EPA/600/R-10/166
December 2010

Arsenic Removal from Drinking Water by Coagulation/Filtration U.S. EPA Demonstration Project at the City of Okanogan, WA Final Performance Evaluation Report

by

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

for

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Sally Gutierrez, Director
National Risk Management Research Laboratory

ABSTRACT

This report documents the activities performed during and the results obtained from the arsenic removal treatment technology demonstration project at the City of Okanogan, WA facility. The objectives of the project were to evaluate: (1) the effectiveness of Filtronics' FH-13 Electromedia®I Arsenic Removal System in removing arsenic to meet the maximum contaminant level (MCL) of 10 µg/L, (2) the reliability of the treatment system for use at small water facilities, (3) the required system operation and maintenance (O&M) and operator skill levels, and (4) the capital and O&M cost of the technology. The project also characterized water in the distribution system and residuals generated by the treatment process. The types of data collected included system operation, water quality, process residuals, and capital and O&M cost.

After review and approval of the engineering plan by the State of Washington, the FH-13 Electromedia®I treatment system was installed and became operational on August 14, 2008. The system consisted of two 4-ft × 8-ft carbon steel contact tanks, and one 7-ft × 9$^1/_3$-ft horizontal carbon steel filter tank loaded with 174 ft^3 of Electromedia®I filter media, 33 ft^3 of support media, and 43 ft^3 of concrete. The filter tank was fitted with semi-elliptical ends and upper and lower manifold assemblies, providing a filtration area of 75 ft^2. At a design flowrate of 750 gal/min (gpm), the hydraulic loading rate to the filter was 10 gpm/ft^2. The system used two chemical addition assemblies, one each for prechlorination and supplemental iron addition. The chlorine addition system was installed to oxidize As(III) and Fe(II) and form As(V)-laden iron solids prior to the filtration tank. The iron addition system was installed to increase the removal of soluble As(V) through adsorption and/or coprecipitation with iron solids. The target chlorine and iron dosages were 0.7 mg/L (as Cl_2) and 0.9 mg/L (as Fe), respectively.

A wastewater recycle system was incorporated into the treatment system to reclaim backwash wastewater and eliminate the need to discharge wastewater into the sanitary sewer. The recycle system consisted of a reclaim pump and a 22,500-gal concrete reclaim tank equipped with high/low float switches.

From August 14, 2008, through August 14, 2009, the treatment system operated for an average of 13.6 hr/day, producing 139,435,000 gal of water. This production rate corresponded to an average flowrate of 527 gpm, comparable to the 550-gpm extraction rate allowed for Well No. 4 by water rights. At 527 gpm, it yielded a contact time of 2.8 min in the two contact tanks and a filtration rate of 7.0 gpm/ft^2.

Source water from Well No. 4 had an average pH value of 7.6 and contained 14.7 to 22.7 µg/L of total arsenic. The predominant arsenic species was As(III) with an average concentration of 13.4 µg/L. Total iron concentrations ranged from <25 to 230 µg/L and averaged 78 µg/L, existing mostly in the soluble form (averaged at 49 µg/L). This amount of soluble iron corresponded to a soluble iron to soluble arsenic ratio of 2.7:1, indicating insufficient iron for arsenic removal. Ferric chloride was added to chlorinated water to achieve a target iron concentration of 0.9 mg/L (50 times the soluble arsenic concentration in source water) for more effective arsenic removal, presumably through adsorption and/or coprecipitation with iron solids.

Total arsenic concentrations after the pressure filter ranged from 2.9 to 14.9 µg/L and averaged 6.2 µg/L. Filter performance was maintained with backwash, which was triggered either by a preset run time of 8 hr or when the water level in the storage reservoir reached the "Stop" setpoint. Backwashing every 8 hr appeared to be adequate to maintain proper filter performance for arsenic and iron removal. The filter tank was backwashed 2.3 times/day, producing approximately 6,150 gal of wastewater/time. A total of 4,667,850 gal of wastewater was produced during the study, equivalent to 3.3% of the total amount of water treated. On average, the backwash wastewater contained 108 mg/L of total suspended solids (TSS), 462 µg/L of arsenic, 38.1 mg/L of iron, and 1,157 µg/L of manganese, with the majority existing as

particulate. During each backwash, 2.5 kg of solids was produced, which included 10.6 g of arsenic, 882 g of iron, and 26.3 g of manganese.

Arsenic levels in distribution system water as sampled at DS3, a non-Lead and Copper Rule (LCR) sampling location, were very close to those in treatment system effluent (i.e., 6.8 versus 6.2 µg/L, on average). Because the other two sampling locations (DS1 and DS2) selected for distribution water sampling were impacted by all four wells supplying Okanogan's distribution system, the effect of the treatment system on the distribution water quality could not be evaluated directly. The average lead concentration within the distribution system was 1.5 µg/L with no samples exceeding the action level of 15 µg/L. The average copper concentration was 61.6 µg/L with no samples exceeding the 1,300 µg/L action level.

The capital investment for the system was $424,817, including $296,430 for equipment, $48,332 for site engineering, and $80,055 for installation, shakedown, and startup. Using the system's rated capacity of 550 gpm (or 792,000 gal/day [gpd]), the capital cost was $772/gpm (or $0.54/gpd). This unit cost does not include the cost of the building to house the treatment system and recycle system utilized to reclaim the backwash water. O&M cost, estimated at $0.18/1,000 gal, included cost for chemicals usage, electricity consumption, and labor.

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ABBREVIATIONS AND ACRONYMS

Δp	differential pressure
AAL	American Analytical Laboratories
AM	adsorptive media
As	arsenic
ATS	Aquatic Treatment Systems
bgs	below ground surface
C/F	coagulation/filtration
Ca	calcium
CDB	community development block
Cl	chlorine
CRF	capital recovery factor
Cu	copper
D	diameter
DBPR	Disinfection Byproducts Rule
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
$FeCl_3$	ferric chloride
G&O	Gray and Osborne
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
H	height
HAAs	heloacetic acids
HIX	hybrid ion exchanger
hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IX	ion exchange
L	length
LCR	(EPA) Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MEI	Magnesium Elektron, Inc.
Mg	magnesium

ABBREVIATIONS AND ACRONYMS (Continued)

μm	micrometer
Mn	manganese
mV	millivolts
Na	sodium
NA	not analyzed/not available
NaOCl	sodium hypochlorite
ND	not detected
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	phosphorus
P&ID	piping and instrumentation diagram
Pb	lead
pCi/L	picocuries per liter
PLC	programmable logic controller
PO_4	phosphate
POU	point-of-use
psi	pounds per square inch
psig	pounds per square inch gauge
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RFQ	request for quotation
RPD	relative percent difference
RO	reverse osmosis
SDWA	Safe Drinking Water Act
SiO_2	silica
SMCL	secondary maximum contaminant level
SO_4	sulfate
SOCs	synthetic organic compounds
STS	Severn Trent Services
TDH	total dynamic head
TDS	total dissolved solids
THMs	trihalomethanes
TOC	total organic carbon
TSS	total suspended solids

ABBREVIATIONS AND ACRONYMS (Continued)

V	vanadium
VOCs	volatile organic compounds
WA DOH	Washington Department of Health
WQE	Water Quality Engineering

ACKNOWLEDGMENTS

The authors wish to extend their sincere appreciation to Mr. Ray Doll and Mr. Loren Howell of the City of Okanogan in Washington. Mr. Doll and Mr. Howell monitored the treatment system and collected samples from the treatment and distribution systems on a regular schedule throughout the study. This performance evaluation would not have been possible without their support and dedication.

Ms. Julia Valigore, who is currently pursuing a doctoral degree at the University of Canterbury in New Zealand, served as the Battelle Study Lead during the planning stage of this demonstration project.

1.0 INTRODUCTION

1.1 Background

The Safe Drinking Water Act (SDWA) mandates that the U.S. Environmental Protection Agency (EPA) identify and regulate drinking-water contaminants that may have adverse human health effects and that are known or anticipated to occur in public water supply systems. In 1975 under the SDWA, EPA established a maximum contaminant level (MCL) for arsenic (As) at 0.05 mg/L. Amended in 1996, the SDWA required that EPA develop an arsenic research strategy and publish a proposal to revise the arsenic MCL by January 2000. On January 18, 2001, EPA finalized the arsenic MCL at 0.01 mg/L (EPA, 2001). To clarify the implementation of the original rule, EPA revised the rule text on March 25, 2003, to express the MCL as 0.010 mg/L (10 μg/L) (EPA, 2003). The final rule 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 for reducing compliance costs. As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, onsite demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems. Shortly thereafter, an announcement published in the *Federal Register* requested water utilities interested in participating in Round 1 of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 of the 115 candidate sites to host the demonstration studies.

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

In 2003, EPA initiated Round 2 arsenic technology demonstration projects that were partially funded with Congressional add-on funding to the EPA budget. In June 2003, EPA selected 32 potential demonstration sites, and the community water system in the City of Okanogan, WA was one of those selected.

In September 2003, EPA again solicited proposals from engineering firms and vendors for arsenic-removal technologies. EPA received 148 technical proposals for the 32 host sites, with each site receiving from two to eight proposals. In April 2004, EPA convened another technical panel to review the proposals and provide recommendations to EPA; the number of proposals per site ranged from none (for two sites) to a maximum of four. Final selection of the treatment technology at sites receiving at least one proposal was made, again, through a joint effort by EPA, the state regulators, and the host site. Since then, four sites have withdrawn from the demonstration program, reducing the number of sites to 28. Filtronics' FH-13 system using Electromedia®I was selected for demonstration at the Okanogan facility.

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

1.2 Treatment Technologies for Arsenic Removal

The technologies selected for the Rounds 1 and 2 demonstration host sites include 25 adsorptive media (AM) systems (the Oregon Institute of Technology [OIT] site has three AM systems), 13 coagulation/filtration (C/F) systems, two ion exchange (IX) systems, and 17 point-of-use (POU) units (including nine under-the-sink reverse osmosis [RO] units at the Sunset Ranch Development site and eight AM units at the OIT site), and one system modification. Table 1-1 summarizes the locations, technologies, vendors, system flowrates, and key source water quality parameters (including As, iron [Fe], and pH) at the 40 demonstration sites. An overview of the technology selection and system design for the 12 Round 1 demonstration sites and the associated capital 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 arsenic demonstration program is to conduct full-scale arsenic treatment technology demonstration studies on the removal of arsenic from drinking-water supplies. The specific objectives are to:

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

This report summarizes the performance of the Filtronics system at the City of Okanogan in Washington from August 14, 2008 through August 14, 2009. The types of data collected include system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and O&M cost.

Table 1-1. Summary of Arsenic Removal Demonstration Sites

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

Table 1-1. Summary of Arsenic Removal Demonstration Sites (Continued)

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

AM = adsorptive media process; C/F = coagulation/filtration; HIX = hybrid ion exchanger; IX = ion exchange process; RO = reverse osmosis
ATS = Aquatic Treatment Systems; MEI = Magnesium Elektron, Inc.; STS = Severn Trent Services
(a) Arsenic existing mostly as As(III).
(b) Design flowrate reduced by 50% due to system reconfiguration from parallel to series operation.
(c) Iron existing mostly as Fe(II).
(d) Withdrew from program in 2007. Selected originally to replace Village of Lyman, NE site, which withdrew from program in June 2006.
(e) Facilities upgraded systems in Springfield, OH from 150 to 250 gpm, Sandusky, MI from 210 to 340 gpm, and Arnaudville, LA from 385 to 770 gpm.
(f) Including nine residential units.
(g) Including eight under-the-sink units.

2.0 SUMMARY AND CONCLUSIONS

Based on the information collected from operation of Filtronics' FH-13 treatment system with Electromedia®I media at the City of Okanogan, WA from August 14, 2008 to August 14, 2009, the following summary and conclusions are provided relating to the overall objectives of the treatment technology demonstration study.

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

- With proper pre-chlorination and supplemental iron addition, Filtronics' FH-13 Electromedia®I system was able to remove arsenic to <10 µg/L.
- Chlorination was effective in oxidizing As(III) to As(V), reducing As(III) concentrations from 13.4 µg/L (on average) in source water to 2.2 µg/L (on average) after the contact tanks.
- At an average filtration rate of 7.0 gpm/ft^2 and filter run time of 8 hr, no particulate arsenic leakage was observed.
- Backwashing at a rate of 17.9 gal/min (gpm)/ft^2 was effective at restoring the pressure filter for subsequent service runs.

Required system O&M and operator skill levels:

- Minimal time was required to operate and maintain the system. The daily demand on the operator to perform routine O&M was 45 min.
- The treatment system was reliable and easy to operate.

Characteristics of residuals produced by the technology:

- Backwash solids were the only residual produced by the treatment system. Approximately 2.5 kg of backwash solids was generated during each backwash event, including 0.4% by weight of arsenic, 35.3% by weight of iron, and 1.1% by weight of manganese.

Capital and O&M cost of the technology:

- The capital investment for the system was $424,817, consisting of $296,430 for equipment, $48,332 for site engineering, and $80,055 for installation, shakedown, and startup.
- The unit capital cost was $772/gpm (or $0.54 gal/day [gpd]) based on a flowrate of 550 gpm. This calculation does not reflect the cost for the building and recycle system, which were funded by the City of Okanogan.
- The O&M cost was 0.18/1,000 gal including incremental cost for chemicals, electricity, and labor.

3.0 MATERIALS AND METHODS

3.1 General Project Approach

Table 3-1 summarizes the pre-demonstration and demonstration activities and completion dates. Following the pre-demonstration activities, the performance evaluation study of the Filtronics treatment system began on August 14, 2008, and ended on August 14, 2009. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall system performance was evaluated based on its ability to consistently remove arsenic to below the target MCL of 10 µg/L through the collection of water samples across the treatment train. The reliability of the system was evaluated by tracking unscheduled system downtime and frequency and extent of repair and replacement. The plant operator recorded unscheduled downtime and repair information on a Repair and Maintenance Log Sheet.

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

Activity	Date
Introductory meeting held	October 28, 2004
Project planning meeting held	May 13, 2005
Draft letter of understanding issued	May 23, 2005
Final letter of understanding issued	August 5, 2005
Request for quotation issued to[(a)]: • Equipment vendor (Filtronics) • System installer (including site engineering) – City of Okanogan/Gray and Osborne (G&O) • System installer (including site engineering) – Triad Mechanical/Water Quality Engineering (WQE)	 July 5, 2005 August 5, 2005 April 12, 2006
Letter report issued	September 30, 2005
Quotation received from: • Filtronics • City/G&O • Triad Mechanical/WQE	 October 7, 2005 January 18, 2006 May 24, 2006
Purchase order established: • Filtronics • Triad Mechanical/WQE	 October 17, 2005 December 11, 2006
Engineering package submitted to WA DOH	May 10, 2007
System permit granted by WA DOH	June 5, 2007
Study plan issued	June 22, 2007
Building construction began	March 3, 2008
Building construction completed	July 11, 2008
FH-13 Electromedia®I system delivered	July 14, 2008
System installation completed	July 24, 2008
System shakedown completed	August 14, 2008
Performance evaluation began	August 14, 2008
Performance evaluation completed	August 14, 2009

(a) Parties performing system installation and site engineering were sought after equipment vendor had declined to include site engineering and system installation in its quote.

WA DOH = Washington Department of Health

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

Evaluation Objective	Data Collection
Performance	Ability to consistently meet 10 μg/L of arsenic 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 operator skill requirements	Pre- and post-treatment requirements Level of automation for system operation and data collection Staffing requirements, including number of operators and laborers Task analysis of preventative 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 management	Quantity and characteristics of aqueous and solid residuals generated by system operation
System cost	Capital cost for equipment, engineering, and installation O&M cost for chemical use, electricity consumption, and labor

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

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

The cost of the system was evaluated based on the capital cost per gpm (or gpd) of design capacity and the O&M cost per 1,000 gal of water treated. This task required tracking the capital cost for equipment, engineering, and installation, as well as the O&M cost for media replacement and disposal, chemical supply, electricity usage, and labor.

3.2 System O&M and Cost Data Collection

The plant operator performed daily, weekly, and monthly system O&M and data collection following the instructions provided by the vendor and Battelle. On a daily basis, the plant operators recorded system operational data such as pressure, flowrate, totalizer, and hour meter readings (see Appendix A) on a Daily System Operation Log Sheet; checked sodium hypochlorite (NaOCl) and ferric chloride ($FeCl_3$) levels; and conducted visual inspections to ensure normal system operations. If any problem occurred, the plant operators contacted the Battelle Study Lead, who determined if the vendor should be contacted for troubleshooting. The plant operators recorded all relevant information, including the problems encountered, course of action taken, materials and supplies used, and associated cost and labor incurred, on a Repair and Maintenance Log Sheet. On a weekly basis, the plant operators measured several water quality parameters onsite, including temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and residual chlorine, and recorded the data on a Weekly Onsite Water Quality Parameters Log Sheet. Backwash data also were recorded on a Backwash Log Sheet.

The capital cost for the arsenic removal system consisted of the expenditure for equipment, site engineering, and system installation. The O&M cost consisted of the expenditure for chemical use, electricity consumption, and labor. Consumption of NaOCl and $FeCl_3$ was tracked on the Daily System Operation Log Sheet. Electricity consumption was determined from utility bills. Labor for various activities such as routine system O&M, troubleshooting and repairs, and demonstration-related work, was tracked using an Operator Labor Hour Log Sheet. Routine system O&M included activities such as completing field logs, replenishing chemical solutions, ordering supplies, performing system inspections, and others as recommended by the vendor. The labor for demonstration-related work, including activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead and the vendor and system installer, was recorded, but not used for the cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected at the wellhead, across the treatment plant, during filter backwash, and from the distribution system. Table 3-3 shows sampling schedules and analytes measured during each sampling event. Figure 3-1 presents a flow diagram of the treatment system along with the analytes and schedules for each sampling location.

Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2004). The procedure for arsenic speciation is described in Appendix A of the QAPP.

3.3.1 Source Water. During the initial site visit on October 28, 2004, one set of source water samples was collected and speciated using an arsenic speciation kit (Section 3.4.1). The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Table 3-3 lists analytes for the source water samples.

3.3.2 Treatment Plant Water. During system inspections and operator training on August 14, 2008, a Battelle staff member and the operators took the first set of treatment plant water samples at the wellhead (IN), after the contact tanks (AC), and after filter tank (TT). The samples were speciated onsite and analyzed for the analytes listed in Table 3-3 under "monthly" treatment plant water (or speciation sampling). Under Battelle's direction, the operators took the second set of samples from the same locations for the analytes listed in Table 3-3 under "weekly" treatment plant water (or regular sampling). Beginning on October 7, 2008, the plant operators used the protocols established to collect treatment plant water samples weekly, on a four-week cycle, for onsite and offsite analyses. For the first week of each four-week cycle, speciation sampling was performed. For the next three weeks, regular sampling was performed. Sampling was skipped during the 2008 Thanksgiving and Christmas holidays and during the week of February 9, 2009.

3.3.3 Backwash Wastewater. The operators collected monthly backwash wastewater samples from October 2008 through July 2009. Backwash wastewater sampling was performed by directing a portion of backwash wastewater at approximately 1 gpm via a plastic tubing connected to the tap on the backwash wastewater discharge line into a clean, 32-gal container over the duration of filter backwash. After the content in the container was thoroughly mixed, composite samples were collected and/or filtered onsite with 0.45-µm disc filters. Analytes for the backwash wastewater samples are listed in Table 3-3.

3.3.4 Distribution System Water. Water samples were collected from the distribution system to determine the impact of the arsenic treatment system on its water chemistry, specifically, the arsenic, lead, and copper levels. Prior to system startup, four monthly baseline distribution water samples were collected from three locations within the distribution system from September 2005 to January 2006.

Table 3-3. Sampling Locations, Schedules, and Analyses

Sample Type	Sample Locations[a]	No. of Samples	Frequency	Analytes	Collection Date(s)
Source Water	IN	1	Once (during initial site visit)	Onsite: pH, temperature, DO, and ORP Offsite: As(III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, Cl, F, NH_3, NO_2, NO_3, SO_4, SiO_2, PO_4, TOC, TDS, turbidity, and alkalinity	10/28/04
Treatment Plant Water	IN, AC, TT	3	Weekly (Regular Sampling)	Onsite[b]: pH, temperature, DO, ORP, and Cl_2 (free and total) Offsite: As (total), Fe (total), Mn (total), SiO_2, P (total), turbidity, and alkalinity	See Appendix B
	IN, AC, TT	3	Monthly (Speciation Sampling)	Same as weekly analytes shown above plus following: Offsite: As (soluble), As(III), As(V), Fe (soluble), Mn (soluble), Ca, Mg, F, NO_3, and SO_4	See Appendix B
Backwash Wastewater	BW	1	Monthly	As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, TDS, and TSS	See Table 4-10
Distribution System Water	Two LCR and one non-LCR residences	3	Monthly	Total As, Fe, Mn, Cu, and Pb, pH, and alkalinity	See Table 4-12
Backwash Solids	BW	1	Once	Total As, Ba, Ca, Fe, Mg, Mn, P, and Si	04/14/09

(a) Abbreviations corresponding to sample locations shown in Figure 3-1: IN = at wellhead; AC = after contact tanks; TT = after filter tank; and BW = at backwash discharge line.
(b) Onsite chlorine measurements not performed at IN.
DO = dissolved oxygen; LCR = Lead and Copper Rule; ORP = oxidation-reduction potential; TDS = total dissolved solids; TOC = total organic carbon.

Following system startup, distribution system water sampling continued on a monthly basis at the same locations. The three locations selected for distribution water sampling included two Lead and Copper Rule (LCR) locations (i.e., 150 Hennepin Street and 650 4th Avenue South) impacted by all wells in the distribution system, and one residence (i.e., 341 River Avenue) impacted predominantly by Well No. 4. Water from Well No. 4 was treated to remove arsenic under this demonstration project (Section 4.1.1). Homeowners collected samples following an instruction sheet developed by Battelle in accordance with

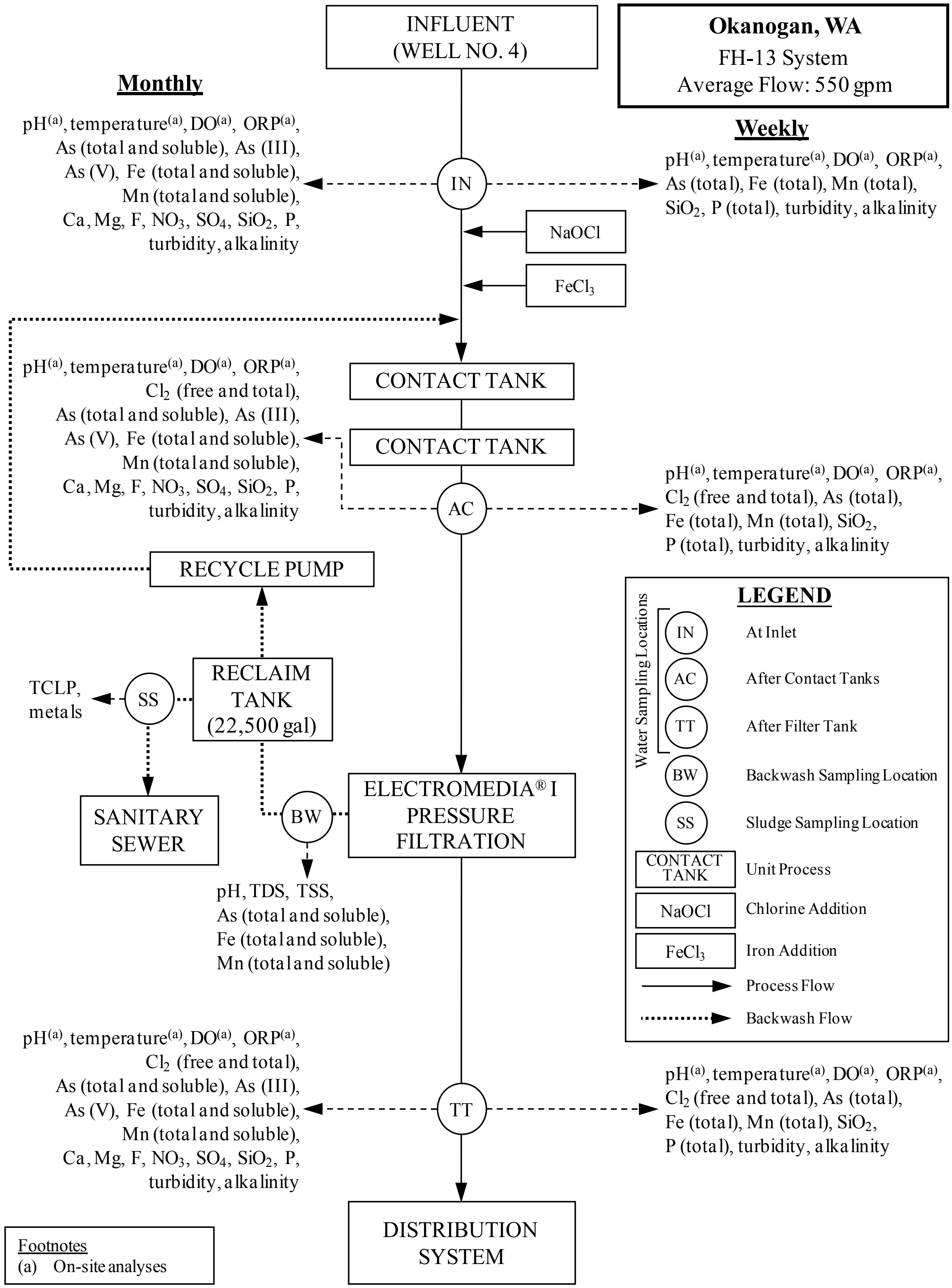

Figure 3-1. Process Flow Diagram and Sampling Schedules and Locations

the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). First-draw samples were collected from cold-water faucets that had not been used for at least 6 hours to ensure that stagnant water was sampled. The sampler recorded the date and time of last water use before sampling, as well as the date and time of sample collection for calculation of the stagnation time. The samples were analyzed for the analytes listed in Table 3-3. Arsenic speciation was not performed on the distribution water samples.

3.3.5 Residual Solids. Residual solids produced by the treatment process consisted of only backwash wastewater solids. After solids in the backwash wastewater containers (Section 3.3.3) had settled and supernatant carefully decanted, residual solids samples were collected on one occasion. The solids/water mixture was air-dried for metals analyses.

3.4 Sampling Logistics

All sampling logistics, including arsenic speciation kits preparation, sample cooler preparation, and sampling shipping and handling, are discussed below.

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

3.4.2 Preparation of Sample Coolers. For each sampling event, a sample cooler was prepared with the appropriate number and type of sample bottles, disc filters, and/or speciation kits. All sample bottles were new and contained appropriate preservatives. Each sample bottle was affixed with a pre-printed, color-coded, waterproof label consisting of the sample identification (ID), date and time of sample collection, collector's name, site location, sample destination, analysis required, and preservative. The sample ID consisted of a two-letter code for the demonstration site, the sampling date, a two-letter code for a specific sampling location, and a one-letter code designating the arsenic speciation bottle (if necessary). The sampling locations at the treatment plant were color-coded for easy identification. The labeled bottles for each sampling location were placed separated in a zip-lock bag (each corresponding to a specific sample location), and packed in the cooler. When needed, the sample cooler also included bottles for the distribution system sampling.

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

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

Samples for metal analyses were stored and analyzed at Battelle's Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) Laboratory. Samples for other water quality analyses were packed in separate coolers and picked up by couriers from American Analytical Laboratories (AAL) in Columbus, OH; TCCI Laboratories in New Lexington, OH; and/or Belmont Labs in Englewood, OH, all 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 disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

3.5 Analytical Procedures

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

Field measurements of pH, temperature, DO, and ORP were conducted by the plant operators using a handheld field 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 operators collected a water sample in a clean, plastic beaker and placed the probe in the beaker until a stable value was obtained. The plant operators also performed free and total chlorine measurements using Hach chlorine test kits following the user's manual.

4.0 RESULTS AND DISCUSSION

4.1 Site Description

4.1.1 Pre-existing Facility. Serving a population of 2,500 people, the water system at the City of Okanogan is supplied by four wells, i.e., Wells No. 2, 3, 4, and 5, each having a capacity of 205, 650, 650, and 550 gpm, respectively. These wells help meet the city's daily demand of approximately 1,000,000 gal during the summer and 450,000 gal during the winter. Well No. 4 was designated for this demonstration study.

Well No. 4 has a 12-in-diameter, 283-ft casing. A 75-horsepower (hp), 6-in submersible pump is set at 215 ft below ground surface (bgs) and can yield 650 gpm of water at 390 ft of total dynamic head (TDH). However, water rights limit the extraction rate to 550 gpm. The well has one 10-in diameter, 60-slot screen and one 10-in diameter, 30-slot screen, extending from 248 to 268 ft bgs and from 268 to 278 ft bgs, respectively. The depth of the static water level is at 19 ft bgs. Figure 4-1 shows Well No. 4 wellhead located in a fenced area. A manhole located outside of the fenced area (Figure 4-2) provides access to an underground vault where a sample tap, a water meter, and a clay valve are located. The clay valve was inoperable, but a gate valve was used to restrict the flow to the 550-gpm extraction limit. The well pressure increases from 115 to 160 lb/in^2 (psi) as the well flowrate decreases from 650 to 550 gpm. Approximately 120 psi is required for distribution.

