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Arsenic Pilot Plant Operation and Results- Anthony, New Mexico

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Abstract

Sandia National Laboratories (SNL) is conducting pilot scale evaluations of the performance and cost of innovative water treatment technologies aimed at meeting the recently revised arsenic maximum contaminant level (MCL) for drinking water. The standard of 10 µg/L (10 ppb) is effective as of January 2006. The 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. The pilot test described in this report was conducted in Anthony, New Mexico between August 2005 and December 2006 at Desert Sands Mutual Domestic Water Consumers Association (MDWCA) (Desert Sands) Well #3. The pilot demonstrations are a part of the Arsenic Water Technology Partnership program, a partnership between the American Water Works Association Research Foundation (AwwaRF), SNL and WERC (A Consortium for Environmental Education and Technology Development).

The Sandia National Laboratories pilot demonstration at the Desert Sands site obtained arsenic removal performance data for fourteen different adsorptive media under intermittent flow conditions. Well water at Desert Sands has approximately 20 ppb arsenic in the unoxidized (arsenite - As(III)) redox state with moderately high total dissolved solids (TDS), mainly due to high sulfate, chloride, and varying concentrations of iron. The water is slightly alkaline with a pH near 8. The study provides estimates of the capacity (bed volumes until breakthrough at 10 ppb arsenic) of adsorptive media in the same chlorinated water. Adsorptive media were compared side-by-side in ambient pH water with intermittent flow operation. This pilot is broken down into four phases, which occurred sequentially, however the phases overlapped in most cases.

Acknowledgements

This project would not have been possible without the generous collaboration of the board and employees of the Desert Sands MDWCA. Special thanks to Karen Nichols and Pete Gutierrez at the Desert Sands MDWCA and Pedro Gutierrez (formerly at the University of Texas at El Paso), without whom this pilot could not have run for the duration required. We acknowledge the invaluable help of Justin Marbury, Emily Wright, Michelle Shedd, Fotini Walton, Andres Sanchez and Carolyn Kirby from Sandia National Laboratories.

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Acronyms and Abbreviations

AA	Atomic Absorption
APHA	American Public Health Association
AwwaRF	American Water Works Association Research Foundation
BET	Brunauer, Emmett and Teller
BV	bed volume
BW	backwash
CVT	capacity verification test
EBCT	empty bed contact time
gpm	gallons per minute
ICP-MS	inductively coupled plasma mass spectrometer
MCL	maximum contaminant level
MDWCA	Mutual Domestic Water Consumers Association
MGD	million gallons per day
mg/L	milligrams per liter
µg/L	micrograms per liter
NSF	National Sanitation Foundation
NTU	nephelometric turbidity units
O&M	operations and maintenance
ppb	parts per billion
POU	point-of-use
psi	pounds per square inch
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
SIVT	systems integrity verification test
SMO	Sample Management Office
SMOCL	Sample Management Office Contract Laboratory
SNL	Sandia National Laboratories
TOC	total organic carbon
TCLP	Toxicity Characteristics Leaching Procedure
TDS	Total Dissolved Solids

TSS	Total Suspended Solids
USEPA	U.S. Environmental Protection Agency
WERC	A Consortium for Environmental Education and Technology Development
WQL	Water Quality Laboratory

1. Introduction

1.1. Fundamentals of Arsenic Removal by Adsorption

Adsorption is a mass transfer process in which a substance is transferred from the liquid phase to the surface of a solid where it becomes bound by chemical or physical forces. In the case of oxyanions such as arsenate and arsenite, adsorption occurs on the oxide water interface by forming a complex with surface sites that may be positively charged, such as a protonated surface hydroxyl group. In other instances, the reaction may involve a ligand exchange mechanism in which the surface hydroxyl group is displaced by the adsorbing ion (AwwaRF 1999). The adsorption reaction mechanism of arsenic species onto solid metal (M) oxyhydroxide surfaces below pH 6.7 may be generically represented by the following chemical reaction (AwwaRF 1999, Edwards 1994, and Manning et al. 1998):

$$\equiv\overline{M\text{-}OH} + H^+ + H_2AsO_4^- \rightarrow \equiv\overline{M\text{-}H_2AsO_4} + H_2O \text{ (arsenate sorption)}$$

$$\equiv\overline{M\text{-}OH} + H_3AsO_3 \rightarrow \equiv\overline{M\text{-}H_2AsO_3} + H_2O \text{ (arsenite sorption)}$$

Ion exchange is a special case of adsorption where ionic species in aqueous solution are removed by exchange with ions of a similar charge (not limited to protons) that are attached to a synthetic resin or mineral surface.

