	52	42	42	12.5	529	481,370	346.0	243	15,508	111,987	325,628
	10/29/07	5,353	8.4	108,624	263,402	58	52	42	42	12.5	535	595,337	427.9	244	7,802	112,505	323,605
59	10/31/07	5,371	8.7	109,183	273,796	57	52	42	42	12.5	540	514,266	369.6	245	7,833	113.040	325.610
	11/13/07	5.427	4.2	110.543	102,803	0	0	0	0	0.0	NR	573.610	412.3	2	7.644	114,160	325.610
	11/14/07	5.433	7.9	110,713	224,587	58	48	38	38	12.5	531	131,979	94.9	3	7,646	114,725	325,601
61	11/15/07	5,444	9.0	111.069	281,670	58	47	38	38	12.5	520	461.098	331.4	3	7.646	114,725	325,607
	11/16/07	5,450	7.8	111,243	225,730	58	43	37	37	12.5	518	22,399	16.1	4	7,607	115,275	325,607
	11/19/07	5,473	7.6	111,921	230,809	8	7	1	0	9.0	NR	50,196	36.1	5	7,683	115,850	323,610
62	11/20/07	5,481	8.5	112,180	262,648	58	47	38	38	12.0	520	289,615	208.2	5	NM	NR	NR
	11/26/07	5.527	7.6	113,568	230,799	10	10	4	4	11.0	NR	368,683	265.0	7	7.663	116,995	323.610
63	11/27/07	5,533	5.9	113,747	179.000	58	47	38	32	12.0	515	533,870	383.7	7	7,663	NR	NR
	11/30/07	5,559	8.3	114,523	245,053	58	47	37	32	12.0	500	109,755	78.9	9	7,637	118,068	NR
	12/03/07	5,579	6.9	115.114	205,565	58	44	38	38	12.5	490	51,996	37.4	10	7,582	118.625	323.625
	12/04/07	5,586	8.1	115,350	248,967	10	10	2	2	11.0	NR	267.669	192.4	10	7,582	NR	NR
64	12/05/07	5 596	8.5	115 601	215 143	58	43	34	33	11.0	513	162 353	116.7	15	14 721	120.265	325 608
	12/06/07	5,603	6.5	115,815	192,000	NM	NM	NM	NM	NM	520	359 550	258.4	15	14 721	NR	NR
	12/07/07	5,608	7.0	115,015	211 107	10	10	12	12	11.0	NR	498 457	358.3	15	14 721	120.265	325.608
	12/10/07	5,633	8.0	116 671	230 727	9	9	2	0	10.0	NR	530 622	381.4	16	14,721	120,200	325,610
	12/11/07	5 641	8.8	116,897	233,290	59	42	35	32	12.5	510	124 577	89.5	10	14,740	120,800	NR
65	12/13/07	5,655	6.9	117,359	234,667	2	2	3	3	3.0	NR	553,516	397.8	17	14,664	121,860	325.609
	12/13/07	5,663	7.6	117,596	212.636	57	52	40	39	12.5	530	202,940	145.9	18	15.543	122,915	NR
	12/17/07	5.685	7.5	118,258	228,879	3	2	0	0	2.5	NR	200.373	144.0	19	15.638	123,972	325.610
	12/18/07	5,696	8.8	118,605	283 909	3	2	0	0	2.5	NR	521.946	375.2	19	15,638	NR	NR
66	12/19/07	5 705	8.9	118,887	259 476	57	52	40	40	12.0	525	167 120	120.1	20	15,630	125.030	325.610
	12/20/07	5 711	7.5	119.068	242,456	57	52	40	40	12.0	545	334 440	240.4	20	NM	NR	NR
	12/21/07	5 718	7.5	119 293	240,000	3	2	0	0	12.0	NR	542 942	390.2	20	NM	NR	NR
	12/24/07	5 741	7.6	0	240,000 NR	10	9	11	11	11.0	NR	577 116	414.8	20	15 652	126.084	325 609
	12/24/07	5 757	8.1	119 998	NR	59	53	42	42	11.5	560	580 390	417.2	21	15,652	126,084	325,609
67	12/27/07	5 768	10.6	120 306	289.882	3	2	0	- 42	4.0	NR	247 665	178.0	22	14 282	126,610	325,609
	12/28/07	5,776	77	120,500	237,000	59	53	38	38	12.0	530	467 584	336.1	22	NM	NR	NR
	12/31/07	5 797	7.1	121,160	211 795	3	2	4	4	4.0	NR	420 181	302.0	23	15 134	127.652	325.610
	01/02/08	5 815	8.8	121,100	261.683	4	2 4	6	6	60	NR	292 510	210.2	23	15,251	128,662	325,610
68	01/02/08	5 820	5.7	121,007	178 000	3	2	4	4	4.0	NR	457 264	328.7	24	15 251	128,662	325,610
	01/04/08	5 831	10.2	122,003	290,939	59	48	38	37	11.5	545	118 761	85.4	25	15 235	129,706	325,610
<u> </u>	01/07/08	5 855	8.2	122,102	246 621	59	40	38	40	12.0	515	105 150	140.3	25	15 164	120,750	325,610
	01/08/08	5 862	5.7	122,507	181 851	57	47	7	40	6.5	NP	300 702	287.3	20	15,160	130,750	325,610
69	01/09/08	5,802	8.8	123,120	272 136	2	1	0	4	3.0	NR	606 504	435.9	20	2 078	131,280	325,610
	01/10/08	5 878	8.9	123,551	250.047	10	10	10	12	12.0	NR	197 588	142.0	27	15 346	131,200	325,610
	01/11/08	5,885	7.0	123.796	219,476	10	10	12	12	11.5	NR	403.332	289.9	27	15,346	131,790	325,610
70	01/14/08	5.907	7.5	124.475	224,928	9	9	0	0	10.0	NR	418,136	300.5	28	15.396	132.815	325.610
	01/11/00	5,207	1.0	121,170	22.,720	/	/	ÿ	, v	10.0	- 1		500.5	20	10,070	102,010	525,010