Figure 4-1. Well No. 4 in a Fenced Area

Figure 4-2. Manhole for Well No. 4

Prior to installation of the arsenic removal system, well water without chlorination was pumped directly into the distribution system and stored in three aboveground reservoirs (East [550,000 gal], North [550,000 gal], and Highland [200,000 gal]) and two underground reservoirs (New West [200,000 gal] and Existing West [200,000 gal]) with a combined capacity of 1,700,000 gal.

4.1.2 Distribution System. The distribution system consists of a 17-mile, mostly looped distribution line supplied by Wells No. 2, 3, 4, and 5. The distribution system material is a combination of 4- to 18-in cast iron (40%), asbestos concrete (35%), polyvinyl chloride (PVC) (15%), and ductile iron (10%). Service lines to individual homes are galvanized steel (75%), copper (25%), and polyethylene (<1%) piping.

The City of Okanogan samples water periodically from the distribution system for a number of parameters, including monthly at two residences for bacterial analysis and once every three years at 10 residences for lead and copper under EPA's LCR. Well No. 1 also is sampled quarterly for arsenic; yearly for partial chemistry and volatile organic compounds (VOCs); once every three years for synthetic organic compounds (SOCs); and once every nine years for metals and radionuclides.

After the arsenic removal system began operation, the City sampled once at three residences for trihalomethanes (THMs) and haloacetic acids (HAAs) under EPA's Disinfection Byproducts Rule (DBPR), as requested by WA DOH. Because of low THM and HAA results, the City was not required to sample THMs and HAAs again.

4.1.3 Source Water Quality. Battelle collected source water samples from Well No. 4 on October 28, 2004 during the initial site visit. Table 4-1 presents the Battelle results and those provided by the facility to EPA for site selection and by the selected technology vendor (Filtronics). Historic raw water data from Well No. 4, obtained from the facility, also are summarized in Table 4-1 and tabulated in Table 4-2. In general, Battelle's data were comparable to those provided by other parties with exception to three outliers found in the historic raw water data provided by the facility (Table 4-2).

Table 4-1. Well No. 4 Water Quality Data

Parameter	Unit	Facility Data	Battelle Data	Filtronics Data	Historical Facility Data
Sampling Date		Not Specified	10/28/04	07/12/05–07/15/05	1985–2004
pH	S.U.	7.6	8.0	8.0–8.1	NA
Temperature	°C	NA	16.0	15.0	NA
DO	mg/L	NA	1.8	NA	NA
ORP	mV	NA	-47	NA	NA
Alkalinity (as $CaCO_3$)	mg/L	NA	185	176	NA
Hardness (as $CaCO_3$)	mg/L	NA	286	NA	179–243
Turbidity	NTU	NA	0.2	NA	0.1–0.5[a]
TDS	mg/L	NA	346	421	NA
TOC	mg/L	NA	<0.7	NA	NA
Nitrate (as N)	mg/L	NA	<0.04	NA	ND–0.15
Nitrite (as N)	mg/L	NA	<0.01	NA	NA
Ammonia (as N)	mg/L	NA	0.05	NA	NA
Chloride	mg/L	ND	2.0	NA	NA
Fluoride	mg/L	NA	0.4	NA	0.5–0.7
Sulfate	mg/L	111	110	NA	108–116
Silica (as SiO_2)	mg/L	NA	24.1	NA	NA
Orthophosphate (as PO_4)	mg/L	NA	<0.06	NA	NA
As (total)	μg/L	17	18.4	18–19	17–20[b]
As (soluble)	μg/L	NA	18.6	NA	NA
As (particulate)	μg/L	NA	<0.1	NA	NA
As(III)	μg/L	NA	3.0	NA	NA
As(V)	μg/L	NA	15.6	NA	NA
Fe (total)	μg/L	70	69	55–78	50–151[c]
Fe (soluble)	μg/L	NA	45	NA	NA
Mn (total)	μg/L	60	70.2	NA	49–92
Mn (soluble)	μg/L	NA	70.3	NA	NA
U (total)	μg/L	NA	0.4	NA	NA
U (soluble)	μg/L	NA	0.5	NA	NA
V (total)	μg/L	NA	0.3	NA	NA
V (soluble)	μg/L	NA	0.3	NA	NA
Na (total)	mg/L	21	30.1	NA	19–25
Ca (total)	mg/L	NA	54.7	NA	NA
Mg (total)	mg/L	NA	36.3	NA	NA

(a) One outlier of 2.7 NTU not included in this range.
(b) One outlier of <10 μg/L not included in this range
(c) One outlier of 1,140 μg/L not included in this range.
DO = dissolved oxygen; NA = not available; NTU = nephelometric turbidity unit; ORP = oxidation-reduction potential; TDS = total dissolved solids; TOC = total organic carbon

Table 4-2. Well No. 4 Historic Water Quality Data

Parameter	Unit	Historical Facility Data											
	Year	1985	1988	1992	1994	1995	1997	1998	1999	2001	2002	2003	2004
Conductivity	μS/cm	530	530	530	-	-	533	-	-	539	-	-	685
Hardness	mg/L	240	240	222	-	223	179	-	-	218	-	-	243
Turbidity	NTU	0.1	0.4	2.7[(a)]	-	-	0.2	-	-	0.5	-	-	0.1
Nitrate	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.15	ND
Fluoride	mg/L	0.5	0.6	0.6	-	0.7	0.6	-	-	0.7	-	-	0.6
Sulfate	mg/L	-	-	-	-	113	111	-	-	108	-	-	116
As (total)	μg/L	<10[(a)]	18	17	-	20	20	-	-	18	20	-	20
Fe (total)	μg/L	100	100	1,140[(a)]	-	50	70	-	-	151	-	-	ND
Mn (total)	μg/L	80	88	92	-	60	60	-	-	49	-	-	64
Na (total)	mg/L	19	21	23	-	22	21	-	-	22	-	-	25

(a) Results not consistent with other data.
ND = not detected.

Arsenic. Historically, total arsenic concentrations ranged from 17 to 20 μg/L, with one exception (<10 μg/L) occurring in 1985 (Table 4-2). Out of 18.4 μg/L of total arsenic measured by Battelle on October 28, 2004, 3.0 μg/L existed as soluble As(III) and 15.6 μg/L as soluble As(V). As such, soluble As(V) was the predominant species. (Note that soluble As[III] became the predominant species during the 1-year performance evaluation study [Section 4.5.1.1]). Chlorine provides near-complete oxidation of As(III) to As(V), typically in less than 30 seconds (Ghuyre and Clifford, 2001). Because NaOCl was added to raw water and more than 2 min of contact time was provided prior to filtration, all As(III) should be oxidized prior to filtration where it was removed along with iron solids formed.

Iron. Source water had low levels of iron (50 to 151 μg/L) with one exception (1,140 μg/L) occurring in 1992 (Table 4-2). Typically, soluble iron concentrations should be at least 20 times soluble arsenic concentrations for effective arsenic removal via coagulation using iron salt as a coagulant. Therefore, ferric iron had to be added to raw water to remove arsenic. Based on the arsenic and native iron data obtained by Battelle, at least 0.3 mg/L of iron would need to be added to raw water to reach the generally recommended ratio of 20:1 between soluble iron and soluble arsenic concentrations for satisfactory arsenic removal.

Manganese. Manganese concentrations ranged from 49 to 92 μg/L, existing almost entirely in a soluble form, based on the speciation result obtained by Battelle on October 28, 2004. Manganese concentrations were over manganese's secondary maximum contaminant level (SMCL) of 0.050 mg/L. Removal of manganese might be achieved via chlorination (to form manganese dioxide solids) and filtration, depending on oxidation kinetics.

Other Water Quality Parameters. pH values of raw water ranged from 7.6 to 8.1, which were within the commonly agreed range of 5.5 to 8.5 for iron coagulation. Therefore, no provisions were made for pH adjustment. Concentrations of all other analytes appear to be low enough not to adversely affect arsenic removal with iron solids and the subsequent pressure filtration process.

4.2 Treatment Process Description

The treatment process involved chlorination, iron addition, adsorption/coprecipitation, and Electromedia®I pressure filtration. The filter media is processed from naturally occurring minerals. The filter media and support gravels are approved for use in drinking water applications under NSF

International (NSF) Standard 61. Information related to the physical properties of the media and support gravels is considered proprietary and is not attainable from the vendor.

Figure 4-3 presents a plan view of the FH-13 treatment system, which consisted of two chemical addition systems (for NaOCl and $FeCl_3$), two contact tanks (arranged in series), one horizontal filter tank, backwash wastewater reclaim equipment, sample taps, and associated instrumentation for pressure and flow monitoring. Fully automated, the system featured a graphic display operator interface panel (OIP), a programmable logic controller (PLC), and a US Robotics 56K external modem that allowed for remote programming changes and troubleshooting. A 2-hp compressor was used to actuate pneumatic solenoid valves, enabling backwash or service mode. The system was skid-mounted with schedule 40 steel piping, 150 lb forged steel flanges, and 125 lb cast iron flange fittings. Table 4-3 specifies key design parameters of the treatment system. Figure 4-4 presents photographs of several system components.

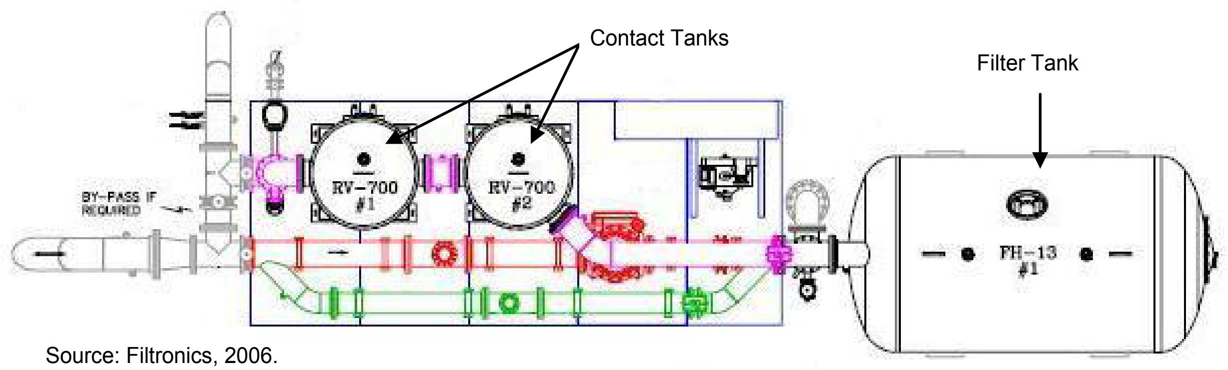

Figure 4-3. Plan View of Filtronics' FH-13 Treatment System

Major process components are discussed as follows:

- **Intake.** Source water was pumped from Well No. 4 at approximately 550 gpm via 10-in schedule 40 steel pipe into the treatment system. The amount of water pumped was tracked with a totalizer installed at the wellhead. The well pump was activated and deactivated based on level sensors in the City's water reservoirs. The well pump was shut down when the water level in the reservoirs reached the "Stop" set level and was turned on when the water level was reduced to the "Start" set level. Figure 4-4 includes a photo of the well pump control box with an hour meter for tracking the system operation hours.
- **Chlorination.** NaOCl at 12.5% was added to raw water to oxidize As(III) to As(V) and Fe(II) to Fe(III). The chlorine addition system consisted of a 1.3-gal/hr (gph) IWAKI WalChem (Model EWC 15 F1-DC) metering pump, a calibration column, a chemical supply manifold, and three 53-gal chemical drums (Figure 4-5). The metering pump was energized only when the well pump was on. To achieve the target chlorine dosage of 0.7 mg/L (as Cl_2), the operator adjusted the speed and stroke length settings of the pump. The NaOCl consumption was tracked by measuring solution levels in the drums using a yardstick. The measurements would be accurate only for the straight-wall portion of the drums.
- **Iron Addition.** A 42% $FeCl_3$ solution was injected to raw water to enhance arsenic removal. Similar to the chlorine addition system, the iron addition system consisted of a 1.3-gph IWAKI WalChem metering pump, a calibration column, a chemical supply manifold, and

Table 4-3. Design Specifications of FH-13 Treatment System

Parameter	Value	Remarks
Pretreatment		
Chlorine Addition (mg/L)	0.7	Field determined
Iron Addition (mg/L)	0.9	Field determined
Contact		
No. of Tanks	2	Arranged in series
Tank Size (ft)	4 D × 8 H	Fitted with semi-elliptical heads
Tank Volume (ft^3/vessel)	100	–
Contact Time (min)	2	Based on design flowrate of 750 gpm and both tanks combined
Filtration		
No. of Tank	1	–
Tank Size (ft)	7 D × $9^1/_3$ L[(a)]	Fitted with semi-elliptical ends
Electromedia-I® (ft^3)	174	25- to 27-in depth
Support Media and Concrete (ft^3)	76	25-in depth
Available Surface Area (ft^2)	75	–
Design Flowrate (gpm)	750	Design capacity
Well Flowrate (gpm)	550	Based on allowed extraction rate
Hydraulic Loading Rate (gpm/ft^2)	10	Based on design flowrate
Backwash		
Backwash Flowrate (gpm)	1,500	Water at 20 °C
Hydraulic Loading Rate (gpm/ft^2)	20	Water at 20 °C
Backwash Duration (min)	4	–
Design Filter-to-Waste Flowrate (gpm)	750	Well flowrate 550 gpm
Filter-to-Waste Duration (min)	1	–
Wastewater Production (gal/cycle)	6,750	–
Frequency (hr/backwash)	8	–

(a) $9^1/_3$ ft is straight length, which does not include inner height of semi-elliptical heads.
D = diameter; L = length; H = height

two 55-gal chemical drums (Figure 4-5). The target iron dosage was 0.9 mg/L (as Fe). The chemical dosage was controlled by the speed and stroke length settings of the pump. The $FeCl_3$ solution consumption was measured based on solution levels using a yardstick. The measurements would be accurate only for the straight-wall portion of the drums.

- **Adsorption/Coprecipitation.** Two 4-ft-diameter × 8-ft-high carbon steel contact tanks fitted with semi-elliptical heads were used to enhance formation of iron flocs prior to pressure filtration. Arranged in series, the skid-mounted tanks provided a total of 2 min of contact time at the design flowrate of 750 gpm. Each tank had two 10-in connections, one 4-in drain, and one 12-in ×16-in access handhole (Figure 4-4).

- **Pressure Filtration.** Removal of arsenic-laden flocs was achieved via downflow filtration of the effluent from the contact tanks. The horizontal filter tank was 7-ft in diameter and 9.3-ft long, fitted with semi-elliptical ends and upper and lower manifold assemblies. The filter tank also had two 10-in connections, one 4-in drain, one 12-in ×16-in access handhole, and one 20-in access manway (Figure 4-4). Constructed of carbon steel, the floor-mounted tank was rated for a working pressure of 150 psi.

  In the filter tank, 25 to 27 in (or 174 ft^3) of Electromedia®I media was loaded on top of three layers of support gravels (i.e., T208, S202, and S200), each having a different nominal

Figure 4-4. Treatment System Components
(from left to right and top to bottom: Contact Tanks; Filtration Vessel; Sample Tap; Backwash and Effluent Flowmeters; PLC Control Panel; Filtration Media; Well Pump Controller and Hour Meter)

Figure 4-5. Chlorine and Iron Addition Systems
(Clockwise from top left: NaOCl Addition System; Iron Addition System; NaOCl and Iron Injection Points)

particle size. The support gravels (33 ft^3 total) were placed, in turn, on top of a concrete layer, which was poured at the bottom of the filter tank with its top surface laid just below the bottom laterals. The total depth of the concrete and support gravel layers was approximately 25 in. Additional layers of light purple gravel and anthracite were then placed on top of Electromedia®I media, leaving approximately 16 to 20 in of freeboard for filter backwashing.

Installation of the multiple filtration and support layers allowed a filtration surface area of approximately 75 ft^2, which would yield a hydraulic loading rate of 10 gpm/ft^2 at the design flowrate of 750 gpm. Actual flowrates and throughput values through the filter tank were monitored using a propeller flow meter/totalizer, as shown in Figure 4-4.

- **Backwash**. Backwashing removes particulates accumulating in the filter bed, thereby reducing pressure buildup. The filter was automatically backwashed by one of two triggers: (1) shutdown of the treatment system when water level in the City's reservoirs reached the "Stop" set level, and (2) preset run time, typically 8 hr (with a 10-psi differential pressure override). There was a time delay before the system went into a backwash cycle. This was incorporated to allow for the flow to stop from the well pump before closing filtered water outlet valves. The chemical feed systems were automatically shut down during backwash. Each backwash cycle involved backwashing the filter at 1,500 gpm (or 20 gpm/ft^2) for 4 min using treated water from the distribution system and rinsing the filter at 550 gpm for 1 min using the effluent from the contact tanks. Backwash flowrate was monitored using a propeller flow meter/totalizer (Filtronics 10-in tube meter), as shown in Figure 4-4.

- **Backwash Reclaim System.** Backwash wastewater was stored in a 22,500-gal reclaim tank provided by the facility (Figure 4-6). The reclaim tank was equipped with high/low float switches interlocked with the PLC, a floating suction strainer (to prevent uptake of solids), a 10-hp reclaim pump, and 2-in recycle loop piping. The lower float switch was for stopping the reclaim pump. Whenever the filter was in the filtration mode and the water level in the reclaim tank was over that of the lower float, the reclaim pump would be activated until the water level hit the lower float. The upper float switch was for the reclaim high level alarm. When the water level was above that of this switch during filtration, the reclaim level light would flash. If the water level in the reclaim tank was above the alarm level when the filter was calling for backwash, the drain valve under the reclaim tank would open until the level in the reclaim tank dropped below the alarm level. The filter would then begin backwash.

  The reclaim pump recycled supernatant from the reclaim tank through the recycle loop piping to the head of the treatment train (downstream of chemical addition points), where the supernatant was blended with raw water at a rate of approximately 7 gpm controlled by a fixed rate orifice flow control valve. For every four backwashes, solids accumulating at the bottom of the reclaim tank were disposed of from the 5% sloped-bottom reclaim tank through a drain to a sewer (Figure 4-6).

Figure 4-6. Reclaim System Components

(From left to right and top to bottom: Reclaim Tank; Reclaim pump; Float Switches in Reclaim Tank; Floating Suction Strainer; Reclaim Tank Drainage)

4.3 Treatment System Installation

At most arsenic removal technology demonstration sites, equipment vendors served as sole subcontractors to Battelle to provide treatment systems and associated engineering and installation services. This turnkey approach was adopted by Battelle to expedite the procurement process and minimize potential disputes among multiple contractors working on the same projects. Filtronics, however, did not provide such services for its treatment system. Gray and Osborne (G&O), the engineering firm responsible for the building design and construction for the City, was initially interested in taking on such responsibilities. However, due to unfamiliarity with Filtronics' system and difficulties of separating the scope of work between the City and Battelle, G&O produced a cost estimate far exceeding the budget. Filtronics was contacted for a list of installers that were familiar with its systems; Triad Mechanical (Triad) was one of the firms identified and contacted. Triad, teaming with Water Quality Engineering (WQE), submitted a cost proposal for engineering and installation services, which was accepted by Battelle. The process of identifying a firm capable of providing engineering and installation services spanned from May 13, 2005, when the initial project planning meeting was held (see Table 3-1) to April 12, 2006, when a request for quotation (RFQ) was issued to Triad, causing repeated delays to the demonstration study.

Upon issuance of a purchase order, Triad/WQE worked with Battelle, Filtronics, and the City/G&O for system permitting, installation, startup, and shakedown. Significant efforts were made by Battelle to coordinate work among all parties involved. To ensure that all project scopes were covered and all project activities were completed in a timely manner, a responsibility matrix was developed by Battelle and is presented in Appendix C.

4.3.1 System Permitting. The system engineering package was prepared by Triad and WQE with input from G&O, and included the following documents and drawings:

- A system design report
- A general arrangement and piping and instrumentation diagram (P&ID)
- Electrical and mechanical drawings and component specifications
- Building construction drawings detailing connections from the system to the inlet piping and the City's water and sanitary sewer systems.

The engineering package was submitted to WA DOH for review and approval on May 10, 2007. After WA DOH's review comments were addressed, the package was resubmitted, along with a permit application, on May 23, 2007. A water supply construction permit was issued by WA DOH on June 5, 2007, and fabrication of the system began thereafter.

4.3.2 Building Construction. A permit for building construction was issued by the City of Okanogan in August 2007. The City opened bids for building construction in August 2007. Due to lack of responses from qualified contractors and due to high bid prices (at least twice the amount of the community development block [CDB] grant the City received) from the two initial bidders, the City rejected the initial bids and reopened the bids in October 2007. Two bids were received, with the lowest bid still $180K higher than the CDB grant. Upon receipt of additional CDB funds, the City applied for and obtained, the City awarded the contract to the lowest bidder, Rains Contracting, Inc. on December 4, 2007. The building construction began on March 3, 2008, and was completed on July 11, 2008. Figure 4-7 shows photographs of the treatment building and reclaim tank under construction. Figure 4-8 presents a photograph of the treatment system building and reclaim tank.

Figure 4-7. New Building and Reclaim Tank Under Construction

Figure 4-8. New Building and Reclaim Tank

4.3.3 System Installation, Startup, and Shakedown. The FH-13 Electromedia®I treatment system was delivered to the site on July 14, 2008. Triad performed offloading (Figure 4-9) and began installation of the system, including connections to the entry and distribution piping and electrical interlocking. System installation and hydraulic testing were completed on July 24, 2008.

Figure 4-9. Equipment Delivery and Unloading

Filtration and support media were loaded into the filter tank following Filtronics' instructions. A layer of concrete was poured at the bottom of the filter tank with its top surface laid 2-in below bottom laterals. On top of the concrete layer were three layers of support gravels (6, 3, 12 in of S200, S202, and T208, respectively), each having a different nominal particle size. The concrete and support layers had a total depth of approximately 25 in. The Electromedia®I media was loaded on top of the support gravels with a depth of 25 to 27 in. A layer of light purple gravel plus a layer of carbon anthracite covered the top of the filtration media bed to prevent media loss during backwash. Figure 4-10 shows the cross section of the horizontal filter tank with layers of filtration and support media in the tank.

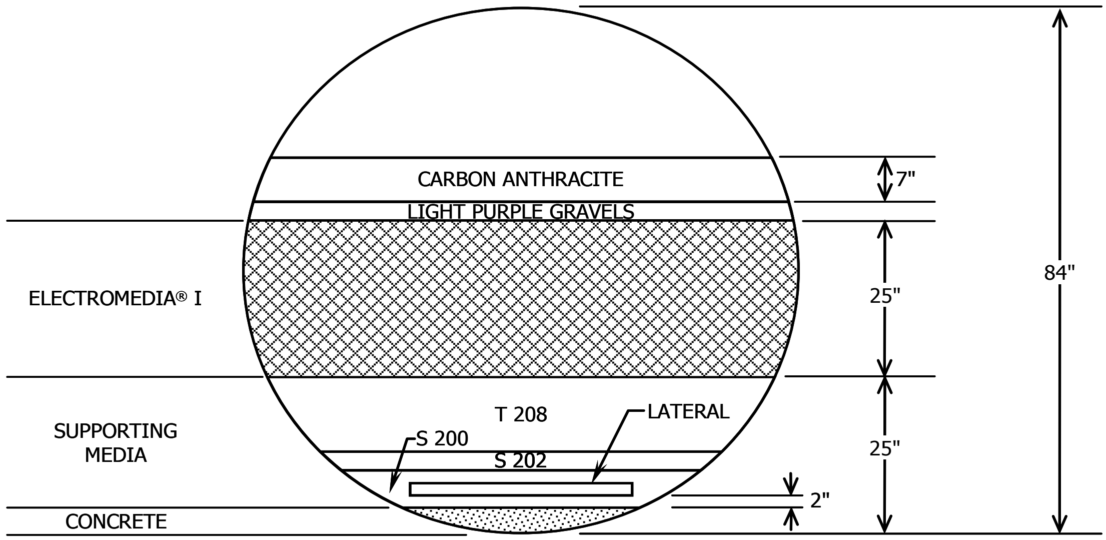

Figure 4-10. Schematic Illustration of Filtration and Supporting Media Layers in Filtration Tank

A water sample was collected and passed bacteriological tests and startup and shakedown activities were completed on August 14, 2008. Startup and shakedown activities included PLC testing, instrument calibration, chlorine disinfection and residual testing, and operator training on system O&M. Startup activities included steps to "break in" the filter according to the schedule shown in Table 4-4. Battelle performed system inspections and operator training on sample and data collection on August 14, 2008. The 1-year demonstration study started on August 14, 2008.

Table 4-4. Filter Break-in Schedule

Day	Maximum Filter Run Time (hr)	Minimum Number of Backwashes	Total Minimum Filter Run Time (hr)
1	2	4	8
2	2	4	8
3	3	3	9
4	4	2	8
5	5	2	10
6	6	2	12
7	7	2	14
8	8	1	8

4.4 System Operation

4.4.1 Service Operation. Operational parameters of the treatment system are tabulated and attached as Appendix A with key parameters summarized in Table 4-5. The performance evaluation study began on August 14, 2008, and ended on August 14, 2009. The treatment system operated for a total of 4,358 hr based on the hour meter of the well pump. Because the operation data log was not filled out during weekends and because the daily log was not necessarily recorded at the same time each day during weekdays, recorded incremental operating times were normalized to obtain daily operating times (by dividing the incremental hours by the number of days since last recording times). As shown in

Table 4-5. Treatment System Operational Parameters

Parameter	Value
Operating Period	08/14/08–08/14/09
Pretreatment Operation	
NaOCl Dosage (mg/L [as Cl_2])[(a)]	0.7 [0.2–1.5]
$FeCl_3$ Dosage (mg/L [as Fe])	0.9 [0.2–4.4]
Service Operation	
Total Operating Time (hr)	4,358
Average Daily Operating Time[(b)] (hr)	13.6
Throughput[(c)] (gal)	139,435,000
Average Daily Demand[(b,c)] (gal)	414,000
Instantaneous Flowrate[(d)] (gpm)	527 [460–590]
Calculated Flowrate[(e)] (gpm)	538 [351–738]
Contact Time in Contact Tanks[(f)] (min)	2.8 [2.5–3.3]
Hydraulic Loading over Pressure Filter[(f)] (gpm/ft^2)	7.0 [6.1–7.9]
Δp Across filter tank[(g)] (psi)	0.8[0–4]
Backwash Operation	
Average Frequency[(h)] (backwash/day)	2.3
Number of Backwash Cycles[(h)]	759
Flowrate[(i)] (gpm)	1,344 [1,000–1,750]
Hydraulic Loading Rate (gpm/ft^2)	17.9 [13.3–23.3]
Duration (min)	4 [4–5]
Backwash Volume (gal/cycle)	5,400 [4,000–7,000]
Filter-to-Waste Volume (gal/cycle)	750
Wastewater Produced (gal/cycle)	6,150 [4,750–7,750]

Note: Data presented included average and [range].
(a) Based on dosage data collected after November 20, 2008, when proper chlorine dosage was established.
(b) Data before October 2, 2008, when system was not operating constantly (Section 4.4.2), were not included in calculation.
(c) Based on totalizer readings at system outlet.
(d) Based on flow meter readings at system outlet.
(e) Calculated flowrates based on incremental throughput and incremental operating time.
(f) Based on instantaneous flowrate readings.
(g) Two outliers (i.e., 10 and 13 psi on 12/24/08 and 12/29/08, respectively) omitted.
(h) Estimated based on backwash totalizer and averaged volume of wastewater generated per backwash.
(i) Based on monthly data recorded on the Backwash Log Sheets.

Figure 4-11, normalized daily operating times fluctuated significantly from 2.5 to 23.8 hr and averaged 13.6 hr (not including two outliers on August 15 and 18, 2008). Seasonal variations were observed with relatively longer operating times during summer months (averaged 17.3 hr from May through August) and relatively shorter operating times during winter months (averaged 10.2 hr from December through March).

