

Arsenic Water Technology Partnership (AWTP) Final Report (FY03)

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Contents

Tables.....	4
Figures.....	4
Acronyms and Abbreviations	4
Acknowledgements.....	5
Executive Summary	6
Introduction.....	7
Chapter 1-Survey of Sites and Technologies for Arsenic Removal	7
INTRODUCTION (TASKS 2-5).....	7
TASK 2 SURVEY OF TECHNOLOGIES- VENDORS FORUM	7
TASK 3 SURVEYS OF SITES FOR PILOT DEPLOYMENTS.....	8
TASK 4 SELECTION OF PILOT SITES AND TECHNOLOGIES	9
TASK 5 PURCHASE LABORATORY AND PILOT EQUIPMENT.....	11
Chapter 2- Pilot Descriptions.....	11
INTRODUCTION (TASKS 6-8).....	11
TASK 6 SOCORRO SPRINGS NM PILOT PLANT	11
TASK 7 DESERT SANDS NM PILOT PLANT	13
TASK 8 DESIGN REPORT (WEATHERFORD, OK)	15
References.....	16

Tables

Table 1. Task Description from FY03 Statement of Work.....	7
Table 2. Groundwater Composition (Unchlorinated) at Select Surveyed Pilot Sites	9
Table 3. Survey of Adsorbent Media Socorro Springs New Mexico	10
Table 4. Survey of Adsorbent Media for Anthony New Mexico	10
Table 5. Media Comparison for Socorro Springs Phase 1	13
Table 6. Media Used and Description of Experimental Phases at Desert Sands	14
Table 7. Media Comparison for all Phases of Pilot Testing-Desert Sands	15

Figures

Figure 1. Socorro Springs Site and Pilot Equipment	12
Figure 2. Desert Sands Site and Pilot Equipment	14

Acronyms and Abbreviations

AWTP	Arsenic Water Treatment Partnership
AwwaRF	American Water Works Association Research Foundation
BV	bed volume
DOE	Department of Energy
EBCT	empty bed contact time
gpm	gallons per minute
MCL	maximum contaminant level
MDWCA	Mutual Domestic Water Consumers Association
µg/L	micrograms per liter
µS/cm	conductivity – microsiemens per centimeter
PMC	Project Management Committee
ppb	parts per billion
ppm	parts per million
SNL	Sandia National Laboratories
WERC	A Consortium for Environmental Education and Technology Development

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Sandia National Laboratories would like to thank the water treatment staff and city government of Socorro New Mexico, Anthony New Mexico and Weatherford Oklahoma. The staff in these small communities extended much needed assistance to our field personnel and provided essential support all along the way. We would also like to thank Narasimhan Consulting Services, Inc. of Phoenix Arizona for their contribution to a successful pilot plant in Weatherford Oklahoma. Special thanks also go to the analytical chemistry staff at the Water Quality Lab at Sandia National Laboratories whose hard work and attention to detail provided high quality data for this report.

Executive Summary

Sandia National Laboratories has participated in a partnership with the Awwa Research Foundation and WERC: A Consortium for Environmental Education and Technology Development for the DOE. These three agencies comprise the Project Management Committee (PMC). This is the final report for the DOE project commissioned in FY03. During the course of the work several publications were produced that addressed individual tasks in the Statement of Work. These reports are referred to as SAND documents and comply with Department of Energy (DOE) Directive G 241.1-1A, which provides the requirements for preparing scientific and technical information. These publications represent the technical progress during the course of this project and are included in the text of this report as URL addresses on the Sandia Arsenic Treatment site.

Each of the listed documents contains detailed reports addressing each of the tasks listed in Table 1 below. Chapter 1 contains a brief synopsis of the reports that address technology and site survey and preparation activities (survey and preparation Tasks 2-5). Chapter 2 provides a short overview of the pilot activities at Socorro NM, Anthony NM and the design report for Weatherford Oklahoma (pilot descriptions section Tasks 6-8).