NR = not recorded $1 BV = 186 ft^3$ 

# US EPA Arsenic Demonstration Project at Vale, OR – Daily System Operation Log Sheet (Study Period II)

	Parameters	Pump Hour Meter	Daily Hour	Master Totalizer	Daily Volume	Booster Pump Pressure (PT4)	System Inlet Pressure (PT1)	Tank A Outlet Pressure	Tank B Outlet Pressure	Product Water Pressure	Finished Water Flowrate	Finished Water Volume Since Last Regen	BV Treated Since Last Regen.	Regen. Counter	Regen Water Totalizer (Per Event)	Fresh Brine Day Tank Totalizer
	Unit	hr	hr/day	kgal	gal/day	psig	psig	psig	psig	psig	gpm	gal	BV		gal	gal
	02/16/09	8,739.8	NR	208,128	NR	60	58	48	1	11.5	288	11,619	8	19	8,245	251,980
1	02/17/09	8,746.7	8.5	208,342	263,385	11	10	12	12	12.0	NR	207,050	141	19	12,789	251,980
	02/18/09	8,754.1	6.2	208,583	202,947	58	53	42	40	12.0	547	428,634	291	19	12,789	251,980
	03/02/09	8,846.9	7.9	211,433	243,416	59	53	43	42	12.0	545	564,199	383	23	12,699	254,962
	03/03/09	8,847.5	0.6	211,452	19,683	20	19	16	16	11.0	260	581,683	395	23	12,699	254,962
3	03/04/09	8,855.5	8.8	211,612	175,878	59	53	43	42	11.5	532	184,164	125	24	13,051	255,682
	03/05/09	8,859.0	2.8	211,786	141,559	9	9	11	11	11.0	NR	284,169	193	24	13,051	255,682
	03/09/09	8,887.6	7.1	212,676	220,966	59	53	43	43	12.5	547	480,300	326	25	12,725	256,439
4	03/11/09	8,901.5	7.0	213,085	205,213	58	53	43	43	12.5	544	236,500	161	26	12,668	257,170
	03/12/09	8,909.6	11.3	213,347	364,522	58	53	43	42	12.5	542	476,392	324	26	12,668	257,170
5	03/18/09	8,953.1	6.7	214,675	205,958	59	53	43	42	12.5	538	457,846	311	28	12,699	258,661
	03/25/09	9,005.9	7.7	216,260	231,246	59	53	42	42	12.5	542	59,084	40	31	12,682	260,844
6	03/26/09	9,017.9	9.4	216,647	302,049	9	8	10	10	10.0	NR	416,060	283	31	12,682	260,845
	03/31/09	9,050.9	6.9	217,630	206,495	10	10	11	11	11.0	NR	84,260	57	33	12,655	262,293
	04/01/09	9,061.9	9.1	217,987	295,448	58	53	42	41	12.0	542	414,217	281	33	12,655	262,293
7	04/02/09	9,066.6	6.4	218,136	204,343	58	53	41	41	12.0	540	551,090	375	33	12,655	262,293
	04/03/09	9,073.8	7.4	218,330	200,258	10	9	11	11	11.0	NR	109,993	75	34	12,697	263,030
	04/06/09	9,097.9	7.8	219,068	238,545	9	9	10	11	11.0	NR	171,948	117	35	12,701	263,768
8	04/07/09	9,121.7	26	219,794	-	10	9	11	11	11.0	NR	22,448	15	36	12,678	264,505
	04/08/09	9,128.4	6.8	220,010	220,596	9	9	11	11	10.0	NR	424,882	289	36	12,678	264,505
	04/20/09	9,229.6	8.3	223,092	252,020	58	52	43	44	12.0	544	70,972	48	41	12,767	268,095
	04/21/09	9,238.9	11.7	223,453	456,000	10	9	11	11	11.0	NR	404,067	275	41	12,767	268,095
10	04/22/09	9,254.6	15.7	223,861	408,000	5	5	8	8	8.0	NR	162,061	110	42	12,679	268,792
	04/23/09	9,268.8	12.4	224,318	398,836	10	10	11	11	11.5	NR	584,472	397	42	12,679	268,792
	04/24/09	9,275.9	7.7	224,509	208,364	NA	NA	NA	NA	NA	NR	140,650	96	43	12,701	269,500
	04/28/09	9,320.1	11.2	225,856	342,095	10	10	8	2	11.0	NR	145,268	99	45	12,659	270,975
11	04/30/09	9,341.5	10.3	226,509	315,015	58	52	41	40	12.0	545	126,680	86	46	12,635	271,685
	05/01/09	9,352.0	11.0	226,847	352,696	10	10	NA	NA	12.0	NR	440,049	299	46	NR	NR
	05/04/09	9,377.9	8.6	227,643	265,333	58	52	41	41	13.0	541	557,387	379	47	12,622	272,420
10	05/05/09	9,387.3	7.8	227,907	220,383	58	52	43	42	12.5	535	181,123	123	48	12,632	273,168
12	05/06/09	9,393.1	7.5	228,093	241,297	59	52	43	43	12.5	521	353,486	240	48	12,632	273,168
	05/08/09	9,409.6	8.2	228,586	244,800	58	52	43	42	12.5	530	189,355	129	49	12,613	273,908
	05/12/09	9,451.5	10.0	229,856	304,293	59	52	42	42	12.5	546	125,277	85	51	12,640	275,382
13	05/13/09	9,461.0	8.8	230,156	276,923	NA	NA	NA	NA	NA	530	402,920	274	51	NR	-
	05/14/09	9,474.1	12.8	230,538	374,204	NA	NA	NA	NA	NA	535	138,366	94	52	12,623	276,110
14	05/19/09	9,528.1	11.4	232,153	340,997	9	9	11	11	11.0	NR	434,234	295	54	1,267	277,567
14	05/22/09	9,570.4	13.0	233,873	526,979	59	54	42	42	12.5	530	381,710	259	56	1,268	279,035
	05/26/09	9,585.3	4.0	234,573	185,635	2	1	NA	NA	NA	NR	806,720	548	58	37,156	279,775
	05/27/09	9,599.6	14.5	234,993	424,421	59	52	43	42	12.5	557	769,698	523	58	49,741	280,452
15	05/28/09	9,615.0	17.0	235,450	504,276	9	9	11	11	11.0	NR	172,559	117	59	12,668	281,170
	05/29/09	9,633.0	14.4	235,989	431,200	59	52	42	42	11.0	530	52,930	36	60	12,677	281,890
16	06/03/09	9,694.9	13.0	237,900	400,559	9	8	10	10	10.0	NR	587,423	399	62	12,692	283,340
16	06/05/09	9,720.5	12.8	238,640	370,000	10	9	11	11	11.0	NR	34,114	23	64	12,660	284,721
	06/08/09	9,748.6	9.3	239,499	284,359	11	10	11	12	11.0	NR	212,475	144	65	12,666	285,424
17	06/09/09	9,755.5	7.2	239,720	230,609	10	9	10	11	10.0	NR	417,977	284	65	NR	-
	06/10/09	9,767.2	10.2	240,055	292,364	9	9	11	11	11.0	NR	108,900	74	66	12,630	286,104
	07/01/09	9,993.7	10.7	246,822	320,964	59	52	40	38	12.0	540	344,380	234	5	1,842	293,400
20	07/02/09	9,996.3	3.0	246,907	99,512	NA	NA	NA	NA	NA	545	412,530	280	5	NR	-
	07/06/09	10,053.3	14.4	248,600	427,705	NA	NA	NA	NA	NA	NR	138,378	94	8	12,710	295,490
	07/08/09	10,082.8	14.7	249,502	448,663	8	8	10	10	11.0	NR	357,543	243	9	12,700	296,160
21	07/09/09	10,097.0	14.7	249,915	426,323	59	51	40	40	12.5	535	122,440	83	10	12,783	296,835
	07/10/09	10,116.1	15.9	250,487	477,496	NA	NA	NA	NA	NA	540	33,650	23	11	12,726	297,525

#### Finished Booster System Water вv Fresh Regen Water Pump Inlet Tank A Tank B Product Finished Volume Treated Brine Day Pump Hour Daily Master Daily Pressure Pressure Outlet Outlet Water Water Since Last Since Last Regen. Totalizer (Per Tank Totalizer (PT4) Parameters Meter Hour Volume (PT1) Pressure Pressure Pressure Flowrate Regen Regen. Counter Event) Totalizer Unit hr/day kgal gal/day hr psig psig psig psig psig gpm gal BV gal gal 435.056 367 12 07/13/09 10,155.3 14.1 251,697 59 51 40 40 12.5 542 539,420 12,696 298,190 22 07/17/09 10,212.8 13.6 253,402 403,153 59 51 41 41 12.0 534 267.078 181 15 12,738 300.245 07/20/09 10,241.0 10.2 254,259 309,293 NA NA NA NA NA NR 444,177 302 16 12,725 300,920 07/21/09 10.258.6 16.1 254,779 475,429 NA NA NA NA NA NR 308,249 209 17 301.570 23 07/22/09 10.276.5 15.8 255,307 465.028 59 50 40 40 12.0 531 180.895 18 12.672 302,200 159 258.038 475.819 10 12 NR 164 12.677 304,536 07/28/09 10,367.9 10 11 10.0 241,137 NA 299 24 07/30/09 10,396.8 13.4 258,916 407,188 59 49 40 40 12.0 550 439,340 23 12.695 305,400 07/31/09 17.7 259,435 524,463 59 49 42 42 12.0 550 300,669 204 24 12,746 306,160 10.414.3 08/04/09 10,466.0 13.0 260,698 317,126 10 7 2 2 11.0 NR 236.355 161 26 12,776 307,470 9.0 261,299 503,163 59 49 38 40 12.0 525 27 12,685 08/05/09 10,476.8 177,010 120 308,110 25 08/06/09 10,487.0 12.6 261.626 402,462 NA NA NA NA NA 545 480.240 326 27 NR NR 08/07/09 10,497,4 11.6 261,916 323.721 10 9 2 2 11.0 NR 129.315 88 28 12.708 308 780 10,545.0 11.2 263,362 340,235 59 53 40 40 535 233,175 158 30 12,857 310,210 08/11/09 12.0 26 08/12/09 10,556.3 13.2 263,722 421,463 NA NA NA 520 568,210 386 30 NR NR NA NA 08/17/09 10,627.2 14.5 265,322 326,115 10 9 2 2 11.0 NR 46,305 31 34 12,879 313,140 27 08/18/09 10,641.3 12.9 266,276 872,229 59 53 40 40 12.0 542 464,470 316 34 NR NR 08/19/09 10.655.4 14.4 266.635 366.638 10 9 2 2 11.0 NR 229,445 156 35 12,907 313.870 08/26/09 10,740.0 12.2 269,221 372,757 10 9 11.0 NR 104.715 71 39 12.911 316,775 2 2 28 08/28/09 10,769.1 12.8 269,815 261.578 59 53 40 40 12.0 535 45.035 31 40 12.935 317,510 344,743 08/31/09 10,800.4 11.2 270,781 59 54 45 45 12.0 536 321,775 219 41 12,934 318,239 29 09/02/09 10.828.0 12.8 271,630 392,475 59 54 45 45 12.0 543 487.940 332 42 12.914 318,965 09/10/09 10,926.1 12.6 274,561 377,517 10 9 11 11 10.0 NR 112,792 77 47 12,889 322,664 30 10.9 274,961 345,946 330 322,604 09/11/09 10,938.7 59 53 43 43 12.0 537 486,293 47 12,889 346,078 09/14/09 10,973.0 11.7 275,974 59 54 45 45 12.0 540 188,347 128 12,916 324,100 49 545 31 09/15/09 10,984.4 10.1 276,333 319,111 522,690 355 49 NR NR 394,537 542 324,840 09/16/09 10,996.2 13.8 276.670 59 54 45 45 12.0 216.000 147 50 12,915 11,053.3 278,403 350,987 59 53 12.0 530 522,700 355 52 12,872 326,316 09/21/09 11.6 45 45 341,538 327,063 09/22/09 11,066.2 11.9 278,773 NR 313,059 213 53 12,874 ----32 09/23/09 11,074.9 9.5 279,050 302,182 NR 570,142 387 53 12,874 327,063 --09/25/09 11,094.8 8.8 279,599 244,000 59 53 43 42 12.0 532 462,186 314 54 12,856 327,809 09/28/09 11,127.1 11.8 280,537 343,695 9 9 11 11 11.0 NR 94,673 64 56 12,821 329,270 11,139.3 12.0 280,924 379,102 10 10 11 12 12.0 NR 454,437 309 56 329,270 09/29/09 12,821 33 11,148.2 281,163 241,516 10 11 11 11.0 NR 57 12,725 09/30/09 9.0 10 56,986 39 330,021 10/01/09 11,158.1 10.0 281,472 312,253 59 53 45 45 12.0 530 344,480 234 57 12,725 330,021 10/02/09 11,165.7 7.4 281,712 235,102 9 9 10 11 11.0 NR 566,402 385 57 12,725 330,021 11,192.6 9.0 282,477 255,000 10 11 11.0 37,083 25 59 331,550 10/05/09 9 11 NR 12,614 10/06/09 11,204.0 11.2 282,835 350,694 10 10 11 12 11.5 NR 368,575 250 59 12,614 331,550 34 11 380 59 10/07/09 11,210.5 6.4 283,041 201,796 9 9 11 11.0 NR 559,404 12,614 331,550 10/09/09 11,229.4 9.5 283,593 278,905 10 10 11 12 11.5 NR 150,513 102 60 12,634 332,300 11,271.4 8.3 284.833 243,934 NR 359,668 244 62 12,569 333,780 10/14/09 35 10/15/09 11,278.8 7.5 285.064 232,615 NR 572,792 389 62 12,569 NR 10/16/09 11.283.0 4.7 285,151 96,369 NR NR NR 63 NR NR 10/20/09 11,316.0 NR 286,138 NR 10 9 11 11 11.0 NR 309.229 210 1 11.109 335,250 36 10/22/09 11.330.0 NR 286.542 NR 4 4 5 6 6.0 NR 66.654 45 2 11.147 335.492 10/27/09 11.368.8 7.4 287.723 225,250 57 50 40 38 12.0 517 540.850 368 3 11.115 336.727 11.377.2 138.260 37 10/28/09 8.5 287.954 232.615 530 94 4 11.100 337.462 10/29/09 11.387.4 9.5 288.273 295,979 505 431.740 293 4 11.100 337.462 11/02/09 11,417.9 7.6 289,151 220,150 54 45 35 34 12.0 452 18.001 12 6 11.031 338,927 338,927 11/03/09 11,420.8 4.0 289,252 140,522 NR 103,182 70 6 38 11/04/09 11,429.0 8.7 289,508 273,067 57 49 38 38 12.0 526 339,549 231 6 11,031 338,927 11/05/09 11,435.3 6.0 289,704 188,160 8 8 10 10 10.0 NR 519,590 353 6 11,031 338,927 11/06/09 11.444.4 9.2 289,944 241,678 10 11 11.0 NR 125,456 85 11.037 11 7 339,655