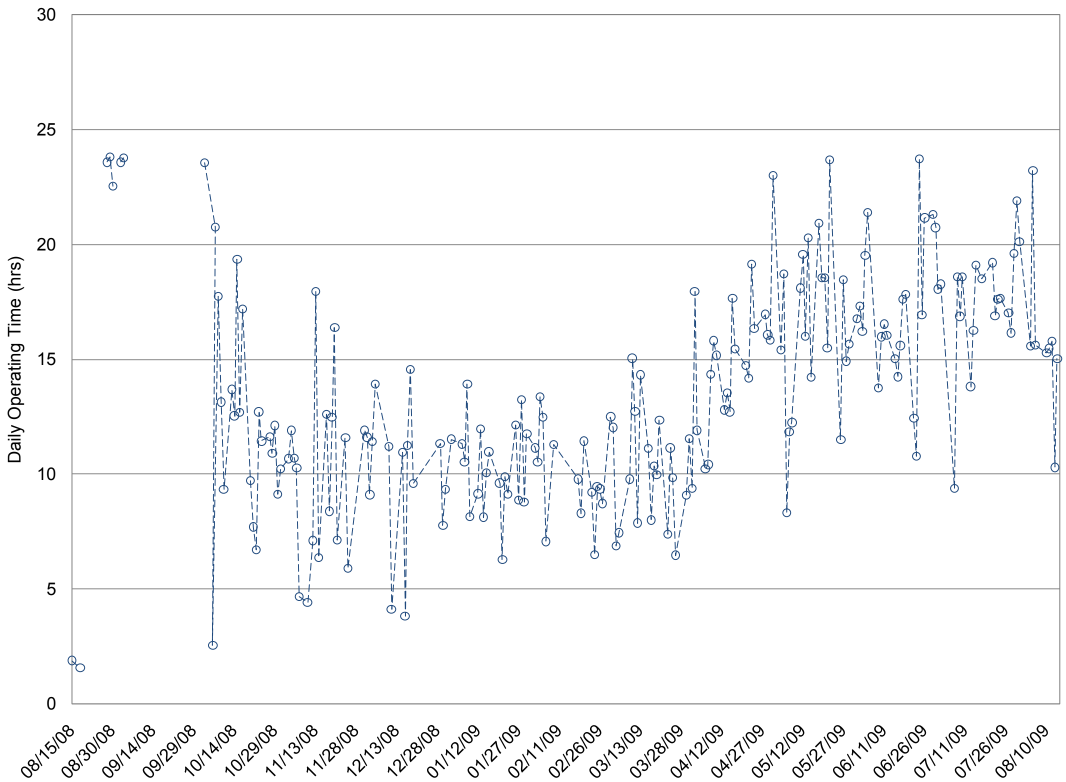

Figure 4-11. Treatment System Normalized Daily Operating Times

Total system throughput was approximately 138,151,000 gal based on flow totalizer readings at the wellhead and was 139,435,000 gal based on flow totalizer readings measured at the system outlet. The throughput values as measured by propeller flow meter/totalizer at the system outlet matched closely with those by electromagnetic flow meter/totalizer (Siemens, SITRANS M MAGFLO MAG 5000) at the wellhead, with only 0.9% difference observed through the 1-year study period. Average daily demand of 414,000 gpd was calculated by dividing the total throughput from October 2, 2008, through August 14, 2009, by the number of operating days during the period. The calculation did not include the data collected before October 2, 2008, because the treatment system did not operate constantly due to shakedown and chlorine dosage tests (Section 4.4.2). The average daily demand increased to 520,000 gpd during summer months (from May through August) and decreased to 332,000 gpd during winter months (from December to March).

System flowrates were tracked by two flow meters/totalizers located at the wellhead and system outlet. Flowrates also were calculated based on readings of the two flow meters/totalizers located at the wellhead and system outlet and corresponding hour meter readings. As shown in Figure 4-12, instantaneous flowrate readings and calculated flowrate values matched closely at both the wellhead and system outlet, with relative error within 2% on average. Instantaneous flowrate readings at the system outlet ranged from 460 to 590 gpm and averaged 527 gpm, compared to the average value of 550 gpm expected at the site (see Table 4-3). The 527 gpm flowrate corresponded to a contact time of 2.8 min in the two contact tanks (compared to the design value of 2.0 min) and a filtration rate of 7.0 gpm/ft^2 over the pressure filter (compare to the design value of 10 gpm/ft^2) (Table 4-3).

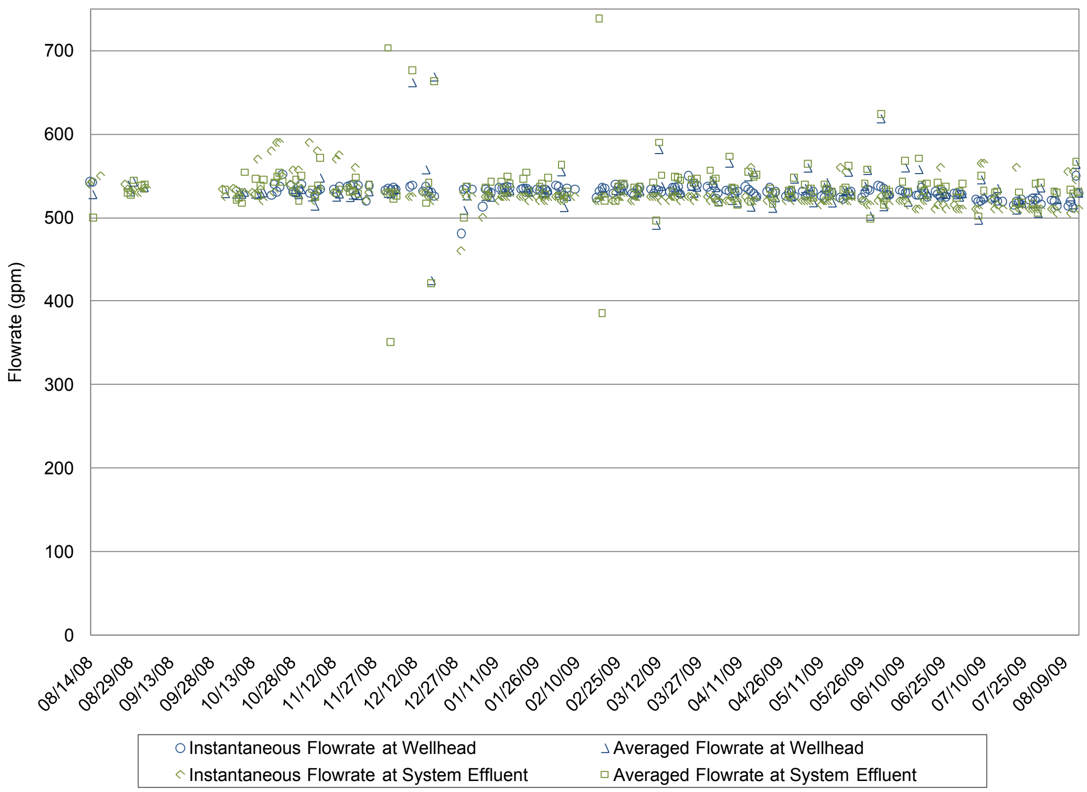

Figure 4-12. Treatment System Flowrates

Differential pressure (Δp) readings across the pressure filter typically ranged from 0 to 4 psi and averaged 0.8 psi (Figure 4-13). As shown in the figure, a few spikes were measured during December 17, 2008, through January 6, 2009, due to malfunctioning of a 10-in control valve on the backwash line (Section 4.4.3.1). These spikes were excluded from Δp calculations in Table 4-5. Figure 4-14 compared Δp readings before and after backwash as recorded on the Backwash Log Sheet (Appendix D). Δp across the filter was typically 1 to 2 psi right before a backwash and was reduced to 0 psi right after a backwash except for a few occasions. This indicates that backwashing was generally effective under the conditions specified in Table 4-5.

4.4.2 Chlorine and Iron Additions. Chemical pretreatments include chlorine and iron additions. During the first three months of system operation, several operational issues/problems related to the chlorine addition system arose and are summarized in Table 4-6.

At the beginning of the performance evaluation study, the chlorine addition system operated at a Battelle recommended residual level of 0.5 mg/L (as Cl_2) in system effluent. On September 8, 2008, Filtronics asked the operator to shut down the treatment plant, claiming that the Electromedia®I might be damaged due to the low chlorine residual (0.5 mg/L [as Cl_2]). Filtronics stated that the free chlorine residual level following the filter tank must be 10% above chlorine breakpoint or 0.5 mg/L, whichever was greater. Filtronics suggested a set of chlorine dosage tests to determine the optimal dosage.

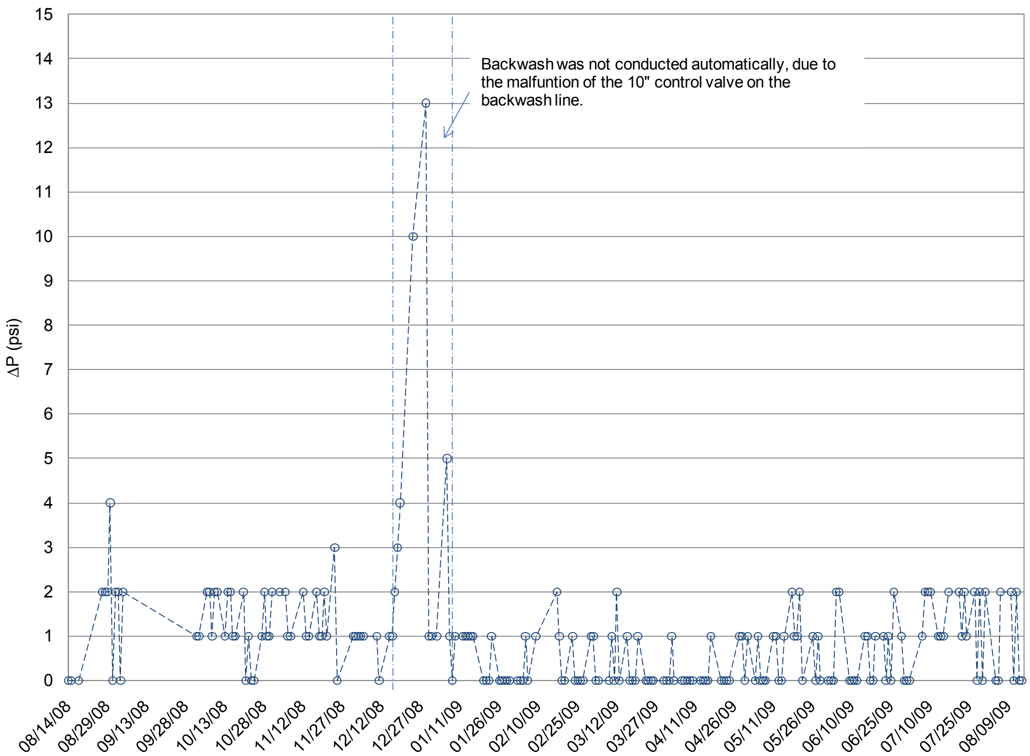

Figure 4-13. Differential Pressure Across Pressure Filter

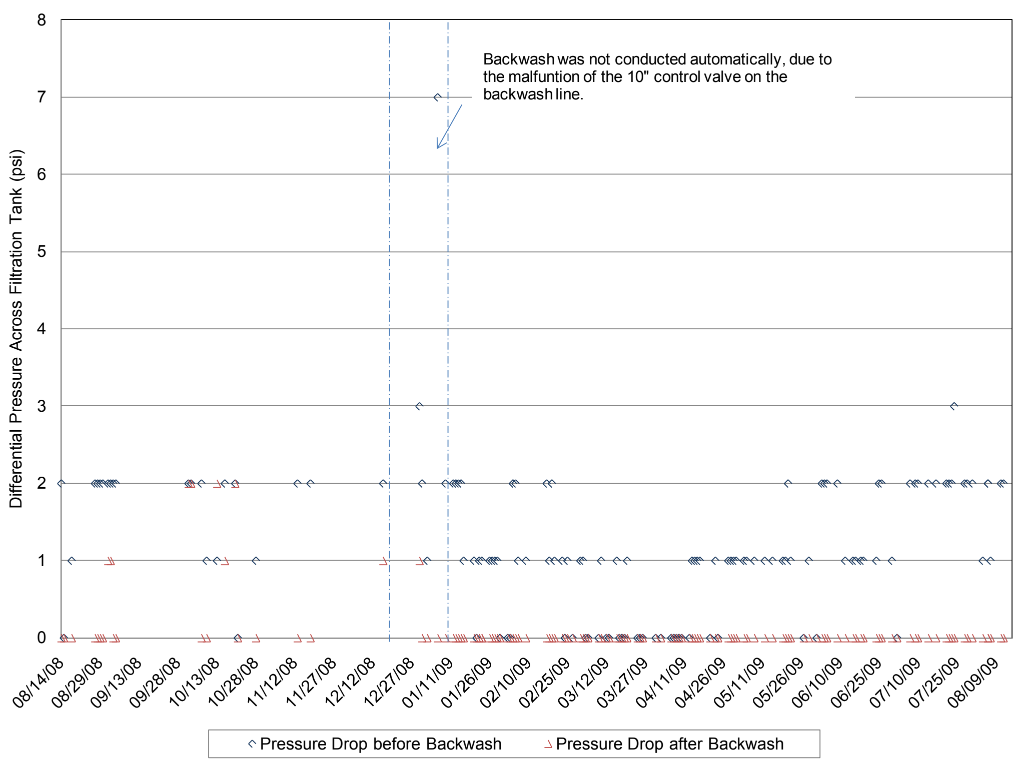

Figure 4-14. Differential Pressure Across Pressure Filter Before and After Backwash

Table 4-6. Issues/Problems Encountered Related to Chlorine Addition System

Date	Issue/Problem Encountered	Corrective Action
09/08/08 to 10/02/08	Filtronics asked to shut down treatment system on 09/08/08, because it believed that the target chlorine residual level of 0.5 mg/L (as Cl_2) in system effluent was lower than what would be required by the system.	Under instructions of Filtronics, a series of chlorine dosage tests were conducted by operator to determine "optimal chlorine dosage." Based on test results, a target chlorine feed rate of 0.7 gph was recommended by Filtronics. Treatment system was put back to service with this feed rate on 10/02/08
08/14/08 to 10/23/08	Airlock observed in chlorine feed line, causing unstable and fluctuating chlorine feed rates	On 10/23/08, leaks in chlorine feed system's manifold identified and repaired
Late October to 11/20/08	City received complaints about red water and chlorine odor in water	A conference call was held on 11/20/08 with city, G&O, EPA, and Battelle; consensus was reached to restore target chlorine residual level to 0.5 mg/L (as Cl_2) in system effluent

With the assistance of the plant operator, a Filtronics technician was onsite to perform the chlorine dosage tests in September 2008. During the tests, the NaOCl feed rate was gradually increased from 0.1 to 0.9 gph at a 0.1 gph increment, and total and free chlorine residuals in system effluent were measured. Actual feed rates during each test also were measured both at the beginning and end of the test. The average chlorine dose added to the influent water at each feed rate was calculated based on the actual system flowrate and average of actual feed rates and plotted in Figure 4-15. These calculations assumed a constant stock chlorine concentration of 12.5% (as Cl_2).

Comparison between calculated chlorine doses at AC and total and chlorine residuals in system effluent during each test indicated some chlorine demand across the pressure filter. For example, 0.53 mg/L of chlorine (as Cl_2) was consumed at a 0.2-gph feed rate (or ~1.0 mg/L [as Cl_2]), leaving 0.47 mg/L (as Cl_2) of total chlorine in system effluent. At 0.7 gph (or ~2.7 mg/L [as Cl_2]), 1.2 mg/L (as Cl_2) was consumed and 1.5 mg/L (as Cl_2) was measured in system effluent. The chlorine demand across the pressure filter continued to increase to 2.0 mg/L (as Cl_2) at a 0.9-gph feed rate (or ~4.5 mg/L [as Cl_2]), leaving 2.5 mg/L (as Cl_2) of total chlorine in system effluent.

Based on the dosage tests, Filtronics determined the chlorine feed rate to be 0.7 gph (or ~2.7 mg/L [as Cl_2]). The treatment system was put back in operation on October 2, 2008. As shown in Figure 4-16, at the target feed rate of 0.7gph, the total chlorine residual measured in system effluent was 1.53 mg/L (as Cl_2). Since system re-startup on October 2 through the end of October, total chlorine residuals measured in the plant effluent ranged from 1.2 to 2.0 mg/L (as Cl_2) (see discussion in Section 4.5.1.5). These high chlorine residuals led to a number of consumer complaints, as discussed below.

Since system startup on August 14 through October 23, 2008, airlocks observed in the chlorine feed system caused unstable and fluctuating chlorine feed rates. The airlock problem was resolved on October 23, 2008, when leaks in the feed system manifold were identified and repaired. A stable chlorine feed rate was established since repair of the leak.

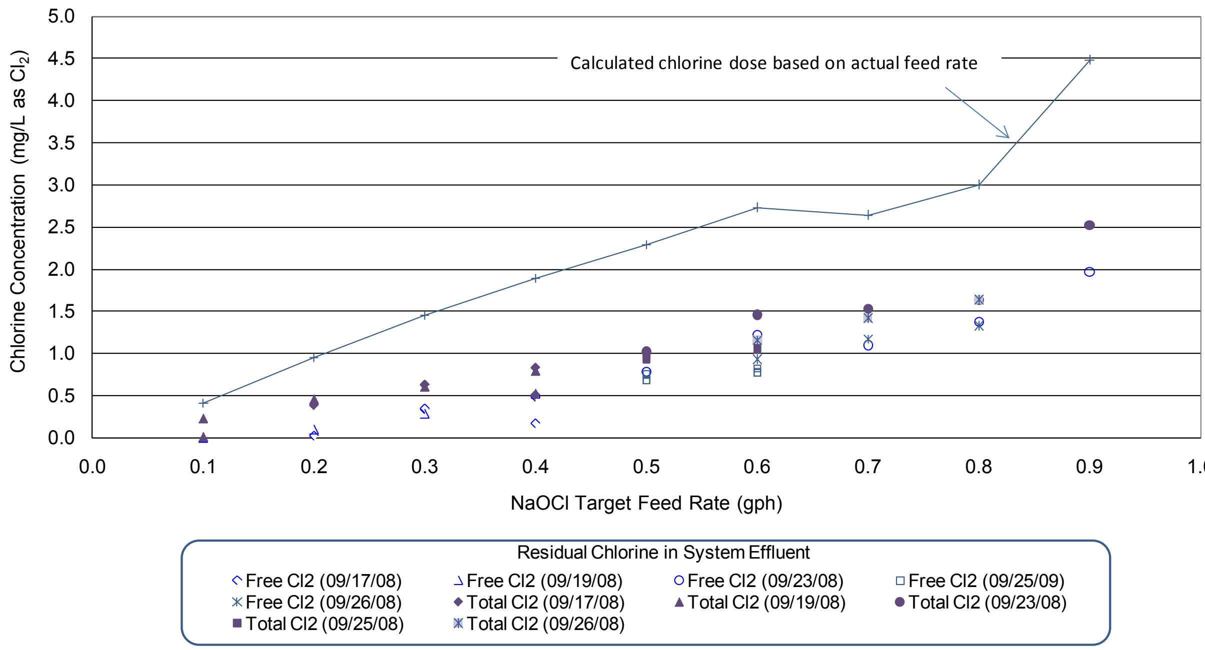

Figure 4-15. Chlorine Dosage Test Results

In late October, the city received complaints about red water and chlorine smell in consumers' tap water. A local newspaper reported the incident on October 29, 2008. Total chlorine residuals measured in plant effluent ranged from 1.2 to 2.7 mg/L (as Cl_2) during the period between October 23 (after the airlock problem was resolved) to November 20, 2008. In response, a teleconference was held on November 20, 2008, with the city, G&O, EPA, and Battelle to discuss the issue. A consensus was reached to reduce the chlorine feed rate so that residual levels in plant effluent could be maintained at approximately 0.5 mg/L (as Cl_2). Upon implementation of this decision, customer complaints discontinued and total chlorine residual levels measured throughout the rest of the study period were from 0.3 to 0.6 mg/L (as Cl_2) and averaged 0.5 mg/L (as Cl_2). With these residual levels, arsenic concentrations in system effluent were maintained at levels below 10 µg/L (except for one occasion on December 3, 2008, when the chlorine pump was not functioning properly as discussed in Section 4.5.1.1).

Figure 4-16 presents chlorine doses, as calculated based on incremental NaOCl consumption (as measured by changes in solution level in the chemical barrel) and corresponding incremental throughput (according to the system effluent totalizer). Between October 2, 2008 (when the system was put back in service with an intended feed rate of 0.7 gph), and October 23, 2008, measured chlorine doses fluctuated significantly due to leaks in the chlorine system's manifold as discussed above. After the manifold was repaired on October 23, 2008, the chlorine feed rate was restored presumably to the target level of 0.7 gph. Total chlorine residuals measured during October 23, 2008, through November 20, 2008 (when the feed rate was reduced to allow for a target total chlorine residual of 0.5 mg/L [as Cl_2] in plant effluent) ranged from 1.2 to 2.7 mg/L (as Cl_2) and averaged 2.1 mg/L (as Cl_2). After November 20, 2008, measured chlorine doses were reduced significantly to levels ranging from 0.2 to 1.5 mg/L (as Cl_2) and averaging 0.7 mg/L, which was very close to the target level of 0.5 mg/L (as Cl_2).

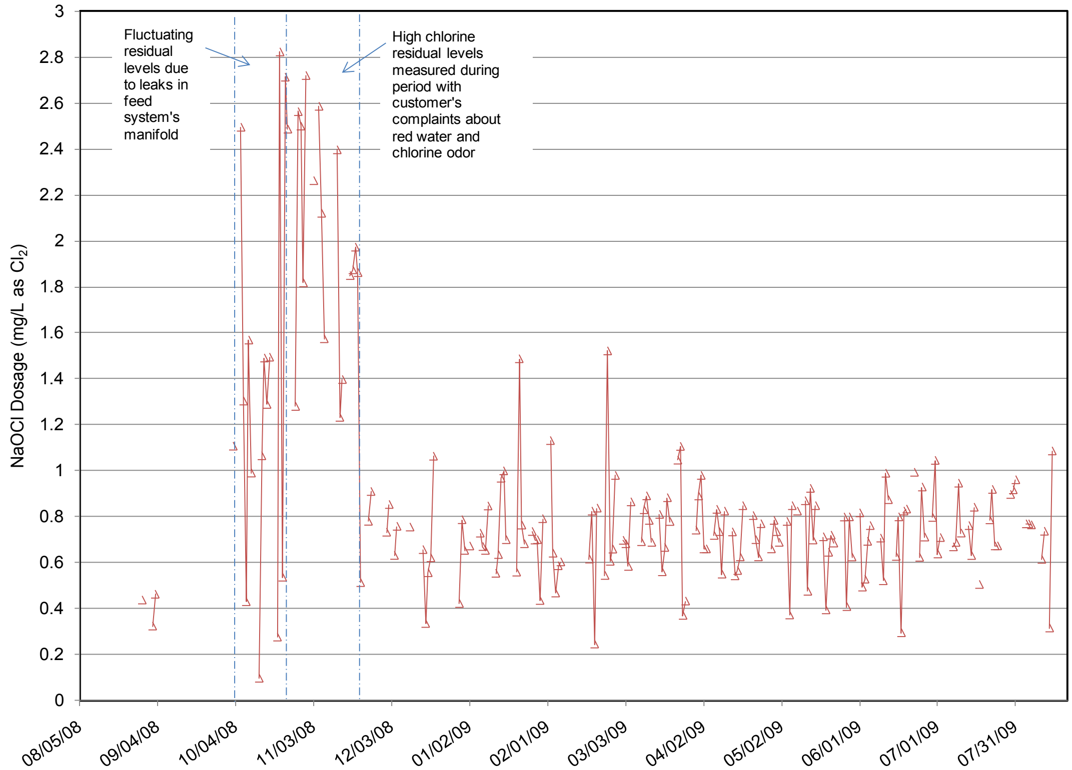

Figure 4-16. Chlorine Doses over Demonstration Study Period

With the amounts of reducing species (such as As[III], Fe[II], and Mn[II]) and ammonia in raw water (see Section 4.5.1), 0.12 mg/L of chlorine (as Cl_2) would be needed to oxidize As(III), Fe(II), and Mn(II) to form As(V), Fe(III), and Mn(IV), and 0.57 mg/L of chlorine (as Cl_2) needed to react with 0.075 mg/L of ammonia (as N) to reach breakpoint chlorination. Therefore, with 0.7 mg/L of chlorine added, 0.01 mg/L (as Cl_2) of free chlorine would be produced in system effluent (Section 4.5.1.5).

Iron was added to source water as a coagulant to remove soluble arsenic through adsorption and/or coprecipitation with iron solids. Figure 4-17 presents calculated $FeCl_3$ doses (mg/L [as Fe]) and iron concentrations (mg/L [as Fe]) measured after the contact tanks (at AC) over the entire study period. Similar to chlorine doses, iron doses were calculated based on incremental $FeCl_3$ consumption (by changes in solution level in the chemical barrel) and the corresponding throughput (according to the system effluent totalizer). Note that Figure 4-17 does not include an outlier of 7.2 mg/L of total iron measured at AC on November 4, 2008, when backwash solids appeared to have been reintroduced from the reclaim tank (Section 4.5.1).

During the entire study period, calculated iron doses ranged from 0.21 to 4.4 mg/L (as Fe) and averaged 0.9 mg/L (as Fe), which was consistent with the iron concentrations in samples taken following the contact tanks (i.e. ranged from 0.16 to 1.3 mg/L [as Fe] and averaged at 0.9 mg/L [as Fe]).

4.4.3 Backwash Operation. The system PLC was set to initiate a backwash based on one of two potential triggers: (1) preset filter run time of 8 hr and (2) automatic shutdown of the treatment system when water level in the city's reservoirs reached the "Stop" set level. Each backwash lasted for 4 min at an average flowrate of 1,344 gpm (Table 4-5 and Appendix D). The filter then underwent a 1-min filter-

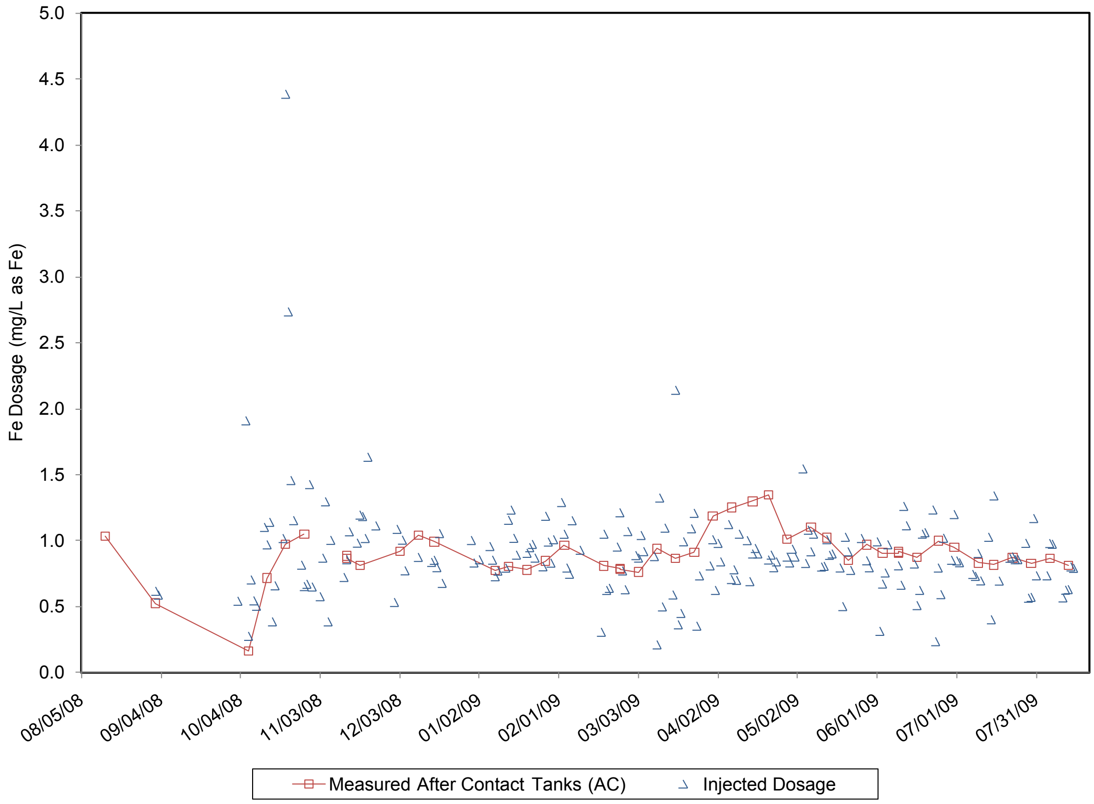

Figure 4-17. Calculated Iron Doses vs. Measured Iron Concentrations

to-waste rinse at up to 550 gpm before returning to filtration service. Estimated based on readings of the backwash wastewater totalizer and average backwash wastewater production, the filter was backwashed 759 times during the performance evaluation study from August 14, 2008, through August 14, 2009. The average backwash frequency was 2.3 times per day. Considering the average daily operation time of 13.6 hr and the preset filter run time of 8 hr, backwash was triggered at least once a day by the preset filter run time. The backwash frequency was higher during the summer (i.e., 3.1 times per day from May to August) and lower during the winter (i.e., 1.5 times per day from December to March), which was consistent with the longer daily operation times in the summer and shorter operation time in the winter. Filter run times between backwash events were either 8 hr, or any time between 0 to 8 hr depending on the trigger of a backwash.

4.4.3.1 Other Problems Related to Backwash System. Two backwash related problems were encountered during the 1-year demonstration study. Starting on December 17, 2008, Δp across the filter surged several times from the typical range of 0 to 2 psi to as high as 13 psi. It was found that backwash was not conducted automatically due to malfunctioning of a 10-in control valve on the backwash line. Differential pressure readings across the filter went back to the normal range after the control valve was taken offline and cleaned on January 14, 2009. On February 6, 2009, the automatic drain valve of the reclaim tank was not functioning automatically. The drain valve was repaired on February 20, 2009.

4.4.4 Residual Management. Residuals produced by the operation of the treatment system consisted of only backwash solids, which accumulated at the bottom of the reclaim tank. The reclaim tank drain valve was set to open every four backwashes to discharge approximately 12 in of sludge to the sewer (Figure 4-7). Approximately 1,670 kg of backwash solids was produced during the performance evaluation study based on 759 backwash events (Table 4-5) and 2.5 kg of backwash solids produced per backwash event (Section 4.5.2).