Introduction

Sandia National Laboratories has participated in a partnership with the Awwa Research Foundation and WERC: A Consortium for Environmental Education and Technology Development for the DOE. These three agencies comprise the Project Management Committee (PMC). This is the final report for the DOE project commissioned in FY03. During the course of the work several publications were produced that addressed individual tasks in the Statement of Work. These reports are referred to as SAND documents and comply with Department of Energy (DOE) Directive G 241.1-1A, which provides the requirements for preparing scientific and technical information.

This report then is a listing of detailed reports that address each of the tasks listed in Table 1 below. A short overview of the reports with relevant data and conclusions are included in Chapter 1 of this report for Tasks 2-5. Pilot Descriptions are given in Chapter 2 and fulfill Tasks 6-8.

Table 1. Task Description from FY03 Statement of Work

Task	Description	Responsibility	SAND #
1	Project management and coordination	PMC	NA
2	Survey technologies-Vendors Forum	SNL	2006-5423
3	Survey of sites for pilot deployments	SNL	2005-1909C
4	Selection of pilot sites and technologies	SNL	2006-7639
5	Purchase laboratory equipment for field analyses	SNL	NA
6	Pilot Test 1- Socorro Springs, NM	SNL	2007-3255
7	Pilot Test 2 - Desert Sands, NM	SNL	2007-6059
8	Pilot Test 3 - Design report (Weatherford, OK)	SNL	2007-2540

Chapter 1-Survey of Sites and Technologies for Arsenic Removal

INTRODUCTION (TASKS 2-5)

Sandia National Laboratories conducted Vendors Forums and solicited information from experts in arsenic water treatment in order to survey technologies and appropriate sites for arsenic treatment pilot activities. Field and laboratory equipment was then purchased prior to fielding arsenic removal pilot plants. These preparation steps are listed in Tasks 2-5.

TASK 2 SURVEY OF TECHNOLOGIES- VENDORS FORUM

As a member of the AWTP, Sandia National Laboratories evaluated cutting-edge commercial products in three annual Arsenic Treatment Technology Vendors Forums held during the annual New Mexico Environmental Health Conferences (NMEHC) in 2003, 2004 and 2005. The Forums were comprised of two parts. At the first session, open

to all conference attendees, commercial developers of innovative treatment technologies gave 15-minute talks that described project histories demonstrating the effectiveness of their products. During the second part, these same technologies were evaluated and ranked in closed sessions by independent technical experts for possible use in pilot-scale field demonstrations being conducted by Sandia National Laboratories. The results of the evaluations including numerical rankings of the products, links to company websites and copies of presentations made by the representatives of the companies are in SAND2006-0121 and are posted on the project website at <http://www.sandia.gov/water/arsenic.htm>. A final task report (SAND2006-5423) summarizes the contents of the website by providing brief descriptions of the technologies represented at the Forums and the results of the evaluations.

See <http://www.sandia.gov/water/docs/VendorsForumsReportSAND2006-5423.pdf>.

TASK 3 SURVEYS OF SITES FOR PILOT DEPLOYMENTS

The goal of site selection is to identify sites that allow examination of treatment processes and systems under conditions that are relevant to different geochemical settings and socioeconomic conditions throughout the country. Naturally occurring arsenic is associated with a large number of different kinds of sources and exhibits a wide concentration range in groundwaters. Arsenic concentrations range from 1.1 µg/L to 6000 µg/L (µg/L ~ ppb) in the 7000 water samples collected in the Western U.S. and described in a study by Welch, Lico and Hughes (1988). Its association with other solutes that can affect the efficiency of the treatment process is also variable (Amy et al. 2004). These interfering solutes include silica, sulfate, vanadate, and phosphate. Arsenic is strongly enriched in silicic volcanics, derived volcanoclastic sediments and associated hydrothermal systems. Arsenic source rocks can also be enriched by potassium metasomatism, a low-temperature alteration process common in closed hydrographic basins in arid climates. In the eastern U.S., arsenic can be derived from sulfides in crystalline bedrock; in the Midwest, glacial deposits may provide the source of arsenic. In other areas, remobilization of arsenic previously sorbed onto the iron-oxide component of sediments is the major source.

