

**Arsenic Removal from Drinking Water by Iron Removal
U.S. EPA Demonstration Project at
Vintage on the Ponds in Delavan, WI
Six-Month Evaluation Report**

by

**H. Tien Shiao
Abraham S.C. Chen
Lili Wang
Wendy E. Condit**

**Battelle
Columbus, OH 43201-2693**

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

for

**Thomas J. Sorg
Task Order Manager**

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

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

DISCLAIMER

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

FOREWORD

The 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 and the results obtained from the first six months of the arsenic removal treatment technology demonstration project at Vintage on the Ponds at Delavan, WI. The objectives of the project are to evaluate (1) the effectiveness of Kinetico's Macrolite[®] pressure filtration process in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 µg/L, (2) the reliability of the treatment system; (3) the required system operation and maintenance (O&M) and operator skill levels; and (4) the capital and O&M cost of the technology. The project also is characterizing water in the distribution system and process residuals produced by the treatment system.

Source water at Vintage on the Ponds contained 14.3 to 29.0 µg/L of total arsenic with As(III) being the predominating species at an average concentration of 16.7 µg/L. The source water also contained 1,165 to 2,478 µg/L of total iron present mostly in the soluble form. The ratio of soluble iron to soluble arsenic concentrations was 78:1, indicating sufficient iron present in the source water for effective arsenic removal.

A Macrolite[®] PM2162D6 system was installed to remove arsenic via iron removal from source water. The system consisted of one 21-in × 62-in contact tank and two 21-in × 62-in pressure vessels, each containing 5 ft³ of Macrolite[®] filter media. The treatment process included chlorine addition to oxidize As(III) to As(V) and Fe(II) to Fe(III), adsorption and/or coprecipitation of As(V) onto/with Fe(III) solids, and filtration of As(V)-laden iron solids with the Macrolite[®] media. The design flowrate was 45 gal/min (gpm) based on the well capacity, which yielded 1.8 min of contact time prior to filtration and 9.4 gpm/ft² of hydraulic loading to the filters. Because the actual treatment flowrates fluctuated with the water demand from the distribution system and never exceeded 20 gpm, the minimum contact time and the maximum hydraulic loading rate would be 4.1 min and 4.2 gpm/ft², respectively. From July 12, 2005, through January 17, 2006, the well operated for a total of 446 hr at 2.4 hr/day (on average). The treatment system processed approximately 1,031,200 gal of water with an average daily demand of 5,485 gal during this time period.

Due to the presence of approximately 3.0 mg/L (as N) of ammonia in source water, chloramines were formed upon chlorine addition. The breakpoint chlorination was not performed because of the unrealistically high chlorine dosage (i.e., up to 23 mg/L [as Cl₂]) that would be required to completely oxidize ammonia and chloramines formed during chlorination and because ammonia could be easily removed by the preexisting softener located downstream from the Macrolite[®] pressure filters, before water entered the distribution system. For the first several months of operation, little or no chlorine residuals were detected in the treated water due to repeated operational problems with the chlorine feed system, including failures of the feed pump and the chlorine injector, pipe leaks due to incompatibility of plumbing materials with a 12.5% sodium hypochlorite (NaOCl) solution, and difficulties associated with chlorine residual and chlorine dosage measurements. After the working condition of the chlorine feed system was restored in late October 2005, chlorine dosing rates varied from 2.1 to 4.1 mg/L (as Cl₂), although <1 mg/L (as Cl₂) of chlorine residuals (i.e., chloramines) were being targeted in order to minimize adverse impact on the resins in the downstream softener. The erratic chlorine residual data might have been caused by the on-demand system operation, which had made it difficult to adjust the dosing rates.

The working condition of the chlorine addition system had direct impacts on the effectiveness of treatment. Among the six arsenic speciation sampling events that took place, there were two events when chlorine was not injected properly so that Fe(II) and As(III) were not oxidized or only partially oxidized, resulting in elevated soluble Fe and As(III) levels after treatment. For the other four events when the

chlorine system was in good working condition, Fe(II) and As(III) were mostly oxidized and total iron and arsenic were removed to less than 25 and 10 µg/L, respectively, after filtration. During this reporting period, total arsenic concentrations exceeded the MCL of 10 µg/L in seven out of the 25 sampling events, mostly caused by poor chlorine addition.

For the four speciation events meeting the treatment goals, As(III) concentrations after the contact tank were reduced to 5.0, 5.8, 4.1 and 9.7 µg/L, respectively, and averaged 6.2 µg/L. This average As(III) concentration corresponded to a 63% conversion rate based on the average 16.7 µg/L of As(III) in raw water. As(III) concentrations after filtration were 5.8, 5.9, 1.5, and 3.9 µg/L, respectively, and averaged 4.3 µg/L, suggesting that additional As(III) oxidation (i.e., 11%) might have occurred in the filters. The conversion of As(III) to As(V) after the contact tank, however, was not as complete as that observed at many other sites where little or no ammonia was present in raw water, suggesting that presence of ammonia in the Vintage's raw water might have impacted the effectiveness of As(III) oxidation. Although monochloramine was reported as an ineffective oxidant for As(III) by other researchers, the observation at the Vintage suggested that when chlorine was added to the water, a fraction of the chlorine reacted with As(III) before it was completely quenched by ammonia to form monochloramine.

Similarly, lower total and soluble iron concentrations were observed after the filtration vessels than after the contact tank (i.e., 29 and <25 µg/L versus 1,363 and 520 µg/L [on average]). As expected, elevated total arsenic concentrations were associated directly with elevated total iron concentrations in the treated water after both filtration vessels. Total manganese concentrations averaged 19.4 µg/L in source water, existing primarily in the soluble form as Mn(II). Manganese remained in the soluble form in the treated water at levels ranging from 17.0 to 20.2 µg/L, indicating insignificant oxidation of Mn by the addition of chlorine.

During the six-month period, the Macrolite[®] system was backwashed approximately 60 times using treated water, each generating approximately 720 gal of wastewater. It processed 7,900 to 26,900 gal of water between two consecutive backwash cycles; thus, the productivity of the filters was 91 to 97%. Backwash wastewater was sampled three times, including two with grab samples and one with composite samples. The composition samples were taken from a side stream of the backwash effluent, which, presumably, was more representative of the overall wastewater quality. The analyses of the composite samples showed 121 and 46 µg/L of total arsenic, 13,543 and 4,486 µg/L of total iron, and 26 and 22 µg/L of total manganese in the samples collected from Vessels A and B, respectively. The total suspended solids (TSS) levels in the backwash water were uncharacteristically low at 5 and 12 mg/L, most likely due to insufficient mixing of solids/water mixtures before sample collection.

Comparison of the distribution system sampling results before and after the system operation showed a decrease in the arsenic, iron, and manganese levels at all three sampling locations. Total arsenic levels in the distribution system (i.e., from 3.1 to 23.3 µg/L) although slightly higher, mirrored the total arsenic levels in the treated water (i.e., from 2.6 to 18.0 µg/L). Neither lead nor copper concentrations at the sample sites appeared to have been affected by the operation of the system.

The capital investment cost was \$60,500, which included \$19,790 for equipment, \$20,580 for engineering, and \$20,130 for installation. Using the system's rated capacity of 45 gal/min (gpm) (64,800 gal/day [gpd]), the capital cost was \$1,344/gpm (\$0.93/gpd).

The O&M cost for the system included only incremental cost associated with the chemical supply, electricity consumption, and labor. The O&M cost was estimated at \$0.33/1,000 gal for the first six months of operation.

CONTENTS

DISCLAIMER	ii
FOREWORD	iii
ABSTRACT.....	iv
FIGURES.....	vii
TABLES	vii
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	5
3.0: MATERIALS AND METHODS.....	7
3.1 General Project Approach.....	7
3.2 System O&M and Cost Data Collection.....	8
3.3 Sample Collection Procedures and Schedules	8
3.3.1 Source Water	11
3.3.2 Treatment Plant Water.....	11
3.3.3 Backwash Water.....	11
3.3.4 Distribution System Water Sample	11
3.3.5 Residual Solids	12
3.4 Sampling Logistics	12
3.4.1 Preparation of Arsenic Speciation Kits.....	12
3.4.2 Preparation of Sampling Coolers.....	12
3.4.3 Sample Shipping and Handling	12
3.5 Analytical Procedures	13
4.0: RESULTS AND DISCUSSION	14
4.1 Facility Description and Pre-Existing Treatment System Infrastructure.....	14
4.1.1 Source Water Quality	14
4.1.2 Distribution System and Treated Quality	18
4.2 Treatment Process Description	18
4.3 System Installation	24
4.3.1 Permitting	24
4.3.2 Building Construction.....	24
4.3.3 System Installation, Shakedown, and Startup.....	24
4.4 System Operation	26
4.4.1 Operational Parameters.....	26
4.4.2 Chlorine Addition.....	29
4.4.3 Residual Management	32
4.4.4 System/Operation Reliability and Simplicity	32
4.5 System Performance	33
4.5.1 Treatment Plant Sampling	33
4.5.2 Backwash Water Sampling.....	40
4.5.3 Distribution System Water Sampling	40

4.6 System Cost.....	42
4.6.1 Capital Cost	42
4.6.2 Operation and Maintenance Cost.....	44
5.0 REFERENCES	46
APPENDIX A: OPERATIONAL DATA	A-1
APPENDIX B: ANALYTICAL DATA	B-1

FIGURES

Figure 3-1. Process Flow Diagram and Sampling Locations.....	10
Figure 4-1. Preexisting Well No. 1 Pump House.....	15
Figure 4-2. Preexisting Well Piping and Pressure Tanks.....	15
Figure 4-3. Preexisting Softener System	16
Figure 4-4. Process Schematic of Macrolite® Pressure Filtration System	19
Figure 4-5. Chlorine Addition System.....	21
Figure 4-6. Contact Tank	22
Figure 4-7. Macrolite® Pressure Filtration System	22
Figure 4-8. Backwash Flow Paths for both Tanks A and B and a Throughput of 18,000 gal Between Backwash Cycles	23
Figure 4-9. Photographs of System Components	25
Figure 4-10. Equipment Off-loading	26
Figure 4-11. Close-up View of Insite® PX-50 GPM-12-V-F Flow Meter.....	26
Figure 4-12. Δp Across Pressure Filtration Vessels A and B and Entire System.....	28
Figure 4-13. Throughput Between Backwash Cycles.....	29
Figure 4-14. Total Chlorine Residuals at AC and TT Locations	30
Figure 4-15. Concentrations of Arsenic Species at IN, AC, and TT Sampling Locations	37
Figure 4-16. Total Arsenic Concentrations at TA, TB, and TT Sampling Location	39
Figure 4-17. Total Iron Concentrations at TA, TB, and TT Sampling Locations.....	39
Figure 4-18. Total Manganese Concentrations at the TA, TB, and TT Sampling Locations	40

TABLES

Table 1-1. Summary of Round 1 and Round 2 Arsenic Removal Demonstration Locations, Technologies, and Source Water Quality.....	3
Table 3-1. Predemonstration Study Activities and Completion Dates	7
Table 3-2. Evaluation Objectives and Supporting Data Collection Activities	8
Table 3-3. Sample Collection Schedule and Analyses	9
Table 4-1. Vintage on the Ponds, WI Water Quality Data	17
Table 4-2. Physical Properties of 40/60 Mesh Macrolite® Media	18
Table 4-3. Design Specifications for Macrolite® PM2162D6 Pressure Filtration System	20
Table 4-4. System Operation from July 12, 2005 to January 17, 2006	27
Table 4-5. Summary of Problems Encountered and Corrective Actions Taken for Chorine Injection System.....	31
Table 4-6. Summary of Arsenic, Iron, and Manganese Analytical Results With and Without Sufficient Chlorine Addition.....	34
Table 4-7. Summary of Analytical Results of Other Water Quality Parameters.....	35

Table 4-8.	Backwash Water Sampling Results	41
Table 4-9.	Distribution Sampling Results	43
Table 4-10.	Summary of Capital Investment for Vintage on the Ponds Treatment System.....	44
Table 4-11.	O&M Cost for the Vintage on the Ponds Treatment System.....	45

ABBREVIATIONS AND ACRONYMS

Δp	
AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
As	arsenic
ATS	Aquatic Treatment Systems
AWWA	
bgs	below ground surface
BTU-hr	British Thermal Units per hour
C/F	coagulation/filtration
Ca	calcium
Cl	chlorine
CRF	capital recovery factor
Cu	copper
DO	dissolved oxygen
DPD	N,N diethyl-p-phenylene diamine
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
FRP	fiberglass reinforced plastic
gpd	gal per day
gpm	gal per minute
HIX	hybrid ion exchanger
hp	horsepower
HR	high range
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IX	ion exchange
LCR	Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MDH	Minnesota Department of Health
MEI	Magnesium Elektron, Inc.;
Mg	magnesium
Mn	manganese
MSDS	Material Safety Data Sheet
Na	sodium

NA	not applicable
NaClO	sodium hypochlorite
NRMRL	National Risk Management Research Laboratory
NTU	nephelometric turbidity units
O&M	operation and maintenance
ORD	Office of Research and Development
ORP	oxidation-reduction potential
P&ID	pipng and instrumentation diagrams
POU	point-of-use
psi	pounds per square inch
PVC	polyvinyl chloride
QA	quality assurance
QAPP	quality assurance project plan
QA/QC	quality assurance/quality control
RO	reverse osmosis
RPD	relative percent difference
SDWA	Safe Drinking Water Act
STS	Severn Trent Services
SMCL	Secondary Maximum Contaminant Level
TDH	total dynamic head
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
V	vanadium
WDNR	Wisconsin Department of Natural Resources

ACKNOWLEDGMENTS

The authors wish to extend their sincere appreciation to Ms. Deborah Ismail, Manager of Vintage on the Ponds in Delavan, WI. Ms. Ismail monitored the treatment system daily during the week and collected samples from the treatment and distribution systems on a regular schedule throughout this reporting period. This performance evaluation would not have been possible without her efforts.

1.0: INTRODUCTION

1.1 Background

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

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

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the 17 host sites. EPA received 70 technical proposals for the 17 host sites, with each site receiving one to six proposals. In April 2003, an independent technical panel reviewed the proposals and provided its recommendations to EPA on the technologies that it determined were acceptable for the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration project. Using the information provided by the review panel, EPA, in cooperation with the host sites and the drinking water programs of the respective states, selected one technical proposal for each site. As of May 2007, 11 of the 12 systems were operational and the performance evaluation of eight systems was completed.

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

In September 2003, EPA, again, solicited proposals from engineering firms and vendors for arsenic removal technologies. EPA received 148 technical proposals for the 32 host sites, with each site receiving from two to eight proposals. In April 2004, another technical panel was convened by EPA to review the proposals and provide recommendations to EPA with the number of proposals per site ranging from none (for two sites) to a maximum of four. The final selection of the treatment technology at the sites that received at least one proposal was made, again, through a joint effort by EPA, the state regulators, and the host site. Since then, four sites have withdrawn from the demonstration program, reducing the number of sites to 28. Kinetico's Macrolite® Arsenic Removal Technology was selected for demonstration at the Vintage on the Ponds facility in September 2004.

1.2 Treatment Technologies for Arsenic Removal

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

1.3 Project Objectives

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

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

This report summarizes the performance of the Kinetico system at Vintage on the Ponds in Delavan, WI during the first six months from July 12, 2005 through January 17, 2006. The types of data collected included system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and preliminary O&M cost.

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

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

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

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH (S.U.)
<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 ^(c)	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; IX = ion exchange; RO = reverse osmosis
ATS = Aquatic Treatment Systems; MEI = Magnesium Elektron, Inc.; STS = Severn Trent Services

- (a) Arsenic existing mostly as As(III).
- (b) Design flowrate reduced by 50% due to system reconfiguration from parallel to series operation.
- (c) Iron existing mostly as Fe(II).
- (d) Replaced Village of Lyman, NE site which withdrew from program in June 2006.
- (e) Facilities upgraded systems in Springfield, OH from 150 to 250 gpm, Sandusky, MI from 210 to 340 gpm, and Arnaudville, LA from 385 to 770 gpm.
- (f) Including nine residential units.
- (g) Including eight under-the-sink units.

2.0: SUMMARY AND CONCLUSIONS

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

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

- The Macrolite[®] filtration system effectively removed arsenic to less than 10 µg/L provided that the chlorine addition system was in good working condition. Improper chlorine addition could result in over 80% of total arsenic, primarily As(III), passing through the pressure filters, thus causing the effluent arsenic levels to exceed the MCL.
- The presence of 3 mg/L of ammonia (as N) in source water presented a challenge in determining an effective chlorine dosage for As(III) oxidation. An average of 74% As(III) was oxidized, including 63% occurring in the contact tank and an additional 11% in the filters. This level of As(III) oxidation was better than anticipated, considering the relatively low chlorine dosage applied (i.e., 2.1 to 4.1 mg/L as Cl₂) in order to protect the cation exchange resin in the downstream softener. The observed As(III) oxidation might have resulted from As(III) reacting with a fraction of the chlorine added and with the monochloramine formed in situ.
- Arsenic speciation is a valuable tool to assess the effectiveness of As(III) oxidation.
- The performance of the Macrolite[®] system was not evaluated at the design loading rate of 9.4 gpm/ft² because the treatment flowrate varied with water demand, which was significantly lower than the well pump flowrate. The maximum hydraulic loading rate achieved during the study was 4.2 gpm/ft², which was 45% of the design value.

Required system O&M and operator skill levels:

- Operational issues associated with the chlorine addition system included failures of the feed pump and the chlorine injector, pipe leaks due to incompatibility of plumbing materials with the 12.5% NaOCl solution, and erratic and inconsistent chlorine residual measurements.
- The filtration system had no unscheduled downtime, however, it was operated without any chlorine addition for 63 days, about one third of the study period.
- The typical daily demand on the operator to maintain the system was about 5 min. However, the chlorine feed system had to be constantly monitored and adjusted to ensure proper working conditions. Additional time was required to troubleshoot and maintain the chemical feed system.
- Operating the chlorine feed system required skills to handle NaOCl solutions, chemical feed pump, and chlorine residual measurements, and may be challenging to person/persons with no prior experience.

Process residuals produced by the technology:

- Backwashing of the Macrolite[®] system occurred once every two to three days, generating 720 gal of wastewater each time. The system processed 7,900 to 26,900 gal of water between two consecutive backwash cycles, corresponding to a productivity of 91 to 97%.

Cost of the technology:

- The unit capital cost is \$0.24/1,000 gal if the system operates at 100% utilization rate. The system's real unit cost is \$2.77/1,000 gal, based on 2.4 hr/day of system operation and 1,031,000 gal of water production for six months of system. The O&M cost is \$0.33/1,000 gal, based on labor, chemical usage, and electricity consumption.

3.0: MATERIALS AND METHODS

3.1 General Project Approach

Following the predemonstration activities summarized in Table 3-1, the performance evaluation study of the Kinetico Macrolite[®] treatment system began on July 12, 2005. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall system performance was evaluated based on its ability to consistently remove arsenic to below the target MCL of 10 µg/L through the collection of water samples across the treatment train. The reliability of the system was evaluated by tracking the unscheduled system downtime and frequency and extent of repair and replacement. The unscheduled downtime and repair information were recorded by the plant operator on a Repair and Maintenance Log Sheet.