4.4.5 System/Operation Reliability and Simplicity. The system experienced a number of downtimes during the initial 7-week of system operation (for chlorine dosage tests as discussed in Section 4.4.2) and a 7-day downtime in February 2009 (for operators to attend a training class). Since then, there was no additional downtime. No major operational problems were encountered during the 1-year demonstration study, except for a few minor issues such as leaks in the chlorine feed system manifold (Section 4.4.2), malfunctioning of a 10-in backwash control valve (Section 4.4.3.1), and malfunctioning of a reclaim tank drain valve (Section 4.4.3.1). The simplicity of system operation and operator skill requirements are discussed according to pre- and post-treatment requirements, levels of system automation, operator skill requirements, preventative maintenance activities, and frequency of chemical/media handling and inventory requirements.

4.4.5.1 Pre- and Post-Treatment Requirements. Pre-treatment consisted of chemical additions to improve arsenic removal. A 12.5% NaOCl solution was added upstream of the contact tanks to oxidize As(III) and Fe(II), and provide chlorine residuals to the distribution system. In addition to measuring solution levels in the NaOCl drums, the operator monitored chlorine concentrations to ensure that residuals existed throughout the treatment train. A 42% $FeCl_3$ solution was added downstream of the chlorine addition point, but upstream of the contact tanks. Solution levels in the $FeCl_3$ drums were tracked daily. No post-treatment was required.

4.4.5.2 System Automation. The treatment system was automatically controlled by the PLC in the central control panel. The control panel also contained a modem and a touch screen OIP to facilitate setting and monitoring of system parameters, such as filter run time, filter backwash time, filter rinse time, backwash wastewater reclaim time, etc. All major functions of the treatment system were automated and required only minimal operator oversight and intervention if all functions were operating as intended. Automated processes included system startup and shutdown, filter backwash and rinse, and chemical addition system on/off. The touch screen OIP also enabled the operator to manually initiate a backwash sequence.

4.4.5.3 Operator Skill Requirements. Under normal operating conditions, the daily demand on the operator was about 45 min for visual inspection of the system and recording of operational parameters such as pressure, volume, flowrate, and chemical usage on field log sheets. After receiving proper training during system startup, the operators understood the PLC, knew how to use the touch screen OIP, and were able to work with the equipment vendor to troubleshoot problems and perform minor onsite repairs.

Based on population served and the treatment technology, the State of Washington required Basic Treatment Operator certification for operating the Filtronics treatment system at the City of Okanogan facility. The State of Washington has five levels of certification for operation of water treatment systems based on population served by the plant, water supply source, and complication of the treatment system (including chemical treatment/addition process, coagulation process, filtration process, clarification/sedimentation process, and residuals disposal, etc.). The certification levels range from Basic Treatment Operator (BTO) for small and simple treatment systems to Water Treatment Plant Operator Levels 1 to 4 for larger and more complicate treatment systems.

4.4.5.4 Preventative Maintenance Activities. Daily preventative maintenance activities included recording pressure and flowrate readings and chemical drum levels and visually checking for leaks, overheating components, and any unusual conditions. To maintain the integrity of the treatment system, the vendor recommended several routine maintenance activities, including checking the oil level in the valve oiler on the filter control panel weekly, checking the temperature of backwash water monthly, and adjusting monthly backwash flowrate according to the "Backwash Rate Versus Temperature Chart". The vendor also recommended checking the filter differential pressure weekly right after a backwash to ensure that the Δp was the same as that recorded at system startup.

4.4.5.5 Chemical Handling and Inventory Requirements. Chlorine and iron additions were required for effective arsenic removal. The operators tracked usage of the chemical solutions daily (by solution levels), coordinated supplies, and started a new chemical drum as needed. A 12.5% NaOCl solution supplied in 53-gal drums and a 42% $FeCl_3$ solution supplied in 55-gal drums by Oxarc, Inc. were injected without dilution. Speed and stroke length settings of the chemical feed pumps were adjusted, as needed, to acquire the target chlorine residuals as measured regularly with a Hach pocket colorimeter and iron concentrations after the contact tanks.

4.5 System Performance

The performance of the Filtronics FH-13 Electromedia®I arsenic removal system was evaluated based on analyses of water samples collected from the treatment plant and distribution system.

4.5.1 Treatment Plant Sampling. The treatment plant water was sampled on 47 occasions (including four duplicate events) during the 1-year performance evaluation period. Field speciation also was performed for 12 of the 47 occasions. Table 4-7 summarizes the analytical results for arsenic, iron, and manganese. Table 4-8 summarizes the results of the other water quality parameters. One outlier with uncharacteristically high arsenic, iron, manganese, and phosphorus concentrations at the AC sampling location on November 4, 2008, was not included in statistical calculations shown in Tables 4-7 and 4-8. These elevated concentrations probably were caused by reintroduction of backwash solids from the reclaim tank. Appendix B contains a complete set of analytical results. The results of the water samples collected across the treatment train are discussed below.

4.5.1.1 Arsenic. Figure 4-18 shows total arsenic concentrations measured across the treatment train and Figure 4-19 presents the results of the 12 speciation events. Total arsenic concentrations in source water ranged from 14.7 to 22.7µg/L and averaged 17.9 µg/L with soluble As(III) existing as the predominant species at 13.4 µg/L (on average). Low concentrations of particulate arsenic and soluble As(V) also were present in source water, with concentrations averaging 0.8 and 4.7 µg/L, respectively.

As shown in Figure 4-19, soluble As(III) was the predominant species in source water during all but two speciation events on November 4, 2008, and February 3, 2009. These results were in contrary to that obtained during the initial site visit on October 28, 2004, when As(V) was predominant (Table 4-1). The reason for the difference observed is unclear. As shown in Table 4-9, for the three sampling events with higher soluble As(V) concentrations, only the sampling event on February 3, 2009, had a higher-than-average DO level that might contribute to the high As(V) concentration measured. ORP values for the three events were either similar to or significantly lower than the average ORP level, which could not contribute to high soluble As(V) concentration. Except for As(III), As(V), and ORP, all other water quality data measured during the 1-year performance evaluation study were consistent with those collected on October 28, 2004.

Following prechlorination and the contact tanks, total arsenic concentrations remained essentially unchanged at 17.8 µg/L (on average). However, arsenic existed primarily as particulate arsenic (8.7 µg/L [on average]) and soluble As(V) (8.1 µg/L [on average]). Note that the average total and particulate arsenic concentrations at the AC location do not include one outlier on November 4, 2008, when the concentrations spiked to over 100 µg/L for total arsenic and 91.5 µg/L for particulate arsenic. Particulate

Table 4-7. Summary of Arsenic, Iron, and Manganese Analytical Results

Parameter	Sampling Location	Unit	Number of Samples	Concentration			Standard Deviation
				Minimum	Maximum	Average	
As (total)	IN	μg/L	47	14.7	22.7	17.9	1.6
	AC	μg/L	46[(a)]	14.5	23	17.8	1.7
	TT	μg/L	45[(b)]	2.9	14.9	6.2	1.7
As (soluble)	IN	μg/L	12	14.9	21.2	18.0	2.0
	AC	μg/L	12	6.4	17.1	10.2	3.7
	TT	μg/L	12	5.0	14.6	6.9	2.6
As (particulate)	IN	μg/L	12	<0.1	2.9	0.8	0.9
	AC	μg/L	11[(a)]	2.7	12.0	8.7	3.2
	TT	μg/L	12	<0.1	1.1	0.3	0.3
As (III)	IN	μg/L	12	3.7	19.8	13.4	4.5
	AC	μg/L	12	0.2	13.9	2.2	4.2
	TT	μg/L	12	0.3	8.9	1.2	2.5
As (V)	IN	μg/L	12	<0.1	14.7	4.7	4.1
	AC	μg/L	12	1.6	16.7	8.1	3.4
	TT	μg/L	12	4.6	8.2	5.7	1.0
Fe (total)	IN	μg/L	47	<25	230	78	31.4
	AC	μg/L	46[(a)]	163	1,345	902	188
	TT	μg/L	45[(b)]	<25	107	20.5	19.9
Fe (soluble)	IN	μg/L	12	<25	89	49	26.6
	AC	μg/L	12	<25	37	<25	9.4
	TT	μg/L	12	<25	26	14	4.0
Mn (total)	IN	μg/L	47	44.1	77.0	62.5	5.6
	AC	μg/L	46[(a)]	46.4	76	63.9	5.8
	TT	μg/L	45[(b)]	0.4	51.9	21.0	11.5
Mn (soluble)	IN	μg/L	12	43.4	74.1	61.4	9.4
	AC	μg/L	12	18.3	77.0	43.2	16.8
	TT	μg/L	12	0.2	43.3	16.3	12.5

(a) One outlier on November 4, 2008 (i.e., 100, 91.5, 7247, and 369 μg/L of total As, particulate As, total Fe, and total Mn; respectively) omitted.
(b) Two outliers on November 13, 2008 (duplicate samples) omitted.

iron and particulate manganese concentrations also spiked to 7,213 and 347 μg/L, suggesting reintroduction of backwash solids from the reclaim tank.

Of the soluble fraction at the AC location, As(III) was less than 0.9 μg/L (except for one data point at 7.2 μg/L on August 14, 2008, and one data point at 13.9 μg/L on December 3, 2008), indicating effective oxidation of As(III) by chlorine. The reason for the high As(III) concentrations on August 14 and December 3, 2008, was insufficient chlorine addition. Total chlorine concentration measured at AC on August 14, 2008 (the system startup day) was 0 mg/L, indicating that the chlorine addition system was not operating properly. On December 3, 2008, the suction tube valve of the chlorine pump was not functioning correctly, causing low total and free chlorine concentrations (0.3 and 0.02 mg/L [as Cl_2], respectively) measured in the system effluent. As much as 8.1 μg/L of As(V) was measured following the contact tanks, suggesting the need for further increasing iron dose rates.

Table 4-8. Summary of Other Water Quality Parameter Results

Parameter	Sampling Location	Unit	Number of Samples	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as $CaCO_3$)	IN	mg/L	47	175	196	183	5.4
	AC	mg/L	47	171	196	181	5.2
	TT	mg/L	47	171	192	181	5.3
Ammonia (as N)	IN	mg/L	1	0.1	0.1	0.1	-
	AC	mg/L	1	0.1	0.1	0.1	-
	TT	mg/L	1	0.1	0.1	0.1	-
Fluoride	IN	mg/L	12	0.6	1.0	0.7	0.1
	AC	mg/L	12	0.6	0.9	0.7	0.1
	TT	mg/L	12	0.6	0.8	0.7	0.1
Sulfate	IN	mg/L	12	119	131	125	3.6
	AC	mg/L	12	119	130	123	3.0
	TT	mg/L	12	119	130	124	3.4
Nitrate (as N)	IN	mg/L	12	<0.05	<0.05	<0.05	-
	AC	mg/L	12	<0.05	0.3	0.05	0.1
	TT	mg/L	12	<0.05	<0.05	<0.05	-
Phosphorus (as P)	IN	μg/L	46	31.3	94.8	50.8	9.7
	AC	μg/L	45[(a)]	33.9	104	49.5	10.3
	TT	μg/L	46	<10	72.0	15.0	13.6
Silica (as SiO_2)	IN	mg/L	47	23.1	29.4	25.9	1.3
	AC	mg/L	47	23.0	32.2	26.0	1.7
	TT	mg/L	47	22.5	28.7	25.6	1.3
Turbidity	IN	NTU	47	0.13	1.8	0.5	0.4
	AC	NTU	47	0.14	16.0	1.4	2.3
	TT	NTU	47	<0.1	2.6	0.6	0.7
pH	IN	S.U.	41	7.4	7.8	7.6	0.1
	AC	S.U.	41	7.5	7.9	7.7	0.1
	TT	S.U.	41	7.6	9.5	7.8	0.3
DO	IN	mg/L	35	1.0	4.2	2.7	0.9
	AC	mg/L	36	1.3	5.6	3.3	0.9
	TT	mg/L	36	1.0	6.1	2.7	1.0
ORP	IN	mV	42	361	486	458	23.3
	AC	mV	42	371	650	512	57.9
	TT	mV	42	358	666	521	61.3
Free Chlorine (as Cl_2)	AC	mg/L	38	0.18	1.8	0.4	0.4
	TT	mg/L	37	0.14	1.8	0.3	0.4
Total Chlorine (as Cl_2)	AC	mg/L	39	0.0	2.0	0.7	0.4
	TT	mg/L	37	0.3	2.0	0.6	0.3
Total Hardness (as $CaCO_3$)	IN	mg/L	12	227	356	269	37.0
	AC	mg/L	12	227	358	272	38.2
	TT	mg/L	12	223	345	271	36.0
Ca Hardness (as $CaCO_3$)	IN	mg/L	12	110	185	137	20.1
	AC	mg/L	12	116	196	141	20.9
	TT	mg/L	12	56.9	201	134	32.8
Mg Hardness (as $CaCO_3$)	IN	mg/L	12	113	241	133	34.8
	AC	mg/L	12	104	240	131	35.6
	TT	mg/L	12	101	234	137	41.0

(a) One outlier (i.e., 362 μg/L on 11/04/08) omitted.

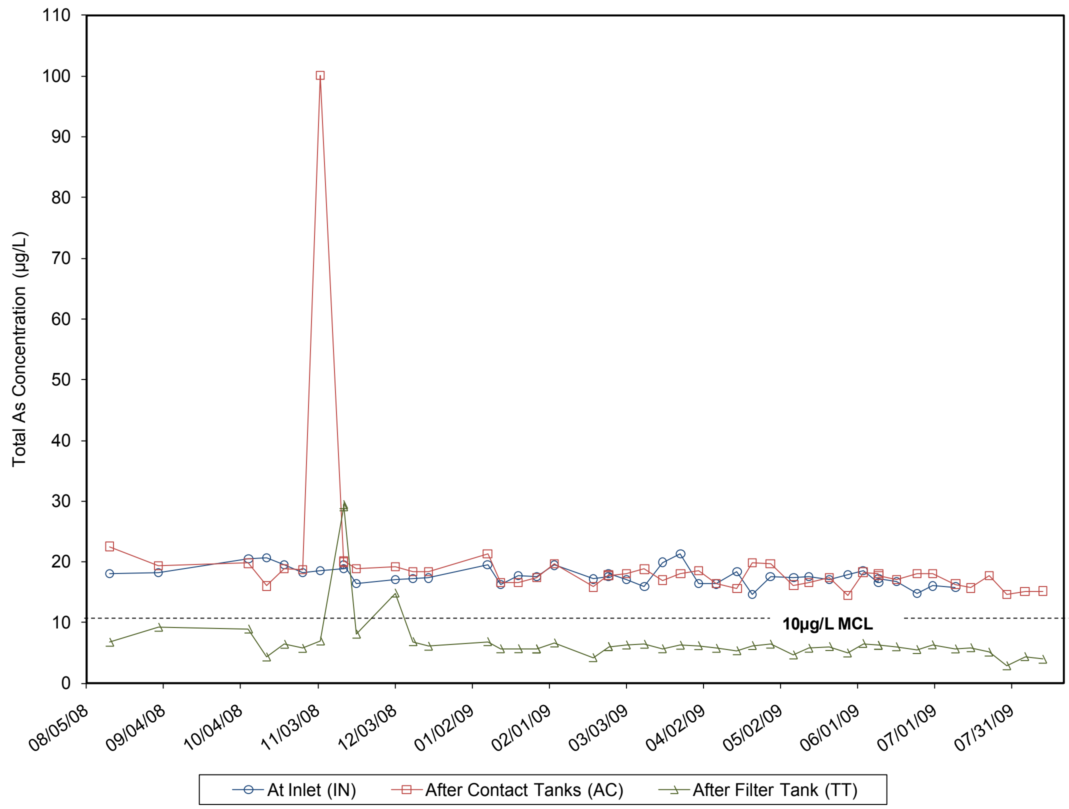

Figure 4-18. Total Arsenic Concentrations Across Treatment Train

Total arsenic concentrations after the pressure filter ranged from 2.9 to 14.9 µg/L and averaged 6.2 µg/L. Based on the speciation results, arsenic in system effluent existed primarily as As(V) with concentrations ranging from 4.6 to 8.2 µg/L and averaging 5.7 µg/L. Some soluble As(III) (1.2 µg/L [on average]) and particulate arsenic (0.3 µg/L [on average]) also were present in system effluent. As shown in Figure 4-18, total arsenic concentrations in system effluent exceeded the arsenic MCL on two occasions on November 13 and December 3, 2008. As discussed above, the December 3, 2008, sampling event resulted in a high As(III) concentration at the AC location due to insufficient chlorine addition, which led to high total arsenic and As(III) concentrations in system effluent. As(III) cannot be effectively removed via the C/F process.

The elevated arsenic concentrations in system effluent on November 13, 2008 appeared to have been caused by a sampling error. Total arsenic, iron, and manganese concentrations measured after the contact tanks on this day were 20.0, 886, and 62.7 µg/L, respectively, which were comparable to the average values measured during the 1-year performance evaluation study, implying that the high concentrations in system effluent were due neither to insufficient iron addition nor to reintroduction of backwash solids. In addition, as shown in Figures 4-18, 4-20, 4-21, concentrations at TT were higher than those at AC for all three metals (As, Fe, and Mn) during the sampling event, suggesting that the high concentrations measured in system effluent were not due to breakthrough of particulate metals. The filter run time during which the sampling event took place was approximately 4 hr, which was only half of the filter run time designed for the filtration system. This also supported the speculation that the high arsenic, iron, and manganese concentrations measured were not caused by particulate metals breakthrough.

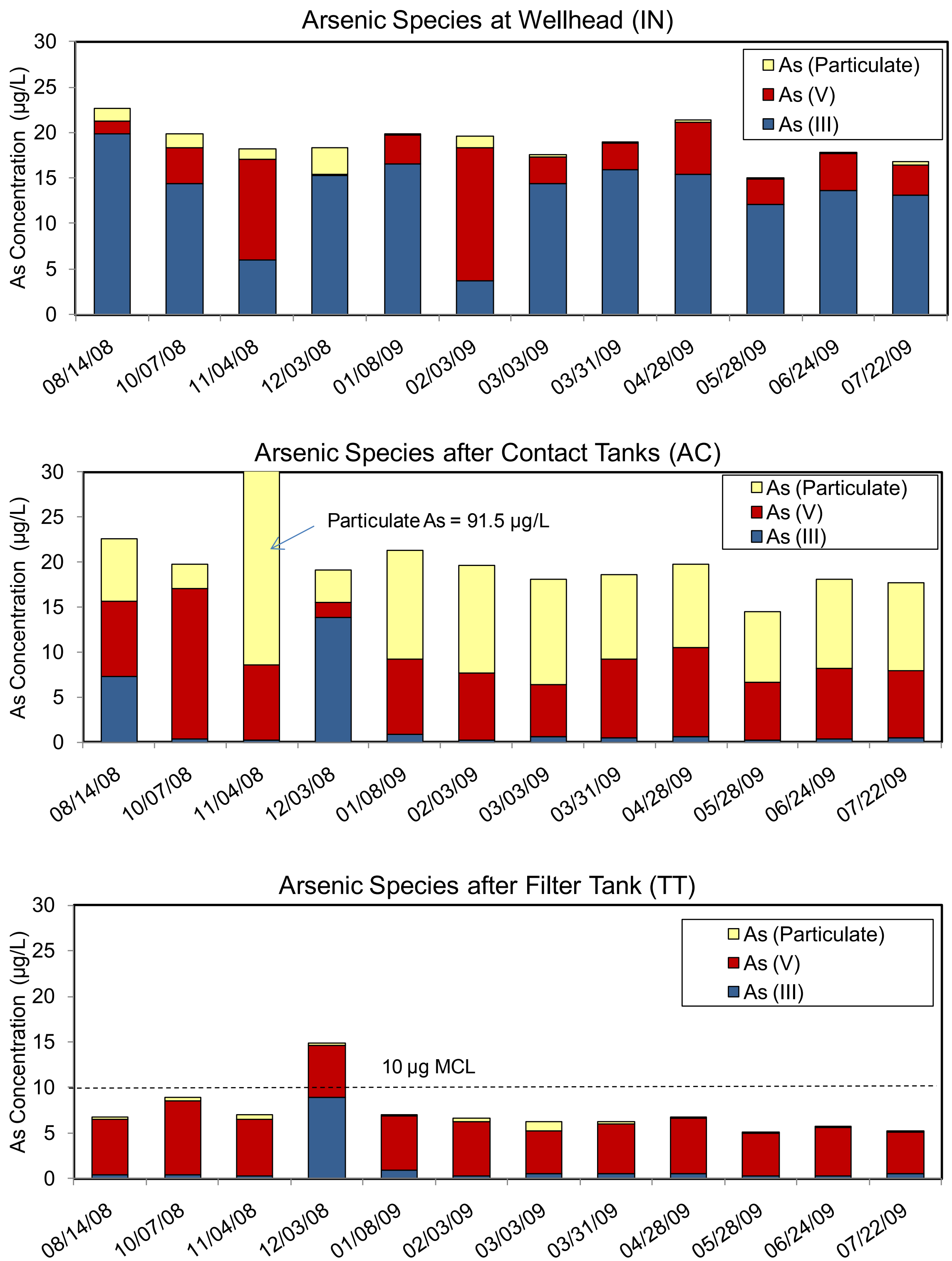

Figure 4-19. Arsenic Speciation Results

Table 4-9. Arsenic Speciation vs. DO and ORP

Date	As(III) (µg/L)	As(V) (µg/L)	DO (mg/L)	ORP (mV)
Average value during 1-year study	13.4	4.7	2.7	458
10/28/04 (initial site visit)	3.0	15.6	1.8	-47
11/04/08	6.0	11.1	2.5	465
02/03/09	3.7	14.7	4.2	460

The particulate arsenic, iron, and manganese concentration spikes observed at AC on November 4, 2008, presumably were caused by the reintroduction of backwash solids but did not cause arsenic breakthrough from the pressure filter.

4.5.1.2 Iron. Figure 4-20 presents total iron concentration measured across the treatment train. Total iron concentrations in source water ranged from <25 to 230 µg/L and averaged 78 µg/L, 63% of which existed in the soluble form.

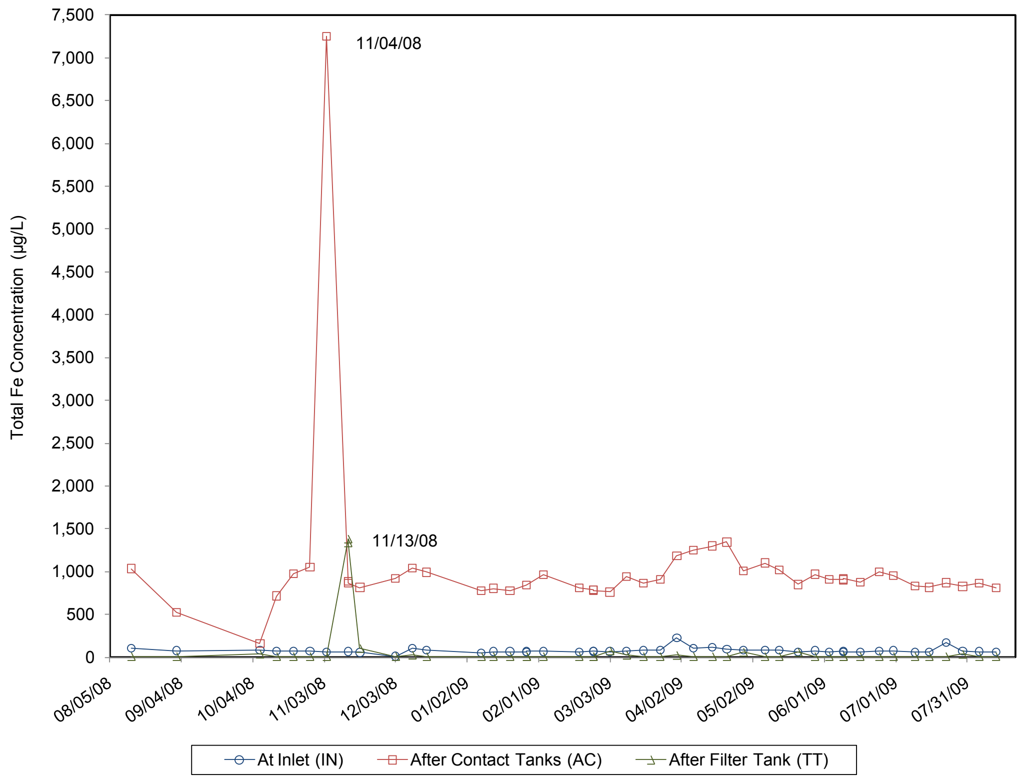

Figure 4-20. Total Iron Concentrations Across Treatment Train

As shown in Figure 4-20, total iron concentration spiked on November 4, 2008, probably due to reintroduction of backwash solids from the reclaim tank (Section 4.5.1.1). Total iron concentrations after the contact tanks varied significantly, ranging from 163 to 1,345 µg/L and averaging 902 µg/L (not including the outlier on November 4, 2008). Total iron concentrations in system effluent ranged from <25 to 107 µg/L, and averaged 20.5 µg/L (not including the outlier on November 13, 2008, caused by a sampling error [Section 4.5.1.1]). Approximately 80% of the samples collected at the system outlet had total iron concentrations below the method reporting limit of 25 µg/L.

4.5.1.3 Manganese. Figure 4-21 presents total manganese concentrations measured during the demonstration study. Manganese concentrations in source water ranged from 44.1 to 77.0 µg/L and averaged 62.5 µg/L, existing almost entirely in the soluble form. After chlorination, iron addition, and the contact tanks, average total manganese concentration remained at a similar level (63.9 µg/L, not including the outlier on November 4, 2008), but average soluble manganese concentrations decreased from 61.4 to 43.2 µg/L. About 30% of the soluble manganese was oxidized and precipitated to become particulate manganese. This rather incomplete Mn(II) oxidation was the result of slow reaction kinetics with chlorine, as reported by Knocke et al. (1987 and 1990). After the pressure filter, 77% of particulate manganese and 62% of soluble manganese were removed, leaving an average of 21.0 and 16.3 µg/L of total and soluble manganese, respectively, in filter effluent. Removal of soluble manganese by filtration media in the presence of free chlorine was observed previously by Knocke et al. (1990) and Cumming et al. (2009) at another arsenic removal demonstration site at Rollinsford in New Hampshire. Knocke et al. reported that the presence of free chlorine promotes Mn(II) removal on MnO_x-coated media. At Rollinsford, in the absence of free chlorine, AD33 adsorption media had a limited adsorptive capacity for Mn(II). With the presence of 0.1 to 0.2 mg/L (as Cl_2) of free chlorine, total manganese concentrations in system effluent were reduced from an average of 100 µg/L (with 77% in the soluble form) to <10 µg/L. At Okanogan, the presence of 0.4 mg/L (as Cl_2) of free chlorine at AC (Table 4-8) might have promoted removal of 62% of soluble manganese through precipitation of Mn(II) on the Electromedia®I filtration media.

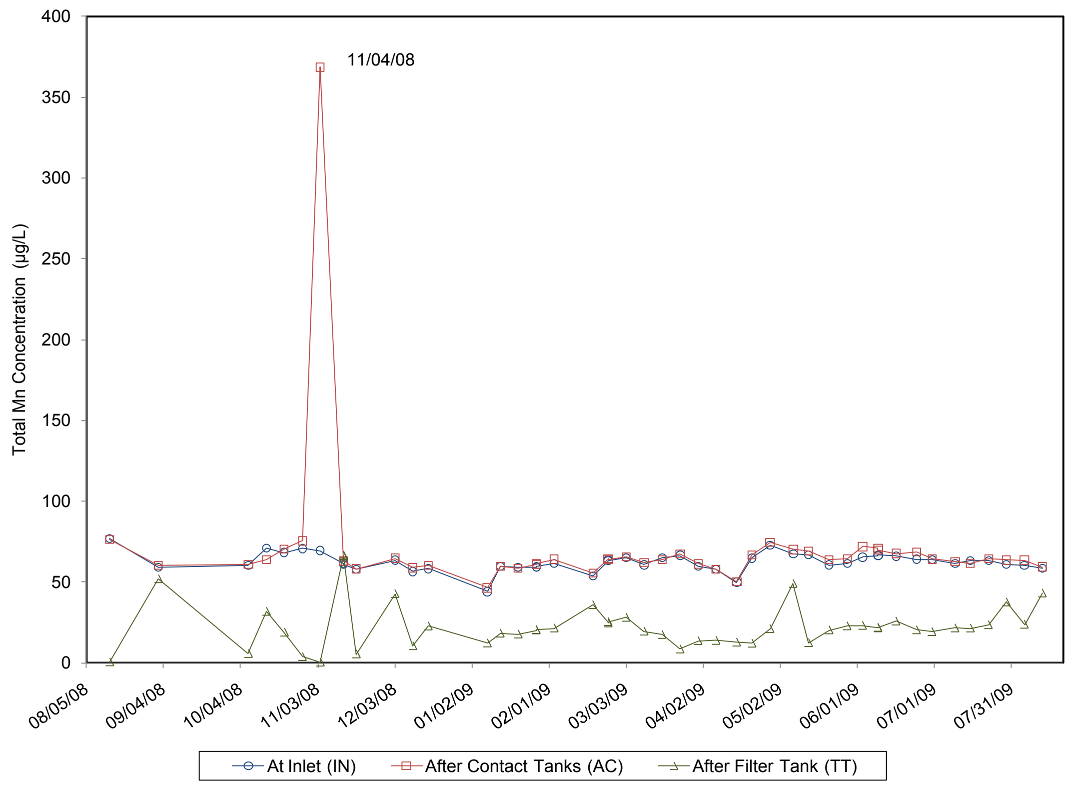

Figure 4-21. Total Manganese Concentrations across Treatment Train

4.5.1.4 pH, DO, and ORP. pH values in source water ranged from 7.4 to 7.8 and averaged 7.6. This average value was slightly lower than the pH measurement taken by Battelle during the source water sampling on October 28, 2004 (i.e., 8.0 in Table 4-1). DO levels of source water ranged from 1.0 to 4.2 mg/L and averaged 2.7 mg/L. DO levels at AC and TT remained rather unchanged at 3.3 and 2.7 mg/L, respectively. ORP readings of source water were uncharacteristically high, ranging from 361 to 486 mV and averaging 458 mV. These high values most likely were caused by the handheld meter, which tends to drift during measurements. After prechlorination, average ORP readings increased significantly to 512 mV after the contact tanks and to 521 mV after the pressure filter.

