

**Arsenic and Antimony Removal from Drinking Water by
Point-of-Entry Reverse Osmosis Coupled with Dual Plumbing Distribution
U.S. EPA Demonstration Project at
Carmel Elementary School in Carmel, ME
Final Performance Evaluation Report**

by

**Lili Wang[‡]
Gary M. Lewis[§]
Abraham S.C. Chen[‡]**

[§]Battelle, Columbus, OH 43201-2693
[‡]ALSA Tech, LLC, Columbus, OH 43219-0693

**Contract No. EP-C-05-057
Task Order No. 0019**

for

**Thomas J. Sorg
Task Order Manager**

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

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

DISCLAIMER

The work reported in this document was funded by the United States Environmental Protection Agency (EPA) under Task Order 0019 of Contract EP-C-05-057 to Battelle. It has been subjected to the Agency's peer and administrative reviews and has been approved for publication as an EPA document. Any opinions expressed in this paper are those of the author(s) and do not, necessarily, reflect the official positions and policies of the EPA. Any mention of products or trade names does not constitute recommendation for use by the EPA.

FOREWORD

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

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

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

Sally Gutierrez, Director
National Risk Management Research Laboratory

ABSTRACT

This report documents the activities performed for and the results obtained from the arsenic and antimony removal treatment technology demonstration project at the Carmel Elementary School (CES) in Carmel, ME. An innovative approach of employing point-of-entry (POE) reverse osmosis (RO) coupled with dual plumbing was demonstrated at CES as a low cost alternative to achieve compliance with arsenic and antimony maximum contaminant levels (MCLs) compared with conventional RO treatment. The objectives of the project were to evaluate the performance of the RO/dual plumbing system in meeting the new arsenic MCL of 10 µg/L and the antimony MCL of 6 µg/L, the reliability of the treatment system, the required system operation and maintenance (O&M) and operator skill levels, and the capital and O&M cost of the technology. Additionally, the project characterized the water quality of the distribution system and process residuals produced by the RO system.

The original treatment system selected for demonstration at CES was a Watts Premier 9,600-gal/day (gpd) RO treatment system, which would require a significant building modification/expansion to house the new system and construction of a larger septic/leach field to receive residual water from the RO system. To reduce the financial burden on the school, a joint decision was made by United States Environmental Protection Agency (EPA), Maine Drinking Water Program (MDWP), CES, and Battelle to use a smaller RO system coupled with a dual plumbing distribution system so that only a portion of raw water would be treated and consumed as potable water while the untreated water was available for non-potable use. The only modification required was re-plumbing of the existing distribution system to convert it into a duplex system with separate potable and non-potable lines. The potable line supplied RO-treated water to the kitchen sinks and dishwasher (both cold and hot water), water fountains in school buildings, and cold water faucets in restrooms. Based on a water demand study conducted upon completing the plumbing modification, it was determined that the potable water demand could be met by a Crane Environmental EPRO-1,200 treatment system. A similar but smaller unit, EPRO-600 system, had been used by EPA/Battelle for a pilot study conducted at CES in 2006 and was effective at removing arsenic and antimony to levels well below their respective MCLs.

The Crane Environmental EPRO-1,200 RO treatment system consisted of an RO unit, a calcite filter for pH adjustment, two 300-gal atmospheric storage tanks, a re-pressurization system, and a post-chlorination system. Major components of the RO unit included a 5-µm sediment filter, a ½-horsepower (hp) booster pump, and two 2.5-in × 40-in thin-film composite RO membrane modules. The RO permeate water passed through the calcite filter to raise its pH level to near neutral, then was stored in two 300-gal atmospheric storage tanks. The water from the storage tank was re-pressurized by a 1-hp booster pump before entering the potable distribution line.

Operation of the EPRO-1,200 RO treatment system began on February 4, 2009, but logging of operational data did not begin until April 16, 2009. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), process residuals, and capital and O&M cost. Through the performance evaluation study period from April 16 through December 15, 2009, the system operated for approximately 1,474 hr, processing approximately 180,700 gal of water. With an average recovery rate of 40%, the system generated 71,100 gal of permeate and 109,600 gal of reject water. Daily system run times averaged 11.7 hr/day when the school was in session and 1.9 hr/day when the school was out of session.

Arsenic concentrations in source water ranged from 13.6 to 22.6 µg/L and averaged 18.2 µg/L. Soluble As(V) was the predominating species, with concentrations ranging from 14.3 to 18.7 µg/L and averaging 16.7 µg/L. Antimony concentration in source water ranged from 8.6 to 13.2 µg/L and averaged 10.8 µg/L, with the majority present in the soluble form. Total arsenic concentrations in permeate water

averaged 0.1 µg/L. Total antimony concentrations in permeate water were below the MDL of 0.1 µg/L. Based on the average arsenic and antimony concentrations in raw and permeate water, the RO system had achieved 99% removal efficiency for both analytes. The RO system had achieved an average of 97% rejection for total dissolved solids (TDS), slightly below the specified 98% rejection.

pH values measured in source water averaged 7.9 and decreased to an average of 6.9 after the RO unit. Alkalinity concentrations were reduced from an average of 206 mg/L (as CaCO₃) in source water to an average of 5.6 mg/L (as CaCO₃) in permeate water, causing the decrease in pH. After pH adjustment via the calcite filter, pH values and alkalinity concentrations were raised, on average, to 7.4 and 16.6 mg/L (as CaCO₃), respectively.

The RO process concentrated the contaminants into the reject water, which was discharged to the existing septic system. During the performance evaluation study, approximately 109,570 gal of reject water was generated. The reject water contained, on average, 31.9 µg/L of arsenic, 17.7 µg/L of antimony, 410 mg/L of TDS, 340 mg/L (as CaCO₃) of alkalinity, 352 mg/L (as CaCO₃) of total hardness, 18.1 mg/L of silica (as SiO₂), and 17.9 mg/L of sulfate. Mass balance calculations showed that the RO process (permeate and reject water) had recovered 107% of arsenic and 100% of antimony from raw water.

Distribution system “first draw” samples were collected from a cold water tap in the kitchen on a monthly basis to determine if the RO treatment had any impacts on the distribution water quality. pH values of the distribution “first draw” samples ranged from 6.8 to 9.2, and averaged 8.4. Alkalinity concentrations ranged from 10.1 to 58.3 mg/L, and averaged 24.6 mg/L. Arsenic and antimony concentrations in the distribution “first draw” samples were both in the sub-parts per billion (ppb) levels (except for one time at 2.7 µg/L of arsenic), similar to those in the treatment effluent. Lead and copper concentrations were well below the respective action levels. Therefore, the RO treatment system did not have any adverse effects on the water quality in the distribution system.

Operational problems encountered during the demonstration study included a bearing failure on the RO motor and pump assembly. The problem was corrected promptly by the vendor and has not re-occurred. The replacement parts were covered under warranty; however, the cost to diagnose the problem and install the replacement parts was not.

The capital investment for the system was \$20,452, including \$8,600 for the dual plumbing and \$11,942 for the EPRO-1,200 RO system. With the system’s rated capacity of 1,200 gpd, the normalized capital cost was \$17.12 per gpd of design capacity.

The O&M cost included the cost incurred by system repairs, electricity consumption, and labor to operate the system. The cost to diagnose and install a faulty RO motor and pump assembly was \$321. Annual electricity consumption was estimated to be 5,078 kWh and cost \$376. Routine labor activities consumed 10 min per day, which translated into \$666/yr. The total annual O&M cost was estimated to be \$1,404, or \$12.89/1,000 gal of permeate water produced.

CONTENTS

DISCLAIMER	ii
FOREWORD	iii
ABSTRACT.....	iv
APPENDICES	vii
FIGURES	vii
TABLES	viii
ABBREVIATIONS AND ACRONYMS	ix
ACKNOWLEDGMENTS	xi
 1.0 INTRODUCTION	 1
1.1 Background.....	1
1.2 Treatment Technologies for Arsenic Removal	2
1.3 Project Objectives	2
 2.0 SUMMARY AND CONCLUSIONS	 6
 3.0 MATERIALS AND METHODS.....	 7
3.1 General Project Approach.....	7
3.3 Sample Collection Procedures and Schedules	8
3.3.1 Source Water.....	8
3.3.2 Treatment Plant Water	9
3.3.3 Residual Wastewater.....	10
3.3.4 Distribution System Water.....	10
3.4 Sampling Logistics.....	10
3.4.1 Preparation of Arsenic Speciation Kits.....	10
3.4.2 Preparation of Sampling Coolers	10
3.4.3 Sample Shipping and Handling	11
3.5 Analytical Procedures	11
 4.0 RESULTS AND DISCUSSION	 12
4.1 Facility Description and Pre-existing Treatment System Infrastructure	12
4.1 Facility Description and Pre-existing Treatment System Infrastructure	13
4.1.1 Source Water Quality.....	14
4.1.2 Distribution System	15
4.2 Treatment Process Description	15
4.2.1 Dual Plumbing	15
4.2.2 Treatment Technology Description and System Design.....	16
4.3 System Installation.....	24
4.3.1 Permitting.....	24
4.3.3 Installation, Shakedown, and Startup.....	24
4.4 System Operation.....	25
4.4.1 Operational Parameters.....	25
4.4.2 Residual Management.....	26
4.4.3 System/Operation Reliability and Simplicity	28
4.5 System Performance	29
4.5.1 Treatment Plant Sampling.....	29
4.5.2 Residual Water Sampling	37
4.5.3 Distribution System Water Sampling	38
4.6 System Cost	39

4.6.1 Capital Cost.....	39
4.6.2 Operation and Maintenance Cost.....	40
5.0 REFERENCES	42

APPENDICES

APPENDIX A: OPERATIONAL DATA
APPENDIX B: ANALYTICAL DATA

FIGURES

Figure 4-1. Pre-existing Facility	12
Figure 4-2. RO Pilot System and Components	13
Figure 4-3. Installation of Dual Plumbing System Using PEX Piping	16
Figure 4-4. Water Demand Monitoring at CES	17
Figure 4-5. Schematic of RO Treatment System	19
Figure 4-6. Process Flow Diagram and Sampling Locations for Carmel, ME Site	20
Figure 4-7. Sediment Filter	21
Figure 4-8. EPRO-1,200 RO Unit.....	21
Figure 4-9. Schematic of RO Membrane Module	22
Figure 4-10. Calcite Filter.....	22
Figure 4-11. Atmospheric Storage Tank (top left), Re-Pressurization Pump (middle), and Pressure Tank and Retention Tanks (top right).....	23
Figure 4-12. Chlorine Addition System at CES.....	23
Figure 4-13. Percent Recovery Calculations	27
Figure 4-14. Flowrate Readings of RO Permeate and Reject Water	27
Figure 4-15. Concentrations of Various Arsenic Species at IN, RO, and AP Sampling Locations.....	33
Figure 4-16. Total Arsenic Concentrations at IN, RO, AP, and RW Sampling Locations.....	34
Figure 4-17. Total Antimony Concentrations at IN, RO, AP, and RW Sampling Locations	34
Figure 4-18. TDS Concentrations at IN, RO, AP, and RW Sampling Locations	35
Figure 4-19. pH Levels at IN, RO, AP, and RW Sampling Locations	35
Figure 4-20. Alkalinity Concentrations at IN, RO, AP, and RW Sampling Locations	36
Figure 4-21. Total Hardness Concentrations at IN, RO, AP, and RW Sampling Locations	36
Figure 4-22. Silica Concentration at IN, RO, AP, and RW Sampling Locations	37

TABLES

Table 1-1.	Summary of Rounds 1, 2, and 2a Arsenic Removal Demonstration Locations, Technologies, and Source Water Quality.....	3
Table 1-2.	Number of Demonstration Sites for Each Type of Arsenic Removal Technology	5
Table 3-1.	Predemonstration Study Activities and Completion Dates	7
Table 3-2.	Evaluation Objectives and Supporting Data Collection Activities	8
Table 3-3.	Sampling Schedule and Analytes.....	9
Table 4-1.	Source Water Quality at Carmel, ME	14
Table 4-2.	Design Specifications of EPRO-1,200 RO System.....	18
Table 4-3.	MDWP Punch-List Items and Corrective Actions.....	24
Table 4-4.	Battelle’s Punch-List Items and Corrective Actions	25
Table 4-5.	Summary of EPRO-1,200 System Operation.....	26
Table 4-6.	Summary of Arsenic, Antimony, Iron, and Manganese Analytical Results	30
Table 4-7.	Summary of Other Water Quality Parameter Results	31
Table 4-8.	Mass Balance Calculations	38
Table 4-9.	Distribution System Sampling Results.....	38
Table 4-10.	Capital Investment Cost for CES at Carmel, ME.....	39
Table 4-11.	Operation and Maintenance Cost for EPRO-1200 RO Unit Treatment System	40

ABBREVIATIONS AND ACRONYMS

AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
AQWS	Advanced Quality Water Solutions
As	arsenic
ATS	Aquatic Treatment Systems
Ca	calcium
CES	Carmel Elementary School
Cl	chloride
C/F	coagulation/filtration
CRF	capital recovery factor
Cu	copper
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
Fe	iron
gpd	gallons per day
gpm	gallons per minute
HDPE	high-density polyethylene
HIX	hybrid ion exchanger
Hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IR	iron removal
IX	ion exchange
LCR	Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MDWP	Maine Drinking Water Program
MEI	Magnesium Elektron, Inc.
Mg	magnesium
Mn	manganese
mV	millivolts
Na	sodium
NA	not analyzed
NaOCl	sodium hypochlorite
NRMRL	National Risk Management Research Laboratory

ABBREVIATIONS AND ACRONYMS (Continued)

NS	not sampled
NSF	NSF International
NTNCWS	non-transient, non-community water system
NTU	nephelometric turbidity unit
O&M	operation and maintenance
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
Pb	lead
PEX	cross-linked polyethylene
P&ID	pipng and instrumentation diagram
PO ₄	orthophosphate
POE	point-of-entry
POU	point-of-use
Ppb	parts per billion
psi	pounds per square inch
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RFP	Request for Proposal
RO	reverse osmosis
RPD	relative percent difference
RW	reject water
Sb	antimony
SDWA	Safe Drinking Water Act
SiO ₂	silica
SO ₄ ²⁻	sulfate
STS	Severn Trent Services
TDS	total dissolved solids
TFC	thin-film composite
VOC	volatile organic compound
VSWS	very small water system

ACKNOWLEDGMENTS

The authors wish to extend their sincere appreciation to Carmel Elementary School in Carmel, ME for monitoring operation of the arsenic removal system and collecting samples from the treatment and distribution systems throughout the performance evaluation study. The authors also appreciate the technical support provided by Jennifer Grant and Greg DuMonthier of the Maine Drinking Water Program and Cindy Klevens of the New Hampshire Department of Environmental Services.

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). In order to clarify the implementation of the original rule, EPA revised the rule text on March 25, 2003, to express the MCL as 0.010 mg/L (10 µg/L) (EPA, 2003). The final rule 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 to reduce compliance costs. As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, on-site demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems. Shortly thereafter, an announcement was published in the *Federal Register* requesting water utilities interested in participating in Round 1 of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 out of 115 sites to host the demonstration studies.

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the 17 host sites. EPA received 70 technical proposals for the 17 host sites, with each site receiving from one to six proposals. In April 2003, an independent technical panel reviewed the proposals and provided its recommendations to EPA on the technologies that it determined were acceptable for the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration 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. In September 2003, EPA again solicited proposals from engineering firms and vendors for arsenic removal technologies. EPA received 148 technical proposals for the 32 host sites, with each site receiving from two to eight proposals. In April 2004, another technical panel was convened by EPA to review the proposals and provide recommendations to EPA with the number of proposals per site ranging from none (for two sites) to a maximum of four. The final selection of the treatment technology at the sites that received at least one proposal was made, again, through a joint effort by EPA, the state regulators, and the host site. Since then, four sites have withdrawn from the demonstration program, reducing the number of sites to 28.

With additional funding from Congress, EPA selected 10 more sites for demonstration under Round 2a. Somewhat different from the Round 1 and Round 2 selection process, Battelle, under EPA's guidance, issued a Request for Proposal (RFP) on February 14, 2007, to solicit technology proposals from vendors and engineering firms. Upon closing of the RFP on April 13, 2007, Battelle received from 14 vendors a total of 44 proposals, which were subsequently reviewed by a three-expert technical review panel convened at EPA on May 2 and 3, 2007. Copies of the proposals and recommendations of the review

panel were later provided to and discussed with representatives of the 10 host sites and state regulators in a technology selection meeting held at each host site during April through August 2007. The final selections of the treatment technology were made, again, through a joint effort by EPA, the respective state regulators, and the host sites.

As one of the 10 Round 2a host sites, the water system at Carmel Elementary School (CES) in Carmel, Maine had elevated arsenic and antimony (Sb) in its water supply. The original technology selected was a 9,600-gal/day (gpd) point-of-entry (POE) reverse osmosis (RO) system designed to treat the entire water supply at the school. This would require expansion of the treatment building and installation of a septic/leach field for discharge of RO reject water. To reduce the treatment cost, a smaller RO system was used to treat only potable water, which was then distributed via a separate distribution system for potable purposes. The system evaluated was a 1,200-gpd EPRO-1200 RO System supplied by Crane Environmental.

As of February 2011, 49 of the 50 systems were operational and performance evaluations of all 49 systems were completed.

1.2 Treatment Technologies for Arsenic Removal

Technologies selected for Rounds 1, 2, and 2a demonstration included adsorptive media (AM), iron removal (IR), coagulation/filtration (C/F), ion exchange (IX), RO, point-of-use (POU) RO, and system/process modification. Table 1-1 summarizes the locations, technologies, vendors, system flowrates, and key source water quality parameters (including As, iron [Fe], and pH). Table 1-2 presents the number of sites for each type of technology. AM technology was demonstrated at 30 sites, including four with IR pretreatment. IR technology was demonstrated at 12 sites, including four with supplemental iron addition. C/F, IX, and RO technologies were demonstrated at three, two, and one sites, respectively. The Sunset Ranch Development site that demonstrated POU RO technology had nine under-the-sink RO units. The Oregon Institute of Technology (OIT) site classified under AM had three AM systems and eight POU AM units. The Lidgerwood site encompassed only system/process modifications. An overview of the technology selection and system design for the 12 Round 1 demonstration sites and the associated capital costs is provided in two EPA reports (Wang et al., 2004; Chen et al., 2004), which are posted on the EPA Web site at <http://www.epa.gov/ORD/NRMRL/arsenic/resource.htm>.

1.3 Project Objectives

The objective of the arsenic demonstration program was to conduct full-scale performance evaluations of treatment technologies for arsenic removal from drinking water supplies. The specific objectives were to:

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

This report summarizes the performance of the Crane Environmental EPRO-1,200 RO system at CES in Carmel, ME, from April 16 through December 15, 2009. The types of data collected included 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 Rounds 1, 2, and 2a Arsenic Removal Demonstration
Locations, Technologies, and Source Water Quality**

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH (S.U.)
Northeast/Ohio							
Carmel, ME	Carmel Elementary School	RO	Norlen’s Water	1,200 gpd	21	<25	7.9
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
Houghton, NY ^(c)	Town of Caneadea	IR (Macrolite)	Kinetico	550	27 ^(a)	1,806 ^(d)	7.6
Woodstock, CT	Woodstock Middle School	AM (Adsorbsia)	Siemens	17	21	<25	7.7
Pomfret, CT	Seely-Brown Village	AM (ArsenX ^{np})	SolmeteX	15	25	<25	7.3
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 ^(d)	7.3
Conneaut Lake, PA	Conneaut Lake Park	IR (Greensand Plus) with ID	AdEdge	250	28 ^(a)	157 ^(d)	8.0
Buckeye Lake, OH	Buckeye Lake Head Start Building	AM (ARM 200)	Kinetico	10	15 ^(a)	1,312 ^(d)	7.6
Springfield, OH	Chateau Estates Mobile Home Park	IR & AM (E33)	AdEdge	250 ^(e)	25 ^(a)	1,615 ^(d)	7.3
Great Lakes/Interior Plains							
Brown City, MI	City of Brown City	AM (E33)	STS	640	14 ^(a)	127 ^(d)	7.3
Pentwater, MI	Village of Pentwater	IR (Macrolite) with ID	Kinetico	400	13 ^(a)	466 ^(d)	6.9
Sandusky, MI	City of Sandusky	IR (Aeralater)	Siemens	340 ^(e)	16 ^(a)	1,387 ^(d)	6.9
Delavan, WI	Vintage on the Ponds	IR (Macrolite)	Kinetico	40	20 ^(a)	1,499 ^(d)	7.5
Goshen, IN	Clinton Christian School	IR & AM (E33)	AdEdge	25	29 ^(a)	810 ^(d)	7.4
Fountain City, IN	Northeastern Elementary School	IR (G2)	US Water	60	27 ^(a)	1,547 ^(d)	7.5
Waynesville, IL	Village of Waynesville	IR (Greensand Plus)	Peerless	96	32 ^(a)	2,543 ^(d)	7.1
Geneseo Hills, IL	Geneseo Hills Subdivision	AM (E33)	AdEdge	200	25 ^(a)	248 ^(d)	7.4
Greenville, WI	Town of Greenville	IR (Macrolite)	Kinetico	375	17 ^(a)	7,827 ^(d)	7.3
Climax, MN	City of Climax	IR (Macrolite) with ID	Kinetico	140	39 ^(a)	546 ^(d)	7.4
Sabin, MN	City of Sabin	IR (Macrolite)	Kinetico	250	34 ^(a)	1,470 ^(d)	7.3
Sauk Centre, MN	Big Sauk Lake Mobile Home Park	IR (Macrolite)	Kinetico	20	25 ^(a)	3,078 ^(d)	7.1
Stewart, MN	City of Stewart	IR &AM (E33)	AdEdge	250	42 ^(a)	1,344 ^(d)	7.7
Lidgerwood, ND	City of Lidgerwood	Process Modification	Kinetico	250	146 ^(a)	1,325 ^(d)	7.2
Lead, SD	Terry Trojan Water District	AM (ArsenX ^{np})	SolmeteX	75	24	<25	7.3
Midwest/Southwest							
Willard, UT	Hot Springs Mobile Home Park	IR & AM (Adsorbsia)	Filter Tech	30	15.4 ^(a)	332 ^(d)	7.5
Arnaudville, LA	United Water Systems	IR (Macrolite)	Kinetico	770 ^(e)	35 ^(a)	2,068 ^(d)	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

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

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

AM = adsorptive media; C/F = coagulation/filtration; HIX = hybrid ion exchanger; IR = iron removal; IR with ID = iron removal with iron addition; 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) Withdrew from program in 2007. Selected originally to replace Village of Lyman, NE site, which withdrew from program in June 2006.