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

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

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

Table 3-1. Predemonstration Study Activities and Completion Dates

Activity	Date
Introductory Meeting Held	09/20/04
Request for Quotation Issued to Vendor	02/22/05
Vendor Quotation Received	03/03/05
Purchase Order Established	03/30/05
Letter of Understanding Issued	02/16/05
Letter Report Issued	05/24/05
Engineering Package Submitted WDNR	04/25/05
Permit Issued by WDNR	06/10/05
Study Plan Issued	06/21/05
Macrolite [®] Unit Shipped by Kinetico	06/17/05
System Installation Completed	07/01/05
System Shakedown Completed	07/12/05
Performance Evaluation Begun	07/12/05

WDNR = Wisconsin Department of Natural Resources

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

Evaluation Objective	Data Collection
Performance	-Ability to consistently meet 10-µg/L arsenic MCL in treated water
Reliability	-Unscheduled system downtime -Frequency and extent of repairs including a description of problems, materials and supplies needed, and associated labor and cost
System O&M and 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 preventive maintenance including number, frequency, and complexity of tasks -Chemical handling and inventory requirements -General knowledge needed for relevant chemical processes and health and safety practices
Residual 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

3.2 System O&M and Cost Data Collection

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

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

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected at the wellhead, across the treatment system, during Macrolite[®] filter backwash, and from the distribution system. The sampling schedules and analytes measured during each sampling event are listed in Table 3-3. In addition, Figure 3-1 presents a

Table 3-3. Sampling Schedule and Analyses

Sample Type	Sample Locations ^(a)	No. of Samples	Frequency	Analytes	Date(s) Samples Collected
Source Water	At Wellhead (IN)	1	Once (during initial site visit)	On-site: pH, temperature, DO, and ORP Off-site: As(III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), U (total and soluble), V (total and soluble), Na, Ca, Mg, Cl, F, NH ₃ , NO ₃ , NO ₂ , SO ₄ , SiO ₂ , PO ₄ , turbidity, alkalinity, TDS, and TOC	09/20/04
Treatment Plant Water	At Wellhead (IN), After Contact Tank (AC), After Tank A (TA), After Tank B (TB)	4	Weekly	On-site: pH, temperature, DO, ORP, and Cl ₂ (total and free) ^(b) Off-site: As (total), Fe (total), Mn (total), SiO ₂ , PO ₄ /P (total), turbidity, and alkalinity	07/19/05, 07/26/05, 08/02/05, 08/16/05, 08/23/05, 08/30/05, 09/06/05, 09/13/05, 09/20/05, 10/04/05, 10/11/05, 10/18/05, 11/01/05, 11/08/05, 11/15/05, 12/06/05, 12/13/05, 01/10/06, 01/17/06
	At Wellhead (IN), After Contact Tank (AC), and After Tanks A and B Combined (TT)	3	Monthly	Same as weekly analytes shown above plus the following: Off-site: As (soluble), As(III), As(V), Fe (soluble), Mn (soluble), Ca, Mg, F, NH ₃ , NO ₃ , SO ₄ , and TOC	07/12/05, 08/09/05, 09/27/05, 10/25/05, 11/29/05, 01/30/06
Backwash Water	At Backwash Discharge Line	2	Monthly	As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, TDS, TSS, and turbidity	09/20/05, 10/11/05, 11/29/05, 01/10/06
Distribution Water	Two LCR and One non-LCR Locations	3	Monthly	As (total), Fe (total), Mn (total), Cu, Pb, pH, alkalinity	Baseline Sampling ^(c) 03/23/05, 04/20/05, 05/31/05, 06/21/05 Monthly Sampling: 07/27/05, 08/30/05, 09/28/05, 10/18/05, 11/29/05, 12/13/05, 01/17/06
Residual Solids	Backwash Solids from Each Tank	2	Twice	Total As, Fe, Mn, Mg, Al, Si, P, Ca, Ni, Cu, Zn, Cd, and Pd	07/13/06

(a) Abbreviations in parentheses corresponding to sample locations in Figure 3-1.

(b) Measured at AC, TA, TB, and TT locations only.

(c) Four baseline sampling events performed before system became operational.

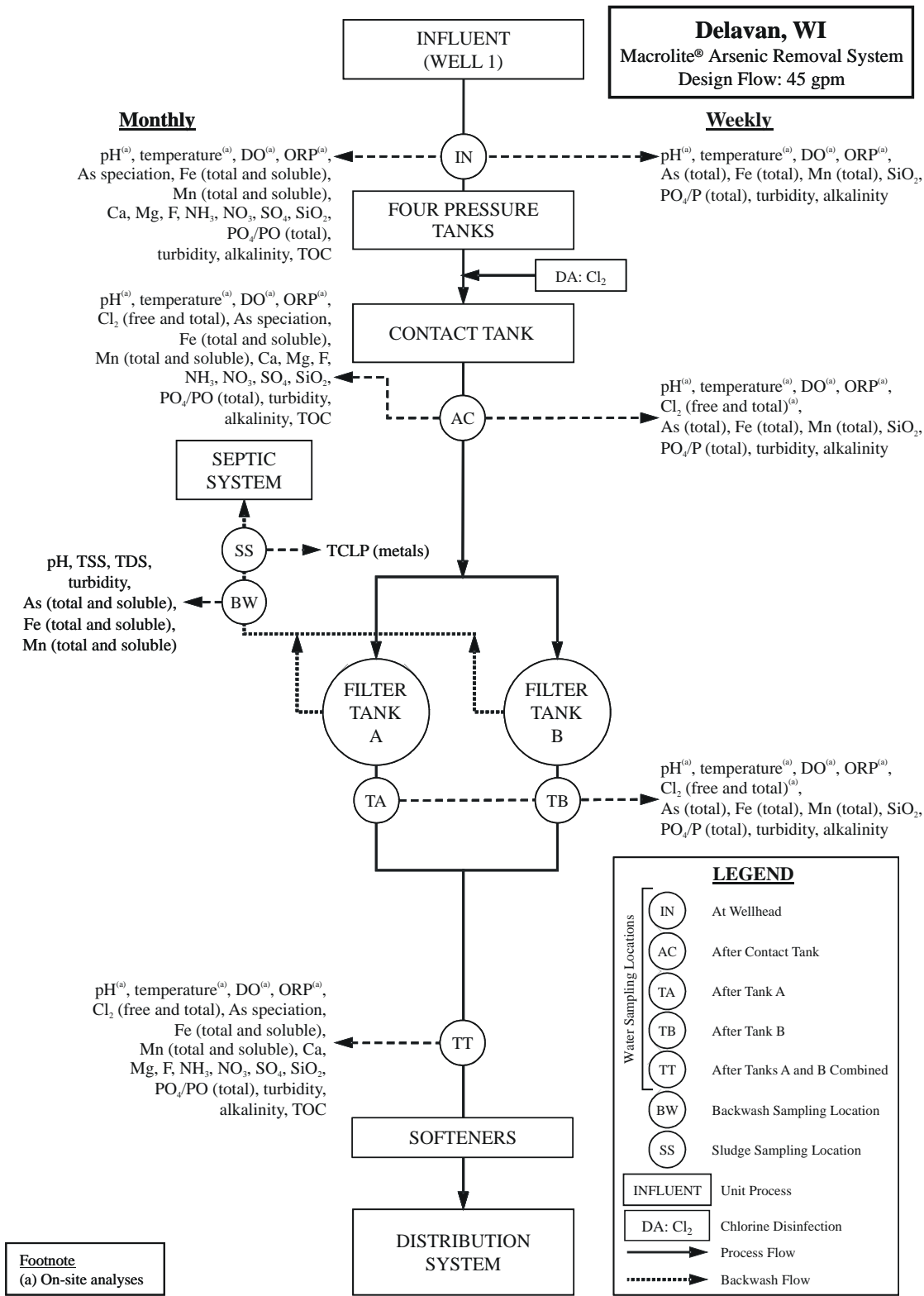


Figure 3-1. Process Flow Diagram and Sampling Locations

flow diagram of the treatment system along with the analytes and schedules at each sampling location. Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2004). The procedure for arsenic speciation is described in Appendix A of the QAPP.

3.3.1 Source Water. During the initial visit to the site, one set of source water samples was collected and speciated using an arsenic speciation kit. Additional samples were collected after the softener to assess the working condition of the softener. Each sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Analytes for the source water samples are listed in Table 3-3.

3.3.2 Treatment Plant Water. During the system performance evaluation study, the plant operator collected samples weekly, on a four-week cycle, for on- and off-site analyses. For the first week of each four-week cycle, samples taken at the wellhead (IN), after the contact tank (AC), and after Tanks A and B combined (TT), were speciated on-site and analyzed for the analytes listed in Table 3-3 for monthly treatment plant water. For the next three weeks, samples were collected at IN, AC, after Tank A (TA), and after Tank B (TB) and analyzed for the analytes listed in Table 3-3 for the weekly treatment plant water.

3.3.3 Backwash Water. Backwash water samples were collected monthly from each pressure filter by the plant operator. Backwash water samples were not taken in July, August, and December 2005, due to the lack of a backwash sample tap and the Christmas holidays, respectively. The backwash water samples taken on November 29, 2005, would not be representative of the actual backwash water quality because the pressure filters had just been backwashed three times in a row due to an operational error (see Section 4.5.2) and, therefore, not included in this report.

For the September and October 2005 sampling events, one grab sample was collected during the backwash of each pressure filter from the sample tap located on the backwash water discharge line, but before the backwash totalizer. Unfiltered samples were measured on-site for pH and off-site for total dissolved solids (TDS) and turbidity. Filtered samples using 0.45- μm disc filters were analyzed for soluble arsenic, iron, and manganese. Starting in November 2005, the backwash water sampling procedure was modified to include the collection of composite samples for total suspended solids (TSS) and total arsenic, iron, and manganese analyses. Tubing, connected to the tap on the discharge line, directed a portion of backwash water at approximately 1 gpm into a clean, 32-gal container over the duration of backwash for each filter. After the content in the container was thoroughly mixed, composite samples were collected and/or filtered on-site with 0.45- μm filters. Analytes for the backwash samples are listed in Table 3-3.

3.3.4 Distribution System Water. Samples were collected from the distribution system by the plant operator to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically, the arsenic, lead, and copper levels. Prior to system startup from March to June 2005, four sets of monthly baseline water samples were collected from three sampling locations within the distribution system. The three sampling locations selected initially included one tap each in the dining room, the shower room in A Wing, and the large suite in B Wing, which were among the five Lead and Copper Rule (LCR) sampling locations at Vintage on the Ponds. However, due to water usage at night from the tap in the dining room, this sampling location was replaced with a tap in the second floor guest room (which is a non-LCR location) starting from the second baseline sampling event. Following system startup, distribution system sampling continued on a monthly basis at the same three locations. Note that all sampling locations were located downstream from two water softeners both before and after the startup of the Macrolite[®] pressure filters.

The operator collected samples following an instruction sheet developed according to the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The dates and times of last water usage before sampling and sample collection were recorded for calculations of the stagnation time. All first draw samples were collected from respective cold-water faucets that had not been used for at least 6 hr to ensure that stagnant water was sampled. Analytes for the baseline samples coincided with the monthly distribution system water samples as described in Table 3-3. Arsenic speciation was not performed for the distribution water samples.

3.3.5 Residual Solids. Residual solids produced by the treatment process included backwash solids, which were collected during the second half of this demonstration. The sampling procedure and analytical results will be provided in the Final Performance Evaluation Report.

3.4 Sampling Logistics

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

3.4.2 Preparation of Sampling Coolers. For each sampling event, a sample cooler was prepared with the appropriate number and type of sample bottles, disc filters, and/or speciation kits. All sample bottles were new and contained appropriate preservatives. Each sample bottle was affixed with a pre-printed, colored-coded label consisting of the sample identification (ID), date and time of sample collection, collector's name, site location, sample destination, analysis required, and preservative. The sample ID consisted of a two-letter code for the 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 locations were placed in separate Ziplock™ 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 off-site analyses were packed carefully in the original coolers with wet ice and shipped to Battelle. Upon receipt, the sample custodian verified that all samples indicated on the chain-of-custody forms were included and intact. Sample IDs were checked against the chain-of-custody forms, and the samples were logged into the laboratory sample receipt log. Discrepancies noted by the sample custodian were addressed with the plant operator by the Battelle Study Lead.

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

3.5 Analytical Procedures

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

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

4.0: RESULTS AND DISCUSSION

4.1 Facility Description and Preexisting Treatment System Infrastructure

Vintage on the Ponds is a nursing home facility located at N4901 Dam Road, Delavan, WI. Well No. 1 (see Figure 4-1 for the existing pump house) supplies water to approximately 52 residents. Based on the water usage data recorded from November 12, 2003, through February 21, 2005, the average daily demand was approximately 6,400 gpd and the peak daily demand was 23,500 gpd.

Well No. 1 was completed on October 15, 1995 with a depth of 350 ft below ground surface (bgs) in a limestone formation. It had a 10-in-diameter borehole lined with a 6-in-diameter casing extending from the ground surface to 244 ft bgs and a 6-in-diameter unlined borehole extending from 244 to 350 ft bgs. The static water level was measured at approximately 45 ft bgs based on the water level readings taken at the time of well installation in 1995. Installed on a 105-ft drop pipe, a 5-horsepower (hp) submersible pump supplied water at 41.5 gpm against a 115.4-ft (or 50-psi) total dynamic head (TDH). To meet the daily demand, the well pump was operated intermittently based on the high and low pressure settings in a set of four pressure tanks, with the well pump on at 40 pounds per square inch (psi) and off at 60 psi. Figure 4-2 shows the piping from the wellhead to the four pressure tanks located within the basement of the nursing home.

Water from the pressure tanks was treated with a 29TMDM-300 softener system consisting of two 24-in × 72-in softener tanks each containing 10 ft³ of Ionac C-249 cation exchange resin manufactured by Sybron Chemicals (see Figure 4-3). The system was designed to treat a continuous flowrate of 68 gpm and a peak flowrate of 91 gpm. The two softener tanks operated alternately, i.e., one tank was in service while the other was on standby. Each softener tank was regenerated after treating about 6,000 gal of water (approximately daily), which was tracked by a 2-in mechanical meter located upstream of the softener unit. When the meter called for regeneration, the tank in service went into regeneration, and the tank on standby came online. When the regeneration process was complete, the tank went into standby until another 6,000 gal of water had been treated. Prior to this demonstration project, there was no chlorination at the wellhead.

4.1.1 Source Water Quality. Source water samples were collected on September 20, 2004, before and after the softener, as discussed in Section 3.3.1. The results of source water analyses, along with those provided by the facility to EPA for the demonstration site selection and those independently collected and analyzed by EPA, WDNR, and the vendor are presented in Table 4-1.

As shown in Table 4-1, total arsenic concentrations in source water ranged from 16.0 to 25.0 µg/L. Approximately 95% of the total arsenic, or 19.1 µg/L, existed as As(III). The presence of As(III) as the predominating arsenic species was consistent with the low DO and ORP readings, which were measured at 1.2 and -123 mV, respectively. Iron concentrations in source water ranged from 1,499 to 2,300 µg/L with almost all existing as soluble iron based on September 20, 2004 results. A rule of thumb is that the soluble iron concentration should be at least 20 times the soluble arsenic concentration for effective removal of arsenic onto iron solids (Sorg, 2002). The results from the September 20, 2004, sampling event indicated that the soluble iron level was approximately 68 times the soluble arsenic level. Therefore, no supplemental iron addition was planned. The manganese levels ranged from 19.0 to 20.2 µg/L, existing almost entirely in the soluble form. pH values of source water ranged from 7.3 to 7.7, which were within the target range of 5.5 to 8.5 for the iron removal process. Hardness ranged from 291 to 346 mg/L, silica from 14.2 to 14.6 mg/L, and sulfate from <1 mg/L to 10 mg/L.



Figure 4-1. Preexisting Well No. 1 Pump House

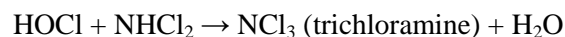
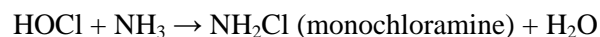


Figure 4-2. Preexisting Well Piping and Pressure Tanks



Figure 4-3. Preexisting Softener System

Ammonia was measured at 2.8 mg/L (as N) in raw water and was reduced to 0.4 mg/L in the softened water. Since the treatment system was to be placed upstream of the softeners, the presence of the elevated level of ammonia in raw water had a significant impact on chlorination. When chlorine is added to raw water, it oxidizes Fe(II), As(III), and other reducing agents and then reacts with ammonia to form chloramines according to the following equations:



The formation of chloramines depends upon water pH, ammonia concentration, and temperature (Clark et al., 1977). In the pH range of 4.5 to 8.5, both mono and dichloramine are formed as combined chlorine. Based on stoichiometric calculations, 1 mg/L of NH_3 (as N) will react with 5 mg/L of HOCl (as Cl_2) to form 5 mg/L of NH_2Cl (as Cl_2). As such, 14 mg/L of HOCl (as Cl_2) would be required to oxidize 2.8 mg/L of NH_3 (as N) to form chloramines. Chlorine added beyond this point will further oxidize chloramines to form oxidized nitrogen compounds, such as nitrous oxide, nitrogen, and nitrogen trichloride. Upon complete oxidation of all chloramines, a “breakpoint” is reached and any additional chlorine added will be present as free chlorine. For Vintage on the Ponds, the “breakpoint” chlorination is not necessary because (1) ammonia can be effectively removed by the existing softeners before entering the distribution system, and (2) the “breakpoint” chlorination would require a high chlorine dosage up to 23 mg/L, which will incur a high chemical cost. Another consideration was the adverse effect of the chlorine residuals on the cationic exchange resin in the downstream softeners. According to the manufacturer, the resin would significantly shorten its life if it is exposed to over 1 mg/L of chlorine

Table 4-1. Vintage on the Ponds, WI Water Quality Data

Parameter	Unit	Utility Source Water Data ^(a)	Kinetico Source Water Data	Battelle Source Water Data	Battelle Softened Water Data	WDNR Source Water Data ^(b)
<i>Date</i>		Not specified	10/29/03	09/20/04	09/20/04	08/08/00–02/23/05
pH		7.6	7.3	7.5	NS	7.7
Temperature	°C	NS	NS	12.7	NS	NS
DO	mg/L	NS	NS	1.2	NS	NS
ORP	mV	NS	NS	-123	NS	NS
Total Alkalinity (as CaCO ₃)	mg/L	188	344	384	371	320
Hardness (as CaCO ₃)	mg/L	291	312	346	4.1	336–340
Turbidity	NTU	NS	NS	20.0	0.5	NS
TDS	mg/L	NS	NS	330	358	NS
TOC	mg/L	NS	NS	1.8	1.8	NS
Nitrate (as N)	mg/L	NS	NS	<0.04	<0.04	<0.04
Nitrite (as N)	mg/L	NS	NS	<0.01	<0.01	<0.01
Ammonia (as N)	mg/L	NS	NS	2.8	0.4	NS
Chloride	mg/L	15	1.9	<1.0	<1.0	<1.0
Fluoride	mg/L	NS	0.20	0.27	0.33	0.26–0.31
Sulfate	mg/L	10	<4.0	<1.0	<1.0	NS
Silica (as SiO ₂)	mg/L	NS	14.2	14.3	14.6	NS
Orthophosphate (as P)	mg/L	NS	<0.5	<0.06	<0.06	NS
As (total)	µg/L	25.0	19.0	20.1	19.1	16.0–23.0
As (soluble)	µg/L	NS	NS	20.5	18.7	NS
As (particulate)	µg/L	NS	NS	<0.1	0.4	NS
As(III)	µg/L	NS	NS	19.1	17.7	NS
As(V)	µg/L	NS	NS	1.4	1.0	NS
Fe (total)	µg/L	1,500	1,600	1,499	<25	2,300
Fe (soluble)	µg/L	NS	NS	1,400	<25	NS
Mn (total)	µg/L	NS	20.0	20.2	0.3	19.0
Mn (soluble)	µg/L	NS	NS	18.3	<0.1	NS
U (total)	µg/L	NS	NS	<0.1	<0.1	NS
U (soluble)	µg/L	NS	NS	<0.1	<0.1	NS
V (total)	µg/L	NS	NS	0.3	0.4	NS
V (soluble)	µg/L	NS	NS	0.1	0.1	NS
Na (total)	Mg/L	10	11.0	12.4	181	12.0–160
Ca (soluble)	Mg/L	NS	62.5	71.4	0.4	72.0
Mg (total)	Mg/L	NS	36.0	40.7	0.08	38.0
Radium-226	pCi/L	NS	NS	NS	NS	0.6
Radium-228	pCi/L	NS	NS	NS	NS	0.9

NS = not sampled

(a) Provided to EPA for site selection

(b) Both compliance and source water samples collected before the softener

residuals (mostly chloramines in this case). Therefore, the chlorine dosage must be carefully controlled to ensure effective oxidation of Fe(II) and As(III) without overdosing chlorine.

4.1.2 Distribution System and Treated Water Quality. The distribution system is supplied by Well No. 1 only. According to a certified utility operator, the distribution system consists primarily of copper piping ranging from ½ to 2-in in size. Under the LCR, samples are collected from five customer taps every year. Vintage on the Ponds also collects water samples periodically for nitrates and monthly for bacterial analysis.

4.2 Treatment Process Description

The treatment train for the Vintage on the Ponds system included prechlorination/oxidation, detention, and Macrolite® pressure filtration. Macrolite® is a spherical, low-density, ceramic media manufactured by Kinetico for high-flow filtration up to 10 gpm/ft². The media is approved for use in drinking water applications under NSF International Standard 61. The physical properties of the media are summarized in Table 4-2. The vendor considers Macrolite® chemically inert and compatible with chemicals such as oxidants and ferric chloride.

Table 4-2. Physical Properties of 40/60 Mesh Macrolite® Media

Property	Value
Color	Taupe, brown to grey
Thermal Stability (°C)	1,100
Sphere Mesh Size	40 × 60
Sphere Size Range (mm)	0.35–0.25
Sphere Size Range (in)	0.0165–0.0098
Uniformity Coefficient	1.2
Bulk Density (g/cm ³)	0.86
Bulk Density (lb/ft ³)	54
Particle Density (g/cm ³)	2.05
Particle Density (lb/ft ³)	129

Source: Kinetico

Figure 4-4 is a schematic of the Macrolite® PM2162D6 pressure filtration system. The pressure filtration system consisted of four preexisting pressure tanks, one chemical feed system for prechlorination, one contact tank, two pressure filtration vessels in parallel, two preexisting softener units, and associated instrumentation for pressure and flowrate.