Adsorption processes commonly used in water treatment are adsorption onto activated alumina, ion exchange, and iron oxyhydroxides (Banerjee et al. 1999, Torrens 1999). Figure 1-1 summarizes the typical treatment setup for the sorption process for arsenic removal. The efficiency of each media depends on operating conditions such as pH, the presence of interfering ions, speciation of arsenic, system dependent parameters (e.g., empty bed contact time, surface loading rates, bed-porosity, etc.), and the use of oxidizing agent(s) in the pre-treatment train. In general, As(V) is easier to remove from water, since it is anionic above a pH of 2.2 and is attracted to positively charged metal hydroxide surfaces. As(III) is uncharged in most natural waters below pH 9.2 and has no charge affinity to surfaces. The charge neutrality makes it difficult to remove As(III) from natural waters (Edwards 1994).

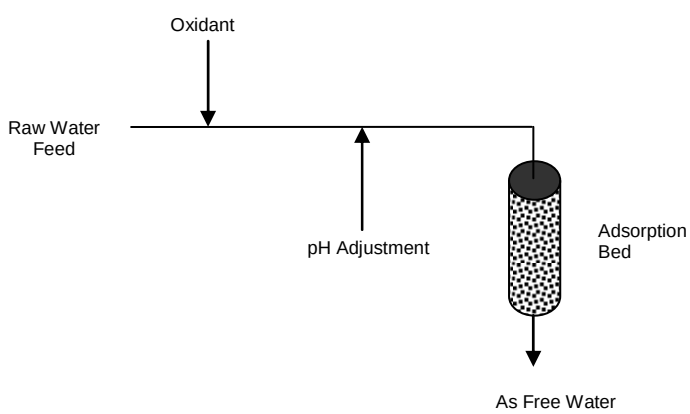

Figure 1-1. Diagram of the Sorption Process for Arsenic Removal

2. Objectives of the Desert Sands Pilot Test

Sandia National Laboratories (SNL) is conducting pilot scale evaluations of the performance and cost of innovative water treatment technologies aimed at meeting the recently revised arsenic maximum contaminant level (MCL) for drinking water. The standard of 10 µg/L is effective as of January 2006. The 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. The pilot test described in this report was conducted in Anthony, New Mexico between August 2005 and December 2006. The pilot demonstration is a project of the Arsenic Water Technology Partnership program, a partnership between the American Water Works Association Research Foundation (AwwaRF), SNL and WERC (A Consortium for Environmental Education and Technology Development).

The pilot tests in Desert Sands consist 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 2003-2005 Vendor Forums held in October of each year at the New Mexico Environmental Health Conference. An expert panel, chosen from broad spectrum of water treatment disciplines, 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**) and summarized in Siegel, McConnell, Everett and Kirby, 2006. The media in this pilot test are listed in Table 2-1.

Table 2-1. Commercial Designation of Media Used at Desert Sands

Type	Manufacturer	Product	Phase
Granular Ferric Oxide	AdEdge	E33	1, 4
Granular Ferric Oxide	BASF	ARM200	1, 3
Granular Ferric Oxide	Kemira	CFH12	1
Granular Titanium Oxide	Dow	ADSORBSIA™GTO™	1
Granular Titanium Oxide	Hydroglobe	Metsorb	1
Nanoparticle Zirconium Oxide	MEI	Isolux 302M	1
Iron Impregnated Resin	Purolite	ArsenX^{np}	1, 2
Iron Coated Resin	Resin Tech	ASM 10HP	1
Fe, Mg-coated Lanthanum	EP Minerals	NXT-2	1, 3
Granular Ferric and Cupric Oxide	Sandia National Laboratories	SANS	2
Coated Silicate	ADA	Amended Silicate	2
Modified GAC	Virotec	Bauxsol-GAC	2
Iron-coated pumice	UTEP	Reddysorb	3
Manganese dioxide solid phase oxidant	AdEdge	AD26	4

The objectives of the Desert Sands Pilot include:

- The comparative treatment performance of fourteen adsorptive media using chlorinated water from the Desert Sands Well at ambient pH and under intermittent flow operation will be used to mimic the full scale operation
- Comparison of media performance to predictions based on vendor data
- Limited assessment of maintenance and operational requirements for all media

3. Description of Pilot Test

3.1. Site Description

The pilot 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 persons) from two wells in a rural community along the New Mexico-Texas state line, north of El Paso. It has a new arsenic water treatment plant built by Severn Trent Corporation that uses the Bayoxide E33 (iron oxide) treatment method. This system was installed as part of the US EPA Arsenic Removal Technology Demonstration Program. Well #3 pumps 240-270 gpm directly into the distribution system; there are two storage tanks located adjacent to each other that are supplied by this well. The system is operated by radio telemetry. Typical water production is 2-4 million gallons per month, or 29 million gallons per year. Figure 3-1 shows the chlorination building at the Desert Sands site.