## US EPA Arsenic Demonstration Project at Vale, OR – Daily System Operation Log Sheet (Study Period II) (Continued)

## US EPA Arsenic Demonstration Project at Vale, OR – Daily System Operation Log Sheet (Study Period II) (Continued)

1	Parameters	Pump Hour Meter	Daily Hour	Master Totalizer	Daily Volume	Booster Pump Pressure (PT4)	System Inlet Pressure (PT1)	Tank A Outlet Pressure	Tank B Outlet Pressure	Product Water Pressure	Finished Water Flowrate	Finished Water Volume Since Last Regen	BV Treated Since Last Regen.	Regen. Counter	Regen Water Totalizer (Per Event)	Fresh Brine Day Tank Totalizer
	Unit	hr	hr/day	kgal	gal/day	psig	psig	psig	psig	psig	gpm	gal	BV		gal	gal
42	12/02/09	11,635.7	7.4	295,917	229,608	56	26	20	20	12.0	360	82,236	56	16	8,748	345,515
42	12/03/09	11,646.0	9.5	296,213	272,358	-	-	-	-	-	NR	356,930	243	16	NR	NR
44	12/16/09	11,752.2	8.2	298,780	198,896	9	9	11	11	11.0	NR	319,637	217	20	9,984	348,208
44	12/17/09	11,762.9	10.6	299,028	245,443	10	9	11	11	11.0	NR	553,145	376	20	9,984	348,208
48	01/15/10	11,809.0	-	299,195	5,740	55	49	38	37	12.0	554	10,605	7	22	9,907	349,540
	01/25/10	11,828.4	1.9	299,835	64,134	9	9	10	10	10.0	NR	590,149	401	22	9,907	349,540
50	01/28/10	11,849.6	7.1	300,501	222,000	9	9	10	10	10.0	NR	579,044	394	23	11,364	350,225
	01/29/10	11,856.6	6.9	300,699	193,959	56	50	39	36	12.0	540	143,810	98	24	11,178	350,870
51	02/02/10	11,884.0	7.0	301,561	219,696	56	51	39	35	12.0	557	316,110	215	25	11,153	351,518
51	02/03/10	11,892.6	6.6	301,837	213,105	56	51	39	33	12.0	545	571,244	388	25	11,153	351,518
	02/08/10	11,925.9	7.1	302,816	208,083	57	52	40	28	12.0	515	246,140	167	27	10,928	352,815
52	02/10/10	11,939.1	6.4	303,214	193,622	2	1	0	3	3.0	NR	12,356	8	28	7,155	353,141
	02/12/10	11,954.5	7.9	303,674	236,150	10	9	11	11	11.0	NR	421,067	286	28	11,380	353,665

NR = Not Recorded 1 BV = 197 ft3 APPENDIX D

ANALYTICAL DATA

## Analytical Results from Long-Term Sampling at Vale, OR (Study Period I)

Sampling Da	ate	09/20/06 IN TA TB TT			0	9/25/06		1	0/02/06		10	/09/06 <sup>(a)</sup>			10/18/	06		1(	)/23/06 <sup>(b)</sup>		
Sampling Loca	ation	IN	TA	TB	TT	IN	ТА	TB	IN	ТА	TB	IN	ТА	TB	IN	ТА	TB	TT	IN	ТА	TB
Parameter	Unit																				
Throughput	gal		653,3	91			NA			14,150		1	32,197			125,7	50		1	181,240	
Alkalinity	mg/L	301	365	363	358	305	227	204	254	355	339	316	182	157	306	209	190	194	308	269	260
(as CaCO <sub>3</sub> )		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.6	0.6	0.7	0.8	-	-	-	-	-	-	-	-	-	0.6	0.6	0.6	0.6	-	-	-
Sulfate	mg/L	73.0	4.0	10.0	9.0	67.0	<1	<1	259 <sup>(c)</sup>	<1	<1	75.0	<1	<1	79.0	<1	<1	<1	88.0	<1	<1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	3.5	3.9	3.9	4.1	3.8	0.5	0.5	4.2	< 0.05	< 0.05	2.5	0.4	0.4	4.6	2.1	1.1	2.3	3.9 <sup>(d)</sup>	2.2	2.5
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as P)	μg/L	325	290	388	370	240	<10	<10	300	<10	<10	322	<10	<10	293	24.7	16.9	21.4	266	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L	57.3	57.9	57.4	55.7	57.7	57.0	56.2	46.1	56.5	57.4	56.1	58.2	10.3	57.0	58.5	59.7	58.6	57.4	56.5	56.4
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	0.5	0.2	0.3	0.4	0.2	0.1	0.2	0.3	0.4	0.8	0.5	0.2	0.7	0.5	0.6	0.7	0.6	0.7	0.4	0.8
	~	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TDS	mg/L	438	484	484	472	460	448	462	766	428	459	470	478	488	462	448	466	462	486	460	468
TOG	a.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	7.3	7.4	7.4	7.4	NA	NA	NA	NA	NA	NA	7.5	7.5	7.5	7.3	7.2	7.1	7.2	7.3	7.4	7.4
Temperature	°C	15.3	15.0	15.1	15.1	NA	NA	NA	NA	NA	NA	15.3	15.4	15.4	14.9	14.8	14.9	14.8	15.6	15.4	15.4
DO	mg/L	1.6	2.1	1.9	2.0	NA	NA	NA	NA	NA	NA	2.3	2.5	2.4	2.1	2.8	2.2	2.7	2.1	2.0	1.8
ORP	mV	127	126	120	118	NA	NA	NA	NA	NA	NA	272	152	146	265	195	182	165	253	229	227
Total Hardness (as CaCO <sub>3</sub> )	mg/L	155	154	154	146	-	-	-	-	-	-	-	-	-	138	140	142	137	-	-	-
Ca Hardness	mg/L	111	109	109	101	-	-	-	-	-	-	-	-	-	94.2	96.2	98.0	92.8	-	-	-
Mg Hardness	mg/L	44.4	44.8	45.4	45.5	-	-	-	-	-	-	-	-	-	44.0	43.9	43.6	43.7	-	-	-
As (total)	μg/L	24.8	19.4	27.7	26.1	18.7	5.7	5.9	25.2	0.5	0.5	22.5	1.8	1.8	24.1	3.2	3.0	3.1	24.9	2.7	2.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	μg/L	22.9	18.7	24.7	24.2	-	-	-	-	-	-	-	-	-	21.8	3.3	2.9	2.9	-	-	-
As (particulate)	μg/L	1.9	0.7	3.0	1.9	-	-	-	-	-	-	-	-	-	2.3	< 0.1	< 0.1	0.1	-	-	]
As (III)	μg/L	0.4	0.4	0.4	0.4	-	-	-	-	-	-	-	-	-	0.8	0.7	0.7	0.6	-	-	-
As (V)	μg/L	22.5	18.3	24.3	23.7	-	-	-	-	-	-	-	-	-	21.0	2.5	2.2	2.3	-	-	-
Fe (total)	μg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	μg/L	<25	<25	<25	<25	-	-	-	-	-	-	-	-	-	<25	<25	<25	<25	-	-	-
Mn (total)	μg/L	0.4	0.4	0.5	0.4	0.7	2.3	1.4	0.5	0.5	0.6	0.7	0.4	0.3	0.4	0.6	0.6	0.6	0.5	0.6	0.5
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	μg/L	0.4	0.4	0.4	0.4	-	-	-	-	-	-	-	-	-	0.4	0.6	0.5	0.6	-	-	-
V (total)	μg/L	59.7	0.6	0.7	0.6	-	-	-	-	-	-	-	-	-	60.3	1.8	2.1	2.0	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (soluble)	μg/L	59.2	0.5	0.7	0.7	-	-	-	-	-	-	-	-	-	58.8	1.7	2.0	1.9	-	-	

(a) Water quality parameters taken on 10/10/06. (b) Water quality parameters taken on 10/26/06. (c) 10/02/06 sample rerun with similar results for sulfate. (d) Reanalysis conducted outside of hold time.