4.5.1.5 Chlorine. Figure 4-22 presents total and free chlorine residuals measured throughout the treatment train. As shown in the figure, before November 20, 2008, total and free chlorine residuals were high, due to the high chlorine dosage requested by the equipment vendor (Section 4.4.2) Average total and free chlorine residuals during this period were 1.4 and 1.3 mg/L (as Cl_2), respectively. After the chlorine dosage was reduced to an average of 0.7 mg/L (as Cl_2), average total and free chlorine residuals were reduced to 0.5 mg/L (as Cl_2) and 0.2 mg/L (as Cl_2), respectively.

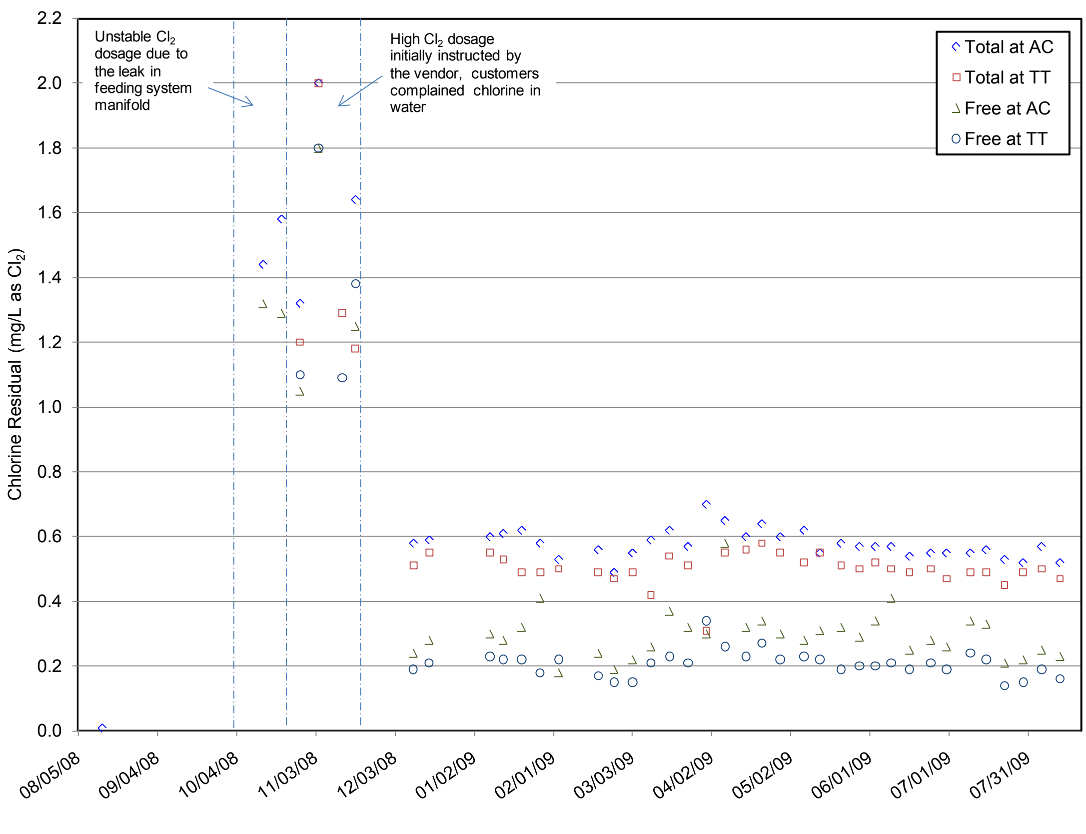

Figure 4-22. Chlorine Residuals Measured Throughout Treatment Train

Assuming that an average of 0.7 mg/L of NaOCl (as Cl_2) had been applied to source water (Section 4.4.2), 0.12 mg/L (as Cl_2) would have reacted with As(III), Fe(II), and Mn(II) based on the respective average concentrations of 13.4, 49.0, and 61.4 µg/L in source water (Table 4-7). The ammonia level in source water was measured twice, once before system startup on October 28, 2004 at 0.05 mg/L (as N) and once after system startup on December 3, 2008 at 0.1 mg/L (as N). Assuming an average ammonia level of 0.075 mg/L (as N) in source water, 0.57 mg/L (as Cl_2) would have reacted with ammonia to reach breakpoint chlorination. As such, 0.01 mg/L (as Cl_2) would have been present as free chlorine in treated water. This theoretical amount appears to fall below the measured levels for total and free residuals as shown in Figure 4-22.

4.5.1.6 Other Water Quality Parameters. Alkalinity, ammonia, fluoride, sulfate, nitrate, silica, hardness and turbidity remained relatively constant across the treatment train and were not affected by the treatment process (Table 4-8). Phosphorus levels after the contact tanks were the same as those in source water (i.e., 49.5 at AC vs. 50.8 µg/L at IN [on average]). Phosphorus levels decreased 70% (to 15 µg/L [on average]) after the pressure filter, indicating removal via C/F.

4.5.2 Filter Run Length Study. A filter run length study was conducted to delineate arsenic and iron breakthrough during the 8-hr preset filter run time on December 2, 2008, after a proper chlorine dosage had been established (Section 4.4.2). Hourly water samples were collected at AC and TT and a portion of the samples was filtered with 0.45 µm disc filters during the 8-hour time period. Iron concentrations at the TT location also were measured onsite. Figure 4-23 presents the study results.

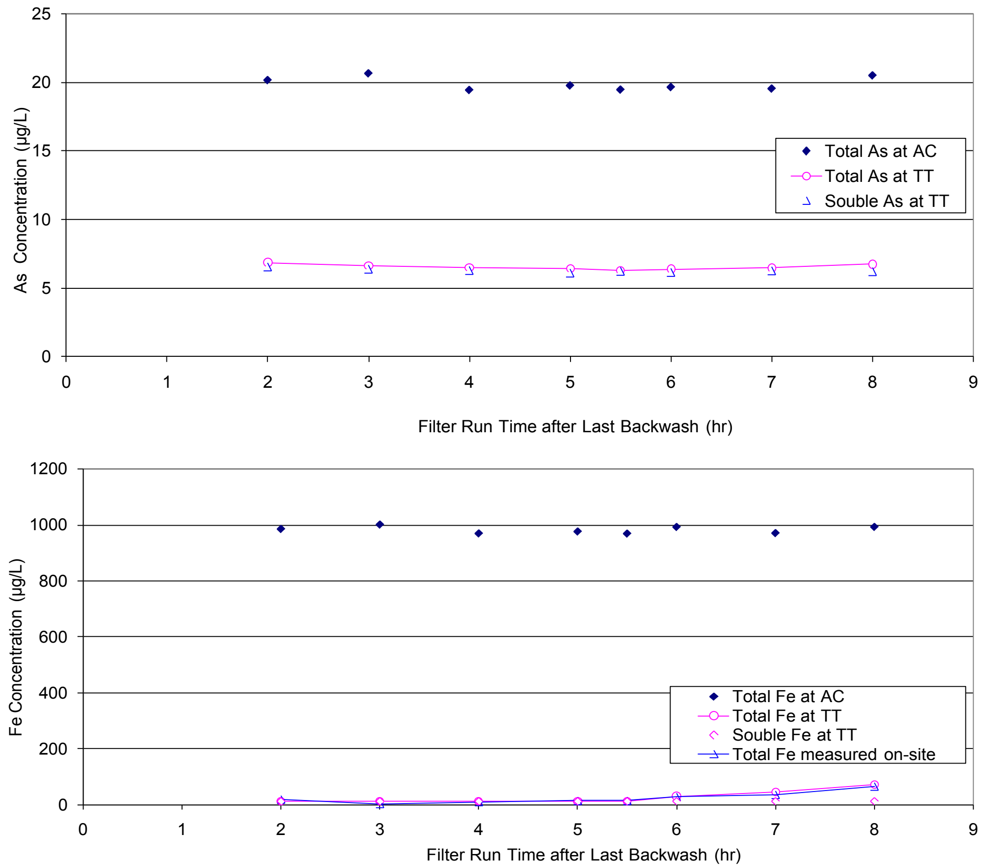

Figure 4-23. Arsenic and Iron Concentrations Measured During Filter Run Length Study

As shown in the figure, total arsenic concentrations measured at TT during the 8-hr filter run ranged from 6.3 to 6.9 µg/L and averaged 6.5 µg/L, existing primarily as soluble arsenic (i.e. over 96%). Total iron was removed to below the MDL of 25 µg/L at TT from the beginning of the filter run to 5.5 hr into the run. Total iron concentrations at TT then began to increase (to 72 µg/L at the end of the 8 hr-run) with soluble iron concentrations remaining at <25 µg/L, indicating particulate iron breakthrough. The results of the run length study suggested that conducting backwash every 8 hr was sufficient to maintain effective filter performance for arsenic and iron removal.

4.5.3 Backwash Water and Solids Sampling. Treated water was used for backwash. Table 4-10 presents analytical results from 11 backwash wastewater sampling events during the 1-year performance evaluation study. Most of the sampling events took place after a filter run time of 8 hr. Events 3 through 6 had shorter filter run times, ranging from 1.5 to 7 hr. The filter run time for Event 1 on October 21, 2008, was not recorded. The results from Events 1 and 6 were excluded from average and range calculations as described below. Excluding the two unrepresentative sampling events, the average filter run time was 7.4 hr.

Table 4-10. Backwash Wastewater Sampling Results

Sampling Event		Filter Run Time	pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)
No.	Date	hr	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
1	10/21/08	-	8.0	340	54	204	7.3	197	16,691	150	537	8.9
2	11/18/08	8.0	7.9	330	195	898	8.0	890	76,519	41	3,170	4.9
3	12/16/08	7.0	7.9	360	114	489	8.9	480	51,395	267	1,236	28.4
4	01/20/09	5.6	7.9	362	100	394	7.0	387	27,028	118	884	26.9
5	02/18/09	5.9	7.8	298	78	259	5.4	253	22,858	59	410	27.0
6	03/17/09	1.5	7.9	348	10	98	5.8	93	5,677	56	204	29.3
7	04/14/09	8.0	7.9	346	94	383	6.6	376	32,486	274	562	24.5
8	05/12/09	8.0	7.9	370	90	420	10.5	409	36,169	563	1,054	42.5
9	06/09/09	8.0	7.8	376	114	450	6.8	444	31,687	122	1,148	34.6
10	07/09/09	8.0	7.8	350	80	389	6.8	382	26,581	131	960	34.3
11	07/29/09	8.0	7.8	400	105	476	3.5	472	38,060	122	992	42.1

TDS = total dissolved solids; TSS = total suspended solids

pH, TDS, and total suspended solids (TSS) values ranged from 7.8 to 7.9 (averaged 7.9), from 298 to 400 mg/L (averaged 355 mg/L), and from 78 to 195 mg/L (averaged 108 mg/L), respectively. The average pH value of backwash wastewater (7.9) was slightly higher than those across the treatment train (i.e., 7.6 at IN, 7.7 at AC, and 7.8 at TT). Concentrations of total arsenic, iron, and manganese ranged from 259 to 898 µg/L (averaged 462 µg/L), from 22.9 to 76.5 mg/L (averaged 38.1 mg/L), and 410 to 3,170 µg/L (averaged 1,157 µg/L), respectively. Over 97.5% of these metals were present in the partculate form.

Assuming that 6,150 gal (Table 4-5) of backwash wastewater would be generated from each backwash event and that 108 mg/L of TSS would be produced, approximately 2.5 kg of solids was generated and discharged into the reclaim tank during each backwash event. Based on the average particulate metal data in Table 4-9, approximately 10.6 g of arsenic (i.e., 0.4% by weight), 882 g of iron (i.e., 35.3 % by weight), and 26.3 g of manganese (i.e., 1.1 % by weight) were generated from each vessel during each backwash event.

Solids loadings to the reclaim tank also were monitored through collection of backwash solids (Section 3.3.5). Table 4-11 presents analytical results of the solid samples collected on April 14, 2009. Arsenic, iron, and manganese levels in solids averaged 3.9 mg/g (or 0.4% by weight), 381 mg/g (or 38.1% by weight), and 1.1 mg/g (or 1% by weight), respectively. These amounts matched very closely with those derived from the backwash wastewater metal analysis (i.e. 0.4%, 35.3%, and 1.1%, respectively).

Table 4-11. Backwash Solids Sampling Results

	Mg	Si	P	Ca	Fe	Mn	As	Ba
Sample ID	**µg/g**	**µg/g**	**µg/g**	**µg/g**	**µg/g**	**µg/g**	**µg/g**	**µg/g**
04-14-09 Sample A	10,262	5,759	12,853	57,890	389,821	10,705	4,031	1,086
04-14-09 Sample B	10,084	5,682	12,496	56,078	372,911	10,308	3,835	1,060
Average	10,173	5,720	12,675	56,984	381,366	10,507	3,933	1,073

4.5.4 Distribution System Water Sampling. Prior to system startup, four monthly baseline distribution water samples were collected from September 2005 to January 2006 at three locations within the distribution system. The three locations selected for distribution system water sampling included two LCR residences and one non-LCR residence. Following system startup, distribution system water sampling continued on a monthly basis at the same locations. The two LCR locations (DS1 and DS2) were impacted by water from all four wells in the distribution system. The non-LCR location (DS3) was impacted by water from all wells before system startup, but was impacted predominantly by water from the treatment plant after system startup. Table 4-12 summarizes results of the distribution system water sampling. All stagnation times for the sampling met the 6-hr minimum stagnation time requirement, except for three occasions on October 7, 2008, at DS1 (5.8 hr), November 13, 2008, at DS2 (1.0 hr), and December 16, 2008, at DS2 (5.5 hr).

There was no change in pH before and after system startup. pH values before startup ranged from 7.6 to 8.4 and averaged 7.9; pH values after system startup ranged from 7.4 to 8.4 and averaged 7.9. Alkalinity levels remained essentially unchanged, with concentrations ranging from 185 to 308 mg/L (as $CaCO_3$) before startup and from 157 to 354 mg/L (as $CaCO_3$) after startup.

Arsenic concentrations during the four baseline sampling events varied significantly, ranging from 3.4 to 15.9 µg/L and averaging 10.3 µg/L, with comparable concentrations among the three sampling locations. The baseline arsenic concentrations observed were significantly lower than those in source water (14.7 to 22.7 µg/L and averaged 17.9 µg/L), as shown in Table 4-7. These results were expected, because before system startup, water at DS1, DS2, and DS3 were from all four wells (Wells 2, 3, 4, and 5) in the distribution system.

After system startup, arsenic concentrations at DS3 (with water supplied by the treatment plant alone) decreased to an average of 6.8 µg/L, which was very close to that in system effluent (6.2 µg/L in Table 4-7). Figure 4-24 illustrates the effects of the treatment system on arsenic, iron, and manganese concentrations in the distribution system.

Table 4-12. Distribution System Sampling Results

Sampling Event		DS1								DS2								DS3[(a)]							
		150 Hennepin St								650 4th Ave South								341 River Ave							
		LCR								LCR								Residence							
		1st draw								1st draw								1st Draw							
		Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu
No.	Date	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	hr	S.U.	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
BL1	09/27/05[(b)]	9.5	7.8	194	13.9	<25	25.6	1.2	67.9	7.8	7.9	185	13.8	<25	28.3	0.3	11.2	8.6	7.9	194	12.0	55	36.2	9.8	4.8
BL2	10/25/05	7.1	7.8	198	9.0	<25	10.3	1.3	147	7.8	7.6	290	4.4	<25	2.0	1.6	238	12.5	7.6	308	3.4	<25	0.3	1.1	66.6
BL3	11/22/05	8.8	7.7	255	7.1	<25	1.6	0.7	246	8.3	7.8	290	5.0	<25	0.8	0.3	160	15.5	7.8	194	10.7	<25	<0.1	0.2	4.4
BL4	01/04/06	10.0	8.0	185	14.4	<25	17.1	1.2	77.9	7.5	8.2	194	14.5	<25	18.3	0.7	48.2	13.0	8.4	189	15.9	<25	<0.1	0.3	5.5
1	09/02/08	7.0	8.0	184	11.1	<25	9.6	1.2	57.8	7.0	8.1	184	8.8	<25	17.4	0.8	30.4	8.3	8.4	186	11.2	43	<0.1	0.8	9.7
2	10/07/08	5.8	7.7	184	7.1	<25	7.4	2.2	117	6.3	7.9	180	6.7	<25	4.0	1.4	58.5	12.0	7.7	175	6.6	<25	0.7	0.7	28.3
3	11/13/08	8.0	7.8	178	8.9	<25	2.0	0.9	63.6	1.0	8.1	178	8.4	<25	1.8	0.1	13.3	NA	8.0	187	7.5	<25	1.7	0.4	5.8
4	12/16/08	7.8	7.9	172	8.2	84	8.7	9.9	87.5	5.5	8.0	176	6.9	<25	7.1	1.1	30.2	NA	8.0	178	7.2	85	9.6	2.6	7.9
5	01/21/09	6.9	7.9	169	6.8	<25	7.3	1.4	77.7	6.0	8.0	174	6.9	<25	9.1	0.5	17.2	11.1	8.2	176	6.4	<25	1.9	0.3	5.0
6	02/18/09	8.5	7.4	221	4.1	<25	11.2	1.4	151	6.8	7.4	347	3.4	<25	3.1	1.8	109	11.0	7.5	354	3.3	<25	0.1	0.4	17.9
7	03/18/09	6.0	7.8	174	6.7	<25	8.8	1.6	86	7.3	8.1	178	6.6	<25	6.3	2.2	123	10.5	8.2	180	7.6	<25	0.7	0.2	5.0
8	04/15/09	9.3	7.6	157	4.5	<25	19.2	0.5	89	6.0	8.0	180	6.1	<25	7.1	0.4	37	10.0	8.2	175	6.8	77	1.3	2.3	18.4
9	05/13/09	6.5	8.0	178	6.1	<25	8.4	2.5	78	6.0	8.1	188	6.6	<25	7.7	2.4	102	9.0	8.2	181	5.6	<25	2.2	1.5	21.7
10	06/04/09	6.3	7.6	198	5.0	<25	5.9	1.9	119	6.0	7.7	190	6.4	<25	9.0	1.7	104	16.0	7.8	200	6.5	<25	0.5	0.2	10.8
11	07/01/09	7.5	7.6	196	5.8	<25	8.1	1.7	130	6.5	7.7	212	4.9	<25	8.0	0.6	69	10.0	8.0	236	6.4	<25	0.9	0.7	18.5
12	08/12/09	NA[(c)]	NA[(c)]	NA[(c)]	NA[(c)]	NA[(c)]	NA[(c)]	NA[(c)]	NA[(c)]	6.0	7.8	190	7.3	<25	7.5	2.2	184	12.0	7.8	183	6.8	<25	5.4	0.5	35.9

(a) Water softener present at this location.

(b) Sample DS3 collected on 09/26/05.

(c) Homeowner was not available during sampling

BL = baseline sampling; NA = data not available.

Lead action level = 15 µg/L; copper action level = 1,300 µg/L.

Alkalinity measured in mg/L as $CaCO_3$.

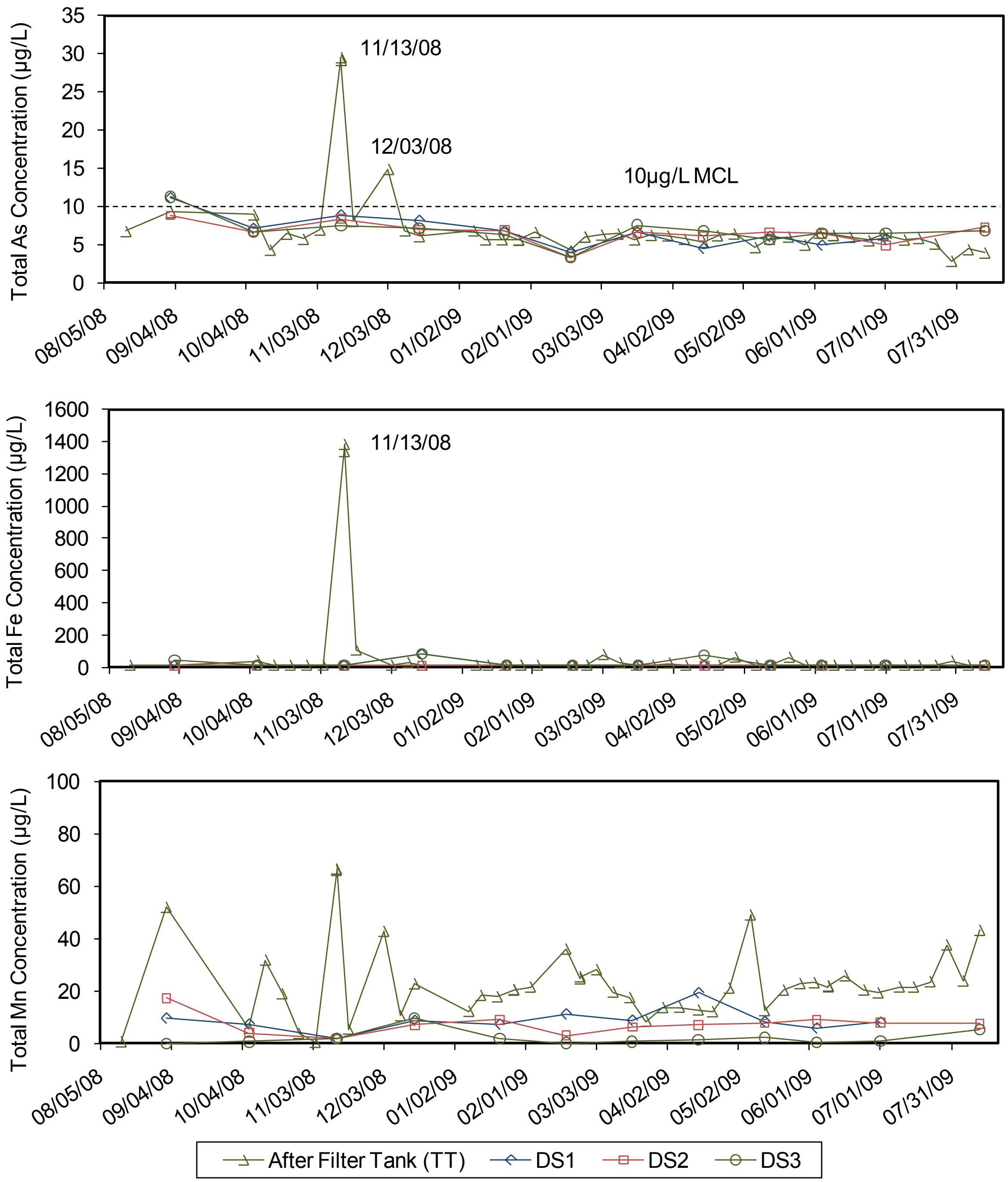

Figure 4-24. Effect of Treatment System on Arsenic, Iron, and Manganese in Distribution System

Iron concentrations in the baseline samples were low, ranging from <25 to 55.5 µg/L and averaging 16.1 µg/L. Similar to arsenic, iron concentrations were lower than those in source water (ranging from <25 to 230 µg/L and averaging 78 µg/L in Table 4-7). After system startup, the average iron concentration at DS3 increased to 26.5 µg/L, which was slightly higher than the average iron concentration of 20.5 µg/L in system effluent (Table 4-7). As shown in Figure 4-24, for the most part, iron concentrations at DS3 were <25 µg/L, which was similar to those in treatment system effluent.

Total manganese concentrations in the distribution system averaged 11.7 µg/L before system startup and decreased to 6.1 µg/L (on average) after system startup. Total manganese concentrations at DS3 averaged 2.1 µg/L, which was lower than those measured in system effluent (i.e. 21 µg/L [on average] at TT location, Table 4-7). The reduction in total manganese concentration might be due to continuing oxidation and precipitation of soluble manganese in the distribution system.

Lead concentrations within the distribution system remained unchanged from the baseline levels; copper concentrations decreased slightly. Baseline lead concentrations ranged from 0.2 to 9.8 µg/L and averaged 1.6 µg/L. After system startup, lead levels remained at 1.5 µg/L (on average) with no samples exceeding the action level of 15 µg/L. Baseline copper concentrations ranged from 4.4 to 246 µg/L and averaged 89.8 µg/L. After system startup, copper concentrations decreased to an average of 61.6 µg/L with no samples exceeding the 1,300 µg/L action level.

4.6 System Cost

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. Capital cost of the treatment system included the expenditure for equipment, site engineering, and system installation, shakedown, and startup. O&M cost included the expenditure for chemicals, electricity, and labor. Cost associated with the building, including the reclaim system was not included in the capital cost because it was not included in the scope of this demonstration project and was funded separately by the City of Okanogan.

4.6.1 Capital Cost. The capital investment for the Filtronics FH-13 Electromedia®I arsenic removal system was $424,817 (Table 4-13). The equipment cost was $296,430 (or 70% of the total capital investment), which included cost for chemicals addition systems, two contact tanks, one filtration vessel, 174 ft^3 of Electromedia®I, 76 ft^3 of supporting media and concrete, instrumentation and controls, miscellaneous materials and supplies, and labor.

The site engineering cost covered the expenditure for preparing the required permit application submittal, including a process design report, a general arrangement drawing, P&IDs, electrical diagrams, interconnecting piping layouts, and obtaining the required permit approval from WA DOH. The engineering cost of $48,332 was 11% of the total capital investment.

The installation, shakedown, and startup cost covered the labor and materials required to unload, install, and test the system for proper operation. The installation activities were performed by Triad Mechanical and the vendor, and startup and shakedown activities were performed by the vendor with the operator's assistance. The installation, startup, and shakedown cost of $80,055 was 19% of the total capital investment.

The total capital cost of $424,817 was normalized to $772/gpm ($0.54/gpd) of design capacity using the system's rated capacity of 550 gpm (or 792,000 gpd). The total capital cost also was converted to an annualized cost of $40,098 gal/yr using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-yr return period. Assuming that the system operated 24 hr/day, 7 day/week at the design flowrate of 550 gpm to produce 289,080,000 gal/yr, the unit capital cost would be $0.14/1,000 gal. During the 1-year demonstration study, the system produced 139,435,000 gal of water (Table 4-5); therefore, the unit capital cost increased to $0.29/1,000 gal. These calculations did not include the building construction cost.

Table 4-13. Capital Investment for Filtronics' FH-13 Electromedia®I System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment			
Filter Vessel	1	$51,540	–
Reaction Vessels Assembly of Two Tanks	1	$32,730	–
Chemical Feed Systems	1	$4,700	–
Pipes, Valves, Fittings, & Skid Mounting	1	$49,970	–
Electromedia and Support Layers	1	$25,500	–
Instrumentation and Controls	1	$57,700	–
Sample Taps and Totalizer/Meters	6	$2,430	–
Reclaim Equipment	1	$15,100	–
Shipping	–	$47,560	–
Labor	–	$9,200	–
Equipment Total	**–**	**$296,430**	**70%**
Engineering			
Contractor	1	$48,332	–
Engineering Total	**–**	**$48,332**	**11%**
Installation, Shakedown, and Startup			
Vendor	1	$7,000	–
Contractor	1	$73,055	–
Installation, Shakedown, and Startup	**–**	**$80,055**	**19%**
Total Capital Investment	**–**	**$424,817**	**100%**

A building was constructed by the City of Okanogan to house the treatment system (Section 4.3.2). In addition to the building, a 22,500-gal concrete backwash/reclaim tank was installed (Section 4.2). The total cost of the building, recycle system, and supporting utilities was approximately $530,000, which was not included in the capital cost.

4.6.2 O&M Cost. The O&M cost included expenditure for chemicals use, electricity consumption, and labor for a combined unit cost of $0.18/1,000 gal (Table 4-14). No cost was incurred for repairs because the system was under warranty. Incremental chemical cost for iron addition was $0.03/1,000 gal and for NaOCl was $0.01/1,000 gal. Electrical power consumption was calculated based on the difference between the average monthly cost from electric bills before and after building construction and system startup. The difference in cost was approximately $910/month or $0.08/1,000 gal of water treated. The routine, non-demonstration related labor activities consumed approximately 45 min/day (Section 4.4.5.3). Based on this time commitment and a labor rate of $30/hr, the labor cost was $0.06/1,000 gal of water treated.

