

# **Oxidation of As(III) by Aeration and Storage**

by

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Contract No. 8C-R433-NTSX

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## Abstract

A study of the effects of aeration and storage on the oxidation of arsenic(III) was undertaken at three utilities in the U.S. to establish the engineering significance of aeration as a potential pre-treatment method for arsenic removal. Aeration has been referred to in the literature as a possible useful pre-treatment method to ensure that arsenic is in the arsenic(V) state before subsequent removal by any of several treatment processes. Since aeration a common process for treating groundwater for iron oxidation, radon, volatile organics, carbon dioxide, and hydrogen sulfide, it is reasonable to investigate its effectiveness for arsenic(III) oxidation.

The results of this study clearly establish that aeration and aerobic storage do not oxidize arsenic(III). The major conclusion is that aeration is not effective for this purpose and should not be relied upon or expected to contribute to the oxidation of arsenic(III). One of the test sites in this study clearly showed that arsenic(III) is significantly removed by the oxidation and precipitation of iron, but this should not be attributed to an oxidation of arsenic(III) to arsenic(V) by dissolved oxygen. Past research has established that iron precipitation can be partially effective for the adsorptive removal of arsenic(III), and this is the likely explanation for the apparent drop in arsenic(III) at the site that had high iron.

The effect of iron precipitation on the removal of arsenic was also present in the long term storage of aerated water in this study. When all of the iron (initial iron at  $\approx 2.7$  mg/L) precipitated from the quiescent storage water, the remaining aqueous total arsenic was entirely dissolved and in the arsenic(V) state. The aqueous arsenic(III) was below detection and apparently completely removed or converted by the insoluble iron. Even in this case it is doubtful if DO was responsible for any oxidation of arsenic(III), because the loss directly correlated to the loss of iron precipitate and no other instance of arsenic(III) oxidation occurred at the other sites. In summary, the data supported the fact that iron is extremely important in the removal of arsenic(III), but did not support the idea that arsenic(III) is oxidized by aeration. This is true at least for the conditions used in this study.

While the subtleties of the results are interesting, especially for the site with high iron, it is important to emphasize the original objective of this study, which was to establish if typical aeration and storage methods could oxidize arsenic(III). Based upon the results of this study, it is concluded that aeration does not oxidize arsenic(III) and that subsequent storage for up to five days does not result in arsenic(III) oxidation. Dissolved oxygen should not be considered as a candidate for arsenic(III) oxidation; however, aeration will continue to be considered a very effective process for the oxidation of iron. In that way, aeration can be said to be effective in bringing about the removal of As via the oxidative precipitation of iron.

# Contents

Foreword .....	iii
Abstract .....	iv
Tables .....	vi
Figures .....	vii
Abbreviations .....	viii
Acknowledgements .....	ix
1.0 Introduction .....	1
1.1 Background .....	1
1.2 Objectives .....	2
2.0 Materials and Procedures .....	3
2.1 Selection of Water Supplies .....	3
2.2 Aeration Systems .....	5
2.3 Storage Container .....	7
2.4 Water Sampling & Data Collection .....	8
2.5 Analytical Procedures .....	9
3.0 Test Results .....	12
3.1 Northeast Site .....	12
3.2 Midwest Site .....	15
3.3 Southwest Site .....	22
4.0 Discussion and Conclusions .....	27
4.1 Oxidation of As(III) by Dissolved Oxygen .....	27
4.2 Sample Analysis Problems .....	28
4.3 Conclusions .....	28
5.0 References .....	29
6.0 Appendices .....	30
Appendix A: Northeast Site Data .....	31
Appendix B: Midwest Site Data .....	39
Appendix C: Southwest Site Data .....	42

## Tables

Table 2-1 Raw Water Quality for the Northeast Site.....	3
Table 2-2 Raw Water Quality for the Midwest Site .....	4
Table 2-3 Raw Water Quality for the Southwest Site.....	5
Table 2-4 Summary of Sampling for Aeration and Storage Testing .....	10
Table 2-5 Analytical Method Summary .....	10

## Figures

Figure 2-1	Spray Aeration nozzle spraying water at 0.5 L/s (8 gpm) .....	6
Figure 2-2	Aeration Systems (bubble - center; tower - left; spray - right).....	6
Figure 2-3	Forced-Draft Tray Aerators .....	7
Figure 3-1	As Speciation Test Results for Well Water, Northeast Site .....	13
Figure 3-2	Avg. Well & Aeration DO Concentrations (2 Test Runs), Northeast Site.....	13
Figure 3-3	As Speciation Test Results for Bubble Aeration (Day 1), Northeast Site .....	14
Figure 3-4	Avg. As Results for the Well & Aerated Samples (Run 1 & 2), Northeast Site .	14
Figure 3-5	As Speciation Test Results for the Storage Water, Northeast Site.....	15
Figure 3-6	As Speciation Test Results for the Blended Well Water, Midwest Site .....	16
Figure 3-7	Avg. Well & Aeration DO Concentrations (2 Runs), Midwest Site .....	17
Figure 3-8	Avg. Fe Test Results for Well & Aerated Water (Run 1), Midwest Site .....	17
Figure 3-9	Avg. Mn Test Results for Well & Aerated Water (Run 1), Midwest Site .....	18
Figure 3-10	pH Results for Well & Aerated Samples (Run 1), Midwest Site.....	18
Figure 3-11	Fe (total) Results for Packed Tower (Run 1 & 2) Samples, Midwest Site .....	19
Figure 3-12	As Speciation Test Results for FDA Samples (Run 1), Midwest Site .....	20
Figure 3-13	As Speciation Results for Well & Aerated Samples (Run 1), Midwest Site .....	21
Figure 3-14	As Speciation Test Results for the Storage Samples, Midwest Site.....	21
Figure 3-15	Fe & Mn Concentrations for Storage Samples, Midwest Site .....	22
Figure 3-16	Avg. Well & Aeration DO Concentrations (2 Test Runs), Southwest Site .....	23
Figure 3-17	pH Results for Well & Aerated Samples (Run 1), Southwest Site .....	23
Figure 3-18	As Speciation Test Results for Well Samples, Southwest Site.....	24
Figure 3-19	As Speciation Test Results for Spray Aeration (Run 2), Southwest Site.....	24
Figure 3-20	Average As Results for the Well & Aerated Samples, Southwest Site .....	25
Figure 3-21	As Speciation Test Results for Storage Water Samples, Southwest Site .....	26

## Abbreviations

AA	activated alumina
As	arsenic
A/W	air to water ratio
BAT	best available technology
BOSC	Board of Scientific Counselors
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
gpd	gallons per day
HPC	heterotrophic plate count
IX	ion exchange
MCL	maximum contaminant level
MHETL	Maine Health and Environmental Testing Laboratory
MF	coagulation microfiltration
RO	reverse osmosis
SDWA	Safe Drinking Water Act
TOC	total organic carbon



## **Acknowledgements**

The authors wish to extend their appreciation to the owner of the Sandy Stream community water system, the City of Albuquerque Water Department, and the owners of the Midwest site water utility. All of the personnel were extremely helpful. They are also grateful to Thomas Sorg who provided important review and editorial commentary. Finally, the authors recognize the laboratory personnel at the Maine Health and Environmental Laboratory for their extraordinary effort to complete the sample analyses for this project.

# 1.0 Introduction

## 1.1 Background

The 1996 Safe Drinking Water Act (SDWA) amendments required EPA to propose a revised arsenic MCL by January, 2000 and to finalize it by January, 2001. The amendments also required that EPA develop an arsenic (As) research strategy to support the revised MCL, and a draft of that plan was prepared in December 1996. The plan identifies the research needed to revise the MCL, and the technologies that are available or anticipated for the removal of As. On June 20, 2000, the EPA published in the Federal Register a notice of proposed rule making to lower the MCL to 0.005 mg/L. Comments were also sought on 3, 10, and 20 µg/L limits. On Monday, January 22, 2001, the Final As Rule was published in the Federal Register. On May 22, 2001, the EPA extended the effective date for the Arsenic Rule from May 22, 2001, to February 22, 2002. The effective date for the final arsenic regulation was previously delayed for 60 days on March 23, 2001, to May 22, 2001. The current standard of 50 µg/L remains the applicable arsenic drinking water standard until the 2006 compliance date for the January 2001 final rule. It is expected that the revised As MCL will be significantly lower than the current 50 µg/L.

Arsenic can be found in drinking water supplies at concentrations ranging from a few µg/L to several mg/L. Arsenic in water can occur in four oxidation states; however, it is normally found as an anion with acid characteristics in only the trivalent (arsenite) and pentavalent (arsenate) forms. These two oxidation states are referred to as As(III) and As(V). A given groundwater may have As(III) and or As(V), depending upon the specific oxidation/reduction characteristics and pH of the water. There are two primary reasons that the oxidation state of As is important: 1) As(III) is a greater health concern compared to As(V), and 2) treatment process efficiency is less for As(III) than for As(V).

The removal of As from drinking water has been studied in the laboratory and in the field. There are existing As removal plants that routinely remove As to low levels, and As(V) is relatively easy to remove by a variety of processes, including ion exchange (IX), reverse osmosis (RO), coagulation + microfiltration (MF), conventional coagulation, iron precipitation/filtration, lime softening, and activated alumina (AA). None of these treatment processes are reliably effective for the removal of As(III). Oxidation is required to convert As(III) to As(V), if it is to be effectively removed by any of the processes listed above.

Very little data exist on the effectiveness of various processes to oxidize As(III) to As(V). One of the major recommendations of an EPA Board of Scientific Counselors (BOSC) review of the EPA draft research plan was that the Agency conduct a specific research task on the methods for oxidation of As(III) to As(V). In response to this recommendation, EPA funded two research projects on the oxidation of As(III). This research project specifically focuses on one aspect of As(III) oxidation, namely the degree of oxidation by dissolved oxygen that may occur during aeration and storage. A second project is currently studying the effectiveness of seven other potential oxidation methods. As(III) can be easily oxidized by contacting the water with a strong oxidant such as chlorine, ozone, or potassium permanganate. Other methods using hydrogen peroxide or oxygen (via aeration) have been mentioned as possibilities, but definitive research has not been conducted to date. During the 1994 EPA Arsenic Treatment Workshop<sup>1</sup> it was concluded that "aeration has been reported in a few instances to oxidize As(III) to As(V); however, the kinetics of aeration with respect to arsenic are poorly understood. Further, it was noted that "Aeration has not been shown to be a reliable and effective process; therefore, further research is warranted." Despite a lack of evidence regarding the efficacy of As(III) by aeration, it continues to be considered as a possibility. In summary, there is no clear evidence that aeration is a potential method for the oxidation of As(III). In fact, the little data that exist indicate that aeration may not be effective in this application.<sup>2,3</sup>

## 1.2 Objectives

Storage and aeration are common aspects of many drinking water treatment schemes. Storage can be utilized before and after treatment, so it may be an important step prior to further treatment to remove As. Aeration is commonly used for the removal of carbon dioxide, volatile organic compounds, and hydrogen sulfide. Greater application of aeration will result in the future because aeration is a Best Available Technology (BAT) for the removal of radon. Radon is due to be regulated in the near future and aeration is the most cost effective method of removal. Storage/decay may also play a significant role in the reduction of radon.

The objective of this project was to investigate the effectiveness of storage and aeration to oxidize of As(III) to As(V) in drinking water systems. Field testing at three different sites that have groundwater containing As(III) was used to study the effects of aeration and storage on the oxidation of As(III) to As(V). Each site was visited for several days to test three different types of aeration and to study the effects of storage over a period of 5 days.

## 2.0 Materials and Procedures

### 2.1 Selection of Water Supplies

Three (3) sites were selected based upon the following criteria:

- one site each from the Northeast (low sulfate/TDS), the Midwest (moderate sulfate/TDS), and the Southwest (high sulfate/TDS) Note that the actual water quality at available sites had varying amounts of TDS and sulfate ranging from low to moderate.
- Total As concentration greater than 20 µg/L, with As(III) being at least 50 percent of the total As present
- groundwater with no chemical oxidant added prior to the testing point in the process train
- pH in the range of 7 to 9
- the total dissolved solids (TDS) in the range of 100 to 1,000 mg/L
- the total organic carbon (TOC) in the range of 0.5 to 5.0 mg/L

#### 2.1.1 Northeast Site

The Northeast Site was a water utility in Unity, ME. Previous experience at this site had determined that the As present was As(III) and that sulfates were relatively low. Further, the As(III) level was known to be in the range of 100 µg/L and the supply met all the other criteria for selection. An As speciation test was conducted to confirm past historical data. A summary of pertinent raw water quality for this site during the two days of testing is given in Table 2-1.

**Table 2-1.** Raw Water Quality for the Northeast Site (No. of samples)

Parameter	Average Value
Total As, mg/L (5)	0.104
Dissolved As, mg/L (5)	0.104
As (III), mg/L (5)	0.099
Sulfate, mg/L (1)	12
Alkalinity, mg/L as CaCO <sub>3</sub> (5)	88
Dissolved Oxygen, mg/L (4)	1.3
Total Iron, mg/L (5)	0.040
Total Manganese, mg/L (5)	0.056
Calcium, mg/L (5)	28
Hardness, mg/L as CaCO <sub>3</sub> (5)	87
Chloride, mg/L (5)	11
Sodium, mg/L (5)	7
Total Dissolved Solids, mg/L (5)	126
Total Organic Carbon, mg/L (5)	ND 1
Temperature, degrees C (10)	11
pH (10)	7.69

The well at the Northeast site has a flow rate of 3.78 L/s (60 gpm) and there is an ion exchange (IX) treatment system that has operated for 10 years. A trace of hydrogen sulfide odor is detectable in the raw water (less than detection at 0.05 mg/L with Hach No. 2238-01 test kit), indicating that the water is in a reduced state. A single well is pumped directly into hydropneumatic tanks or through the treatment system to distribution. The treatment system includes an oxidizing filter followed by an IX bed and is located between the pressure tanks and distribution. All source water for aeration and storage testing was untreated well water.

### 2.1.2 Midwest Site

The Midwest site has a multiple well source of groundwater, and has a lime softening system that removes hardness and Fe. An aeration step prior to lime softening is used to remove CO<sub>2</sub> to raise pH, and oxidize Fe present in the raw water. Historical water quality data for this site had established that a significant portion of the As present was As(III). The blend of the wells being pumped determines the level of As present. The typical level of As(III) in the blend was known to be in the range of 30 - 40 µg/L and the supply met the other criteria for selection. A summary of pertinent water quality for this site during the two days of testing is given in Table 2-2. All source water for testing at this site was untreated water taken from a tap in a main water line before aeration.

**Table 2-2.** Raw Water Quality for the Midwest Site<sup>a</sup> (No. of samples)

Parameter	Average Value
Total As, mg/L (5)	0.041
Dissolved As, mg/L (5)	0.036
As (III), mg/L (5)	0.032
Sulfate, mg/L (1)	0 - 4
Alkalinity, mg/L as CaCO <sub>3</sub> (4)	416
Dissolved Oxygen, mg/L (4)	0.3
Total Iron, mg/L (5)	2.68
Total Manganese, mg/L (5)	0.100
Calcium, mg/L (5)	89
Hardness, mg/L as CaCO <sub>3</sub> (5)	340
Chloride, mg/L (5)	23
Sodium, mg/L (5)	33
Total Dissolved Solids, mg/L (5)	460
Total Organic Carbon, mg/L (5)	2.5
Temperature, degrees C (4)	22
pH (4)	7.0

a – values vary depending on blend of wells pumped

### 2.1.3 Southwest Site

A single well (Walker) in the City of Albuquerque, NM water system was selected as the Southwest Site. Historical water quality data for this well had determined that a significant portion of the As present was As(III). Further, the As(III) level was known to be in the range of 0.015 mg/L and the supply met the other criteria for selection. A separate As speciation test was done, even though others had speciated this well supply several times over the previous 8-year period. The result of this speciation test confirmed the previous values for total As and As(III), further establishing that the As concentrations are relatively constant. The levels for total As, dissolved As, and As(III) were 0.035, 0.033, and 0.015 mg/L, respectively. A summary of pertinent water quality for this site during the two day testing is given in Table 2-3.