## Analytical Results from Long-Term Sampling at Vale, OR (Study Period I)

Sampling Date Sampling Location			10/31/06 <sup>(a)</sup>			11/06/06 <sup>(b)</sup>			11/14	4/06 <sup>(c)</sup>			11/28/06			12/04/06 <sup>(d)</sup>	)		12/13/06 <sup>(e)</sup>	)
Sampling Locat	ion	IN	IN TA TB		IN	TA	TB	IN	TA	TB	TT	IN	TA	TB	IN	ТА	TB	IN	ТА	TT
Parameter	tion IN TA Unit Sal NA																			
Throughput	gal		NA			443,420			407	,330			547,771			69,595			216,079	
Alkalinity	mg/L	331	398	303	311	376	370	315	380	374	376	314	356	354	326	171	145	326	316	303
(as CaCO <sub>3</sub> )		-	-	-	-	-	-	-	-	-	-	-	-	-	337	174	143	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	0.6	0.5	0.6	0.6	-	-	-	-	-	-	1.1	0.5	0.6
Sulfate	mg/L	78.0	<1	<1	76.0	2.0	1.0	79.0	1.0	2.0	2.0	90.0	28.0	33.0	90.0	4.0	3.0	76.0	<1	<1
		-	-	-	-	-	-	-	-	-	-	-	-	-	89.0	4.0	3.0	-	-	-
Nitrate (as N)	mg/L	4.8	2.1	0.1	4.8	3.8	4.5	5.3	3.3	4.4	3.8	6.0	9.8	7.5	6.4	4.6	4.7	5.4	0.9	0.9
		-	-	-	-	-	-	-	-	-	-	-	-	-	6.8	4.5	5.0	-	-	-
Total P (as P)	µg/L	320	16.6	<10	253	97.4	197	272	59.7	121	93.1	251	403	308	218	<10	<10	256	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-	-	212	<10	<10	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L	55.3	56.8	54.7	57.0	56.4	55.6	55.2	55.1	54.7	56.1	55.6	55.5	55.5	55.5	55.1	54.2	56.1	55.4	55.4
		-	-	-	-	-	-	-	-	-	-	-	-	-	55.7	56.7	55.5	-	-	-
Turbidity	NTU	0.9	0.7	0.8	0.5	0.6	0.8	0.6	0.9	0.5	0.7	0.8	0.4	0.6	0.5	0.4	0.5	0.4	0.4	0.4
		-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	0.4	0.6	-	-	-
TDS	mg/L	486	470	468	462	438	432	494	442	442	448	490	468	464	500	486	498	434	412	498
		-	-	-	-	-	-	-	-	-	-	-	-	-	488	478	502	-	-	-
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pН	S.U.	7.3	7.3	7.4	7.5	7.6	7.6	7.3	7.5	7.4	7.4	NA	NA	NA	7.3	7.5	7.4	7.7	7.7	7.6
Temperature	°C	15.0	15.2	15.0	16.3	16.1	16.1	15.6	15.6	15.4	15.3	NA	NA	NA	14.6	14.5	14.5	15.0	15.0	15.0
DO	mg/L	2.1	2.6	2.6	3.1	3.5	3.4	5.3	6.1	6.9	5.8	NA	NA	NA	3.4	4.2	3.4	5.4	5.2	5.8
ORP	mV	260	229	231	278	235	206	268	244	241	241	NA	NA	NA	252	230	229	272	257	247
Total Hardness (as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-	161	159	162	165	-	-	-	-	-	-	169	162	167
Ca Hardness	mg/L	-	-	-	-	-	-	105	104	107	109	-	-	-	-	-	-	121	117	120
Mg Hardness	mg/L	-	-	-	-	-	-	55.7	55.1	55.1	55.5	-	-	-	-	-	-	47.6	44.7	46.9
As (total)	µg/L	23.6	1.8	0.4	24.6	9.2	17.9	24.0	5.0	9.7	7.7	22.3	32.7	26.3	19.6	4.5	4.5	20.9	1.5	1.5
		-	-	-	-	-	-	-	-	-	-	-	-	-	20.2	4.2	4.3	-	-	-
As (soluble)	μg/L	-	-	-	-	-	-	21.4	4.5	9.1	6.7	-	-	-	-	-	-	21.0	1.6	1.8
As (particulate)	μg/L	-	-	-	-	-	-	2.6	0.5	0.5	1.0	-	-	-	-	-	-	< 0.1	< 0.1	< 0.1
As (III)	µg/L	-	-	-	-	-	-	0.7	0.7	0.7	0.6	-	-	-	-	-	-	0.9	0.9	0.9
As (V)	μg/L	-	-	-	-	-	-	20.7	3.8	8.4	6.1	-	-	-	-	-	-	20.1	0.8	1.0
Fe (total)	μg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	<25	<25	<25	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	<25	<25	<25	<25	-	-	-	-	-	-	<25	<25	<25
Mn (total)	μg/L	0.4	0.6	0.6	2.1	0.6	0.4	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.4	0.4	0.4
		-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.2	0.3	-	-	-
Mn (soluble)	μg/L	-	-	-	-	-	-	0.4	0.4	0.4	0.4	-	-	-	-	-	-	0.4	0.4	0.5
V (total)	μg/L	-	-	-	-	-	-	60.5	1.9	2.2	2.0	-	-	-	-	-	-	57.9	2.3	2.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (soluble)	µg/L	-	-	-	-	-	-	61.2	1.8	2.2	2.0	-	-	-	-	-	-	56.1	2.5	2.2

(a) Water quality parameters taken on 11/03/06. (b) Water quality parameters taken on 11/08/06. (c) Water quality parameters taken on 11/15/06. (d) Water quality parameters taken on 12/05/06. (e) Water quality parameters taken on 12/14/06.

Sampling Date Sampling Location		1	2/18/06 <sup>(a)</sup>		0	1/02/07 <sup>(b)</sup>			01/10	/07		(	01/17/07		(	01/24/07		(	01/30/07	
Sampling Loca	ation	IN	TA	TB	IN	TA	TB	IN	TA	TB	TT	IN	TA	TB	IN	TA	TB	IN	TA	TB
Parameter	Unit																			
Throughput	gal		115,597			449,702			451,9	96			189,175			294,135		4	143,388	
Alkalinity	mg/L	337	229	186	345	421	427	349	411	417	400	331	311	290	326	391	376	356	432	425
(as CaCO <sub>3</sub> )		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	0.6	0.5	1.4	0.7	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	97.0	<1	<1	77.0	5.0	1.0	86.0	3.0	2.0	7.0	82.0	<1	<1	84.0	<1	<1	81.0	2.0	7.0
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	6.3	1.3	1.4	5.2	3.7	3.8	5.2	2.9	3.6	4.1	6.3	1.0	1.1	6.1	< 0.05	< 0.05	6.4	4.4	5.4
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as P)	μg/L	272	<10	<10	255	214	136	301	194	210	317	231	<10	<10	218	<10	<10	323	311	397
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as $SiO_2$ )	mg/L	56.9	56.6	55.8	56.1	57.0	56.8	54.9	55.5	55.9	54.6	55.6	57.0	55.9	54.4	54.1	54.9	54.3	53.8	53.3
TD 1 11	NEEL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	0.3	0.7	0.5	0.2	0.3	0.6	0.4	0.3	0.6	0.5	0.4	0.5	0.6	0.4	0.5	0.6	0.2	0.7	0.3
TDC	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IDS	mg/L	506	526	496	522	4/8	480	468	456	464	464	484	470	464	540	482	4/8	504	4/4	436
TOC		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IUC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
рн	S.U.	1.5	7.4	7.4	1.1	1.4	1.4	1.4	1.4	1.4	1.4	1.5	1.4	1.3	NA	NA	NA NA	NA	NA	NA
Temperature	·C	15.0	14.9	14.9	15.6	15.5	15.4	15.5	15.5	15.5	15.5	14.0	14.0	14.0	NA	NA	NA	NA	NA	NA
DU	mg/L	4.0	5.7	4.9	4.5	4.8	4.4	4.8	4.7	4.5	4.8	4.8	4.1	5.0	NA	NA	NA NA	NA	NA	NA
ORP	mv	248	235	231	255	227	226	256	227	227	227	255	233	231	NA	NA	NA	NA	NA	NA
(as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-	164	164	157	159	-	-	-	-	-	-	-	-	-
Ca Hardness	mg/L	-	-	-	-	-	-	111	112	105	106	-	-	-	-	-	-	-	-	-
Mg Hardness	mg/L	-	-	-	-	-	-	52.6	52.3	52.0	52.4	-	-	-	-	-	-	-	-	-
As (total)	μg/L	21.4	1.8	1.7	25.5	18.6	11.2	21.3	14.6	12.6	19.6	18.3	1.7	1.9	21.7	0.8	1.0	27.0	25.0	33.8
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	μg/L	-	-	-	-	-	-	19.2	14.5	10.2	19.4	-	-	-	-	-	-	-	-	-
As (particulate)	μg/L	-	-	-	-	-	-	2.1	0.1	2.3	0.1	-	-	-	-	-	-	-	-	-
As (III)	μg/L	-	-	-	-	-	-	1.0	0.9	0.8	0.9	-	-	-	-	-	-	-	-	-
As (V)	μg/L	-	-	-	-	-	-	18.2	13.6	9.4	18.5	-	-	-	-	-	-	-	-	-
Fe (total)	μg/L	<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	0.4	0.5	0.6	0.4	0.4	0.4	0.3	0.3	0.3	0.3	< 0.1	< 0.1	< 0.1	0.3	0.4	0.3	0.8	1.0	1.3
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	- '	-
Mn (soluble)	μg/L	-	-	-	-	-	-	0.3	0.3	0.3	0.3	-	-	-	-	-	-	-	-	-
V (total)	μg/L	-	-	-	-	-	-	49.8	0.8	0.7	1.0	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	- '	-
V (soluble)	μg/L	-	-	-	-	-	-	49.7	0.9	0.6	1.0	-	-	-	-	-	-	-	-	-

(a) Water quality parameters taken on 12/20/06. (b) Water quality parameters taken on 01/05/07.