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

(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.

Table 1-2. Number of Demonstration Sites for Each Type of Arsenic Removal Technology

Type of Technologies	Number of Sites
Adsorptive Media ^(a)	26
Adsorptive Media with Iron Removal Pretreatment	4
Iron Removal (Oxidation/Filtration)	8
Iron Removal with Supplemental Iron Addition	4
Coagulation/Filtration	3
Ion Exchange	2
Reverse Osmosis	1
Point-of-Use Reverse Osmosis ^(b)	1
System/Process Modifications	1

(a) OIT site at Klamath Falls, OR had three AM systems and eight POU AM units.

(b) Including nine under-the-sink RO units.

2.0 SUMMARY AND CONCLUSIONS

Based on the information collected during the 10-month system operation, the following conclusions were made relating to the overall objectives of the treatment technology demonstration study.

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

- The dual plumbing system with a smaller 1,200-gpd RO unit was found to be more cost effective than the originally proposed 9,600-gpd RO unit treating the entire water supply. The major cost saving was from the reduced quantity of reject water that could be discharged to the existing septic system.
- The POE RO system was effective in removing arsenic from source water, reducing its concentrations (total) from 18.2 to 0.1 µg/L (on average) in permeate water.
- The POE RO system was effective in removing antimony from source water, reducing its concentrations from 10.8 to <0.1 µg/L in permeate water.
- The POE RO system also was effective in removing total dissolved solids (TDS), manganese, and silica, achieving 97%, 95%, and 96% removal, respectively, for these analytes. pH values were initially reduced to 6.9 (on average) due to reduction in alkalinity by RO, but was increased to 7.4 (on average) after pH adjustment.

Process residuals produced by the technology:

- The only process residual produced by the RO system was reject water. The amount produced was high, accounting for 60% of feed water. The reject water was discharged to the existing septic system at the school.
- The reject water contained, on average, 31.9 µg/L of arsenic, 17.7 µg/L of antimony, and 410 mg/L of TDS. The pH of the reject water was 8.0 (on average).

Required system O&M and operator skill levels:

- Under normal operating conditions, the skills required to operate the EPRO-1,200 RO system were minimal. The daily demand on the operator was typically 10 min to visually inspect the system and record operational parameters.

Capital and O&M cost of the technology:

- Total capital cost was \$20,542, including \$8,600 for dual plumbing and \$11,942 for the EPRO-1,200 RO system.
- The annual O&M cost was \$1,404, or \$12.89/1,000 gal of permeate water treated.

3.0 MATERIALS AND METHODS

3.1 General Project Approach

Following the predemonstration activities summarized in Table 3-1, the performance evaluation study of the EPRO-1,200 RO unit began on April 16, 2009, and ended on December 15, 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 and antimony to below their respective MCLs of 10 and 6 µg/L through the collection of water samples across the treatment train, as described in the Study Plan (Battelle, 2009). The reliability of the system was evaluated by tracking the 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. The vendor (Norlen's Water Treatment Service [Norlen's Water]) was contracted by Battelle for system installation and assisted in tracking system operation.

Table 3-1. Predemonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	July 24, 2007
Project Planning Meeting Held	September 17, 2008
Request for Quotation Issued to Vendor	October 10, 2008
Vendor Quotation Received by Battelle	November 4, 2008
Purchase Order Completed and Signed	December 11, 2008
Permit Issued by MDWP	December 19, 2008
Installation of Dual Plumbing System Begun	July 1, 2008
Installation of Dual Plumbing System Completed	October 1, 2008
RO Equipment Arrived	January 5, 2009
System Installation and Shakedown Completed	February 4, 2009
Performance Evaluation Begun	April 16, 2009
Final Study Plan Issued	April 23, 2009

MDWP = Maine Drinking Water Program

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

The cost of the system was evaluated based on the capital cost per gal/min (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, electrical usage, and labor.

3.2 System O&M and Cost Data Collection

The plant operator performed daily, biweekly, and monthly system O&M and data collection according to instructions provided by the vendor and Battelle. On a regular basis, the plant operator recorded system operational data such as pressure, flowrate, totalizer, and hour meter readings on a System Operation Log

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

Evaluation Objectives	Data Collection
Performance	–Ability to consistently meet 10 µg/L of arsenic MCL in treated water –Ability to consistently meet 6 µg/L of antimony MCL in treated water
Reliability	–Unscheduled system downtime –Frequency and extent of repairs including a description of problems encountered, materials and supplies needed, and associated labor and cost incurred
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
Cost Effectiveness	–Capital cost for equipment, engineering, and installation –O&M cost for chemical usage, electricity consumption, and labor

Sheet and conducted visual inspections to ensure normal system operations. If any problems occurred, the plant operator contacted the Battelle Study Lead and/or Norlen's Water for troubleshooting. The plant operator recorded all relevant information, including the problems encountered, course of actions taken, materials and supplies used, and associated cost and labor incurred on the Repair and Maintenance Log Sheet. On a monthly basis, Norlen's Water measured temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and chlorine residuals and recorded the data on an Onsite Water Quality Parameters Log Sheet.

The capital cost for the arsenic removal system consisted of the cost for equipment, site engineering, and system installation. The O&M cost consisted of the cost for electricity consumption and labor. Labor for various activities, such as the routine system O&M, troubleshooting and repairs, and demonstration-related work, were tracked using an Operator Labor Hour Log Sheet. The routine system O&M included activities such as completing field logs, performing system inspections, and others as recommended by the vendor. The labor for demonstration-related work, including activities such as performing field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead and the vendor, was recorded, but not used for cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected from the wellheads, across the treatment plant, and from the distribution system. Table 3-3 presents the sampling schedules and analytes measured during each sampling event. Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2007). The procedure for arsenic speciation is described in Appendix A of the QAPP.

3.3.1 Source Water. Source water characterization was performed by Battelle before and during an EPA pilot study in 2005 and 2006 under a separate EAP task order. Source water samples were collected

Table 3-3. Sampling Schedule and Analytes

Sample Type	Sample Locations ^(a)	No. of Samples	Planned Frequency	Analytes	Actual Sampling Date
Treatment Plant Water (Speciation Sampling)	IN, RO, and AP	3	First week of each four-week cycle	Onsite: pH, temperature, DO, and/or ORP Offsite: As(III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), Sb (total and soluble), Ca, Mg, NO ₃ , SO ₄ , SiO ₂ , P, TDS, turbidity, and alkalinity	04/30/09, 05/27/09, 06/30/09, 07/29/09, 09/02/09, 09/28/09, 10/28/09, 12/03/09
Treatment Plant Water (Regular Sampling)			Second, third, and fourth week of each four-week cycle	Onsite: pH, temperature, DO, and/or ORP Offsite: As (total), Fe (total), Mn (total), Sb (total), Ca, Mg, SiO ₂ , TDS, turbidity, and alkalinity	04/16/09, 05/12/09, 05/20/09, 06/04/09, 06/17/09, 09/08/09, 09/14/09, 09/30/09, 10/07/09, 10/20/09, 10/27/09, 11/17/09, 12/15/09
Residual Wastewater	RW	1	Weekly ^(b)	Onsite: pH Offsite: As (total), Fe (total), Mn (total), Sb (total), Ca, Mg, NO ₃ , SO ₄ , SiO ₂ , P, TDS, turbidity, and alkalinity	05/27/09, 06/17/09, 06/30/09, 07/29/09, 09/02/09, 09/08/09, 09/14/09, 09/28/09, 09/30/09, 10/07/09, 10/20/09, 10/27/09, 10/28/09, 11/17/09, 12/03/09, 12/15/09
Distribution System Water	Tap in school (DS1)	1	Monthly	Onsite: free and total Cl ₂ Offsite: As (total), Fe (total), Mn (total), Sb (total), Cu (total), Pb (total), pH, and alkalinity	05/20/09, 06/17/09, 07/09/09, 08/27/09, 09/08/09, 09/29/09, 10/27/09, 11/19/09

(a) Abbreviations in parenthesis corresponding to sample locations shown in Figure 4-6, i.e., IN = blended source water; RO = RO permeate; AP = after pH adjustment; RW = reject water; DS1 = distribution system.

(b) Actual sampling spanned from 1 day to 3 weeks.

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

from Wells No. 1 and No. 2 on September 13, 2005, during the initial site visit prior to the pilot study. More complete source water characterization was conducted on the blended water from both wells during the pilot study from March 7 through July 11, 2006. These samples were filtered for soluble arsenic and antimony and then speciated for As(III) and As(V) using a field arsenic speciation kit (see Section 3.4.1). Results of these source water sampling events are discussed in Section 4.1.

3.3.2 Treatment Plant Water. Battelle Study Plan (2009) called for weekly sampling of treatment plant water samples for onsite and offsite analyses. For the first week of each four-week cycle, samples were taken (1) after water from Wells No. 1 and No. 2 had blended (IN), (2) at the RO permeate port (RO), and (3) after pH adjustment (AP), speciated onsite, and analyzed for the analytes listed in

Table 3-3 under “Treatment Plant Water (Speciation Sampling).” For the second, third, and fourth weeks of each four-week cycle, samples were collected at the same three locations and analyzed for the analytes listed in Table 3-3 under “Treatment Plant Water (Regular Sampling).” During the performance evaluation study, actual sampling frequencies spanned from one day to three weeks, with speciation samples taken approximately once a month on eight sampling occasions and regular samples taken once every one to four weeks on 13 sampling occasions. During the summer break from June 13 through August 25, only three sets of samples were taken, including one on June 17 for regular sampling and two on June 30 and July 29 for speciation sampling.

3.3.3 Residual Wastewater. The Battelle Study Plan (2009) called for weekly sampling of reject water (RW) from a sampling tap on the RW discharge line leading to the septic system. Actual sampling frequencies spanned from 1 days to three weeks. For each sampling event, an unfiltered sample from the reject water discharge line was collected in an unpreserved 1-gal wide-mouth high-density polyethylene (HDPE) bottle and a 60-mL filtered sample (using 0.45- μ m filters) was collected into a 125-mL HDPE bottle preserved with nitric acid. Analytes for the reject water samples are listed in Table 3-3.

3.3.4 Distribution System Water. Water samples were collected from the distribution system monthly to determine the impact of the RO system on the water chemistry in the distribution system, specifically, the pH, arsenic, antimony, lead, and copper levels.

The plant operator collected the samples following an instruction sheet developed in accordance with the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The date and time of last water usage before sampling and of actual sample collection were recorded for calculation of sample stagnation time. All samples were collected from a cold-water faucet that had not been used for at least 6 hr to ensure that stagnant water was sampled.

3.4 Sampling Logistics

3.4.1 Preparation of Arsenic Speciation Kits. The arsenic field speciation method used an anion exchange resin column to separate the soluble arsenic species, As(V) and As(III) (Edwards et al., 1998). Resin columns were prepared in batches at Battelle laboratories in accordance with the procedures detailed in Appendix A of the EPA-endorsed QAPP (Battelle, 2007).

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

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

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

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

3.5 Analytical Procedures

The analytical procedures described in detail in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2007) were followed by Battelle's ICP-MS laboratory and AAL. Laboratory quality assurance/quality control (QA/QC) of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection limits (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 vendor using a VWR Symphony SP90M5 Handheld Multimeter, which was calibrated for pH and DO prior to use following the procedures provided in the user's manual. The ORP probe also was checked for accuracy by measuring the ORP of a standard solution and comparing it to the expected value. The vendor collected a water sample in a clean, plastic beaker and placed the Symphony SP90M5 probe in the beaker until a stable value was obtained. The vendor also performed free and total chlorine measurements using Hach chlorine test kits following the user's manual.

4.0 RESULTS AND DISCUSSION

4.1 Facility Description and Pre-existing Treatment System Infrastructure

CES is located on 50 Plymouth Road in Carmel, Maine. Serving approximately 200 students and faculty members, the facility is a non-transient, non-community water system (NTNCWS) supplied by two wells, i.e., Wells No. 1 and No. 2, with a combined capacity of 30 gpm. The average daily demand was 1,700 to 1,800 gal during the school year. The pre-existing system consisted of a 576-gal storage tank, a chlorine addition system, and three contact/retention tanks configured in parallel (Figure 4-1). About 0.3 mg/L (as Cl_2) of free chlorine residual was maintained in treated water for disinfection purposes.



Figure 4-1. Pre-existing Facility

(Clockwise from Top: School Building, Storage Tank, Contact Tanks, and Chlorination System)

Under a separate EPA task order, Battelle conducted a four-month pilot study on a 600-gpd, skid-mounted RO system from March 2 through July 11, 2006. The pilot system was supplied by Crane Environmental and installed by Norlen's Water. The pilot system received a split flow at 2 gpm from the wells with the balance (i.e., 28 gpm) continued to supply the school's water demand. Major components of the pilot system included a 5- μm sediment pre-filter, a 1/2-horsepower (hp) positive displacement rotary vane booster pump, and a single 2.5-in \times 40-in thin-film composite RO membrane (Figure 4-2). During the pilot study, the RO system operated for a total of 740 hr, processing approximately 76,500 gal of water. The system produced 16,300 gal of permeate, corresponding to a recovery rate of 21%. Both permeate and reject water were discharged to the septic system.

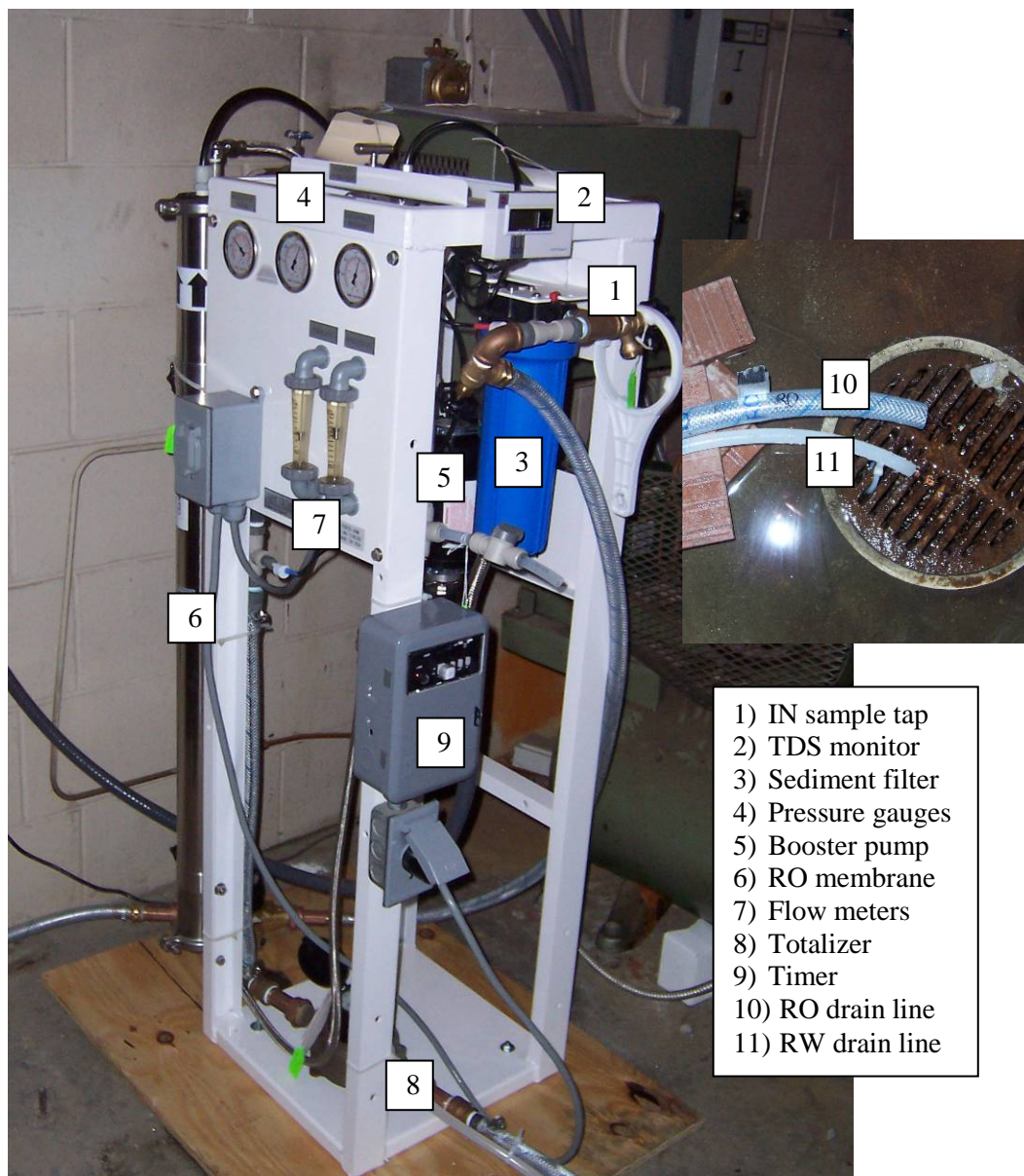


Figure 4-2. RO Pilot System and Components

Results of the pilot study were summarized in a letter report dated December 29, 2006. Key conclusions are highlighted below:

- The RO system was effective in removing arsenic and antimony to levels well below their respective MCLs.
- A considerable amount of residual wastewater was produced (i.e., 79% of the influent flow) by the single-stage RO membrane element. A multiple-stage RO system can achieve a higher recovery rate.
- Blending the RO permeate with raw water can help neutralize permeate, reduce the volume of reject water, and lower the overall treatment cost.

4.1.1 Source Water Quality. Analytical results from the source water sampling events in 2005 and 2006 are presented in Table 4-1 and discussed as follows.

Table 4-1. Source Water Quality at Carmel, ME

Parameter	Unit	Battelle Source Water Data			
	<i>Date</i>	09/13/05 ^(a)		03/07/06 ^(b)	03/21/06– 07/11/06 ^(c)
	<i>Well</i>	No. 1	No. 2	No. 1 & 2	No. 1 & 2
Alkalinity (as CaCO ₃)	mg/L	NA	NA	216	202–225
Chloride	mg/L	NA	NA	24	NA
Fluoride	mg/L	NA	NA	<0.1	NA
Sulfate	mg/L	NA	NA	11.2	NA
Silica (as SiO ₂)	mg/L	NA	NA	9.6	NA
TDS	mg/L	NA	NA	246	240–264
pH	S.U.	7.9	7.7	7.9	7.5–7.8
Temperature	°C	NA	NA	NA	11.0–14.1
Total Hardness (as CaCO ₃)	mg/L	NA	NA	226	184–247
Ca Hardness (as CaCO ₃)	mg/L	NA	NA	107	91.2–127
Mg Hardness (as CaCO ₃)	mg/L	NA	NA	119	88.3–128
Al (total)	µg/L	NA	NA	<10	NA
As (total)	µg/L	21.2	28.2	21.1	19.7–29.8
As (soluble)	µg/L	21.5	28.0	20.3	19.1–29.8
As (particulate)	µg/L	<0.1	0.2	0.8	<0.1–0.8
As (III)	µg/L	0.7	0.7	0.5	0.3–0.7
As (V)	µg/L	20.9	27.3	19.8	6.2–29.1
Fe (total)	µg/L	<25	<25	<25	<25
Fe (soluble)	µg/L	<25	<25	<25	NA
Mn (total)	µg/L	1.7	1.6	2.0	2.1
Mn (soluble)	µg/L	1.6	1.6	1.9	NA
Sb (total)	µg/L	13.6	14.1	12.6	9.7–12.1
Sb (soluble)	µg/L	NA	NA	12.4	10.1–12.5
V (total)	µg/L	NA	NA	0.5	NA
V (soluble)	µg/L	NA	NA	0.6	NA
Na (total)	mg/L	NA	NA	25.0	NA

(a) Samples collected during initial site visit

(b) Samples collected during startup of pilot system.

(c) Samples collected during pilot study

NA = data not available

Arsenic. Based on the September 13, 2005 sampling data, Well No. 1 water contained a slightly lower arsenic concentration than Well No. 2 (i.e., 21.2 vs 28.2 µg/L). These concentrations were well within the range of 19.7 to 29.8 µg/L measured in blended source water during the four-month pilot study. Most arsenic was present as soluble As(V) with only 0.3 to 0.7 µg/L present as As(III). Therefore, oxidation of the water prior to the RO treatment was not required.