**Table 2-3. Raw Water Quality for the Southwest Site (No. of samples)**

Parameter	Average Value
Total As, mg/L (6)	0.035
Dissolved As, mg/L (6)	0.033
As (III), mg/L (5)	0.015
Sulfate, mg/L (1)	35
Alkalinity, mg/L as CaCO <sub>3</sub> (6)	141
Dissolved Oxygen, mg/L (5)	5.3
Total Iron, mg/L (6)	ND 0.02
Total Manganese, mg/L (6)	0.020
Calcium, mg/L (6)	39
Hardness, mg/L as CaCO <sub>3</sub> (6)	120
Chloride, mg/L (6)	84
Sodium, mg/L (6)	78
Total Dissolved Solids, mg/L (6)	370
Total Organic Carbon, mg/L (6)	< 1
Temperature, degrees C (6)	28
pH (6)	7.8

Walker well is pumped directly into the distribution system with no treatment provided. All source water for testing was taken from taps in the main water line between the well and the distribution system. The well was pumped continuously at a flow rate of 150 L/min (2,380 gpm) during the entire test period.

## 2.2 Aeration Systems

### 2.2.1 Spray Aeration

A fabricated spray aeration system was used at the Northeastern and Southwest sites and was operated at 0.35 L/s (5.6 gpm) and 0.50 L/s (8 gpm), respectively. The system consisted of a hose with a spray nozzle on the end, and the water was discharged into a 65-gal polyethylene tank having a 10" lid that was removed during testing. The tank continually drained during testing, thereby serving as a chamber to contain the water spray. The spray nozzle produced a helical pattern as shown in Figure 2-1. Other than the flow rate, there are no specific design parameters to describe the spray aeration system.

### 2.2.2 Staged Bubble Aeration

A three-stage bubble aeration system<sup>a</sup> was tested at all three sites. The system consisted of the aeration vessel, with a 1.08 m<sup>3</sup>/min (38 cfm) regenerative blower<sup>b</sup> providing air to three individual aerators, one per stage. Static water depth was 15" and the flow was by gravity through the vessel at a flow of 0.63 L/s (10 gpm) at the three sites. The air to water (A/W) ratio was 25. The A/W ratio for ≈ 90 percent oxygen saturation with this system would be approximately 15 at 10 degrees C, so the system was conservatively designed with respect to oxygen transfer. The bubble aeration system is shown in Figure 2-2.

<sup>a</sup> manufactured by Lowry Systems, Inc.

<sup>b</sup> Model R103 manufactured by Gast, Inc.



Figure 2-1 – Spray Aeration nozzle spraying water at 0.5 L/s (8 gpm)



Figure 2-2 –Aeration Systems (bubble - center;  
Tower - left; spray - right)

### **2.2.3 Packed Tower Aeration**

A 15.2 cm (6") diameter stainless steel counter-current packed tower was fabricated for this project and tested at all three sites. Overall tower height was 3.65 m (12 ft) and packing depth was 3.05 m (10 ft). Tower packing<sup>c</sup> was the loose-fill type. The flow rate to the tower ranged from 0.50 L/s (8 gpm) to 0.63 L/s (10 gpm). The air was supplied by a 1.19 m<sup>3</sup>/min (42 cfm) regenerative blower (same as used for bubble aeration, at a different pressure/flow). The liquid loading rate was approximately 14.3 L/m<sup>3</sup>-min (40.7 gpm/ft<sup>2</sup>). A photo of the packed tower is shown in Figure 2-2.

### **2.2.4 Forced-Draft Tray Aeration**

A forced-draft tray aerator was used in lieu of the spray system at the Midwest site. This aerator was a part of the treatment train at this site and presented an opportunity to document a full-scale operation. The aerator operated at 47.3 – 56.7 L/s (750 - 900 gpm) during our testing period. A photo of the forced draft aerator is shown in Figure 2-3.



Figure 2-3 – Forced-Draft Tray Aerators

## **2.3 Storage Container**

The storage container<sup>a</sup> used at all three locations was a 56.7 L (15 gal) polyethylene carboy. The carboy was filled with raw water from a hose at the beginning of the site visit and allowed to sit in a quiescent state for the duration of the time spent at each site. Two different approaches were used in doing the storage experiments: 1) at the Southwest site, the storage container was filled with unaerated well water,

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<sup>c</sup> 1" Polypro Tri-Packs manufactured by Tri-Mer Corp.

<sup>a</sup> Nalgene brand



and 2) at the Midwest and Northeast sites the water was aerated prior to filling the storage container aeration. At the end of the test period (varied by site - approx. 48 hrs), enough water was transferred into 3.78 L (1 gal) or 1-L polyethylene containers for later samplings necessary to complete the five-day storage experiment. These samples were transferred back to the office for processing at the specified storage times. Samples were taken from a plastic spigot installed in the side of the carboy at 3" off the bottom.

## **2.4 Water Sampling & Data Collection**

### **2.4.1 General Field Procedures**

In preparation for a site visit for testing, necessary treatment equipment and supplies were shipped or transported to the site. Upon arrival, the equipment was set up, the 15 gallon storage volume was transferred into the storage container (see above), and the "Pre-test" samples were taken and processed. D.O. and pH were measured and As speciation separations were performed, while the equipment was flow-calibrated and allowed to run at steady state for approximately 30 to 60 min. Calibration for flow was done by the bucket and stopwatch method, using a calibrated 5-gal container.

Aeration and storage testing was performed at each site, as described below (Sections 2.4.3 and 2.4.4). At the end of the on-site aeration and storage testing the equipment was dismantled and packed for shipment to the next site or to equipment storage. After the Midwest site, it was necessary to clean the tower packing and the bubble aeration system before it was shipped to the Southwest site. Cleaning was necessary because of iron precipitation at the Midwest site. Cleaning was accomplished by soaking all of the packing in a 3:1 solution of water and muriatic acid. The cleaned packing was completely free of all traces of visible Fe.

### **2.4.2 Pre and Post Test Well Sampling**

In addition to the As testing required to determine speciation, each water source was characterized before and after each set of concurrent aeration tests for pH, alkalinity, dissolved oxygen, iron (dissolved and total), manganese (dissolved and total), TOC, calcium, magnesium, total hardness, chloride, sodium, TDS, and heterotrophic plate count (HPC). A total of 5, 5, and 6 well samples were taken at the Northeast, Midwest, and Southwest sites, respectively. HPC samples numbered 1, 4, and at the Northeast, Midwest, and Southwest sites, respectively.

All pre and post test well samples were taken at spigots in the well supply piping. Samples to be processed on-site were collected in a single 800 ml polyethylene beaker. The pH, Fe and Mn, and As samples were all taken from the single sample volume. D.O. samples were collected in standard clear glass BOD bottles. Remaining samples for laboratory analysis were taken in laboratory supplied 250-ml polyethylene wide-mouth bottles or in 1-L collapsible polyethylene containers.

### **2.4.3 Aeration Sampling**

The aeration testing was designed to be conducted over a 6-hr period, with treated water samples collected at 30-min intervals. Each water sample was analyzed for pH, As (total, dissolved, and III), dissolved oxygen, total and dissolved iron, and total and dissolved manganese. Each aeration test was repeated for a total of two (2) test runs per site per aeration method. Separation of dissolved from total As and As(III) from As(V) was accomplished with an on-site As speciation procedure, as detailed in Section 2.5.2.

Testing was done for all three aeration methods concurrently, for each day and at each site. Samples were collected and the As separations, pH, and D.O. were completed within the 30-min interval when possible. For the D.O. measurements, it was often times impossible to complete the settling and titration steps before the next sampling round. In those cases, additional D.O. bottles were used to collect the samples on time; however, at certain times it was not possible to do the D.O. every 30 min and some samples were not taken.

Aeration samples were taken at the discharge end of the process. For the bubble, tower and spray methods this was at the discharge fitting or hose. For the forced-draft aerator the sample was taken from a spigot at the bottom of the device. Samples were collected in a single 800 ml polyethylene beaker. The pH, Fe and Mn, and As samples were all taken from the single sample volume. D.O. samples were collected in standard clear glass BOD bottles.

The aeration methods afforded different times of actual contact. The bubble aeration gave 3.4 min of contact at 0.63 L/s (10 gpm), and the tower and spray methods gave several seconds (estimate). The residence time for the forced-draft aerator is not known.

#### **2.4.4 Storage Sampling**

It was intended that storage water samples would be taken at 1, 6, 12, 24, 36, 48, 72, and 120 hr and analyzed for arsenic, dissolved oxygen, iron (dissolved and total), manganese (dissolved and total) and temperature. Actual times varied as dictated by travel schedule and the aeration sample processing activities. The arsenic analyses included total and dissolved As, As(III), and As(V). Separation of dissolved from total As and As(III) from As(V) was accomplished with an on-site As speciation procedure, as detailed in Section 2.5.2.

Storage sampling was done without shaking or mixing the contents of the storage container. At the Midwest site, significant Fe precipitation occurred during storage, which settled in the container and adhered to the container sides. Mixing was not done to better depict the quiescent storage conditions typical of actual facilities.

#### **2.4.5 Summary of Sampling**

Table 2-4 is a summary of the samples collected for aeration and storage testing.

### **2.5 Analytical Procedures**

#### **2.5.1 Chemical Analyses**

Dissolved oxygen, pH, filter separations, and As speciation separations were conducted and recorded on-site due to the instability of these samples over the time required in transport to the laboratory. The HPC samples were either conducted by a local laboratory near the site (Northeast site), or at the laboratory of the participating water utility (Midwest and Southwest sites). At the Northeastern site the testing occurred through a weekend and it was not possible to do all of the HPC testing originally planned because the hold time was 24-hr maximum and the available laboratories were not open for sample receiving within the hold time. All of the other samples were analyzed at the Maine Health and Environmental Testing Laboratory (MHETL). Table 2-5 is a summary of the analytical methods used in this study.

**Table 2-4. Summary of Sampling for Aeration and Storage Testing**

Parameter	Pre & Post Samples	Aeration Samples	Storage Samples
Total As	√	√	√
Dissolved As	√	√	√
As(III) & As(V)	√	√	√
Total Fe	√	√	√
Dissolved Fe	√	√	√
Total Mn	√	√	√
Dissolved Mn	√	√	√
Chloride	√	–	–
TDS	√	–	–
Calcium	√	–	–
Sodium	√	–	–
Hardness	√	–	–
Alkalinity	√	–	–
TOC	√	–	–
HPC	√	–	–
D.O.	√	√	√
pH	√	√	√
Temperature	√	√	√
Notes	4- 6 sets/ site	12 sets in 6-hr & duplicated per method/site	8 sets/site over 5-days

Note: Actual time and number of samples taken are in Appendix A, B, & C

**Table 2-5. Analytical Method Summary**

Analysis	Method	Method No.	Reference	Detection Limit, mg/L
As	ICAP	200.7	EPA <sup>a</sup>	0.002
As	AA		EPA <sup>d</sup>	
Fe	ICAP	200.7	EPA <sup>a</sup>	0.002
Mn	ICAP	200.7	EPA <sup>a</sup>	0.0001
D.O.		4500-OC	Std. Methods <sup>b</sup>	0.50
Sulfate		375.2	EPA	2
pH	electrometric		Std. Methods <sup>b</sup>	--
Alk.	titration	2320B		0 by definition
Hardness	ICAP	200.7	EPA	0.1
TOC	IR	5310B	Std. Methods <sup>c</sup>	1.0
Ca	ICAP	200.7	EPA	0.01
Na	ICAP	200.7	EPA	0.1
Cl		325.2	EPA	3
HPC	filter	9215	Std. Methods <sup>b</sup>	
TDS		2540C	Std. Methods <sup>b</sup>	20

a – EPA-600/4-91-010 (1994)

b – "Standard Methods for the Examination of Water and Wastewater," 19<sup>th</sup> ed., 1995

c - "Standard Methods for the Examination of Water and Wastewater," 20<sup>th</sup> ed., 1998

d – EP A-XXX

### **2.5.2 As Speciation**

Water samples were speciated for As according to the anion exchange separation method published by Ficklin<sup>4</sup> and further refined by Edwards<sup>5</sup>, et. al. Purolite A300E resin was converted from the chloride form to the acetate form using the procedure given by Ficklin. A deviation from the Ficklin method is that the resin had a mesh size of 16 x 50.

As speciation kits were prepared for each site and transported to the sites by automobile (Northeast) or by air (Midwest and Southwest). The field kits were prepared and used, following the method summarized by Batelle<sup>6</sup>. The syringe filter (Nalgene nylon membrane) rating was 0.45  $\mu$ . The "total As" sample was collected in an 800 mL polyethylene beaker. A portion of that volume was syringed and filtered into the "dissolved As" bottle, and a portion of that volume was poured through the IX resin column (Bio-Rad chromatography column – 20 ml) and became the "As(III)" sample.

## 3.0 Test Results

All test results are tabulated in Appendix A, B, and C for the Northeast, Midwest, and Southwest, respectively.

### 3.1 Northeast Site

#### 3.1.1. Aeration

The bubble aeration, packed tower aeration, and spray aeration systems were operated at 0.63 L/s (10.0 gpm), 0.45 L/s (7.14 gpm), and 0.35 L/s (5.6 gpm), respectively, on both days of testing. Flow was reasonably steady at  $\pm 5$  percent and was checked before and after each 6-hr test period.

Testing on Day 1 was hectic due to this being the first site setup. Testing commenced late in the day and was terminated at 5 hr, rather than the planned 6 hr, due to the lateness of the day and our proximity to nearby residents. One (1) DO and several pH measurements were missed, as it was difficult to keep up with the 30-min sampling schedule. Day 2 proceeded more smoothly as efficiencies were improved and a better system of sample processing developed. After the experience at this site, we decided to not collect separate Fe and Mn sample containers, since the total As and dissolved As (bottles were preserved and would give the total and dissolved Fe/Mn from the results of the ICAP analysis).

The well water quality for this site is in line with what might be expected for a groundwater containing appreciable As(III). The DO was low at an average of 1.3 mg/L, with two samples showing approximately 0.75 mg/L. There was a noticeable hydrogen sulfide odor in the raw water, although the hydrogen sulfide was below a detection limit of 0.05 mg/L. The total As averaged 0.104 mg/L in the five (5) "pre" and "post" observations. The raw water As levels are summarized in Figure 3-1. Note that the dissolved As appeared to be slightly greater than the total As; however, the difference between means was not statistically significant ( $\alpha = 0.05$ ). Therefore the total and dissolved As in the well were considered to be equal. The dissolved As was 94 percent As(III) and the difference between the mean values for dissolved and As(III) was significant ( $\alpha = 0.05$ ). This indicated that there was approximately 6 percent As(V) present in the well water.