Sampling D	ate	0	2/06/07			02/12/	07		0.	2/19/07		0	2/27/07		0	3/05/07			03/12/0	7 <sup>(a,b)</sup>	
Sampling Loc	ation	IN	TA	TB	IN	TA	TB	TT	IN	TA	TB	IN	TA	TB	IN	TA	TB	IN	TA	TB	TT
Parameter	Unit																				
Throughput	gal	2	278,676			475,3	37		2	51,951		2	87,695			NA			543,8	62	
Alkalinity	mg/L	353	395	381	339	406	401	399	344	368	352	343	401	392	346	378	380	346	374	381	384
(as CaCO <sub>3</sub> )		-	-	-	-	-	-	-	-	-	-	340	404	394	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	0.6	1.1	0.6	0.5	-	-	-	-	-	-	-	-	-	1.1	1.1	1.0	1.3
Sulfate	mg/L	84.0	<1	<1	81.0	9.0	18.0	13.0	93.0	<1	<1	92.0	<1	<1	79.0	36.0	35.0	86.1	38.0	38.0	40.0
		-	-	-	-	-	-	-	-	-	-	93.0	<1	<1	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	7.2	0.9	0.9	6.4	5.6	7.2	6.0	6.4	1.2	1.2	7.4	1.0	1.0	6.5	9.9	8.9	1.4	1.4	1.4	1.6
		-	-	-	-	-	-	-	-	-	-	7.6	0.9	1.1	-	-	-	-	-	-	-
Total P (as P)	μg/L	272	<10	<10	285	329	402	394	337	43.1	43.0	290	<10	<10	281	664	454	305	659	458	559
		-	-	-	-	-	-	-	-	-	-	296	<10	<10	-	-	-	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L	53.6	53.6	53.6	59.2	60.0	59.8	59.9	55.4	56.0	55.8	55.4	55.4	54.8	55.1	55.2	55.1	55.5	55.2	54.1	55.2
		-	-	-	-	-	-	-	-	-	-	55.2	55.1	55.5	-	-	-	-	-	-	-
Turbidity	NTU	0.3	0.4	0.4	0.3	0.4	0.5	0.4	0.6	0.7	1.6	0.4	0.3	0.1	0.3	0.7	0.6	0.4	0.3	0.3	0.4
	~	-	-	-	-	-	-	-	-	-	-	0.4	0.3	0.1	-	-	-	-	-	-	-
TDS	mg/L	536	498	504	514	480	488	430	540	508	506	526	472	480	542	528	526	554	532	550	532
TOC	a	-	-	-	-	-	-	-	-	-	-	520	492	470	-	-	-	-	-	-	-
100	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
рН	S.U.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7.2	7.4	7.4	7.4
Temperature	°C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	14.8	14.7	14.7	14.9
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.3	2.8	2.9	2.8
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	226	217	212	252
Total Hardness (as CaCO <sub>3</sub> )	mg/L	-	-	-	170	182	189	192	-	-	-	-	-	-	-	-	-	251	240	241	229
Ca Hardness	mg/L	-	-	-	120	128	134	136	-	-	-	-	-	-	-	-	-	187	178	179	169
Mg Hardness	mg/L	-	-	-	49.8	53.7	55.2	56.4	-	-	-	-	-	-	-	-	-	63.9	61.8	61.6	59.8
As (total)	μg/L	19.4	0.9	1.0	19.9	22.2	27.3	26.6	31.8	8.4	9.1	20.4	1.4	1.1	18.4	39.4	27.6	22.9	45.8	32.3	39.3
		-	-	-	-	-	-	-	-	-	-	20.8	1.3	1.1	-	-	-	-	-	-	-
As (soluble)	μg/L	-	-	-	20.9	21.5	27.2	25.4	-	-	-	-	-	-	-	-	-	20.1	42.1	29.8	35.9
As (particulate)	μg/L	-	-	-	< 0.1	0.7	0.1	1.2	-	-	-	-	-	-	-	-	-	2.8	3.6	2.5	3.4
As (III)	μg/L	-	-	-	0.9	0.4	0.3	0.3	-	-	-	-	-	-	-	-	-	2.3	2.5	2.8	2.7
As (V)	μg/L	-	-	-	20.0	21.1	26.9	25.1	-	-	-	-	-	-	-	-	-	17.8	39.6	27.0	33.1
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	<25	-	-	-	-	-	-	-
Fe (soluble)	μg/L	-	-	-	<25	<25	<25	<25	-	-	-	-	-	-	-	-	-	<25	<25	<25	<25
Mn (total)	μg/L	0.3	0.3	0.3	0.5	0.5	0.5	0.5	1.1	1.2	1.3	0.2	0.2	0.2	0.3	0.3	0.3	< 0.1	0.3	< 0.1	< 0.1
		-	-	-	-	-	-	-	-	-	-	0.2	0.1	0.2	-	-	-	-	-	-	-
Mn (soluble)	μg/L	-	-	-	0.5	0.5	0.5	0.5	-	-	-	-	-	-	-	-	-	< 0.1	0.2	< 0.1	< 0.1
V (total)	μg/L	-	-	-	50.5	2.1	2.4	2.4	-	-	-	-	-	-	-	-	-	50.1	3.0	2.6	2.9
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (soluble)	μg/L	-	-	-	50.4	1.8	2.3	2.2	-	-	-	-	-	-	-	-	-	49.9	2.9	2.4	2.9

(a) Water quality parameters taken on 03/14/07. (b) Process samples taken in counter-current mode.

Sampling Da	te		03/19/07			03/26/07			04/02/07			04/10	0/07 <sup>(a)</sup>			04/1	6/07		07/16/07	07/25/07	08/01/07
Sampling Loca	tion																				
Parameter	Unit	IN	ТА	TB	IN	TA	TB	IN	ТА	TB	IN	ТА	TB	TT	IN	TA	TB	TT	TT	TT	TT
Throughput	gal		415,021			346,850			376,943			114	,230			371	,129		242,110	50,201	300,162
Alkalinity (as CaCO3)	mg/L	350	409	416	- 342	412	412	358	427	423	357	286	- 251	282	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	0.5	0.5	0.5	0.5	-	-	-	-	-	-	-
Sulfate	mg/L	81.0	11.0	7.0	79.0	<1	<1	73.1	5.0	2.0	83.0	<1	<1	<1	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	6.1 -	5.3	5.1	6.7 -	2.5	1.7 -	4.0	5.9 -	5.5 -	7.6 -	1.9 -	2.3	2.1	-	-	-	-	0.4	0.4	-
Total P (as P)	μg/L	294	344	249	263	46.1	<10	285	249	154	279	10.7	<10	<10	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L	- 56.3	- 56.9	57.2	- 55.9	- 55.3	- 55.2	- 55.0	- 55.1	- 56.4	- 53.8	- 54.5	54.6	- 55.3	-	-	-	-	-	-	-
		0.4	0.6	0.7	0.5	0.3	0.8	0.5	1.2	0.7	0.9	0.8	1.5	1.1	-	-	-	-	-	-	-
Turbidity	NTU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TDS	mg/L	570	606	544	564	496	478	586	560	540	572	542	550	554	-	-	-	-	-	-	-
TOC		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	mg/L	-	- NIA	- NIA	-	- 7.4	- 7.4	-	-	-	-	- 7.1	- 7.0	- 7.1	2.0	-	-	-	- NA	- NIA	- N A
рп т	3.U.	NA	NA NA	NA	1.2	14	14.0	14.9	1.5	7.0	14.9	/.1	7.0	/.1	8.0 16.2	0.5	0.2	0.2	NA	NA NA	NA
Temperature	-С та/Г	NA	NA NA	NA	14.7	14.8	14.8	14.8	14.8	14.8	14.8	14.4	14.5	14.0	10.5	16.0	10.1	16.0	NA NA	NA	NA NA
OPP	mg/L	NA	NA	NA	225	2.0	2.9	252	224	4.5	204	261	249	242	259	0.4	0.5	222	NA	NA	NA
Total Hardness	mg/L	-	-	-	-	-	-	-	-	-	158	165	164	169	-	-	-	-	-	-	-
Ca Hardness	mg/L	-	-	-	-	-	-	-	-	-	110	115	115	122	-	-	-	-	-	-	-
Mg Hardness	mg/L	-	-	-	-	-	-	-	-	-	48.3	50.4	48.9	47.4	-	-	-	-	-	-	-
As (total)	μg/L	28.8	30.4	20.0	19.5	3.6	0.8	24.1	18.3	11.1	24.2	1.7	1.8	1.6	-	-	-	-	-	3.6	0.9
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	μg/L	-	-	-	-	-	-	-	-	-	20.5	1.7	1.8	1.6	-	-	-	-	-	-	-
As (particulate)	μg/L	-	-	-	-	-	-	-	-	-	3.7	< 0.1	< 0.1	< 0.1	-	-	-	-	-	-	-
As (III)	μg/L	-	-	-	-	-	-	-	-	-	0.8	0.8	0.7	0.7	-	-	-	-	-	-	-
As (V)	μg/L	-	-	-	-	-	-	-	-	-	19.7	0.9	1.0	0.9	-	-	-	-	-	-	-
Fe (total)	μg/L	<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	0.6	0.6	0.5	< 0.1	< 0.1	< 0.1	0.2	0.2	0.3	0.2	0.3	0.3	0.3	-	-	-	-	-	-	-
Mn (soluble)	uø/L	-	-	-	-	-	-	-	-	-	0.3	0.3	03	0.3	-	-	-	-	-	-	-
(soluble)	46/1	-	-	-	-	-	-	-	-	-	46.5	3.6	4.5	3.9	-	-	-	-	-	-	-
V (total)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (soluble)	μg/L	-	-	-	-	-	-	-	-	-	48.5	3.5	4.5	3.5	-	-	-	-	-	-	-

(a) Weekly sampling temporarily stopped after 04/10/07.