The EPA full-scale demonstration study at the site using E33 from Severn Trent/AdEdge with chlorinated well water was operated at the same time as this pilot. This allows for some comparison between the two scales of operation. The EPA study provided full scale performance and cost data and was in progress for two years. The Sandia study will provide estimates of the capacity (bed volumes until breakthrough at 10 ppb As) of E33 as well as several other adsorptive media in the same chlorinated water.

Figure 3-1. Desert Sands Pilot Plant Site

3.2. Pilot Plant Description

3.2.1. Pilot Test Design

The pilot-scale columns were designed based on full-scale design parameters to minimize scaling effects, thereby improving confidence in the results. It is understood that pilot-scale columns are sub-optimal for representation of full-scale maintenance and operational requirements; however, we have collected some operational parameters that will help define and characterize operational factors. These included the pressure drop across the media and the corresponding backwash requirements (frequency and volume) and the adsorptive capacity of all media to breakthrough (defined as 10 µg/L or 10 ppb). Pilot-scale operational parameters for each media are based upon full-scale operating conditions as provided by the respective vendors. Tables 3-1 (a-b) provide a summary of the basis for design of the pilot columns for all media.

3.2.2. Pilot Equipment

The Desert Sands pilot system is made up of the following modular components:

1. Raw water makeup system
    a. Solenoid valve, connected to Desert Sands flow switch (opens valve when Desert Sands has flow to their arsenic treatment system)
    b. Contact vessel for chlorine (allows full arsenite oxidation to arsenate),
    c. Pressure control and relief;
2. Column skid

During this pilot test, a portion of the chlorinated Desert Sands Site water was diverted to the arsenic adsorption media filters. The arsenic adsorption media filters were located inside the chlorination building located near the well. The treated water and backwash wastewater from the arsenic adsorption media filters was discharged to an on-site infiltration gallery via floor drains. All water disposal was coordinated through the Desert Sands MDWCA.

The pilot equipment, shown in Figure 3-2, was housed within a concrete block building. The building and power drop and the treated water disposal infiltration gallery were secured within a seven foot chain link fence. The building was heated by a small unit heater, and cooling was by a small refrigerated air conditioner. Temperatures were between 50-80°F. Chlorinated water was provided to the pilot test equipment at pressures of 50-86 psi.

Appendix A gives a chronological log of pilot plant operation. Various operating changes are chronicled as well as descriptions of repairs and adjustments. Appendix C includes flow diagrams for the pilot operation

Figure 3-2. Desert Sands Pilot Skid Unit

Table 3-1a. Summary of Column Design and Operation, Phase 1

Vendor Media	**MEI** Isolux 302M	**Kemira** CFH12	**AdEdge** E33	**BASF** ARM200	**Dow** ADSORBSIA™	**Hydroglobe** Metsorb	**Purolite** ArsenX^{np}	**Resin Tech** ASM-10HP
Hydraulic Loading Rate, gpm/ft^2	1.24	6	6	6	6	6	6	6
Column Number	1	4	5	6	7	8	9	10
Design EBCT, min	7.5	3	3	3	3	3	3	3
Average EBCT, min	7.5	4.1	3.6	4.3	3.1	3.8	3.8	4.6
Pre-filtration required?	5 µm	No	No	No	No	No	No	No
Column Height, in	42" (cartridge)	50	50	50	50	50	50	50
Column Diameter, in	5 (OD[1])	3	3	3	3	3	3	3
Media Depth, in	N/A[2]	33.9	34.4	34.0	29.2	33.7	34.6	38.0
Media Volume, L	8.5	3.9	4.0	3.9	3.4	3.9	4.0	4.4
Design Flow Rate, gpm	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Avg Water Flow Rate, gpm	0.25-0.4	0.2-0.3	0.2-0.35	0.2-0.35	0.2-0.35	0.2-0.35	0.2-0.35	0.2-0.35
Backwash Flow Rate, gpm	N/A	0.2-0.4	0.2-0.4	0.2-0.4	0.2-0.4	0.2-0.4	0.2-0.4	0.2-0.4