The A/W ratio for bubble and tower aeration was 28.4 and 44, respectively. The spray was operated at a lower flow rate because it was not as an efficient method of aeration. In all three cases, the DO was raised to near the saturation level of 11.0 mg/L at 11 degrees C. This is illustrated in Figure 3-2. Clearly, even at the lower flow rate the spray device was not as efficient in transferring oxygen. The spray would have been more effective if a fan had been used to continually replenish the air contained in the semi-open spray chamber. In any event, it can be stated that all three aeration methods provided a maximum opportunity for the oxidation of As(III), as the DO levels were high and the mixing of air and water was very good.

An example of results from an aeration test is shown in Figure 3-3, for Run 1 of the bubble aeration unit. The results show that aeration had no effect on the oxidation of As(III). The aeration processes were operated in a steady state mode, therefore, one would not expect any temporal change in As levels. Thus, all of the samples would be expected to be duplicates over time, with each subsequent sample reinforcing the same observation. Relatively constant As(III) levels in the raw and treated water are illustrated in Figure 3-3. A statistical analysis of the bubble aeration data for Run 1 showed that there was no significant ( $\alpha = 0.05$ ) difference between the well and aerated As(III) levels. In addition, there was no significant ( $\alpha = 0.05$ ) difference between the total and dissolved As levels in the aerated samples.

The constancy of As(III) levels is best illustrated in Figure 3-4, where all of the raw and aerated average sample results are presented. These results show that aeration did not oxidize As(III) at this site.

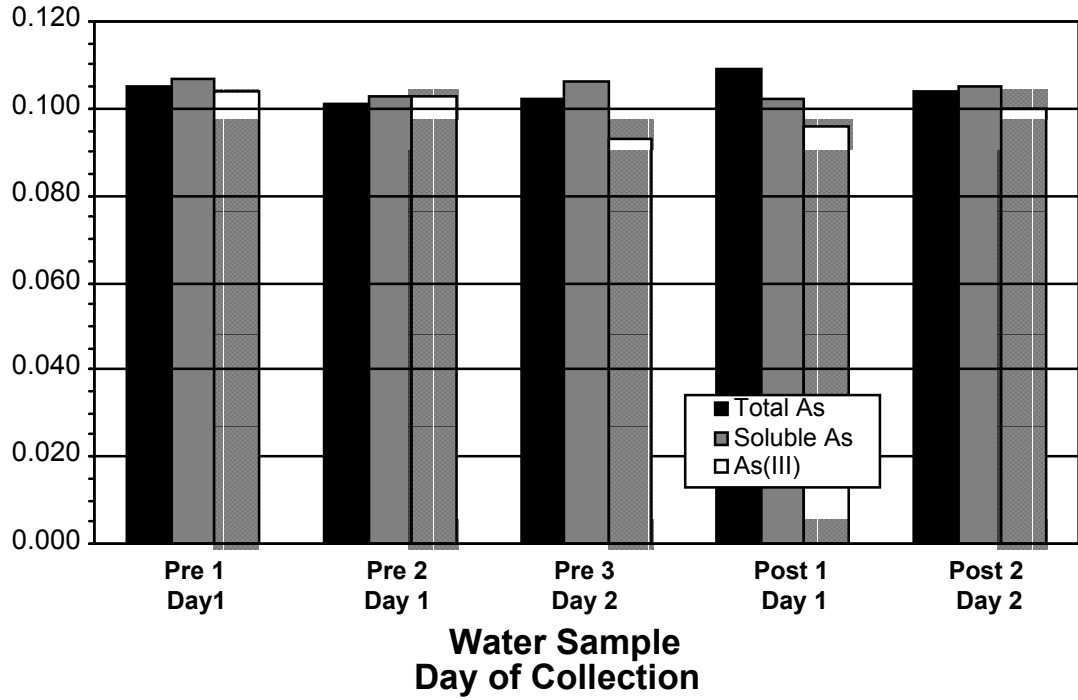


Figure 3-1. As Speciation Test Results for Well Water, Northeast Site

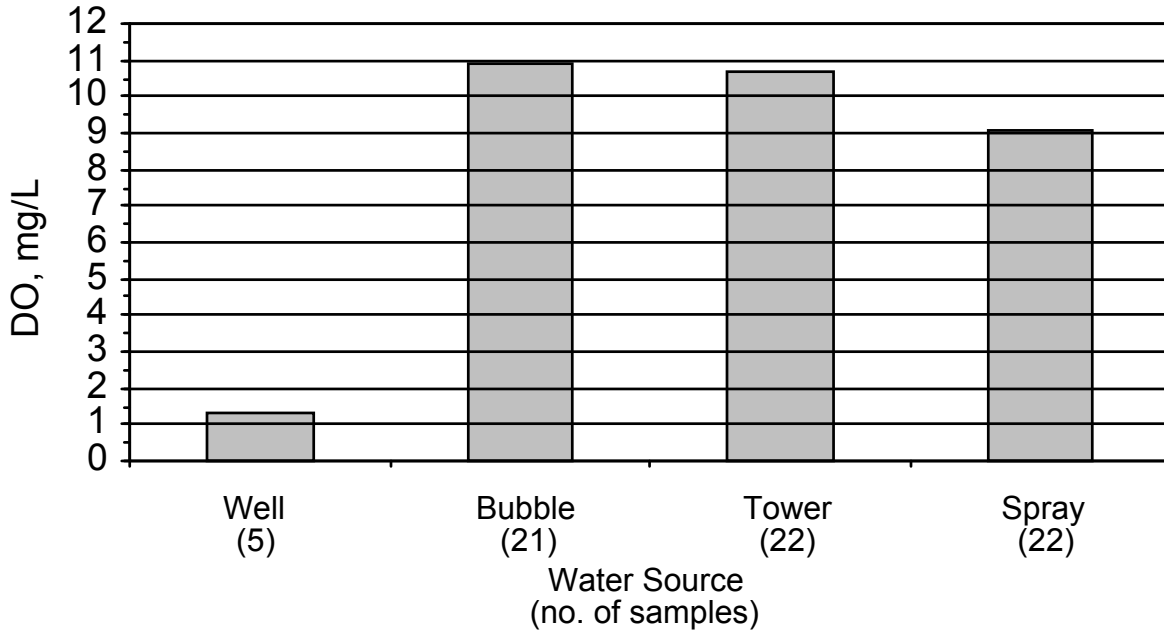


Figure 3-2. Avg. Well & Aeration DO Concentrations (2 Test Runs), Northeast Site\

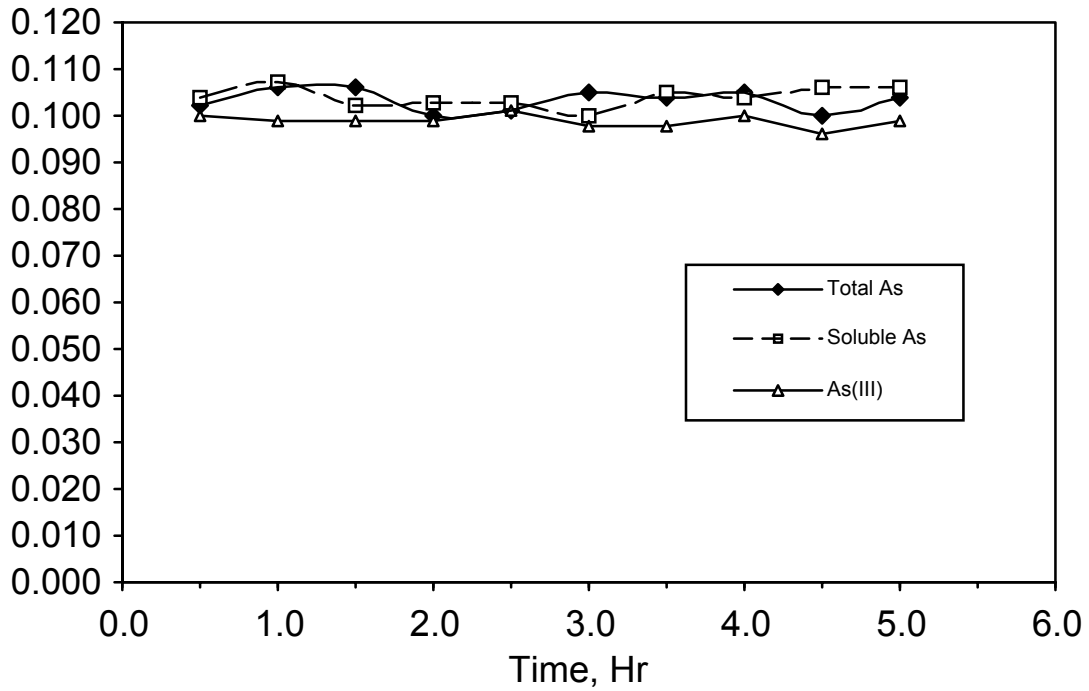


Figure 3-3. As Speciation Test Results for Bubble Aeration (Day 1), Northeast Site

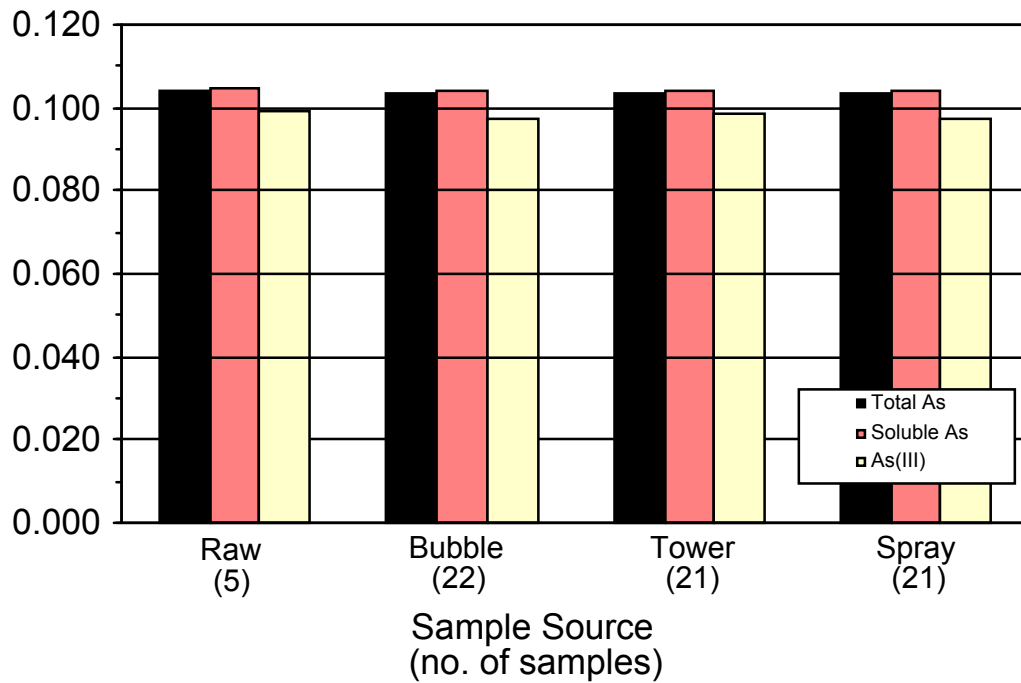


Figure 3-4. Avg. As Results for Well & Aerated Samples (Run 1 & 2), Northeast Site

### 3.1.2 Storage

The results from the storage test are summarized in Figure 3-5. The results do not show a general trend of oxidation of As(III). Considering the fact that appreciable DO (7 to 8+ mg/L) was present during storage, it appears conditions of aerobic storage did not oxidize As(III). The average level of As(III) was several percent lower than in the other As(III) samples from the aeration experiments; however, with the lack of any progression of oxidation over time this is not considered important.

## 3.2 Midwest Site

### 3.2.1 Aeration

The forced draft aeration (Unit No. 4), bubble aeration, and packed tower aeration systems were operated at 56.7 L/s (900 gpm), 0.63 L/s (10.0 gpm), and 0.50 L/s (8.0 gpm), respectively, on both days of testing. Flow to the bubble and tower units was reasonably steady at  $\pm 5$  percent and was checked before and after each 6-hr test period for the two small aeration systems. The flow rate for the forced draft aerator was monitored by the existing plant flow metering equipment.

The raw water quality for this site is in line with what might be expected for a groundwater containing a significant fraction of As(III). The DO was nearly zero with an average of 0.3 mg/L. Iron and manganese were very high at 2.76 mg/L and 0.155 mg/L, respectively. Essentially all of the raw water Fe and Mn was in the dissolved form.

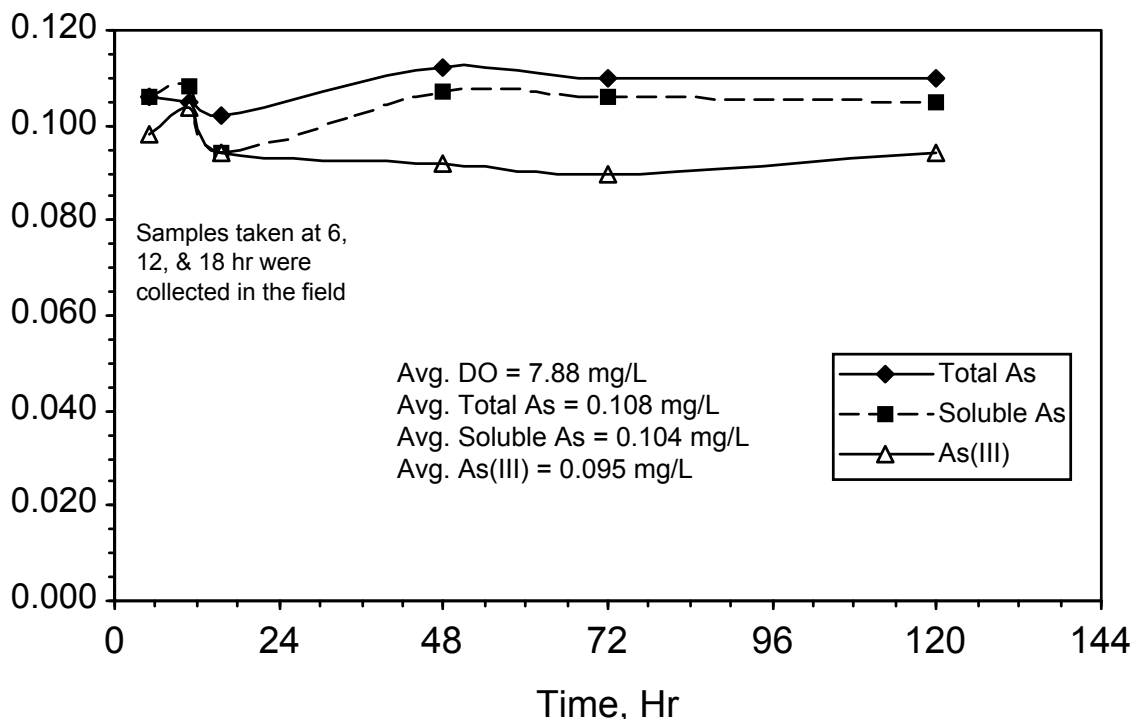


Figure 3-5. As Speciation Test Results for the Storage Water, Northeast Site



The raw water As levels for Day 1 and Day 2 are summarized in Figure 3-6. On Day 1 the As levels were very consistent, with a total As average of 0.041 mg/L. The dissolved As averaged 0.0355 mg/L (77.5 percent) and the As(III) was 0.0315 mg/L (83.9 percent of dissolved As). The Day 2 As level was significantly lower than on Day 1 due to a change in the blend of well water being pumped. On Day 1, Wells 7 (higher As), 8, and 9 were pumped and starting at midnight on Day 2, only Wells 8 and 9 were pumped. In addition to being lower overall, the Day 2 As levels fluctuated during the 6-hr testing period. A sharp rise in concentration occurred toward the end of the test period when the pumping schedule changed back to Wells 7, 8, and 9. For this reason, the remainder of the result presentation focuses on Day 1, as those data present the clearest view of the aeration results. Day 2 data show the identical result as Day 1, except with a fluctuating inlet As level, and are tabulated in Appendix B.