Antimony. Water from Wells No. 1 and No. 2 contained similar levels of antimony at 13.6 and 14.1 µg/L, respectively, based on the September 13, 2005 data. Total antimony concentrations measured in the blended source water during the pilot study ranged from 9.7 to 12.6 µg/L. Most antimony was present in the soluble form with concentrations ranging from 10.1 to 12.5 µg/L.

Other Water Quality Parameters. TDS concentrations in combined source water ranged from 240 to 264 mg/L, which were composed primarily of calcium (36 to 51 mg/L), magnesium (35 to 51 mg/L), sodium (25.0 mg/L), sulfate (11.2 mg/L), silica (9.6 mg/L), and chloride (24 mg/L). Hardness concentrations ranged from 184 to 247 mg/L (as CaCO₃); alkalinity from 202 to 225 mg/L (as CaCO₃); pH values ranged from 7.5 to 7.9.

4.1.2 Distribution System. Based on the information provided by the school, the distribution system material was comprised of a combination of galvanized and copper piping. In preparation for the installation of the 1,200-gpd RO unit, the distribution system was modified to be a duplex system in July 2008, for both potable and non-potable water distribution. Installation of the duplex distribution system is further discussed in Section 4.2.1.

One location inside the school building was selected for monthly distribution system water sampling to evaluate the effect of the RO treatment system on the distribution system water quality.

4.2 Treatment Process Description

4.2.1 Dual Plumbing. The original treatment technology selected for CES was a Watts Premier 9,600-gpd RO system proposed by Advanced Quality Water Solutions (AQWS) in 2007. The system consisted of two Goulds V260 HydroPro diaphragm tanks, a water softener, an RO unit, a 3,000-gal atmospheric storage tank, a 30-gpm booster pump, and two acid neutralizers. During an onsite introductory meeting attended by EPA, Battelle, MDWP, AQWS, and an engineering firm representing CES on July 24, 2007, two main issues were identified: (1) the existing building would need to be modified/expanded to house the new 9,600-gpd RO system and (2) a new septic/leach field would need to be built to handle residual wastewater produced by the RO system. Based on a rough estimate, the cost for constructing a new septic/leach field alone would range from \$30,000 to \$35,000. CES expressed concerns over its ability to cover the cost of these two new requirements.

To reduce the financial burden on CES, a dual plumbing approach was discussed and later adopted by the project team. This approach involved installing a parallel plumbing system dedicated to the potable water distribution only and had been successfully employed at schools and small businesses in the State of New Hampshire. Because most water consumed at CES was for non-potable use (i.e., lavatory), only a portion of raw water would need to be treated for potable use (i.e., kitchen sinks, water fountains, etc.). Therefore, a smaller RO system with a separate distribution system was used to meet the potable water demand, thus reducing the capital and O&M cost.

In July 2008, Battelle contracted Patriot Plumbing in Etna, ME to perform the plumbing work necessary to convert the existing distribution system into a duplex system. Cross-linked polyethylene (PEX) piping with 0.5 and 0.75-in nominal sizes was installed from the boiler room, where the RO system was to be housed, to the existing cold water line supplying water fountains and bathroom, break-room, kitchen, and locker-room sinks. The PEX piping was installed at hallway ceilings and extended to locations near the fixtures receiving potable water. The pre-existing piping at the ceiling feeding these fixtures was capped off and the PEX piping was connected to the piping going to the fixtures. The PEX piping is NSF International (NSF) 61 certified for use in drinking water systems. Figure 4-3 presents photos of the installation of the dual plumbing system using the PEX piping. A water meter was installed on the potable line to monitor the water demand. An existing water meter was used to monitor the raw water demand (potable and non-potable).

During a project planning meeting attended by EPA, Battelle, MDWP, and CES on September 17, 2008, the size of the RO system was discussed. The school expressed a desire that the hot water line supplying the kitchen sinks and dishwashers be treated because the hot water might be used for food preparation.



Figure 4-3. Installation of Dual Plumbing System Using PEX Piping
(from left to right: prior to Installation, through Ceilings, and to a Hot Water Tank)

As such, two options were discussed as either refurbishing the old EPRO-600 RO pilot system capable of producing 600 gpd or purchasing a new EPRO-1,200 RO system capable of producing 1,200 gpd. A final decision was made based on the potable water demand (both hot and cold water) and a cost comparison of these two options.

In October 2008, Patriot Plumbing was contracted again to modify the plumbing to provide RO-treated water to a newly installed 62-gal hot water tank supplying the kitchen sinks and dishwashers. PEX piping was installed to supply RO-treated water to the hot water tank located in the boiler room and from the hot water tank to the kitchen sinks and dishwashers (Figure 4-3). Another water meter was installed on the hot water tank feed line to monitor the hot water demand. The existing boiler continued to be fed with non-RO water to supply hot water to the rest of the building, i.e., hot water taps in the bathrooms and the shower rooms in the gym.

Water demands were monitored from August 29, 2008, through January 16, 2009, and are shown in Figure 4-4. Daily total water demands ranged from 403 to 3,613 gpd and averaged 1,588 gpd, including 16 to 147 gpd (41 gpd [on average]) of cold potable water and 125 to 401 gpd (223 gpd [on average]) of hot potable water. Thus, total daily potable water demands requiring the RO treatment ranged from 143 to 456 gpd and averaged 257 gpd. This average daily potable water demand accounted for 16% of the total daily water demand.

In November 2008, quotations were received from Norlen's Water for the cost to refurbish the existing 600-gpd RO system used for the pilot study and the cost to purchase and install a new 1,200-gpd RO system. Upon review of the quotations and further discussion with EPA, the EPRO-1,200 RO treatment system was selected because: (1) the difference in cost to refurbish the 600-gpd system or to purchase the new 1,200-gpd system was rather insignificant, and (2) the larger system could better meet CES' peak demand during lunch time.

4.2.2 Treatment Technology Description and System Design. The RO system used thin-film composite (TFC) RO membranes to remove dissolved solids from source water. Source water was delivered under pressure to the membranes with dissolved solids removed through RO and permeate passed through the membranes. The dissolved solids rejected by the membranes were concentrated into the residual wastewater stream and discharged to the existing septic system.

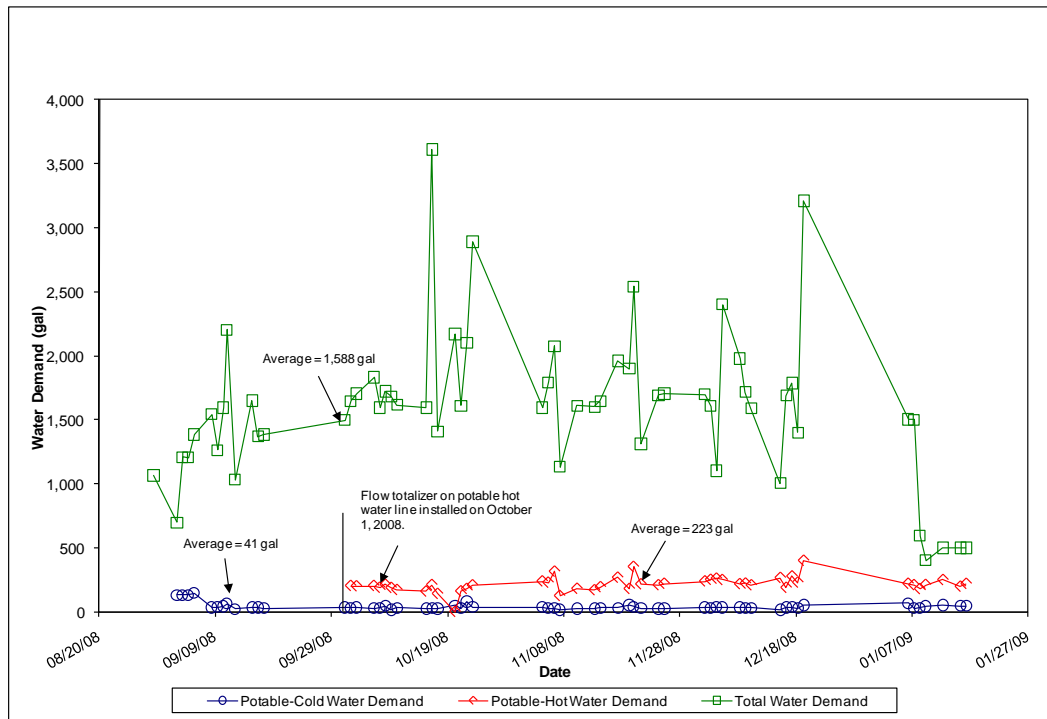


Figure 4-4. Water Demand Monitoring at CES

The Crane Environmental EPRO-1,200 RO treatment process consisted of an RO unit, a pH adjustment unit, two 300-gal atmospheric storage tanks, re-pressurization system, and post-chlorination system. Table 4-2 summarizes key system design parameters of the treatment system. Figure 4-5 presents a schematic of the treatment system. Figure 4-6 shows a process flowchart, along with the sampling/analysis schedule for the treatment system. The key process components of the treatment system are discussed as follows:

- Intake** – Source water was pumped from Wells No. 1 and No. 2 and stored in the pre-existing 576-gal storage tank. Upon exiting the storage tank, source water was split into potable and non-potable water lines. The non-potable water line led water through a retention tank to the school non-potable distribution system. The potable water line fed water to the RO system. A pre-existing flow meter and a pressure gauge monitored the volume and flowrate of intake water and the inlet pressure to the treatment system. A sample tap located at the RO intake line was used for the collection of source water samples for water quality analysis.
- Sediment Filter** – Prior to entering the RO unit, source water flowed through a 5- μ m, 2.75-in \times 10-in sediment filter (Figure 4-7) to remove any particulates that could potentially foul the RO membranes. The manufacturer recommended that the sediment filter be changed on a monthly basis or when the differential pressure became greater than 10% between the pressure reading before and after the sediment filter.
- RO System** – Major components of the skid-mounted RO system included a ½-hp positive displacement, a rotary vane booster pump, a TDS monitor, and two 2.5-in \times 40-in TFC RO membrane modules (Figure 4-8). Figure 4-9 presents a schematic of an RO membrane module. The RO system was rated for 1,200 gpd of permeate production with a 40% recovery (or 2.5:1, that is, for every 2.5 gal of feed water, 1 gal of permeate water and

Table 4-2. Design Specifications of EPRO-1,200 RO System

Parameter	Value
<i>System Components</i>	
No. of Pre-filters	1
Pre-filter Size (µm)	5
No. of RO Membrane Elements	2
RO Membrane Construction	Thin film composite
Size of Membrane Elements	2.5-in D × 40-in H
<i>Inlet Water Quality Requirements</i>	
Max. Operating Pressure (psi)	300
Max. Operating Temperature (°F)	113
pH Range (S.U.)	2–11
Max. Free Chlorine (mg/L [as Cl ₂])	<0.1
Max. Turbidity (NTU)	1
Max. Silica (mg/L)	<1
Max. Iron (mg/L)	<0.01
Max. (mg/L)	<1,000
<i>Operating Specifications</i>	
Feed Flow (gpd)	3,000
Daily Permeate Production (gpd)	1,200
Recovery (%)	40
Min. Rejection (%)	98

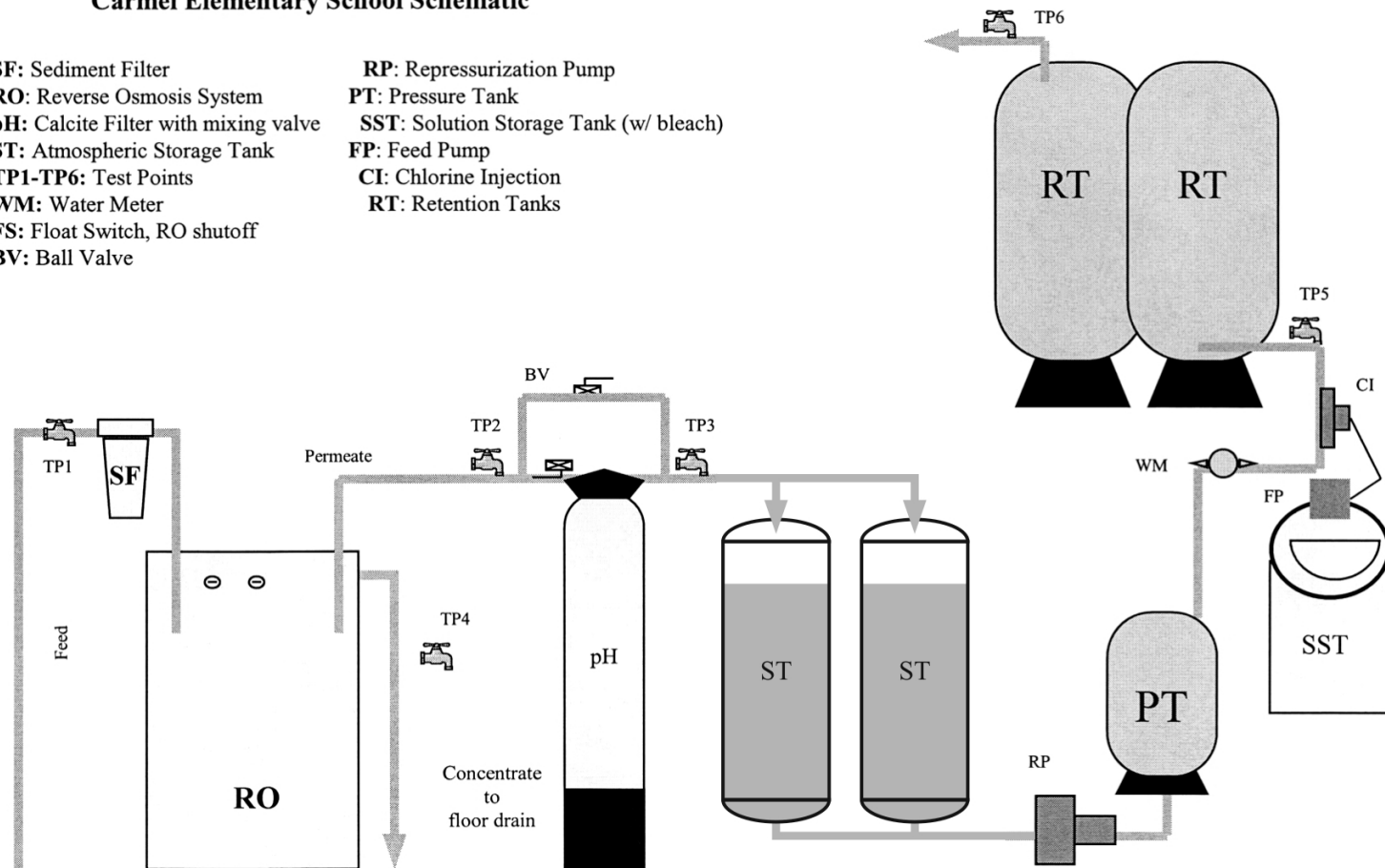
1.5 gal of reject water will be produced). The reject water was discharged into the existing septic system. Both permeate and reject water lines were equipped with flow meters and totalizers, pressure gauges, and sample taps for monitoring purposes.

- **pH Adjustment** – After passing through the RO unit, permeate water flowed through a 10-in × 44-in neutralization tank containing 1.25 ft³ of calcite (Figure 4-10). Based on results of the pilot study, alkalinity concentrations were reduced from 211 mg/L (as CaCO₃) in raw water to 3 mg/L (as CaCO₃) in permeate water while pH values were reduced from 7.7 to 5.7, on average. Therefore, it was necessary to raise the pH of the permeate water prior to distribution. The calcite filter intended to re-mineralize the permeate water and raise its pH to a near neutral level prior to entering the two 300-gal atmospheric storage tanks.
- **Storage Tank and Re-pressurization System** – After passing through the calcite filter, permeate water was stored in two 300-gal atmospheric storage tanks equipped with float switches that controlled the RO unit on/off based on tank levels. A re-pressurization system consisted of a Goulds Model J10S 1-hp re-pressurization pump and a 40-gal non-corrosive fiberglass pressure tank to supply water to the distribution system at a rate of 16 gpm and an average pressure of 38 psi. Figure 4-11 presents photographs of an atmospheric storage tank and re-pressurization system.
- **Chlorination** – The existing chlorination system was relocated to after the re-pressurization system to chlorinate the RO permeate. The chlorine injection system consisted of a 37-gal solution storage tank, a Chem-Tech Series 100 chemical feed pump rated at 30 gpd, and two existing contact/retention tanks (Figure 4-12). The chemical feed pump was tied into the re-pressurization pump to chlorinate the water as water was pumped to the distribution system. The contact/retention tanks were used to allow mixing of the chlorine solution with permeate water. The target chlorine residual was 0.6 mg/L.

**Norlen's Water Treatment
Service, LLC
P.O.Box 46, Route 15**

Carmel Elementary School Schematic

SF: Sediment Filter
RO: Reverse Osmosis System
pH: Calcite Filter with mixing valve
ST: Atmospheric Storage Tank
TP1-TP6: Test Points
WM: Water Meter
FS: Float Switch, RO shutoff
BV: Ball Valve
RP: Repressurization Pump
PT: Pressure Tank
SST: Solution Storage Tank (w/ bleach)
FP: Feed Pump
CI: Chlorine Injection
RT: Retention Tanks



NWT DIAGRAM.CDR

Figure 4-5. Schematic of RO Treatment System

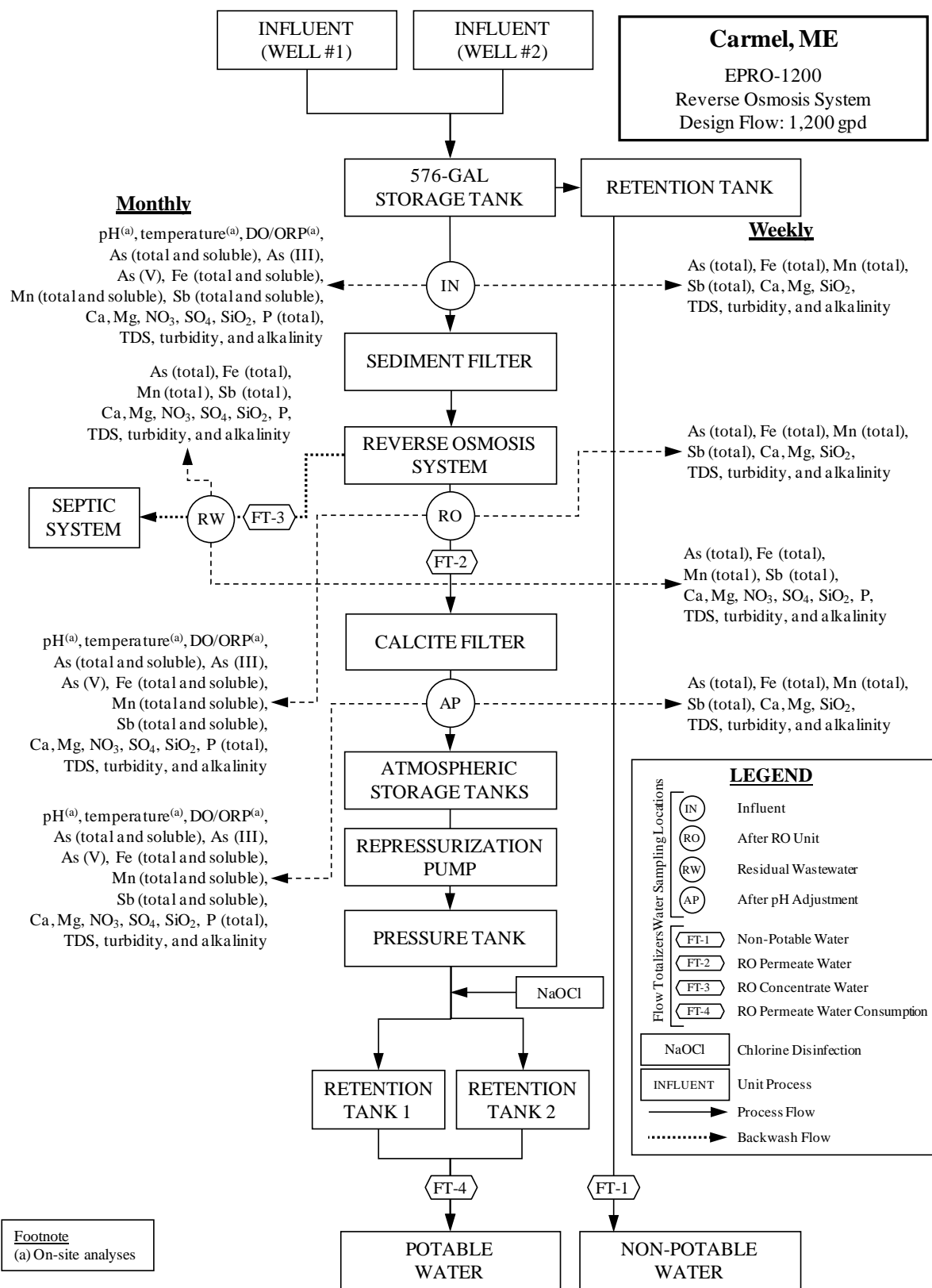


Figure 4-6. Process Flow Diagram and Sampling Locations for Carmel, ME Site



Figure 4-7. Sediment Filter

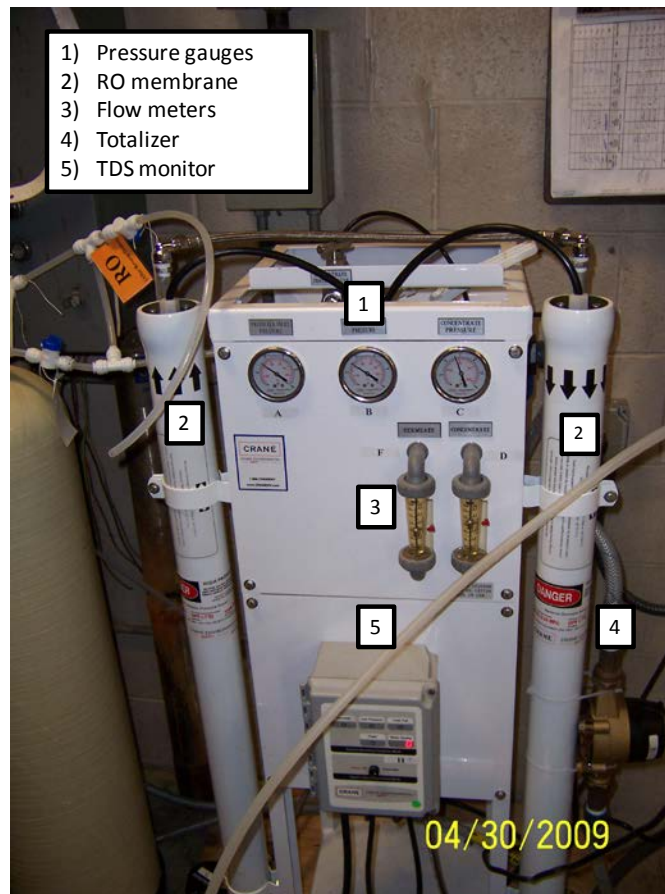
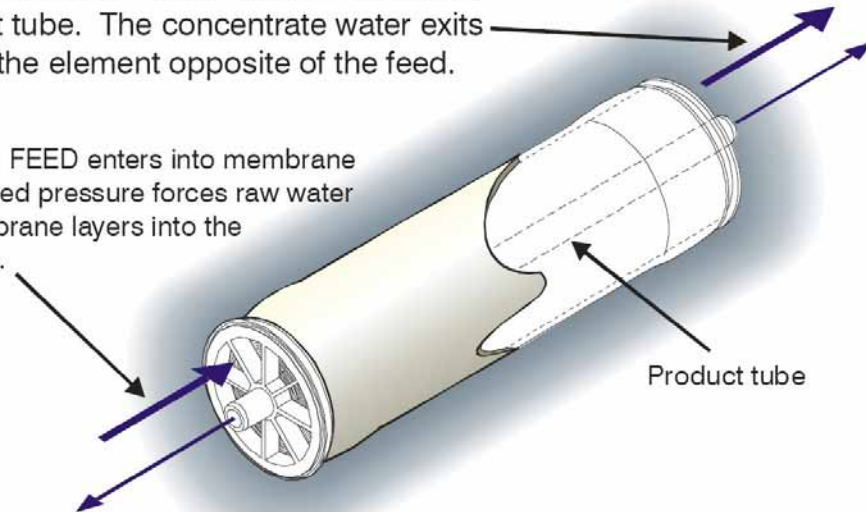


Figure 4-8. EPRO-1,200 RO Unit

CONCENTRATE WATER containing salts is rejected by the membrane and does not enter the product tube. The concentrate water exits the side of the element opposite of the feed.