[1] OD = Outside Diameter, as provided by vendor

[2] MEI Isolux cartridge is never backwashed

Table 3-1b. Summary of Column Design and Operation, Phases 2-4

Vendor Media	**ADA** Am. Si.	**Sandia** SANS	**Purolite** ArsenX^{np} [1]	**Virotec** Bauxsol-GAC	**BASF** ARM200[1]	**EP Minerals** NXT-2	**UTEP** Reddysorb	**AdEdge** AD26	**AdEdge** E33
Hydraulic Loading Rate, gpm/ft^2	3	6	6	4	6	6	1.1	8	8
Column Number	2	3	9	12	10	11	12	2	12
Design EBCT, min	5	3	3	5	3	3	10	2.5	2.5
Average EBCT, min	6.7	3.7	3.3	6.4	3.2	3.5	9.3	2.0	2.7
Pre-filtration required?	No	No	No	No	No	No	No	No	No
Column Height, in	50	50	50	50	50	50	50	50	50
Column Diameter, in	4	3	3	4	3	3	4	4	4
Media Depth, in	20.1	30.6	30.0	29.9	29.3	31.3	25.8	17.8	17.5
Media Volume, L	4.1	3.5	3.5	6.2	3.4	3.6	4.4	3.7	3.6
Design Flow Rate, gpm	0.2	0.3	0.3	0.2	0.3	0.3	0.1	0.5	0.4
Avg Water Flow Rate, gpm	0.2	0.27	0.28	0.25	0.28	0.28	0.15	0.5	0.4
Backwash Flow Rate, gpm	0.1-0.25	0.2-0.4	0.2-0.4	0.1-0.25	0.2-0.4	0.2-0.4	0.1-0.25	0.2-0.4	0.2-0.4

[1] These were new formulations provided by vendors

The conceptual treatment process for all arsenic adsorption media filters is based on passing arsenic-contaminated feed water through a fixed bed of media that has a strong affinity for arsenic. The arsenic is removed in fixed bed filtration via adsorption, the physical attachment of the adsorbate (arsenic) to the surface of the adsorbent media grains. The removal capacity and effectiveness of the arsenic removal media is dependent on a number of factors, such as surface area. The surface area is a function of the accessibility of the porosity of the media grains (Siegel 2007). Adsorbent media contains a large quantity of very small pores throughout the media grains. Other factors that determine the capacity and effectiveness of adsorbent media are accessibility of the pore sites for arsenic ions, time available for arsenic ions to migrate to pore sites, competing ions for pore sites, concentration of arsenic in the feed water, pH of the feed water, and flow characteristics of the feed water that conveys the arsenic into the bed of adsorbent media.

It is well-known that intermittent operation of an arsenic treatment system will allow for extended capacity of arsenic removal media. As in many systems, the Desert Sands Well #3 is off for 8-12 hours per day, depending on the system demand. This "rest" time allows for better utilization of the media and longer media life, as compared to continuous flow.

The time available for arsenic sorption is proportional to the EBCT. The design basis (manufacturer's suggestions) for pilot EBCT is shown in Tables 3-1(a-b) and varies between 3 and 10 minutes. In this pilot, the design flow rate was not maintained. This is mainly due to the intermittent operation and manual control of flow. The pilot site was visited twice per week, but the columns' flow rates were consistently below their set points by 10-20%. This led to a higher EBCT than designed. A higher EBCT is advantageous for all media, and the difference was minimal (actual EBCT was generally 10-20% higher than the design EBCT). The Isolux media is inside a vendor-provided radial cartridge that is designed for low EBCT operation.

As water passes down through a filter vessel containing fixed bed media, the effluent arsenic concentration declines until it is no longer detectable. As the upper portion of the media becomes saturated, the treatment region (mass transfer zone) progresses downward until some adsorptive capacity is used and arsenic breakthrough occurs. At this point the media would have to be replaced if series operation is not utilized. If the adsorbent media perform as expected, no arsenic will be detected in the treated water for at least 4 to 6 months. The lower limit of detection for arsenic using the Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) at SNL's Water Quality Laboratory (WQL) is less than 1 µg/L. As the adsorbent capacity of an adsorbent medium is exhausted, detectable amounts of arsenic will appear in the treated water. The concentration of arsenic will gradually increase, and when the capacity of the medium is completely exhausted, the arsenic concentrations in the untreated and treated water will be the same.

3.3. Water Quality

Average values of Desert Sands raw water quality parameters are presented on Table 3-2. The water is generally of good quality except for arsenic, which exceeds the new MCL effective in January 2006. The water has raised levels of TDS, caused mainly by chloride and sulfate. The arsenic level is just over two times the January 2006 MCL of 10 µg/L (10 ppb).