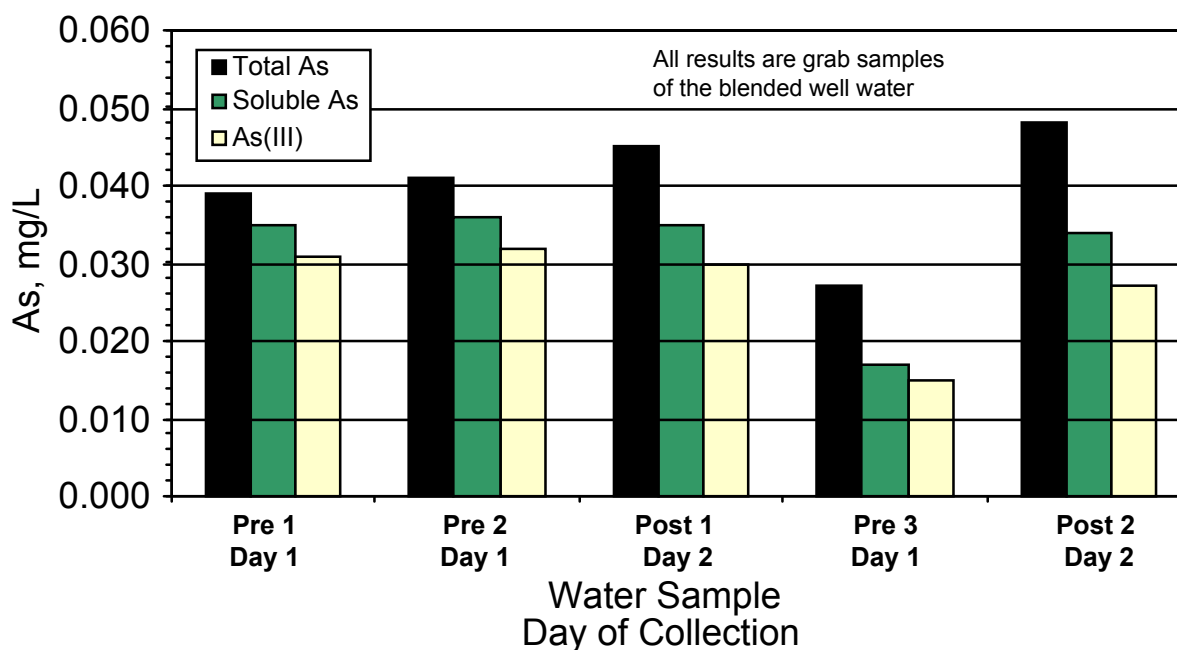


Figure 3-6. As Speciation Test Results for the Blended Well Water, Midwest Site

The DO levels for the raw and aerated water are illustrated in Figure 3-7. The A/W ratio for bubble and tower aeration was 28.4 and 39.0, respectively. The exact design parameters for the forced draft aerator were not known, but it is known that this device is not as effective as the other two methods of aeration. The DO was raised to near the saturation level of 8.7 mg/L at 22.2 degrees C by the bubble (8.21 mg/L) and tower (8.28 mg/L) aerators. The forced draft aerator raised the DO to an average of 7.39 mg/L. In any event, it can be stated that all three aeration methods provided a maximum opportunity for the oxidation of As(III), as the DO levels were relatively high and the mixing of air and water was very good.

Due to the high Fe and Mn present in the raw water and their possible related importance, it is useful to present those data before looking at the As data. Figures 3-8 and 3-9 summarize the Fe and Mn test results, respectively. Aeration had a dramatic effect on the solubility of the Fe for this water supply, and oxidized over 98 percent of the dissolved Fe to particulate Fe. The effect for Mn was much less, as would be expected from basic process chemistry at a pH of approximately 8.0 in the aerated waters. Figure 3-10 show the pH data for the raw and aerated samples on Day 1.

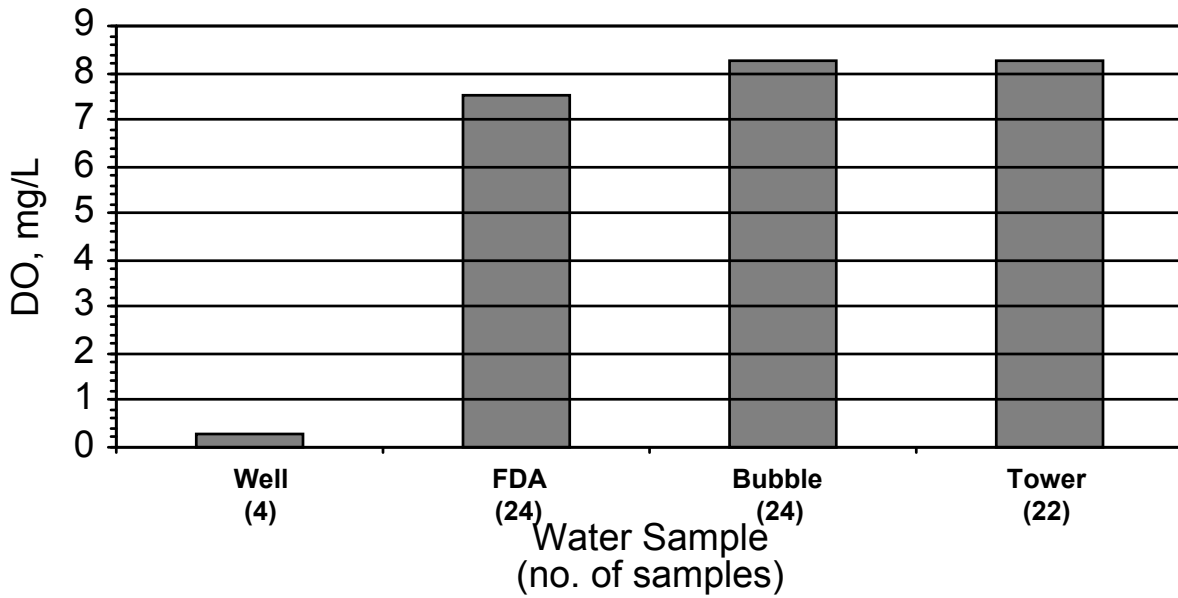


Figure 3-7. Avg. Well & Aeration DO Concentrations (2 Runs), Midwest Site

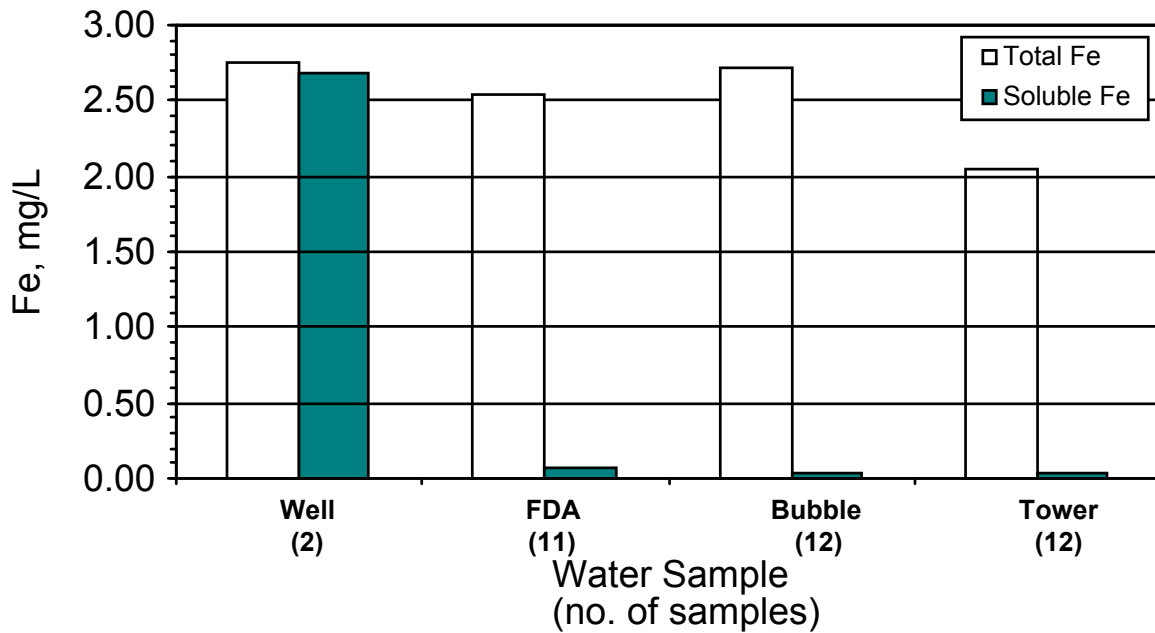


Figure 3-8. Avg. Fe Test Results for Well & Aerated Water (Run 1), Midwest Site

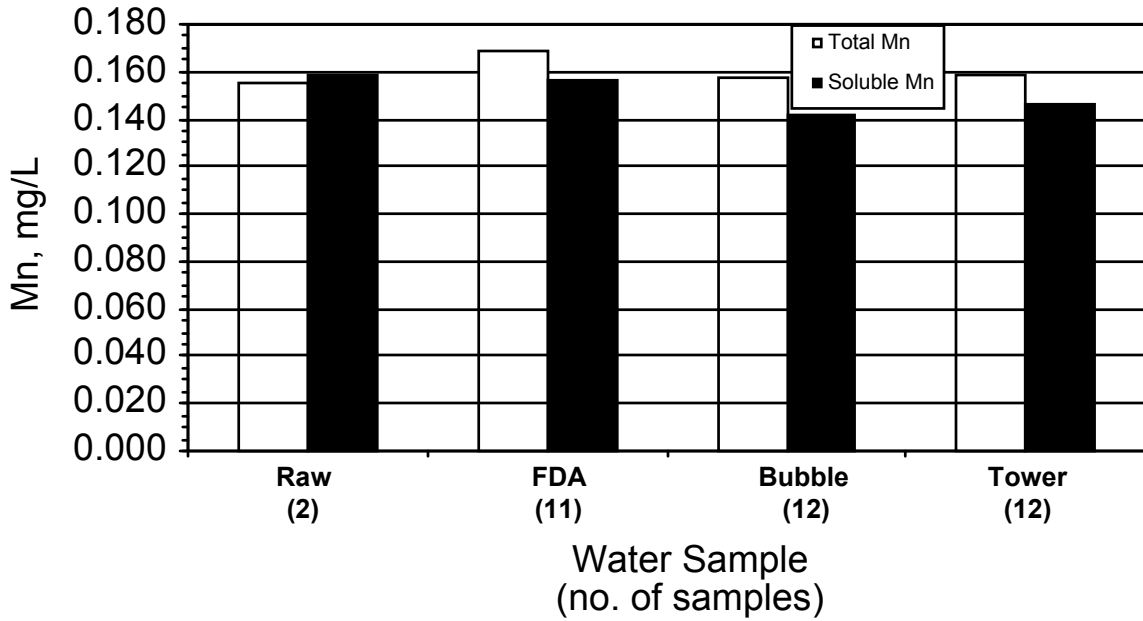


Figure 3-9. Avg. Mn Test Results for Well & Aerated Water (Run 1), Midwest Site

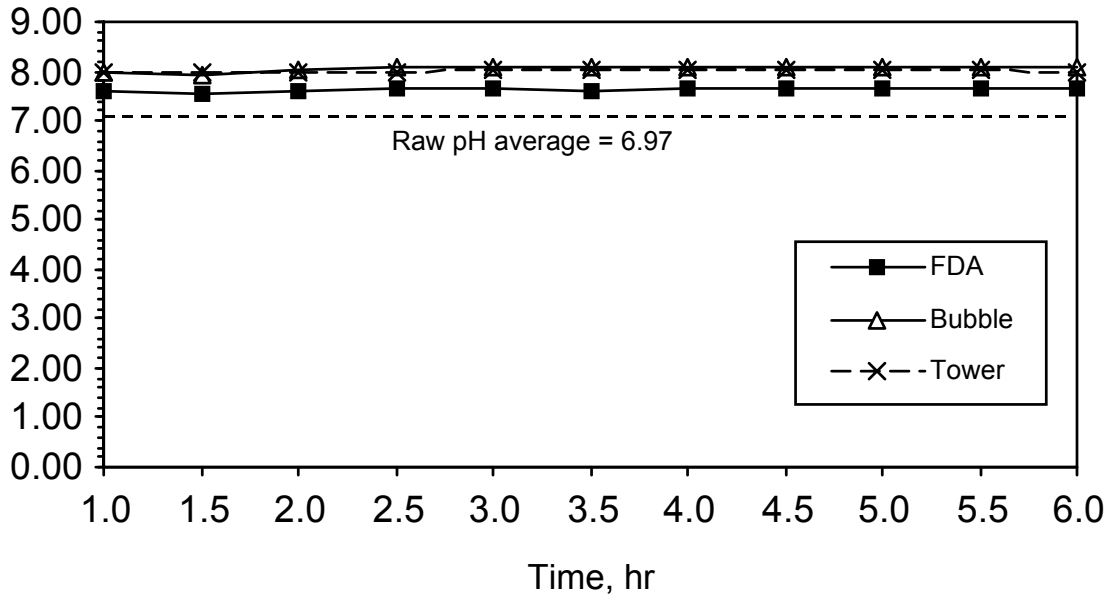


Figure 3-10. pH Results for Well & Aerated Samples (Run 1), Midwest Site

The total Fe should remain the same through aeration unless Fe is being removed from the water. Because aeration without subsequent downstream sedimentation or filtration normally would not show a removal of Fe – only an oxidation effect – it was surprising to observe that the packed tower appeared to actually reduce the total Fe. This is illustrated in Figure 3-8. Upon termination of the testing, the tower was examined and the packing media was found to be loaded with precipitated Fe. Mass calculations show that the Fe removed by the packing could have resulted in the lower Fe exiting the tower. For example, at an Fe removal of 0.75 mg/L and a flow rate of 0.50 L/s (8 gpm), only 8.18 grams of Fe would have been captured by the packing media. The bubble unit also showed a similar coating of Fe, but to a much lesser degree. The Fe data for the packed tower aerator are summarized in Figure 3-11. The packed tower data on Day 1 at first showed no removal, but as the testing period proceeded removal progressively increased. The Day 2 tower data showed even more removal of Fe by the tower packing and the removal leveled off at approximately 1.0 mg/L across the unit. The trend of progressive removal by the packing is clear. The last data point is representative of an interruption in the normal flow through the treatment unit and the test on the tower was terminated early.

The As speciation test results for Run 1 of the forced-draft tray aerator are presented in Figure 3-12. These results are typical of a 6-hr aeration test for this site, and the bubble and packed tower results were very similar. The As levels are reasonably consistent for the 6-hr test period. Because the aeration processes were operated in a steady state mode, temporal change in As levels would not be expected as long as the well levels remained consistent. Therefore, all of the samples would be expected to be duplicates over time, with each subsequent sample reinforcing the same observation.