Sampling Dat	e	08/08/07	08/14/07	08/21/07	08/28/07	09/11/07	09/17/07	09/24/07	10/01/07	10/08/07	10/16/07	10/22/07	10/29/07	11/14/07	11/19/07
Sampling Locat	ion														
Parameter	Unit	TT	TT												
Throughput	gal	21,930	243,014	26,825	359,292	94,079	163,149	346,796	167,558	243,918	NA	377,889	595,337	131,979	50,196
Alkalinity (as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	1.0	0.8	1.9 -	0.7	1.4 -	1.1 -	0.7	1.1 -	0.8	1.0	0.7	6.1 -	3.7 <sup>(a)</sup>	3.5 <sup>(a)</sup>
Total P (as P)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L	-	-	-	-	-		-	-	-		-	-	-	-
Turbidity	NTU	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TDS	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOC	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pН	S.U.	NA	NA	NA	NA	NA	8.2	NA	NA						
Temperature	°C	NA	NA	NA	NA	NA	16.3	NA	NA						
DO	mg/L	NA	NA	NA	NA	NA	6.5	NA	NA						
ORP	mV	NA	NA	NA	NA	NA	233	NA	NA						
Total Hardness (as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	μg/L	2.0	2.1	4.3	1.4 -	1.5 -	2.8	0.8	1.5	1.2	0.7	2.1	33.5	11.8 <sup>(a)</sup>	10.2 <sup>(a)</sup>
As (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (total)	н <i>а</i> /I	-	-	-	-	-	-	-	-	-	-	-	1.1	-	-
v (total)	μg/г	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(a) Concentrations elevated due to glitches in PLC when reused brine time was set to zero, causing TA regen to be bypassed. Problem fixed on 12/10/07.

Sampling Da	ate	11/27/07	12/03/07	12/10/07	12/17/07	01/07/08	01/14/08
Sampling Loca	ation						
Parameter	Unit	TT	TT	TT	TT	TT	TT
Throughput	gal	533,870	51,996	530,622	200,373	195,150	418,136
Alkalinity (as CaCO <sub>2</sub> )	mg/L	-	-	-	-	-	-
Fluoride	mg/L					_	
Sulfate	mg/L	-	-	-	-	-	-
Builde	ing/1	-	-	-	-	-	-
	~	6.5	3.3 <sup>(a)</sup>	7.1	1.1	0.7	4.0
Nitrate (as N)	mg/L	-	-	-	-	-	-
Total D (as D)	ug/I	-	-	-	-	-	-
Total F (as F)	µg/L	-	-	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L	-	-	-	-	-	-
·	Ð	-	-	-	-	-	-
Turbidity	NTU	-	-	-	-	-	-
-		-	-	-	-	-	-
TDS	mg/L	-	-	-	-	-	-
TOC	ma/I	-	-	-	-	-	-
IUC	nig/L	-	-	-	-	-	-
pri Tommonotumo	3.U.	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA
DO	c ma/I	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA
OPP	mg/L	INA NA	INA NA	NA NA	NA NA	NA NA	NA NA
OKP Total Hardness	Шv	INA	INA	NA	INA	NA	NA
(as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-
Ca Hardness	mg/L	-	-	-	-	-	-
Mg Hardness	mg/L	-	-	-	-	-	-
As (total)	uø/L	33.8	11.9 <sup>(a)</sup>	48.7	1.3	2.2	20.6
115 (total)	µg 2	-	-	-	-	-	-
As (soluble)	μg/L	-	-	-	-	-	-
As (particulate)	μg/L	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-
Fe (total)	μg/L	-	-	-	-	-	-
Fe (soluble)	ug/L	-	-	-	-	-	-
Mn (total)	µg/L	-	-	-	-	-	-
		-	-	-	-	-	-
Mn (soluble)	μg/L	-	-	-	-	-	-
V (total)	μg/L	-	-	-	-	-	-
V (soluble)	μg/L	-	-	-	-	-	-

(a) Concentrations elevated due to glitches in PLC when reused brine time was set to zero , causing TA regen to be bypassed. Problem fixed on 12/10/07.

# Analytical Results from Long-Term Sampling at Vale, OR (Study Period II) (Continued)

Sampling Da	ite		03/2	5/09			04/0	2/09			04/0	8/09			04/2	2/09			04/2	8/09	
Sampling Loca	ation	IN	ТА	TB	тт	IN	ТА	TB	тт	IN	ТА	TB	тт	IN	ТА	TB	тт	IN	ТА	TB	тт
Parameter	Unit		171	10		II.	171	15		II.	171	10			111	10			171	TD	
Throughput	gal		59,	084			551	,090			424	,882			162	,061			145	,268	
Alkalinity	mg/L	310	76.0	26.4	52.8	320	368	372	372	321	326	296	310	313	241	236	246	311	228	180	204
(as CaCO <sub>3</sub> )	ing/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	74.5 -	0.2	0.2	0.2	74.5 -	- 21.2	- 10.4	15.1 -	72.6 -	<0.1	<0.1	0.1	74.4 -	0.3	0.2	0.3	71.1 -	- 0.4	0.6 -	0.6 -
Nitrate (as N)	mg/L	5.7	2.1	2.7	2.9	5.5	6.3 -	4.9 -	5.7	4.4 -	0.8	0.9	0.9	6.8 -	1.3 -	1.3 -	1.3 -	5.2	1.3 -	1.2	1.4 -
Total P (as P)	μg/L	266 -	<10	<10 -	<10	262	332	296 -	303	345 -	<10	<10	<10 -	308	14.5 -	14.3 -	13.7 -	293	20.2	17.2	19.4 -
Silica (as SiO <sub>2</sub> )	mg/L	56.5	57.0	57.4	56.7	- 54.5	54.9 -	- 54.4	53.6	57.9	57.9	58.2	58.6	56.0	59.4 -	59.2	59.1	66.2	62.8	67.2	63.2
Turbidity	NTU	0.2	1.3	0.3	0.4	0.3	0.4	0.4	0.2	<0.1	0.3	<0.1	0.5	0.3	0.2	0.2	0.3	0.1	<0.1	0.2	0.1
TDS	mg/L	496	596 -	622	596 -	496	474	456	452	502	478	476	480	520	480	488	488	508	468	488	502
TOC	mg/L	1.6	<1.0	<1.0	<1.0	1.8	<1.0	<1.0	<1.0	1.7	<1.0	<1.0	<1.0	2.0	<1.0	<1.0	<1.0	1.6	<1.0	<1.0	<1.0
pH	S.U.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
As (total)	μg/L	21.7	2.9	4.5	3.9	- 18.4	21.9	19.3 -	- 20.4	19.4 -	1.3 -	1.5 -	1.4 -	23.3	2.4	2.8	2.6	22.3	2.9	3.2	3.0
As (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	μg/L	<25	<25	<25	<25	<25 -	<25	<25	<25	<25	<25 -	<25	<25	<25	<25	<25	<25	<25 -	<25	<25	<25
Fe (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	0.2	0.4	0.5	0.5	0.2	0.1	0.2	0.6 -	0.3	0.3	0.3	0.3	0.5	0.4	0.8	0.4	0.4 -	0.5	0.7	1.2 -
Mn (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (total)	µg/L	49.2	7.3	- 14.5	- 11.5	52.6	7.1	1.2	6.0	49.8	1.3	1.7	1.7	59.4	3.4	3.6	3.5	57.8	3.3	4.9	4.2
V (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Sampling Da	ate		05/0	6/09			05/1	9/09			05/2	8/09			06/0	03/09			06/0	9/09	
Sampling Loca	ation	IN	TA	тр	TT	IN	ТА	тр	TT	IN	ТА	тр	TT	IN	ТА	тр	TT	IN	ТА	тр	TT
Parameter	Unit	IIN	IA	ID	11	IIN	IA	ID	11	IIN	IA	ID	11	IIN	IA	ID	11	IIN	IA	ID	11
Throughput	gal		353,	,486			434	,234			172,	,559			587	,423			417	977	
Alkalinity (as CaCO <sub>3</sub> )	mg/L	316	360	374	356	323	381	384	396 -	310	281	229	- 246	322	354	377	360	305	372	376	368
Sulfate	mg/L	77.6	<0.1	0.2	0.1	83.2	1.6 -	0.1	0.9	81.2	0.1	0.2	0.2	76.6	21.2	- 11.5	- 15.4	- 74.4	0.4	0.2	0.3
Nitrate (as N)	mg/L	6.1	1.1	0.7	0.9	6.3 -	4.4	2.3	3.6	5.8 -	1.2	1.2	1.5 -	5.9 -	9.9 -	9.9 -	9.3 -	5.2	3.3	1.1 -	1.8 -
Total P (as P)	μg/L	300	<10	<10	<10 -	258	172	<10 -	89.2	251	<10 -	<10	<10	279 -	452 -	447 -	457 -	285	75.3	<10 -	29.4
Silica (as SiO <sub>2</sub> )	mg/L	63.6	61.4 -	63.7	63.9 -	62.4	62.6	62.5	63.0	58.5 -	59.4 -	59.7 -	59.7 -	61.7 -	61.4 -	62.0	62.0	60.3	60.5	61.4 -	60.6 -
Turbidity	NTU	0.4	0.2	0.5	0.3	<0.1	0.3	0.1	0.1	<0.1	0.1	0.3	0.3	0.2	0.2	0.1	0.3	0.4	0.9	0.5	0.3
TDS	mg/L	498 -	422	460 -	448 -	510	482	486 -	464 -	496 -	482	472	486	528	512	496 -	508	506	466 -	460	468 -
TOC	mg/L	2.1	<1.0	<1.0	<1.0	1.7	<1.0	<1.0	<1.0	2.0	<1.0	<1.0	<1.0	2.0	<1.0	<1.0	<1.0	2.0	<1.0	<1.0	<1.0
pН	S.U.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
As (total)	μg/L	18.1	0.6	0.6	0.6	20.3	- 11.2	1.1 -	6.0	16.0 -	0.6	1.0	1.0	20.7	30.8	31.1	31.4	20.2	4.9 -	0.5	2.4
As (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	μg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Fe (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	μg/L	0.3	0.3	0.3	0.3	0.9 -	0.4 -	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Mn (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (total)	μg/L	50.2	0.8	0.9	0.9	49.2	0.8	0.8	0.8	47.0	1.7	2.9	2.7	54.7 -	4.8	3.1	4.1 -	55.2	0.8	0.9 -	0.9
V (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