Table 4-14. O&M Costs for Filtronics' FH-13 Electromedia®I System

Category	Value	Remarks
Volume Processed (1,000 gal)	139,435	From 08/14/08 through 08/14/09
Chemical Usage		
42% $FeCl_3$ Unit Cost ($/lb)	$0.50	Supplied in 12 55-gal drums (665 lb) including freight
$FeCl_3$ Consumption (1b/1,000 gal)	0.057	–
$FeCl_3$ Cost ($/1,000 gal)	$0.03	–
12.5% NaOCl Unit Cost ($/lb)	$0.23	Supplied in 16 53-gal drums (530 lb) including freight
NaOCl Consumption (1b/1,000 gal)	0.061	–
NaOCl Cost ($/1,000 gal)	$0.01	–
Total Chemicals Cost ($/1,000 gal)	**$0.04**	–
Electricity Consumption		
Electricity Cost ($/month)	$910.00	Average incremental consumption after system startup; including building heating and lighting
Electricity Cost ($/1,000 gal)	**$0.08**	–
Labor		
Labor (hr/week)	5.25	45 min/day, 7 day/week
Labor Cost ($/1,000 gal)	**$0.06**	Labor rate = $30/hr
Total O&M Cost ($/1,000 gal)	$0.18	–

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APPENDIX A

OPERATIONAL DATA

Table A-1. EPA Demonstration Project At Okanogan, WA – Daily Operational Log Sheet

Week No.	Date	Hour Meter (hr)	Incre. Run Time (hr)	Well #4 Inst. Flow (gpm)	Well #4 Totalizer (kgal)	Well #4 Avg Flow (gpm)	Filter Inst. Flow (gpm)	Filter Totalizer (kgal)	Filter Avg Flow (gpm)	Filter Inlet (psi)	Filter Outlet (psi)	dP across Filter (psig)	Filter Run time Preset (hr)	Filter Run time actual (hr)	BW Counter Preset (#)	BW Counter actual (#)	BW totalizer (Kgal)	42% $FeCl_3$ Usage (gal/hr)	12.5% NaOCl Usage (gal/hr)
-	08/14/08	27,848.9	NA	543	129	NA	540	144	NA	100	100	0	-	-	-	-	84	-	-
	08/15/08	27,850.1	1.2	542	167	528	543	180	500	100	100	0	-	-	-	-	89	-	-
	08/16/08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	08/17/08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	08/18/08	27,854.8	4.7		316	528	550	329	528	100	100	0	-	-	-	-	117	-	-
	08/19/08	Treatment System Shakedown																	
-	08/26/08																		
	08/27/08	27,883.1	28.3	-	1,232	539	540	1,223	527	102	100	2	-	-	-	-	164	-	-
	08/28/08	27,914.7	31.6	-	2,255	540	534	2,227	530	102	100	2	-	-	-	-	184	-	-
	08/29/08	27,932.4	17.7	-	2,819	531	532	2,787	527	102	100	2	-	-	-	-	194	-	0.09
	08/30/08	27,955.4	23.0	-	3,568	543	533	3,539	545	104	100	4	-	-	-	-	209	-	-
	08/31/08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
-	09/01/08	28,003.0	47.6	-	-	NA	530	5,081	540	102	100	2	-	-	-	-	240	-	-
	09/02/08	28,027.0	24.0	-	5,869	536	530	5,857	539	102	100	2	-	-	-	-	255	0.09	0.07
	09/03/08	28,047.8	20.8	-	6,538	536	535	6,530	539	100	100	0	-	-	-	-	270	0.09	0.10
	09/04/08	28,011.4	NA	-	7,291	NA	535	7,298	NA	102	100	2	-	-	-	-	285	-	-
	09/05/08	Treatment System Taken Offline for Chlorine Dosage Tests																	
1	10/01/08																		
	10/02/08	28,223.0	-	-	12,140	-	534	12,143	-	101	100	1	-	-	-	-	403	-	-
	10/03/08	28,246.0	23.0	-	12,870	529	525	12,879	533	102	101	1	-	-	-	-	413	0.08	0.23
	10/04/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	-	-	-	-	NM[a]	-	-
	10/05/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	-	-	-	-	NM[a]	-	-
2	10/06/08	28,253.7	7.7	-	13,102	502	535	13,106	491	102	100	2	-	-	-	-	424	0.29	0.53
	10/07/08	28,275.9	22.2	-	13,806	529	533	13,801	522	102	100	2	-	-	-	-	439	0.04	0.28
	10/08/08	28,291.8	15.9	-	14,313	531	527	14,301	524	102	101	1	-	-	-	-	449	0.11	0.09
	10/09/08	28,305.4	13.6	-	14,744	528	530	14,723	517	102	100	2	-	-	-	-	460	0.08	0.33
	10/10/08	28,315.2	9.8	-	15,056	531	530	15,049	554	102	100	2	-	-	-	-	481	0.08	0.21
	10/11/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	-	-	-	-	NM[a]	-	-
	10/12/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	-	-	-	-	NM[a]	-	-
3	10/13/08	28,355.6	40.4	-	16,335	528	530	16,353	538	102	101	1	-	-	-	-	517	0.17	0.02
	10/14/08	28,368.4	12.8	-	16,741	529	528	16,773	547	101	100	2	-	-	-	-	532	0.15	0.22
	10/15/08	28,380.5	12.1	-	17,124	528	570	17,155	526	102	100	2	-	-	-	-	542	0.19	0.34
	10/16/08	28,393.2	12.7	-	17,527	529	534	17,565	538	102	101	1	-	-	-	-	557	0.06	0.28
	10/17/08	28,410.4	17.2	-	18,074	530	520	18,128	546	102	101	1	-	-	-	-	573	0.10	0.31
	10/18/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	-	-	-	-	NM[a]	-	-
	10/19/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	-	-	-	-	NM[a]	-	-
4	10/20/08	28,442.6	32.2	527	NM[b]	-	580	19,161	535	102	100	2	-	-	-	-	608	0.17	0.06
	10/21/08	28,450.5	7.9	540	NM[b]	-	530	19,418	542	100	100	0	-	-	-	-	618	0.66	0.60
	10/22/08	28,457.0	6.5	531	NM[b]	-	590	19,632	549	101	100	1	-	-	-	-	628	0.46	0.13
	10/23/08	28,469.2	12.2	537	NM[b]	-	590	20,037	553	100	100	0	-	-	-	-	666	0.25	0.64
	10/24/08	28,481.6	12.4	552	NM[b]	-	550	20,441	543	100	100	0	-	-	-	-	677	0.18	0.55
	10/25/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	-	-	-	-	NM[a]	-	-
	10/26/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	-	-	-	-	NM[a]	-	-
5	10/27/08	28,517.3	35.7	538	21,465	-	540	21,612	547	101	100	1	8	-	10	7	715	0.25	0.14
	10/28/08	28,528.1	10.8	531	21,811	534	557	21,956	531	102	100	2	8	6:25	10	5	726	0.52	0.11
	10/29/08	28,542.7	14.6	530	22,276	531	535	22,434	546	101	100	1	8	4:27	10	3	736	0.49	0.11
	10/30/08	28,549.3	6.6	533	22,485	528	557	22,640	520	101	100	1	8	6:45	10	1	747	0.37	0.25
	10/31/08	28,560.6	11.3	540	22,847	534	535	23,013	550	101	99	2	8	7:51	10	9	757	0.53	0.11
	11/01/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	11/02/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
6	11/03/08	28,591.4	30.8	529	23,829	531	590	24,010	540	102	100	2	8	5:25	10	4	784	0.10	0.53
	11/04/08	28,602.7	11.3	NM[a]	24,185	525	NM[a]	24,372	534	NM[a]	NM[a]	NM[a]	N	8:00	10	2	794	0.13	0.33
	11/05/08	28,613.4	10.7	527	24,515	514	520	24,709	525	102	100	2	8	4:39	10	1	800	0.19	0.54
	11/06/08	28,625.1	11.7	532	24,890	534	580	25,087	538	101	100	1	8	6:56	-	-	810	0.06	0.49
	11/07/08	28,630.0	4.9	534	25,051	548	533	25,255	571	101	100	1	8	7:37	10	7	820	0.15	0.34
	11/08/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	11/09/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
7	11/10/08	28,642.6	12.6	NM[a]	25,442	517	NM[a]	25,664	541	NM[a]	NM[a]	NM[a]	NM[a]	0:00	10	2	845	0.12	0.07
	11/11/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	11/12/08	28,658.0	15.4	534	25,943	542	530	26,180	558	101	99	2	8	5:30	10	9	861	0.11	0.51
	11/13/08	28,674.1	16.1	529	26,450	525	570	26,692	530	102	101	1	8	6:10	10	6	877	0.14	0.28
	11/14/08	28,680.5	6.4	537	26,653	529	575	26,897	534	100	99	1	8	7:18	10	5	882	0.18	0.32
	11/15/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	11/16/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
8	11/17/08	28,717.9	37.4	537	27,840	529	535	28,101	537	102	100	2	8	7:47	10	9	914	0.15	0.40
	11/18/08	28,726.1	8.2	539	28,098	524	535	28,362	530	101	100	1	8	7:37	10	8	919	0.18	0.40
	11/19/08	28,742.5	16.4	540	28,617	527	540	28,885	532	100	99	1	8	7:49	10	5	935	0.18	0.43
	11/20/08	28,756.3	13.8	527	29,059	534	560	29,339	548	103	101	2	8	5:41	10	3	946	0.16	0.42
	11/21/08	28,763.8	7.5	539	29,296	527	535	29,577	529	100	99	1	8	7:29	10	1	957	0.25	0.11
	11/22/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	11/23/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
9	11/24/08	28,795.5	31.7	520	30,299	527	520	30,602	539	103	100	3	8	8:00	10	7	977	0.17	0.16
	11/25/08	28,801.9	6.4	538	30,503	531	530	30,809	539	100	100	0	8	7:37	10	5	988	0.82	0.19
	11/26/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	11/27/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	11/28/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	11/29/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	11/30/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-

Table A-1. US EPA Demonstration Project At Okanogan, WA – Daily Operational Log Sheet (Continued)

Week No.	Date	Hour Meter (hr)	Incre. Run Time (hr)	Well #4 Inst. Flow (gpm)	Well #4 Totalizer (kgal)	Well #4 Avg Flow (gpm)	Filter Inst. Flow (gpm)	Filter Totalizer (kgal)	Filter Avg Flow (gpm)	Filter Inlet (psi)	Filter Outlet (psi)	Filter dP across Filter (psig)	Filter Run time Preset (hr)	Filter Run time actual (hr)	BW Counter Preset (#)	BW Counter actual (#)	BW totalizer (Kgal)	42% $FeCl_3$ Usage (gal/hr)	12.5% NaOCl Usage (gal/hr)
	12/01/08	28,876.1	74.2	533	32,853	528	530	33,195	536	101	100	1	8	6:55	10	3	1049	0.08	0.16
	12/02/08	28,885.2	9.1	535	33,142	529	530	33,579	703	101	100	1	8	6:40	10	1	1059	0.16	0.18
	12/03/08	28,894.5	9.3	534	33,437	529	530	33,775	351	101	100	1	8	6:40	10	9	1070	0.02	0.02
10	12/04/08	28,906.8	12.3	536	33,830	533	530	34,161	523	101	100	1	8	7:12	10	6	1083	0.15	0.13
	12/05/08	28,919.6	12.8	534	34,240	534	530	34,565	526	101	100	1	8	6:18	10	4	1093	0.12	0.16
	12/06/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/07/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/08/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/09/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/10/08	28,976.7	57.1	537	36,059	531	525	36,391	533	101	100	1	8	7:34	4	2	1138	0.13	0.16
11	12/11/08	28,980.0	3.3	539	36,190	662	525	36,525	677	100	100	0	8	7:45	4	1	1142	2.27	2.49
	12/12/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/13/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/14/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/15/08	29,027.3	47.3	532	37,673	523	530	38,037	533	101	100	1	8	4:25	4	2	1177	0.13	0.14
	12/16/08	29,030.2	2.9	537	37,770	557	530	38,127	517	100	99	1	8	6:29	4	3	1183	0.13	0.07
	12/17/08	29,044.3	14.1	531	38,223	535	525	38,585	541	101	99	2	8	5:40	4	1	1188	0.12	0.12
12	12/18/08	29,058.5	14.2	530	38,585	425	525	38,944	421	102	99	3	8	7:18	4	3	1189	0.16	0.13
	12/19/08	29,067.8	9.3	526	38,958	668	520	39,314	663	103	99	4	8	6:42	4	1	1189	0.10	0.22
	12/20/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/21/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/22/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/23/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/24/08	NM[a]	-	500	40,490	-	495	40,831	-	109	99	10	8	5:00	4	1	1190	-	-
13	12/25/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/26/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/27/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/28/08	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	12/29/08	29,179.2	111.4	481	42,276	267	460	42,599	265	113	100	13	8	9:36	4	3	1191	0.07	0.08
	12/30/08	29,186.6	7.4	534	42,502	509	530	42,821	500	100	99	1	8	2:52	4	3	1204	0.15	0.17
	12/31/08	29,198.6	12.0	536	42,881	526	525	43,208	538	100	99	1	8	5:45	4	1	1212	0.12	0.14
14	01/01/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	01/02/09	29,219.0	20.4	534	43,533	533	525	43,869	540	100	99	1	8	13:40	4	1	1235	0.13	0.14
	01/03/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	01/04/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	01/05/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	01/06/09	29,264.2	45.2	513	44,946	521	500	45,278	520	105	100	5	8	7:10	4	1	1239	0.14	0.15
	01/07/09	29,275.9	11.7	534	45,315	526	525	45,654	536	101	100	1	8	5:10	4	1	1267	0.13	0.14
15	01/08/09	29,287.9	12.0	532	45,700	535	525	46,033	526	100	100	0	8	6:47	4	3	1279	0.11	0.14
	01/09/09	29,296.0	8.1	530	45,955	525	525	46,297	543	101	100	1	8	3:50	4	2	1285	0.12	0.18
	01/10/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	01/11/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	01/12/09	29,324.6	28.6	536	46,871	682	520	47,219	691	100	99	1	8	6:17	4	1	1311	0.12	0.12
	01/13/09	29,335.4	10.8	535	47,217	534	525	47,571	543	100	99	1	8	6:26	4	3	1322	0.17	0.13
	01/14/09	29,343.5	8.1	536	47,475	531	525	47,830	533	100	99	1	8	6:06	4	2	1333	0.19	0.20
16	01/15/09	29,353.3	9.8	537	47,787	531	525	48,153	549	100	99	1	8	6:38	4	4	1344	0.15	0.21
	01/16/09	29,364.5	11.2	536	48,145	533	525	48,516	540	100	99	1	8	6:15	4	2	1354	0.13	0.15
	01/17/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	01/18/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	01/19/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	01/20/09	29,403.1	38.6	534	49,380	533	525	49,768	541	100	100	0	8	6:38	4	3	1380	0.14	0.12
	01/21/09	29,411.0	7.9	535	49,634	536	525	50,027	546	100	100	0	8	6:10	4	1	1380	0.14	0.31
17	01/22/09	29,418.7	7.7	535	49,881	535	525	50,283	554	100	100	0	8	5:46	4	3	1389	0.15	0.16
	01/23/09	29,427.4	8.7	533	50,158	531	520	50,560	531	100	99	1	8	6:16	4	1	1395	0.13	0.14
	01/24/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	01/25/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	01/26/09	29,464.7	37.3	534	51,347	655	525	51,749	655	100	100	0	8	6:50	4	2	1424	0.12	0.15
	01/27/09	29,473.2	8.5	533	51,619	533	520	52,023	537	100	100	0	8	4:46	4	4	1434	0.18	0.15
	01/28/09	29,485.8	12.6	534	52,020	530	525	52,432	541	100	100	0	8	7:00	4	2	1448	0.15	0.15
18	01/29/09	29,494.9	9.1	534	52,309	529	520	52,720	527	100	100	0	8	6:12	4	4	1459	0.12	0.09
	01/30/09	29,507.4	12.5	531	52,709	533	520	53,131	548	100	100	0	8	3:37	4	2	1469	0.15	0.16
	01/31/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	02/01/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	02/02/09	29,540.3	32.9	539	53,756	733	525	54,176	738	100	100	0	8	7:53	4	4	1492	0.19	0.24
	02/03/09	29,551.0	10.7	537	54,096	530	525	54,514	526	100	100	0	8	7:21	4	4	1513	0.16	0.13
	02/04/09	29,563.7	12.7	532	54,519	555	520	54,943	563	100	100	0	8	5:34	1	1	1522	0.12	0.10
19	02/05/09	29,577.2	13.5	527	54,934	512	520	55,366	522	101	100	1	8	1:45	2	1	1533	0.11	0.12
	02/06/09	29,583.7	6.5	535	55,139	526	525	55,573	531	100	100	0	8	6:53	2	1	1544	0.17	0.13
	02/07/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	02/08/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	02/09/09	29,617.3	33.6	534	56,210	633	525	56,656	640	101	100	1	8	6:39	4	1	1577	0.14	-
	02/10/09																		
	02/11/09																		
20	02/12/09																		
	02/13/09	Treatment System Shut Down for Operators to Attend Training Class																	
	02/14/09																		
	02/15/09																		
	02/16/09																		
	02/17/09	29,625.5	8.2	524	56,474	537	520	56,915	526	102	100	2	8	0:29	4	3	1589	0.05	0.65
	02/18/09	29,632.7	7.2	532	56,702	528	520	57,234	738	101	100	1	8	6:01	4	1	1601	0.16	0.17
21	02/19/09	29,640.7	8.0	536	56,959	535	525	57,419	385	100	100	0	8	6:40	4	3	1612	0.09	0.05
	02/20/09	29,652.4	11.7	535	57,331	530	525	57,784	520	100	100	0	8	6:16	4	4	1624	0.10	0.18
	02/21/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	02/22/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-

Table A-1. US EPA Demonstration Project At Okanogan, WA – Daily Operational Log Sheet (Continued)

Week No.	Date	Hour Meter (hr)	Incre. Run Time (hr)	Well #4 Inst. Flow (gpm)	Well #4 Totalizer (kgal)	Well #4 Avg Flow (gpm)	Filter Inst. Flow (gpm)	Filter Totalizer (kgal)	Filter Avg Flow (gpm)	Filter Inlet (psi)	Filter Outlet (psi)	Filter dP across Filter (psig)	Filter Run time Preset (hr)	Filter Run time actual (hr)	BW Counter Preset (#)	BW Counter actual (#)	BW totalizer (Kgal)	42% $FeCl_3$ Usage (gal/hr)	12.5% NaOCl Usage (gal/hr)
22	02/23/09	29,681.5	29.1	529	58,258	744	520	58,727	749	101	100	1	8	3:23	4	4	1648	0.14	0.11
	02/24/09	29,686.6	5.1	540	58,421	533	530	58,886	520	100	100	0	8	7:52	4	2	1656	0.18	0.32
	02/25/09	29,696.4	9.8	536	58,734	532	520	59,202	537	100	100	0	8	6:40	4	1	1663	0.11	0.13
	02/26/09	29,708.3	11.9	535	59,116	535	525	59,588	541	100	100	0	8	6:06	4	3	1673	0.09	0.14
	02/27/09	29,715.3	7.0	538	59,340	533	525	59,815	540	100	100	0	8	6:35	4	2	1679	0.16	0.21
	02/28/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	03/01/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
23	03/02/09	29,752.2	36.9	529	60,519	634	520	61,014	644	101	100	1	8	1:23	4	4	1714	0.13	0.14
	03/03/09	29,763.8	11.6	527	60,888	530	520	61,387	536	101	100	1	8	0:35	4	2	1725	0.13	0.14
	03/04/09	29,772.2	8.4	534	61,155	530	525	61,656	534	100	100	0	8	7:07	4	4	1737	0.16	0.12
	03/05/09	29,779.0	6.8	536	61,372	532	525	61,875	537	100	100	0	8	6:42	4	2	1749	0.14	0.18
	03/06/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	03/07/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	03/08/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
24	03/09/09	29,818.7	39.7	534	62,646	535	525	63,179	547	100	100	0	8	4:40	4	3	1790	0.13	0.15
	03/10/09	29,830.5	11.8	529	63,025	535	525	63,563	542	101	100	1	8	1:06	4	1	1801	0.03	0.17
	03/11/09	29,843.7	13.2	534	63,414	491	525	63,956	496	100	100	0	8	6:18	4	2	1819	0.20	0.19
	03/12/09	29,853.7	10.0	533	63,763	582	525	64,310	590	102	100	2	8	6:49	4	4	1829	0.07	0.16
	03/13/09	29,865.2	11.5	531	64,134	538	520	64,690	551	100	100	0	8	6:40	4	1	1847	0.16	0.14
	03/14/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	03/15/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
25	03/16/09	29,899.4	34.2	531	65,221	530	520	65,802	542	101	100	1	8	1:50	4	3	1883	0.09	0.17
	03/17/09	29,906.4	7.0	536	65,445	533	525	66,025	531	100	100	0	8	7:16	4	1	1895	0.32	0.12
	03/18/09	29,916.7	10.3	536	65,775	534	525	66,364	549	100	100	0	8	7:13	4	2	1912	0.05	0.14
	03/19/09	29,927.8	11.1	537	66,130	533	525	66,729	548	100	100	0	8	7:20	4	4	1924	0.07	0.19
	03/20/09	29,940.5	12.7	528	66,534	530	520	67,144	545	101	100	1	8	2:46	4	4	1935	0.15	0.16
	03/21/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	03/22/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
26	03/23/09	29,961.1	20.6	550	67,193	533	525	67,815	543	100	100	0	8	8:00	4	1	1965	0.16	0.22
	03/24/09	29,973.5	12.4	538	67,593	538	525	68,221	546	100	100	0	8	7:26	4	3	1977	0.18	0.23
	03/25/09	29,984.2	10.7	541	67,933	530	520	68,569	542	100	100	0	8	7:50	4	4	1994	0.05	0.08
	03/26/09	29,991.0	6.8	539	68,152	537	525	68,792	547	100	100	0	8	7:37	4	2	2006	0.11	0.09
	03/27/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	03/28/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	03/29/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
27	03/30/09	30,028.0	37.0	537	69,344	537	525	69,998	543	99	99	0	8	6:20	4	3	2048	0.12	0.16
	03/31/09	30,038.0	10.0	530	69,671	545	520	70,332	557	100	100	0	8	1:52	4	2	2054	0.15	0.19
	04/01/09	30,046.0	8.0	539	69,931	542	525	70,593	544	99	99	0	8	7:23	4	3	2071	0.09	0.21
	04/02/09	30,064.0	18.0	523	70,510	536	520	71,184	547	101	100	1	8	0:08	4	1	2083	0.15	0.14
	04/03/09	30,076.0	12.0	529	70,884	519	520	71,557	518	100	100	0	8	6:31	4	1	2108	0.12	0.14
	04/04/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	04/05/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
28	04/06/09	30,106.3	30.3	533	71,837	524	520	72,529	535	100	100	0	8	7:35	4	3	2144	0.17	0.15
	04/07/09	30,117.0	10.7	532	72,200	565	520	72,897	573	100	100	0	8	6:09	4	3	2162	0.11	0.17
	04/08/09	30,133.0	16.0	534	72,700	521	525	73,412	536	100	100	0	8	6:08	4	1	2174	0.12	0.15
	04/09/09	30,151.0	18.0	530	73,272	530	520	73,989	534	100	100	0	8	2:51	4	2	2192	0.10	0.11
	04/10/09	30,163.0	12.0	532	73,645	518	520	74,360	515	100	100	0	8	6:37	4	3	2209	0.16	0.17
	04/11/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	04/12/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
29	04/13/09	30,200.4	37.4	537	74,828	527	525	75,558	534	100	100	0	8	7:41	4	1	2242	0.15	0.15
	04/14/09	30,215.0	14.6	534	75,309	549	520	76,044	555	100	100	0	8	6:14	4	2	2258	0.10	0.11
	04/15/09	30,228.0	13.0	532	75,709	513	560	76,449	519	100	100	0	8	5:47	4	4	2269	0.14	0.13
	04/16/09	30,247.0	19.0	529	76,341	554	520	77,075	549	100	100	0	8	4:16	4	1	2286	0.14	0.13
	04/17/09	30,261.0	14.0	525	76,784	527	520	77,538	551	101	100	1	8	0:20	4	3	2298	0.13	0.18
	04/18/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	04/19/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
30	04/20/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	04/21/09	30,320.0	59.0	531	78,663	531	520	79,427	534	100	100	0	8	6:17	4	1	2353	0.13	0.17
	04/22/09	30,334.0	14.0	536	79,108	530	525	79,876	535	100	100	0	8	6:17	4	3	2363	0.13	0.15
	04/23/09	30,353.0	19.0	530	79,691	511	520	80,465	517	100	100	0	8	6:11	4	3	2385	0.12	0.13
	04/24/09	30,371.0	18.0	531	80,257	524	520	81,038	531	100	100	0	8	6:00	4	4	2400	0.12	0.16
	04/25/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	04/26/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
31	04/27/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	04/28/09	30,440.0	69.0	526	82,458	532	520	83,258	536	101	100	1	8	1:20	4	2	2458	0.13	0.14
	04/29/09	30,455.0	15.0	530	82,935	530	525	83,737	532	101	100	1	8	7:13	4	3	2475	0.12	0.16
	04/30/09	30,471.0	16.0	531	83,439	525	525	84,249	533	100	100	0	8	2:58	4	1	2485	0.14	0.15
	05/01/09	30,494.0	23.0	526	84,193	546	520	85,005	548	101	100	1	8	2:51	4	2	2503	0.13	0.14
	05/02/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	05/03/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
32	05/04/09	30,539.7	45.7	532	85,606	515	520	86,436	522	100	100	0	8	6:13	4	1	2554	0.23	0.16
	05/05/09	30,561.0	21.3	526	86,290	535	520	87,125	539	101	100	1	8	2:42	4	1	2572	0.12	0.08
	05/06/09	30,568.0	7.0	528	86,525	560	520	87,362	564	100	100	0	8	6:06	4	4	2583	0.16	0.18
	05/07/09	30,579.0	11.0	528	86,877	533	520	87,715	535	100	100	0	8	7:20	4	2	2594	0.14	0.00
	05/08/09	30,591.0	12.0	531	87,250	518	520	88,092	524	100	100	0	8	7:25	4	4	2605	0.16	0.17
	05/09/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	05/10/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
33	05/11/09	30,645.0	54.0	526	88,952	525	515	89,810	530	101	100	1	8	3:50	4	4	2650	0.12	0.18
	05/12/09	30,670.0	25.0	524	89,757	537	520	90,620	540	101	100	1	8	0:21	4	1	2667	0.12	0.10
	05/13/09	30,685.0	15.0	533	90,245	542	520	91,101	534	100	100	0	8	6:41	4	2	2683	0.15	0.19
	05/14/09	30,702.0	17.0	532	90,783	527	520	91,640	528	100	100	0	8	7:50	4	3	2699	0.13	0.15
	05/15/09	30,716.0	14.0	530	91,218	518	520	92,086	531	101	100	1	8	6:56	4	1	2710	0.13	0.18
	05/16/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	05/17/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-

Table A-1. US EPA Demonstration Project At Okanogan, WA – Daily Operational Log Sheet (Continued)