Table 3-2. Desert Sands Water Composition (Average Values)

Parameter	Unchlorinated Feed Water	Chlorinated Feed Water
Conductivity (µS/cm)	1351	1350
Temperature (°C)	31	31
pH	7.8	7.8
Free Chlorine (ppm as Cl_2)	0	0.5
Turbidity (NTU)	1.4	0.4
Alkalinity (ppm)	178	182
Nitrate (ppm)	ND	ND
Iron (ppm)	0.26	0.17
Particulate As (ppb)	1.5	1.4
As (III) (ppb)	18.3	2.8
As (V) (ppb)	1.8	17.8
Total Arsenic (ppb)	20	20
Vanadium (ppb)	<5	<5
Fluoride (ppm)	0.5	0.5
Chloride (ppm)	172	174
Sulfate (ppm)	181	182
Sodium (ppm)	247	246
Magnesium (ppm)	3.9	3.9
Manganese (ppb)	12	12
Calcium (ppm)	26	26
Silica (ppm)	37	37
TSS (ppm)	0.52	0.26
TOC (ppm)	0.7	0.8

3.4. Media Description

The Desert Sands pilot study tested fourteen media at ambient pH with intermittent operation. These included three granular iron-based media, one granular iron- and copper-based media, two granular titanium-based media, one nanoparticle zirconia-based media, two iron-modified resins, four coated media, and a solid phase oxidant.

Most vendors indicated that no pretreatment is required for their respective arsenic adsorption media; MEI utilizes a 5-µm, pleated pre-filter cartridge to minimize potential plugging of the media cartridge by particulate matter.

3.5. Sampling and Analysis Plan

A detailed sampling plan was previously published as SAND 2006-1324 (Siegel, et. al., 2006a). This test plan was used as a starting point and modified to meet time and budget constraints. Several analytes were not tested or minimally tested, as they were determined to be unnecessary for the objectives of this study. The essential procedures for the actual operation of the Desert Sands Pilot are summarized in Table 3-3. There are two periods of sampling during the pilot study: the Systems Integrity Verification Test (SIVT) and the Capacity Verification Test (CVT). The SIVT is a 2-week period at the start of the pilot used to evaluate the reliability of equipment

operation under the environmental and hydraulic conditions at the Desert Sands pilot site and to determine whether performance objectives can be achieved for arsenic removal at the design operating parameters for the arsenic adsorption media system. The CVT period produces operational and water quality data up through and beyond the defined breakthrough arsenic level (10 µg/L) for each sorptive media.

Table 3-3. Water Quality Sampling and Analysis Plan

Parameter	Sampling Frequency (IVT)	Sampling Frequency (CVT)	Method Used[1]	Comments
On-Site Analyses				
Conductivity	Daily	Bi-Weekly	HACH 8160B (Direct Measurement Method)	Equivalent to EPA 120.1, Standard Method 2510B
Temperature	Daily	Bi-Weekly	Standard Method 2550B	Utilized digital thermometer on HACH conductivity meter
pH	Daily	Bi-Weekly	Standard Method 4500-H^+	
Free Chlorine	Daily	Bi-Weekly	HACH 8021 (DPD)	Equivalent to Standard Method 4500-Cl G
Turbidity	Daily	Bi-Weekly	Standard Method 2130 B	
Laboratory Analyses				
Total Arsenic	Daily	Bi-Weekly	EPA 200.8	Total Arsenic measured within 48 hours of sampling by ICP-MS in the WQL in lieu of on-site qualitative analysis.
Speciated Arsenic	Weekly	Weekly	EPA 200.8	Separation of As(III) from As(V) done by aluminosilicate adsorbent cartridge. See Appendix E of the Siegel, et. al., 2006a (SAND2006-1324) for details.
Iron	Daily	Weekly or Monthly	EPA 200.7 – SMOCL, AA Spectroscopy – WQL	
Titanium	Daily	Weekly or Monthly	EPA 200.8	Analyses only for Hydroglobe columns
Zirconium	Daily	Weekly or Monthly	EPA 200.8 – SMOCL AA Spectroscopy – WQL	Analyses only for MEI cartridges
Alkalinity	Daily	Weekly or Monthly	Standard Method 2320 B	
TSS	Three times	Monthly	Standard Method 2540 B	SMOCL Only
Nitrate	Three times	Not Tested	EPA 300.0	SMOCL Only
Metals	Weekly	Weekly or Monthly	EPA 200.7 – SMOCL AA Spectroscopy, EPA 200.8 – WQL	As, Ti, V, Al, Mn, Zr by EPA 200.8; Other metals by AA Spectroscopy at WQL
Silica	Weekly	Weekly or Monthly	EPA 200.7 – SMOCL HACH 8185 – WQL	HACH method is the Silicomolybdate Method
Anions	Weekly	Weekly or Monthly	EPA 300.0	
TOC	Three times	Not Tested	SW-46 9060	SMOCL Only

1. Reference for the Standards Methods is APHA, 1998; reference for EPA Methods is USEPA, 2005; reference for Hach methods is www.hach.com.