RAW WATER FEED enters into membrane layers. Applied pressure forces raw water across membrane layers into the product tube.



PRODUCT WATER collects in the product tube and can be output from either end of the membrane element.

Figure 4-9. Schematic of RO Membrane Module



Figure 4-10. Calcite Filter



Figure 4-11. Atmospheric Storage Tank (top left), Re-Pressurization Pump (bottom), and Pressure Tank and Retention Tanks (top right)



Figure 4-12. Chlorine Addition System at CES

4.3 System Installation

Norlen's Water was contracted by Battelle to install the RO system at CES. The installation and shakedown of the system was completed on February 4, 2009. This section briefly summarizes the system installation activities, including permitting, system offloading, installation, shakedown, and startup.

4.3.1 Permitting. A treatment system approval package, which included a schematic of the proposed system, was submitted to MDWP by Norlen's Water on December 15, 2008. MDWP did not have any review comments and issued approval on December 19, 2008.

4.3.2 Installation, Shakedown, and Startup. System components were delivered to Norlen's Water's office during the week of December 22, 2008, and arrived at CES on January 5, 2009. The system was installed during the weeks of January 5, 12, and 19, 2009, with installation completed on January 26, 2009. Installation activities included offloading, placing, and connecting the EPRO-1,200 RO unit and re-pressurization system, connecting the system at the tie-in points, completing electrical wiring, and relocating the chlorination system to post-treatment. System shakedown was completed on February 4, 2009.

On February 27, 2009, two members from MDWP were onsite to inspect the system and noted several punch-list items that needed to be addressed prior to final approval. Table 4-3 summarizes the punch-list items and corrective actions taken. MDWP also collected water samples from the distribution system for arsenic and antimony analysis. Analytical results indicated that arsenic and antimony concentrations were below 0.5 µg/L. Based on these results, MDWP officially lifted off the "DO NOT DRINK ORDER" previously imposed on CES.

Table 4-3. MDWP Punch-List Items and Corrective Actions

Date	Issues/Problems Identified	Corrective Action Taken	Date(s) of Corrective Action	Work Performed by
02/27/09	Valves on RO unit not labeled with appropriate positions	Labeled all valves with their appropriate positions	04/15/09	Norlen's Water
02/27/09	Difficult to distinguish between potable and non-potable water lines in boiler room	Labeled all water lines as either potable or non-potable	04/15/09	Norlen's Water
02/27/09	Lines leading to floor drain not raised	Raised lines leading to floor drain	04/15/09	Norlen's Water
02/27/09	Level III operator required to operate the system	Hired Norlen's Water as school's contract operator	03/01/10	CES

On April 30, 2009, two Battelle staff members visited CES. While onsite, they inspected the treatment system, trained the CES personnel on collection of operational data and water samples, and discussed how the remainder of the project would be conducted. Battelle requested the installation of an hour meter and a pump discharge pressure gauge on the RO system to help track system operation. Also, they noted that the RO system could not keep up with the school's peak water demand. Upon discussion with EPA and Norlen's Water, it was decided that a second 300-gal atmospheric storage tank would be necessary to ensure water supply during peak hours. Table 4-4 summarizes the punch-list items and corrective actions taken.

Table 4-4. Battelle's Punch-List Items and Corrective Actions

Date	Issues/Problems Identified	Corrective Action Taken	Date(s) of Corrective Action	Work Performed by
04/30/09	System operational hours not tracked	Installed an hour meter installed on RO unit to track operational hours	06/29/09	Norlen's Water
04/30/09	No pump discharge pressure gauge on the system	Installed a pump discharge pressure gauge to help track system operation	05/19/09	Norlen's Water
04/30/09	System couldn't meet demand during peak hours	Installed a second 300-gal atmospheric storage tank to ensure an adequate supply of treated water during peak hours	05/05/09	Norlen's Water

4.4 System Operation

4.4.1 Operational Parameters. The operational parameters for the 10-month demonstration study were tabulated and are attached as Appendix A. Table 4-5 summarizes key operational parameters. The system began operation on February 4, 2009, but logging of operational data did not begin until April 16, 2009, when a technician from Norlen's Water travelled to CES to provide training to its personnel on data recording. Because an hour meter was not installed until June 29, 2009, recording of hour meter readings did not begin until July 7, 2009. From July 7, 2009, through the end of the performance evaluation study on December 15, 2009, the system operated for 953.7 hr. Daily system run time averaged 11.7 hr/day when the school was in session (from August 25 through December 15, 2009, for a total of 76 days excluding weekends) and 1.9 hr/day when the school was out of session (from July 7 through August 24, 2009, for a total of 35 days excluding weekends). Based on these average run time values, the system was assumed to have operated for 519.9 hr from April 16 through July 7, 2009 (including 491.4 hr from April 16 through June 12, 2009, when the school was in session and for 28.5 hr from June 15 through July 2, 2009, when the school was out of session). Therefore, the total system operating time was estimated to be 1473.6 hr starting from April 16, 2009, 2,011.8 hr starting from February 4, 2009, or 2,269.2 hr for the year of 2009.

During the 1,473.6 hr of operation from April 16 through December 15, 2009, the RO system treated approximately 180,700 gal of water, generating 71,100 gal of permeate and 109,600 gal of reject water. Recovery, specified at 40% by the manufacturer, ranged from 33 to 45% and averaged 40% based on incremental totalizer readings. The recovery of the RO system was calculated using Equation 1 below and presented in Appendix A. Figure 4-13 plots the daily recovery rates during the study period.

$$\text{Recovery (\%)} = 100 \times V_p / (V_p + V_r) \quad (1)$$

where

V_p = Volume of permeate (gal)

V_r = Volume of reject water (gal)

The potable water demand averaged 562 gpd when the school was in session and 91 gpd when the school was out of session. The in-session demand was more than twice the amount recorded during August 28, 2008 and January 16, 2009, prior to system installation. The non-potable water demand averaged 924 gpd when the school was in session and 118 gpd when the school was out of session. The in-session

Table 4-5. Summary of EPRO-1,200 System Operation

Operational Parameter	Value/Condition
Duration	04/16/09 ^(a) –12/15/09
Average Daily Run Time (hr/day)	11.7 (when school was in session) 1.9 (when school was out of session)
Total Operating Time (hr)	1,473.6
Number of Days System in Operation (day)	168
Volume of Permeate (gal)	71,111 ^(b)
Volume of Reject Water (gal)	109,567 ^(c)
Volume of Feed Water to System (gal)	180,678 ^(d)
Average (Range) Recovery (%)	40 (33–45) ^(e)
Average (Range) Permeate Water Flowrate (gpm)	0.8 (0.8–1.4)
Average (Range) Reject Water Flowrate (gpm)	1.2 (1.2–1.3)
Average (Range) Inlet Water Pressure (psi)	37 (30–42)
Average (Range) Feed Water Pressure (psi)	37 (28–40)
Average (Range) of Δp Across Sediment Filter (psi)	0.3 (0–6)
Average (Range) Permeate Discharge Pressure (psi)	145 (120–185)
Average (Range) Reject Water Discharge Pressure (psi)	141 (110–175)
Average (Range) Re-Pressurization System Pressure (psi)	38 (30–45)

- (a) System placed into service on 02/04/09, but logging of operational data did not begin until 04/16/09.
- (b) Permeate volume from 04/27/09 through end of study read from permeate totalizer; permeate volume from 04/16/09 through 04/24/09 estimated based on 0.8-gpm flowrate and 11.7-hr/day daily run time for 7 days.
- (c) Reject water volume from 04/27/09 through end of study read from reject water totalizer; reject water volume from 04/16/09 through 04/24/09 estimated based 1.2-gpm flowrate and 11.7-hr/day daily run time for 7 days.
- (d) Sum of permeate volume and reject water volume.
- (e) Calculated by dividing incremental volume of permeate by incremental volume of feed water to system.

average total daily demand (including potable and on-potable demand) was 1,486 gal, which is very close to the 1,588 gpd value measured prior to system installation.

Flowrate, pressure, and TDS also were monitored. As shown in Table 4-5 and Figure 4-14, flowrate readings of permeate and reject water stayed consistently at 0.8 and 1.2 gpm, respectively. Both inlet and feed water pressure averaged 37 psi with pressure loss across the sediment filter ranging from 0 to 6 psi and averaging 0.3 psi. Permeate and reject water discharge pressures were similar, averaging 145 and 141 psi, respectively. The re-pressurization system pressure ranged from 30 to 45 psi and averaged 38 psi. All system pressures were within the specified ranges. The permeate TDS monitor showed zero readings most of the time except for five times when the reading was 2 mg/L. In contrast, laboratory TDS results of the permeate ranged from <2.0 to 34.0 mg/L and averaged 8.6 mg/L. Because the onsite TDS monitor was a low-end meter, it was used as a “quick check” of the system performance in the field.

4.4.2 Residual Management. Residuals generated from the RO system operation included RO reject water, which was discharged to the existing septic system.

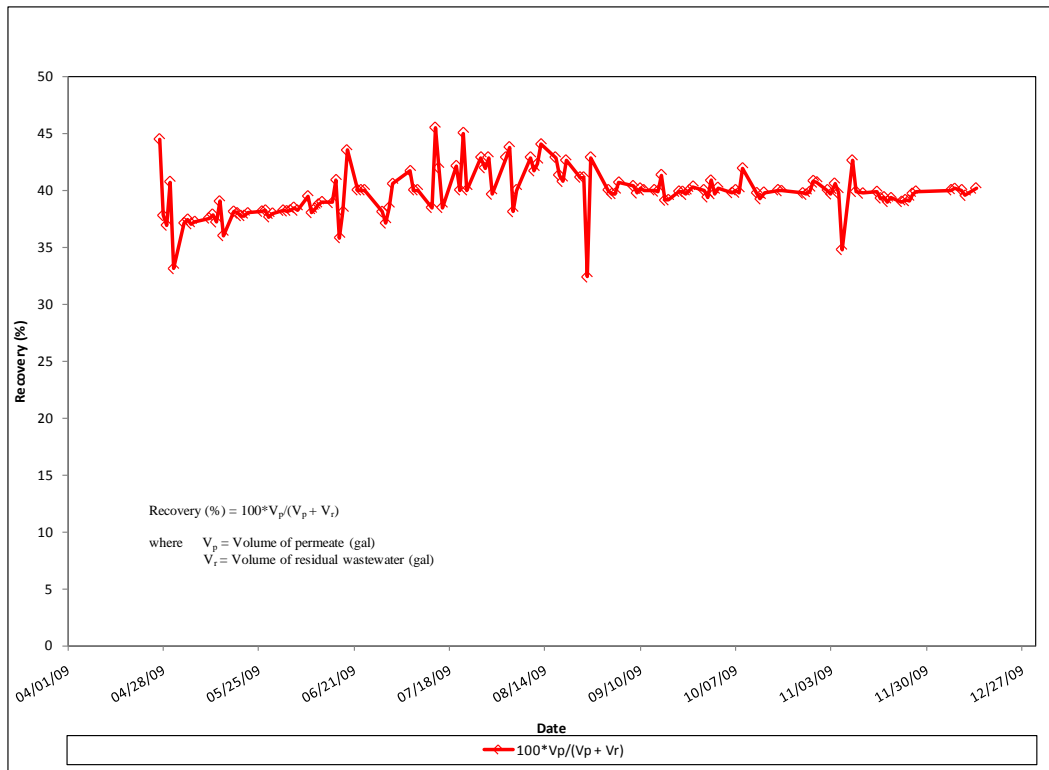


Figure 4-13. Percent Recovery Calculations

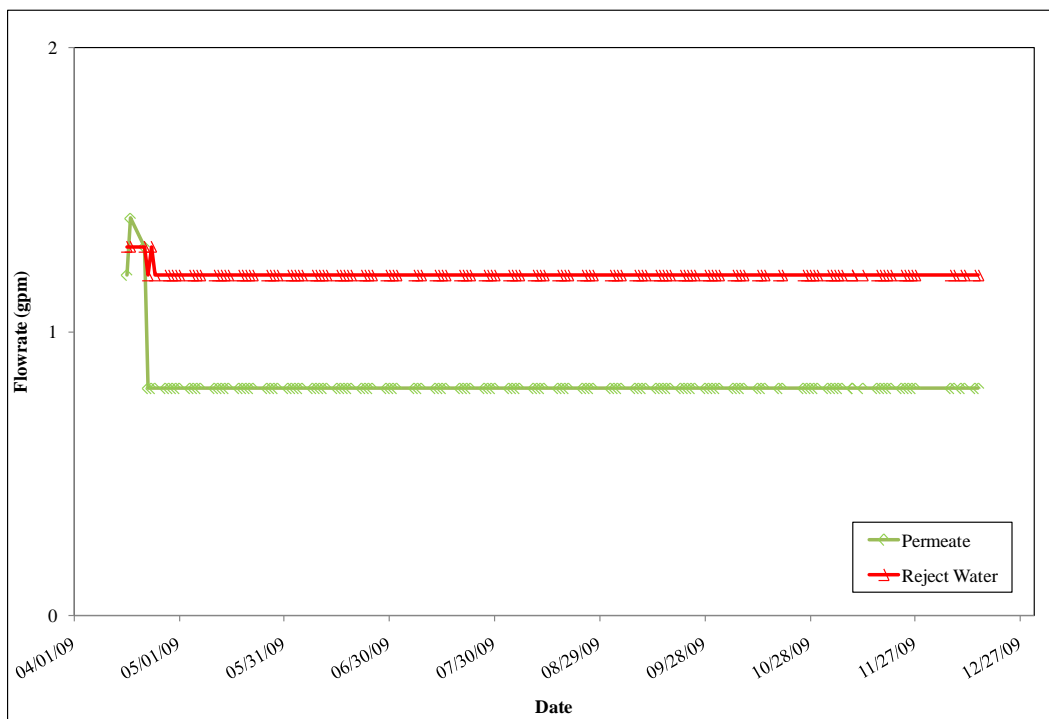


Figure 4-14. Flowrate Readings of RO Permeate and Reject Water

4.4.3 System/Operation Reliability and Simplicity. The main operational issue with the EPRO-1,200 RO unit was a RO pump and motor that needed to be replaced. When a CES personnel noticed that the system was louder than normal, Norlen's Water visited the site on October 19, 2009, to diagnose the problem. After inspections, it was determined that bearings on the RO motor were failing and should be replaced along with the RO pump. On October 29, 2009, Norlen's Water installed a new RO motor and pump.

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

Pre- and Post-Treatment Requirements. Pre-treatment requirements for the EPRO-1,200 RO unit included a 5- μ m sediment filter to remove any particulates that could potentially foul the RO membrane. Post-treatment requirements included a calcite filter to raise the pH of permeate from an average of 6.9 after the RO unit to an average of 7.4. Although not a post-treatment requirement, the existing chlorination system was placed after the RO unit to provide chlorine residuals in the distribution system.

System Automation. All major functions of the EPRO-1,200 RO unit were automated and would require only minimal operator oversight and intervention if all functions were operating as intended. The operator controlled the system operation manually. Once the permeate water in the two atmospheric storage tanks reached a pre-set level, a float switch was triggered, and the RO unit shut off. The chemical feed pump was tied into the re-pressurization pump to chlorinate the water as water was pumped to the distribution system.

Operator Skill Requirements. Under normal operating conditions, the skills required to operate the EPRO-1,200 RO unit were minimal. The operator was typically onsite five times per week and spent approximately 10 min each day performing visual inspections and recording system operating parameters on the daily log sheets. Normal operation of the system did not require additional skills beyond those necessary to operate the existing water supply equipment.

The level of operator certification is determined by the type and class of public drinking water systems. MDWP's drinking water rules require all community and non-transient, non-community public drinking water and distribution systems to be classified based on potential health risks. Classifications range from "very small water system (VSWS)" (lowest) to "Class IV" (highest) for treatment systems and from "VSWS" to "Class IV" for distribution systems, depending on such factors as the system's complexity, size, and source water. CES is classified as a "VSWS" distribution system and, therefore, a plant operator with a "VSWS" certificate was required by the MDWP. To fulfill the plant operator requirements, CES hired Nolen's Water to be their contract operator since they have the appropriate credentials and are familiar with the system.

Preventive Maintenance Activities. The only regularly scheduled maintenance activities required for system operations were (1) replacing the sediment filter on a monthly basis or when the differential pressure was greater than 10% and (2) replenishing calcite in the calcite filter as it became depleted. Replacement of the sediment filter and calcite replenishment was not required during this performance evaluation study.

Chemical/Media Handling and Inventory Requirements. NaOCl solution was used for chlorination. The 35-gal chlorine tank was filled with a diluted NaOCl solution using a 3:1 water to 12.5% NaOCl (as Cl₂) ratio.

4.5 System Performance

The performance of the Crane Environmental EPRO -1,200 RO system was evaluated based on analyses of water samples collected from the treatment plant and the distribution system.

4.5.1 Treatment Plant Sampling. A total of four locations were sampled from the treatment system, including IN, RO, AP, and RW. Water samples were collected on 22 occasions, including one duplicate sample, with field speciation performed during eight occasions at IN, RO, and AP. Beginning May 27, 2009, sampling was conducted at the RW sample tap so there were only 16 sampling events for RW.

Table 4-6 summarizes the analytical results of arsenic, antimony, iron, and manganese measured at the four sampling locations across the treatment train. Table 4-7 summarizes the results of other water quality parameters. Appendix B contains a complete set of analytical results for the demonstration study. The results of the analysis of the water samples collected throughout the treatment system are discussed below.

Arsenic. The key parameters for evaluating the effectiveness of the RO treatment system were the arsenic and antimony concentrations in treated water.

Figure 4-15 contains four bar charts showing concentrations of arsenic species, including particulate arsenic, As(III), and As(V) at the IN, RO, and AP locations for each of the eight speciation events. Total arsenic concentrations in source water ranged from 13.6 to 22.6 µg/L and averaged 18.2 µg/L (Table 4-6). Of the soluble fraction, As(V) was the predominating species, with concentrations ranging from 14.3 to 18.7 µg/L and averaging 16.7 µg/L. Particulate arsenic concentrations were low, with all concentrations below the MDL of 0.1 µg/L except for one outlier. Only a trace amount of As(III) existed, ranging from <0.1 to 0.5 µg/L and averaging 0.2 µg/L. The concentrations of source water arsenic species measured during the performance evaluation study were consistent with those measured on September 13, 2005, and during the pilot study from March 7, 2006 to July 11, 2006 (Table 4-1).