Because the filtration system was placed after the four pressure tanks, it operated at variable flowrates based on instantaneous demand from the distribution system. Backwash of the Macrolite® system was triggered by a throughput of 18,000 gal through each vessel. All plumbing for the system was Schedule 80 polyvinyl chloride (PVC) and the skid-mounted unit was pre-plumbed with the necessary isolation valves, check valves, sampling ports, and other features. Table 4-3 summarizes the design features of the system. The major process steps and system components are presented as follows:

- **Intake** – Raw water was pumped from Well No. 1 at approximately 45 gpm into a series of four 120-gal Well-X-Trol pressure tanks (Model No. WX-350), which controlled the well pump on/off with pressure settings at 40/60 psi and served as temporary water storage. Each pressure tank was individually connected to a 2-in copper header pipe. Upon a call from the distribution system, the pressure tanks supplied raw water to the Macrolite® filtration system and the downstream softener. After the pressure tanks were gradually emptied and the tank pressure was reduced to 40 psi, the well pump was turned on to refill the tanks and supply the water demand. The well pump was turned off as the tank pressure reached the high pressure setting of 60 psi.

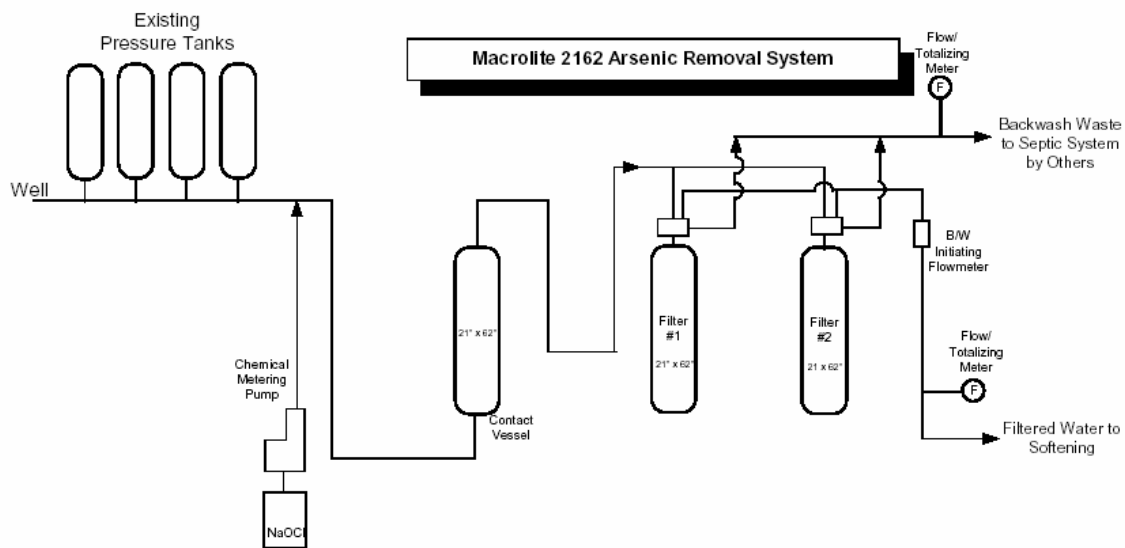


Figure 4-4. Process Schematic of Macrolite® Pressure Filtration System

- Prechlorination/Oxidation** – NaClO was injected into a 2-in PVC “tee” to oxidize As(III) and Fe(II) before entering the contact tank. The chemical feed system consisted of a 15-gal polyethylene day tank with secondary containment and a Pulsatron Plus Series E Model LPA2 flow-paced metering pump with a maximum capacity of 6 gpd (or 0.9 L/hr). The metering pump can adjust its speed automatically based on the pulse signals received from a Multi-jet Cold Water flow meter located between the contact tank and the filtration vessels. A 5.25% NaClO solution was originally used from the system startup on July 12 but was switched to a 12.5% NaClO solution on October 26, 2005 to increase the chlorine dosage. The operation of the NaClO feed system was monitored daily by measuring chlorine residuals and the chlorine consumption in the day tank. Figure 4-5 is a composite of photographs of the chlorine feed system and its components.

The target chlorine residual after the pressure filters was 1 mg/L of total chlorine (as Cl₂) to minimize any adverse impacts on the resin in the softeners. According to WDNR’s permit approval letter dated June 10, 2005, the chlorine residual through the softening system was limited to 1 mg/L of free chlorine (as Cl₂). However, free chlorine was not expected to be present due to the high ammonia level in source water. Upon further consultation with the resin manufacturer, combined chlorine also would have, perhaps to a lesser extent, adverse impacts on the resin.

- Detention** – One 21-in × 62-in fiberglass reinforced plastic (FRP) tank (see Figure 4-6) was designed to provide approximately 2 min of contact time at the peak flowrate of 45 gpm. The actual contact time varied based on the instantaneous water demand from the distribution system. The on-demand flowrates observed were much lower than the peak flowrate during the first six months of system operation. The detention was designed to aid in the formation of iron flocs prior to filtration.

Table 4-3. Design Specifications for Macrolite® PM2162D6 Pressure Filtration System

Parameter	Value	Remarks
<i>Pretreatment</i>		
Target Prechlorination Dosage (mg/L as Cl ₂)	3.0	1 mg/L of chlorine demand estimated for As(III), Fe(II), and Mn(II); actual demand could be higher due to presence of total organic carbon (TOC). Total chlorine residuals of 1.0 mg/L (as Cl ₂) targeted after pressure filters to protect cationic ion exchange resin in softeners
<i>Detention</i>		
Tank Quantity	1	–
Tank Size (in)	21 D × 62 H	–
Tank Volume (gal)	82.4	–
Contact Time (min)	1.8	Based on design flowrate of 45 gpm and contact tank volume of 82.4 gal; actual contact time based on instantaneous on-demand flowrates
<i>Filtration</i>		
Vessel Quantity	2	Parallel configuration
Vessel Size (in)	21 D × 62 H	–
Vessel Cross-Sectional Area (ft ² /vessel)	2.4	–
Media Volume (ft ³ /vessel)	4.8	24-in bed depth of 40/60 mesh Macrolite® in each vessel
Peak Flowrate (gpm/ft ²)	45	Actual flowrate based on instantaneous on-demand flowrates from distribution system
Filtration Rate (gpm/ft ²)	9.4	Based on 22.5-gpm flowrate through each filtration vessel; actual filtration rates based on instantaneous on-demand flowrates
Δp across vessel (psi)	15	Across a clean bed
Maximum Daily Production (gpd)	64,800	Based on peak flowrate of 45 gpm operating at 24 hr/day
Hydraulic Utilization (%)	36	Estimated based on peak daily demand of 23,500 gal
<i>Backwash</i>		
Frequency (gal/vessel)	18,000	Throughput between two consecutive backwash cycles
Hydraulic Loading Rate (gpm/ft ²)	10	Based on 25 gpm backwash flowrate through each filtration vessel
Backwash Duration (min)	12	–
Service-to-Waste Duration (min)	4	15 gpm flowrate
Wastewater Production from Backwash (gal/vessel)	300	–
Wastewater Production from Service-to-Waste (gal/vessel)	60	–

- Pressure Filtration** – The Macrolite® filtration system involved downflow filtration through two pressure filters arranged in parallel (see Figure 4-7). Mounted on a polyurethane-coated steel frame, the filtration system consisted of two 21-in × 62-in FRP pressure vessels, each equipped with an upper 0.5-in slotted plastic diffuser, a lower 0.01-in slotted polyethylene hub and lateral, and 6-in top and bottom flanges. Each vessel was filled with approximately 24 in (4.8 ft³) of 40/60 mesh Macrolite® media, supported by 6-in of 30/40 mesh garnet underbedding. The standard operation had both tanks on-line with each vessel treating a



Figure 4-5. Chlorine Addition System

(Clockwise from top: *Chlorine Injection Point; Chemical Day Tank and Secondary Containment; Flow-paced Chemical Metering Pump; Chlorine Addition System*)

maximum of 22.5 gpm for a hydraulic loading rate of 9.4 gpm/ft². However, because the system was operated “on-demand”, the actual flowrate through the system varied based on water demand.

- Backwash Operations** – Backwash was a fully automated process pre-set on the backwash timer assembly for a throughput of 18,000 gal (through each vessel) determined by a flow totalizer installed on the treated water line (see Figure 4-7). The spent filtration vessel was backwashed with water from the contact tank and the resulting wastewater was sent to a septic system. The backwash duration for each vessel was 16 min from start to finish, including 12 min of backwash at 25 gpm and 4 min of service-to-waste rinse at 15 gpm, producing approximately 360 gal of wastewater per vessel. Figure 4-8 depicts the backwash flow paths for both Tanks A and B, which were backwashed on an alternating basis, i.e., one vessel was backwashed while the other continued to provide treated water to the distribution system. The backwash cycles were repeated as shown in Steps 4 through 6 during system operation. Therefore, the filtration vessels, if viewed as one unit, always had a filtration capacity between 25% (immediately after backwash of one tank at Step 4) and 75% (immediately before backwash of the other tank at Step 5).



Figure 4-6. Contact Tank



Figure 4-7. Macrolite® Pressure Filtration System
*(Clockwise from Left: Pressure Filters; Backwash Timer Assembly;
Totalizer on Treated Waterline)*

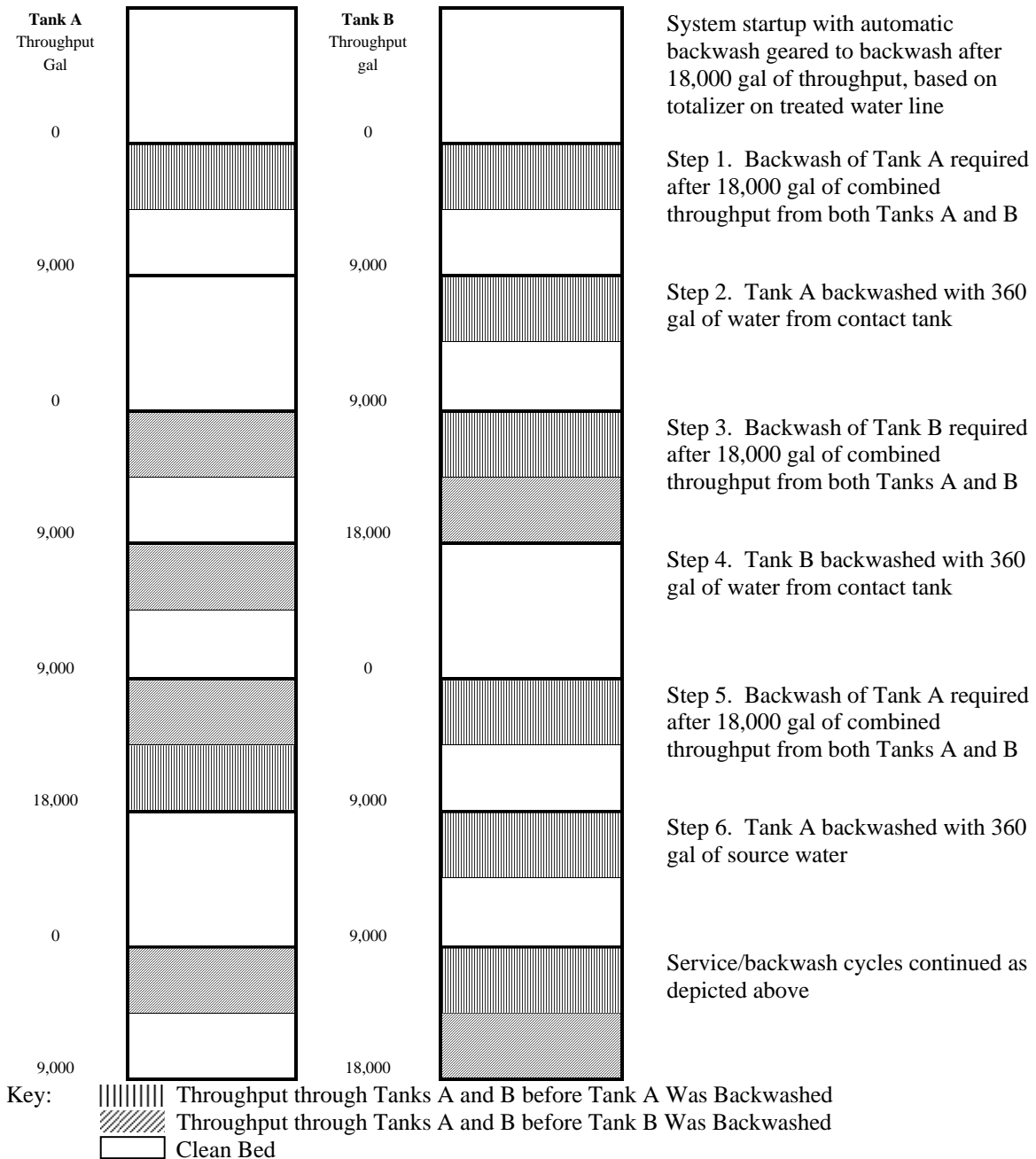


Figure 4-8. Backwash Flow Paths for Both Tanks A and B and a Throughput of 18,000 gal Between Backwash Cycles

- **Softening** – Downstream from the pressure filters, the treated water was routed to an Addie Model No. 29TDM-300 water softening system composed of two 24-in-diameter by 48-in-tall softener vessels and one 1,200-lb salt capacity brine tank (Figure 4-3). The water softening system operated with one vessel while the other vessel was in standby mode. Section 4.1 provides additional details of the softening process.

4.3 System Installation

This section summarizes system/building installation activities, including permitting, building preparation, and system offloading, installation, shake down, and start up.

4.3.1 Permitting. The engineering plans, prepared by Kineticco, included diagrams and specifications for the Macrolite[®] PM2162D6 arsenic removal system, as well as drawings detailing the connections to the preexisting facility infrastructure. The engineering plans were certified by a Professional Engineer registered in the State of Ohio and submitted to WDNR on April 25, 2005. WDNR's preliminary review comments, received on April 29, 2005, requested a summary table of all design parameters and a chemical feeder submittal checklist. In addition, WDNR requested the facility to provide the design information for the existing softener system and a reporting schedule for the analytical and operational data collected during the one year demonstration project. After incorporating responses to comments, the engineering plans were resubmitted to WDNR on May 24, 2005. WDNR granted the system permit on June 10, 2005 with, among others, two approval conditions related to system installation:

- The discharge piping for the spent brine from the softeners and the backwash water from the Macrolite[®] filters should have a "2D" (two times the diameter of the discharge piping) air gap. A vacuum beaker tee was actually installed instead of the "2D" air gap, which also prevents a sewer backup from entering the water system (Figure 4-9).
- The 15-gal NaClO chemical day tank should be graduated using a maximum of 0.5 gal increments (Figure 4-9).

In addition, WDNR requested verbally during its startup inspection site visit that the NaClO feed pump be remounted above the solution level to avoid any siphoning of the chemical (Figure 4-9).

On August 29, 2005, WDNR granted approval to the relocation of the NaClO injection point and the contact flow meter from before to after the four pressure tanks. The request was made because prolonged contact with over 1 mg/L (as Cl₂) of total chlorine potentially could damage the butyl rubber in the pressure tanks. Further, WDNR granted approval on October 21, 2005 to the use of a 12.5% NaClO solution to replace the previously approved 5.25% solution in order to meet the higher chlorine demand due to the presence of about 3.0 mg/L (as N) of NH₃ in raw water.

4.3.2 Building Construction. The existing basement had an adequate footprint to house the arsenic removal system and did not require any modifications before system installation.

4.3.3 System Installation, Shakedown, and Startup. The Macrolite[®] system was installed by a vendor subcontractor, LTM Water Treatment, beginning on June 17, 2005. The installation activities, which lasted about two weeks, included offloading the Macrolite[®] PM2162D6 arsenic removal system (Figure 4-10), connecting system piping at the tie-in points (including the tie-ins from the discharge piping with the required vacuum breaker tee), completing electrical wiring and connections, and assembling the chlorine addition system. System installation was completed by July 1, 2005.

Upon completion of system installation, the pressure filtration vessels were tested hydraulically before media loading; the Macrolite[®] filtration media was backwashed thoroughly to remove media fines; the contact and filtration tanks were disinfected according to the applicable American Water Works Association (AWWA) procedures; and the chemical feed pump was fine tuned for a target total chlorine residual of 0.5 mg/L (as Cl₂) after the filtration vessels. A water sample was collected for bacteria



Figure 4-9. Photographs of System Components

(Clockwise from Top: Vacuum Breaker Tee; Chlorine Day Tank with Required Graduation; Pump Relocated from below to above Chlorine Tank Level; Chlorine Injection before Pressure Tanks; Chlorine Injection Point Relocated to after Pressure Tanks; Flow Meter on Treated Water Line)

analysis on July 5, 2006, and the system was bypassed until the result for the bacteria analysis was received on July 7, 2006, and faxed to WDNR the same day.

Battelle arrived at the site on July 12, 2005, to perform system inspections and conduct operator training for system sampling and data collection. Upon completion of the operator training, a set of samples was collected across the treatment train by the operator with the assistance of Battelle's Study Lead on July 12, 2005. Meanwhile, the operator and Battelle's Study Lead performed arsenic speciation and onsite measurements for pH, temperature, DO, and ORP using a handheld field meter (see Section 3.5). Further, upon careful inspections of the system, a punch list was developed and summarized as follows:

- Remount the chlorine feed pump to above the chlorine tank level to avoid potential siphoning of the chemical (Figure 4-9)
- Install a backwash sample tap
- Install an hour meter
- Install a flow meter on the treated water line and backwash line (Figure 4-9 shows the flow meter on the treated water line)
- Relocate the chlorine injection point and the contact flow meter to after the four pressure tanks to avoid using the pressure tanks as settling tanks and prevent butyl rubber in the pressure tanks from being damaged due to the presence of elevated levels of chlorine in water. In addition, moving the chlorine injection point would increase the distance between

source water sample tap (denoted as “IN” in Table 3-3) and the chlorine injection point to over 10 ft to avoid any cross contamination (Figure 4-9).

On August 19, 2005, a vendor subcontractor was onsite to remount the chlorine feed pump, install a backwash sample tap, and increase the setting of the chlorine feed pump to achieve the target chlorine residual. On September 14 and then from 19 to 20, 2005, one Insite® PX-50 GPM-12-V-F flow meter (Figure 4-11) was installed each on the treated water line and the backwash line. On September 22, 2005, the chlorine injection point and the contact flow meter were relocated from before to after the pressure tanks. All action items were completed after the vendor had installed the hour meter in the pump house during the subcontractor’s October 25, 2005 site visit.



Figure 4-10. Equipment Off-loading



Figure 4-11. Close-up View of Insite® PX-50 GPM-12-V-F Flow Meter

4.4 System Operation

4.4.1 Operational Parameters. Table 4-4 summarizes the operational parameters for the first six months of system operation, including operational time, throughput, flowrate, and pressure. Detailed daily operational information also is provided in Appendix A.

Table 4-4. System Operation from July 12, 2005 to January 17, 2006

Parameter	Values
Well Pump (Well No. 1)	
Total Operating Time (hr)	446.2
Average Daily Operating Time (hr)	2.4
Average Flowrate (gpm)	40
System Throughput/Demand	
Throughput to Distribution (gal)	1,031,200 ^(a)
Average Daily Demand (gpd)	5,485
Peak Daily Demand (gpd)	10,700 ^(a)
Total Operating Time (hr)	System on demand
Average Daily Operating Time (hr)	System on demand
PM2162D6 System – Service Mode	
Flowrate (gpm)	20 (max.)
Contact Times (min)	4.1 (min.)
Hydraulic Loading Rates to Filters (gpm/ft ²)	4.2 (max.)
System Inlet Pressure (psi)	44 to 59 ^(b)
System Outlet Pressure (psi)	10 to 40
Δp across Filtration Vessels A and B (psi)	5 to 28 ^(c)
Δp across System (psi)	21 to 42
PM2162D6 System – Backwash Mode	
Number of Backwash Cycles (times)	60 ^(d)
Throughput between Backwash Cycles (gal)	7,900 to 26,900 ^(a)
Daily Backwash Cycles (times/day)	0 to 2 ^(e)

- (a) Based on totalizer on treated water line
- (b) Based on readings from pressure gauge installed on four pressure tanks
- (c) Excluding two readings at 1 and 33 psi
- (d) Based on totalizer readings on backwash discharge line and 300 gal/vessel of backwash water produced during each backwash cycle
- (e) Excluding manual backwash cycles and backwash occurring on September 30, 2005

Between July 12, 2005 and January 17, 2006, the well operated for approximately 446 hr with an average daily operating time of 2.4 hr. Because of lack of an hour meter, the well operating time was estimated based on the total throughput through the raw water line and a pump flowrate of 40 gpm. The pump flowrate was the average of three values measured by the totalizer on the raw water line and a stopwatch. The hour meter in the pump house was not installed until after the first six-month period.