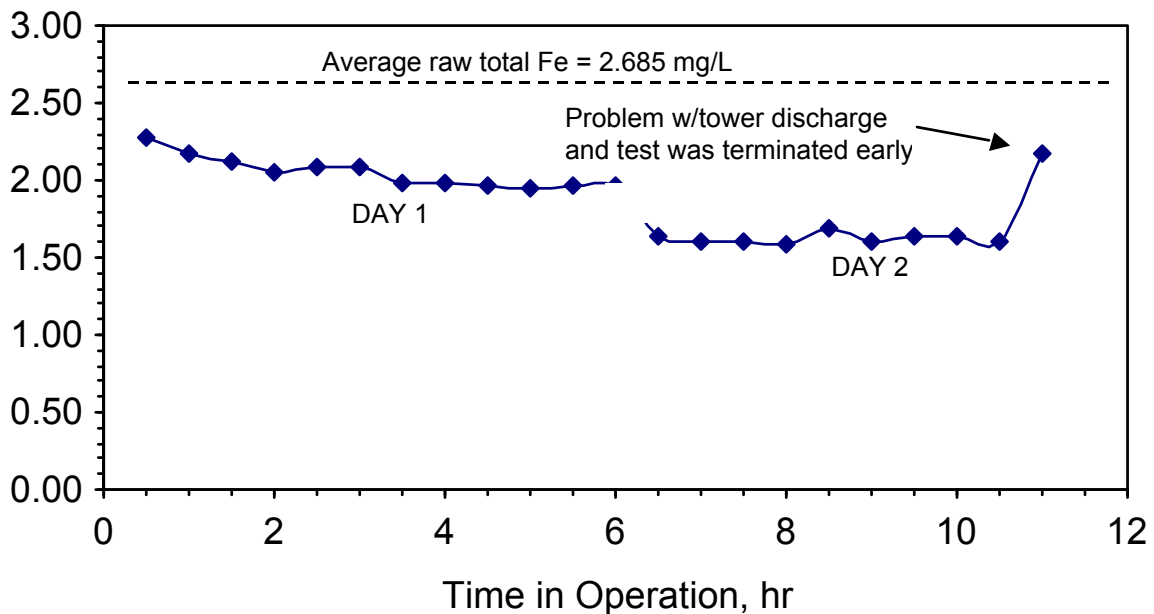


Figure 3-11. Fe (total) Results for Packed Tower (Run 1 & 2) Samples, Midwest Site

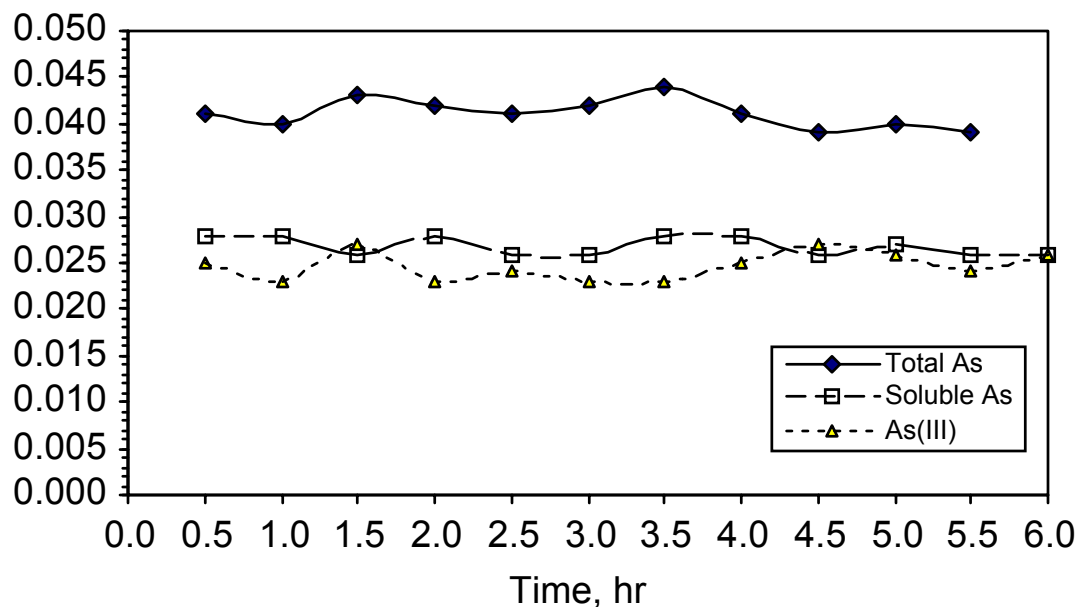


Figure 3-12. As Speciation Test Results for FDA Samples (Run 1), Midwest Site

All of the raw and aerated water As results for Day 1 are summarized in Figure 3-13. A comparison between the raw and aerated results show a significant drop in the level of As(III) after aeration. These results are very typical of other iron removal sites reported in the literature, where aeration is used to oxidize dissolved  $Fe^{+2}$ . This oxidation causes precipitation of  $Fe^{+3}$  and the removal of As associated with Fe.

The reduction in dissolved As(III) across the aeration step averaged 22 percent. The real question is whether the loss of dissolved As(III) was: 1) a result of As(III) oxidation to As(V) followed by adsorption, and/or 2) an adsorptive removal of part of the As(III) directly by the precipitated Fe. This will be discussed further in Section 4.

### 3.2.2 Storage

The arsenic results for the storage test are summarized in Figure 3-14. These results reflect the effect of precipitated Fe settling in the container, which is shown in Figure 3-15. A lesser fraction of the Mn also precipitated and settled during storage. Samples after 36 hr had less Fe and As than previous samples, and this effect became more pronounced with time. Essentially all of the precipitated Fe settled from the water after 36 hrs. Insoluble Fe was left in the storage and sample containers used for transport after Day 2, as the Fe settled and coated the walls of the containers. The samples at 48-hr and beyond showed less than  $\approx 30$  percent of the original total As and less than 3 percent of the total initial Fe at the beginning of storage. All of the As (0.012 mg/L) was in the dissolved form by the end of the storage period and almost all of the dissolved As was As(III). By 48-hr As (III) was below the detection limit of 0.003 mg/L.

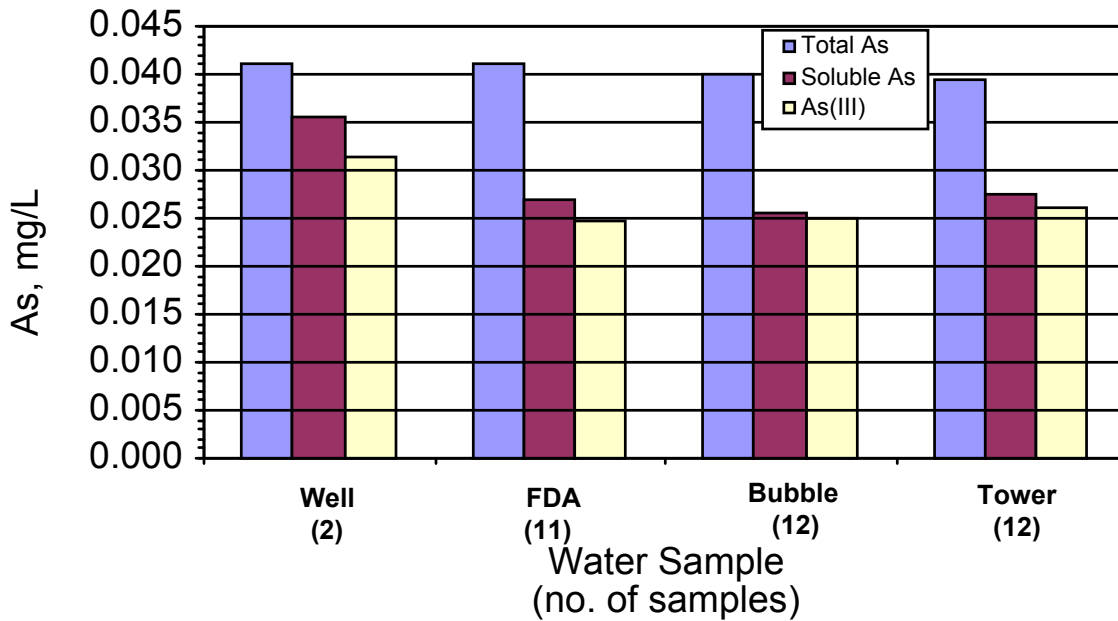


Figure 3-13. As Speciation Results for Well & Aerated Samples (Run 1), Midwest Site

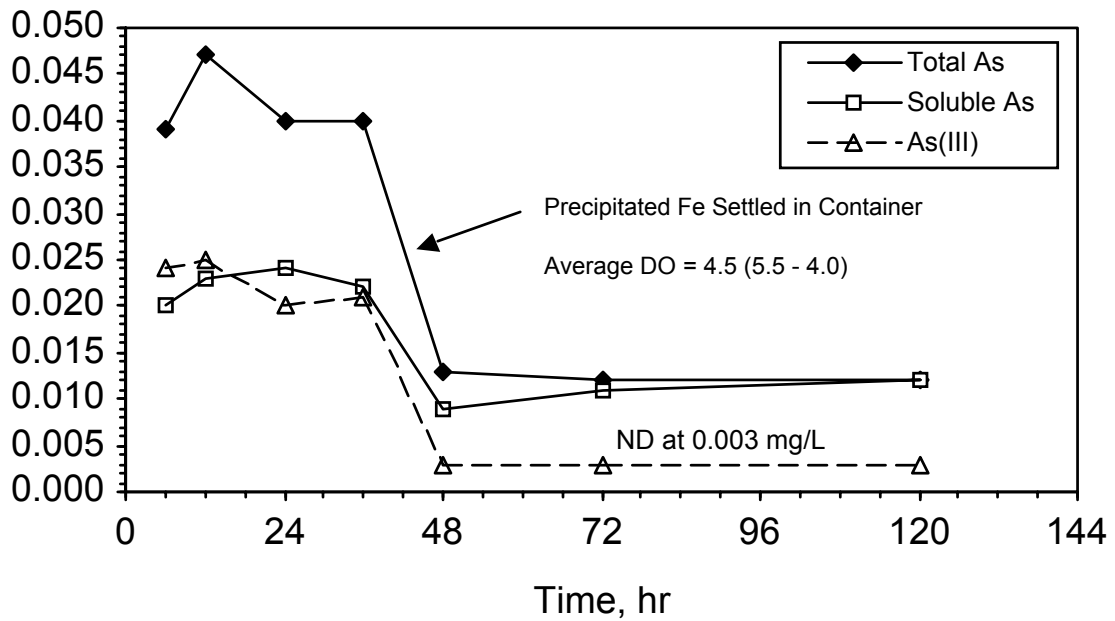


Figure 3-14. As Speciation Test Results for the Storage Samples, Midwest Site

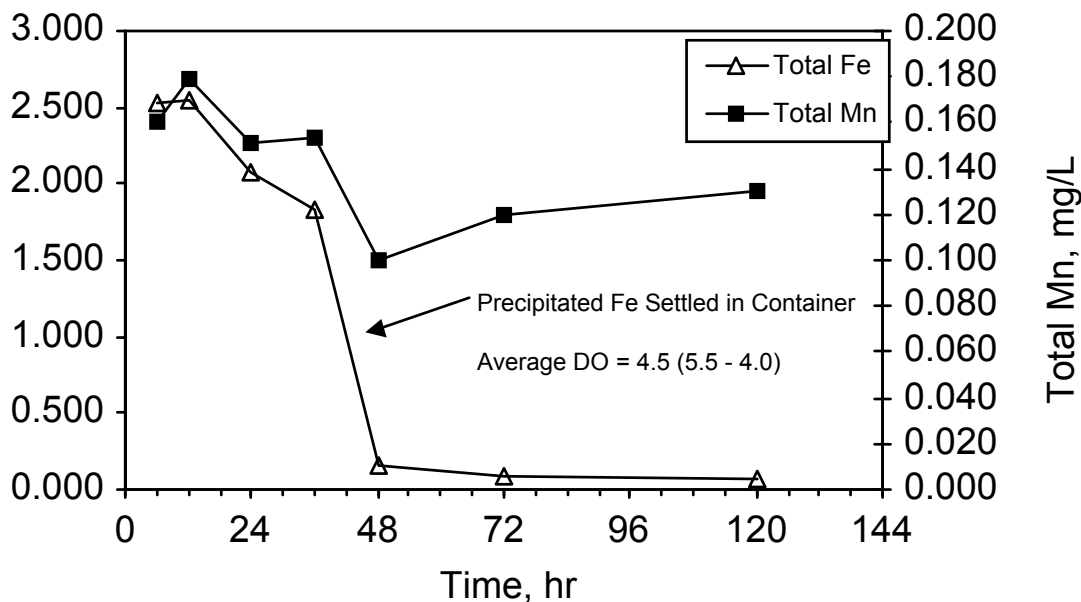


Figure 3-15. Fe & Mn Concentrations for Storage Samples, Midwest Site

### 3.3 Southwest Site

#### 3.3.1 Aeration

The bubble aeration, packed tower aeration, and spray aeration systems were operated at 0.63 L/s (10.0 gpm), 0.50 L/s (8.0 gpm), and 0.50 L/s (8.0 gpm), respectively, on both days of testing. Flow was reasonably steady at  $\pm 5$  percent and was checked before and after each 6-hr test period. The well water DO was greater than 5 mg/L. This was considered to be relatively high for a groundwater containing appreciable As(III). The DO levels in the raw and aerated samples are presented in Figure 3-16. The A/W ratio for bubble and packed tower aeration was 28.4 and 44, respectively. In all three cases, the DO measured was significantly lower than expected, as compared to the saturation level of 7.8 mg/L at 28 degrees C. The exact cause of this was not known, but the precipitation steps in the DO analysis were difficult and notably time consuming. On the second day, the DO was measured on only a few samples. Despite the problems with the DO analysis, it is certain that all three aeration methods provided a maximum opportunity for the oxidation of As(III), as the DO levels were high and the mixing of air and water was very good.

The aeration units raised the raw water pH to more than 8.0, as shown in Figure 3-17. The pattern of aerated pH values was similar to that for DO, as would be expected. The magnitude of pH rise is a function of the degree of carbon dioxide removal, given that the alkalinity was the same in each case. All of the systems raised the pH from the raw value of 7.8 to over 8.0. The range of aerated pH was 8.01 to 8.52.

The total As averaged 0.035 mg/L in the five (5) "pre" and "post" test observations. The As was 93.1 percent dissolved and 45.4 percent of the dissolved fraction was As(III). The raw water As levels are summarized in Figure 3-18.