by      by     &lt;	Sampling Da	ate		06/1	7/09		06/3	0/09		07/0	8/09			07/1	3/09			07/2	0/09			08/0	4/09	
Parameter         Unit	Sampling Loca	ation	DI	TA	TD	TT	TN	TT	TNI	<b>T</b> 4	TD	TT	TNI	<b>T</b> 4	TD	TT	IN	TA	TD	TT	IN	TA	TD	TT
Image         <t< td=""><td>Parameter</td><td>Unit</td><td>IIN</td><td>IA</td><td>IB</td><td>11</td><td>IIN</td><td>11</td><td>IIN</td><td>IA</td><td>IВ</td><td>11</td><td>IIN</td><td>IA</td><td>IB</td><td>11</td><td>IN</td><td>IA</td><td>IВ</td><td>11</td><td>IIN</td><td>IA</td><td>IB</td><td>11</td></t<>	Parameter	Unit	IIN	IA	IB	11	IIN	11	IIN	IA	IВ	11	IIN	IA	IB	11	IN	IA	IВ	11	IIN	IA	IB	11
Altaling         Pl         <	Throughput	gal		339	,974		528	,358		357	,543			539	,420			444	,177			236	,355	
base cond         image	Alkalinity	ma/I	306	368	355	364	315	358	312	376	372	369	304	345	352	349	312	386	390	383	297	322	288	302
Salia         mgL         r.1.6         0.1         0.2         7.4         0.8         7.7         0.7	(as CaCO <sub>3</sub> )	ing/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
new         new         n <td>Sulfate</td> <td>mø/L</td> <td>71.6</td> <td>0.1</td> <td>0.1</td> <td>0.2</td> <td>74.6</td> <td>6.8</td> <td>71.7</td> <td>61.7</td> <td>0.2</td> <td>0.3</td> <td>75.2</td> <td>20.5</td> <td>9.2</td> <td>13.7</td> <td>71.1</td> <td>0.5</td> <td>&lt; 0.1</td> <td>0.4</td> <td>72.8</td> <td>0.2</td> <td>0.3</td> <td>0.3</td>	Sulfate	mø/L	71.6	0.1	0.1	0.2	74.6	6.8	71.7	61.7	0.2	0.3	75.2	20.5	9.2	13.7	71.1	0.5	< 0.1	0.4	72.8	0.2	0.3	0.3
Nine (a N)         ne (a N)         5.1         0.7         1.0         5.3         5.4         2.8         0.7         0.8         5.6         5.7         5.3         9.1         1.0         0.0         5.8         0.1         1.0	Sunne	g/ 12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
number of a bit	Nitrate (as N)	mø/L	5.1	0.7	0.6	0.7	5.1	5.3	5.4	2.8	0.7	0.8	5.6	6.6	5.8	5.7	5.3	3.9	1.4	3.0	5.8	0.8	1.1	1.0
		g/ 12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10         1	Total P (as P)	ug/L	279	<10	<10	<10	304	291	262	<10	<10	<10	263	355	325	326	263	85.3	<10	44.1	279	<10	<10	<10
Shife (a Ga S0)         mgL         59.6         59.9         60.3         60.2         7.9         7.87         7.80         7.87         7.80         7.87         7.80         7.87         7.80         7.87         7.80         7.87         7.80         7.87         7.80         7.87         7.80         7.87         7.80         7.87         7.80         7.87         7.80         7.87         7.80         7.87         7.80         7.87         7.80         7.8 </td <td>. ,</td> <td>10</td> <td>-</td>	. ,	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Image: biase interm	Silica (as SiO <sub>2</sub> )	mg/L	59.6	59.9	60.3	60.2	57.9	58.7	58.0	58.5	58.7	59.1	57.9	59.1	58.9	58.8	62.2	62.4	62.7	62.5	60.2	60.3	60.5	60.6
Turbidity         NTU         0.5         1.2         0.8         0.6         0.1         0.1         0.3         0.2         0.4         0.4         0.2         0.3         0.2         0.1         1.0         0.0         0.5         0.2         0.1         0.1         0.1         0.1         0.1         0.1         0.1         0.1         0.1         0.1         0.1         0.1         0.1         0.1			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Turbidity	NTU	0.5	1.2	0.8	0.6	0.1	0.1	0.3	0.2	0.4	0.4	0.2	0.3	0.2	<0.1	1.0	1.0	0.9	1.5	0.2	0.1	0.8	0.2
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ind         ind <td>TDS</td> <td>mg/L</td> <td>450</td> <td>416</td> <td>420</td> <td>438</td> <td>470</td> <td>440</td> <td>498</td> <td>462</td> <td>464</td> <td>368</td> <td>460</td> <td>460</td> <td>468</td> <td>466</td> <td>456</td> <td>452</td> <td>434</td> <td>428</td> <td>532</td> <td>502</td> <td>500</td> <td>506</td>	TDS	mg/L	450	416	420	438	470	440	498	462	464	368	460	460	468	466	456	452	434	428	532	502	500	506
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	TOC		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	all	nig/L	1.9 NA	<1.0	<1.0	<1.0 NA	1.0 NA	<1.0 NA	1.0 NA	<1.0 NA	<1.0	<1.0	1.7 NA	-	<1.0	<1.0	1.7 NA	<1.0	<1.0 NA	<1.0 NA	2.2 NA	<1.0 NA	<1.0 NA	<1.0 NA
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	Tomporatura	3.U. ℃	INA NA	NA NA	NA NA	NA	NA NA	INA NA	NA NA	NA	NA	NA	NA	NA	NA NA	NA	NA	NA	NA	NA NA	NA NA	NA	NA	NA
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$		mg/I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	OPP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
As (tota) $\mu gL$ $1.0^{\circ}$ $0.0^{\circ}$ $0.0^{\circ}$ $1.0^{\circ}$	OKI	III V	10.0	0.5	0.6	0.6	22.8	10.0	10.8	0.7	0.6	0.7	18.0	25.3	22.6	23.0	18.6	53	0.6	3.2	21.0	1.6	1.5	1.4
As (soluble) $\mu g/L$ $\cdot$ <td>As (total)</td> <td>μg/L</td> <td>- 19.0</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> <td></td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> <td>- 23.0</td> <td>-</td> <td>-</td> <td>-</td> <td>5.2</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td>	As (total)	μg/L	- 19.0	-	-	-	-	-		-	-	-	-	-	-	- 23.0	-	-	-	5.2	-	-	-	-
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	As (soluble)	μσ/L		_	_	-	_	-	-	-	-	-	-	-	_	-	-	_	-			-	-	-
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	As (particulate)	μ <u>σ/L</u>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$10^{\circ}$ <t< td=""><td>As (III)</td><td>ug/L</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></t<>	As (III)	ug/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	As (V)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$		10	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Fe (total)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Fe (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$		~	0.3	0.2	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	4.0	3.2	3.3	3.0	0.2	0.3	0.4	0.3
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Mn (total)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	Mn (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (soluble) ug/L	V (total)	μg/L	54.3	1.0	1.1	1.1	49.7	0.9	51.5	0.3	0.3	0.3	50.4	2.1	1.0	1.3	50.2	<0.1	<0.1	<0.1	51.3	1.4	2.0	1.8
	V (soluble)	ug/L	-	_	_	-	-	_	_	-	-	_	-	-	_	_	_	_	-	_	_	-	_	_