The site selection criteria included both hydrochemical characteristics and sociological factors such as:

- Arsenic concentration >10 ppb (maximum contaminant level =MCL)
- Example of class of groundwater composition spanning ranges of
 - pH, TDS, concentrations of foulants such as iron (Fe), manganese (Mn), silica, and organic compounds
 - As(III)/As(V)
 - Concentrations of competing ions: vanadate (VO_4^{3-}), sulfate (SO_4^{2-}), etc.
 - Presence of other metals and radionuclides of concern/benefit
- Small system size to be treated (< 10,000 users)
- Community support (water utility and municipal government), facilitating rapid deployment
- Ability to deal with residuals/treated effluent

A number of candidate sites have been identified through reviews of groundwater quality databases, conference proceedings and discussions with state and local officials. The initial pilot tests in the program were to be conducted in New Mexico. An additional site was identified in Oklahoma (Weatherford). Table 2 lists the sites identified as part of FY 03 work.

Table 2. Groundwater Composition (Unchlorinated) at Select Surveyed Pilot Sites

Solute	Socorro NM	Desert Sands NM	Weatherford OK	Jemez Pueblo NM
As III (ppb)	0	18	0	19
As V (ppb)	42	1.8	20	2
As total (ppb)	42	20	20	21
pH	7.9	7.8	7.3	8.0
F (ppm)	0.53	0.5	0.2	1.3
SiO ₂ (ppm)	25	38	25	49
Fe (ppm)	0.05	0.26	0.5	1.0
Mn (ppm)	0.001	0.012	0.001	0.9
SO ₄ (ppm)	30	181	103	26
Cond.(μ S/cm)	340	1350	560	880
Temp ($^{\circ}$ F)	92	88	69	68

Site survey including bench testing and technology descriptions can be found in <http://www.sandia.gov/water/docs/SAND2005-1909C.pdf>, (SAND2005-1909C).

TASK 4 SELECTION OF PILOT SITES AND TECHNOLOGIES

Most of the treatment technologies being considered for pilots fall into two broad categories: 1) sorption processes that use fixed bed adsorbents and 2) filtration processes including coagulation/filtration with or without electrochemical processes. Several innovations that could lead to lower treatment costs have been proposed for adsorptive media systems. These include: 1) higher capacity and selectivity using mixed oxides composed of iron and other transition metals, titanium and zirconium-based oxides, or mixed resin-metal oxides composite media; 2) improved durability of virgin media and greater chemical stability of the spent media; and 3) use of inexpensive natural or recycled materials with a coating that has a high affinity for arsenic. Improvements to filtration-based treatment systems include: 1) enhanced coagulation using improved iron compounds, polyelectrolytes, and electrical gradients or via electrochemical reactions and 2) improved filtration with nanocomposite materials.

The first two pilot plant locations selected were Socorro New Mexico and Desert Sands New Mexico (See Table 1). These plants were designed and built as adsorptive media plants and adsorbents were chosen based on Vendors Forum selection criteria and other information.

Table 3 lists the adsorbents chosen for the Socorro while Table 4 lists the adsorbents shown for the Desert Sands pilot. Tests at Socorro Springs were divided into Phase 1 and

Phase 2. Phase 1 was performed using the incoming spring water at ambient pH (approximately 7.7); Phase 2 tests were to be performed at a pH of approximately 6.8 by slightly acidifying the feed stream using carbon dioxide. Phase 2 tests are not covered in this report. Phase 1 also included a test to evaluate one media (Adedge E33) at three different empty bed contact times (EBCTs). These tests were aimed at evaluating the effect of various EBCTs in order to provide design performance to evaluate the effect of adsorbent bed geometry and hydraulic feed rate. These results were then evaluated in terms of economic implications.

Table 3. Survey of Adsorbent Media Socorro Springs New Mexico

Socorro Springs-Phase 1	
Media Type	Vendor/ Media
Iron oxy/hydroxide	BASF/ARM200
Iron impregnated resin	Purolite/ArsenX ^{np}
Titanium dioxide	Hydroglobe/Metsorb
Zirconium oxide	MEI/Isolux
Iron oxy/hydroxide	AdEdge/E33*
Iron oxy/hydroxide	AdEdge/E33*
Iron oxy/hydroxide	AdEdge/E33*

*Tests designed to test effect of EBCT

The list of media candidates for Desert Sands was somewhat larger than the list at Socorro. The Desert Sands candidates include a number of new experimental media of many types including iron, titanium, diatomaceous earth and manganese dioxide based formulations.