During the first six months of system operation, the system treated approximately 1,031,000 gal of water. The average daily demand was 5,485 gal/day, compared to 6,400 gal/day provided by the facility prior to the demonstration study. The peak daily demand occurred on December 7, 2005, at 10,700 gal, compared to 23,500 gpd provided by the facility. Due to the on-demand system configuration, the total and daily system operating times were not tracked. The on-demand flowrates through the system varied and were tracked by an Insite[®] PX-50 GPM-12-V-F flow meter installed on the treated water line. Because the flow meter installed had 2.5-gpm increments up to 50 gpm, accurate flowrate data were not attainable especially over the lower end of the applicable range. Nonetheless, examination of all flowrate data revealed that the maximum flowrate recorded throughout the study period was approximately 20 gpm. Using this value as a basis, the minimum contact time in the contact tank was 4.1 min (compared to the design value of 1.8 min) and the maximum hydraulic loading rate to the Macrolite[®] filters was 4.2 gpm/ft² (compared to the design value of 9.4 gpm/ft²).

At flowrates of less than 20 gpm, the inlet pressure readings to the system ranged from 44 to 59 psi, which were within the operating range from 40 to 60 psi for the pressure tanks. The outlet pressure readings to the downstream softeners ranged from 10 to 40 psi. The pressure differential (Δp) readings across Vessels A and B ranged from 5 to 28 psi (excluding two readings at 1 and 33 psi [note that the 33-psi reading was taken after about 18,600 gal of water had been treated]) based on readings on the inlet and outlet pressure gauges. As shown in Figure 4-12, Δp readings rose gradually from 5 to 9 psi immediately after system startup and stabilized at about 20 psi approximately one month into system operation. Because the Δp readings were recorded at different stages of various service cycles, the spikes shown in the figure most likely represented the times when the filters were about to be backwashed. The pressure Δp readings across the system ranged from 21 to 42 psi.

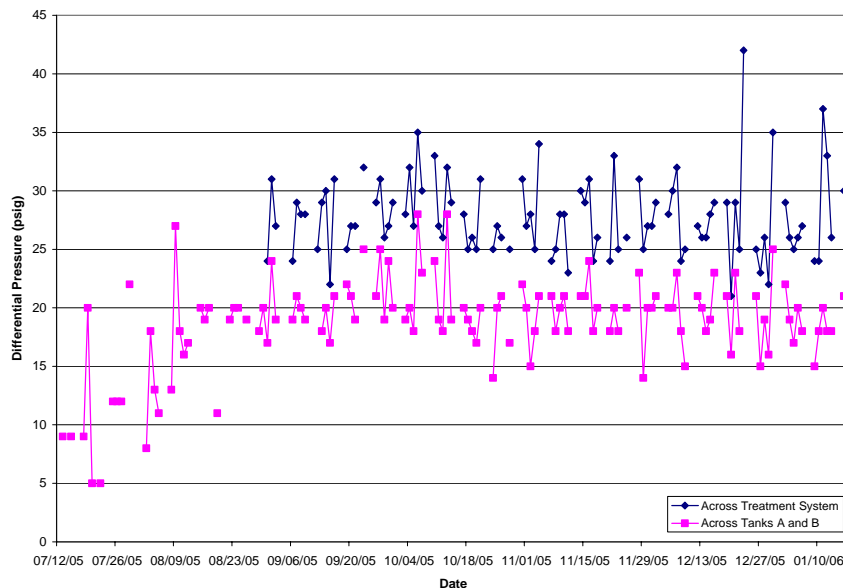


Figure 4-12. Δp Across Vessels A and B and Entire System

During this time period, approximately 60 backwash cycles took place. The throughput between two consecutive backwash cycles ranged from approximately 7,900 to 26,900 gal and averaged 18,530 gal (Figure 4-13), compared to the design throughput of 18,000 gal. The number of backwash cycles per day and throughput between backwash cycles excluded five manual backwash cycles triggered by the operator for backwash water sampling on September 19 (only for a practice), September 20, October 11, and November 29, 2005, and January 10, 2006. Since these manual backwash cycles did not reset the respective throughput volumes, the throughput readings were not included in data calculations. In addition, for an unknown reason, five backwash cycles took place on September 30, 2005 and also were excluded from the data calculations.

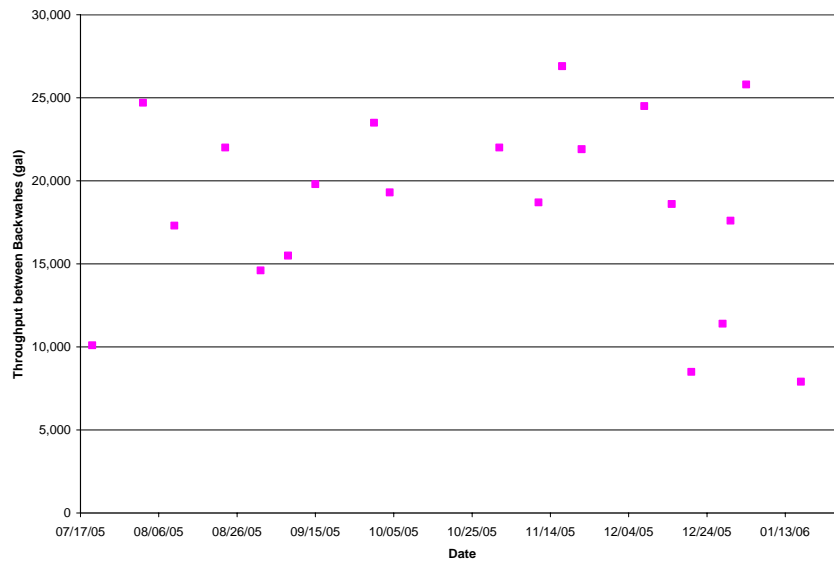


Figure 4-13. Throughput Between Backwash Cycles

4.4.2 Chlorine Addition. As described in Section 4.2., chlorine was added to oxidize Fe(II) and As(III) prior to filtration. Due to the presence of 2.8 mg/L of ammonia, total chlorine residuals measured in the water comprised of primarily mono and dichloramines with little or no free chlorine (since breakpoint chlorination was not performed). As such only total chlorine residual data are discussed herein. The total chlorine residuals measured after the contact tank (AC) and in the plant effluent (TT) are plotted in Figure 4-14. The erratic chlorine residuals measured were primarily caused by operational difficulties encountered with the chlorine injection system, which were summarized in Table 4-5 and discussed below.

For the first three months of system operation through late October 2005, little or no chlorine residuals were measured except for a few sampling occasions. The difficulties of detecting chlorine residuals in the water were attributed to several factors, including problems with the chlorine test kit, mechanical failures of the chlorine feed pump and chlorine injector, and insufficient chlorine dosage with the use of a 5.25% NaClO solution. Initial attempts to correct the problems included replacing a potentially malfunctioning N,N diethyl-p-phenylene diamine (DPD) reagent dispenser with DPD pillows for chlorine residual measurements and increasing the chlorine injection rate by stepping up the stroke length of the chlorine feed pump from 70 to 83.5%. Since August 23, 2005, the operator noticed no change in the chlorine tank level, indicating no chlorine addition. A broken compression fitting on the chlorine feed pump was later identified as the cause and was replaced on September 19 and 20, 2005. Two days later, the chlorine injection point was relocated from before to after the pressure tanks to prevent potential damage to the butyl rubber diaphragms in the pressure tanks. After relocation, the chlorine injector was found not to bleed properly and had to be repaired by the vendor’s subcontractor a week later.

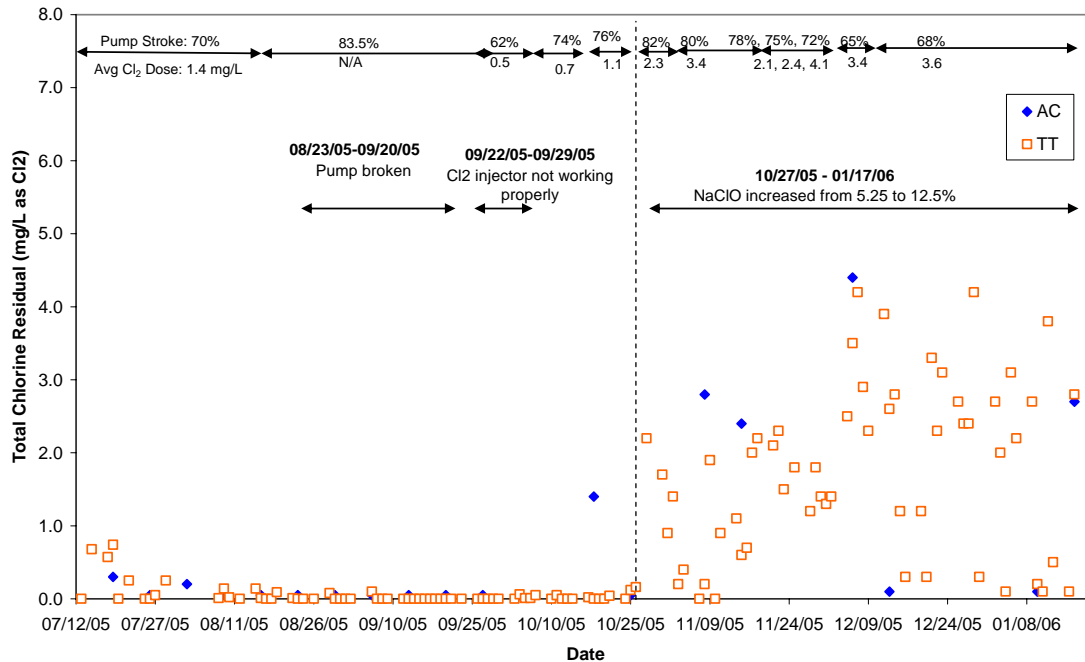


Figure 4-14. Total Chlorine Residuals at AC and TT Locations

After switching to a 12.5% NaClO solution on October 27, 2005, both chlorine dosages and chlorine residuals were increased significantly, as shown in Figure 4-14. The actual chlorine dosages based on chlorine tank level measurements ranged from 2.1 to 4.1 mg/L (as Cl₂). With approximately 1 mg/L (as Cl₂) of chlorine demand for Fe(II), Mn(II), and As(III) and an unknown amount for the organic matter in raw water, total chlorine residuals in the treated water should be no more than 1.1 to 3.1 mg/L (as Cl₂), a range that covered the majority of the measured residual data points as shown in Figure 4-14. It is suspected that the measured total chlorine residual data might be somewhat higher than the actual concentrations due to the inadvertent use of high range (HR) test kits designed for a higher concentration range (i.e., from 0.1 to 8.0 mg/L [as Cl₂]). During a site visit in July 2006, Battelle’s Study Lead measured a set of samples using both the high range and low range (designed for 0.02 to 2.0 mg/L [as Cl₂]) test kits and obtained 0.2 to 0.3 and 0.4 to 1.4 mg/L (as Cl₂) of total chlorine residuals, respectively. Therefore, the use of high range test kits could have skewed the test results to some extent.

A series of leaks were developed after switching to the 12.5 % NaClO solution due to incompatibility of the plumbing material with the stronger NaClO solution. A leak was first discovered between the ½-in copper chlorine injector and 2-in copper “tee” on November 4, 2005. After being patched, the leak continued at the 2-in copper “tee”. The ½-in copper chlorine injector and 2-in copper “tee” were then replaced with the equivalent PVC parts on November 7, 2005. A leak was discovered again on the 2-in PVC “tee” on November 11, 2005, caused by a cracked plastic fitting, and was fixed on the same day. Since then, no more repairs have been performed on the chlorine addition system, except for the pump’s [losing prime] periodically due to airlocks, causing little or no consumption of the chlorine solution.

Table 4-5. Summary of Problems Encountered and Corrective Actions Taken for Chlorine Injection System

Duration	Problem Encountered	Corrective Actions Taken	Work Performed by/on
07/12/05 – 08/23/05	Little or no chlorine residuals measured	<ul style="list-style-type: none"> • Examined Hach test kit and switched from DPD reagent dispenser to DPD reagent powder pillows since 07/19/05 • Remounted pump and increased pump stroke length from 70 to 83.5% on 08/19/05 	<ul style="list-style-type: none"> • Operator • Vendor’s Subcontractor on 08/19/05
08/23/05 – 09/20/05	No change in chlorine tank level and no chlorine residuals measured	<ul style="list-style-type: none"> • Replaced broken compression fitting on pump 	<ul style="list-style-type: none"> • Vendor’s Subcontractor on 09/19-20/05
07/12/05 – 09/22/05	Chlorine injection point installed before pressure tanks	<ul style="list-style-type: none"> • Relocated ½-in copper injection point from before to after pressure tanks 	<ul style="list-style-type: none"> • Vendor’s Subcontractor on 09/22/05
09/22/05 – 09/29/05	No chlorine residuals measured	<ul style="list-style-type: none"> • Fixed chlorine injector that did not bleed properly after its relocation on 09/22/05 • Adjusted pump stroke length to 62% 	<ul style="list-style-type: none"> • Vendor’s Subcontractor on 09/29/05
09/29/05 – 10/27/05	No chlorine residuals measured	<ul style="list-style-type: none"> • Adjusted pump stroke length to 74%, then 76% • Cleaned pump injection fitting • Replaced chlorine stock solution from 5.25 to 12.5% 	<ul style="list-style-type: none"> • Operator and vendor’s Subcontractor on 10/11/05 • Vendor’s Subcontractor on 10/18-19/05 followed by vendor technician on 10/25-27/05
11/04/05	Leak between ½-in copper chlorine injector and 2-in copper pipe observed	<ul style="list-style-type: none"> • Patched leaks between ½-in copper chlorine injector and 2-in copper pipe 	<ul style="list-style-type: none"> • Vendor’s subcontractor on 11/04/05
11/07/05	Leak between ½-in copper chlorine injector and 2-in copper pipe observed	<ul style="list-style-type: none"> • Replaced ½-in copper chlorine injector and 2-in copper “tee” with equivalent PVC injector and “tee” 	<ul style="list-style-type: none"> • Vendor’s Subcontractor on 11/07/05
11/11/05	Leak on 2-in PVC pipe observed	<ul style="list-style-type: none"> • Replaced a cracked PVC fitting on 2-in PVC “tee” installed on 11/07/05 	<ul style="list-style-type: none"> • Vendor’s Subcontractor on 11/11/05

To control the total chlorine residuals not to exceed the 1 mg/L (as Cl₂) target before entering the downstream softener, constant adjustments had to be made to the pump stroke length, i.e., from 82 to 80, 78, 75, 72, 65, and 68%. However, the resulting chlorine dosage based on the day tank measurements did not appear to respond to the stroke length adjustment. For example, when the stroke length was reduced from 80 to 68%, the chlorine dosage, in effect, increased from 3.4 to 3.6 mg/L. (Note that the dosages based on the pump rated capacity at 80 and 68% stroke lengths were 3.2 and 2.7 mg/L [as Cl₂], respectively.) The following reasons might have contributed to such discrepancies: (1) it was difficult to accurately measure the chlorine dosages by reading tank levels with 0.5-gal graduations, (2) leaks, airlocks, and varying injection rates by the paced pump could affect the amount of chlorine metered into the water, and (3) the pump might not have been properly calibrated to ensure that the flow sensor,

generated correct pulse signals at varying flowrates and that the pulse signals were properly converted to the pump speed.

4.4.3 Residual Management. Residuals produced by the operation of the Macrolite[®] system included only backwash water, which was discharged to pumped to a nearby sanitary sewer line for disposal. Backwash frequency and quantities of backwash wastewater generated were discussed in Section 4.4.1.

4.4.4 System/Operation Reliability and Simplicity. During the first six months of system adflakjsdf;lakjsdf;loperation, a total of nine visits were made by the vendor and/or its subcontractor to fix the chlorine addition system and leaks at the chlorine injection point as described in Section 4.4.2 and summarized in Table 4-5. There was no unscheduled downtime for the system, but the system was allowed to operate without the use of chlorine for 63 days from August 23 to September 20, 2005, and from September 22 to October 27, 2005.

Pre- and Post-Treatment Requirements. The only pretreatment required was prechlorination for the oxidation of arsenic and iron. However, as noted in section 4.4.2, issues related to the chemical feed pump prevented chlorine from being added to the water before October 27, 2005. Specific chemical handling requirements are further discussed below under chemical handling and inventory requirements. The post-treatment included preexisting 29TMDM-300 softener system located after the pressure filters.

System Automation. All major functions of the treatment system were automated and required only minimal operator oversight and intervention if all functions were operating as intended. Automated processes included system startup in service mode when the well was energized, filter backwash and fast rinse based on a preset throughput value, and chemical feed. The flow-paced chemical feed pump, although automatically triggered by the contact meter, had to be frequently monitored for airlocks after it was repaired on October 27, 2005. Air bubbles in the pump head were discharged through an air bleed valve and a return line to the chemical day tank. No other issues arose with the automated backwash and associated equipment during this reporting period.

Operator Skill Requirements. Under normal operating conditions, the skill sets required to operate the Macrolite[®] pressure filtration system included maintaining proper operation of the process equipment; observing and recording associated operating parameters, such as pressure, flow, and chlorine residuals; keeping track of the NaClO solution consumption and replenishing the chemical day tank, when necessary; performing on-site chlorine residual measurements to help meet the target total chlorine residual after the pressure filters; and working with the vendor to troubleshoot and perform minor on-site repairs. Difficulties were encountered when trying to maintain proper operation of the chemical feed pump (as discussed in Section 4.4.2), taking the flow readings due to normally low on-demand flowrates and the oversized flow-meter installed (as discussed in Section 4.3.3), and performing routine on-site chlorine residual measurements. Because the certified operator retained by Vintage of the Ponds was located one and a half hours away from the site, all O&M activities were performed by the nursing home manager (referred to, in this report, as the operator), who had very little prior experience of operating a water treatment system.

According the plant operator, daily demand on the operator was about 5 min to visually inspect the system and record the operating parameters on the log sheets. There was additional time demand for troubleshooting and maintaining proper operation of the chemical feed system.

For operator certification in the state of Wisconsin, there is only one class and five subclasses, i.e., O, Z, I, L, and V, which are classified based on types of treatment (<http://dnr.wi.gov/org/es/science/opcert>). Subclass O certification is for those who operate general water treatment systems; Subclass Z for zeolite

and resin treatment; Subclass I for oxidation and filtration treatment; Subclass L for lime-soda ash treatment; and Subclass V for specialized treatment. The operator for Vintage on the Ponds has a Subclass O certificate. Each subclass requires a high school or equivalent diploma, at least two years of experience operating a water system prior to December 1, 2000, and successful completion of application and examination for that specific subclass.

Preventive Maintenance Activities. Preventive maintenance tasks recommended by the vendor included daily to monthly visual inspections of the piping, valves, tanks, flow meters, and other system components. Specific O&M activities performed by the vendor for this reporting period are summarized in Table 4-5.

Chemical/Media Handling and Inventory Requirements. With the assistance of the certified operator, all personal protective equipment, including neoprene rubber gloves, chemical safety goggles, a protective apron, and an emergency shower and eyewash station, was purchased by the facility, satisfying the safety requirements for the NaClO chemical handling as specified in the NaClO Material Safety Data Sheet (MSDS). The operator refilled the chemical day tank with a handheld pump to 15-gal every time the volume was down to 10-gal, which occurred approximately once every four weeks. Refilling the chlorine took about 10 min to complete. The chemical consumption in the day tank, along with total chlorine residuals in the filter effluent at the TT sampling location, were checked daily as part of the routine operational data collection as required by WDNR.

4.5 System Performance

The performance of the Macrolite[®] PM2162D6 Arsenic Removal System was evaluated based on analyses of water samples collected from the treatment plant, backwash lines, and distribution system.

4.5.1 Treatment Plant Sampling. Water samples were collected at five locations (i.e., IN, AC, TA, TB, and TT) across the treatment train. Table 4-6 summarizes the arsenic, iron, and manganese analytical results. Table 4-7 summarizes the results of the other water quality parameters. Appendix B contains a complete set of analytical results through the first six months of system operation. The results of the water samples collected throughout the treatment plant are discussed below.

Arsenic and Iron. The key parameter for evaluating the effectiveness of the Macrolite[®] filtration system was the concentration of total arsenic in the treated water. The treatment plant water was sampled on 27 occasions (including two duplicate sampling events) during this reporting period, with field speciation performed six times. Figure 4-15 shows the arsenic speciation results across the treatment train.

Total arsenic concentrations in source water ranged from 14.3 to 29.0 µg/L and averaged 18.3 µg/L (Table 4-6). As(III) was the predominant species in source water, ranging from 14.0 to 18.6 µg/L and averaging 16.7 µg/L. Only trace amounts of particulate arsenic and As(V) existed, with concentrations averaging 2.5 and 1.0 µg/L, respectively. An outlier existed on September 27, 2005, with total and particulate arsenic concentrations at 29.0 and 13.3 µg/L, respectively. The arsenic concentrations measured during this six-month period were consistent with those in source water sample collected on September 20, 2004 (Table 4-1).

Total iron concentrations in source water ranged from 1,165 to 2,478 µg/L and averaged 1,456 µg/L, which existed primarily in the soluble form with an average value of 1,377 µg/L. The iron:arsenic ratio was 78:1 given the average soluble iron and soluble arsenic levels in source water. An outlier existed on September 27, 2005, with total and particulate iron at 2,478 and 1,251 µg/L, respectively.