Total arsenic concentrations measured at IN, RO, AP, and RW are plotted on Figures 4-16. The concentrations in the permeate ranged from <0.1 to 0.3 µg/L, averaging 0.1 µg/L. Based on the average concentration in source water, the RO unit achieved 99% of arsenic removal. After pH adjustment by the calcite filter, total arsenic concentration remained unchanged, as expected. Total arsenic concentration in reject water averaged 31.9 µg/L, which was 1.75 times the average raw water concentration, as a result of the RO membrane separation.

Antimony. Total antimony concentrations measured at IN, RO, AP, and RW are plotted on Figures 4-17. The concentrations in source water ranged from 8.6 to 13.2 µg/L and averaged 10.8 µg/L with the majority present in the soluble form. During the performance evaluation, antimony was consistently removed by the RO unit to below the MDL of 0.1 µg/L, achieving a 99% removal rate. As expected, antimony concentrations after pH adjustment did not change. Total antimony concentration in reject water averaged 17.7 µg/L, which was 1.64 times the average raw water concentration, as a result of the RO membrane separation.

Iron and Manganese. Total iron concentrations in source water were all below the MDL of 25 µg/L. Total manganese concentrations in source water ranged from 0.5 to 6.3 µg/L and averaged 2.2 µg/L with the majority present in the soluble form at an average concentration of 1.3 µg/L. Total manganese concentrations after the RO unit were less than the MDL of 0.1 µg/L for all samples, except for three measurements at 0.11, 0.25, and 0.28 µg/L. As expected, manganese concentrations after pH adjustment remained the same.

Table 4-6. Summary of Arsenic, Antimony, Iron, and Manganese Analytical Results

Parameter	Sampling Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
As (total)	IN	µg/L	22	13.6	22.6	18.2	2.2
	RO	µg/L	22	<0.1	0.3	0.1	0.1
	AP	µg/L	21 ^(a)	<0.1	0.2	0.1	0.0
	RW	µg/L	17	23.6	38.1	31.9	4.1
As (soluble)	IN	µg/L	8	14.4	19.0	16.9	1.7
	RO	µg/L	8	<0.1	0.3	0.1	0.1
	AP	µg/L	7	<0.1	<0.1	<0.1	-
As (particulate)	IN	µg/L	7 ^(b)	<0.1	<0.1	<0.1	-
	RO	µg/L	8	<0.1	<0.1	<0.1	-
	AP	µg/L	7	<0.1	<.01	<0.1	-
As (III)	IN	µg/L	8	<0.1	0.5	0.2	0.2
	RO	µg/L	8	<0.1	0.1	0.1	0.0
	AP	µg/L	7	<0.1	<0.1	<0.1	-
As (V)	IN	µg/L	8	14.3	18.7	16.7	1.6
	RO	µg/L	8	<0.1	0.1	0.1	0.0
	AP	µg/L	7	<0.1	0.1	0.1	0.0
Sb (total)	IN	µg/L	22	8.6	13.2	10.8	1.1
	RO	µg/L	22	<0.1	<0.1	<0.1	-
	AP	µg/L	20 ^(c)	<0.1	<0.1	<0.1	-
	RW	µg/L	17	14.5	22.0	17.7	-
Sb (soluble)	IN	µg/L	7	9.7	13.3	10.9	1.5
	RO	µg/L	7	<0.1	<0.1	<0.1	-
	AP	µg/L	7	<0.1	<0.1	<0.1	-
Fe (total)	IN	µg/L	20 ^(d)	<25	<25	<25	-
	RO	µg/L	21	<25	<25	<25	-
	AP	µg/L	21	<25	<25	<25	-
	RW	µg/L	17	<25	<25	<25	-
Fe (soluble)	IN	µg/L	8	<25	<25	<25	-
	RO	µg/L	7 ^(e)	<25	<25	<25	-
	AP	µg/L	7	<25	<25	<25	-
Mn (total)	IN	µg/L	22	0.5	6.3	2.2	1.3
	RO	µg/L	22	<0.1	0.3	<0.1	-
	AP	µg/L	21	<0.1	1.2	0.4	0.3
	RW	µg/L	16 ^(f)	1.0	3.1	2.0	0.8
Mn (soluble)	IN	µg/L	7	<0.1	2.4	1.3	1.0
	RO	µg/L	7 ^(g)	<0.1	<0.1	<0.1	-
	AP	µg/L	7	<0.1	0.5	0.2	0.2

(a) One outlier (i.e., 10.0 µg/L on 09/14/09) omitted.

(b) One outlier (i.e., 1.2 µg/L on 07/29/09) omitted.

(c) One outlier (i.e., 7.6 µg/L on 09/14/09) omitted.

(d) Two outliers (i.e., 231 µg/L on 06/30/09 and 34.4 µg/L on 10/07/09) omitted.

(e) One outlier (i.e., 74 µg/L on 06/30/09) omitted.

(f) One outlier (i.e., <0.1 on 06/30/09) omitted.

(g) One outlier (i.e., 1.7 µg/L on 06/30/09) omitted.

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

Table 4-7. Summary of Other Water Quality Parameter Results

Parameter	Sampling Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as CaCO ₃)	IN	mg/L	22	186	220	206	10.1
	RO	mg/L	22	1.6	20.7	5.6	5.3
	AP	mg/L	20 ^(a)	2.3	25.9	16.6	5.3
	RW	mg/L	17	308	375	340	16.0
Sulfate	IN	mg/L	8	6.09	11.9	9.8	1.9
	RO	mg/L	8	<0.1	0.2	<0.1	-
	AP	mg/L	7	<0.1	0.1	<0.1	-
	RW	mg/L	7	16.3	19.0	17.9	1.0
Nitrate (as N)	IN	mg/L	8	0.1	0.3	0.2	0.1
	RO	mg/L	8	<0.05	0.1	<0.05	-
	AP	mg/L	7	<0.05	0.1	<0.05	-
	RW	mg/L	7	0.1	0.5	0.2	0.1
Silica (as SiO ₂)	IN	mg/L	22	10.0	12.9	11.2	0.6
	RO	mg/L	22	0.3	1.0	0.5	0.2
	AP	mg/L	21	0.3	0.9	0.5	0.2
	RW	mg/L	17	16.6	19.8	18.1	0.8
Phosphorous (as P)	IN	µg/L	8	<10.0	<10.0	<10.0	-
	RO	µg/L	8	<10.0	12.5	<10.0	-
	AP	µg/L	7	<10.0	<10.0	<10.0	-
	RW	µg/L	7	<10.0	<10.0	<10.0	-
Turbidity	IN	NTU	22	0.2	10.0	2.3	2.4
	RO	NTU	22	0.1	2.7	1.0	0.7
	AP	NTU	21	<0.1	9.4	1.2	2.0
	RW	NTU	17	0.2	3.7	1.2	1.0
TDS	IN	mg/L	22	216	286	255	18.3
	RO	mg/L	22	<2.0	34.0	8.6	7.8
	AP	mg/L	21	<2.0	52.0	19.3	13.3
	RW	mg/L	17	354	468	410	31.7
pH	IN	S.U.	16	7.8	8.0	7.9	0.1
	RO	S.U.	16	6.5	7.2	6.9	0.2
	AP	S.U.	16	6.8	8.9	7.4	0.6
	RW	S.U.	16	7.9	8.0	8.0	0.0
Temperature	IN	°C	7	12.6	25.3	21.6	4.5
	RO	°C	7	14.0	25.3	21.8	4.0
	AP	°C	6	14.3	25.5	21.8	4.3
DO	IN	mg/L	7	3.6	5.2	4.3	0.6
	RO	mg/L	7	1.0	4.4	3.1	1.2
	AP	mg/L	6	1.4	4.6	3.1	1.2
ORP	IN	mV	7	310	445	351	43.7
	RO	mV	7	324	457	373	42.8
	AP	mV	6	323	457	364	48.3
Total Hardness (as CaCO ₃)	IN	mg/L	22	183	275	217	23.6
	RO	mg/L	22	0.6	2.0	1.2	0.5
	AP	mg/L	20 ^(b)	8.8	30.1	18.3	5.9
	RW	mg/L	17	300	496	352	43.6
Ca Hardness (as CaCO ₃)	IN	mg/L	21	70	150	107	18.1
	RO	mg/L	21	<0.25	1.4	0.5	0.3
	AP	mg/L	20	7.9	64.6	19.3	5.6
	RW	mg/L	17	113	271	172	34.3

Table 4-7. Summary of Other Water Quality Parameter Results (Continued)

Parameter	Sampling Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Mg Hardness (as CaCO ₃)	IN	mg/L	21	84.8	128	110	10.2
	RO	mg/L	21	0.3	1.0	1.0	0.7
	AP	mg/L	20 ^(c)	0.7	2.6	1.3	0.5
	RW	mg/L	17	144	225	180	17.8

(a) One outlier (i.e., 341 mg/L on 09/30/09) omitted.

(b) One outlier (i.e., 136 mg/L on 09/14/09) omitted.

(c) One outlier (i.e., 71.3 mg/L on 09/14/09) omitted.

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

TDS. Salt rejection is an important parameter for a RO system. The manufacturer specified a minimum rejection rate to be 98% (Table 4-2), which was calculated according to Equation 2:

$$\text{Rejection (\%)} = 100 * (\text{TDS}_{\text{IN}} - \text{TDS}_{\text{RO}}) / \text{TDS}_{\text{IN}} \quad (2)$$

where

TDS_{IN} = TDS in raw water (mg/L)

TDS_{RO} = TDS in permeate (mg/L)

TDS concentrations ranged from 216 to 286 mg/L and averaged 255 mg/L in raw water, and ranged from <2 to 34 mg/L and averaged 8.6 mg/L in the RO permeate. The rejection rates varied from 88 to 99.6% and averaged 96.7%. Therefore, the RO system did not consistently achieve the minimal rejection rate of 98% as specified. TDS concentrations increased slightly after pH adjustment to an average concentration of 19.3 mg/L as expected. Figure 4-18 presents TDS concentrations and rejection rates measured during the performance evaluation study.

pH and Alkalinity. Source water pH values measured at the IN location ranged from 7.8 to 8.0 and averaged 7.9. pH values of the RO permeate water ranged from 6.5 to 7.2 and averaged 6.9. The observed pH drop was caused by the reduction in total alkalinity. The RO unit reduced alkalinity values from an average of 206 mg/L (as CaCO₃) in source water to an average of 5.6 mg/L (as CaCO₃) in RO permeate, a 97% reduction on average. After pH adjustment, pH values increased to levels ranging from 6.8 to 8.9 and averaging 7.4. The rise in pH was attributed to an increase in alkalinity, which averaged 16.6 mg/L (as CaCO₃). pH levels and alkalinity concentrations measured during the performance evaluation study are presented in Figures 4-19 and 4-20, respectively.

Other Water Quality Parameters. Total hardness in source water ranged from 183 to 275 mg/L (as CaCO₃) and averaged 217 mg/L (as CaCO₃) consisting of approximately 49% calcium hardness and 51% magnesium hardness. The total hardness was initially reduced to an average concentration of 1.2 mg/L (as CaCO₃) in the RO permeate water. However, as expected, total hardness concentrations were elevated after the calcite filter to an average of 18.3 mg/L (as CaCO₃). Figure 4-21 presents total hardness concentrations measured during the performance evaluation study. Silica concentrations in source water ranged from 10.0 to 12.9 mg/L (as SiO₂) and averaged 11.2 mg/L (as SiO₂), which was above the vendor-suggested maximum value of 10 mg/L in the feed water to the RO unit. Silica concentrations in RO permeate water ranged from 0.3 to 1.0 mg/L (as SiO₂) and averaged 0.5 mg/L (as SiO₂), indicating effective removal by the RO unit. Figure 4-22 presents silica concentrations measured during the performance evaluation study. Sulfate and nitrate (as N) concentrations were low in source water, i.e., an average of 9.8 and 0.2 mg/L, respectively, and were completely removed to below their respective MDLs of 1.0 and 0.05 mg/L.

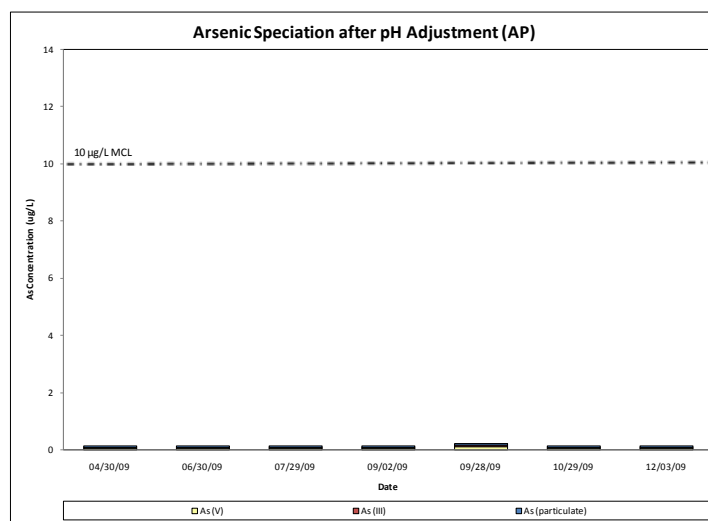
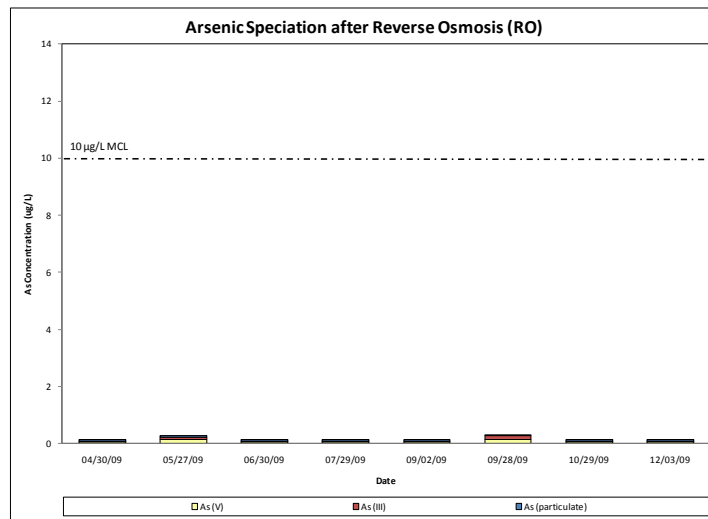
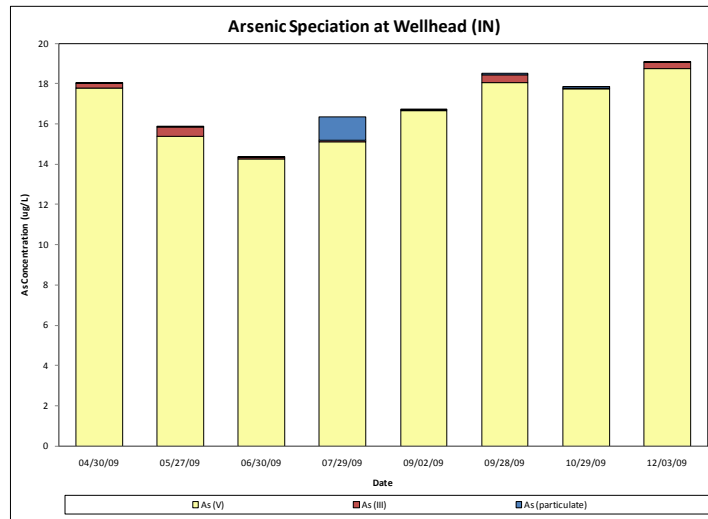


Figure 4-15. Concentrations of Various Arsenic Species at IN, RO, and AP Sampling Locations

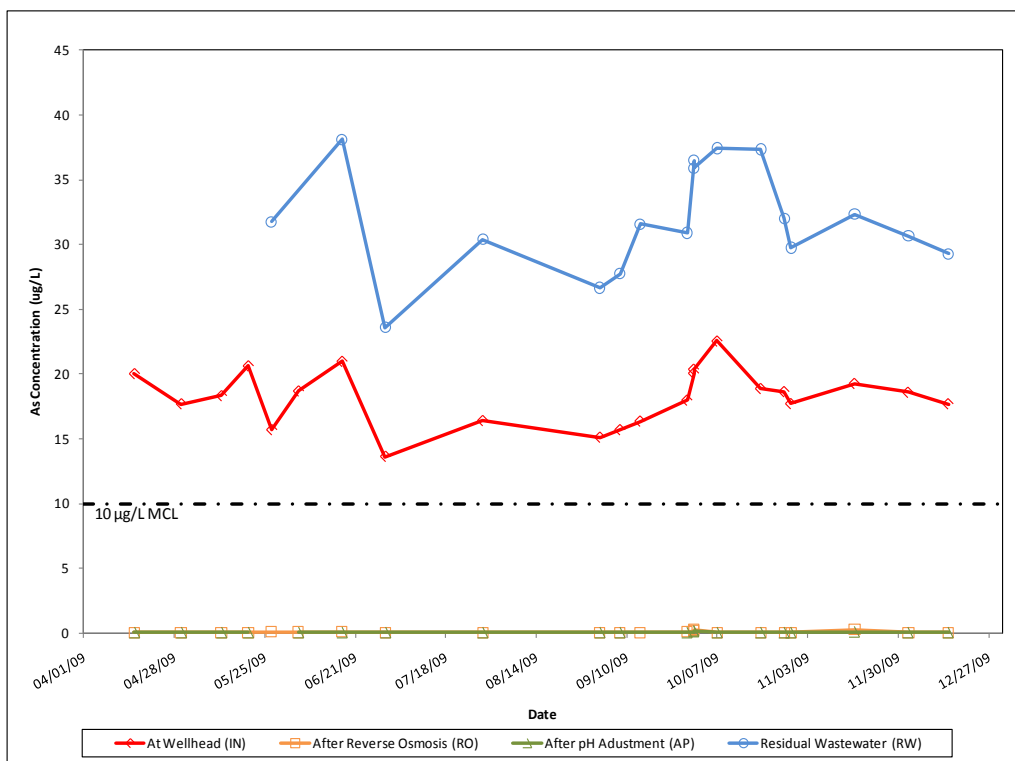


Figure 4-16. Total Arsenic Concentrations at IN, RO, AP, and RW Sampling Locations

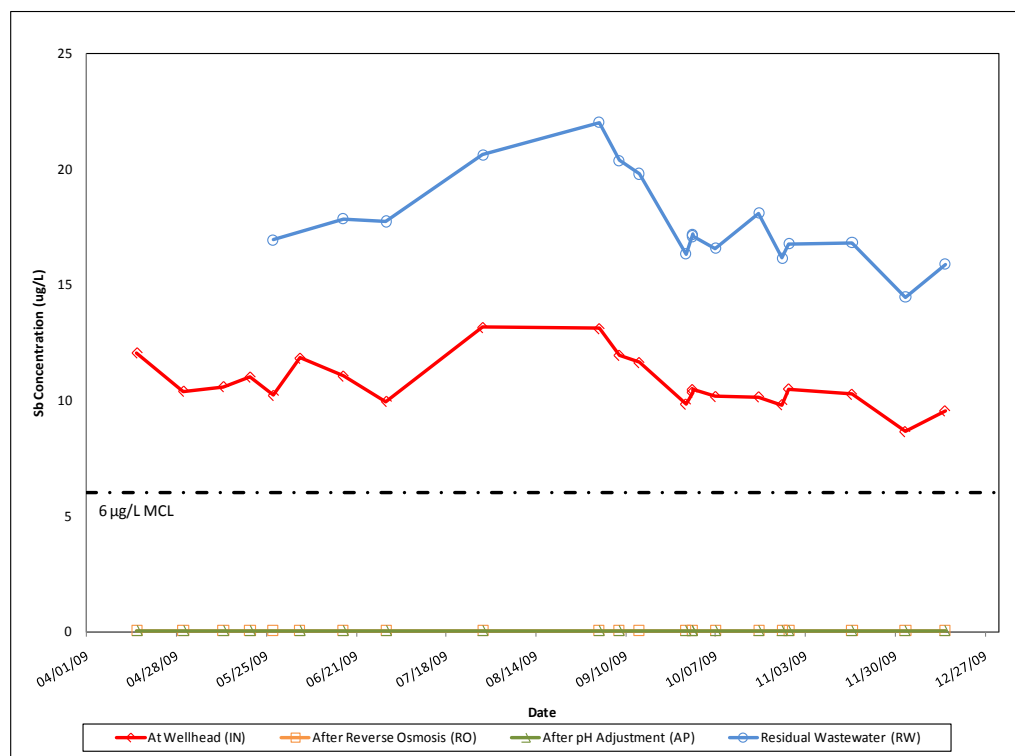


Figure 4-17. Total Antimony Concentrations at IN, RO, AP, and RW Sampling Locations