Table 4. Survey of Adsorbent Media for Anthony New Mexico

Desert Sands	
Media Type	Vendor/ Media
Zirconium oxide	MEI/Isolux
Amended silicate	ADA/Am Si
Iron oxy/hydroxide	Kemira/CFH12
Iron oxy/hydroxide	AdEdge/E33
Iron oxy/hydroxide	BASF/ARM200
Iron/Copper oxy/hydroxide	Sandia/SANS
Iron impregnated resin	Purolite/ArsenX ^{np}
Iron coated resin	Resin Tech/ASM 10HP
Titanium dioxide	Hydroglobe/Metsorb
Titanium dioxide	Dow/ADSORBSIA TM GTO TM
La-coated diatomaceous earth	EP Minerals/NXT-2
Modified alumina	Virotec/Bauxsol
Iron-coated pumice	UTEP/Redisorb
Manganese dioxide based	AdEdge/AD-26

These media represent a wide range of materials and provide diverse surface properties for pilot testing in columns to evaluate quantitative arsenic removal. Both the Socorro and Desert Sands pilot tests were unique in that they performed tests on such an extensive list of media and comprehensively tested to full-media-depletion rather than simply to breakthrough at 10 ppb (MCL value). Site and Technology Selection are covered in depth in <http://www.sandia.gov/water/docs/PilotSum2006-7639P.pdf>, (SAND 2006-7639).

TASK 5 PURCHASE LABORATORY AND PILOT EQUIPMENT

Sandia National Laboratories purchased instrumentation, equipment and hardware for construction, operation and testing for pilot plants to be operated in Socorro and Desert Sands New Mexico. This equipment included a variety of handheld analysis probes and portable colorimetric tests as well as columns, valves, metering pumps, piping and data acquisition instrumentation for fabrication of continuously running arsenic sorption beds. These beds were fabricated by SNL personnel using Unistrut® framing and constituted rugged, reliable and easily modified modules for extensive long term testing.

Chapter 2- Pilot Descriptions

INTRODUCTION (TASKS 6-8)

Sandia National Laboratories conducted pilot scale evaluations of the performance and cost of innovative water treatment technologies aimed at meeting the recently revised arsenic MCL for drinking water. The standard of 10µg/L is effective as of January 2006. The first pilot tests have been conducted in New Mexico where over 90 sites that exceed the new MCL have been identified by the New Mexico Environment Department.

TASK 6 SOCORRO SPRINGS NM PILOT PLANT

The pilot tests in Socorro New Mexico consisted of granular adsorption media packed in cylindrical columns. Water flow is distributed from the top of the bed. Technologies were considered based primarily on the results of the 2003 and 2004 Vendor Forums held in October of each year at the New Mexico Environmental Health Conference. An expert panel evaluated the potential arsenic removal technologies being presented. Results of these evaluations are described in the Forum website: <http://www.sandia.gov/water/forums.htm>.

Figure 1 shows the site location and pilot plant equipment used at Socorro. The verification test site is the "Springs Site," located off Evergreen Road in Socorro, NM. The Springs Site has a permitted capacity of 550 gallons per minute (gpm). The sources of the supply are Socorro and Sedillo Springs located in the foothills west of the city of Socorro. Existing treatment consists of gas chlorination prior to storage in the Springs Site Water Tank. The two springs, Socorro and Sedillo, supplying continuous water to the Springs Site are composed of spring boxes located in the foothills approximately three-quarters of a mile to the southwest at an elevation approximately fifty feet above the Springs Site. Full details of the Socorro Phase 1 pilot tests are included in

http://www.sandia.gov/water/docs/SS_SAND2007-3255_revM_052407.pdf, (SAND 2007-3255).