Among the six speciation sampling events, four speciation events had achieved the treatment goals of less than 10 µg/L of As and less than 25 µg/L of Fe. For the other two events occurring on September 27 and October 25, 2005, insufficient chlorine was added due to problems with the chlorine addition system,

Table 4-6. Summary of Arsenic, Iron, and Manganese Analytical Results With and Without Sufficient Chlorine Addition^(a)

Parameter	Sampling Location	Unit	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
As (total)	IN	µg/L	26 ^(b)	14.3	29.0	18.3	3.0
	AC	µg/L	18 [9]	15.1 [14.0]	22.8 [20.5]	18.1 [17.3]	2.0 [2.4]
	TA	µg/L	14 [7]	2.5 [8.1]	7.2 [19.9]	4.6 [13.3]	1.6 [4.9]
	TB	µg/L	14 [7]	2.5 [7.8]	6.8 [21.0]	4.4 [13.1]	1.6 [5.5]
	TT	µg/L	4 [2]	2.6 [12.7]	7.6 [16.7]	5.3 [14.7]	2.1 [2.8]
As (soluble)	IN	µg/L	4 [2]	17.5 [15.7]	19.2 [17.5]	18.3 [16.6]	0.8 [1.3]
	AC	µg/L	4 [2]	7.7 [12.6]	15.5 [15.1]	10.6 [13.9]	3.5 [1.8]
	TT	µg/L	4 [2]	2.6 [11.6]	7.7 [16.8]	5.4 [14.2]	2.2 [3.7]
As (particulate)	IN	µg/L	4 [2]	<0.1 [1.0]	0.7 [13.3]	0.2 [7.2]	0.3 [8.7]
	AC	µg/L	4 [2]	2.6 [3.2]	12.8 [4.9]	8.4 [4.0]	4.3 [1.3]
	TT	µg/L	4 [2]	<0.1 [0.1]	<0.1 [1.1]	<0.1 [0.6]	- [0.7]
As (III)	IN	µg/L	4 [2]	16.4 [14.0]	18.6 [17.2]	17.3 [15.6]	1.0 [2.3]
	AC	µg/L	4 [2]	4.1 [8.0]	9.7 [13.6]	6.1 [10.8]	2.5 [3.9]
	TT	µg/L	4 [2]	1.5 [9.9]	5.9 [15.1]	4.3 [12.5]	2.1 [3.7]
As (V)	IN	µg/L	4 [2]	0.6 [0.3]	1.2 [1.7]	0.9 [1.0]	0.2 [0.9]
	AC	µg/L	4 [2]	2.7 [0.05]	5.8 [7.1]	4.5 [3.6]	1.3 [5.0]
	TT	µg/L	4 [2]	0.5 [1.8]	1.8 [1.8]	1.1 [1.8]	0.5 [0.0]
Fe (total)	IN	µg/L	26 ^(b)	1165	2478	1456	242
	AC	µg/L	18 [9]	1237 [1232]	1905 [1602]	1402 [1443]	156 [131]
	TA	µg/L	14 [7]	<25 [537]	542 [1499]	107 [1039]	152 [420]
	TB	µg/L	14 [7]	<25 [448]	291 [1525]	90.3 [1010]	102 [467]
	TT	µg/L	4 [2]	<25 [834]	39.2 [1596]	<25 [1215]	13.4 [539]
Fe (soluble)	IN	µg/L	4 [2]	996 [1227]	1613 [1480]	1389 [1353]	272 [179]
	AC	µg/L	4 [2]	130 [12.5]	1120 [1131]	520 [578]	423 [791]
	TT	µg/L	4 [2]	<25 [832]	<25 [1417]	<25 [1125]	- [414]
Mn (total)	IN	µg/L	26 ^(b)	15.6	35.8	19.4	4.6
	AC	µg/L	18 [9]	15.7 [16.1]	20.3 [19.2]	18.3 [17.8]	1.2 [1.1]
	TA	µg/L	14 [7]	15.8 [15.9]	19.2 [19.5]	17.7 [17.4]	1.1 [1.2]
	TB	µg/L	14 [7]	15.4 [15.8]	19.7 [19.7]	17.9 [17.5]	1.3 [1.3]
	TT	µg/L	4 [2]	16.2 [19.2]	20.4 [21.0]	18.7 [20.1]	1.8 [1.2]
Mn (soluble)	IN	µg/L	4 [2]	17.0 [19.2]	20.2 [19.5]	19.2 [19.3]	1.5 [0.2]
	AC	µg/L	4 [2]	16.3 [11.8]	19.2 [18.7]	18.2 [15.2]	1.4 [4.9]
	TT	µg/L	4 [2]	16.2 [20.8]	20.6 [20.8]	19.0 [20.8]	2.0 [0.0]

(a) Numbers in parentheses representing data compiled from sampling events having problems with chlorine addition system on 08/30/05, 09/06/05, 09/13/05, 09/27/05, 10/04/05, 10/11/05, 10/18/05, and 10/25/05.

(b) For samples taken on August 30, 2005, total arsenic, iron, and manganese at IN location not available.

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

Duplicate samples are included in calculations.

Table 4-7. Summary of Analytical Results of Other Water Quality Parameters

Parameter	Sampling Location	Units	Number of Samples	Minimum Concentration	Maximum Concentration	Average Concentration	Standard Deviation
Alkalinity	IN	mg/L	27	330	374	358	10.4
	AC	mg/L	27	334	374	360	10.5
	TA	mg/L	21	352	374	362	8.3
	TB	mg/L	21	348	392	364	10.7
	TT	mg/L	6	352	374	359	9.1
Ammonia	IN	mg/L	9	2.9	3.2	3.0	0.1
	AC	mg/L	8	2.7	3.0	2.9	0.1
	TA	mg/L	7	2.7	3.2	2.9	0.2
	TB	mg/L	7	2.8	3.1	2.9	0.1
	TT	mg/L	1	2.9	2.9	2.9	NA
Fluoride	IN	mg/L	9	0.2	0.3	0.2	0.0
	AC	mg/L	9	0.2	0.3	0.2	0.0
	TA	mg/L	3	0.2	0.3	0.2	0.0
	TB	mg/L	3	0.2	0.3	0.2	0.0
	TT	mg/L	6	0.2	0.2	0.2	0.0
Sulfate	IN	mg/L	9	<1	<1	<1	0.0
	AC	mg/L	9	<1	<1	<1	0.0
	TA	mg/L	3	<1	<1	<1	0.0
	TB	mg/L	3	<1	<1	<1	0.0
	TT	mg/L	6	<1	<1	<1	0.0
Total P (as P)	IN	µg/L	14	<10	84.5	65.4	19.3
	AC	µg/L	14	<10	92.1	64.5	21.0
	TA	µg/L	11	<10	41.2	8.3	10.9
	TB	µg/L	11	<10	35.8	8.6	9.4
	TT	µg/L	3	<10	14.2	8.1	5.3
Silica (as SiO ₂)	IN	mg/L	27	13.0	16.6	14.4	0.8
	AC	mg/L	27	13.0	16.8	14.4	0.8
	TA	mg/L	21	13.3	16.8	14.5	0.7
	TB	mg/L	21	13.1	16.2	14.3	0.7
	TT	mg/L	6	13.1	16.0	14.4	1.0
Nitrate (as N)	IN	mg/L	9	<0.05	0.11	0.04	0.03
	AC	mg/L	9	<0.05	0.11	0.05	0.03
	TA	mg/L	3	<0.05	0.17	0.09	0.07
	TB	mg/L	3	<0.05	0.24	0.10	0.12
	TT	mg/L	6	<0.05	0.15	0.05	0.05
Turbidity	IN	NTU	27	10.0	20.0	16.2	2.5
	AC	NTU	27	1.7	18.0	6.2	5.4
	TA	NTU	21	<0.1	20.4	5.8	7.3
	TB	NTU	21	<0.1	19.0	5.5	7.1
	TT	NTU	6	<0.1	20.0	5.4	8.4

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

Parameter	Sampling Location	Units	Sample Count	Minimum Concentration	Maximum Concentration	Average Concentration	Standard Deviation
pH	IN	S.U.	24	7.2	8.1	7.5	0.2
	AC	S.U.	24	7.2	8.0	7.5	0.2
	TA	S.U.	19	7.3	8.0	7.5	0.2
	TB	S.U.	19	7.3	8.1	7.5	0.2
	TT	S.U.	5	7.4	7.7	7.5	0.1
Temperature	IN	°C	24	11.8	16.3	13.9	1.1
	AC	°C	24	10.9	16.0	13.6	1.1
	TA	°C	19	11.6	15.5	13.5	1.0
	TB	°C	19	11.2	15.3	13.5	1.3
	TT	°C	5	13.0	15.4	14.0	0.9
Total Hardness (as CaCO ₃)	IN	mg/L	6	295	510	346	81.6
	AC	mg/L	6	281	338	311	21.7
	TT	mg/L	6	283	333	315	20.5
Ca Hardness (as CaCO ₃)	IN	mg/L	6	147	260	181	40.1
	AC	mg/L	6	143	184	164	16.8
	TT	mg/L	6	143	177	166	15.6
Mg Hardness (as CaCO ₃)	IN	mg/L	6	141	250	165	42.1
	AC	mg/L	6	138	156	147	7.7
	TT	mg/L	6	141	156	149	7.2

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

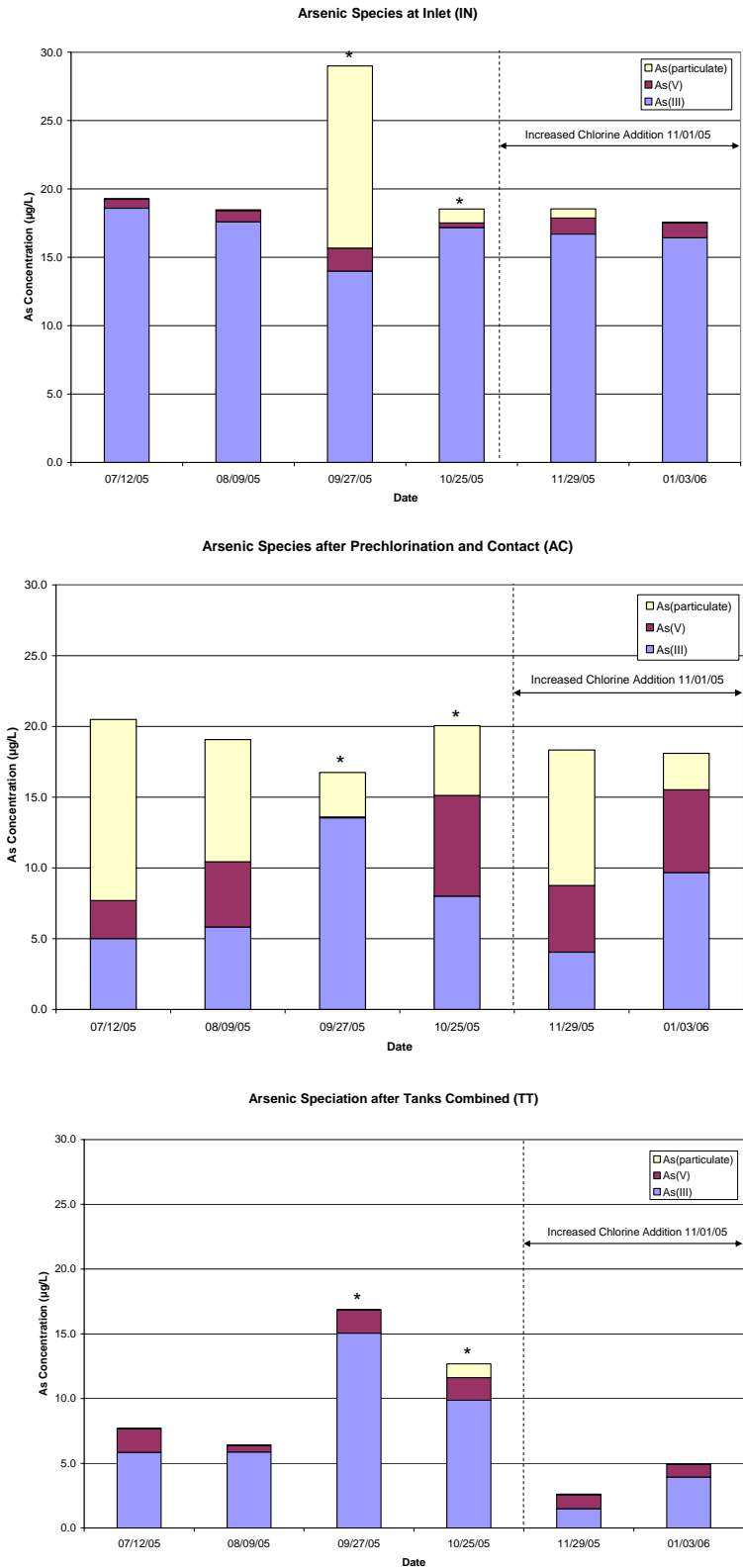
Duplicate samples included in calculations.

resulting in elevated soluble Fe and As concentrations after treatment. For example, total arsenic concentrations at the TT location were 16.6 and 12.7 µg/L, most of which existed as As(III), i.e., 15.1 and 9.9 µg/L, respectively. The corresponding total iron concentrations were 1,596 and 834 µg/L, and the soluble iron concentrations were 1,417 and 832 µg/L.

For the four events meeting the treatment goals, As(III) concentrations after the contact tank were reduced to 5.0, 5.8, 4.1 and 9.7 µg/L, respectively, and averaged 6.2 µg/L. This average As(III) concentration corresponded to a 63% conversion rate based on 16.7 µg/L of As(III) (on average) in raw water. The As(III) concentrations after filtration were 5.8, 5.9, 1.5, and 3.9 µg/L, respectively, and averaged 4.3 µg/L, suggesting that additional As(III) oxidation (i.e., 11%) might have occurred in the filters. The particulate arsenic levels at the TT location remained <0.1 µg/L.

The addition of chlorine decreased As(III) concentrations and increased particulate arsenic concentrations after the contact tank. The conversion of As(III) to As(V) after the contact tank, however, was not as significant as those observed at many other demonstration sites, where As(III) was almost completely converted to either As(V) and/or particulate arsenic (Condit and Chen et al., 2006). Most of these sites had little or no ammonia in raw water, suggesting that presence of ammonia in the Vintage's raw water might have impacted the effectiveness of As(III) oxidation. Ghurye and Clifford (2001) reported that pre-formed monochloramines were ineffective for As(III) oxidation and that limited oxidation could be obtained when monochloramine was formed in situ. The injected chlorine probably reacted with As(III) before being quenched by ammonia to form chloramines.

Incomplete iron oxidation also was observed after the contact tank. For the four speciation events where total iron was removed to less than 25 µg/L after filtration, soluble iron concentrations were measured at



* Chlorine feed system not in good working condition

Figure 4-15. Concentrations of Arsenic Species at IN, AC, and TT Sampling Locations

130, 385, 444, and 1,120 µg/L, respectively, after the contact tank. These elevated soluble iron concentrations suggested that prolonged contact times might be needed to completely oxidize Fe(II) when monochloramine was formed in situ (Vikesland and Valentine, 2002). After filtration, total iron concentrations were <25 µg/L (except for one at 39 µg/L) and soluble iron concentrations were all below 25 µg/L. The data further suggested the possibility of slower but continuing oxidation of iron after the contact tank, similar to As(III) oxidation. Particulate As in the treated water was below the detection limit (i.e., < 0.1 µg/L), indicating the complete removal of iron particles by the pressure filters.

From July 12, 2005 to January 17, 2006, total arsenic concentrations in the filter effluent exceeded the 10 µg/L MCL in seven out of 25 sampling events, all of which were probably due to improper chlorine addition (see Figure 4-16). As expected, elevated total arsenic concentrations were associated directly with elevated total iron concentrations in the treated water (see Figure 4-16 and 4-17).

Manganese. Total manganese levels in source water ranged from 15.6 to 35.8 µg/L and averaged 19.4 µg/L, which were below Secondary Maximum Contaminant Level (SMCL) of 50 µg/L (see Table 4-6). Manganese in source water existed primarily in the soluble form at levels ranging from 17.0 to 20.2 µg/L and averaging 19.3 µg/L. For the two speciation events without proper chlorine addition, soluble manganese concentrations after the contact tank ranged from 11.8 to 18.7 µg/L and averaged 15.2 µg/L. For the four speciation events with proper chlorine addition, soluble manganese concentrations after the contact were at similar levels, ranging from 16.3 to 19.2 µg/L and averaged 18.2 µg/L. Therefore, chloramines formed during prechlorination apparently were ineffective for Mn(II) oxidation.

Manganese after chlorination remained in the soluble form, which was not filtered out by the Macrolite[®] filters. Soluble manganese in the treated water was measured at levels averaging 20.8 µg/L for the sampling events without proper chlorine addition and 19.0 µg/L with proper chlorine addition (Figure 4-18). The results again suggested ineffective oxidation of Mn(II) by chloramines.

Other Water Quality Parameters. In addition to arsenic, iron, and manganese analyses, other water quality parameters were analyzed to provide insight into the chemical processes occurring with the treatment systems. As shown in Table 4-7, ammonia concentrations in source water ranged from 2.9 to 3.2 mg/L (as N) and averaged 3.0 mg/L (as N). The maximum amount of ammonia removed upon chlorination, as calculated by subtracting the maximum concentration in raw water by the minimum concentration in AC, TA, TB, or TT, was 0.5 mg/L [as N], which would result in 2.5 mg/L of total (or combined) chlorine (as Cl₂) in treated water. Based on the average amount of ammonia removed, i.e., 0.1 mg/L (as N) as shown in Table 4-7, only 0.5 mg/L of total (or combined) chlorine would be formed. This level of residuals was within the range of actual measurements (see Figure 4-14). Although not monitored, the majority of ammonia at the TT location was expected to be removed by the downstream softener before entering the distribution system.

Average total hardness results ranged from 311 to 346 mg/L (as CaCO₃) across the treatment train; total hardness is the sum of calcium hardness and magnesium hardness. The water had an almost equal split between calcium and magnesium hardness. Fluoride concentrations ranged from 0.2 to 0.3 mg/L in source water and after contact tank and were not affected by the Macrolite[®] filtration. Average nitrate concentrations ranged from 0.04 to 0.1 mg/L (as N) and average total phosphorus concentrations ranged from <10 to 41.2 µg/L (as P) across the treatment train. Silica (as SiO₂) concentration remained at approximately 14.4 mg/L across the treatment train. Turbidity values ranged from 10.0 to 20.0 nephelometric turbidity units (NTU) (averaged 16.2 NTU) in source water to <0.1 to 20.0 NTU (averaged 5.4 NTU) in the combined filter effluent. No significant levels of sulfate were detected in source water or across the treatment train.