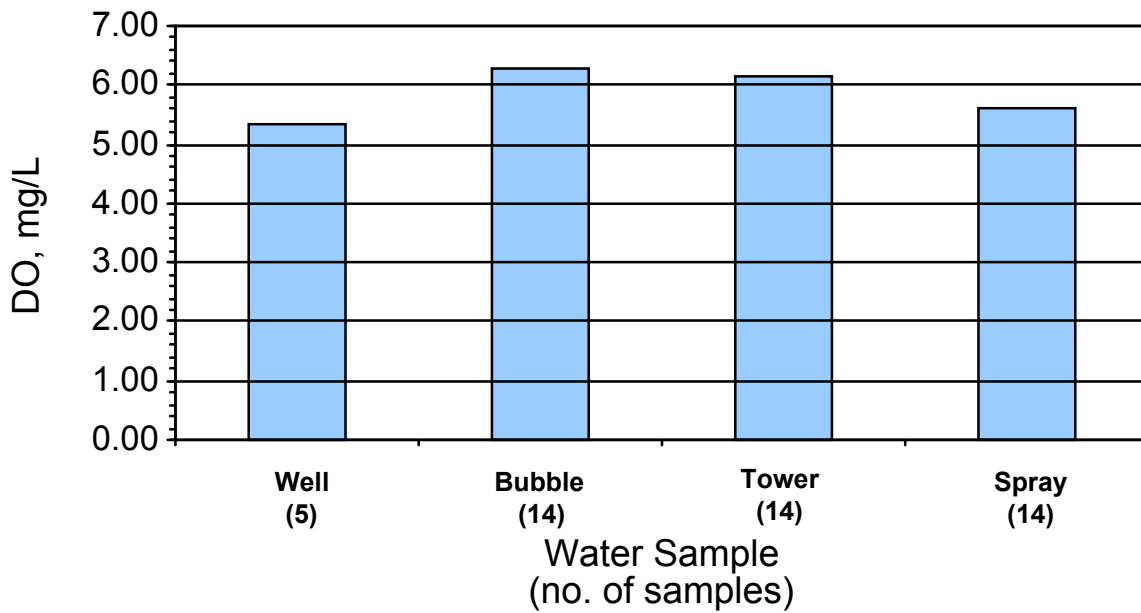


Figure 3-16. Avg. Well & Aeration DO Concentrations (2 Test Runs), Southwest Site

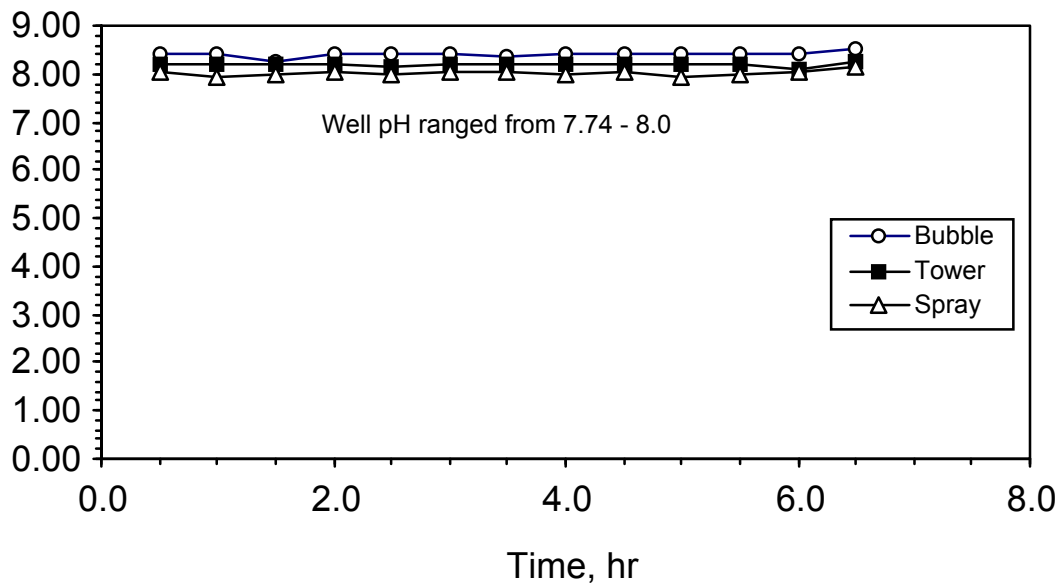


Figure 3-17. pH Results for Well & Aerated Samples (Run 1), Southwest Site



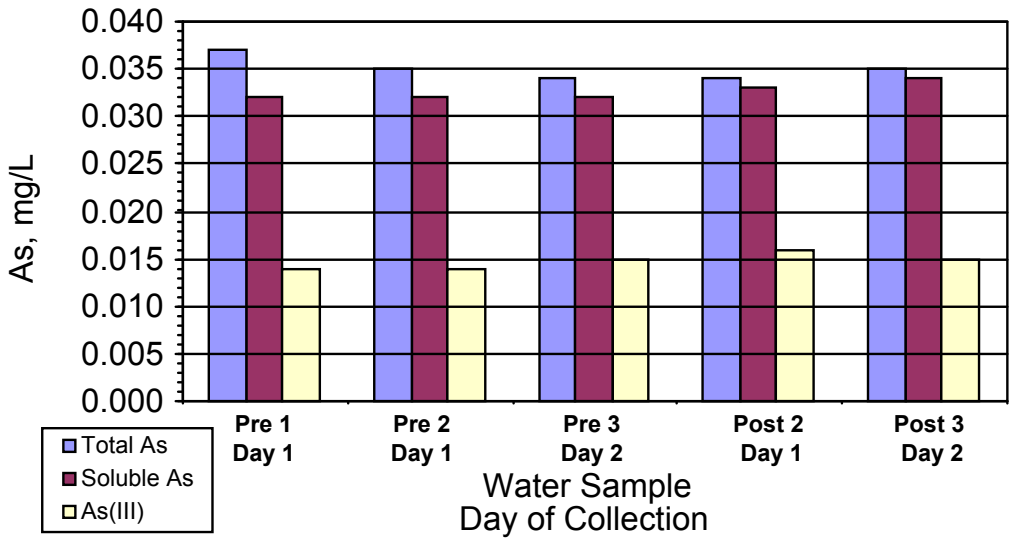


Figure 3-18. As Speciation Test Results for Well Samples, Southwest Site

The results of the packed tower aeration As results for Day 2 are shown in Figure 3-19. These data show that an oxidation of As(III) by aeration did not occur. Because the aeration processes were operated in a steady state mode, temporal change in As levels would not be expected as long as the well levels remained consistent. Therefore, all of the samples would be expected to be duplicates over time, with each subsequent sample reinforcing the same observation. This is the result that was observed, with the As(III) levels in the raw and treated waters remaining relatively constant.

The lack of an aeration effect on As(III) is best illustrated in Figure 3-20, where all of the raw and aerated sample results are presented. These results clearly demonstrate that aeration did not oxidize As(III) at this site.

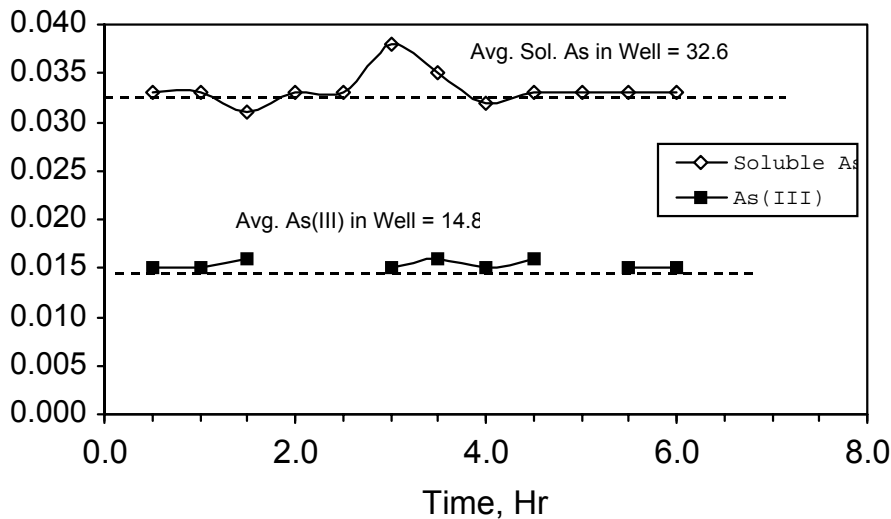


Figure 3-19. As Speciation Test Results for PTA (Run 2), Southwest Site

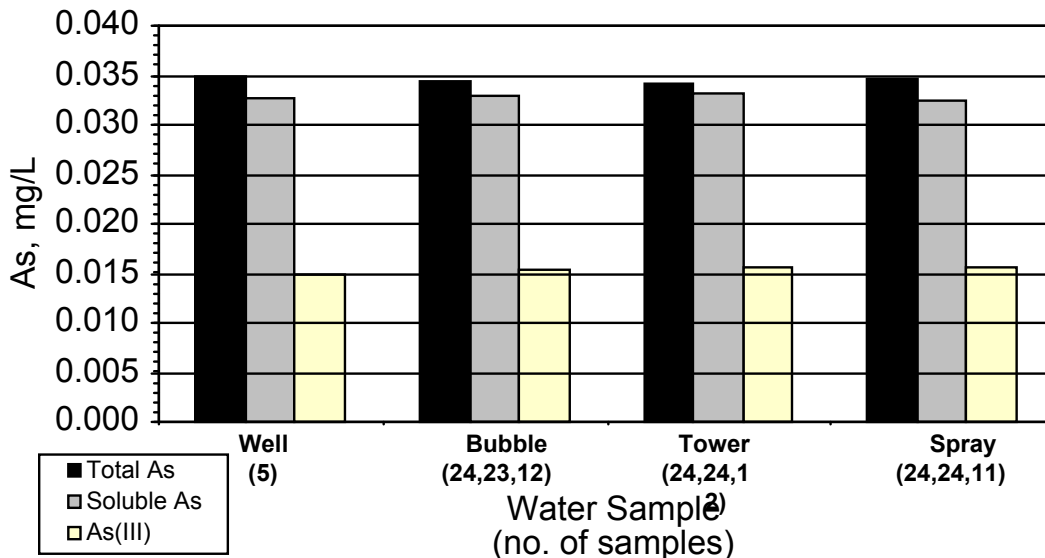


Figure 3-20. Avg. As Results for the Well & Aerated Samples, Southwest Site

### 3.3.2 Speciation Problem

A problem was experienced at the Southwest site due to a change in the method of speciation used in the field. The normal speciation procedure used at the other sites used the resin column once, or at most two times, before it was discarded. For a variety of reasons thought to be valid at the time of testing, the resin columns were not changed between each sample. All of the prepared resin columns lost their liquid fraction in transit due to the changes in air pressure that occur in air travel. This was aggravated by the dry climate in Albuquerque. The columns had to be re-packed to rid the resin of air pockets and this was time consuming, especially when it was discovered during the testing. A decision was made to use the columns for several samples, because it was believed at the time that the capacity of the column was very high in comparison to the throughput. Previous experience with the chloride-form resin speciation had shown this to be the case<sup>7</sup>. Later, the sample test results made it clear that this change in procedure caused some invalid As(III) measurements.

In addition to the misconception about column capacity, two other changes were made that exacerbated the column capacity problem. First, slightly more nitric and sulfuric acid was added to the bottles to offset the inevitable loss of acid that occurred anytime the empty sample bottles were shipped. The problem was first noticed at the Midwest site and confirmed by the utility personnel at that site, who also received similar samples by air that were associated with another EPA research project. They reported that their sample bottles always leaked acid in transit. Secondly, the analytical laboratory requested that additional As(III) sample be provided for analysis so the volume of sample poured through the resin column was increased. These changes decreased the capacity of the column because the sulfuric acid limits the throughput at only  $\approx 18$  BV under normal acid loading<sup>5</sup>.

The failure to recognize the BV limitation due to selecting sulfuric acid for acidification of the dissolved As sample in the As speciation method led to the loss of some of the Southwest Site As(III) data. Unfortunately the analytical laboratory used all of the extra dissolved sample for this site due to repeated ICAP runs on these samples. This was a separate problem thought to be related to silica precipitation in the analysis that resulted in repeated costly repairs to their ICAP instrument. Had this analytical problem

not taken the extra dissolved As sample volume, the resin treatment step could have been repeated to produce another As(III) sample. The dissolved As(III) samples were finally successfully run by graphite furnace AA.

Even with the loss of some of the sample results, there are ample data that clearly demonstrate the inability of aeration to oxidize As for the Southwest site. The criteria for discounting samples was the number of times the column was used. If a column was used one or two times, then the results were taken to be valid because sulfate breakthrough should not have been a factor. Any test done with a column that had already been used two times previously, was deemed invalid. Most of those tests did show an Arsenic peaking effect.

### 3.3.3 Storage

The storage results for the Southwest site are summarized in Figure 3-21. The data do not support an oxidation of As(III) as no general trend of oxidation was measured. The higher As(III) samples were typical ( $\approx 0.015$  mg/L) of what was measured in the raw and aerated water samples, and it is the samples at the beginning and end of the storage test that are atypically low ( $\approx 0.010$  mg/L). In general, these data do not indicate a significant oxidation by DO and storage.

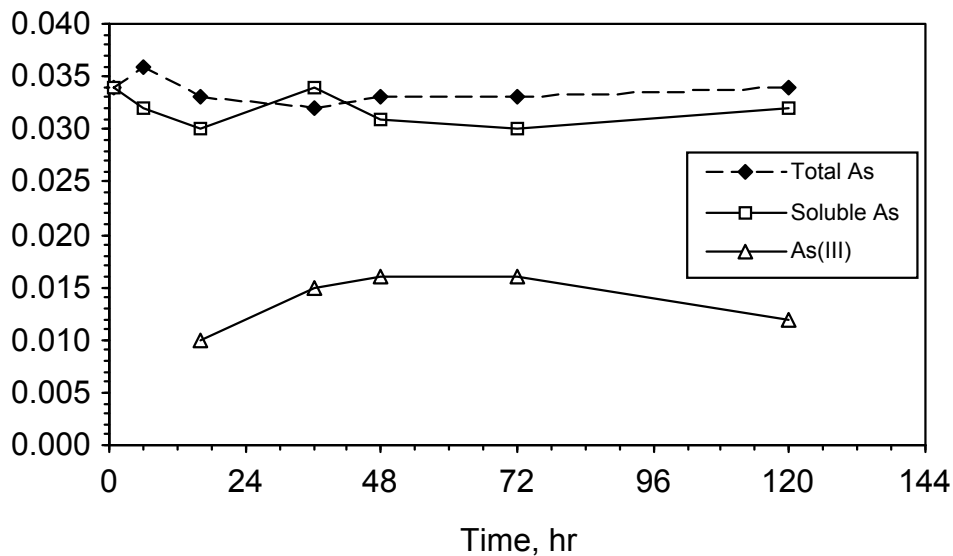


Figure 3-21. As Speciation Test Results for Storage Water Samples, Southwest Site

## 4. 0 Discussion and Conclusions

### 4.1 Oxidation of As(III) by Dissolved Oxygen

#### 4.1.1 Oxidation by Aeration

The conditions set up in this research were conducive to the oxidation of As(III) by DO. Dissolved oxygen and mixing of oxygen and water were equal to or greater than the normal design parameters for the transfer of oxygen into water. The data at the Northeast and the Southwest test sites support the hypothesis that As(III) is not oxidized by oxygen. Relatively high DO did not appear to cause any measurable oxidation of As(III), both in the aeration tests and the storage tests. The Northeast site had very high dissolved As(III) and there was no measurable oxidation by aeration and/or storage. The water at this site was relatively cold at 11 degrees C, so it was speculated that a higher temperature might increase the rate, if any, of As(III) oxidation by dissolved oxygen. The higher temperature condition was tested at the Southwest site, where the well water temperature was 28 degrees C. There was no measurable oxidation of As(III) due to aeration for the higher temperature condition.

The Midwest site provided an interesting observation in that there was an apparent significant reduction in As(III) as a result of aeration. However, this reduction in As(III) is thought to be entirely associated with the oxidation and precipitation of Fe. It is believed that As(III) is partially removed by precipitated iron, as has been reported in the literature.<sup>8,9,10,11</sup> It should be noted that at a pH of over 8.0, similar to that reached by the aeration systems in this study, some ( $\approx$  of the As(III)) would exist as the charged  $\text{As}(\text{OH})_4^-$ . Lastly, this study did not show the mechanism for the As(III) reduction at the Midwest site, so it is a possibility that the As(III) was converted to As(V) and removed by iron. In any event, the most important factor appeared to be the precipitation of Fe and not the presence of DO during aeration.