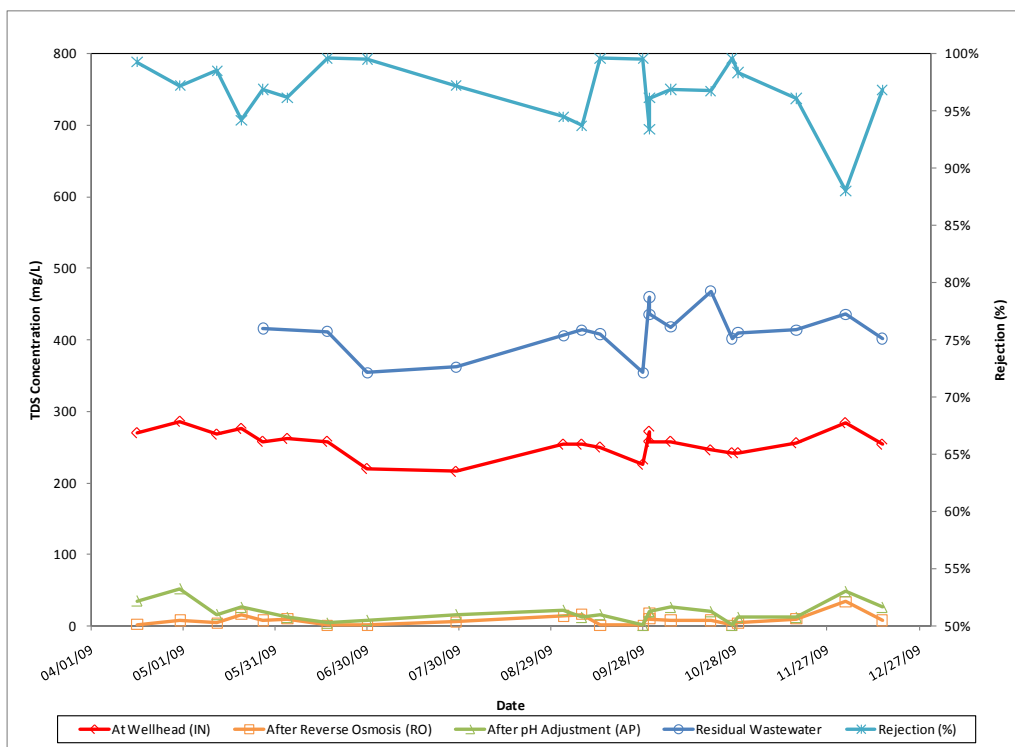


Figure 4-18. TDS Concentrations at IN, RO, AP, and RW Sampling Locations

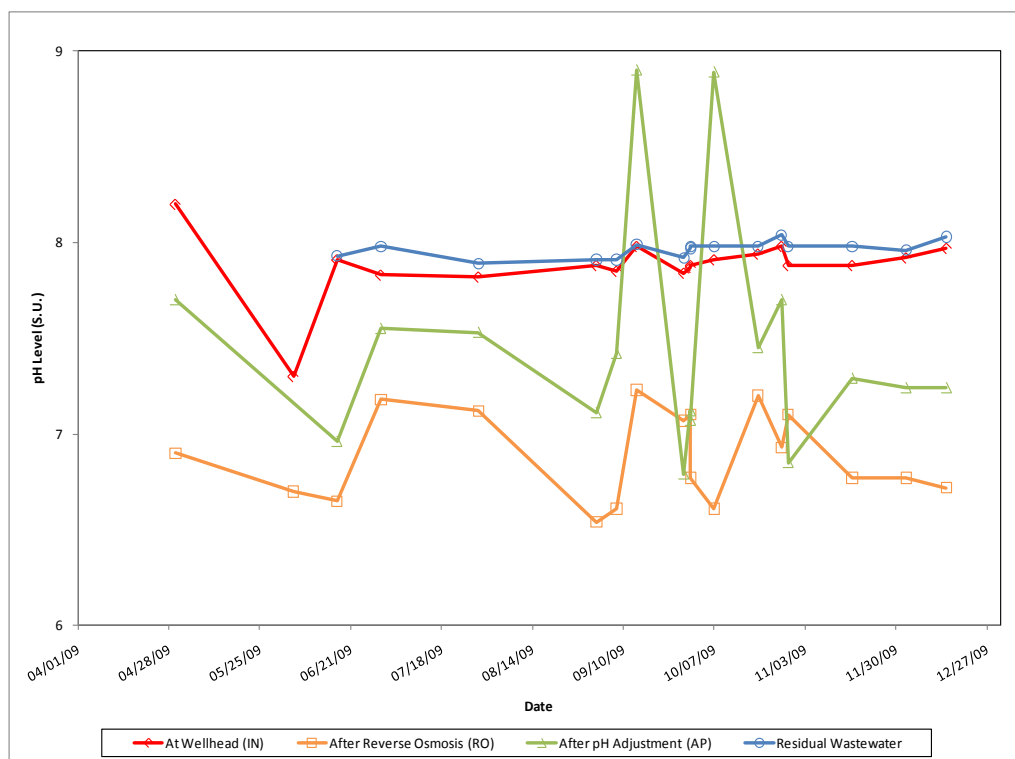


Figure 4-19. pH Levels at IN, RO, AP, and RW Sampling Locations

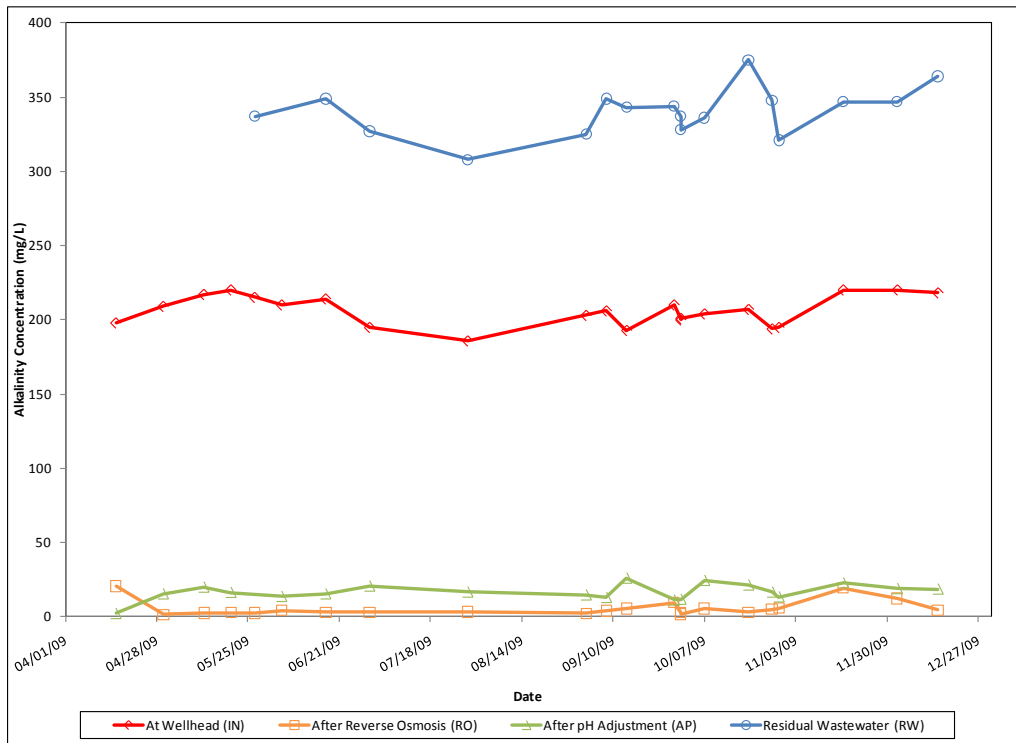


Figure 4-20. Alkalinity Concentrations at IN, RO, AP, and RW Sampling Locations

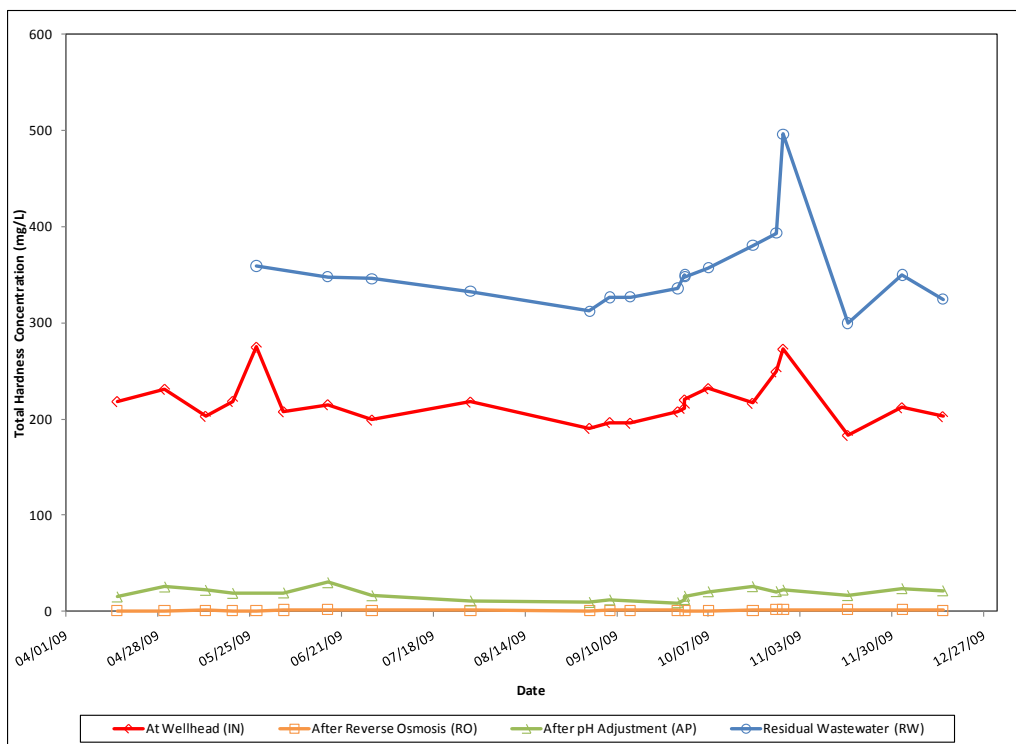


Figure 4-21. Total Hardness Concentrations at IN, RO, AP, and RW Sampling Locations

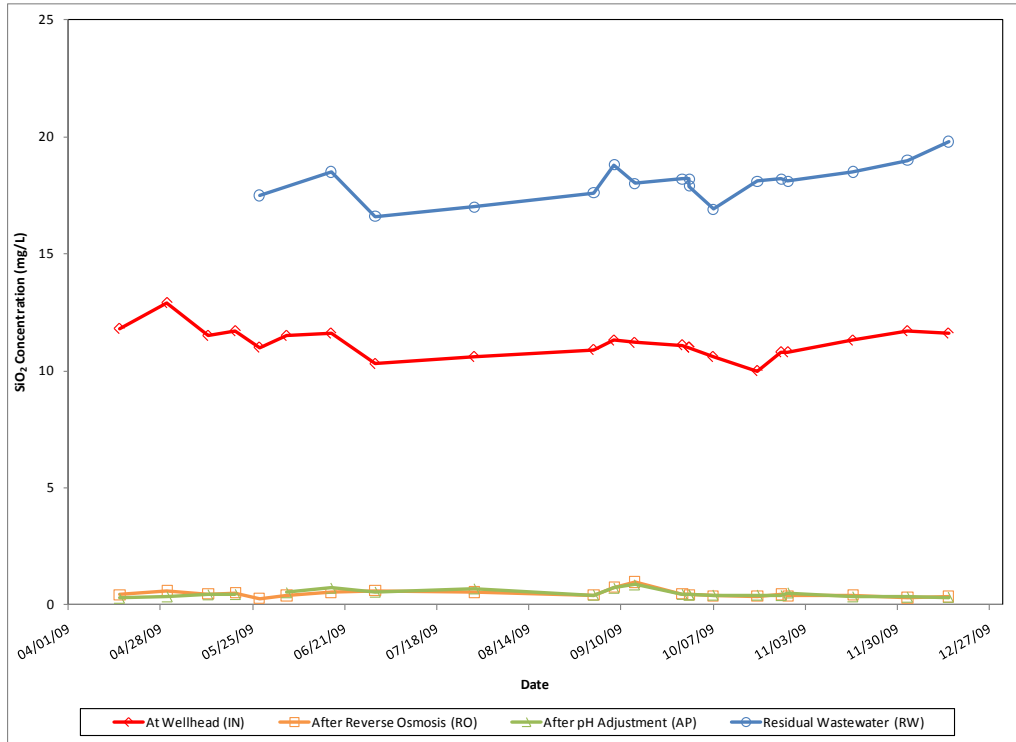


Figure 4-22. Silica Concentration at IN, RO, AP, and RW Sampling Locations

4.5.2 Residual Water Sampling. RW samples were collected from the reject water discharge line beginning May 27, 2009, for a total of 16 sampling events. The analytical results from the residual sampling are summarized in Tables 4-6 and 4-7 and presented in Figures 4-16 through 4-22. As expected, residual water contained higher concentrations of arsenic, antimony, TDS, alkalinity, total hardness, silica (as SiO₂), and sulfate at 31.9 µg/L, 17.7 µg/L, 410 mg/L, 340 mg/L, 352 mg/L, 18.1 mg/L, and 17.9 mg/L, respectively, on average. Manganese and nitrate concentrations were similar to source water concentrations averaging 2.0 µg/L and 0.2 mg/L (as N), respectively.

Calculations of mass balance for total arsenic and antimony were performed using the average concentrations at IN, RO, and RW and the volume of each stream according to Equation 3 as follows:

$$C_f V_f = C_p V_p + C_r V_r \quad (3)$$

where

- C_f = feed water total arsenic or antimony concentration
- V_f = volume of feed water
- C_p = permeate water total arsenic or antimony concentration
- V_p = volume of permeate water
- C_r = reject water total arsenic or antimony concentration
- V_r = volume of reject water.

Results of the mass balance calculations are presented in Table 4-8. During the performance evaluation, mass balance data in terms of the mass recovered in the permeate and reject water against the mass in feed water were 107% and 100% for total arsenic and antimony, respectively.

Table 4-8. Mass Balance Calculations

Analyte	Feed		Permeate		Reject		$C_p V_p + C_r V_r$	$C_f V_f$	Mass Balance
	C_f	V_f	C_p	V_p	C_r	V_r			
	$\mu\text{g/L}$	gal	$\mu\text{g/L}$	gal	$\mu\text{g/L}$	gal	mg	mg	%
Arsenic	18.2	177,390 ^(a)	0.1	69,780	31.9	107,610	13,019	12,220	107
Antimony	10.8	177,390 ^(a)	0.05 ^(b)	69,780	17.7	107,610	7,222	7,251	100

(a) Calculated based on permeate and residual wastewater production.

(b) All antimony concentrations were below MDL of 0.1 $\mu\text{g/L}$. Thus, one-half the detection limit was used for calculation.

4.5.3 Distribution System Water Sampling. Following the startup of the RO treatment system, distribution system “first draw” samples were collected from a cold water tap in the kitchen on a monthly basis from May through November 2009. Table 4-9 presents results of the distribution sampling.

Table 4-9. Distribution System Sampling Results

No. of Sampling Events	Location		DS1							
			Kitchen Sink							
	Sample Type		LCR							
	Flushed/1st Draw		1st Draw							
	Sampling Date	Stagnation Time	pH	Alkalinity	As	Fe	Mn	Pb	Cu	Sb
No.	Date	hrs	S.U.	mg/L	$\mu\text{g/L}$	$\mu\text{g/L}$	$\mu\text{g/L}$	$\mu\text{g/L}$	$\mu\text{g/L}$	$\mu\text{g/L}$
1	05/20/09	12.0	6.8	10.1	0.2	<25	0.1	1.0	211	0.1
2	06/17/09	14.0	8.9	22.1	0.3	<25	0.2	0.8	163	0.1
3	07/09/09	NA	7.0	13.9	0.2	<25	0.6	1.4	117	0.4
4	08/27/09	15.0	8.5	58.3	0.5	48.6	0.3	1.2	135	0.3
5	09/08/09	12.0	8.9	22.9	<0.1	<25	<0.1	0.7	147	0.2
6	09/29/09	13.0	9.2	24.7	0.2	<25	1.5	1.9	190	0.1
7	10/27/09	13.5	9.1	19.1	<0.1	<25	0.4	0.5	144	0.1
8	11/19/09	12.0	9.2	25.4	2.7	166	0.3	<0.1	57.6	<0.1
	Average	13.1	8.4	24.6	0.5	36	0.4	1.0	146	0.2

NA = not available

Alkalinity concentrations in the distribution “first draw” samples ranged from 10.1 to 58.3 mg/L, and averaged 24.6 mg/L, which was slightly higher than the average concentration in the pH-adjusted water (i.e., 16.6 mg/L). The slightly higher alkalinity concentration may have partially contributed to the elevated pH level in the distribution system which ranged from 6.8 to 9.2, and averaged 8.4, in comparison with that of the pH-adjusted water (i.e., ranging from 6.8 to 8.9 and averaging 7.4). Since the distribution sample pH was measured in an off-site laboratory, whereas the treatment sample pH was measured on site, it is possible that the pH measurement might have also contributed to the one pH unit difference (pH 7.4 vs. 8.4) between the distribution water and the pH-adjusted water.

Arsenic and antimony concentrations in the distribution “first draw” samples were similar to those in the system effluent. They were both in the sub-parts per billion (ppb) levels (except for one time at 2.7 µg/L of arsenic).

Lead concentrations in the distribution system ranged from <0.01 to 1.9 µg/L and averaged 1.0 µg/L. All of the lead values were, therefore, below the action level of 15 µg/L. Copper concentrations ranged between 57.6 to 211 µg/L and averaged 146 µg/L, with no samples exceeding the 1,300 µg/L action level. Therefore, the RO treatment system did not have any adverse effects on the water quality in the distribution system during the performance evaluation study.

4.6 System Cost

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

4.6.1 Capital Cost. The total capital investment for the dual plumbing and EPRO-1,200 RO unit was \$20,542 (Table 4-10). The dual plumbing installation cost was \$8,600 (or 42% of the total capital investment), which included \$2,650 for the plumbing materials and \$5,950 for the labor to convert the existing plumbing into a duplex distribution system. The cost of the EPRO-1,200 RO treatment system was \$11,942, including \$8,471 for equipment and parts, \$300 for shipping, and \$3,171 for installation.

Table 4-10. Capital Investment Cost for CES at Carmel, ME

Description	Quantity	Cost	% of Capital Investment Cost
Dual Plumbing			
PEX Piping and Materials	1	\$2,650	–
Vendor Labor	1	\$5,950	–
<i>Subtotal</i>	–	<i>\$8,600</i>	<i>42%</i>
EPRO-1,200 RO System			
Crane Environmental EPRO-1,200 RO Unit Calcite Filter (1.25 ft ³), two 300-gal Atmospheric Storage Tanks w/Float Controls	1	\$6,227	–
230 V Solution Feed Pump	1	\$429	–
Re-pressurization System	1	\$946	–
Flow Totalizer	1	\$149	–
Pump Discharge Pressure Gauge	1	\$80	–
Process Valves and Piping	1	\$640	–
Shipping	1	\$300	–
Vendor Labor	–	\$3,171	–
<i>Subtotal</i>	–	<i>\$11,942</i>	<i>58%</i>
Total Capital Investment	–	\$20,542	100%

The capital cost of \$20,542 was normalized to the system’s rated capacity of 1,200 gpd of permeate, which results in \$17.12/gpd of design capacity. The capital cost also was converted to an annualized cost of \$1,939/yr using a capital recovery factor (CRF) of 0.09439 based on a 7% interest rate and a 20-year return period. Assuming that the system operated 365 days annually at the design capacity of 1,200 gpd,

the system would produce 438,000 gal of permeate water. The unit capital cost would be \$4.43/1,000 gal. During the 10-month demonstration study, the system produced 96,576 gal of permeate. The annual production was estimated to be 108,912 gal (see Table 4-11); at this reduced rate of production, the unit capital cost was increased to \$17.80/1,000 gal of water treated.

4.6.2 Operation and Maintenance Cost. The O&M cost included the cost incurred by system repairs, electricity, and labor, as summarized in Table 4-11. As described in Section 4.4.3, the main operational issue that occurred during the study period was replacement of a RO pump and motor assembly in November 2009. The equipment was covered under the manufacturer's warranty, but the cost of labor to install the replacement parts was not covered by the warranty. The cost of labor to install the replacement parts was \$321, which included \$96 for diagnostics, \$160 for labor, and \$65 for shipping. This cost was normalized to the volume of permeate water produced between February 4 and December 15, 2009 during the demonstration study. Therefore, the cost per 1,000 gal of permeate water was \$3.32/1,000 gal.

The school did not have a separate electrical meter for the EPRO-1,200 RO system. Based on the total operational hours and the rated horsepower of the RO pump and the re-pressurization pump, the annual electricity consumption was estimated to be 5,078 kWh. Applying a local electricity rate of 0.074/kWh, the annual electrical cost associated with the system operation was estimated to be \$376, or \$3.45/1,000 gal of permeate water.

Table 4-11. Operation and Maintenance Cost for EPRO-1200 RO Unit Treatment System

Cost Category	Value	Assumptions
Permeate Water Volume (gal)	96,576	February 4 through December 15, 2009 (2,012 hr of operation, 0.8 gpm)
Annual Permeate Production (gal/yr)	108,912	January 1 through December 31, 2009 (assuming 2,269 hr of operation, 0.8 gpm)
<i>RO Pump and Motor Assembly Replacement</i>		
Diagnostics	\$96	–
Labor	\$160	–
Shipping	\$65	–
<i>Subtotal</i>	<i>\$321</i>	–
Cost (\$/1,000 gal)	\$3.32	Permeate produced = 96,576 gal
<i>Electricity</i>		
Annual Electricity Consumption (kWh/yr)	5,078	1, ½-hp RO pump, 1 1-hp re-pressurization pump, 50% efficiency, 2,269 hr of annual operation
Annual Electricity Cost (kWh/yr)	\$376	\$0.074/kWh
Electricity Cost (\$/1,000 gal)	\$3.45	Annual production of 108,912 gal
<i>Labor</i>		
Average Weekly Labor (hr)	0.8	10 min/day, 5 days a week
Annual Labor (hr/yr)	41.6	52 weeks a year
Annual Labor Cost (\$/yr)	\$666	Labor rate = \$16/hr
Labor Cost (\$/1,000 gal)	\$6.12	Annual production of 108,912 gal
Total O&M Cost/1,000 gal	\$12.89	Total O&M cost = \$3.32+\$3.45 + \$6.12

Under normal operating conditions, routine labor activities to operate and maintain the system consumed 10 min per day, or 50 min per week. With a labor rate of \$16/hr, the estimated annual labor cost was \$666, or \$6.12/1,000 gal of permeate water produced.