Figure 1. Socorro Springs Site and Pilot Equipment



The objectives of the Socorro Pilot include evaluation of:

- The comparative treatment performance of five adsorptive media using chlorinated water from the Socorro Springs;
- Comparison of media performance to predictions based on vendor data.
- Limited assessment of maintenance and operational requirements for all media;
- The effect of contact time on the performance of one of the media; and
- The effects of pH adjustment on the performance of selected media.

The commercial media for these tests and their description are listed in Table 3. During testing operational parameters regarding differential pressure and ease of backwashing were noted for all the media. This data is very important since media performance not only depends on the ability of a particular adsorbent to capture arsenic, but also takes into account the physical filterability and long term durability of the media in a fixed adsorbent bed.

Water quality for the Socorro Springs Site is listed in Table 2. All of the arsenic exists as the arsenate ion (As V). The water is geothermal in origin and has a somewhat elevated temperature (92°F)

The quantitative performances of the adsorptive media at the Socorro Springs pilot have been tabulated in Table 5. Column three of the table lists number of bed volumes to breakthrough at 10 ppb. Column four lists the capacity of the media for adsorbing arsenic and are reported as mg of arsenic sorbed per gram of media, (mg As/g media) normalized to 35,000 BV. These results show that E33 media operated at a 4 and 5 minute EBCT performed the best overall and exhibited the most arsenic sorption capacity.

Table 5. Media Comparison for Socorro Springs Phase 1

Media	EBCT-pilot	BVs to 10ppb-pilot	Capacity @ 10 ppb (mg/g)
Isolux	0.3	32,000	1.3
ARM200	4	8,600	0.6
Metsorb	2	13,000	0.7
ArsenX ^{np}	3	27,000	1.4
E33-5min	5	52,000	4.2
E33-4min	4	43,000	3.6
E33-2min	2	24,000	1.9

TASK 7 DESERT SANDS NM PILOT PLANT

A second pilot demonstration was conducted in Anthony New Mexico. The verification test site is the Desert Sands Mutual Domestic Water Consumers Association (MDWCA) Well Site #3, or simply the “Desert Sands site”, located just off I-10 in Anthony, New Mexico. Desert Sands serves a segment of the Anthony population (approximately 1,820) from two wells in a rural community along the New Mexico-Texas line, north of El Paso. It has a new water treatment plant built by Severn Trent Corp. that uses the iron oxide treatment method. The two wells pump 240-270 gpm directly into the distribution system and from it fill two storage tanks located adjacent to each other. The system is operated by radio telemetry. Typical water production is 2-4 million gallons per month, or 29 million gallons per year. The EPA conducted a full-scale demonstration study at the site using a Granular Ferric Oxide adsorptive media (E33) system from Severn Trent/AdEdge (Coonfare-2005) with chlorinated well water. The EPA study provided full scale performance and cost data and has been in progress for two years. The Sandia study will provide estimates of the capacity (bed volumes until breakthrough at 10 ppb As) of other adsorptive media in the same chlorinated water. The Table 4 above lists the media surveyed for the Desert Sands tests; virtually all of those listed in Table 4 were in fact used at the site tested.

Figure 2 shows the pilot equipment skid and an external view of the arsenic treatment building at the Desert Sands Pilot. The Desert Sands Pilot can be described by four different phases.

Figure 2. Desert Sands Site and Pilot Equipment



Table 6 contains a summary of the phases as well as a list of media tested at Desert Sands. At the beginning of each phase, the new media was backwashed immediately following installation. The Isolux 302M cartridge does not require backwash and was installed at the start of the first phase (August 2005). Several of the vendors provided new and/or improved products for later phases (ArsenX^{np}, ARM200, E33, NXT-2). Phases 1-3 operated on an intermittent basis. During Phase 4, a new batch of E33 was installed and was operated continuously.