Sampling Da	te		08/1	2/09			08/1	9/09			08/2	6/09			09/0	2/09			09/1	0/09	
Sampling Loca Parameter	tion Unit	IN	TA	TB	TT	IN	TA	TB	TT	IN	TA	TB	TT	IN	TA	TB	TT	IN	TA	TB	TT
Throughput	gal		568	,210			229	,445			104	,715			487	,940			112	792	
Alkalinity	a	302	336	345	343	298	317	287	303	296	187	117	161	293	337	353	347	282	180	118	143
(as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/I	63.6	19.5	10.1	14.8	71.8	< 0.1	0.2	0.1	70.6	0.1	0.2	0.1	79.2	7.5	0.2	3.6	72.4	< 0.1	0.2	0.1
Sunac	Ing/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	4.7	5.8	5.5	5.7	5.3	0.7	1.1	0.9	5.3	1.2	1.7	1.2	5.3	5.2	3.7	4.3	5.7	0.1	1.6	0.1
	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as P)	μg/L	275	376	362	375	269	<10	<10	<10	265	<10	<10	<10	272	386	70	239	281	<10	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L	58.7	58.5	58.5	58.7	57.9	58.4	58.7	58.4	59.5	59.0	60.0	60.1	60.0	01.2	60.4	59.6	59.8	60.8	61.0	60.5
		0.2	0.3	- 0.4	- 0.3	- 0.2	- 0.2	- 0.5	- 0.3	0.2	- 0.8	-	- 0.1	- 0.4	-	-	- 0.4	- 0.1	- 0.2	0.3	0.2
Turbidity	NTU	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-
		588	484	474	494	500	448	478	480	468	466	512	456	474	448	450	444	474	440	504	474
TDS	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOC	mg/L	2.2	<1.0	<1.0	<1.0	2.1	<1.0	<1.0	<1.0	1.9	<1.0	<1.0	<1.0	2.0	<1.0	<1.0	<1.0	1.8	<1.0	<1.0	<1.0
pH	S.U.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
As (total)	ug/L	18.0	23.0	21.7	22.3	20.5	1.7	1.9	2.0	19.7	1.9	2.8	2.6	18.5	23.4	3.3	13.7	19.0	0.8	1.4	1.2
,	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	μg/L ~	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	µg/L		25		25	25	25	25	25			25		25	25		- 25	- 25	25	25	- 25
Fe (total)	μg/L	-	-	<23	<23	<23	<25	<23	<25	-	-	<23	<23		<23	<23	-	-	<23	-	<25
Fe (soluble)	ug/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		0.3	0.3	0.3	0.3	2.6	2.2	2.3	2.6	0.3	0.5	0.4	0.2	0.3	0.2	0.3	0.2	0.3	0.2	0.3	0.3
Mn (total)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (total)	u a/I	0.3	0.3	0.3	0.3	2.6	2.2	2.3	2.6	0.3	0.5	0.4	0.2	49.1	1.6	0.8	1.2	48.6	3.1	4.8	4.2
v (total)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Sampling Da	te		09/1	5/09			09/2	3/09			09/3	0/09			10/0	07/09			10/1	4/09	
Sampling Loca Parameter	tion Unit	IN	TA	TB	TT	IN	TA	TB	TT	IN	TA	TB	TT	IN	TA	TB	TT	IN	TA	TB	TT
Throughput	gal		522.	,690			570	,142			56,	986			559	,404			359	,668	
Alkalinity	(7	279	343	345	337	293	322	337	333	298	107	29.0	63.5	300	336	356	358	312	370	370	375
(as CaCO <sub>3</sub> )	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/I	66.4	11.0	3.1	6.8	69.2	19.0	11.5	14.8	74.0	< 0.1	0.1	0.1	67.3	24.8	16.0	21.3	72.8	< 0.1	0.1	< 0.1
Sunac	Ing/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	4.5	5.5	4.4	5.1	4.0	6.2	5.3	5.7	5.7	1.5	1.9	1.8	6.7	8.0	8.8	9.0	5.7	2.9	0.9	1.6
		290	348	253	291	253	346	283	313	272	<10	14	<10	276	449	340	397	272	<10	<10	<10
Total P (as P)	μg/L	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	~	59.7	59.4	58.4	59.3	56.0	56.2	56.1	55.2	59.9	60.8	60.6	60.4	58.2	58.4	58.3	58.4	55.3	55.7	54.8	54.5
Silica (as SiO <sub>2</sub> )	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	2.6	0.3	0.5	2.1	0.1	0.1	0.1	0.1	0.4	0.2	0.3	0.1	0.4	1.0	0.2	0.3	0.2	0.1	0.1	0.1
Turblany	NIU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TDS	mø/L	434	462	454	446	466	438	426	430	540	606	724	650	502	468	454	466	486	442	454	460
125	ing 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOC	mg/L	1.9	<1.0	<1.0	<1.0	1.8	<1.0	<1.0	<1.0	1.6	<1.0	<1.0	<1.0	1.5	<1.0	<1.0	<1.0	1.4	<1.0	<1.0	<1.0
pH	S.U.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
As (total)	μg/L	21.1	25.1	17.7 -	19.2	19.5 -	25.8	21.4	23.2	21.7	1.7	3.3	2.9	22.2	34.7	26.3	30.4	- 18.4	0.1	<0.1	<0.1
As (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	μg/L	<25	<25	<25	<25	<25	26	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Fe (soluble)	uø/L	_	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10 (5514510)	μgı	5.3	1.1	0.3	0.2	0.3	0.8	0.3	0.2	0.2	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.3	0.5	0.2
Mn (total)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (total)	μg/L	49.4 -	<0.1	<0.1	<0.1	48.7	3.5 -	2.2	2.4	49.1 -	3.9 -	9.7 -	7.4 -	52.5	3.2	2.2	2.7	46.9 -	<0.1	<0.1	<0.1
V (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Sampling Da	nte		10/2	27/09			11/0	4/09			12/1	0/09			12/1	6/09			02/0	2/10	
Sampling Loca	ation	IN	TA	TD	TT	IN	TA	TD	TT	IN	TA	TD	TT	IN	TA	TD	TT	IN	TA	TD	TT
Parameter	Unit	IIN	IA	ID	11	IIN	IA	ID	11	IIN	IA	ID	11	IIN	IA	ID	11	IIN	IA	ID	11
Throughput	gal		540	,850			339	,549			27,	963			319,	,637			316,	110	
Alkalinity	mg/I	293	327	331	327	305	370	366	370	346	169	45.6	123	329	402	387	400	332	386	366	381
(as CaCO <sub>3</sub> )	ing/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	72.8	19.9	14.1	17.0	75.3	< 0.1	< 0.1	< 0.1	80.6	0.5	0.1	0.3	81.1	0.2	0.1	0.4	76.4	0.2	0.2	0.2
	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	5.7	7.8	7.2	7.1	6.2	1.2	0.8	1.0	6.8	2.1	2.7	2.6	7.5	4.5	1.0	3.0	5.6	1.5	1.0	1.2
	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as P)	μg/L	267	420	343	380	257	<10	<10	<10	249	12.5	16.8	13.4	277	22.3	<10	12.8	271	<10	<10	<10
	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO <sub>2</sub> )	mg/L	62.5	62.9	62.6	62.0	58.7	58.8	58.3	58.0	58.6	59.3	59.3	60.2	58.2	62.3	62.4	62.0	64.1	65.2	65.2	64.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	0.8	0.8	0.9	0.6	0.2	0.5	0.2	0.4	0.2	0.2	0.2	0.5	0.3	0.5	0.4	0.6	0.2	0.5	0.2	0.4
		- 490	-	-	-	-	-	- 420	-	- 550	-	-	-	- 529	-	-	-	- 502	-	-	- 470
TDS	mg/L	480	402	444	400	404	450	420	400	550	554	008	580	556	500	400	504	502	470	402	470
TOC	mg/L	1.6	<1.0	<1.0	<1.0	1.6	<1.0	<1.0	<1.0	1.8	<1.0	<1.0	<1.0	1.8	<1	<1	<1	19	<1	<1	<1
nH	SU	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	~	18.4	26.9	22.0	24.6	16.4	0.3	0.2	0.2	18.1	2.3	4.0	3.3	20.5	2.2	1.6	1.9	17.7	0.7	0.6	0.6
As (total)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (total)	uø/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
10 (10111)	46/2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (total)	μg/L	0.4	0.5	0.6	0.5	0.3	0.5	0.5	0.4	0.6	0.9	0.4	0.3	0.4	0.3	0.4	0.3	0.3	0.2	0.3	0.2
	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V (total)	μg/L	49.5	1.6	1.5	1.5	50.7	0.9	0.9	0.7	51.7	6.5	12.9	9.8	57.8	1.9	2.8	2.0	53.7	1.3	1.4	1.5
V (soluble)	μg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10																				

Sampling Da	ıte		02/08/10	)	
Sampling Loca	tion	DI	<b>T</b> 4	TD	TT
Parameter	Unit	IIN	IA	ID	11
Throughput	gal		246,140	)	
Alkalinity (as CaCO <sub>3</sub> )	mg/L	338	395	357	386
Sulfate	mg/L	77.6	0.2	0.3	0.2
Nitrate (as N)	mg/L	5.9	0.8	1.1	0.9
Total P (as P)	μg/L	260	127	<10	<10
Silica (as SiO <sub>2</sub> )	mg/L	60.0	60.9	60.9	60.0
Turbidity	NTU	0.2	0.1	0.6	0.2
TDS	mg/L	526	474	476	484
TOC	mg/L	1.9	<1	<1	<1
pH	S.U.	NA	NA	NA	NA
Temperature	°C	NA	NA	NA	NA
DO	mg/L	NA	NA	NA	NA
ORP	mV	NA	NA	NA	NA
As (total)	µg/L	18.3	0.8	1.1 -	1.0
As (soluble)	µg/L	-	-	-	-
As (particulate)	μg/L	-	-	-	-
As (III)	μg/L	-	-	-	-
As (V)	μg/L	-	-	-	-
Fe (total)	μg/L	<25	<25	<25	<25
Fe (soluble)	μg/L	-	-	-	-
Mn (total)	μg/L	0.2	0.5	0.5	0.2
Mn (soluble)	μg/L	-	-	-	-
V (total)	μg/L	53.6	1.7	2.5	2.0
V (soluble)	μg/L	-	-	-	-