Week No.	Date	Hour Meter (hr)	Incre. Run Time (hr)	Well #4 Inst. Flow (gpm)	Well #4 Totalizer (kgal)	Well #4 Avg Flow (gpm)	Filter Inst. Flow (gpm)	Filter Totalizer (kgal)	Filter Avg Flow (gpm)	Filter Inlet (psi)	Filter Outlet (psi)	Filter dP across Filter (psig)	Filter Run time Preset (hr)	Filter Run time actual (hr)	BW Counter Preset (#)	BW Counter actual (#)	BW totalizer (Kgal)	42% $FeCl_3$ Usage (gal/hr)	12.5% NaOCl Usage (gal/hr)
	05/18/09	30,777.9	61.9	524	93,160	523	560	94,034	525	103	101	2	8	5:38	4	4	2758	0.13	0.16
	05/19/09	30,798.0	20.1	522	93,801	532	520	94,677	533	101	100	1	8	0:35	4	2	2768	0.07	0.08
	05/20/09	30,821.0	23.0	526	94,536	533	555	95,416	536	101	100	1	8	3:51	4	2	2788	0.16	0.14
34	05/21/09	30,832.0	11.0	530	94,902	555	520	95,787	562	102	100	2	8	1:10	4	4	2799	0.14	0.15
	05/22/09	30,858.0	26.0	532	95,726	528	520	96,608	526	100	100	0	8	7:07	4	4	2819	0.12	0.14
	05/23/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	05/24/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	05/25/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	05/26/09	30,902.6	44.6	524	97,122	522	520	98,012	525	101	100	1	8	2:48	4	2	2851	0.15	0.17
	05/27/09	30,922.0	19.4	530	97,748	538	520	98,641	540	100	100	0	8	1:50	4	3	2867	0.00	0.08
35	05/28/09	30,937.0	15.0	534	98,249	557	515	99,143	558	101	100	1	8	6:28	4	4	2883	0.12	0.16
	05/29/09	30,953.0	16.0	533	98,731	528	515	99,622	531	100	100	0	8	6:09	4	1	2899	0.12	0.13
	05/30/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	05/31/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	06/01/09	31,005.1	52.1	538	100,331	512	520	101,247	520	100	100	0	8	7:52	4	3	2953	0.15	0.17
	06/02/09	31,021.0	15.9	537	100,921	618	525	101,842	624	100	100	0	8	7:27	4	3	2973	0.05	0.10
	06/03/09	31,036.0	15.0	535	101,383	513	520	102,306	516	100	100	0	8	6:27	4	1	2983	0.10	0.11
36	06/04/09	31,056.0	20.0	528	102,016	528	520	102,946	533	102	100	2	8	2:37	4	2	2998	0.11	0.14
	06/05/09	31,077.0	21.0	527	102,683	529	515	103,615	531	102	100	2	8	2:40	4	3	3012	0.14	0.16
	06/06/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	06/07/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	06/08/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	06/09/09	31,133.0	56.0	533	104,475	533	520	105,445	545	100	100	0	8	6:40	4	3	3097	0.12	0.15
	06/10/09	31,152.0	19.0	532	105,078	529	520	106,064	543	100	100	0	8	7:28	4	2	3124	0.10	0.11
37	06/11/09	31,164.0	12.0	530	105,481	560	520	106,473	568	100	100	0	8	6:10	4	4	3135	0.19	0.21
	06/12/09	31,180.0	28.0	529	105,979	536	515	106,983	547	100	100	0	8	3:20	4	1	3151	0.09	0.10
	06/13/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	06/14/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	06/15/09	31,229.9	49.9	527	107,545	523	510	108,562	527	101	100	1	8	4:12	4	4	3197	0.12	0.13
	06/16/09	31,240.0	10.1	527	107,883	558	510	108,908	571	101	100	1	8	3:08	4	1	3213	0.07	0.16
	06/17/09	31,260.0	20.0	536	108,529	538	525	109,555	539	100	100	0	8	4:06	4	1	3233	0.09	0.06
38	06/18/09	31,272.0	12.0	531	108,909	528	520	109,938	532	100	100	0	8	6:16	4	2	3249	0.16	0.17
	06/19/09	31,291.0	19.0	525	109,513	530	520	110,555	541	101	100	1	8	2:40	4	3	3264	0.16	0.17
	06/20/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	06/21/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	06/22/09	31,330.6	39.6	531	110,745	519	510	111,797	523	102	101	1	8	7:42	4	2	3315	0.18	0.20
	06/23/09	31,341.4	10.8	528	111,090	532	515	112,148	542	100	100	0	8	6:43	4	3	3332	0.03	0.00
	06/24/09	31,359.1	17.7	525	111,650	527	560	112,716	535	101	100	1	8	5:40	4	1	3343	0.13	0.14
39	06/25/09	31,376.3	17.2	531	112,196	529	515	113,263	530	100	100	0	8	6:30	4	1	3364	0.09	0.19
	06/26/09	31,399.0	22.7	525	112,915	528	510	113,994	537	102	100	2	8	1:54	4	2	3379	0.15	0.14
	06/27/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	06/28/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	06/29/09	31,461.7	62.7	529	114,896	527	515	115,959	522	101	100	1	8	7:33	4	4	3431	0.13	0.16
	06/30/09	31,481.0	19.3	529	115,507	528	510	116,566	524	100	100	0	8	7:19	4	1	3447	0.17	0.21
	07/01/09	31,499.2	18.2	528	116,080	525	510	117,146	531	100	100	0	8	6:26	4	1	3469	0.12	0.13
40	07/02/09	31,517.7	18.5	528	116,667	529	510	117,746	541	100	100	0	8	6:31	4	1	3490	0.12	0.14
	07/03/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	07/04/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	07/05/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	07/06/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	07/07/09	31,566.0	48.3	522	118,205	531	510	119,309	539	101	100	1	8	1:36	4	3	3543	0.11	0.14
	07/08/09	31,583.6	17.6	519	118,730	497	510	119,839	502	102	100	2	8	0:35	4	4	3560	0.11	0.14
41	07/09/09	31,599.0	15.4	520	119,234	545	565	120,347	550	102	100	2	8	3:49	4	4	3580	0.15	0.21
	07/10/09	31,619.0	20.0	522	119,864	525	565	120,986	533	102	100	2	8	5:07	4	4	3602	0.11	0.16
	07/11/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	07/12/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	07/13/09	31,663.2	44.2	522	121,237	518	520	122,373	523	101	100	1	8	4:44	4	3	3649	0.15	0.16
	07/14/09	31,676.0	12.8	523	121,640	525	510	122,780	530	101	100	1	8	4:00	4	1	3660	0.06	0.13
	07/15/09	31,695.0	19.0	520	122,250	535	515	123,386	532	101	100	1	8	5:10	4	2	3676	0.20	0.17
42	07/16/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	07/17/09	31,732.0	37.0	519	123,403	519	510	124,560	529	102	100	2	8	4:48	4	3	3713	0.10	0.16
	07/18/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	07/19/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	07/20/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	07/21/09	31,809.0	77.0	515	125,837	527	510	127,011	531	102	100	2	8	0:55	4	2	3782	0.13	0.16
	07/22/09	31,825.0	16.0	520	126,326	509	560	127,508	518	101	100	1	8	4:38	4	2	3804	0.14	0.21
43	07/23/09	31,843.0	18.0	518	126,889	521	510	128,081	531	102	100	2	8	2:40	4	2	3825	0.12	0.14
	07/24/09	31,861.0	18.0	522	127,448	518	510	128,641	519	101	100	1	8	6:14	4	3	3841	0.12	0.14
	07/25/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	07/26/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	07/27/09	31,910.8	49.8	521	129,025	528	510	130,231	532	102	100	2	8	5:19	4	3	3882	0.14	0.03
	07/28/09	31,929.0	18.2	523	129,589	516	510	130,795	516	100	100	0	8	6:20	4	4	3897	0.08	0.00
	07/29/09	31,947.0	18.0	521	130,165	533	510	131,379	541	102	100	2	8	2:28	4	1	3913	0.08	0.18
44	07/30/09	31,969.0	22.0	523	130,832	505	510	132,046	505	100	100	0	8	6:52	4	1	3933	0.17	0.19
	07/31/09	31,990.0	21.0	516	131,507	536	510	132,729	542	102	100	2	8	3:08	4	2	3947	0.11	0.20
	08/01/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	08/02/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-

Table A-1. US EPA Demonstration Project At Okanogan, WA – Daily Operational Log Sheet (Continued)

Week No.	Date	Hour Meter (hr)	Incre. Run Time (hr)	Well #4 Inst. Flow (gpm)	Well #4 Totalizer (kgal)	Well #4 Avg Flow (gpm)	Filter Inst. Flow (gpm)	Filter Totalizer (kgal)	Filter Avg Flow (gpm)	Filter Inlet (psi)	Filter Outlet (psi)	Filter dP across Filter (psig)	Filter Run time Preset (hr)	Filter Run time actual (hr)	BW Counter Preset (#)	BW Counter actual (#)	BW totalizer (Kgal)	42% $FeCl_3$ Usage (gal/hr)	12.5% NaOCl Usage (gal/hr)
45	08/03/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	08/04/09	32,053.0	63.0	521	133,454	515	510	134,690	519	100	100	0	8	7:43	4	1	4014	0.11	0.16
	08/05/09	32,074.0	21.0	520	134,122	530	510	135,360	532	100	100	0	8	7:30	4	2	4030	0.14	0.16
	08/06/09	32,090.0	16.0	514	134,623	522	505	135,869	530	102	100	2	8	2:39	4	4	4040	0.14	0.15
	08/07/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	08/08/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
	08/09/09	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	-	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	NM[a]	-	-
46	08/10/09	32,150.4	60.4	514	136,474	511	555	137,750	519	102	100	2	8	3:50	4	2	4114	0.09	0.14
	08/11/09	32,167.0	16.6	519	136,997	525	505	138,281	533	100	100	0	8	7:20	4	2	4137	0.09	0.15
	08/12/09	32,182.0	15.0	512	137,461	516	555	138,757	529	102	100	2	8	3:44	4	3	4154	0.10	0.00
	08/13/09	32,194.0	12.0	550	137,867	564	545	139,165	567	100	100	0	8	7:30	4	4	4170	0.12	0.07
	08/14/09	32,207.0	13.0	529	138,280	529	510	139,579	531	100	100	0	8	7:10	4	2	4180	0.12	0.22

Highlighted columns indicate calculated values.
(a) Operational data not recorded during weekends and holidays.

APPENDIX B

ANALYTICAL DATA TABLE

Table B-1. Analytical Results from Long Term Sampling at Okanogan, WA

Sampling Date		08/14/08			09/02/08			10/07/08			10/14/08			10/21/08		
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT
Alkalinity (as $CaCO_3$)	mg/L	183 -	181 -	188 -	182 -	180 -	184 -	177 -	184 -	177 -	175 -	177 -	175 -	183 -	181 -	183 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.7	0.7	0.8	-	-	-	0.6	0.6	0.6	-	-	-	-	-	-
Sulfate	mg/L	126	123	122	-	-	-	123	125	125	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-
Total P (as P)	μg/L	50.1 -	47.1 -	<10 -	NA -	NA -	NA -	60.0 -	54.0 -	16.4 -	43.2 -	41.1 -	<10 -	44.0 -	47.6 -	12.2 -
Silica (as SiO_2)	mg/L	26.9 -	27.1 -	25.8 -	27.0 -	26.8 -	26.7 -	26.8 -	26.8 -	27.1 -	24.1 -	23.4 -	23.7 -	23.3 -	23.0 -	22.5 -
Turbidity	NTU	0.3 -	1.3 -	0.2 -	0.2 -	0.4 -	<0.1 -	0.1 -	0.1 -	1.4 -	0.2 -	0.6 -	0.1 -	0.3 -	1.7 -	0.1 -
pH	S.U.	7.7	7.8	9.5(a)	NA(b)	NA(b)	NA(b)	7.5	7.8	7.8	7.7	7.8	7.9	7.8	7.8	7.9
Temperature	°C	21.7	21.5	20.5	NA(b)	NA(b)	NA(b)	16.4	16.4	16.4	16.4	16.3	16.4	16.7	16.5	16.5
DO	mg/L	2.0	2.0	1.0	NA(b)	NA(b)	NA(b)	3.6	4.2	4.0	NA(c)	NA(c)	NA(c)	NA(c)	NA(c)	NA(c)
ORP	mV	361	374	358	NA(b)	NA(b)	NA(b)	381	615	628	428	424	416	460	440	512
Free Chlorine (as Cl_2)	mg/L	-	NA	NA	-	NA(b)	NA(b)	-	NA	NA	-	1.3	NA	-	1.3	NA
Total Chlorine (as Cl_2)	mg/L	-	0.0	NA	-	NA(b)	NA(b)	-	NA	NA	-	1.4	NA	-	1.6	NA
Total Hardness (as $CaCO_3$)	mg/L	272	261	267	-	-	-	274	277	273	-	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	142	138	56.9	-	-	-	145	149	146	-	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	130	123	210	-	-	-	129	128	127	-	-	-	-	-	-
As (total)	μg/L	22.7 -	22.5 -	6.8 -	18.6 -	19.3 -	9.2 -	19.9 -	19.8 -	8.9 -	18.1 -	16.1 -	4.3 -	18.1 -	18.8 -	6.4 -
As (soluble)	μg/L	21.2	15.6	6.5	-	-	-	18.3	17.1	8.6	-	-	-	-	-	-
As (particulate)	μg/L	1.5	6.9	0.3	-	-	-	1.6	2.7	0.3	-	-	-	-	-	-
As(III)	μg/L	19.8	7.2	0.4	-	-	-	14.4	0.4	0.4	-	-	-	-	-	-
As(V)	μg/L	1.4	8.4	6.1	-	-	-	3.9	16.7	8.2	-	-	-	-	-	-
Fe (total)	μg/L	104 -	1,036 -	<25 -	78 -	526 -	<25 -	84 -	163 -	41 -	73 -	717 -	<25 -	73 -	972 -	<25 -
Fe (soluble)	μg/L	89	<25	<25	-	-	-	<25	<25	<25	-	-	-	-	-	-
Mn (total)	μg/L	77.0 -	76.2 -	0.6 -	59.3 -	60.5 -	51.9 -	60.5 -	61.0 -	5.7 -	71.1 -	63.9 -	31.8 -	68.4 -	70.5 -	18.9 -
Mn (soluble)	μg/L	74.1	77.0	0.3	-	-	-	62.5	18.3	0.9	-	-	-	-	-	-

(a) The high pH value measured caused by media manufacturing process.
(b) Water quality data not measured on 09/02/08.
(c) DO probe not functional, waiting for Battelle to send a new probe.

Table B-1. Analytical Results from Long Term Sampling at Okanogan, WA (Continued)

Sampling Date		10/28/08			11/04/08			11/13/08			11/18/08			12/03/08			12/10/08		
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT
Alkalinity (as $CaCO_3$)	mg/L	179 -	175 -	175 -	182 -	184 -	179 -	180 178	180 178	178 185	179 -	179 -	176 -	182 -	186 -	182 -	182 -	178 -	176 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.1	0.1	0.1	-	-	-
Fluoride	mg/L	-	-	-	0.6	0.8	0.6	-	-	-	-	-	-	0.6	0.6	0.6	-	-	-
Sulfate	mg/L	-	-	-	119	119	120	-	-	-	-	-	-	127	124	120	-	-	-
Nitrate (as N)	mg/L	-	-	-	<0.05	0.3	<0.05	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-
Total P (as P)	µg/L	52.0 -	54.5 -	13.4 -	57.3 -	362 -	19.3 -	67.9 49.7	47.6 50.1	70.7 72.0	47.5 -	45.7 -	15.5 -	56.4 -	58.3 -	17.8 -	58.5 -	54.2 -	17.1 -
Silica (as SiO_2)	mg/L	26.8 -	26.7 -	26.1 -	24.9 -	32.2 -	24.2 -	26.6 26.3	26.5 26.3	26.9 26.1	26.0 -	26.1 -	26.3 -	25.4 -	26.1 -	25.3 -	25.2 -	25.5 -	25.3 -
Turbidity	NTU	0.1 -	0.6 -	<0.1 -	0.5 -	16.0 -	0.2 -	0.6 1.2	1.7 2.5	2.3 2.1	0.1 -	0.7 -	0.2 -	0.9 -	1.6 -	0.3 -	0.4 -	0.7 -	0.1 -
pH	S.U.	7.7	7.8	7.8	7.5	7.6	7.7	7.6	7.7	7.8	7.4	7.6	7.7	7.6	7.7	7.8	7.6	7.7	7.7
Temperature	°C	16.2	16.0	16.0	16.1	16.1	16.2	15.7	15.6	15.6	16.9	16.9	16.9	15.8	15.7	15.6	15.3	15.4	15.4
DO	mg/L	4.1	4.3	4.0	2.5	2.5	2.5	3.6	3.7	3.5	2.6	3.0	3.3	NA	NA	NA	3.0	2.5	2.2
ORP	mV	467	635	648	465	650	666	461	638	636	456	641	650	455	371	365	470	530	532
Free Chlorine (as Cl_2)	mg/L	-	1.1	1.1	-	1.8	1.8	-	NA	1.1	-	1.3	1.4	-	0.04	0.02	-	0.2	0.2
Total Chlorine (as Cl_2)	mg/L	-	1.3	1.2	-	2.0	2.0	-	NA	1.3	-	1.6	1.2	-	0.4	0.3	-	0.6	0.5
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	232	230	248	-	-	-	-	-	-	269	270	273	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	115	116	128	-	-	-	-	-	-	145	144	145	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	117	114	120	-	-	-	-	-	-	124	126	128	-	-	-
As (total)	µg/L	18.1 -	18.8 -	5.8 -	18.2 -	100.1[(d)] -	7.0 -	20.5 20.6	20.0 20.1	29.1 29.4	19.6 -	18.8 -	8.1 -	18.2 -	19.2 -	14.9[(e)] -	18.5 -	18.4 -	6.9 -
As (soluble)	µg/L	-	-	-	17.1	8.6	6.6	-	-	-	-	-	-	15.3	15.5	14.6[(e)]	-	-	-
As (particulate)	µg/L	-	-	-	1.2	91.5[(d)]	0.4	-	-	-	-	-	-	2.9	3.7	0.2	-	-	-
As(III)	µg/L	-	-	-	6.0	0.3	0.3	-	-	-	-	-	-	15.3	13.9[(e)]	8.9[(e)]	-	-	-
As(V)	µg/L	-	-	-	11.1	8.3	6.3	-	-	-	-	-	-	<0.1	1.6	5.7	-	-	-
Fe (total)	µg/L	75 -	1,052 -	<25 -	61 -	7247[(d)] -	<25 -	67 67	886 867	1,383 1,338	58 -	815 -	107 -	<25 -	920 -	<25 -	109 -	1,041 -	29 -
Fe (soluble)	µg/L	-	-	-	52	34	<25	-	-	-	-	-	-	<25	<25	<25	-	-	-
Mn (total)	µg/L	70.8 -	75.5 -	3.8 -	69.5 -	369 -	0.4 -	61.8 60.8	62.7 63.1	66.5 66.0	58.1 -	58.2 -	5.4 -	63.5 -	64.8 -	42.8 -	56.6 -	58.9 -	10.5 -
Mn (soluble)	µg/L	-	-	-	67.8	21.9	0.2	-	-	-	-	-	-	43.4	65.9	43.3	-	-	-

(d) Unusually high As and Fe concentrations confirmed by sample reanalysis and might be due to sampling error.

(e) High As(III), indicating insufficient chlorination, which might cause high total As concentration at TT.

Table B-1. Analytical Results from Long Term Sampling at Okanogan, WA (Continued)

Sampling Date		12/16/08			01/08/09			01/13/09			01/20/09			01/27/09		
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT
Alkalinity (as $CaCO_3$)	mg/L	178 -	178 -	178 -	178 -	178 -	175 -	176 -	174 -	174 -	180 -	176 -	178 -	175 178	171 173	175 175
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	0.6	0.6	0.6	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	122	120	122	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	51.8 -	52.0 -	15.5 -	94.8 -	104 -	37.2 -	53.9 -	55.5 -	16.2 -	58.6 -	56.6 -	16.7 -	52.0 54.7	53.3 53.7	14.7 14.8
Silica (as SiO_2)	mg/L	23.6 -	23.3 -	23.5 -	24.4 -	24.4 -	23.8 -	25.2 -	25.0 -	25.3 -	24.6 -	24.5 -	24.2 -	26.0 26.6	26.1 25.6	25.4 25.4
Turbidity	NTU	0.2 -	0.6 -	0.1 -	0.1 -	0.7 -	0.1 -	0.2 -	0.6 -	0.1 -	0.4 -	0.8 -	0.2 -	0.2 0.2	0.6 0.6	0.1 0.1
pH	S.U.	7.8	7.9	7.9	7.7	7.8	7.8	7.5	7.7	7.8	7.4	7.6	7.7	7.5	7.7	7.8
Temperature	°C	10.9	11.1	11.3	12.9	12.8	12.8	14.3	14.5	14.5	13.1	13.3	13.4	16.5	16.5	16.5
DO	mg/L	3.5	3.9	3.2	3.8	4.6	3.9	5.2	5.6	4.4	NA	3.5	3.8	3.3	4.3	2.5
ORP	mV	477	505	502	483	500	513	449	503	503	467	501	517	461	481	519
Free Chlorine (as Cl_2)	mg/L	-	0.3	0.2	-	0.3	0.2	-	0.3	0.2	-	0.3	0.2	-	0.4	0.2
Total Chlorine (as Cl_2)	mg/L	-	0.6	0.6	-	0.6	0.6	-	0.6	0.5	-	0.6	0.5	-	0.6	0.5
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	356	358	345	-	-	-	-	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	116	118	111	-	-	-	-	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	241	240	234	-	-	-	-	-	-	-	-	-
As (total)	µg/L	18.9 -	18.4 -	6.1 -	19.5 -	21.3 -	6.9 -	16.4 -	16.6 -	5.7 -	17.1 -	16.6 -	5.7 -	17.3 17.3	17.4 17.4	5.7 5.6
As (soluble)	µg/L	-	-	-	19.7	9.3	6.9	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	<0.1	12.0	<0.1	-	-	-	-	-	-	-	-	-
As(III)	µg/L	-	-	-	16.5	0.9	0.9	-	-	-	-	-	-	-	-	-
As(V)	µg/L	-	-	-	3.2	8.3	6.0	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	84 -	993 -	<25 -	53 -	777 -	<25 -	66 -	803 -	<25 -	67 -	779 -	<25 -	66 69	847 846	<25 <25
Fe (soluble)	µg/L	-	-	-	<25	<25	<25	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	58.3 -	60.2 -	22.7 -	44.1 -	46.4 -	12.2 -	59.8 -	60.0 -	18.3 -	59.1 -	58.5 -	17.8 -	59.2 59.5	60.9 61.3	20.3 20.5
Mn (soluble)	µg/L	-	-	-	43.6	29.5	8.9	-	-	-	-	-	-	-	-	-

Table B-1. Analytical Results from Long Term Sampling at Okanogan, WA (Continued)

Sampling Date		02/03/09			02/18/09			02/24/09			03/03/09			03/10/09		
Parameter (Sampling Location)	Unit	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT
Alkalinity (as $CaCO_3$)	mg/L	178 -	175 -	173 -	188 -	186 -	183 -	177 175	175 173	177 173	184 -	179 -	181 -	181 -	179 -	179 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.6	0.6	0.7	-	-	-	-	-	-	1.0	0.9	0.7	-	-	-
Sulfate	mg/L	125	125	126	-	-	-	-	-	-	128	123	127	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-
Total P (as P)	μg/L	47.1 -	42.5 -	<10 -	43.7 -	42.1 -	12.3 -	53.0 53.4	51.6 53.3	17.8 18.4	53.6 -	53.4 -	19.6 -	58.4 -	55.7 -	16.4 -
Silica (as SiO_2)	mg/L	26.3 -	27.2 -	25.9 -	24.6 -	24.2 -	23.9 -	25.8 26.0	25.8 25.7	25.3 25.7	26.4 -	26.4 -	26 -	25.6 -	25.7 -	25.6 -
Turbidity	NTU	0.2 -	0.7 -	0.1 -	0.2 -	0.7 -	0.2 -	0.2 0.2	0.6 0.6	0.1 <0.1	0.2 -	0.6 -	<0.1 -	0.1 -	0.6 -	0.1 -
pH	S.U.	7.6	7.7	7.7	7.6	7.7	7.8	7.5	7.6	7.6	7.6	7.7	7.7	7.6	7.6	7.6
Temperature	°C	17.5	17.4	17.5	17.1	17.0	17.0	16.5	16.3	16.1	16.2	16.1	16.1	15.9	15.8	15.8
DO	mg/L	4.2	4.1	2.3	3.8	3.8	6.1	2.9	1.8	1.5	1.2	2.8	1.4	1.8	2.3	1.5
ORP	mV	460	512	516	473	532	507	486	516	506	455	500	493	466	507	518
Free Chlorine (as Cl_2)	mg/L	-	0.2	0.2	-	0.2	0.2	-	0.2	0.2	-	0.2	0.2	-	0.3	0.2
Total Chlorine (as Cl_2)	mg/L	-	0.5	0.5	-	0.6	0.5	-	0.5	0.5	-	0.6	0.5	-	0.6	0.4
Total Hardness (as $CaCO_3$)	mg/L	259	257	254	-	-	-	-	-	-	237	227	223	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	136	138	137	-	-	-	-	-	-	124	123	121	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	123	119	117	-	-	-	-	-	-	113	104	101	-	-	-
As (total)	μg/L	19.6 -	19.7 -	6.6 -	16.2 -	15.9 -	4.2 -	17.7 17.6	17.8 17.7	6.1 6.0	17.5 -	18.1 -	6.3 -	19.5 -	18.8 -	6.4 -
As (soluble)	μg/L	18.3	7.7	6.2	-	-	-	-	-	-	17.3	6.4	5.2	-	-	-
As (particulate)	μg/L	1.2	12.0	0.4	-	-	-	-	-	-	0.3	11.6	1.1	-	-	-
As(III)	μg/L	3.7	0.2	0.3	-	-	-	-	-	-	14.4	0.6	0.6	-	-	-
As(V)	μg/L	14.7	7.5	6.0	-	-	-	-	-	-	2.9	5.8	4.6	-	-	-
Fe (total)	μg/L	69 -	964 -	<25 -	63 -	810 -	<25 -	71 68	790 782	<25 <25	67.5 -	762 -	78.5 -	72.3 -	939 -	27.6 -
Fe (soluble)	μg/L	67	<25	<25	-	-	-	-	-	-	40.8	<25	<25	-	-	-
Mn (total)	μg/L	61.4 -	64.2 -	21.5 -	53.7 -	55.5 -	36.0 -	63.6 63.4	64.5 63.9	24.6 25.4	65.2 -	65.9 -	28.1 -	60.7 -	62.1 -	19.6 -
Mn (soluble)	μg/L	63.6	46.3	21.7	-	-	-	-	-	-	62.0	35.7	22.2	-	-	-

Table B-1. Analytical Results from Long Term Sampling at Okanogan, WA (Continued)

Sampling Date		03/17/09			03/24/09			03/31/09			04/07/09			04/15/09		
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT
Alkalinity (as $CaCO_3$)	mg/L	180 -	178 -	176 -	180 -	176 -	182 -	190 -	182 -	177 -	193 -	186 -	186 -	178 -	178 -	171 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	0.7	0.6	0.6	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	124	121	125	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-
Total P (as P)	µg/L	49.1 -	45.3 -	12.6 -	49.9 -	49.3 -	14.4 -	31.3 -	33.9 -	<10 -	54.4 -	52.3 -	<10 -	56.4 -	54.1 -	12.3 -
Silica (as SiO_2)	mg/L	24.9 -	25.3 -	25.1 -	24.5 -	24.3 -	24.4 -	23.3 -	23.8 -	23.7 -	23.1 -	23.1 -	22.7 -	28.4 -	27.6 -	26.6 -
Turbidity	NTU	0.2 -	0.6 -	0.1 -	0.5 -	0.6 -	<0.1 -	1.2 -	1.6 -	0.9 -	0.6 -	0.8 -	0.3 -	0.5 -	1.1 -	0.7 -
pH	S.U.	7.6	7.7	7.8	7.8	7.7	7.9	7.7	7.7	7.7	NA	NA	NA	7.6	7.6	7.7
Temperature	°C	16.4	16.3	16.3	16.0	16.3	15.9	16.3	16.3	16.3	16.6	16.5	16.5	16.1	16.1	16.0
DO	mg/L	1.6	3.1	2.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.0	1.8	1.2
ORP	mV	458	491	524	456	515	516	460	514	516	446	519	543	457	524	527
Free Chlorine (as Cl_2)	mg/L	-	0.4	0.2	-	0.3	0.2	-	0.3	0.3	-	0.6	0.3	-	0.3	0.2
Total Chlorine (as Cl_2)	mg/L	-	0.6	0.5	-	0.6	0.5	-	0.7	0.3	-	0.7	0.6	-	0.6	0.6
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	261	263	258	-	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	134	135	132	-	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	127	128	126	-	-	-	-	-	-
As (total)	µg/L	17.2 -	17.0 -	5.7 -	17.6 -	18.1 -	6.3 -	18.1 -	18.6 -	6.2 -	17.1 -	16.5 -	5.8 -	16.0 -	15.7 -	5.4 -
As (soluble)	µg/L	-	-	-	-	-	-	18.8	9.2	6.0	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	<0.1	9.4	0.2	-	-	-	-	-	-
As(III)	µg/L	-	-	-	-	-	-	15.9	0.6	0.6	-	-	-	-	-	-
As(V)	µg/L	-	-	-	-	-	-	2.9	8.6	5.4	-	-	-	-	-	-
Fe (total)	µg/L	78.8 -	867 -	<25 -	84.3 -	910 -	<25 -	230 -	1,186 -	26 -	109 -	1,251 -	<25 -	116 -	1,299 -	<25 -
Fe (soluble)	µg/L	-	-	-	-	-	-	45	37	<25	-	-	-	-	-	-
Mn (total)	µg/L	65.2 -	63.8 -	17.5 -	66.6 -	67.6 -	8.5 -	59.6 -	61.3 -	13.7 -	58.1 -	57.9 -	13.8 -	50.0 -	50.2 -	12.7 -
Mn (soluble)	µg/L	-	-	-	-	-	-	58.6	40.3	12.1	-	-	-	-	-	-

Table B-1. Analytical Results from Long Term Sampling at Okanogan, WA (Continued)

Sampling Date		04/21/09			04/28/09			05/07/09			05/13/09			05/21/09		
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT
Alkalinity (as $CaCO_3$)	mg/L	182 -	182 -	182 -	188 -	178 -	180 -	187 -	184 -	184 -	186 -	181 -	181 -	183 -	183 -	183 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	0.6	0.7	0.6	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	122	121	119	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	56.8 -	57.7 -	<10 -	61.5 -	54.2 -	19.4 -	49.2 -	50.4 -	11.1 -	49.6 -	48.5 -	12.0 -	45.6 -	44.5 -	11.4 -
Silica (as SiO_2)	mg/L	26.8 -	26.2 -	24.9 -	29.4 -	29.8 -	28.7 -	27.7 -	27.7 -	27.6 -	27.7 -	28.3 -	28.3 -	27.5 -	27.2 -	26.9 -
Turbidity	NTU	0.5 -	1.0 -	0.4 -	0.6 -	1.4 -	0.3 -	1.0 -	3.4 -	1.6 -	0.2 -	2.0 -	2.4 -	1.0 -	2.4 -	2.6 -
pH	S.U.	7.4	7.5	7.6	7.5	7.7	7.7	7.4	7.5	7.6	7.7	7.8	7.8	7.6	7.7	7.7
Temperature	°C	16.0	16.0	16.0	16.2	16.1	16.1	15.6	15.7	15.6	15.9	15.8	15.9	16.5	16.4	16.5
DO	mg/L	1.1	1.3	1.1	2.9	3.1	3.2	2.6	2.7	3.2	2.9	4.7	2.3	1.9	2.4	1.9
ORP	mV	457	525	550	482	481	532	459	515	513	471	508	525	444	504	515
Free Chlorine (as Cl_2)	mg/L	-	0.3	0.3	-	0.3	0.2	-	0.3	0.2	-	0.3	0.2	-	0.3	0.2
Total Chlorine (as Cl_2)	mg/L	-	0.6	0.6	-	0.6	0.6	-	0.6	0.5	-	0.6	0.6	-	0.6	0.5
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	227	258	270	-	-	-	-	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	110	143	155	-	-	-	-	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	117	115	116	-	-	-	-	-	-	-	-	-
As (total)	µg/L	19.9 -	19.8 -	6.2 -	21.3 -	19.7 -	6.5 -	16.5 -	16.2 -	4.7 -	16.4 -	16.6 -	5.8 -	18.4 -	17.4 -	6.1 -
As (soluble)	µg/L	-	-	-	21.1	10.5	6.6	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	0.2	9.2	<0.1	-	-	-	-	-	-	-	-	-
As(III)	µg/L	-	-	-	15.4	0.7	0.6	-	-	-	-	-	-	-	-	-
As(V)	µg/L	-	-	-	5.7	9.9	6.0	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	96 -	1,345 -	<25 -	85 -	1,011 -	63 -	83 -	1,102 -	<25 -	82 -	1,022 -	<25 -	62 -	851 -	61 -
Fe (soluble)	µg/L	-	-	-	84	27	26	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	64.8 -	67.0 -	12.1 -	72.7 -	74.8 -	21.1 -	67.4 -	70.2 -	49.0 -	67.0 -	69.2 -	12.5 -	60.6 -	63.8 -	20.3 -
Mn (soluble)	µg/L	-	-	-	70.6	52.5	20.4	-	-	-	-	-	-	-	-	-