While the subtleties of arsenic removal associated with Fe precipitation are interesting, it is important to emphasize that the original objective was to establish if typical aeration methods could oxidize As(III). The results of this study show that aeration, or more specifically DO, is not effective in this regard. Aeration should not be considered as a candidate for As(III) oxidation; however, it will continue to be considered a very effective process for the oxidation of Fe. In that way, aeration can be said to be effective in bringing about the adsorptive removal of As via the oxidative precipitation of Fe.

#### 4.1.2 Oxidation of As(III) During Storage

The storage holding times under aerobic conditions were typical of what would occur in clearwells, standpipes, and/or reservoirs. These conditions should have resulted in some degree of oxidation of As(III), if aeration is a potential method for oxidation. At the Northeast and Southwest sites, there was no evidence of oxidation of As(III) by DO under the conditions of storage in this study.

The importance of Fe precipitation and associated As(III) removal from the aqueous phase was noted in the storage testing for the Midwest site, but there was no determination made for the actual mechanism of removal. After 36 hr of storage, approximately 97 percent of the Fe had settled in the storage and sample containers. Total As and As(III) were reduced concurrently with Fe precipitation. The remaining As in the dissolved phase was As(V), indicating a conversion of As(III) to As(V) or a preferential removal of As(III) over As(V). The later is considered unlikely, so it is speculated that an oxidation did occur in the aqueous phase. However, there were no data that indicated an oxidation of As(III) specifically, or solely by DO. Other possibilities for conversion include oxidation by manganese oxides, ferric oxyhydroxides, or microbial oxidation.<sup>2</sup> Based upon the storage results at the other test sites, it is believed that the apparent As(III) conversion was not simply a result of DO and time during storage.

## 4.2 Sample Analysis Problems

In addition to the speciation problems in the field at the Southwest Site, there was a major problem that the analytical laboratory experienced with the dissolved As speciation samples from that site. The dissolved As sample was preserved with sulfuric acid as a part of the specified method. It was concluded by the laboratory that something contained in the chemistry of these samples, interacting with the sulfuric acid, caused the ICAP method to fail. Physically, a deposit of an acid "white precipitate" ruined replaceable parts of the ICAP instrument and it was at least one (1) month before the problem was finally attributed entirely to the sample and not the instrument. This was particularly unfortunate for three (3) reasons: 1) it delayed all of the As analyses from the Midwest and the Southwest sites, 2) almost all of the dissolved As sample volume from the Southwest site was used, which could have been used to generate another As(III) sample to replace the invalid As(III) samples due to As peaking in the resin column, and 3) the dissolved Fe data were not useable because the laboratory used the ICAP As samples for the total and dissolved Fe, respectively. Fortunately, all but one (1) of the dissolved As samples from the Southwest site were finally run on the graphite furnace, with good results.

Aside from the problems with the ICAP analysis for the Southwest site, the analytical results for this project appear to be very good. The results allow the objectives of the study to be met and the conclusions are well supported.

## 4.3 Conclusions

Based upon the results from this study and for the conditions under which it was conducted, the following conclusion are made:

1. Aeration, and specifically DO, did not cause an oxidation of As(III).
2. DO and a storage time of five (5) days did not cause an oxidation of As(III) in low Fe waters.
3. Fe oxidation and precipitation brought about by DO in aeration and storage processes can remove a significant fraction of As, presumably as As(III).
4. A complete precipitation and removal of Fe under the storage conditions of the Midwest site apparently caused or was concurrent with a conversion of As(III) to As(V) in the dissolved phase.

From an engineering perspective, the results of this study lead to the conclusion that aeration should not be considered for the oxidation of As(III). Further, long contact with DO, as afforded by water storage, should not be considered effective in the oxidation of As(III). With respect to the oxidation of As(III), there appears to be no benefit from contacting water with DO.

## 5. References

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## **6. Appendices**

- Appendix A. Northeast Site Data
- Appendix B. Midwest Site Data
- Appendix C. Southwest Site Data

## Appendix A: Northeast Site Data







Sandy Stream, Unity, ME 5/14&15/99

Source Hr. Total As Sol. As As(III) Total Fe Sol. Fe Total Mn Sol. Mn Cl TDS Ca Na Hardness TOC Alk. HPC DO pH  
 Sandy Stream, Unity, ME 5/14&15/99

Source	Hr.	Total As	Sol. As	As(III)	Total Fe	Sol. Fe	Total Mn	Sol. Mn	Cl	TDS	Ca	Na	Hardness	TOC	Alk.	HPC	DO	pH
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L		mg/L	
Storage	5.0	0.106	0.106	0.098	0.04	ND	0.055	0.053									7.00	7.41
Storage	11.0	0.105	0.108	0.104	0.04	ND	0.054	0.054									6.74	7.31
Storage	15.5	0.102	0.094	0.094	0.05	ND	0.061	0.054									7.30	8.61
Storage	48.0	0.112	0.107	0.092	0.04	ND	0.058	0.054									9.80	8.20
Storage	72.0	0.110	0.106	0.090	0.04	ND	0.058	0.054									8.32	8.36
Storage	120.0	0.110	0.105	0.094	0.04	ND	0.054	0.049									8.12	8.35
	Avg	0.1075	0.1043	0.0953	0.0417		0.057	0.053									7.880	
	Std Dev	0.0038	0.0052	0.0050	0.0041		0.003	0.002									1.127	
	n	6.0000	6.0000	6.0000	6.0000		6.000	6.000									6.000	
BUBBLE	AVG	0.1033	0.1040	0.0972	0.0410		0.056	0.053									10.890	
	STD DEV	0.0022	0.0019	0.0024	0.0044		0.002	0.004									0.476	
	N	22.0000	22.0000	22.0000	21.0000		21.000	21.000									21.000	
TOWER	AVG	0.1033	0.1041	0.0983	0.0424		0.056	0.053									10.685	
	STD DEV	0.0015	0.0020	0.0024	0.0118		0.002	0.004									0.494	
	N	21.0000	22.0000	22.0000	21.0000		21.000	21.000									22.000	
SPRAY	AVG	0.1034	0.1043	0.0975	0.0430		0.056	0.052									9.065	
	STD DEV	0.0014	0.0014	0.0024	0.0066		0.002	0.003									0.845	
	N	21.0000	22.0000	22.0000	20.0000		20.000	21.000									22.000	

## Appendix B: Midwest Site Data



Midwest Site 6/1&2/99

Source	Hr.	Total As mg/L	Sol. As mg/L	As(III) mg/L	Tot. Fe mg/L	Sol. Fe mg/L	Tot. Mn mg/L	Sol Mn mg/L	Cl mg/L	TDS mg/L	Ca mg/L	Na mg/L	Hardness mg/L	TOC mg/L	Alk mg/L	HPC mg/L	DO mg/L	pH
PTA	3.5	0.037	0.029	0.028	1.990	0.020	0.153	0.146									7.8	8.02
PTA	4.0	0.040	0.025	0.027	1.990	0.030	0.152	0.140									8.6	8.03
PTA	4.5	0.040	0.026	0.023	1.970	0.200	0.154	0.140									8.4	8.02
PTA	5.0	0.037	0.026	0.028	1.950	0.020	0.149	0.141									7.8	8.01
PTA	5.5	0.040	0.027	0.021	1.970	0.030	0.152	0.141									8.8	8.03
PTA	6.0	0.039	0.028	0.029	1.970	0.020	0.155	0.149									8.8	8.00
Tower Fe Data																		
average		0.0396	0.0275	0.0260	2.0525	0.0400	0.1585	0.1467									8.283	
std dev		0.001311	0.001446	0.002449	0.099282	0.050632	0.015849	0.013323			0.5	2.270					0.6576	
N		12	12	12	12	12	12	12			1	2.180					12	
TOWER:			22.54%	0.008							1.5	2.120						
			17.46%	0.005							2	2.060						
											2.5	2.080						
											3	2.080						
											3.5	1.990						
Forced Draft	0.5	0.026	0.011	0.012	2.880	0.020	0.186	0.159			4	1.990					7.4	7.86
Forced Draft	1.0	0.021	0.012	0.013	2.010	0.020	0.177	0.171			4.5	1.970					7.8	7.9
Forced Draft	1.5	0.023	0.013	0.011	2.050	0.020	0.169	0.159			5	1.950					7.8	7.88
Forced Draft	2.0	0.024	0.01	0.012	1.970	0.030	0.161	0.156			5.5	1.970					7.6	7.9
Forced Draft	2.5	0.023	0.012	0.013	1.880	0.020	0.163	0.152			6	1.970					7.2	7.9
Forced Draft	3.0	0.023	0.013	0.011	2.190	0.030	0.166	0.153			6.5	1.630					7.6	7.92
Forced Draft	3.5	0.024	0.014	0.013	2.130	0.020	0.182	0.165			7	1.610					8.0	7.9
Forced Draft	4.0	0.022	0.012	0.013	2.070	0.020	0.168	0.145			7.5	1.610					7.8	7.92
Forced Draft	4.5	0.022	0.013	0.013	2.080	0.020	0.166	0.155			8	1.590					7.6	7.92
Forced Draft	5.0	0.041	0.026	0.022	2.930	0.020	0.158	0.145			8.5	1.690					7.8	7.83
Forced Draft	5.5	0.038	0.025	0.026	2.600	0.080	0.153	0.148			9	1.610					8.2	7.84
Forced Draft	6.0	0.038	0.028	0.026	2.530	0.080	0.156	0.147			9.5	1.640					7.2	7.86
											10	1.640						
AVG	3.250	0.027	0.016	0.015	2.277	0.032	0.167	0.155			10.5	1.610					7.667	
STD DEV	1.8028	0.007329	0.0064965	0.005712	0.362299	0.022896	0.010193	0.008051			11	2.180					0.2995	
N	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0									12.0	
Bubble	0.5	0.022	0.013	0.012	2.220	0.040	0.166	0.152									8.8	8.28
Bubble	1.0	0.022	0.014	0.013	2.200	0.020	0.159	0.154									8.2	8.27
Bubble	1.5	0.023	0.013	0.012	2.240	0.030	0.165	0.148									8.0	8.21
Bubble	2.0	0.023	0.013	0.012	2.310	0.020	0.170	0.146									8.4	8.23
Bubble	2.5	0.025	0.012	0.014	2.260	0.020	0.168	0.151									8.8	8.29
Bubble	3.0	0.025	0.011	0.013	2.270	0.020	0.171	0.155									8.0	8.27
Bubble	3.5	0.022	0.012	0.014	2.230	0.020	0.164	0.150									7.8	8.3
Bubble	4.0	0.020	0.013	0.014	2.240	0.020	0.166	0.152									8.4	8.28
Bubble	4.5	0.023	0.013	0.014	2.350	0.030	0.169	0.158									8.4	8.29
Bubble	5.0	0.043	0.024	0.026	2.760	0.020	0.154	0.139									8.4	8.24
Bubble	5.5	0.042	0.028	0.022	2.800	0.030	0.155	0.145									7.8	8.24
Bubble	6.0	0.039	0.027	0.025	2.780	0.020	0.160	0.143									8.4	8.28
AVG	3.250	0.027	0.016	0.016	2.388	0.024	0.164	0.149									8.283	
STD DEV	1.8028	0.008544	0.0062879	0.005213	0.23969	0.006686	0.005696	0.005435									0.3353	
N	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0									12.0	
PTA	0.5	0.026	0.013	0.014	1.630	0.020	0.166	0.152									8.0	8.16

Midwest Site 6/1&2/99

Source	Hr.	Total As mg/L	Sol. As mg/L	As(III) mg/L	Tot. Fe mg/L	Sol. Fe mg/L	Tot. Mn mg/L	Sol Mn mg/L	Cl mg/L	TDS mg/L	Ca mg/L	Na mg/L	Hardness mg/L	TOC mg/L	Alk mg/L	HPC mg/L	DO mg/L	pH		
PTA	1.0	0.025	0.013	0.013	1.610	0.020	0.161	0.154									8.2	8.16		
PTA	1.5	0.021	0.013	0.012	1.610	0.020	0.166	0.157									9.2	8.09		
PTA	2.0	0.024	0.015	0.013	1.590	0.020	0.164	0.159									9.0	8.13		
PTA	2.5	0.023	0.014	0.013	1.690	0.020	0.164	0.154									7.2	8.16		
PTA	3.0	0.021	0.013	0.013	1.610	0.020	0.184	0.169									8.0	8.15		
PTA	3.5	0.022	0.013	0.012	1.640	0.030	0.166	0.157									8.4	8.19		
PTA	4.0	0.022	0.015	0.014	1.640	0.020	0.162	0.157									8.0	8.16		
PTA	4.5	0.022	0.013	0.012	1.610	0.020	0.164	0.153									7.6	8.17		
PTA	5.0	0.044	0.029	0.024	2.180	0.020	0.161	0.149									8.4	8.1		
AVG	2.750	0.025	0.015	0.014	1.681	0.021	0.166	0.156									8.200			
STD DEV	1.5138	0.00688	0.0049542	0.00359	0.177479	0.003162	0.00668	0.005405									0.5963			
N	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0									10.0			
ST	6.0	0.039	0.020	0.024	2.530	0.020	0.160	0.142									5.5	7.02		
ST	12.0	0.047	0.023	0.025	2.550	0.020	0.179	0.160									5.1	7.12		
ST	24.0	0.040	0.024	0.020	2.070	0.020	0.151	0.153									4.6			
ST	36.0	0.040	0.022	0.021	1.830	0.020	0.153	0.139									4.2	7.43		
ST	48	0.013	0.009	0.003	0.150	ND .02	0.100	0.100									4.2	7.45		
ST	72	0.012	0.011	0.003	0.080	ND .02	0.120	0.130									4.0	7.51		
ST	120	0.012	0.012	0.003	0.070	ND .02	0.130	0.120									4.2	7.54		
POST-3 (day 2)		0.045	0.035	0.030	2.860	2.730	0.158	0.160	22	452	85.9	31.6	327	2.00	406	-	0.3	7.00		
POST-4 (day 2)		0.048	0.034	0.027	2.850	2.750	0.163	0.162	21	458	86.6	31.1	330	2.00	407	150	0.3			
Raw avg		0.040	0.031	0.026	2.685	2.585	0.160	0.163									RAW DO	AVG	0.29	6.973
std dev		0.009287	0.009037	0.007616	0.280297	0.259551	0.003697	0.004509									STD DEV		0.1	0.023
n		4.000	4.000	4.000	4.000	4.000	4.000	4.000									N		4.0	3.000
																	FDA DO	AVG	7.530	
																	STD DEV		0.4	
																	N		24.0	
																	BUBBLE DO	AVG	8.246	
																	STD DEV		0.4	
																	N		24.0	
																	TOWER DO	AVG	8.245	
																	STD DEV		0.6	
																	N		22.0	