4. Test Results

4.1. Pilot Phase Description

The Desert Sands Pilot can be described by four different phases, as summarized in Table 4-2. 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 2006). Several of the vendors provided new and/or improved products for later phases (ArsenX^{np}, ARM200, NXT-2, E33). Arsenic removal data is not presented for the initial ArsenX^{np} or NXT-2 media, as they were not run long enough to obtain useful information (effluent levels of arsenic were still at non-detectable levels).

Phases 1-3 operated on an intermittent basis as described in section 3.2. During Phase 4, a new batch of E33 was installed and was operated continuously.

Table 4-1. Summary of Desert Sands Phases

Phase 1 Aug 2005-Dec 2006	**Phase 2** Dec 2005-Dec 2006	**Phase 3** June 2006-Dec 2006	**Phase 4** Sept 2006-Dec 2006
Isolux 302M - MEI	Amended Silicate - ADA	ARM200 - BASF (2nd 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 (2nd batch)		
ADSORBSIA - DOW			
Metsorb - Hydroglobe			
ArsenX^{np} - Purolite			
ASM-10HP - ResinTech			
NXT-2 - EP Minerals			

4.2. Water Chemistry Effects

Appendix B presents the water chemistry measurements for the Desert Sands pilot study. Most analytes were unaffected by the adsorption media as attested by the low standard deviations noted for both feed and product water. Three exceptions however are pH, silica, and iron in product water.

4.2.1 Discussion of pH and Silica

Each of the media affected the pH in the effluent streams, due to the leaching of acidic groups (depress the pH) or of basic groups (raise the pH). As shown in Table 4-2, NXT-2, Bauxsol-GAC, and the UTEP media each increased the pH by 5-32% and the rest of the media depressed the pH by 5-60%. All media had effluent pH values within 10% of the influent after 1500 bed volumes had been treated. Appendix D presents pH data for each media.

Table 4-2. Summary of pH Changes by Adsorptive Media

Phase	Media	Initial pH change from influent avg (%)	BV until pH change less than +/- 10%
1	Isolux 302M	-60%	900
1	ArsenX^{np}	-60%	500
1	Metsorb	-33%	900
1	ADSORBSIA	-33%	900
3	NXT-2	32%	1000
1	CFH12	-31%	1000
1	NXT-2	28%	1500
1	ARM200	-14%	1300
1	ASM-10HP	-10%	100
1	E33	-8%	0
2	Bauxsol-GAC	7%	0
2	ArsenX^{np}	-6%	0
3	Reddysorb	5%	0
1	Amended Silicate	-5%	0
1	SANS	-5%	0
2	ARM200	-4%	0

Many of the adsorption media are affected by silica, as it is adsorbed very rapidly in the early stages of treatment. Silica typically breaks through within 5000 bed volumes, with effluent silica levels equal to influent levels. As shown in Table 4-3, each of the Phase 1 media adsorbed silica, with CFH12 adsorbing it for the longest period and ArsenX^{np} the least. Silica testing was omitted during the initial testing period for the other phases. Silica is known to decrease the effectiveness of arsenic removal media, potentially by blocking adsorptive sites for arsenic (Clifford, et al. 2004). Appendix D presents silica measurements for each media in Phase 1.

Table 4-3. Summary of Silica Adsorption by Adsorptive Media

Media	BV until SiO_2 change less than +/- 10%
CFH12	6400
ARM200	3200
Isolux 302M	2800
NXT-2	2500
ADSORBSIA	2100
Metsorb	2000
ASM-10HP	1700
E33	1200
ArsenX^{np}	1100

4.2.2 Backwash Information (Phase 1 – Phase 4)

During Phase 1, each of the media was dry loaded into the columns. Each column was filled with chlorinated water from the bottom up to the top to remove air. This caused the two titanium media (ADSORBSIA™ and Metsorb) to clump and not allow water to flow initially. A clean stainless steel rod was used to break up the clog in the ADSORBSIA™. The top 6-8 inches of Metsorb media was removed after attempts with the rod were unsuccessful. Dow provides a helpful loading and backwashing document now that covers proper procedures to mitigate these

issues, but it was not available at the time of this pilot's start-up. In Dow's procedure, the media is loaded dry into a vessel, then slowly filled with water and backwashed for a period of time until the turbidity in the backwash effluent is less than 100 NTU. Appendix E contains Dow's procedure; their website (www.adsorbsia.com) has additional information.

During Phases 2-4, each of the media was wet-loaded, or the columns were filled with water and media was added to the water. After loading, each column was filled with chlorinated water from the bottom up to the top to remove the rest of the air.

The media was backwashed immediately following installation. Each column was backwashed for 10-90 minutes until the backwash effluent no longer had visible color. Appendix E summarizes the initial backwash duration and volume for each column. Most media required less than 40 minutes of backwash. ArsenX^{np} and ASM-10HP required the least amount of backwashing at 20 and 10 minutes, respectively. Metsorb required the most backwashing at 89 minutes. It should be noted that the condition used to stop backwashing was primarily visual, when little or no color was visible, backwashing stopped.