Table B-1. Analytical Results from Long Term Sampling at Okanogan, WA (Continued)

Sampling Date		05/28/09			06/03/09			06/09/09			06/16/09			06/24/09		
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT
Alkalinity (as $CaCO_3$)	mg/L	187 -	185 -	185 -	192 -	190 -	192 -	186 190	184 186	186 186	190 -	190 -	188 -	191 -	187 -	189 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.6	0.8	0.8	-	-	-	-	-	-	-	-	-	0.6	0.6	0.6
Sulfate	mg/L	131	130	130	-	-	-	-	-	-	-	-	-	124	123	127
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05
Total P (as P)	µg/L	45.8 -	45.7 -	13.9 -	38.9 -	40.1 -	<10 -	38.0 41.6	39.0 41.2	<10 <10	43.3 -	42.4 -	<10 -	45.2 -	44.7 -	<10 -
Silica (as SiO_2)	mg/L	26.5 -	25.9 -	25.9 -	27.2 -	27.0 -	27.1 -	26.2 26.5	26.4 26.7	26.3 26	26.5 -	26.4 -	26.2 -	25.9 -	26.0 -	25.6 -
Turbidity	NTU	0.4 -	0.8 -	0.3 -	0.6 -	1.2 -	0.3 -	1.4 1.8	1.6 1.0	1.6 0.9	0.9 -	1.7 -	0.7 -	0.5 -	1.2 -	0.5 -
pH	S.U.	7.8	7.8	7.9	7.6	7.6	7.7	7.6	7.6	7.7	7.6	7.7	7.8	7.6	7.7	7.7
Temperature	°C	16.8	16.7	16.9	16.6	16.6	16.7	16.9	16.9	16.8	16.9	17.0	17.1	16.4	16.4	16.5
DO	mg/L	2.5	4.2	2.9	2.0	3.3	2.8	2.6	3.5	2.7	3.8	3.9	2.8	3.5	4.0	2.7
ORP	mV	477	487	500	470	517	523	446	475	517	459	485	521	459	510	521
Free Chlorine (as Cl_2)	mg/L	-	0.3	0.2	-	0.3	0.2	-	0.4	0.2	-	0.3	0.2	-	0.3	0.2
Total Chlorine (as Cl_2)	mg/L	-	0.6	0.5	-	0.6	0.5	-	0.6	0.5	-	0.5	0.5	-	0.6	0.5
Total Hardness (as $CaCO_3$)	mg/L	323	334	340	-	-	-	-	-	-	-	-	-	268	273	255
Ca Hardness (as $CaCO_3$)	mg/L	185	196	201	-	-	-	-	-	-	-	-	-	149	152	141
Mg Hardness (as $CaCO_3$)	mg/L	138	138	140	-	-	-	-	-	-	-	-	-	119	121	114
As (total)	µg/L	14.7 -	14.5 -	5.0 -	17.6 -	18.3 -	6.6 -	17.4 17.5	18.0 17.7	6.3 6.2	17.1 -	17.1 -	6.0 -	17.9 -	18.1 -	5.6 -
As (soluble)	µg/L	14.9	6.6	5.0	-	-	-	-	-	-	-	-	-	17.8	8.2	5.6
As (particulate)	µg/L	<0.1	7.9	<0.1	-	-	-	-	-	-	-	-	-	0.1	9.9	<0.1
As(III)	µg/L	12.1	0.2	0.3	-	-	-	-	-	-	-	-	-	13.7	0.3	0.3
As(V)	µg/L	2.8	6.4	4.7	-	-	-	-	-	-	-	-	-	4.1	7.9	5.3
Fe (total)	µg/L	78 -	970 -	<25 -	60 -	908 -	<25 -	72 64	904 916	<25 <25	61 -	874 -	<25 -	76 -	999 -	<25 -
Fe (soluble)	µg/L	55	<25	<25	-	-	-	-	-	-	-	-	-	71.2	<25	<25
Mn (total)	µg/L	61.6 -	64.5 -	22.8 -	65.5 -	72.0 -	23.1 -	66.2 66.6	71.0 70.0	21.6 21.9	66.1 -	67.7 -	25.8 -	64.2 -	68.7 -	20.4 -
Mn (soluble)	µg/L	63.1	42.8	22.2	-	-	-	-	-	-	-	-	-	65.6	44.9	20.5

Table B-1. Analytical Results from Long Term Sampling at Okanogan, WA (Continued)

Sampling Date		06/30/09			07/09/09			07/15/09			07/22/09			07/29/09		
Sampling Location Parameter	Unit	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT	IN	AC	TT
Alkalinity (as $CaCO_3$)	mg/L	189 -	185 -	189 -	196 -	196 -	191 -	189 -	187 -	189 -	177 -	179 -	184 -	181 -	174 -	177 -
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	0.7	0.6	0.6	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	131	126	124	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-
Total P (as P)	µg/L	47.6 -	45.9 -	11.9 -	37.0 -	35.9 -	<10 -	39.9 -	35.4 -	<10 -	48.4 -	48.2 -	12.3 -	50.3 -	51.1 -	15.6 -
Silica (as SiO_2)	mg/L	25.6 -	25.8 -	25.7 -	26.3 -	26.1 -	25.6 -	26.5 -	26.6 -	25.6 -	27.7 -	27.2 -	27.2 -	26.0 -	25.9 -	25.9 -
Turbidity	NTU	0.3 -	0.8 -	0.3 -	0.6 -	1.0 -	0.7 -	0.4 -	0.8 -	0.5 -	1.5 -	2.0 -	1.8 -	0.3 -	0.7 -	0.7 -
pH	S.U.	7.6	7.8	7.8	7.6	7.7	7.7	7.5	7.6	7.7	7.5	7.6	7.7	7.7	7.7	7.8
Temperature	°C	16.7	16.6	16.6	16.9	16.9	16.9	16.8	16.8	16.8	17.3	17.2	17.2	18.8	18.7	18.7
DO	mg/L	1.5	3.2	1.7	2.3	4.2	3.2	3.1	2.4	2.9	2.7	3.6	2.5	2.5	3.8	3.3
ORP	mV	471	511	523	444	505	534	482	524	521	451	490	511	453	517	443
Free Chlorine (as Cl_2)	mg/L	-	0.3	0.2	-	0.3	0.2	-	0.3	0.2	-	0.2	0.1	-	0.2	0.2
Total Chlorine (as Cl_2)	mg/L	-	0.6	0.5	-	0.6	0.5	-	0.6	0.5	-	0.5	0.5	-	0.5	0.5
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	253	253	251	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	139	140	139	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-	-	-	-	114	113	112	-	-	-
As (total)	µg/L	18.6 -	18.1 -	6.3 -	16.6 -	16.3 -	5.7 -	17.2 -	15.7 -	5.9 -	16.8 -	17.7 -	5.1 -	14.8 -	14.6 -	2.9 -
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	16.4	7.9	5.2	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	0.4	9.8	<0.1	-	-	-
As(III)	µg/L	-	-	-	-	-	-	-	-	-	13.1	0.6	0.5	-	-	-
As(V)	µg/L	-	-	-	-	-	-	-	-	-	3.3	7.3	4.7	-	-	-
Fe (total)	µg/L	78 -	952 -	<25 -	57 -	832 -	<25 -	60 -	818 -	<25 -	169 -	871 -	<25 -	70 -	829 -	39 -
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	-	46	<25	<25	-	-	-
Mn (total)	µg/L	64.0 -	64.2 -	19.3 -	61.6 -	62.6 -	21.5 -	63.5 -	61.6 -	21.5 -	63.3 -	64.4 -	23.5 -	61.1 -	63.7 -	37.6 -
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	-	61.9	43.3	23.0	-	-	-

Table B-1. Analytical Results from Long Term Sampling at Okanogan, WA (Continued)

Sampling Date		08/05/09			08/12/09		
Sampling Location		IN	AC	TT	IN	AC	TT
Parameter	Unit						
Alkalinity (as $CaCO_3$)	mg/L	178	178	178	183	183	178
		-	-	-	-	-	-
Ammonia (as N)	mg/L	-	-	-	-	-	-
Fluoride	mg/L	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-
Total P (as P)	µg/L	47.2	48.2	12.8	48.4	46.2	11.7
		-	-	-	-	-	-
Silica (as SiO_2)	mg/L	24.8	23.2	26.0	25.1	25.4	25.1
		-	-	-	-	-	-
Turbidity	NTU	0.4	1.0	0.3	0.7	1.5	0.5
		-	-	-	-	-	-
pH	S.U.	7.6	7.7	7.8	7.6	7.7	7.7
Temperature	°C	17.7	17.5	17.6	16.9	16.8	16.9
DO	mg/L	2.1	3.0	2.5	3.7	3.2	2.4
ORP	mV	466	531	521	450	490	468
Free Chlorine (as Cl_2)	mg/L	-	0.3	0.2	-	0.2	0.2
Total Chlorine (as Cl_2)	mg/L	-	0.6	0.5	-	0.5	0.5
Total Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-
Ca Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-
Mg Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-	-
As (total)	µg/L	16.0	15.2	4.4	15.8	15.2	4.0
		-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-
As(III)	µg/L	-	-	-	-	-	-
As(V)	µg/L	-	-	-	-	-	-
Fe (total)	µg/L	68	868	<25	61	810	<25
		-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-
Mn (total)	µg/L	60.2	63.6	23.8	58.5	59.4	43.1
		-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-

APPENDIX C

SUMMARY OF RESPONSIBILITIES
ARSENIC DEMONSTRATION PROJECT AT OKANOGAN, WA

Table C-1. Summary of Responsibilities

Task	Subtask	Responsible Party			
		Filtronics	Triad/WQE	City of Okanogan/ G&O	Battelle
Engineering	System drawings (P&IDs, tank arrangement, and control panel assembly drawings)	√			
	System technical specifications and electrical/conduit requirements	√			
	Site engineering drawings required for electrical and mechanical tie-ins		√		
	Package including engineering drawings and report stamped by WA PE and submitted to WA DOH		√		
	As-built engineering drawings and other post-construction documentation		√		
	Building engineering and permitting including all non-Filtronics supplied equipment and residuals handling			√	
Equipment Supply	Electromedia®-I, FH-13 System for 750 gpm and other equipment per Quotation No. 050802-1.A	√			
	Shop testing of PLC input/output to reduce on-site needs	√			
	Spare parts for installation/startup	√			
	3 copies including: O&M instructions, as-built drawings, and manufacturers' bulletins	√			
	Shipment to the Okanogan, WA site	√			
	Receive and inspect shipment for damage/missing parts		√		
	Staging area/storage at site prior to installation/startup			√	
	Reclaim tank			√	
Installation	Photographs of equipment arrival, unloading, placement, media loading, etc.		√	√	
	Periodic installation inspection and supervision as needed		√		
	Equipment unloading and placement including provision of crane/fork lift, jacking pads, etc.		√		
	Equipment leveling, alignment, grouting, and anchoring		√		
	Reclaim tank anchoring			√	
	FH-13 and Proposed Equipment Installation		√		
	Filter vessel and internals (1)		√		
	Reaction vessels (2)		√		
	Concrete, sealant, and filter media loading		√		
	Floating strainer and suction hose for reclaim tank		√		
	Recycle pump installation, alignment, and lubrication		√		
	Chemical feed equipment and manifold assemblies installation (2)		√		
	Air compressor and starter installation		√		
	Finish paint on installed equipment and piping as required		√		
	Instrumentation and Controls Installation		√		
	Allen Bradley SLC 5/05 programmable controller including field interconnection wiring		√		

Table C-1. Summary of Responsibilities (Continued)

Task	Subtask	Responsible Party			
		Filtronics	**Triad/WQE**	**City of Okanogan/ G&O**	**Battelle**
Installation (Continued)	Panelview operator interface panel		√		
	Solenoid valves and field interconnection wiring to PLC		√		
	Flow control valve, butterfly valves, and check valve		√		
	Reclaim tank float switches and wiring to PLC		√		
	Pressure gauges installation for filter headloss measurements		√		
	Pressure switch for low air pressure		√		
	Tube meter for backwash and treated water including wiring to PLC		√		
	Backwash flow control valve		√		
	Piping and Other Mechanical Connections		√		
	All equipment lubrication		√		
	All pipes and fittings, supports/hangers, and valves for filtering, draining, and backwashing per drawings		√		
	Face piping and valve assembly		√		
	Installation of sample tap assemblies (to be provided by Filtronics)		√		
	Installation of air vent valve (to be provided by Filtronics)		√		
	Air tubing for pneumatic butterfly valve actuators		√		
	Electrical and Control Wiring Connections		√		
	Equipment grounding (vessels, pumps, compressor, etc.)		√		
	Interlock the system operation with the well pump and reservoir		√		
	All conduits and electrical wiring from process equipment to power distribution panel/MCC		√		
	All conduits, electrical wiring, and signal wiring to/from instrumentation to PLC		√		
	Circuit breaker panel		√		
	Recycle pump and starter wiring		√		
Shakedown, Startup, Inspection	System startup/shakedown**	√	√	√	
	Mechanical, electrical, and instrumentation inspection	√			
	PLC input/output testing and instrumentation calibration/adjustment	√			
	Electrical continuity testing and motor rotation checks		√		
	Cleaning, flushing, and draining of all tanks and piping prior to startup to remove debris		√		
	Fill tanks and piping with clean water for leak/pressure testing (hydrostatic test)		√	√	
	Fill tanks and piping with clean water for hydraulic shakedown/leak testing		√	√	

Table C-1. Summary of Responsibilities (Continued)

Task	Subtask	Responsible Party: Filtronics	Triad/WQE	City of Okanogan/ G&O	Battelle
Shakedown, Startup, Inspection (Continued)	Operator training on system O&M	√			
	Disinfection and bacteriological testing prior to startup to distribution			√	
Chemical Supply	Ferric chloride				√
	Sodium hypochlorite				√
	Secondary containment of chemicals			√	
	Safety equipment/signs for chemical use/storage			√	
Well Pumps	Motor starter for well pump			√	
	Communication point in building for control interface with well pumps and reservoirs through SCADA			√	
	Hour meter/totalizer on well pump			√	
Building	Building infrastructure			√	
	Watermains from building to distribution system			√	
	Floor drains			√	
	Wastewater drain lines to sanitary sewer			√	
	Backwash/residuals handling and backwash storage tank			√	
	Utilities (heat, light, electricity, potable water, etc.)			√	
	Grounding location			√	
	Phone line for troubleshooting via modem			√	
	Power distribution panel for all equipment and 3/4" conduit to within 10 ft of skid			√	
	Site sign identifying Okanogan as participant in EPA's program				√
	Drinking fountains, if desired			√	
	Emergency shower, if desired			√	
	Restroom, if desired			√	
Demo Study	One-year of technical assistance for troubleshooting	√			
	Repair or replace faulty Filtronics-supplied parts or equipment through warranty period	√			
	Repair or replace faulty installation work through warranty period		√		
	Treatment system O&M			√	
	Prepare Study Plan describing protocol for collecting data during the demonstration				√
	Monitor treatment system and provide data to EPA, City, Filtronics, and WA DOH quarterly				√

Note: For system shakedown and startup, Triad provided mechanical/electrical labor for assistance during shakedown activities; the City provided operator.

APPENDIX D

BACKWASH LOG SHEETS
EPA ARSENIC DEMONSTRATION PROJECT AT OKANOGAN, WA

Table D-1. Backwash Log Sheets

Date	Δp Before Backwash	Δp After Backwash	Backwash Start		Backwash End		Backwash Flowrate	Backwash Duration	Wastewater Generated	Average Flowrate
	psig	psig	Time	kgal	Time	kgal	gpm	min	Kgal	gpm
08/14/08	2	0	-	78	-	84	1250	4	5.9	1475
08/15/08	0	0	10:47	90	-	95	1200	4	5.0	1250
08/18/08	1	0	11:55	112	11:59	117	1250	4	5.0	1250
08/27/08	2	0	11:57	164	12:01	169	1100	4	5.0	1250
08/28/08	2	0	16:21	185	16:25	189	1400	4	4.0	1000
08/29/08	2	0	8:33	194	8:38	199	1320	5	5.0	1000
08/30/08	2	0	8:54	209	-	214	1190	4	5.0	1250
09/01/08	2	1	9:34	240	9:38	245	1250	4	5.0	1250
09/02/08	2	1	9:55	245	9:59	250	1200	4	5.0	1250
09/03/08	2	0	10:19	270	10:23	275	1100	4	5.0	1250
09/04/08	2	0	10:30	285	10:34	290	1200	4	5.0	1250
10/02/08	2	2	15:52	403	15:56	408	1250	4	5.0	1250
10/03/08	2	2	8:06	413	8:10	419	1250	4	6.0	1500
10/07/08	2	0[(a)]	12:35	439	12:39	445	1250	4	6.0	1500
10/09/08	1	0[(a)]	11:50	460	11:54	465	1200	4	5.0	1250
10/13/08	1	2	11:43	517	11:47	522	1200	4	5.0	1250
10/16/08	2	1	15:29	557	15:33	562	1250	4	5.0	1250
10/20/08	2	2	13:44	608	13:48	613	1300	4	5.0	1250
10/21/08	0	0	10:05	618	10:09	624	1200	4	6.0	1500
10/28/08	1	0[(a)]	15:24	726	15:28	731	1150	4	5.0	1250
11/13/08	2	0[(a)]	14:36	877	14:40	882	1200	4	5.0	1250
11/18/08	2	0[(a)]	15:12	919	15:16	924	1200	4	5.0	1250
12/16/08	2	1	13:26	1183	13:30	1188	1500	4	5.0	1250
12/30/08	3	1	14:53	1204	14:55	1206	720	2	2	1000
12/31/08	2	0	14:56	1212	15:00	1218	1500	4	6.0	1500
01/02/09	1	0	14:57	1235	15:01	1239	1000	4	4.0	1000
01/09/09	2	0	11:14	1285	11:18	1290	1250	4	5.0	1250
01/12/09	2	0	14:47	1311	14:51	1316	1250	4	5.0	1250
01/13/09	2	0	14:08	1322	14:12	1327	1250	4	5.0	1250
01/14/09	2	0	14:01	1333	14:05	1338	1250	4	5.0	1250
01/15/09	2	0	14:05	1344	14:09	1349	1250	4	5.0	1250
01/16/09	1	0	13:27	1354	13:31	1359	1250	4	5.0	1250
01/21/09	0	0	15:42	1380	15:46	1385	1250	4	5.0	1250
01/22/09	1	0	13:07	1389	13:11	1393	1000	4	4.0	1000
01/23/09		0	14:56	1396	15:00	1400	1000	4	4.0	1000
01/26/09	1	0	15:10	1424	15:14	1429	1250	4	5.0	1250
01/27/09	1	0	13:30	1434	13:38	1443	1100	8	9	1125
01/28/09	1	0	14:03	1448	14:07	1453	1250	4	5.0	1250
01/29/09	1	0	13:30	1459	13:34	1464	1250	4	5.0	1250
01/30/09	0	0	11:15	1469	11:19	1473	1000	4	4.0	1000
02/02/09	0	0	10:06	1492	10:10	1497	1200	4	5.0	1250
02/03/09	0	0	10:40	1513	10:44	1519	1250	4	6.0	1500

Table D-1. Backwash Log Sheets (Continued)

Date	Δp Before Backwash	Δp After Backwash	Backwash Start		Backwash End		Backwash Flowrate	Backwash Duration	Wastewater Generated	Average Flowrate
	psig	psig	Time	kgal	Time	kgal	gpm	min	kgal	gpm
02/04/09	2	0	13:19	1522	13:23	1528	1500	4	6.0	1500
02/05/09	2	0	12:20	1533	12:24	1538	1250	4	5.0	1250
02/06/09	1	0	13:22	1544	13:26	1550	1500	4	6.0	1500
02/09/09	1	0[a]	8:36	1577	8:40	1583	1250	4	6.0	1500
02/17/09	2	0	15:43	1589	15:47	1595	1500	4	6.0	1500
02/18/09	1	0	12:40	1601	12:44	1607	1500	4	6.0	1500
02/19/09	2	0	14:45	1612	14:49	1618	1500	4	6.0	1500
02/20/09	1	0	11:29	1624	11:33	1629	1250	4	5.0	1250
02/23/09	1	0	13:10	1648	13:14	1653	1250	4	5.0	1250
02/24/09	0	0	15:00	1656	15:04	1662	1300	4	6.0	1500
02/25/09	1	0	14:02	1662	14:06	1668	1300	4	6.0	1500
02/27/09	0	0	14:45	1679	14:49	1685	1500	4	6.0	1500
03/02/09	1	0	9:15	1714	9:19	1719	1300	4	5.0	1250
03/03/09	1	0	8:21	1725	8:25	1731	1400	4	6.0	1500
03/04/09	0	0	15:00	1737	15:04	1743	1400	4	6.0	1500
03/05/09	0	0	14:36	1749	14:40	1755	1375	4	6.0	1500
03/09/09	0	0	12:21	1790	12:25	1796	1400	4	6.0	1500
03/10/09	1	0	11:55	1801	11:59	1807	1400	4	6.0	1500
03/12/09	0	0	9:29	1829	9:33	1835	1400	4	6.0	1500
03/13/09	0	0	11:55	1847	11:59	1853	1400	4	6.0	1500
03/16/09	1	0[a]	12:38	1883	12:42	1889	1400	4	6.0	1500
03/17/09	0	0	9:15	1895	9:19	1901	1400	4	6.0	1500
03/18/09	0	0[a]	13:03	1912	13:07	1918	1400	4	6.0	1500
03/19/09	0	0	14:37	1924	14:41	1930	1400	4	6.0	1500
03/20/09	1	0	12:12	1935	12:16	1941	1400	4	6.0	1500
03/24/09	0	0	9:50	1977	9:54	1983	1400	4	6.0	1500
03/25/09	0	0	15:07	1994	15:11	2000	1350	4	6.0	1500
03/26/09	0	0	13:58	2006	14:02	2012	1400	4	6.0	1500
03/31/09	0	0	12:45	2054	12:49	2060	1400	4	6.0	1500
04/02/09	0	0	7:44	2083	7:48	2090	1450	4	7.0	1750
04/06/09	0	0	7:11	2144	7:15	2150	1450	4	6.0	1500
04/07/09	0	0	13:38	2162	13:42	2168	1420	4	6.0	1500
04/08/09	0	0	13:09	2174	13:13	2180	1450	4	6.0	1500
04/09/09	0	0	13:59	2192	14:03	2198	1400	4	6.0	1500
04/10/09	0	0	15:10	2209	15:14	2215	1350	4	6.0	1500
04/13/09	0	0	6:57	2242	7:01	2247	1300	4	5.0	1250
04/14/09	1	0	14:45	2258	14:49	2264	1300	4	6.0	1500
04/15/09	1	0	14:50	2269	14:54	2275	1350	4	6.0	1500
04/16/09	1	0	15:08	2286	15:12	2292	1400	4	6.0	1500
04/17/09	1	0	8:55	2298	8:59	2303	1400	4	5.0	1250
04/21/09	0	0	15:04	2353	15:08	2358	1400	4	5.0	1250
04/23/09	1	0	14:27	2385	14:31	2390	1400	4	5.0	1250
04/24/09	0	0	13:30	2400	13:34	2406	1400	4	6.0	1500

Table D-1. Backwash Log Sheets (Continued)

Date	Δp Before Backwash	Δp After Backwash	Backwash Start		Backwash End		Backwash Flowrate	Backwash Duration	Wastewater Generated	Average Flowrate
	psig	psig	Time	kgal	Time	kgal	gpm	min	kgal	gpm
04/28/09	1	0	13:06	2458	13:10	2464	1400	4	6.0	1500
04/29/09	1	0	16:02	2475	16:06	2481	1400	4	6.0	1500
04/30/09	1	0	13:32	2487	13:36	2492	1400	4	5.0	1250
05/01/09	1	0	13:29	2503	13:33	2509	1400	4	6.0	1500
05/04/09	1	0	15:24	2554	15:29	2560	1350	5	6.0	1200
05/05/09	1	0[(a)]	13:39	2572	13:43	2577	1400	4	5.0	1250
05/08/09	1	0	12:10	2605	12:14	2611	1350	4	6.0	1500
05/12/09	1	0	14:12	2667	14:16	2672	1350	4	5.0	1250
05/15/09	1	0[(a)]	9:25	2710	9:29	2716	1350	4	6.0	1500
05/19/09	1	0	9:25	2768	9:29	2773	1350	4	5.0	1250
05/20/09	1	0	15:04	2788	15:08	2794	1350	4	6.0	1500
05/21/09	2	0	8:41	2799	8:45	2805	1350	4	6.0	1500
05/22/09	1	0	14:48	2819	14:52	2824	1300	4	5.0	1250
05/27/09	0	0	8:50	2867	8:54	2872	1300	4	5.0	1250
05/29/09	1	0	13:14	2899	13:18	2904	1300	4	5.0	1250
06/01/09	0	0	11:48	2953	11:52	2958	1300	4	5.0	1250
06/03/09	2	0	13:42	2983	13:46	2988	1350	4	5.0	1250
06/04/09	2	0	9:56	2998	10:00	3002	1150	4	4.0	1000
06/05/09	2	0	8:24	3012	8:28	3017	1350	4	5.0	1250
06/09/09	2	0	15:20	3097	15:24	3103	1350	4	6.0	1500
06/12/09	1	0	7:59	3151	8:03	3156	1325	4	5.0	1250
06/15/09	1	0	15:16	3197	15:20	3202	1325	4	5.0	1250
06/16/09	1	0	16:54	3218	16:58	3223	1300	4	5.0	1250
06/18/09	1	0[(a)]	11:20	3249	11:24	3254	1300	4	5.0	1250
06/19/09	1	0	9:25	3264	9:29	3269	1300	4	5.0	1250
06/24/09	1	0	9:20	3343	9:24	3348	1300	4	5.0	1250
06/25/09	2	0	13:00	3364	13:04	3369	1350	4	5.0	1250
06/26/09	2	0	9:52	3379	9:56	3385	1350	4	6.0	1500
06/30/09	1	0	10:25	3447	10:29	3453	1300	4	6.0	1500
07/02/09	0	0	10:00	3490	10:04	3495	1300	4	5.0	1250
07/07/09	2	0	10:52	3543	10:56	3549	1350	4	6.0	1500
07/09/09	2	0	9:00	3581	9:04	3586	1350	4	5.0	1250
07/10/09	2	0	13:16	3602	13:20	3607	1325	4	5.0	1250
07/14/09	2	0	12:22	3660	12:26	3665	1300	4	5.0	1250
07/17/09	2	0	8:37	3713	9:01	3718	1350	4	5.0	1250
07/21/09	2	0	8:49	3782	8:53	3788	1400	4	6.0	1500
07/22/09	2	0	9:11	3804	9:15	3809	1350	4	5.0	1250
07/23/09	2	0	8:46	3825	8:50	3830	1400	4	5.0	1250
07/24/09	3	0	14:19	3841	14:23	3846	1300	4	5.0	1250
07/28/09	2	0	15:23	3897	15:27	3902	1350	4	5.0	1250
07/29/09	2	0	9:03	3913	9:07	3918	1350	4	5.0	1250
07/31/09	2	0	9:53	3947	9:57	3952	1300	4	5.0	1250
08/04/09	1	0	14:22	4014	14:26	4020	1400	4	6.0	1500

Table D-1. Backwash Log Sheets (Continued)

Date	Δp Before Backwash	Δp After Backwash	Backwash Start		Backwash End		Backwash Flowrate	Backwash Duration	Wastewater Generated	Average Flowrate
	psig	psig	Time	kgal	Time	kgal	gpm	min	kgal	Gpm
08/06/09	2	0	14:32	4044	14:56	4049	1400	4	5.0	1250
08/07/09	1	0	16:22	4065	16:26	4071	1400	4	6.0	1500
08/11/09	2	0	13:29	4137	13:33	4143	1400	4	6.0	1500
08/12/09	2	0[a]	10:41	4154	10:45	4159	1350	4	5.0	1250

(a) Pressure drop across the filter is zero because reservoirs full and system shutdown.