## Appendix C: Southwest Site Data



Albuquerque, NM 6/12&13/99

Source	Day	Hr.	Total As mg/L	Sol. As mg/L	Bad As(III)		Total Fe mg/L	Sol. Fe mg/L	Total Mn mg/L	Sol. Mn mg/L	Cl mg/L	TDS mg/L	Ca mg/L	Na mg/L	Hardness mg/L	TOC mg/L	Alk. mg/L	DO mg/L	pH	
					mg/L	mg/L														
PRE-6 (day 1)	1		0.0	0.037	0.032	0.014		0.140	0.080	0.023	ND 0.001	83	370	39	78	120	<1	141	5.1	7.74
Bubble	1	0.5	0.036	0.031	0.015		ND 0.02	0.350	0.019	0.001									5.0	8.42
Bubble	1	1.0	0.033	0.037	0.015		ND 0.02	NOT DONE	0.020	NOT DONE									6.2	8.4
Bubble	1	1.5	0.034	0.034	0.016		0.020	NOT DONE	0.019	NOT DONE									6.4	8.25
Bubble	1	2.0	0.036	0.037			0.021	ND 0.02	ND 0.02	0.019	0.025								6.6	8.41
Bubble	1	2.5	0.036		0.015		ND 0.02	0.230	0.020	ND 0.001									6.4	8.42
Bubble	1	3.0	0.034	0.034	0.017		0.020	NOT DONE	0.019	NOT DONE									6.4	8.42
Bubble	1	3.5	0.031	0.030			0.021	ND 0.02	0.39	0.020	0.005								6.4	8.38
Bubble	1	4.0	0.035	0.034			0.032	ND 0.02	0.360	0.021	0.002								6.0	8.42
Bubble	1	4.5	0.034	0.032			0.067	ND 0.02	ND 0.02	0.020	ND 0.001								6.6	8.42
Bubble	1	5.0	0.034	0.033			0.040	ND 0.02	ND 0.02	0.020	0.019								6.2	8.4
Bubble	1	5.5	0.036	0.030			0.035	ND 0.02	ND 0.02	0.020	0.018								6.0	8.42
Bubble	1	6.0	0.035	0.037			0.033	ND 0.02	ND 0.02	0.020	ND 0.001								5.8	8.44
		avg	0.035	0.034	0.016		0.036		0.020	0.012									6.167	
		std dev	0.002	0.003	0.001		0.016		0.001	0.010									0.442	
		N	12.000	11.000	5.000		7.000		12.000	6.000									12.000	
Packed Tower	1	0.5	0.034	0.035	0.017		ND 0.02	ND 0.02	0.019	0.020									6.2	8.2
Packed Tower	1	1.0	0.035	0.031			0.033	ND 0.02	0.170	0.020	ND 0.001								6.4	8.19
Packed Tower	1	1.5	0.034	0.034			0.060	ND 0.02	ND 0.02	0.020	ND 0.001								5.4	8.2
Packed Tower	1	2.0	0.035	0.034			0.037	ND 0.02	0.140	0.020	ND 0.001								5.8	8.18
Packed Tower	1	2.5	0.035	0.032	0.015		ND 0.02	0.190	0.020	ND 0.001									6.2	8.16
Packed Tower	1	3.0	0.034	0.032	0.016		NOT DONE	0.35	NOT DONE	0.001									6.6	8.2
Packed Tower	1	3.5	0.034	0.034			0.021	ND 0.02	0.130	0.021	ND 0.001								6.6	8.21
Packed Tower	1	4.0	0.033	0.033			0.048	ND 0.02	0.54	0.020	0.002								5.8	8.18
Packed Tower	1	4.5	0.034	0.033			0.034	0.020	ND 0.02	0.020	0.027								5.4	8.2
Packed Tower	1	5.0	0.034	0.031			0.034	ND 0.02	ND 0.02	0.020	0.026								6.6	8.21
Packed Tower	1	5.5	0.034	0.035			0.033	0.290	NOT DONE	0.020	NOT DONE								6.0	8.21
Packed Tower	1	6.0	0.033	0.034			0.033	ND 0.02	ND 0.02	0.020	0.020								6.8	8.09
		avg	0.034	0.033	0.016		0.037		0.020	0.016									6.150	
		std dev	0.001	0.001	0.001		0.011		0.000	0.012									0.476	
		N	12.000	12.000	3.000		9.000		11.000	6.000									12.000	
Spray	1	0.5	0.034	0.030	0.016		ND 0.02	ND 0.02	0.020	ND 0.001									5.8	8.03
Spray	1	1.0	0.032	0.036	0.016		ND 0.02	0.020	0.020	0.040									5.8	7.96
Spray	1	1.5	0.034	0.033	0.017		0.020	0.160	0.019	ND 0.001									5.8	8.01
Spray	1	2.0	0.034	0.035			0.031	ND 0.02	ND 0.02	0.019	0.004								5.6	8.04
Spray	1	2.5	0.035	0.033	0.016		0.016	ND 0.02	0.1	0.020	ND 0.001								5.4	8.01
Spray	1	3.0	0.033	0.030	0.016		0.016	ND 0.02	0.18	0.020	0.001								5.2	8.03
Spray	1	3.5	0.037	0.031			0.019	ND 0.02	ND 0.02	0.020	0.010								5.2	8.02
Spray	1	4.0	0.034	0.029			0.084	ND 0.02	0.41	0.020	0.001								6.2	8
Spray	1	4.5	0.035	0.033			0.040	0.020	0.32	0.020	0.001								5.8	8.04
Spray	1	5.0	0.036	0.036			0.033	0.020	ND 0.02	0.020	ND 0.001								5.2	7.94
Spray	1	5.5	0.034	0.033			0.033	ND 0.02	ND 0.02	0.020	0.018								5.8	8.01
Spray	1	6.0	0.034	0.032			0.032	ND 0.02	ND 0.02	0.020	ND 0.001								5.8	8.03
		avg	0.034	0.033	0.016		0.039		0.020	0.011									5.633	
		std dev	0.001	0.002	0.000		0.021		0.000	0.014									0.317	
		N	12.000	12.000	5.000		9.000		12.000	7.000									12.000	
POST-6 (day 1)	1		0.036	0.033			0.033	ND 0.02	ND 0.02	0.022	ND 0.001	84	342	39	78	120	<1	141	4.8	8
PRE-7 (day 2)	2		0.035	0.032	0.014		ND 0.02	0.100	0.017	ND 0.001		84	372	40	78	120	1	141	5.6	7.78

Time bubble tower spray

0.5	8.42	8.20	8.03
1.0	8.40	8.19	7.96
1.5	8.25	8.20	8.01
2.0	8.41	8.18	8.04
2.5	8.42	8.16	8.01
3.0	8.42	8.20	8.03
3.5	8.38	8.21	8.02
4.0	8.42	8.18	8.00
4.5	8.42	8.20	8.04
5.0	8.40	8.21	7.94
5.5	8.42	8.21	8.01
6.0	8.44	8.09	8.03
6.5	8.51	8.25	8.16
0.5	8.50	8.31	8.09
1.0	8.52	8.31	8.10
1.5	8.51	8.30	
2.0	8.51	8.29	8.11
2.5	8.52	8.30	8.12
3.0	8.51	8.28	8.12
3.5	8.52	8.28	8.11
4.0	8.51	8.28	8.12
4.5	8.51	8.31	8.11
5.0	8.51	8.30	8.04
5.5	8.51	8.32	8.10
6.0			
6.5			
6.150			
0.476			
12.000			
5.8	8.03		
5.8	7.96		
5.8	8.01		
5.6	8.04		
5.4	8.01		
5.2	8.03		
5.2	8.02		
6.2	8		
5.8	8.04		
5.2	7.94		
5.8	8.01		
5.8	8.03		
5.633			
0.317			
12.000			
4.8	8		
5.6	7.78		

Albuquerque, NM 6/12&13/99

Source	Day	Hr.	Total As mg/L	Sol. As mg/L	As(III) mg/L	Bad As(III) mg/L		Total Fe mg/L	Sol. Fe mg/L	Total Mn mg/L	Sol. Mn mg/L	Cl mg/L	TDS mg/L	Ca mg/L	Na mg/L	Hardness mg/L	TOC mg/L	Alk. mg/L	DO mg/L	pH	
PRE-8 (day 2)	2		0.0	0.034	0.032	0.015		ND 0.02	NOT DONE	0.017	NOT DONE		84	368	39	78	120	<1	141	7.8	
Bubble	2	0.5	0.034	0.033	0.014		ND 0.02	ND 0.02		0.017	ND 0.001										8.51
Bubble	2	1.0	0.035	0.031	0.018		ND 0.02	0.270		0.016	0.001										8.5
Bubble	2	1.5	0.034	0.034			0.021	ND 0.02	0.900	0.016	0.006										8.52
Bubble	2	2.0	0.032	0.032			0.070	ND 0.02	0.130	0.017	ND 0.001										8.51
Bubble	2	2.5	0.034	0.032			0.038	ND 0.02	ND 0.02	0.017	0.018										8.51
Bubble	2	3.0	0.034	0.033	0.015		ND 0.02	0.160		0.017	ND 0.001										8.52
Bubble	2	3.5	0.034	0.032	0.015		ND 0.02	ND 0.02		0.017	0.019									7.6	8.51
Bubble	2	4.0	0.036	0.035	0.016		ND 0.02	ND 0.02		0.018	0.018										8.52
Bubble	2	4.5	0.033	0.030			0.022	ND 0.02	0.590	0.017	0.003	100									8.51
Bubble	2	5.0	0.034	0.031			0.069	ND 0.02	0.310	0.018	0.001										8.51
Bubble	2	5.5	0.035	0.032	0.014		ND 0.02	ND 0.02		0.021	0.014										8.51
Bubble	2	6.0	0.035	0.031	0.015		ND 0.02	ND 0.02		0.018	0.020									6.4	8.51
		avg	0.034	0.032	0.015	0.044				0.017	0.011										7.000
		std dev	0.001	0.001	0.001	0.024				0.001	0.008										0.849
		N	12.000	12.000	7.000	5.000				12.000	9.000										2.000
Packed Tower	2	0.5	0.034	0.033	0.015		ND 0.02	NOT DONE		0.017	NOT DONE										8.25
Packed Tower	2	1.0	0.033	0.033	0.015		ND 0.02	0.070		0.017	ND 0.001										8.31
Packed Tower	2	1.5	0.036	0.031	0.016		ND 0.02	ND 0.02		0.016	0.015										8.31
Packed Tower	2	2.0	0.035	0.033			0.025	ND 0.02	NOT DONE	0.016	NOT DONE										8.3
Packed Tower	2	2.5	0.034	0.033			0.080	ND 0.02	ND 0.02	0.017	ND 0.001										8.29
Packed Tower	2	3.0	0.035	0.038	0.015		ND 0.02	0.08		0.017	0.011										8.3
Packed Tower	2	3.5	0.035	0.035	0.016		ND 0.02	0.130		0.017	ND 0.001									6.0	8.28
Packed Tower	2	4.0	0.035	0.032	0.015		ND 0.02	ND 0.02		0.017	0.023										8.28
Packed Tower	2	4.5	0.033	0.033	0.016		ND 0.02	ND 0.02		0.017	0.015										8.28
Packed Tower	2	5.0	0.032	0.033			0.036	ND 0.02	0.25	0.017	ND 0.001										8.31
Packed Tower	2	5.5	0.034	0.033	0.015		ND 0.02	ND 0.02		0.021	ND 0.001										8.3
Packed Tower	2	6.0	0.033	0.033	0.015		ND 0.02	0.290		0.017	ND 0.001									6.0	8.32
		avg	0.034	0.033	0.015	0.047				0.017	0.016										6.000
		std dev	0.001	0.002	0.000	0.029				0.001	0.005										0.000
		N	12.000	12.000	9.000	3.000				12.000	4.000										2.000
Spray	2	0.5	0.035	0.025	0.015		ND 0.02	0.14		0.017	ND 0.001										8.16
Spray	2	1.0	0.032	0.033	0.016		ND 0.02	0.050		0.017	ND 0.001										8.09
Spray	2	1.5	0.034	0.034			0.036	ND 0.02	ND 0.02	0.017	0.017										8.1
Spray	2	2.0	0.034	0.033			0.060	ND 0.02	0.150	0.017	ND 0.001										
Spray	2	2.5	0.036	0.033			0.064	0.020	ND 0.02	0.017	ND 0.001										8.11
Spray	2	3.0	0.038	0.033	0.015		ND 0.02	0.120		0.017	ND 0.001										8.12
Spray	2	3.5	0.032	0.033	0.016		ND 0.02	0.24		0.018	ND 0.001									5.8	8.12
Spray	2	4.0	0.034	0.033			0.022	ND 0.02	0.020	0.017	ND 0.001										8.11
Spray	2	4.5	0.036	0.032			0.075	ND 0.02	0.240	0.017	ND 0.001										8.12
Spray	2	5.0	0.035	0.032			0.041	ND 0.02	ND 0.02	0.017	0.003										8.11
Spray	2	5.5	0.037	0.033	0.015		ND 0.02	NOT DONE		0.026	NOT DONE										8.04
Spray	2	6.0	0.037	0.032	0.015		ND 0.02	ND 0.02		0.017	0.021									5.2	8.1

Albuquerque, NM 6/12&13/99

Source	Day	Hr.	Total As mg/L	Sol. As mg/L	Bad As(III)		Total Fe mg/L	Sol. Fe mg/L	Total Mn mg/L	Sol. Mn mg/L	Cl mg/L	TDS mg/L	Ca mg/L	Na mg/L	Hardness mg/L	TOC mg/L	Alk. mg/L	DO mg/L	pH
					As(III) mg/L	As(III) mg/L													
			avg 0.035	0.032	0.015	0.050			0.018	0.014								5.500	
			std dev 0.002	0.002	0.001	0.020			0.003	0.009								0.424	
			N 12.000	12.000	6.000	6.000			12.000	3.000								2.000	
POST-7 (day 2)	2		0.034	0.033	0.016	ND 0.02	0.290	0.018	0.001	84	368	39	78	120	<1	141		5.6	7.8
POST-8 (day 2)	2		0.035	0.034	0.015	ND 0.02	0.050	0.018	ND 0.001	83	374	39	78	120	1	141		5.6	7.8
Storage		1.0	0.034	0.034		0.058	0.020	0.260	0.024	ND 0.001								4.6	7.94
Storage		6.0	0.036	0.032		0.033	0.030	0.03	0.027	0.034								5.6	8
Storage		16.0	0.033	0.030	0.010	NOT DONE	ND 0.02	NOT DONE	0.008									5.8	8.22
Storage		36.0	0.032	0.034	0.015	ND .02			0.012									6.0	7.94
Storage		48.0	0.033	0.031	0.016	ND .02			0.015										7.94
Storage		72.0	0.033	0.030	0.016	ND .02			0.018										7.93
Storage		120.0	0.034	0.032	0.012														7.98
			avg 0.034	0.032	0.014	0.046			0.019	0.021								5.500	
			std dev 0.001	0.002	0.003	0.018			0.006	0.018								0.622	
			n																
All Raw Water:			avg 0.0350	0.0326	0.0148													All Raw Water: avg 5.34	7.820
			std dev 0.001	0.001	0.001													DO std dev 0.4	0.091
			n 5.000	5.000	5.000													n 5.000	6.000
All Bubble:			avg 0.0343	0.0328	0.0154													All Bubble: avg 6.29	8.456
			std dev 0.001	0.002	0.001													DO std dev 0.559	0.067
			n 24.000	23.000	12.000													n 14.000	24.000
All Tower:			avg 0.0341	0.0333	0.0155													All Tower: avg 6.13	8.240
			std dev 0.001	0.002	0.001													DO std dev 0.441	0.062
			n 24.000	24.000	12.000													n 14.000	24.000
All Spray:			avg 0.0347	0.0324	0.0157													All Spray: avg 5.61	8.057
			std dev 0.002	0.002	0.001													DO std dev 0.318	0.058
			n 24.000	24.000	11.000													n 14.000	23.000

Well

7.74  
8.00  
7.78  
7.80  
7.80  
7.80