During pilot operation, the influent and effluent pressure of each column was measured and recorded at least twice per week. Columns were backwashed when the pressure drop across the bed was near 10 psi or larger. Appendix E summarizes the backwash frequency for each column in each phase. One of the causes of the relatively frequent backwashing is thought to have been caused by the iron content in the feed water. This iron is oxidized by the chlorine feed and is removed by the arsenic removal media. This was seen as a reddish color on the titanium oxide media (ADSORBSIA, Metsorb) and as a gel-like layer at the top of the ArsenX^{np} column. These results are shown qualitatively in Figures 4-1 and 4-2. In addition, RSSCT studies at SNL by Alicia Aragon (unpublished) indicate that a combination of high pH and high silica can cause more frequent backwashing. Lastly, the higher TDS of the water and hydraulic nuances of small column operation could also affect the backwashing frequencies and duration. A comparison can be made between the intermittently operated E33 column and the continuously operated E33 column: the continuously operated column was never backwashed. It should be noted that the continuous column had a 20 μm pre-filter installed that was changed 2 times in the first month it was in operation, but not changed after that.

Figure 4-1. Dow (left) and Hydroglobe (right) media with iron at tops of each column

Figure 4-2. ArsenX^{np} media with iron at top of column

4.3. Adsorptive Media Performance

4.3.1. Vendor Predictions

Vendors were asked to provide estimates of the media performance in the Desert Sands waters based on their previous studies. The information obtained from vendors is summarized in Table 4-4.

Table 4-4. Predictions of Media Performance

Company/ Media	**Anticipated treatment capacity** (breakthrough at 10 ppb unless otherwise noted)	**Anticipated cost/ 1000 gallon**	**Comments**
ADA/ Amended Silicate	>10,000 bed volumes	No Information	No Information
AdEdge/ E33	> 50,000 bed volumes	No Information	Based on no PO_4
Dow/ ADSORBSIA™	39,000 bed volumes	No Information	Based on 20 ppb As(V), pH 7.8, 34 ppm SiO_2
EP Minerals/ NXT-2	> 80,000 bed volumes	No Information	Is dependent on the level of phosphates and other potential interferents
BASF/ ARM 200	32,000 bed volumes	No Information	Based on As(III) removal, 5 min EBCT
Hydroglobe/ Metsorb	40,000 bed volumes	No Information	Based on pH near 7.0
Purolite/ $ArsenX^{np}$	Estimated BVs to 8 ppb breakthrough: 20,000-39,000 BVs, depending on PO_4 level	~ $0.25 to $0.35 if media is regenerated ~$1.30 for throwaway media	125 ppb PO_4 - 39,000 BVs 250 ppb PO_4 - 26,000 BVs 400 ppb PO_4 - 20,000 BVs
Resin Tech/ ASM-10HP	2,800 bed volumes	No Information	At pH 7 – 23,900 BV At pH 6.5 – 56,000 BV
UTEP/ Reddysorb	4,000 bed volumes @ pH 7	Anticipated cost of media $1-3/lb ($38-115/ft^3)	Designed for small systems where cost and ease of media disposal are critical.

4.3.2. Pilot Performance

The effectiveness of an adsorptive bed is measured in the amount of water that it can treat to meet the 10 ppb arsenic standard. One means of reporting this is referred to as bed volumes (BV) of water passing through the media columns until the regulatory limit (10 ppb) was exceeded in the effluent. Bed volumes are a common thread between pilot scale and full scale operations. A utility would simply need to multiply the pilot BV for a specific media and water chemistry by the total volume of media required for a full scale system to obtain the amount of water that could be treated before exceeding the MCL. Another measure of performance, the arsenic sorption capacity of the media, was calculated from the mass balance. It is reported as milligrams of arsenic sorbed per gram of media at breakthrough (when the effluent reaches 10 ppb). For the pilot tests, the values of BV and capacity at breakthrough show a fairly consistent relationship.

Of the fourteen media tested at the Desert Sands site, performance data for the top 8 are shown as breakthrough curves in Figures 4-1. This figure presents time averaged data for purposes of clarity. Although many of the top performing media were only run to 8-10 ppb or less, one can clearly see the relative performance of each media. An arsenic value between 8-10 ppb in the treated effluent indicates that the media would be replaced. In this report abbreviations are used for ease in graph formatting and are summarized below in Table 4-5.