In summary, the total O&M cost was estimated to be \$12.89/1,000 gal of permeate water produced based on the cost data collected during the performance evaluation study.

5.0 REFERENCES

- Battelle. 2007. *Quality Assurance Project Plan for Evaluation of Arsenic Removal Technology (QAPP ID 355-Q-6-0)*. Prepared under Contract No. EP-C-05-057. Task Order No. 0019, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Battelle. 2009. *System Performance Evaluation Study Plan: U.S. EPA Demonstration of Arsenic Removal Technology Round 2a at Carmel Elementary School in Carmel, Maine*. Prepared under Contract No. EP-C-05-057, Task Order No. 0019, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Chen, A.S.C., L. Wang, J.L. Oxenham, and W.E. Condit. 2004. *Capital Costs of Arsenic Removal Technologies: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1*. EPA/600/R-04/201. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Edwards, M., S. Patel, L. McNeill, H. Chen, M. Frey, A.D. Eaton, R.C. Antweiler, and H.E. Taylor. 1998. "Considerations in As Analysis and Speciation." *JAWWA*, 90(3): 103-113.
- EPA. 2001. National Primary Drinking Water Regulations: Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring. *Federal Register*, 40 CFR Parts 9, 141, and 142.
- EPA. 2002. *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems*. EPA/816/R-02/009. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.
- EPA. 2003. Minor Clarification of the National Primary Drinking Water Regulation for Arsenic. *Federal Register*, 40 CFR Part 141.
- Wang, L., W.E. Condit, and A.S.C. Chen. 2004. *Technology Selection and System Design: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1*. EPA/600/R-05/001. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.

APPENDIX A

OPERATIONAL DATA

Table A-1. EPA Arsenic Demonstration Project at Carmel Elementary School at Carmel, ME -- Daily System Operation Log Sheet

Wk	Date	Time	Non-Potable Water	Pre-Filter	RO Unit									Re-pressurization System	
			FT-1	Inlet Pressure	Feed Pressure	Hour Meter	Concentrate			Permeate			Recovery	Pressure	FT-4
							Pressure	Flowrate	FT-2	Flowrate	FT-3	Pump Discharge Pressure			
gal	psig	psig	hrs	psig	gpm	gal	gpm	gal	psi	%	psig	gal			
1	04/16/09	11:30	NA	32	30	NA	160	1.3	NA	1.2	NA	NA	NA	32	212,725
	04/17/09	9:40	NA	32	30	NA	NA	1.3	NA	1.4	NA	NA	NA	32	212,890
2	04/21/09	8:30	NA	32	32	NA	160	1.3	181,840	1.3	NA	NA	NA	45	212,940
	04/22/09	8:30	NA	32	32	NA	160	1.2	181,890	0.8	NA	NA	NA	45	212,990
	04/23/09	8:00	NA	32	32	NA	160	1.3	181,920	0.8	NA	NA	NA	40	213,030
	04/24/09	8:00	NA	32	32	NA	150	1.2	NA	0.8	NA	NA	NA	32	NA
3	04/27/09	8:00	NA	35	32	NA	140	1.2	182,420	0.8	400	NA	44	35	213,160
	04/28/09	8:00	NA	32	32	NA	140	1.2	183,310	0.8	940	NA	38	30	213,670
	04/29/09	8:00	2,957,300	35	32	NA	145	1.2	184,250	0.8	1,490	NA	37	45	214,210
	04/30/09	8:00	2,958,500	40	38	NA	145	1.2	185,240	0.8	2,170	NA	41	40	214,790
	05/01/09	8:00	2,959,700	34	34	NA	140	1.2	186,250	0.8	2,670	NA	33	35	215,340
4	05/04/09	8:00	2,960,800	34	34	NA	140	1.2	187,250	0.8	3,260	NA	37	35	215,900
	05/05/09 ^(a)	8:00	2,962,000	40	40	NA	140	1.2	188,220	0.8	3,840	NA	37	40	216,470
	05/06/09	8:00	2,963,100	35	35	NA	140	1.2	189,580	0.8	4,640	NA	37	35	217,000
	05/07/09	8:00	2,964,100	35	35	NA	140	1.2	190,710	0.8	5,310	NA	37	40	217,630
5	05/11/09	8:00	2,966,500	40	38	NA	140	1.2	192,990	0.8	6,680	NA	38	45	218,820
	05/12/09	8:00	2,967,600	40	35	NA	140	1.2	193,860	0.8	7,210	NA	38	40	219,330
	05/13/09	8:00	2,968,500	40	40	NA	140	1.2	194,890	0.8	7,820	NA	37	35	219,910
	05/14/09	8:00	2,969,900	40	40	NA	140	1.2	196,000	0.8	8,530	NA	39	35	220,620
	05/15/09	8:00	2,970,900	35	35	NA	140	1.2	196,960	0.8	9,070	NA	36	45	221,120
	05/18/09	8:00	2,972,100	35	35	NA	140	1.2	198,470	0.8	10,000	NA	38	35	221,940
6	05/19/09 ^(b)	8:00	2,973,000	35	35	NA	140	1.2	199,450	0.8	10,600	135	38	40	222,490
	05/20/09	8:00	2,974,100	35	35	NA	140	1.2	200,390	0.8	11,170	135	38	45	223,040
	05/21/09	8:00	2,975,100	35	35	NA	140	1.2	201,610	0.8	11,910	135	38	40	223,660
	05/22/09	8:00	2,976,200	42	36	NA	140	1.2	202,590	0.8	12,510	135	38	44	224,240
7	05/26/09	8:00	2,977,200	35	35	NA	140	1.2	203,450	0.8	13,040	140	38	40	224,700
	05/27/09	8:00	2,978,200	35	35	NA	140	1.2	204,630	0.8	13,770	140	38	40	225,380
	05/28/09	8:00	2,979,300	30	30	NA	140	1.2	205,740	0.8	14,440	148	38	45	226,000
	05/29/09	8:00	2,980,800	35	35	NA	140	1.2	206,770	0.8	15,070	140	38	40	226,620
8	06/01/09	8:00	2,982,200	35	35	NA	140	1.2	207,740	0.8	15,670	145	38	40	227,140
	06/02/09	8:00	2,983,300	35	35	NA	140	1.2	208,680	0.8	16,250	145	38	40	227,700
	06/03/09	8:00	2,984,700	40	40	NA	140	1.2	209,860	0.8	16,980	145	38	40	228,380

**Table A-1. EPA Arsenic Demonstration Project at Carmel Elementary School at Carmel, ME -- Daily System Operation
Log Sheet (Continued)**

Wk	Date	Time	Non-Potable Water	Pre-Filter	RO Unit									Re-pressurization System	
			FT-1 gal	Inlet Pressure psig	Feed Pressure psig	Hour Meter hrs	Concentrate			Permeate			Recovery %	Pressure psig	FT-4 gal
							Pressure	Flowrate	FT-2	Flowrate	FT-3	Pump Discharge Pressure			
							psig	gpm	gal	gpm	gal	psi			
	06/04/09	8:00	2,985,700	40	40	NA	140	1.2	210,660	0.8	17,480	145	38	40	228,888
	06/05/09	8:00	2,986,900	35	35	NA	140	1.2	212,050	0.8	18,340	145	38	40	229,750
9	06/08/09	8:00	2,988,000	35	35	NA	140	1.2	212,940	0.8	18,920	140	39	40	230,290
	06/09/09	8:00	2,989,100	35	35	NA	140	1.2	214,000	0.8	19,570	140	38	35	230,900
	06/10/09	8:00	2,990,200	40	40	NA	140	1.2	214,980	0.8	20,180	140	38	40	231,490
	06/11/09	8:00	2,991,500	35	35	NA	140	1.2	215,960	0.8	20,800	140	39	35	232,070
	06/12/09	8:00	2,992,600	35	35	NA	140	1.2	217,010	0.8	21,470	140	39	35	232,700
	06/15/09	8:30	2,993,700	40	40	NA	140	1.2	217,890	0.8	22,030	140	39	45	233,250
10	06/16/09	8:30	2,994,700	35	35	NA	140	1.2	218,700	0.8	22,590	140	41	35	233,780
	06/17/09	8:30	2,995,200	40	40	NA	140	1.2	219,130	0.8	22,830	140	36	45	233,940
	06/18/09	8:30	2,995,200	40	40	NA	140	1.2	219,260	0.8	22,910	140	38	40	233,960
	06/19/09	8:30	2,995,300	40	40	NA	140	1.2	219,390	0.8	23,010	140	43	40	233,980
	06/22/09	8:00	2,995,400	40	40	NA	135	1.2	219,570	0.8	23,130	140	40	35	234,000
11	06/23/09	8:00	2,995,500	40	40	NA	140	1.2	219,900	0.8	23,350	140	40	35	234,060
	06/24/09	8:00	2,995,500	35	35	NA	140	1.2	219,990	0.8	23,410	140	40	35	234,090
	06/25/09	8:00	2,995,600	40	40	NA	140	1.2	220,160	0.8	23,600	140	NA	40	234,130
	06/29/09	8:30	2,995,600	40	40	NA	140	1.2	220,420	0.8	23,760	140	38	40	234,160
12	06/30/09	8:30	2,995,700	35	35	NA	140	1.2	220,810	0.8	23,990	140	37	40	234,370
	07/01/09	8:30	2,995,900	35	35	NA	140	1.2	220,970	0.8	24,090	140	38	40	234,460
	07/02/09	8:30	2,996,100	40	40	NA	140	1.2	221,190	0.8	24,240	140	41	40	234,550
	07/07/09	8:30	2,996,400	35	35	36.3	140	1.2	221,680	0.8	24,590	140	42	40	234,640
13	07/08/09	8:30	2,996,600	35	35	38.1	140	1.2	221,800	0.8	24,670	140	40	40	234,730
	07/09/09	8:30	2,996,700	35	35	41.5	140	1.2	222,010	0.8	24,810	140	40	40	234,790
	07/13/09	8:30	2,996,800	35	35	42.3	140	1.2	222,090	0.8	24,860	140	38	35	234,850
14	07/14/09	8:30	2,996,900	35	35	44.1	135	1.2	222,210	0.8	24,960	140	45	35	234,930
	07/15/09	8:30	2,997,100	35	35	47.6	135	1.2	222,390	0.8	25,090	140	42	35	235,010
	07/16/09	8:30	2,997,300	35	35	48.8	135	1.2	222,470	0.8	25,140	140	38	35	235,090
	07/20/09	7:00	2,997,300	38	37	50.7	115	1.2	222,580	0.8	25,220	120	42	40	235,150
15	07/21/09	6:50	2,997,400	30	28	52.1	110	1.2	222,670	0.8	25,280	125	40	34	235,200
	07/22/09	7:20	2,997,500	37	36	53.9	120	1.2	222,780	0.8	25,370	120	45	33	235,260
	07/23/09	7:15	2,997,600	30	28	56.8	115	1.2	222,960	0.8	25,490	120	40	37	235,360
	07/27/09	8:00	2,997,700	38	38	60.7	130	1.2	223,200	0.8	25,670	140	43	35	235,490
16	07/28/09	8:00	2,997,800	35	35	63.7	135	1.2	223,380	0.8	25,800	140	42	35	235,580
	07/29/09	8:00	2,997,900	40	40	65	115	1.2	223,460	0.8	25,860	130	43	42	235,630

**Table A-1. EPA Arsenic Demonstration Project at Carmel Elementary School at Carmel, ME -- Daily System Operation
Log Sheet (Continued)**

Wk	Date	Time	Non-Potable Water	Pre-Filter	RO Unit									Re-pressurization System	
			FT-1 gal	Inlet Pressure psig	Feed Pressure psig	Hour Meter hrs	Concentrate		FT-2 gal	Permeate			Recovery %	Pressure psig	FT-4 gal
							Pressure	Flowrate		Flowrate	FT-3	Pump Discharge Pressure			
							psig	gpm		gpm	gal	psi			
	07/30/09	8:00	2,998,100	40	40	69.4	135	1.2	223,780	0.8	26,070	140	40	40	235,740
17	08/03/09	8:30	2,998,200	40	40	72.5	140	1.2	223,940	0.8	26,190	140	43	35	235,840
	08/04/09	8:30	2,998,300	35	35	74.4	135	1.2	224,030	0.8	26,260	135	44	35	235,910
	08/05/09	8:30	2,998,400	35	35	76.2	135	1.2	224,160	0.8	26,340	135	38	35	235,960
	08/06/09	8:30	2,998,500	35	35	77.5	130	1.2	224,250	0.8	26,400	135	40	35	236,030
	08/10/09	8:30	2,998,600	40	40	81.5	135	1.2	224,490	0.8	26,580	140	43	35	236,180
18	08/11/09	8:30	2,998,700	40	40	84.0	135	1.2	224,630	0.8	26,680	140	42	35	236,280
	08/12/09	8:30	2,998,800	40	40	86.3	135	1.2	224,780	0.8	26,790	140	42	35	236,360
	08/13/09	8:30	2,998,800	40	40	86.3	135	1.2	224,780	0.8	26,790	135	NA	35	236,370
	08/17/09	8:30	2,998,900	40	40	88.8	135	1.2	224,920	0.8	26,900	140	44	35	236,430
19	08/18/09	8:30	2,999,000	40	38	89.3	135	1.2	224,960	0.8	26,930	140	43	35	236,490
	08/19/09	8:30	2,999,400	40	40	93.8	135	1.2	225,230	0.8	27,120	140	41	35	236,680
	08/20/09	8:30	2,999,600	40	40	96.5	135	1.2	225,390	0.8	27,230	140	41	35	236,800
	08/24/09	8:30	2,999,700	40	40	101.7	135	1.2	225,700	0.8	27,460	140	43	35	236,970
20	08/25/09	8:30	2,999,800	40	40	110.4	135	1.2	226,230	0.8	27,830	140	41	35	237,300
	08/26/09	8:30	2,999,900	40	40	111.4	135	1.2	226,590	0.8	28,090	140	42	35	237,560
	08/27/09	8:30	3,000,100	40	40	112.4	135	1.2	227,100	0.8	28,430	140	40	35	237,920
	09/01/09	8:00	3,000,700	35	35	130.6	130	1.2	227,460	0.8	28,700	140	43	35	238,260
21	09/02/09	8:00	3,001,800	35	35	144.9	130	1.2	228,360	0.8	29,300	140	40	40	238,840
	09/03/09	8:00	3,002,700	35	35	156.0	130	1.2	229,060	0.8	29,760	140	40	40	239,260
	09/04/09	8:00	3,003,600	35	35	179.0	135	1.2	229,820	0.8	30,260	140	40	40	239,780
	09/08/09	8:00	3,004,500	35	35	190.9	135	1.2	231,250	0.8	31,240	140	41	40	240,690
22	09/09/09	8:00	3,005,300	40	40	212.6	135	1.2	232,610	0.8	32,160	140	40	40	241,580
	09/10/09	8:00	3,006,400	35	35	220.5	135	1.2	233,490	0.8	32,740	140	40	40	242,190
	09/11/09	8:00	3,007,400	35	35	240.0	135	1.2	234,340	0.8	33,310	140	40	40	242,760
	09/14/09	8:00	3,008,400	35	35	254.6	130	1.2	235,270	0.8	33,930	140	40	35	243,260
23	09/15/09	8:00	3,009,300	40	40	268.9	130	1.2	236,170	0.8	34,530	140	40	35	243,850
	09/16/09	8:00	3,010,300	40	40	286.3	130	1.2	237,270	0.8	35,260	140	40	40	244,580
	09/17/09	8:00	3,011,300	35	35	297.4	130	1.2	237,980	0.8	35,760	140	41	40	245,030
	09/18/09	8:00	3,012,300	35	35	310.0	130	1.2	238,790	0.8	36,280	140	39	40	245,540
24	09/21/09	8:30	3,013,200	35	35	325.0	140	1.2	239,770	0.8	36,910	140	39	35	246,210
	09/22/09	8:30	3,014,100	40	40	341.1	140	1.2	240,750	0.8	37,560	140	40	35	246,840
	09/23/09	8:30	3,015,100	40	40	354.1	135	1.2	241,580	0.8	38,110	140	40	35	247,370
	09/24/09	8:30	3,015,800	40	40	363.7	135	1.2	242,190	0.8	38,510	140	40	35	247,770

**Table A-1. EPA Arsenic Demonstration Project at Carmel Elementary School at Carmel, ME -- Daily System Operation
Log Sheet (Continued)**

Wk	Date	Time	Non-Potable Water	Pre-Filter	RO Unit									Re-pressurization System	
			FT-1 gal	Inlet Pressure psig	Feed Pressure psig	Hour Meter hrs	Concentrate			Permeate			Recovery %	Pressure psig	FT-4 gal
							Pressure	Flowrate	FT-2	Flowrate	FT-3	Pump Discharge Pressure			
							psig	gpm	gal	gpm	gal	psi			
	09/25/09	8:30	3,016,711	40	40	379.1	135	1.2	243,210	0.8	39,190	140	40	40	248,440
25	09/28/09	8:30	3,017,600	40	40	392.0	130	1.2	243,980	0.8	39,710	140	40	40	248,930
	09/29/09	8:30	3,018,600	35	35	404.8	130	1.2	244,790	0.8	40,250	140	40	40	249,470
	09/30/09	8:30	3,019,500	35	35	423.3	130	1.2	245,960	0.8	41,010	140	39	40	250,210
	10/01/09	8:30	3,020,400	40	40	434.4	130	1.2	246,670	0.8	41,500	140	41	40	250,710
	10/02/09	8:30	3,021,300	40	40	445.9	130	1.2	247,400	0.8	41,980	140	40	40	251,180
	10/06/09	8:00	3,023,200	40	40	474.0	130	1.2	249,170	0.8	43,170	140	40	40	252,320
26	10/07/09	8:00	3,024,200	35	35	489.1	130	1.2	250,170	0.8	43,830	140	40	35	252,990
	10/08/09	8:00	3,025,200	35	35	505.8	130	1.2	251,190	0.8	44,510	140	40	35	253,640
	10/09/09	8:00	3,025,900	35	35	515.2	130	1.2	251,780	0.8	44,900	140	40	40	254,040
	10/13/09	8:00	3,026,000	35	35	525.3	140	1.2	252,390	0.8	45,340	140	42	40	254,260
27	10/14/09	8:00	3,026,900	35	35	540.0	140	1.2	253,330	0.8	45,960	140	40	40	254,880
	10/15/09	8:00	3,027,700	35	35	554.6	140	1.2	254,260	0.8	46,560	140	39	40	255,440
28	10/19/09	8:00	3,029,800	35	35	580.9	140	1.2	255,940	0.8	47,670	140	40	35	256,510
	10/20/09	8:00	3,030,700	35	35	592.5	140	1.2	256,690	0.8	48,170	140	40	35	256,980
29	10/26/09	8:30	3,034,600	35	35	640.3	140	1.2	259,850	0.8	50,270	140	40	40	259,020
	10/27/09	8:30	3,035,500	35	35	653.5	140	1.2	260,730	0.8	50,850	140	40	40	259,580
	10/28/09	8:30	3,036,400	35	35	667.5	140	1.2	261,660	0.8	51,460	140	40	35	260,160
	10/29/09	8:30	3,037,400	35	35	680.0	140	1.2	262,490	0.8	52,010	140	40	40	260,720
	10/30/09	8:30	3,038,300	35	35	690.2	140	1.2	263,230	0.8	52,520	140	41	35	261,190
	11/02/09	8:30	3,039,300	35	32	699.9	170	1.2	263,930	0.8	53,000	180	41	32	261,670
30	11/03/09	8:00	3,040,100	40	36	709.6	170	1.2	264,650	0.8	53,480	180	40	35	262,140
	11/04/09	8:15	3,041,100	30	30	723.2	170	1.2	265,670	0.8	54,150	180	40	45	262,800
	11/05/09	8:00	3,042,100	40	40	731.7	175	1.2	266,300	0.8	54,580	185	41	32	263,230
	11/06/09	8:00	3,043,200	34	32	743.6	175	1.2	267,180	0.8	55,160	185	40	45	263,750
	11/09/09	8:00	3,043,600	40	40	744.6	175	1.2	267,480	0.8	55,320	180	35	45	263,900
31	11/10/09	8:00	3,044,100	40	40	755.9	175	1.2	268,100	0.8	55,780	180	43	45	264,320
	11/12/09	8:30	3,045,100	38	36	767.4	175	1.2	268,960	0.8	56,350	180	40	40	264,880
	11/16/09	8:00	3,047,100	40	40	789.8	155	1.2	270,630	0.8	57,450	160	40	40	265,900
32	11/17/09	8:00	3,048,100	35	35	800.6	155	1.2	271,430	0.8	57,980	170	40	35	266,420
	11/18/09	8:00	3,049,200	35	35	812.1	160	1.2	272,280	0.8	58,530	170	39	35	266,950
	11/19/09	8:00	3,050,100	35	35	825.1	155	1.2	273,250	0.8	59,160	165	39	40	267,560
	11/20/09	8:00	3,051,100	40	40	834.1	155	1.2	273,970	0.8	59,620	160	39	35	268,030
	11/23/09	8:00	3,054,000	40	40	876.6	160	1.2	277,090	0.8	61,640	165	39	40	269,850

**Table A-1. EPA Arsenic Demonstration Project at Carmel Elementary School at Carmel, ME -- Daily System Operation
Log Sheet (Continued)**

Wk	Date	Time	Non-Potable Water	Pre-Filter	RO Unit									Re-pressurization System	
			FT-1 gal	Inlet Pressure psig	Feed Pressure psig	Hour Meter hrs	Concentrate		FT-2 gal	Flowrate gpm	Permeate		Recovery %	Pressure psig	FT-4 gal
							Pressure	Flowrate			Flowrate	FT-3 gal	Pump Discharge Pressure psi		
							psig	gpm			gpm	gal	psi		
	11/24/09	8:00	3,054,800	40	40	886.3	160	1.2	277,810	0.8	62,100	165	39	40	270,310
	11/25/09	8:00	3,055,900	40	40	897.6	160	1.2	278,650	0.8	62,640	165	39	40	270,810
	11/26/09	8:00	3,056,900	40	40	908.1	160	1.2	279,430	0.8	63,140	165	39	40	271,280
	11/27/09	8:00	3,057,800	40	40	918.3	160	1.2	280,190	0.8	63,640	165	40	35	271,780
35	12/07/09	8:00	3,058,900	40	40	931.4	155	1.2	281,170	0.8	64,290	165	40	40	272,320
	12/08/09	8:00	3,059,800	40	40	943.6	150	1.2	282,070	0.8	64,890	155	40	35	272,900
	12/10/09	8:00	3,061,000	40	40	958.3	155	1.2	283,160	0.8	65,620	155	40	40	273,590
	12/11/09	8:00	3,061,900	40	40	969.2	155	1.2	283,970	0.8	66,160	155	40	35	274,120
36	12/14/09	8:00	3,063,100	40	40	979.3	150	1.2	284,720	0.8	66,650	165	40	40	274,580
	12/15/09	8:00	3,064,000	40	40	990.0	150	1.2	285,510	0.8	67,180	150	40	40	275,100

(a) Norlen's Water installed second 300-gal atmospheric storage tank.