Table 6. Media Used and Description of Experimental Phases at Desert Sands

Phase 1	Phase 2	Phase 3	Phase 4
Aug 2005-Dec 2006	Dec 2005-Dec 2006	June 2006-Dec 2006	Sept 2006-Dec 2006
Isolux 302M - MEI	Amended Silicate - ADA	ARM200 - BASF (2 nd batch)	AD26 - AdEdge
CFH12 - Kemira	SANS - Sandia National Labs	NXT-2 - EP Minerals	E33 - AdEdge
E33 - AdEdge	Bauxsol-Coated GAC - Virotec	Reddysorb - UTEP	
ARM200 - BASF	ArsenX ^{np} - Purolite (2 nd batch)		
Adsorbsia - DOW			
Metsorb - Hydroglobe			
ArsenX ^{np} - Purolite			
ASM-10HP - ResinTech			
NXT-2 - EP Minerals			

The Desert Sands Pilot testing was unique in that a number of experimental (noncommercial) media were tested for the first time in a pilot test. Some of these media had been developed through university collaborations (Reddysorb), or in applications for other industries (Bauxsol-Virotec). Still others were developmental media from various suppliers that had yet to see large scale deployment. For this reason the results shown in

Table 7 are rather comprehensive. Full details of the pilot testing at Desert Sands are listed in http://www.sandia.gov/water/docs/FINAL_DS_SAND076059-rj.pdf (SAND 2007-6059). Values in italics are estimations of bed volumes approximated by a curve fitting algorithm. These results indicate that the best performance is provided by Adedge E33 media, and that some enhanced performance is noted for the intermittent operation due to a slight increase in capacity when operated in this fashion. It was also noted during operation that the adsorption beds had to be backwashed rather frequently (between 17-40 days for phase 1). The increased backwashing was as the result of column backpressure buildup likely due to particulate plugging (high iron) and the effect from high TDS and pH of the water.

Table 7. Media Comparison for all Phases of Pilot Testing-Desert Sands

Phase	Media	Column No.	BV to 10 ppb	Capacity at 10 ppb (mg/g)
2	Bauxsol-GAC	12	<1000	0.43
3	Reddysorb	12	800	0.5
2	Amended Silicate	2	2,300	0.15
1	ASM-10HP	10	7,500	0.17
3	ARM200	10	13,000	0.37
1	ARM200	6	13,500	0.38
1	Isolux 302M	1	22,000	0.41
2	ArsenX ^{pp}	9	28,000	0.54
1	Metsorb	8	30,000	0.57
1	Adsorbsia	7	34,000	0.4
2	SANS	3	34,000	0.63
3	<i>NXT-2</i>	11	<i>40,000</i>	<i>0.48</i>
1	CFH12	4	45,000	0.71
4	<i>E33 (cont)</i>	12	<i>56,000</i>	<i>1.93</i>
1	<i>E33 (int)</i>	5	<i>66,000</i>	<i>1.75</i>

TASK 8 DESIGN REPORT (WEATHERFORD, OK)

The final task for FY 03 funds was to develop a design report for a pilot plant in the community of Weatherford, Oklahoma. Sandia contracted with Narasimhan Consulting Services, Inc. of Phoenix AZ, to design and test a pilot experiment using four adsorption beds and one coagulation/filtration (C/F) unit.

Weatherford is located 60 miles from Oklahoma City and supplies potable water service to a population of approximately 10,400. The pilot evaluation was conducted at Well #30 of the City of Weatherford. Well water contained arsenic in the range of 16 to 29 ppb during the study. Based on discussions held between SNL and Narasimhan, the selected adsorption media included Adsorbsia GTOTM manufactured by DOW Chemical, npRio by Solmetex, Kemira CFH0818 by Kemira Water Solutions and E33 by Adedge. Details of the media properties and pilot column specifications are described in http://www.sandia.gov/water/docs/OK_SAND2007-2540online.pdf (SAND 2007-2540). For the C/F study, ferric chloride was used as the coagulant and anthracite media was used for filtration. Details of the C/F pilot unit specifications are also described in Chapter 2. The four adsorption beds were designed for a 2.5 minute EBCT and had a nominal flow rate of 1.2 gpm. The C/F plant was designed to be 12” in diameter, 44” tall

fiber reinforced plastic vessel. Anthracite was used as the filtration medium. Details of the design as well as the completed testing runs are given in SAND2007-2540.

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