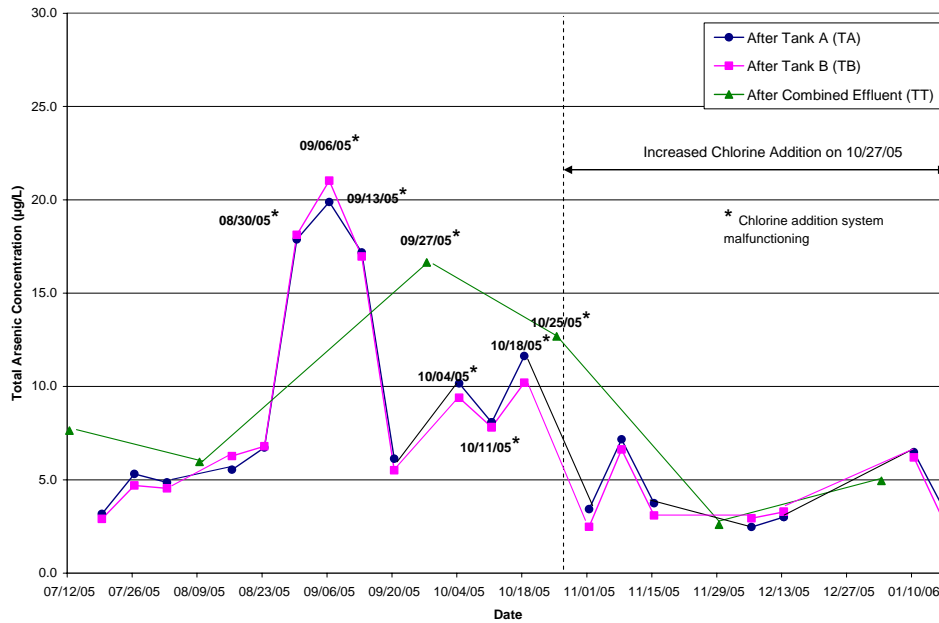


Figure 4-16. Total Arsenic Concentrations at TA, TB, and TT Sampling Location

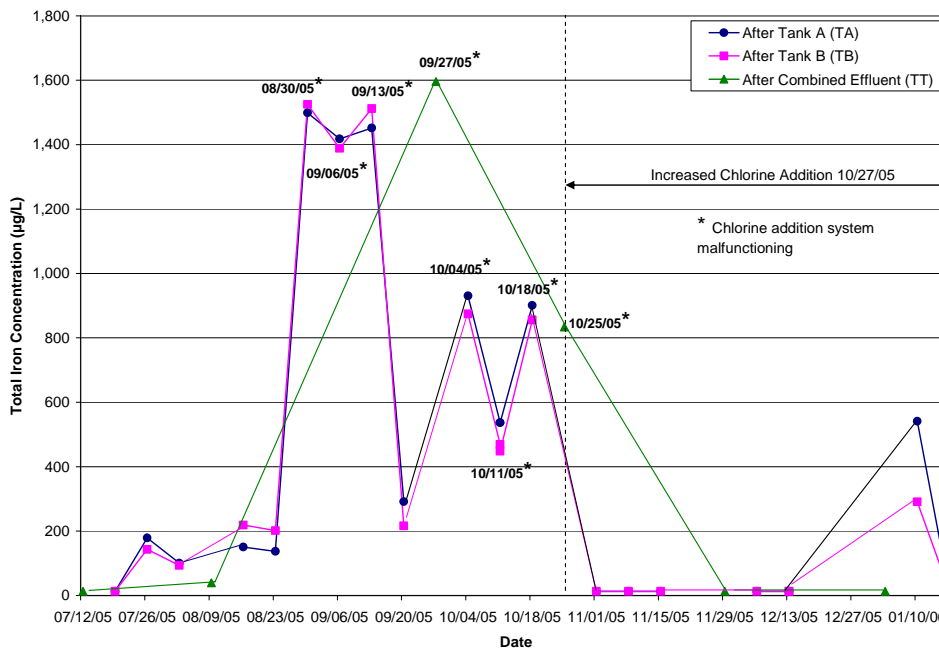


Figure 4-17. Total Iron Concentrations at TA, TB, and TT Sampling Locations

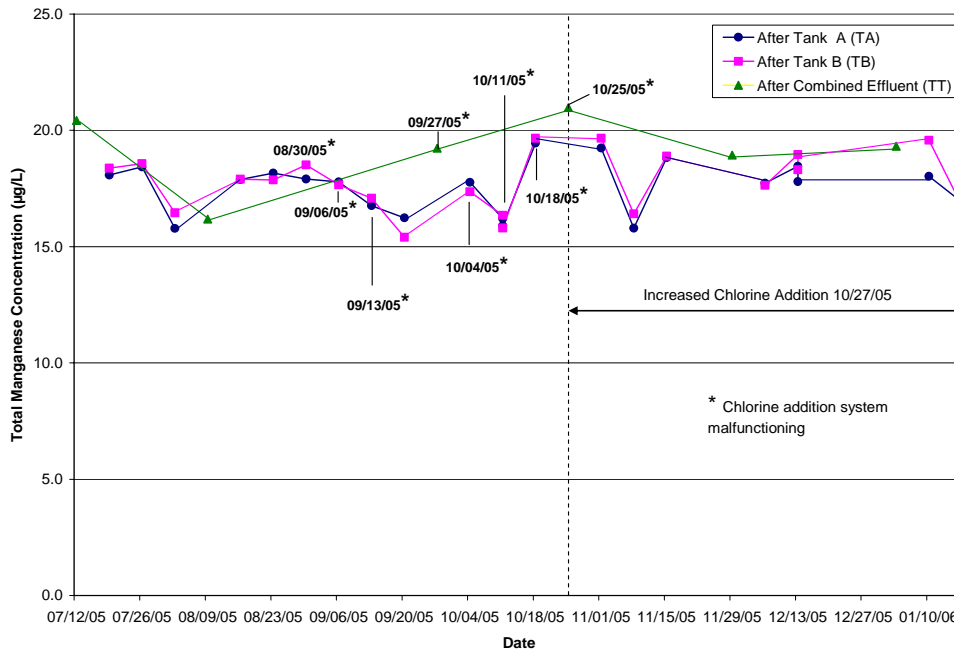


Figure 4-18. Total Manganese Concentrations at TA, TB, and TT Sampling Locations

4.5.2 Backwash Water Sampling. Table 4-8 summarizes the analytical results from three backwash water sampling events which took place on September 20, 2005, October 11, 2005, and January 10, 2006. Backwash water sampling also was performed on November 29, 2005; however, due to three consecutive backwash cycles inadvertently triggered by the operator prior to sampling, the samples collected were not analyzed. For the first two sampling events, grab samples were taken for pH, turbidity, TDS, and soluble arsenic, iron, and manganese analyses. The analytical results showed 6.3 to 12.2 µg/L of soluble arsenic, <25 to 593 µg/L of soluble iron, and 14.9 to 22.6 µg/L of soluble manganese, which were similar to those in the contact tank water used for backwash.

For the third sampling event (and those taking place after November 29, 2005), composite samples were taken for pH, turbidity, TDS, TSS, and total and soluble arsenic, iron, and manganese analyses. Total arsenic concentrations in the backwash water ranged from 46 to 121 µg/L; total iron concentrations ranged from 4,486 to 13,543 µg/L; and total manganese concentrations ranged from 22 to 26 µg/L. The TSS levels in the backwash water were low, ranging from 5 to 12 mg/L. The uncharacteristically low TSS levels in the backwash water samples were thought to have been caused, and confirmed by the operator, by insufficient mixing of solids/water mixtures in the 32-gal container before sampling. The operator believed, however, that the contents in the containers were thoroughly mixed before sampling for total arsenic, iron, and manganese. Assuming 300 gal of backwash water generated per vessel, about 2.1×10^{-4} lb of arsenic, 0.02 lb of iron, and 6.0×10^{-5} lb of manganese were discharged into the septic system during each backwash event.

4.5.3 Distribution System Water Sampling. The results of distribution system water sampling are summarized in Table 4-9. As shown in the table, the stagnation times before the samples were taken ranged from 7.0 to 11.0 hr and averaged 9.3 hr. There was no major change in pH values before (i.e., 7.1 to 7.6) and after (i.e., 7.1 to 7.8) the system became operational. Alkalinity levels also remained approximately the same before (i.e., 330 to 395 mg/L [as CaCO₃]) and after (i.e. 352 to 374 mg/L [as CaCO₃]) treatment system startup.

Table 4-8. Backwash Water Sampling Results

Sampling Event		Vessel A											Vessel B										
		pH	Turbidity	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)	pH	Turbidity	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)
No.	Date	S.U.	NTU	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	S.U.	NTU	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
1	09/20/05	7.5	150	358	NS	NS	7.0	NS	NS	<25	NS	14.9	7.5	20.0	356	NS	NS	6.3	NS	NS	<25	NS	15.0
2	10/11/05	7.3	68.0	386	NS	NS	7.9	NS	NS	593	NS	22.6	7.5	4.5	332	NS	NS	12.2	NS	NS	116	NS	15.3
3	01/10/06 ^(a)	7.5	NS	320	12	121	6.7	114	13,543	141	25.7	20.6	7.7	NS	304	5	45.5	9.6	35.9	4,486	223	22.1	20.1

(a) Vessel B backwashed twice.
TDS = total dissolved solids
NS = not sampled

Arsenic concentrations in the baseline samples ranged from 9.5 to 18.2 µg/L and averaged 15.2 µg/L. These values were slightly lower than those in the historical raw water samples (i.e. from 16.0 to 25.0 µg/L) shown in Table 4-1, and those in the samples collected after system startup from August 30 through September 28, 2005 (i.e., Events 2 to 4) when the chlorine addition system did not function properly (i.e., from 11.9 to 23.3 µg/L). For the samples collected with proper operation of the chlorine addition system (i.e., Events 1, 5, 6, and 7), arsenic concentrations decreased to less than 10 µg/L at each of the three sampling locations, except for two outliers at DS1 on December 13, 2005 and January 17, 2006. In all cases, total arsenic levels in the distribution system mirrored those in the treated water. The average arsenic level in the distribution system (excluding the data points taken during Events 2 to 4 and Events 6 and 7 at DS1) was slightly higher than at the entry point (i.e., 4.3 versus 3.4 µg/L), suggesting some solubilization, destabilization, and/or desorption of arsenic-laden particles/scales in the distribution system (Lytle, 2005).

Iron concentrations remained below the method detection limit of 25 µg/L, except for one outlier at 37.3 µg/L before and after the baseline samples. Before system startup, iron, existing mostly in the soluble form, was removed by the softeners before entering the distribution system. After system startup, iron, existing mostly in the particulate form, was removed by the Macrolite[®] pressure filters. The manganese levels averaged 1.7 µg/L in the baseline samples and decreased to an average of 0.4 µg/L after system startup. Although little manganese was removed by the pressure filter, manganese at 19.4 µg/L (on average) existing almost entirely in the soluble form, was removed by the downstream softeners.

Lead levels in the distribution system ranged from less than the method reporting limit of 0.1 µg/L to 5.4 µg/L both before and after system startup. Copper concentrations before system startup ranged from 4.1 to 126 µg/L; copper concentrations after system startup ranged from 4.7 to 160 µg/L. None of the lead and copper results exceeded the corresponding action levels of 15 and 1,300 µg/L. Factors that may increase the solubility of lead and copper in the distribution system include low pH, high temperature, and soft water with fewer dissolved minerals. The arsenic removal system did not appear to have exerted any impact on the lead and copper levels in the distribution system.

4.6 System Cost

The cost of the system was evaluated based on the capital cost per gpm (or gpd) of design capacity and the O&M cost per 1,000 gal of water treated. The evaluation required the tracking of the capital cost for equipment, engineering, and installation and the O&M cost for chemical supply, electrical power use, and labor. However, the cost associated with the installation of an emergency shower and an eyewash station required for NaClO chemical handling as part of building improvements was paid for by Vintage on the Ponds and, therefore, not included in the treatment system.

4.6.1 Capital Cost. The capital investment was \$60,500, which included \$19,790 for equipment, \$20,580 for site engineering, and \$20,130 for installation. Table 4-10 presents the breakdown of the capital cost provided by the vendor in its proposal to Battelle dated March 15, 2005. The equipment cost was about 33% of the total capital investment for a contact tank, two pressure filtration tanks, Macrolite[®] media, distributors, process valves and piping, instrumentation and controls, a chemical feed system (including a flow-paced pump and a tapered chemical storage tank with a secondary containment), additional sample taps, totalizer/meters, shipping, and equipment assembly labor.

The engineering cost included the cost for preparing a process design report and required engineering plans, including a general arrangement drawing, piping and instrumentation diagrams (P&IDs), interconnecting piping layouts, tank fill details, an electrical on-line diagram, and other associated drawings. After certification by an Ohio-registered professional engineer, the plans were submitted to

Table 4-9. Distribution Sampling Results

No. of Sampling Events	Sample Location		DS1 ^(a)								DS2 ^(a)						DS3 ^(a)									
			Second Floor Suite								Shower Room A Wing						Large Suite B Wing									
	Sample Date	Total As at Entry Point (µg/L)	Stagnation Time (hr)	pH (S.U.)	Alkalinity (mg/L as CaCO ₃)	Total As (µg/L)	Total Fe (µg/L)	Total Mn (µg/L)	Pb (µg/L)	Cu (µg/L)	Stagnation Time (hr)	pH (S.U.)	Alkalinity (mg/L as CaCO ₃)	Total As (µg/L)	Total Fe (µg/L)	Total Mn (µg/L)	Pb (µg/L)	Cu (µg/L)	Stagnation Time (hr)	pH (S.U.)	Alkalinity (mg/L as CaCO ₃)	Total As (µg/L)	Total Fe (µg/L)	Total Mn (µg/L)	Pb (µg/L)	Cu (µg/L)
BL1	03/23/05 ^(b)	NA	7.0	7.1	362	18.2	<25	0.7	0.2	95.2	NA	7.2	367	14.8	37.3	14.2	5.4	126.0	NA	7.2	376	17.1	<25	0.6	0.8	93.3
BL2	04/20/05	NA	11.0	7.6	386	14.7	<25	0.4	<0.1	51.9	11.0	7.6	395	15.6	<25	0.1	0.1	13.8	11.0	7.6	382	16.8	<25	0.1	0.4	38.2
BL3	05/31/05	NA	NA	7.2	381	9.5	<25	0.2	0.4	103.4	NA	7.3	385	14.8	<25	<0.1	<0.1	4.4	NA	7.3	381	15.2	<25	<0.1	0.5	77.1
BL4	06/21/05	NA	9.2	7.5	330	13.9	<25	0.2	0.1	15.2	9.1	7.5	365	18.0	<25	0.2	<0.1	13.9	9.3	7.5	361	14.3	<25	0.5	0.1	4.1
1	07/27/05 ^(d)	5.0	9.0	7.4	352	5.9	<25	0.3	1.1	111.0	9.0	7.4	361	5.4	<25	<0.1	0.1	7.2	9.0	7.4	352	6.6	<25	<0.1	0.2	17.9
2	08/30/05 ^(d)	18.0	9.3	7.1	361	18.0	<25	<0.1	<0.1	29.6	9.0	7.3	370	18.2	<25	0.2	0.1	6.6	9.2	7.2	352	16.2	<25	0.3	0.4	38.4
3	09/28/05 ^(d)	16.6	10.0	7.3	365	11.9	<25	0.1	0.9	57.9	9.3	7.3	374	16.9	<25	0.4	0.6	23.6	9.3	7.4	374	17.1	<25	0.2	1.0	49.2
4	10/18/05 ^(d)	10.9	9.0	7.4	360	15.5	<25	<0.1	0.3	33.1	9.2	7.4	365	16.9	<25	<0.1	<0.1	4.7	9.0	7.4	361	23.3	<25	0.1	0.4	14.2
5	11/29/05	2.6	9.2	7.5	352	6.9	<25	0.3	0.3	54.6	9.1	7.7	352	3.6	<25	0.1	0.2	23.5	9.0	7.6	352	7.5	<25	0.4	1.7	45.7
6	12/13/05	3.2	9.2	7.7	370	18.6 ^(c)	<25	<0.1	0.2	49.8	9.0	7.5	365	6.7	<25	0.2	0.5	29.0	9.1	7.8	374	6.2	<25	0.2	0.8	41.9
7	01/17/06	2.9	9.6	7.4	365	17.7 ^(c)	<25	0.3	0.9	95.7	9.7	7.5	356	3.1	<25	<0.1	0.5	160	9.8	7.5	356	8.8	<25	0.4	2.5	38.6

(a) Samples taken after softeners.

(b) DS1 sampled at dining room.

(c) Samples reanalyzed but showing similar results.

(d) Sampling events taking place when chlorine addition system did not function properly.

NA = not analyzed; BL = baseline sampling

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

µg/L as unit except for pH (S.U.) and alkalinity (mg/L [as CaCO₃])

Table 4-10. Summary of Capital Investment for the Vintage on the Ponds Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
<i>Equipment Cost</i>			
Tanks	3	\$2,500	–
Media	3.5 ft ³ /tank	\$1,540	–
Distributors	2	\$175	–
Process Valves and Piping	1	\$2,100	–
Chemical Feed System	1	\$2,405	–
Instrumentation and Controls	1	\$2,500	–
Additional Flow meters/Totalizers	1	\$2,400	–
Shipping	–	\$1,000	–
Labor	–	\$5,170	–
Equipment Total	–	\$19,790	33%
<i>Engineering Cost</i>			
Labor	–	\$19,080	–
Travel	–	\$1,500	–
Engineering Total	–	\$20,580	34%
<i>Installation Cost</i>			
Labor	–	\$6,380	–
Travel	–	\$2,500	–
Subcontractor	–	\$11,250	–
Installation Total	–	\$20,130	33%
Total Capital Investment	–	\$60,500	100%

WDNR for permit review and approval (Section 4.3.1). The engineering cost was \$20,580, which was 34% of the total capital investment.

The installation cost included the cost for labor and materials for system unloading and anchoring, plumbing, and mechanical and electrical connections (Section 4.3.3). The installation cost was \$20,130 or 33% of the total capital investment.

Using the system’s rated capacity of 45 gpm (or 64,800 gpd), the capital cost was normalized to be \$1,344/gpm (or \$0.93/gpd). The capital cost of \$60,500 was converted to an annualized cost of \$5,710/year using a capital recovery factor of 0.09439 based on a 7% interest rate and a 20-year return. Assuming that the system was operated 24 hours a day, 7 days a week at the design flow rate of 45 gpm to produce 23,600,000 gal of water per year, the unit capital cost would be \$0.24/1,000 gal. However, since the system produced only 1,031,200 gal of water during the six-month period, the unit capital cost was increased to \$2.77/1,000 gal at this reduced rate of production.

4.6.2 Operation and Maintenance Cost. O&M cost includes primarily cost associated with chemical supply, electricity consumption, and labor (Table 4-11). The consumption rate for the 12.5% NaClO stock solution was approximately 80 gal or 79.5 lb per year. Incremental electricity power consumption was calculated for the chemical feed pump. The power demand was calculated based on the total operational hours of the well pump during the six-month study, the additional power demand needed to cover the pressure loss across the filter beds, the chemical feed pump horsepower, and the unit cost from the utility bills. The routine, non-demonstration related labor activities consumed about 5 min/day, 5 days a week, as noted in Section 4.4.4. Based on this time commitment and a labor rate of \$10.75/hr, the labor cost was \$0.11/1,000 gal of water treated. In summary, the total O&M cost was approximately \$0.33/1,000 gal. The O&M cost will be verified during the next reporting period.

Table 4-11. O&M Cost for the Vintage on the Ponds Treatment System

Cost Category	Value	Assumption
Projected Volume Processed (gal)	1,031,200	From 07/12/05 through 01/17/06 (see Table 4-4)
<i>Chemical Cost</i>		
Chemical Unit Price (\$/gal)	\$4.14	12.5% NaClO in a 5-gal drum
Total Chemical Consumption (gal)	40	80 gal or 79.5 lb of NaClO per year
Chemical Usage (gal/1,000 gal)	0.04	
Total Chemical Cost (\$)	\$165.40	
Unit Chemical Cost (\$/1,000 gal)	\$0.16	
<i>Electricity Cost</i>		
Electricity Unit Cost (\$/kwh)	0.067	
Estimated Electricity Usage (kwh)	1,041	Calculated based on: <ul style="list-style-type: none"> • 16 hr/day of operation of a 0.17-hp chemical feed pump • Additional power used by well pump to overcome pressure loss across filters with pumps operating 2.4 hr/day at 40 gpm
Estimated Electricity Cost (\$)	\$69.7	
Estimated Power Use (\$/1,000 gal)	\$0.067	
<i>Labor Cost</i>		
Average Weekly Labor (hr)	0.42	5 min/day; 5 day/wk
Total Labor (hr)	11	26 weeks
Total Labor Cost (\$)	\$118.25	Labor rate = \$10.75/hr
Labor Cost (\$/1,000 gal)	\$0.11	
Total O&M Cost/1,000 gal	\$0.33	

5.0 REFERENCES

- Battelle. 2004. *Revised Quality Assurance Project Plan for Evaluation of Arsenic Removal Technology*. Prepared under Contract No. 68-C-00-185, Task Order No. 0029, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- 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.
- Clark, J.W., W. Viessman, and M.J. Hammer. 1977. *Water Supply and Pollution Control*. IEP, a Dun-Donnelley Publisher, New York, NY.
- Condit, W.E. and A.S.C. Chen. 2006. Arsenic Removal from Drinking Water by Iron Removal, U.S. EPA Demonstration Project at Climax, MN, Final Performance Evaluation Report. Prepared under Contract No. 68-C-00-185, Task Order No. 0019 for 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." *J. AWWA*, 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, DC.
- EPA. 2003. Minor Clarification of the National Primary Drinking Water Regulation for Arsenic. *Federal Register*, 40 CFR Part 141.
- Ghurye, G.. and D. Clifford. 2001. *Laboratory Study on the Oxidation of Arsenic III to Arsenic V*. EPA/600/R-01/021. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Lytle, D. 2005. *Coagulation/Filtration: Iron Removal Processes Full-Scale Experience*. EPA Workshop on Arsenic Removal from Drinking Water in Cincinnati, OH.
- Sorg, T.J. 2002. "Iron Treatment for Arsenic Removal Neglected." *Opflow*, AWWA, 28(11):15.
- Vikesland, P.J. and R.L. Valentine. 2002. "Modeling the Kinetics of Ferrous Iron Oxidation by Monochloramine." *Environ. Sci. and Technol.* 36(4):662-668.
- 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. Daily System Operation Log Sheet