(b) Norlen's Water installed pump discharge pressure gauge.

NA = not available

APPENDIX B
ANALYTICAL DATA

Table B-1. Analytical Results from Long-Term Sampling at Carmel, ME

Sampling Date		04/16/09			04/30/09			05/12/09			05/20/09			05/27/09			
Sampling Location		IN	RO	AP	IN	RO	AP	IN	RO	AP	IN	RO	AP	IN	RO	AP	RW
Parameter	Unit																
Alkalinity (as CaCO ₃)	mg/L	198	2.3	20.7	209	1.6	15.4	217	2.5	19.9	220	2.7	16.4	215	2.4	NA ^(a)	337
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	11.9	<0.1	<0.1	-	-	-	-	-	-	6.1	<0.1	NA ^(a)	17.7
Nitrate (as N)	mg/L	-	-	-	0.1	<0.05	<0.05	-	-	-	-	-	-	0.2	<0.05	NA ^(a)	0.2
Total P (as P)	µg/L	-	-	-	<10	<10	<10	-	-	-	-	-	-	<10	<10	NA ^(a)	<10
Silica (as SiO ₂)	mg/L	11.8	0.4	0.3	12.9	0.6	0.3	11.5	0.5	0.4	11.7	0.5	0.4	11.0	0.3	NA ^(a)	17.5
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	0.8	0.9	9.4	2.9	1.2	1.6	2.2	0.9	1.6	2.5	1.1	0.7	10.0	2.7	NA ^(a)	0.7
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TDS	mg/L	270	2.0	35.0	286	8.0	52.0	268	4.0	16.0	276	16.0	26.0	258	8.0	NA ^(a)	416
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
		NA	NA	NA	8.2	6.9	7.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
Temperature	°C	NA	NA	NA	12.6	14.0	14.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
DO	mg/L	NA	NA	NA	5.2	1.0	1.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
ORP	mV	NA	NA	NA	445	457	457	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
Total Hardness (as CaCO ₃)	mg/L	218	0.6	15.0	231	0.9	25.5	203	1.1	22.0	218	0.9	18.8	275	0.7	NA ^(a)	359
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	112	0.3	14.3	110	0.4	24.2	94.2	0.4	20.1	111	<0.25	17.2	150	0.4	NA ^(a)	197
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	106	0.3	0.7	121	0.6	1.4	109	0.7	1.9	107	0.6	1.5	125	0.3	NA ^(a)	162
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L	20.0	<0.1	<0.1	17.7	<0.1	<0.1	18.3	<0.1	<0.1	20.6	<0.1	<0.1	15.7	0.1	NA ^(a)	31.8
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	18.0	<0.1	<0.1	-	-	-	-	-	-	15.8	0.2	NA ^(a)	-
As (particulate)	µg/L	-	-	-	<0.1	<0.1	<0.1	-	-	-	-	-	-	<0.1	<0.1	NA ^(a)	-
As (III)	µg/L	-	-	-	0.2	<0.1	<0.1	-	-	-	-	-	-	0.5	0.1	NA ^(a)	-
As (V)	µg/L	-	-	-	17.8	<0.1	<0.1	-	-	-	-	-	-	15.4	0.1	NA ^(a)	-
Fe (total)	µg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	NA ^(a)	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	<25	<25	<25	-	-	-	-	-	-	<25	<25	NA ^(a)	-
Mn (total)	µg/L	4.7	<0.1	1.0	2.1	<0.1	1.2	2.3	<0.1	0.7	2.8	<0.1	0.3	2.7	<0.1	NA ^(a)	3.0
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	2.2	<0.1	0.1	-	-	-	-	-	-	2.2	<0.1	NA ^(a)	-
Sb (total)	µg/L	12.1	<0.1	<0.1	10.4	<0.1	<0.1	10.6	<0.1	<0.1	11.0	<0.1	<0.1	10.2	<0.1	NA ^(a)	16.9
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sb (soluble)	µg/L	-	-	-	10.5	<0.1	<0.1	-	-	-	-	-	-	10.1	<0.1	NA ^(a)	-

(a) Data from AP water samples were discarded due to collection of samples from wrong sampling tap.

NA = not available

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

Sampling Date		06/04/09			06/17/09				06/30/09				07/29/09				09/02/09			
Sampling Location		IN	RO	AP	IN	RO	AP	RW	IN	RO	AP	RW	IN	RO	AP	RW	IN	RO	AP	RW
Parameter	Unit																			
Alkalinity (as CaCO ₃)	mg/L	210	4.2	13.7	214	2.9	15.4	349	195	2.9	20.6	327	186	3.2	16.6	308	203	2.3	14.7	325
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	9.4	<0.1	<0.1	16.3	8.3	<0.1	<0.1	19.0	11.1	<0.1	<0.1	19.0
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	0.2	<0.05	<0.05	0.3	0.3	0.1	0.1	0.5	0.1	<0.05	<0.05	0.1
Total P (as P)	µg/L	-	-	-	-	-	-	-	<10	<10	<10	<10	<10	12.5	<10	<10	<10	<10	<10	<10
Silica (as SiO ₂)	mg/L	11.5	0.4	0.5	11.6	0.5	0.7	18.5	10.3	0.6	0.5	16.6	10.6	0.5	0.7	17.0	10.9	0.4	0.4	17.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	0.9	0.5	0.3	2.0	2.0	0.4	1.1	1.0	0.5	0.5	0.4	3.3	1.0	0.6	0.8	1.8	2.4	1.8	2.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TDS	mg/L	262	10.0	12.0	258	<2	4.0	412	220	<2	8.0	354	216	6.0	16.0	362	254	14.0	22.0	406
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	7.3	6.7	NA	7.9	6.7	7.0	7.9	7.8	7.2	7.6	8.0	7.8	7.1	7.5	7.9	7.9	6.5	7.1	7.9
		NA	NA	NA	-	-	-	-	6.8	6.5	7.4	-	7.3	6.6	7.1	-	7.3	6.5	7.6	-
Temperature	°C	22.5	22.3	NA	NA	NA	NA	-	25.0	25.0	25.0	-	25.3	25.3	25.5	-	25.0	25.0	25.0	-
DO	mg/L	4.7	4.3	NA	NA	NA	NA	-	3.9	2.2	2.9	-	3.5	2.9	2.8	-	4.3	3.9	3.6	-
ORP	mV	327	352	NA	NA	NA	NA	-	350	365	363	-	340	346	340	-	336	377	378	-
Total Hardness (as CaCO ₃)	mg/L	208	1.7	19.2	215	1.8	30.1	348	199	1.2	16.2	346	218	1.3	10.7	333	190	0.6	9.1	312
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	107	0.9	17.5	111	0.8	27.5	176	114	0.7	15.2	201	94.9	0.6	9.5	145	88.7	0.2	8.4	139
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	100	0.8	1.7	104	1.0	2.6	172	84.8	0.5	1.1	144	123	0.6	1.2	188	102	0.4	0.7	172
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L	18.7	0.1	<0.1	21.0	0.1	<0.1	38.1	13.6	<0.1	<0.1	23.6	16.4	<0.1	<0.1	30.4	15.1	<0.1	<0.1	26.7
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	-	14.4	<0.1	<0.1	-	15.2	<0.1	<0.1	-	16.7	<0.1	<0.1	-
As (particulate)	µg/L	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	-	1.2	<0.1	<0.1	-	<0.1	<0.1	<0.1	-
As (III)	µg/L	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	-
As (V)	µg/L	-	-	-	-	-	-	-	14.3	<0.1	<0.1	-	15.1	<0.1	<0.1	-	16.6	<0.1	<0.1	-
Fe (total)	µg/L	<25	<25	<25	<25	<25	<25	<25	231 ^(a)	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	-	<25	74.0 ^(b)	<25	-	<25	<25	<25	-	-	-	-	-
Mn (total)	µg/L	1.9	<0.1	0.2	1.9	<0.1	0.1	1.1	6.3	<0.1	<0.1	<0.1	1.0	<0.1	<0.1	1.7	1.1	<0.1	<0.1	1.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	-	<0.1	1.7 ^(a)	<0.1	-	0.6	<0.1	0.1	-	-	-	-	-
Sb (total)	µg/L	11.8	<0.1	<0.1	11.1	<0.1	<0.1	17.9	10.0	<0.1	<0.1	17.7	13.2	<0.1	<0.1	20.6	13.1	<0.1	<0.1	22.0
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sb (soluble)	µg/L	-	-	-	-	-	-	-	10.4	<0.1	<0.1	-	12.9	<0.1	<0.1	-	13.3	<0.1	<0.1	-

(a) Outlier.

NA = not available

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

Sampling Date		09/08/09				09/14/09				09/28/09				09/30/09				10/07/09			
Sampling Location		IN	RO	AP	RW	IN	RO	AP	RW	IN	RO	AP	RW	IN	RO	AP	RW	IN	RO	AP	RW
Parameter	Unit																				
Alkalinity (as CaCO ₃)	mg/L	206	4.0	13.0	349	193	5.6	25.9	343	210	9.5	11.3	344	200	2.7	341 ^(a)	337	204	5.4	24.4	336
		-	-	-	-	-	-	-	-	-	-	-	-	201	1.8	11.8	328	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	9.8	<0.1	<0.1	18.0	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	0.2	<0.05	<0.05	0.1	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	-	-	-	-	-	-	-	-	<10	<10	<10	<10	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	11.3	0.8	0.7	18.8	11.2	1.0	0.9	18.0	11.1	0.5	0.5	18.2	11.0	0.4	0.4	18.2	10.6	0.4	0.4	16.9
		-	-	-	-	-	-	-	-	-	-	-	-	11.0	0.4	0.4	17.9	-	-	-	-
Turbidity	NTU	1.6	1.6	0.6	0.9	1.2	0.9	0.6	0.2	0.3	0.1	<0.1	0.2	0.2	0.3	0.2	0.6	1.8	0.7	0.9	1.8
		-	-	-	-	-	-	-	-	-	-	-	-	0.4	0.1	0.1	0.5	-	-	-	-
TDS	mg/L	254	16.0	12.0	414	250	<2	16.0	408	226	<2	<2	354	272	18.0	20.0	460	258	8.0	26.0	418
		-	-	-	-	-	-	-	-	-	-	-	-	258	10.0	20.0	436	-	-	-	-
pH	S.U.	7.9	6.6	7.4	7.9	8.0	7.2	8.9	8.0	7.8	7.1	6.8	7.9	7.9	7.1	7.1	7.5	7.9	6.6	8.9	8.0
		-	-	-	-	-	-	-	-	-	-	-	-	7.9	6.8	7.1	8.0	-	-	-	-
Temperature	°C	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA	-
DO	mg/L	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA	-
ORP	mV	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA	-
Total Hardness (as CaCO ₃)	mg/L	196	1.2	11.8	326	196	1.2	136 ^(a)	327	208	0.9	8.8	336	211	0.8	12.3	350	232	0.8	20.5	357
		-	-	-	-	-	-	-	-	-	-	-	-	220	0.8	15.8	348	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	89.0	0.5	10.1	146	88.5	0.5	64.6 ^(a)	148	105	<0.25	7.9	168	103	<0.25	11.4	169	112	0.2	19.2	172
		-	-	-	-	-	-	-	-	-	-	-	-	106	<0.25	14.8	169	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	107	0.7	1.7	180	107	0.7	71.3 ^(a)	179	103	0.7	0.9	167	108	0.6	0.8	181	119	0.6	1.3	185
		-	-	-	-	-	-	-	-	-	-	-	-	114	0.6	0.9	178	-	-	-	-
As (total)	µg/L	15.7	<0.1	<0.1	27.7	16.4	<0.1	10.0 ^(a)	31.6	18.0	0.1	<0.1	30.9	20.1	0.2	0.1	36.5	22.6	<0.1	<0.1	37.4
		-	-	-	-	-	-	-	-	-	-	-	-	20.4	0.3	0.2	35.9	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	-	-	18.4	0.3	0.2	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	0.4	0.1	<0.1	-	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	18.1	0.1	0.1	-	-	-	-	-	-	-	-	-
Fe (total)	µg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	34	<25	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	<25	<25	<25	<25	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	<25	<25	<25	-	-	-	-	-	-	-	-	-
Mn (total)	µg/L	0.5	<0.1	<0.1	1.0	0.5	<0.1	0.5	1.1	1.1	<0.1	0.1	1.7	1.6	<0.1	0.2	2.3	3.7	<0.1	0.4	2.1
		-	-	-	-	-	-	-	-	-	-	-	-	1.7	<0.1	0.3	2.3	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	0.7	<0.1	<0.1	-	-	-	-	-	-	-	-	-
Sb (total)	µg/L	12.0	<0.1	<0.1	20.4	11.6	<0.1	7.6 ^(a)	19.8	9.8	<0.1	<0.1	16.3	10.4	<0.1	<0.1	17.2	10.2	<0.1	<0.1	16.6
		-	-	-	-	-	-	-	-	-	-	-	-	10.5	<0.1	<0.1	17.1	-	-	-	-
Sb (soluble)	µg/L	-	-	-	-	-	-	-	-	9.7	<0.1	<0.1	-	-	-	-	-	-	-	-	-

(a) Outliers

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

Sampling Date		10/20/09				10/27/09				10/28/09				11/17/09				12/03/09			
Sampling Location		IN	RO	AP	RW	IN	RO	AP	RW	IN	RO	AP	RW	IN	RO	AP	RW	IN	RO	AP	RW
Parameter	Unit																				
Alkalinity (as CaCO ₃)	mg/L	207	3.0	21.3	375	194	4.9	16.6	348	195	5.7	13.4	321	220	19.3	22.7	347	220	12.2	18.9	347
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	10.6	0.2	0.1	18.2	-	-	-	-	11.0	<0.1	<0.1	17.3
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	0.1	<0.05	<0.05	0.2	-	-	-	-	0.1	<0.05	<0.05	0.2
Total P (as P)	µg/L	-	-	-	-	-	-	-	-	<10	<10	<10	<10	-	-	-	-	<10	<10	<10	<10
Silica (as SiO ₂)	mg/L	10.0	0.4	0.4	18.1	10.8	0.4	0.4	18.2	10.8	0.4	0.5	18.1	11.3	0.4	0.3	18.5	11.7	0.3	0.3	19.0
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	8.3	2.2	3.4	3.7	1.0	0.7	0.3	0.8	3.8	1.2	0.5	3.0	0.9	0.4	0.8	1.2	1.5	1.0	0.9	1.8
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TDS	mg/L	246	8.0	20.0	468	242	<2	<2	402	242	4.0	12.0	410	256	10.0	12.0	414	284	34.0	48.0	436
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pH	S.U.	7.9	7.2	7.5	8.0	8.0	6.9	7.7	8.0	7.9	7.1	6.9	8.0	7.9	6.8	7.3	8.0	7.9	6.8	7.2	8.0
		-	-	-	-	-	-	-	-	7.4	6.7	7.5	-	-	-	-	-	7.6	6.6	8.3	-
Temperature	°C	NA	NA	NA	-	NA	NA	NA	-	20.4	20.5	20.5	-	-	-	-	-	20.7	20.7	20.7	-
DO	mg/L	NA	NA	NA	-	NA	NA	NA	-	4.3	4.4	4.6	-	-	-	-	-	3.9	2.9	2.3	-
ORP	mV	NA	NA	NA	-	NA	NA	NA	-	310	324	323	-	-	-	-	-	349	389	366	-
Total Hardness (as CaCO ₃)	mg/L	216	1.1	25.9	380	249	1.8	20.7	393	273	1.9	22.3	496	183	1.9	16.5	300	212	2.0	23.8	350
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	102	0.3	24.1	179	125	1.0	19.3	198	144	0.9	21.0	271	70	0.8	15.3	113	108	1.4	22.8	176
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	114	0.8	1.8	202	124	0.9	1.3	196	128	1.0	1.3	225	113	1.0	1.2	187	104	0.7	1.0	174
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L	18.9	<0.1	<0.1	37.3	18.6	<0.1	<0.1	32.0	17.7	<0.1	<0.1	29.7	19.3	0.3	0.1	32.3	18.6	<0.1	<0.1	30.7
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	-	-	-	-	-	-	-	-	17.9	<0.1	<0.1	-	-	-	-	-	19.0	<0.1	<0.1	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	-	-	-	-	-	<0.1	<0.1	<0.1	-
As (III)	µg/L	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	-	-	-	-	-	0.3	<0.1	<0.1	-
As (V)	µg/L	-	-	-	-	-	-	-	-	17.8	<0.1	<0.1	-	-	-	-	-	18.7	<0.1	<0.1	-
Fe (total)	µg/L	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	-	-	-	-	-	-	-	-	<25	<25	<25	-	-	-	-	-	<25	<25	<25	-
Mn (total)	µg/L	1.8	0.1	0.3	3.0	2.2	0.3	0.5	2.8	2.5	0.3	0.4	3.0	1.8	<0.1	<0.1	2.3	2.4	<0.1	0.5	3.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	-	-	-	-	-	-	-	-	2.4	<0.1	0.5	-	-	-	-	-	2.2	<0.1	0.5	-
Sb (total)	µg/L	10.2	<0.1	<0.1	18.1	9.8	<0.1	<0.1	16.2	10.5	<0.1	<0.1	16.8	10.3	<0.1	<0.1	16.8	8.6	<0.1	<0.1	14.5
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sb (soluble)	µg/L	-	-	-	-	-	-	-	-	10.5	<0.1	<0.1	-	-	-	-	-	9.7	<0.1	<0.1	-

(a) Outliers
NA = not available

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

Sampling Date		12/15/09			
Sampling Location		IN	RO	AP	RW
Parameter	Unit				
Alkalinity (as CaCO ₃)	mg/L	218	4.6	18.6	364
		-	-	-	-
Sulfate	mg/L	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-
Total P (as P)	µg/L	-	-	-	-
Silica (as SiO ₂)	mg/L	11.6	0.4	0.3	19.8
		-	-	-	-
Turbidity	NTU	2.0	0.6	0.5	0.9
		-	-	-	-
TDS	mg/L	254	8.0	26.0	402
		-	-	-	-
pH	S.U.	8.0	6.7	7.2	8.0
		-	-	-	-
Temperature	°C	-	-	-	-
DO	mg/L	-	-	-	-
ORP	mV	-	-	-	-
Total Hardness (as CaCO ₃)	mg/L	202	1.1	21.5	324
		-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	101	0.4	20.2	161
		-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	101	0.7	1.4	163
		-	-	-	-
As (total)	µg/L	17.7	<0.1	<0.1	29.3
		-	-	-	-
As (soluble)	µg/L	-	-	-	-
As (particulate)	µg/L	-	-	-	-
As (III)	µg/L	-	-	-	-
As (V)	µg/L	-	-	-	-
Fe (total)	µg/L	<25	<25	<25	<25
		-	-	-	-
Fe (soluble)	µg/L	-	-	-	-
Mn (total)	µg/L	1.8	<0.1	1.2	0.5
		-	-	-	-
Mn (soluble)	µg/L	-	-	-	-
Sb (total)	µg/L	9.5	<0.1	<0.1	15.9
		-	-	-	-
Sb (soluble)	µg/L	-	-	-	-