Week No.	Date	Time	Volume to Treatment		Pressure					Volume to Distribution		Backwash			NaOCl Application	
			Totalizer (gal)	Incremental Volume (gal)	Pressure Tanks (psi)	After Contact Tank (psi)	After Filters (psi)	ΔP across System (psi)	ΔP across Filters (psi)	Totalizer (kgal)	Incremental Volume (gal)	Totalizer (gal)	Wastewater Produced (gal)	Throughput Between Backwash Cycles (gal)	NaOCl Tank Level (gal) ^(c)	Average Cl ₂ Dose (mg/L)
1	07/13/05	15:00	84,200	NA	NM	39	30	NA	9	13,967.2	NA	3,650	NA	NA	1.00	NA
	07/14/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
	07/15/05	14:30	93,100	8,900	NM	49	40	NA	9	13,976.1	8,900	3,650	0	NA	0.30	1.7
	07/16/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
	07/17/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
2	07/18/05	14:15	109,900	16,800	NM	39	30	NA	9	13992.4	16,300	4,020	370	NA	0.30	0.9
	07/19/05	13:20	116,300	6,400	NM	49	29	NA	20	13998.7	6,300	4,020	0	NA	0.30	2.4
	07/20/05	15:00	120,000	3,700	NM	41	36	NA	5	14002.0	3,300	4,370	350	10,100	0.20	2.7
	07/21/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
	07/22/05	14:00	132,800	12,800	NM	42	37	NA	5	14014.7	12,700	4,370	0	NA	0.30	1.2
	07/23/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
	07/24/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
3	07/25/05	16:30	151,500	18,700	NM	43	31	NA	12	14032.9	18,200	4,730	360	31,500	0.50	1.3
	07/26/05	16:40	156,600	5,100	NM	43	31	NA	12	14037.9	5,000	4,730	0	NA	0.10	1.0
	07/27/05	15:30	160,800	4,200	NM	41	29	NA	12	14042.1	4,200	4,730	0	NA	0.10	1.2
	07/28/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
	07/29/05	09:35	169,900	9,100	NM	39	17	NA	22	14050.8	8,700	5,090	360	18,400	0.19	1.1
	07/30/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
	07/31/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
4	08/01/05	15:10	188,800	18,900	NM	39	38	NA	1	14,069.4	18,600	5,090	0	NA	NM	NA
	08/02/05	13:00	194,600	5,800	NM	41	33	NA	8	14,074.8	5,400	5,440	350	24,700	NM	NA
	08/03/05	13:30	199,300	4,700	NM	43	25	NA	18	14,079.5	4,700	5,440	0	NA	NM	NA
	08/04/05	12:40	203,700	4,400	NM	43	30	NA	13	14,083.8	4,300	5,440	0	NA	NM	NA
	08/05/05	15:03	208,500	4,800	NM	41	30	NA	11	14,088.6	4,800	5,440	0	NA	NM	NA
	08/06/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
	08/07/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
5	08/08/05	16:05	223,900	15,400	NM	42	29	NA	13	14,103.5	14,900	5,790	350	29,300	0.30	1.0
	08/09/05	14:05	234,500	10,600	NM	39	12	NA	27	14,114.0	10,500	5,790	0	NA	0.30	1.4
	08/10/05	15:30	241,200	6,700	NM	49	31	NA	18	14,120.2	6,200	6,150	360	17,300	0.10	0.8
	08/11/05	14:00	246,200	5,000	NM	48	32	NA	16	14,125.2	5,000	6,150	0	NA	NM	NA
	08/12/05	15:05	251,200	5,000	NM	39	22	NA	17	14,130.1	4,900	6,150	0	NA	0.10	1.0
	08/13/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
	08/14/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
6	08/15/05	16:05	268,300	17,100	NM	43	23	NA	20	14,146.6	16,500	6,500	350	27,100	0.40	1.2
	08/16/05	14:30	273,000	4,700	NM	39	20	NA	19	14,151.7	5,100	6,500	0	NA	0.20	2.1
	08/17/05	14:35	278,500	5,500	NM	44	24	NA	20	14,156.8	5,100	6,500	0	NA	0.20	1.8
	08/18/05	08:00	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	0.10	NA
	08/19/05	13:00	288,900	10,400	NM	39	28	NA	11	14,166.8	10,000	6,860	360	20,600	0.10	0.5
	08/20/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
	08/21/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
7	08/22/05	15:50	305,400	16,500	NM	42	23	NA	19	14,183.1	16,300	6,860	0	NA	0.20	0.6
	08/23/05	15:35	310,900	5,500	NM	43	23	NA	20	14,188.2	5,100	7,220	360	22,000	0.00	0.0
	08/24/05	10:00	314,100	3,200	NM	44	24	NA	20	14,191.3	3,100	7,220	0	NA	0.00	0.0
	08/25/05	NM	NM	NA	NM	39	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
	08/26/05	15:15	326,100	12,000	NM	40	21	NA	19	14,203.2	11,900	7,220	0	NA	0.00	0.0
	08/27/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
	08/28/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA

Table A-1. Daily System Operation Log Sheet (Continued)

Week No.	Date	Time	Volume to Treatment		Pressure					Volume to Distribution		Backwash			NaOCl Application	
			Totalizer (gal)	Incremental Volume (gal)	Pressure Tanks (psi)	After Contact Tank (psi)	After Filters (psi)	ΔP across System (psi)	ΔP across Filters (psi)	Totalizer (kgal)	Incremental Volume (gal)	Totalizer (gal)	Wastewater Produced (gal)	Throughput Between Backwash Cycles (gal)	NaOCl Tank Level (gal) ^(c)	Average Cl ₂ Dose (mg/L)
8	08/29/05	15:40	343,600	17,500	NM	39	21	NA	18	14,220.2	17,000	7,570	350	32,700	0.00	0.0
	08/30/05	16:40	349,300	5,700	NM	44	24	NA	20	14,225.8	5,600	7,570	0	NA	0.00	0.0
	08/31/05 ^(a)	15:30	354,100	4,800	47	40	23	24	17	14,230.6	4,800	7,570	0	NA	0.00	0.0
	09/01/05	13:15	358,200	4,100	55	48	24	31	24	14,234.3	3,700	7,920	350	14,600	0.00	0.0
	09/02/05	16:15	364,600	6,400	48	40	21	27	19	14,240.7	6,400	7,920	0	NA	0.00	0.0
	09/03/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
09/04/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
9	09/05/05 ^(b)	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
	09/06/05	12:30	388,000	23,400	48	43	24	24	19	14,263.4	22,700	8,300	380	29,800	0.00	0.0
	09/07/05	16:30	396,400	8,400	48	40	19	29	21	14,271.7	8,300	8,300	0	NA	0.00	0.0
	09/08/05	16:20	403,500	7,100	48	40	20	28	20	14,278.4	6,700	8,650	350	15,500	0.00	0.0
	09/09/05	15:35	409,100	5,600	51	42	23	28	19	14,284.0	5,600	8,650	0	NA	0.00	0.0
	09/10/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
09/11/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
10	09/12/05	16:40	430,700	21,600	47	39	22	25	NA	14,305	21,000	9,010	360	27,200	0.00	NA
	09/13/05	14:30	436,800	6,100	54	43	25	29	18	14,311	6,000	9,010	0	NA	0.00	0.0
	09/14/05	15:00	443,900	7,100	53	43	23	30	20	14,318	7,100	9,010	0	NA	0.00	0.0
	09/15/05	14:30	450,500	6,600	44	39	22	22	17	14,325	6,600	9,370	360	19,800	0.00	0.0
	09/16/05	16:00	456,000	5,500	53	43	22	31	21	14,330	5,100	9,370	0	NA	0.00	0.0
	09/17/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
	09/18/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
11	09/19/05	03:45	471,000	15,000	47	44	22	25	22	14,344.6	14,800	9,370	720	NA	0.40	1.3
	09/20/05	03:20	476,600	5,600	49	43	22	27	21	14,349.4	4,800	10,080	710	NA	0.20	1.8
	09/21/05	03:30	481,100	4,500	49	41	22	27	19	14,353.9	4,500	10,080	0	NA	0.00	0.0
	09/22/05	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NM	NM
	09/23/05	NM	490,400	9,300	50	43	18	32	25	14,362.4	8,500	10,080	0	NA	0.30	1.6
	09/24/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
09/25/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
12	09/26/05	11:30	503,400	13,000	52	44	23	29	21	14,375.0	12,600	10,430	350	NA	0.00	0.0
	09/27/05	02:30	509,200	5,800	49	43	18	31	25	14,380.9	5,900	10,430	0	NA	0.00	0.0
	09/28/05	03:30	514,200	5,000	48	41	22	26	19	14,385.9	5,000	10,430	0	NA	0.02	0.2
	09/29/05	09:10	518,600	4,400	52	49	25	27	24	14,390.3	4,400	10,430	0	NA	0.01	0.1
	09/30/05	04:45	526,900	8,300	53	44	24	29	20	14,396.6	6,300	12,210	1,780	23,500	0.01	0.1
	10/01/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
10/02/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
13	10/03/05	16:50	541,200	14,300	52	43	24	28	19	14,411.1	14,500	12,210	0	NA	0.10	0.4
	10/04/05	15:00	546,200	5,000	57	45	25	32	20	14,415.7	4,600	12,560	350	19,300	0.10	1.0
	10/05/05	16:00	552,500	6,300	50	41	23	27	18	14,420.7	5,000	12,560	0	NA	0.10	0.8
	10/06/05	12:50	557,500	5,000	55	48	20	35	28	14,425.7	5,000	12,560	0	NA	0.10	1.0
	10/07/05	15:40	563,600	6,100	48	41	18	30	23	14,431.8	6,100	12,560	0	NA	0.00	0.0
	10/08/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
10/09/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
14	10/10/05	16:00	576,900	13,300	53	44	20	33	24	14,444.8	13,000	12,910	350	30,700	0.20	0.8
	10/11/05	15:40	581,600	4,700	50	42	23	27	19	14,448.7	3,900	13,630	720	NA	0.10	1.1
	10/12/05	11:30	585,100	3,500	48	40	22	26	18	14,452.2	3,500	13,630	0	NA	0.10	1.4
	10/13/05	14:05	590,600	5,500	52	48	20	32	28	14,457.8	5,600	13,630	0	NA	0.10	0.9
	10/14/05	15:00	595,500	4,900	54	44	25	29	19	14,462.6	4,800	13,630	0	NA	0.00	0.0
	10/15/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA
10/16/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	

Daily System Operation Log Sheet (Continued)

Week No.	Date	Time	Volume to Treatment		Pressure					Volume to Distribution		Backwash			NaOCl Application		
			Totalizer (gal)	Incremental Volume (gal)	Pressure Tanks (psi)	After Contact Tank (psi)	After Filters (psi)	ΔP across System (psi)	ΔP across Filters (psi)	Totalizer (kgal)	Incremental Volume (gal)	Totalizer (gal)	Wastewater Produced (gal)	Throughput Between Backwash Cycles (gal)	NaOCl Tank Level (gal) ^(c)	Average Cl ₂ Dose (mg/L)	
15	10/17/05	15:40	610,800	15,300	48	40	20	28	20	14,477.8	15,200	13,980	350	NA	0.00	0.0	
	10/18/05	16:50	616,100	5,300	45	39	20	25	19	14,483.1	5,300	13,980	0	NA	0.00	0.0	
	10/19/05	15:15	619,800	3,700	48	40	22	26	18	14,486.8	3,700	13,980	0	NA	0.20	2.7	
	10/20/05	14:25	624,600	4,800	50	42	25	25	17	14,491.5	4,700	13,980	0	NA	0.10	1.0	
	10/21/05	13:45	629,500	4,900	56	45	25	31	20	14,496.5	5,000	13,980	0	NA	0.10	1.0	
	10/22/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
	10/23/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
16	10/24/05	16:10	642,500	13,000	55	44	30	25	14	14,509.2	12,700	14,330	350	31,700	0.20	0.8	
	10/25/05	12:00	646,600	4,100	47	40	20	27	20	14,513.4	4,200	14,330	0	NA	0.10	1.2	
	10/26/05	14:00	653,900	7,300	45	40	19	26	21	14,520.1	6,700	14,330	0	NA	0.10	0.7	
	10/27/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
	10/28/05	14:40	664,800	10,900	48	40	23	25	17	14,530.2	10,100	14,700	370	22,300	14.50	NA	
	10/29/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
	10/30/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
17	10/31/05 ^(d)	15:50	681,200	16,400	52	43	21	31	22	14,546.8	16,600	14,700	0	NA	14.00	1.7	
	11/01/05	16:20	686,800	5,600	49	42	22	27	20	14,551.6	4,800	15,050	350	22,000	14.00		
	11/02/05	15:20	696,300	9,500	56	43	28	28	15	14,556.9	5,300	15,050	0	NA	13.50		
	11/03/05	15:50	711,400	15,100	55	48	30	25	18	14,560.8	3,900	15,050	0	NA	13.50		
	11/04/05	15:40	715,800	4,400	53	40	19	34	21	14,565.2	4,400	15,050	0	NA	13.50		
	11/05/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM		NA
	11/06/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM		NA
18	11/07/05	16:00	731,000	15,200	53	50	29	24	21	14,579.8	14,600	15,410	360	44,200	13.25	4.8	
	11/08/05	12:00	735,000	4,000	45	38	20	25	18	14,584.0	4,200	15,410	0	NA	13.00		
	11/09/05	15:20	739,900	4,900	52	44	24	28	20	14,588.8	4,800	15,410	0	NA	12.75		
	11/10/05	14:05	744,000	4,100	47	40	19	28	21	14,592.9	4,100	15,410	0	NA	12.50		
	11/11/05	15:40	749,700	5,700	55	50	32	23	18	14,597.8	4,900	16,100	690	18,700	12.50		
	11/12/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM		NA
	11/13/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM		NA
19	11/14/05	15:45	762,200	12,500	49	40	19	30	21	14,610.8	13,000	16,100	0	NA	12.00	1.6	
	11/15/05	16:15	767,700	5,500	51	43	22	29	21	14,615.9	5,100	16,100	0	NA	12.00		
	11/16/05	15:30	772,200	4,500	56	49	25	31	24	14,620.4	4,500	16,100	0	NA	12.00		
	11/17/05	14:10	776,600	4,400	50	44	26	24	18	14,624.5	4,100	16,460	360	26,900	11.75		
	11/18/05	15:05	781,200	4,600	49	43	23	26	20	14,629.2	4,700	16,460	0	NA	11.75		
	11/19/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM		NA
	11/20/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM		NA
20	11/21/05	15:10	793,600	12,400	53	47	29	24	18	14,641.7	12,500	16,460	0	NA	11.25	2.9	
	11/22/05	15:45	798,500	4,900	57	44	24	33	20	14,646.3	4,600	16,830	370	21,900	11.25		
	11/23/05	15:30	802,700	4,200	45	38	20	25	18	14,650.5	4,200	16,830	0	NA	11.00		
	11/24/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM		NA
	11/25/05	15:10	814,000	11,300	46	40	20	26	20	14,661.9	11,400	16,830	0	NA	10.75		
	11/26/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM		NA
	11/27/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM		NA
21	11/28/05	15:45	830,500	16,500	53	45	22	31	23	14,678.2	16,300	17,190	360	32,000	10.25	5.9	
	11/29/05	12:40	835,600	5,100	55	44	30	25	14	14,682.1	3,900	18,230	1,040	NA	10.50		
	11/30/05	15:45	840,200	4,600	50	43	23	27	20	14,686.9	4,800	18,230	0	NA	14.50		
	12/01/05	15:45	844,800	4,600	47	40	20	27	20	14,691.5	4,600	18,230	0	NA	14.50		
	12/02/05	15:40	850,700	5,900	48	40	19	29	21	14,697.4	5,900	18,230	0	NA	14.25		
	12/03/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM		NA
12/04/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA		

Daily System Operation Log Sheet (Continued)

Week No.	Date	Time	Volume to Treatment		Pressure					Volume to Distribution		Backwash			NaOCl Application	
			Totalizer (gal)	Incremental Volume (gal)	Pressure Tanks (psi)	After Contact Tank (psi)	After Filters (psi)	ΔP across System (psi)	ΔP across Filters (psi)	Totalizer (kgal)	Incremental Volume (gal)	Totalizer (gal)	Wastewater Produced (gal)	Throughput Between Backwash Cycles (gal)	NaOCl Tank Level (gal) ^(c)	Average Cl ₂ Dose (mg/L)
22	12/05/05	16:40	865,200	14,500	51	43	23	28	20	14,711.7	14,300	18,580	350	NA	14.00	4.0
	12/06/05	13:35	869,000	3,800	54	44	24	30	20	14,715.6	3,900	18,580	0	NA	13.75	
	12/07/05	15:30	879,600	10,600	53	44	21	32	23	14,726.3	10,700	18,580	0	NA	13.50	
	12/08/05	14:25	889,700	10,100	54	48	30	24	18	14,736.0	9,700	18,930	350	24,500	13.00	
	12/09/05	15:00	894,700	5,000	55	45	30	25	15	14,741.2	5,200	18,930	0	NA	13.00	
	12/10/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	
12/11/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
23	12/12/05	15:30	911,600	16,900	45	39	18	27	21	14,757.9	16,700	19,220	290	21,900	12.50	2.3
	12/13/05	13:00	916,500	4,900	49	43	23	26	20	14,762.9	5,000	19,220	0	NA	12.50	
	12/14/05	15:00	923,600	7,100	49	41	23	26	18	14,770.0	7,100	19,220	0	NA	12.25	
	12/15/05	12:55	930,200	6,600	51	42	23	28	19	14,776.3	6,300	19,630	410	18,600	12.00	
	12/16/05	12:30	937,100	6,900	54	48	25	29	23	14,783.3	7,000	19,630	0	NA	12.00	
	12/17/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	
12/18/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
24	12/19/05	14:10	960,300	23,200	59	51	30	29	21	14,806.3	23,000	19,980	350	30,100	11.25	4.4
	12/20/05	14:05	968,800	8,500	46	41	25	21	16	14,814.6	8,300	20,330	350	8,500	11.00	
	12/21/05	14:30	975,500	6,700	51	45	22	29	23	14,821.4	6,800	20,330	0	NA	10.75	
	12/22/05	14:40	981,600	6,100	57	50	32	25	18	14,827.5	6,100	20,330	0	NA	10.50	
	12/23/05	14:25	987,400	5,800	52	43	10	42	33	14,833.5	6,000	20,330	0	NA	10.25	
	12/24/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	
12/25/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
25	12/26/05	15:00	1,007,000	19,600	52	48	27	25	21	14,852.8	19,300	20,680	350	38,200	10.00	3.1
	12/27/05	14:35	1,012,500	5,500	50	42	27	23	15	14,858.4	5,600	20,680	0	NA	14.25	
	12/28/05	15:00	1,018,400	5,900	50	43	24	26	19	14,864.0	5,600	21,040	360	11,400	14.00	
	12/29/05	14:25	1,028,500	10,100	46	40	24	22	16	14,873.7	9,700	21,040	0	NA	13.75	
	12/30/05	14:00	1,036,000	7,500	53	43	18	35	25	14,881.0	7,300	21,380	340	17,600	13.50	
	12/31/05	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	
01/01/06	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
26	01/02/06	16:00	1,055,300	19,300	52	45	23	29	22	14,900.4	19,400	21,380	0	NA	13.00	2.5
	01/03/06	14:00	1,061,800	6,500	47	40	21	26	19	14,906.6	6,200	21,730	350	25,800	13.00	
	01/04/06	15:00	1,068,400	6,600	47	39	22	25	17	14,913.4	6,800	21,730	0	NA	12.75	
	01/05/06	14:30	1,072,700	4,300	56	50	30	26	20	14,917.6	4,200	21,730	0	NA	12.50	
	01/06/06	15:30	1,079,500	6,800	49	40	22	27	18	14,924.6	7,000	21,730	0	NA	12.50	
	01/07/06	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	
01/08/06	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
27	01/09/06	15:00	1,098,900	19,400	53	44	29	24	15	14,943.8	19,200	22,100	370	37,100	12.00	3.0
	01/10/06	15:55	1,107,000	8,100	56	50	32	24	18	14,950.4	6,600	23,350	1,250	6,600	11.75	
	01/11/06	16:30	1,113,100	6,100	57	40	20	37	20	14,956.7	6,300	23,350	0	NA	11.50	
	01/12/06	14:30	1,118,200	5,100	55	40	22	33	18	14,961.8	5,100	23,350	0	NA	11.25	
	01/13/06	15:45	1,127,200	9,000	58	50	32	26	18	14,970.8	9,000	23,550	200	NA	11.28	
	01/14/06	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	
01/15/06	NM	NM	NA	NM	NM	NM	NA	NA	NM	NA	NM	NA	NA	NM	NA	
28	01/16/06	16:00	1,147,200	20,000	52	43	22	30	21	14,990.8	20,000	23,720	170	20,000	10.50	3.8
	01/17/06	16:30	1,155,100	7,900	55	50	30	25	20	14,998.4	7,600	24,080	360	7,900	10.25	

Note:

- (a) On 08/31/05, pressure reading of the four pressure tanks started being recorded.
- (b) Labor day holiday.
- (c) Change in NaOCl tank level recorded up to 10/28/06 when actual NaOCl tank level started being recorded.
- (d) Flow meters, one on treated water line and one on backwash line, installed on 09/20/06 but readings not recorded until 10/31/06.

NM = not measured; NA = not available.

APPENDIX B
ANALYTICAL DATA

Table B-1. Analytical Results from Treatment Plant Sampling at Delavan, WI

Sampling Date		07/12/05			07/19/05				07/26/05 ^(a)				08/02/05				08/09/05 ^(a)		
Sampling Location		IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT
Parameter	Unit																		
Stroke Length	%	70			70				70				70				70		
Alkalinity (as CaCO ₃)	mg/L	352	352	352	365	361	365	365	370	365	361	374	352	352	356	352	356	361	356
Fluoride	mg/L	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sulfate	mg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrate (as N)	mg/L	0.1	<0.05	<0.05	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	<0.05	0.08	<0.05	<0.05	<0.05	<0.05	0.2
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Orthophosphate (as P)	µg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total P (as P)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	13.9	14.2	13.8	14.2	14.2	14.0	14.2	14.5	14.1	14.2	14	14.0	14.3	14.5	14.1	15.1	14.9	14.7
Turbidity	NTU	14.0	1.7	0.3	18.0	1.8	0.6	0.2	16.0	2.4	2.3	1.3	14.0	2.2	0.7	0.5	10.0	2.3	0.3
pH	S.U.	7.4	7.4	7.5	7.4	7.4	7.4	7.5	7.5	7.7	7.6	7.3	7.5	7.6	7.4	7.5	7.6	7.6	7.6
Temperature	°C	14.1	15.5	15.4	13.9	13.2	13.1	14.5	13.3	14.1	13.8	12.9	13.8	13.5	12.7	15.0	14.3	13.0	13.4
DO	mg/L	0.8	1.9	1.7	2.6	1.2	3.2	3.9	0.0	0.0	0.0	3.2	2.1	3.1	1.7	2.1	0.0	0.0	0.0
ORP	mV	-52	174	241	-60	73	221	284	-35	40	34	43	-51	49	49	73	127	35	98
Free Chlorine	mg/L	-	-	<0.02	-	<0.02	<0.02	<0.02	-	<0.02	<0.02	<0.02	-	<0.02	<0.02	<0.02	-	<0.02	<0.02
Total Chlorine	mg/L	-	-	0.1	-	0.3	0.2	0.2	-	<0.1	<0.1	<0.1	-	0.2	<0.1	0.1	-	<0.1	0.1
Total Hardness (as CaCO ₃)	mg/L	304	318	329	-	-	-	-	-	-	-	-	-	-	-	-	295	290	297
Ca Hardness (as CaCO ₃)	mg/L	162	170	175	-	-	-	-	-	-	-	-	-	-	-	-	147	144	149
Mg Hardness (as CaCO ₃)	mg/L	141	148	153	-	-	-	-	-	-	-	-	-	-	-	-	148	146	149
As (total)	µg/L	18.6	20.5	7.6	21.7	16.6	3.2	2.9	17.4	16.4	5.3	4.7	15.8	15.6	4.9	4.5	17.8	19.1	6.0
As (soluble)	µg/L	19.2	7.7	7.7	-	-	-	-	-	-	-	-	-	-	-	-	18.4	10.4	6.4
As (particulate)	µg/L	<0.1	12.8	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1
As (III)	µg/L	18.6	5.0	5.8	-	-	-	-	-	-	-	-	-	-	-	-	17.6	5.8	5.9
As (V)	µg/L	0.6	2.7	1.8	-	-	-	-	-	-	-	-	-	-	-	-	0.8	4.6	0.5
Fe(total)	µg/L	1,557	1,419	<25	1,471	1,446	<25	<25	1,388	1,349	179	143	1,472	1,311	100	94	1,183	1,237	39
Fe(soluble)	µg/L	1,509	130	<25	-	-	-	-	-	-	-	-	-	-	-	-	996	385	<25
Mn(total)	µg/L	19.5	18.9	20.4	19.0	19.3	18.1	18.4	18.2	18.2	18.4	18.6	18.2	17.4	15.8	16.5	16.1	17.2	16.2
Mn(soluble)	µg/L	19.8	18.3	20.3	-	-	-	-	-	-	-	-	-	-	-	-	17.0	16.3	16.2

(a) Sampling error using DO probe.

IN = influent; AC = after chlorination; TA = after tank A; TB = after tank B; TT = after combined effluent. NA = not available.

Table B-1. Analytical Results from Treatment Plant Sampling at Delavan, WI (Continued)

Sampling Date		08/16/05				08/23/05				08/30/05 ^(a)				09/06/05				09/13/05				
Sampling Location		IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	
Parameter	Unit	70				83.5				83.5				83.5				83.5				
Stroke Length	%	70				83.5				83.5				83.5				83.5				
Alkalinity (as CaCO ₃)	mg/L	330	352	352	356	352	352	356	356	365	352	352	356	352	361	356	361	361	361	356	352	361
Fluoride	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Orthophosphate (as P)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total P (as P)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	14.6	14.5	15.0	14.7	13.8	14.3	14.4	14.1	16.6	16.8	16.8	16.2	15.3	14.6	14.9	14.8	14.4	14.7	14.9	14.7	
Turbidity	NTU	14.0	2.0	1.4	2.3	14.7	11.3	20.4	19.0	12.0	13.0	20.0	19.0	14.0	13.0	18.0	17.0	14.0	18.0	18.0	18.0	
pH	S.U.	7.7	7.6	7.5	7.6	7.7	7.6	7.6	7.5	7.6	7.5	7.5	7.4	7.5	7.5	7.3	7.5	7.6	7.5	7.6	7.5	
Temperature	°C	13.0	13.1	13.1	13.1	13.6	13.3	13.3	13.0	15.6	12.6	13.3	12.9	16.3	13.9	14.6	14.2	14.5	13.2	13.5	13.7	
DO	mg/L	3.6	3.5	1.8	1.9	2.8	2.6	2.6	2.5	2.6	3.7	1.6	1.9	2.6	2.0	2.1	1.9	2.4	2.1	3.1	2.0	
ORP	mV	-40	-33	-50	-46	-49	-37	-47	-36	-36	-59	-68	-60	-22	-66	-59	-70	-68	-69	-51	-56	
Free Chlorine	mg/L	-	<0.02	<0.02	<0.02	-	<0.02	<0.02	<0.02	-	<0.02	<0.02	<0.02	-	0.09	0.03	<0.02	-	<0.02	0.12	<0.02	
Total Chlorine	mg/L	-	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	
Total Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Ca Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Mg Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
As (total)	µg/L	17.5	16.8	5.5	6.3	19.0	19.1	6.7	6.8	NA	17.2	17.9	18.1	20.7	19.9	19.9	21.0	16.8	17.6	17.2	17.0	
As (soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
As (particulate)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
As (III)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
As (V)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Fe(total)	µg/L	1,466	1,406	150	219	1,319	1,324	137	202	NA	1,416	1,499	1,525	1,350	1,351	1,418	1,389	1,443	1,556	1,452	1,512	
Fe(soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Mn(total)	µg/L	18.4	17.9	17.9	17.9	17.4	18.0	18.2	17.9	NA	17.8	17.9	18.5	18.5	17.5	17.8	17.7	17.4	17.4	16.8	17.1	
Mn(soluble)	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

(a) Samples sent day after sampling and some analytes may be out of hold time.
 IN = influent; AC = after chlorination; TA = after tank A; TB = after tank B; TT = after combined effluent. NA = not available.

Table B-1. Analytical Results from Treatment Plant Sampling at Delavan, WI (Continued)

Sampling Date		09/20/05				09/27/05			10/04/05				10/11/05 ^(b)				10/18/05			
Sampling Location		IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB
Parameter	Unit	83.5				83.5			62				74				74			
Stroke Length	%	83.5				83.5			62				74				74			
Alkalinity (as CaCO ₃)	mg/L	352	370	374	370	361	361	365	361	374	370	374	361 361	374 370	361 361	356 356	356	356	352	365
Fluoride	mg/L	-	-	-	-	0.2	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	<1	<1	<1	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Orthophosphate (as P)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	-	-	-	-	-	-	-	-	-	-	-	54.5 55.0	52.5 58.8	<10 <10	<10 <10	77.2	76.7	41.2	35.8
Silica (as SiO ₂)	mg/L	13.0	13.0	13.3	13.1	16.2	16.3	16.0	14.2	14.5	13.8	15.3	13.6 13.6	13.3 13.8	14.2 14.7	13.6 14.0	13.0	13.3	14.3	13.4
Turbidity	NTU	16.0	2.2	3.2	2.0	16.0	18.0	20.0	20.0	6.1	7.5	11.0	14.0 15.0	5.3 11.0	7.2 7.0	6.8 5.5	18.0	2.7	11.0	9.9
pH	S.U.	7.3	7.2	7.4	7.4	7.5	7.5	7.7	7.4	7.5	7.5	7.4	8.1	8.0	8.0	8.1	7.4	7.4	7.4	7.4
Temperature	°C	15.1	16.0	15.5	14.9	13.5	13.4	13.9	14.0	13.8	13.5	13.8	15.1	14.4	14.0	14.1	15.2	15.5	15.1	15.3
DO	mg/L	1.9	2.7	2.4	2.1	2.0	2.0	3.9	2.8	2.1	2.3	2.1	2.7	3.1	2.9	2.9	2.3	2.1	2.3	2.3
ORP	mV	-73	-18	-27	-28	-81	-76	-67	-81	-53	-50	-60	-74	-49	-34	-19	-74	-66	-59	-31
Free Chlorine	mg/L	-	<0.02	<0.02	<0.02	-	<0.02	<0.02	-	<0.02	<0.02	<0.02	-	<0.02	<0.02	0.04	-	<0.02	<0.02	<0.02
Total Chlorine	mg/L	-	<0.1	<0.1	<0.1	-	<0.1	<0.1	-	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	-	1.4	<0.1	<0.1
Total Hardness (as CaCO ₃)	mg/L	-	-	-	-	510	281	283	-	-	-	-	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	-	-	-	-	260	143	143	-	-	-	-	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	-	-	-	-	250	138	141	-	-	-	-	-	-	-	-	-	-	-	-
As (total)	µg/L	15.4	15.1	6.1	5.5	29.0	15.8	16.6	15.9	16.2	10.2	9.4	14.3 14.3	14.0 14.5	8.1 8.1	7.8 7.8	20.7	20.5	11.6	10.2
As (soluble)	µg/L	-	-	-	-	15.7	12.6	16.8	-	-	-	-	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	13.3	3.1	<0.1	-	-	-	-	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	14.0	13.5	15.1	-	-	-	-	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	1.7	<0.1	1.8	-	-	-	-	-	-	-	-	-	-	-	-
Fe(total)	µg/L	1,449	1,294	291	216	2,478	1,602 ^(a)	1,596	1,512	1,525	930	874	1,169 1,165	1,232 1,274	537 537	469 448	1,535	1,526	901	856
Fe(soluble)	µg/L	-	-	-	-	1,227	<25 ^(a)	1,417	-	-	-	-	-	-	-	-	-	-	-	-
Mn(total)	µg/L	17.0	15.7	16.2	15.4	32.9	19.2	19.2	17.8	17.9	17.8	17.4	15.8 15.6	16.1 16.4	16.2 15.9	16.3 15.8	19.1	19.2	19.5	19.7
Mn(soluble)	µg/L	-	-	-	-	19.5	11.8	20.8	-	-	-	-	-	-	-	-	-	-	-	-

(a) Samples reanalyzed by laboratory showed similar results. (b) Starting 10/11/05, total phosphorous analyzed instead of orthophosphate.

IN = influent; AC = after chlorination; TA = after tank A; TB = after tank B; TT = after combined effluent. NA = not available.

Table B-1. Analytical Results from Treatment Plant Sampling at Delavan, WI (Continued)

Sampling Date		10/25/05 ^(a)			11/01/05				11/08/05				11/15/05				11/29/05 ^(c)		
Sampling Location		IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT
Parameter	Unit																		
Stroke Length	%	82			82				80				80				78		
Alkalinity (as CaCO ₃)	mg/L	352	356	352	352	343	352	348	365	361	361	361	361	352	365	392	352	361	352
Fluoride	mg/L	0.2	0.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.2	0.2
Sulfate	mg/L	<1	<1	<1	-	-	-	-	-	-	-	-	-	-	-	-	<1	<1	<1
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05
Ammonia (as N)	mg/L	3.0	-	-	-	-	-	-	2.9	2.7	2.8	2.8	2.9	2.8	2.7	2.8	NA	NA	NA
Orthophosphate (as P)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	75.2	79.4	14.2	72.6	79.9	<10	<10	70.7	69.3	<10	14.3	74.6	92.1	<10	<10	71.7	59.7	<10
Silica (as SiO ₂)	mg/L	13.4	13.8	13.1	14.3	14.4	14.2	14.5	14.0	14.5	14.0	14.0	14.2	14.5	14.1	14.1	14.5	14.6	14.2
Turbidity	NTU	19.0	6.4	11.0	16.0	2.9	0.1	0.1	19.0	2.6	0.4	0.2	16.0	4.8	0.4	0.3	20.0	3.2	<0.1
pH	S.U.	7.4	7.6	7.4	7.5	7.5	7.5	7.5	7.4	7.6	7.6	7.4	7.4	7.5	7.5	7.4	7.5	7.5	7.4
Temperature	°C	13.1	13.3	13	14.6	14.8	14.6	15.0	12.5	13.6	13.3	12.1	14.3	13.1	14.3	14.5	13.5	13.5	14.2
DO	mg/L	2.4	3.6	1.4	2.9	3.8	2.8	2.3	2.3	3.2	2.5	2.2	2.9	3.5	2.4	2.5	3.1	3.5	1.7
ORP	mV	-71	-45	-32	-69	-8	111	113	-85	110	100	102	-69	46	26	98	-49	54	57
Free Chlorine	mg/L	-	<0.02	0.03	-	1.5 ^(b)	<0.02	0.7	-	0.5	0.3 ^(b)	0.5	-	0.1	2.3	0.2	-	0.4	0.8
Total Chlorine	mg/L	-	<0.1	0.2	-	0.4 ^(b)	1.2	1.0	-	2.8	<0.1 ^(b)	0.8	-	2.4	1.9	1.4	-	0.4	1.8
Total Hardness (as CaCO ₃)	mg/L	328	338	333	-	-	-	-	-	-	-	-	-	-	-	-	308	311	316
Ca Hardness (as CaCO ₃)	mg/L	175	184	177	-	-	-	-	-	-	-	-	-	-	-	-	167	174	175
Mg Hardness (as CaCO ₃)	mg/L	153	154	156	-	-	-	-	-	-	-	-	-	-	-	-	141	138	141
As (total)	µg/L	18.5	20.1	12.7	15.9	17.0	3.4	2.5	22.3	21.6	7.2	6.6	21.3	22.8	3.7	3.1	18.5	18.3	2.6
As (soluble)	µg/L	17.5	15.1	11.6	-	-	-	-	-	-	-	-	-	-	-	-	17.9	8.8	2.6
As (particulate)	µg/L	1.0	4.9	1.1	-	-	-	-	-	-	-	-	-	-	-	-	0.7	9.6	<0.1
As (III)	µg/L	17.2	8.0	9.9	-	-	-	-	-	-	-	-	-	-	-	-	16.7	4.1	1.5
As (V)	µg/L	0.3	7.1	1.8	-	-	-	-	-	-	-	-	-	-	-	-	1.2	4.7	1.1
Fe(total)	µg/L	1,530	1,501	834	1,436	1,590	<25	<25	1,542	1,302	<25	<25	1,606	1,905	<25	<25	1,558	1,531	<25
Fe(soluble)	µg/L	1,480	1,131	832	-	-	-	-	-	-	-	-	-	-	-	-	1,613	444	<25
Mn(total)	µg/L	19.1	19.0	21.0	19.0	20.3	19.2	19.7	17.5	17.1	15.8	16.4	19.6	20.2	18.8	18.9	19.5	19.8	18.9
Mn(soluble)	µg/L	19.2	18.7	20.8	-	-	-	-	-	-	-	-	-	-	-	-	20.2	19.1	19.0

(a) Started ammonia analysis. (b) Cl₂ readings may not be accurate due to problems with chlorine dispenser. (c) Changed to use total and free Cl₂ pillows starting 11/29/05.

IN = influent; AC = after chlorination; TA = after tank A; TB = after tank B; TT = after combined effluent. NA = not available.

Table B-1. Analytical Results from Treatment Plant Sampling at Delavan, WI (Continued)

Sampling Date		12/06/05				12/13/05				01/30/06 ^(a)			01/10/06				01/17/06			
Sampling Location		IN	AC	TA	TB	IN	AC	TA	TB	IN	AC	TT	IN	AC	TA	TB	IN	AC	TA	TB
Parameter	Unit	72				65				68			68				68			
Stroke Length	%	72				65				68			68				68			
Alkalinity (as CaCO ₃)	mg/L	334	348	356	352	361 370	374 374	374 374	370 370	374	374	374	370	334	370	378	374	370	374	374
Fluoride	mg/L	-	-	-	-	-	-	-	-	0.2	0.2	0.2	-	-	-	-	-	-	-	-
Sulfate	mg/L	-	-	-	-	-	-	-	-	<1	<1	<1	-	-	-	-	-	-	-	-
Nitrate (as N)	mg/L	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	2.9	2.8	2.9	2.9	3.0 3.0	2.9 2.9	2.9 3.2	2.9 3.1	3.2	2.9	2.9	3.0	2.9	2.9	2.8	3.0	3.0	2.9	2.9
Orthophosphate (as P)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total P (as P)	µg/L	84.5	82.3	<10	<10	69.1 71.0	68.2 69.5	<10 <10	<10 <10	60.7	59.4	<10	<10	<10	<10	<10	74.2	49.4	<10	<10
Silica (as SiO ₂)	mg/L	14.2	14.5	14.2	14.3	14.7 14.4	14.7 14.7	14.9 14.1	14.3 14.0	14.4	13.0	14.3	15.0	14.8	14.4	14.6	15.3	15.2	14.7	14.7
Turbidity	NTU	18.0	2.3	<0.1	0.1	16.0 19.0	1.9 2.0	0.4 0.1	0.1 0.6	18.0	10.0	0.5	17.0	16.0	2.5	0.6	19.0	2.3	0.7	0.4
pH	S.U.	7.5	7.5	7.4	7.5	7.5	7.4	7.7	7.5	NA	NA	NA	7.2	7.3	7.3	7.3	7.3	7.5	7.5	7.4
Temperature	°C	12.5	12.2	11.8	11.6	11.8	10.9	12.4	11.2	NA	NA	NA	13.5	13.0	12.9	12.7	13.0	12.6	11.6	11.3
DO	mg/L	2.9	4.1	2.8	3.8	3.6	3.3	2.6	3.9	NA	NA	NA	1.7	1.8	1.4	2.0	1.8	2.7	1.7	1.0
ORP	mV	-46	104	111	116	-45	36	69	67	NA	NA	NA	132	127	128	126	60	66	91	92
Free Chlorine	mg/L	-	1.5	3.3	1.4	-	0.8	<0.02	<0.02	-	NA	NA	-	0.2	0.2	<0.02	-	0.7	2.3	2.1
Total Chlorine	mg/L	-	4.4	2.9	4.0	-	0.1	0.3	<0.1	-	NA	NA	-	0.1	0.1	<0.1	-	2.7	1.8	0.8
Total Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	330	327	331	-	-	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	174	171	175	-	-	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	-	-	-	-	-	-	-	-	155	156	156	-	-	-	-	-	-	-	-
As (total)	µg/L	18.6	18.9	2.5	2.9	17.1 17.3	17.5 17.6	3.0 3.0	3.3 3.3	17.4	18.1	4.9	16.4	17.1	6.5	6.2	17.5	17.0	3.2	2.5
As (soluble)	µg/L	-	-	-	-	-	-	-	-	17.5	15.5	4.9	-	-	-	-	-	-	-	-
As (particulate)	µg/L	-	-	-	-	-	-	-	-	<0.1	2.6	<0.1	-	-	-	-	-	-	-	-
As (III)	µg/L	-	-	-	-	-	-	-	-	16.4	9.7	3.9	-	-	-	-	-	-	-	-
As (V)	µg/L	-	-	-	-	-	-	-	-	1.1	5.8	1.0	-	-	-	-	-	-	-	-
Fe(total)	µg/L	1,388	1,384	<25	<25	1,373 1,445	1,446 1,407	<25 <25	<25 <25	1,438	1,265	<25	1,303	1,340	542	291	1,267	1,278	<25	<25
Fe(soluble)	µg/L	-	-	-	-	-	-	-	-	1,437	1,120	<25	-	-	-	-	-	-	-	-
Mn(total)	µg/L	35.8	18.4	17.7	17.6	18.2 19.3	18.8 18.2	18.5 17.8	19.0 18.3	19.0	18.1	19.3	17.1	17.4	18.0	19.6	18.0	18.1	16.9	16.8
Mn(soluble)	µg/L	-	-	-	-	-	-	-	-	20.0	19.2	20.6	-	-	-	-	-	-	-	-

(a) Onsite water quality parameters not taken because field meter back at Battelle for troubleshooting.

IN = influent; AC = after chlorination; TA = after tank A; TB = after tank B; TT = after combined effluent. NA = not available.