Table 4-5. Media Abbreviations

Manufacturer	**Media**	**Media Abbreviation**
AdEdge	E33 – continuous flow E33 – intermittent flow	E33 (cont) E33 (int)
BASF	ARM200 – Phase 1 ARM200 – Phase 3	ARM200 (A) ARM200 (B)
Kemira	CFH12	CFH12
Dow	ADSORBSIA™GTO™	ADSORBSIA
Hydroglobe	Metsorb	Metsorb
MEI	Isolux 302M	Isolux
Purolite	ArsenX^{np} – Phase 1 ArsenX^{np} – Phase 2	AsX (A) AsX (B)
Resin Tech	ASM-10HP	ASM-10HP
EP Minerals	NXT-2 – Phase 3	NXT-2
Sandia National Laboratories	SANS	SANS
ADA	Amended Silicate	ADA
Virotec	Bauxsol/GAC	Bauxsol/GAC
UTEP	Reddysorb	UTEP
AdEdge	AD26	AD26

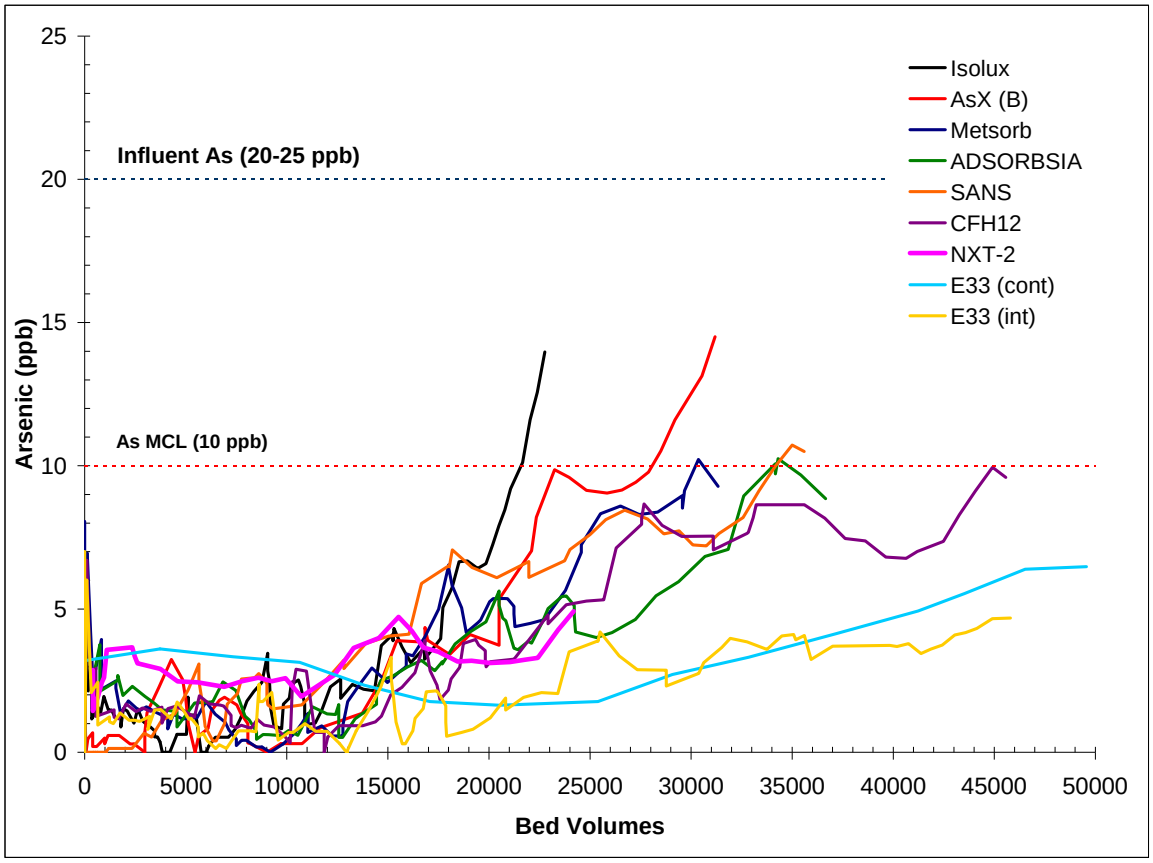

Figure 4-3. Desert Sands Top Performing Media Arsenic Breakthrough Curves

Figure 4-2 compares the arsenic removal by the two E33 columns, one which was operated intermittently, the other continuously. The intermittent operation E33 column had a higher EBCT (3.6 minutes) than the continuously operated E33 column (2.7 minutes). Using approximated breakthrough volumes for each column, there is an 18% increase in media efficiency using intermittent operation (18% more water is treated prior to effluent levels reaching 10 ppb). Estimates of breakthrough were made for the media utilizing a curve fit of the data with extrapolation to arsenic values greater than 10 ppb.

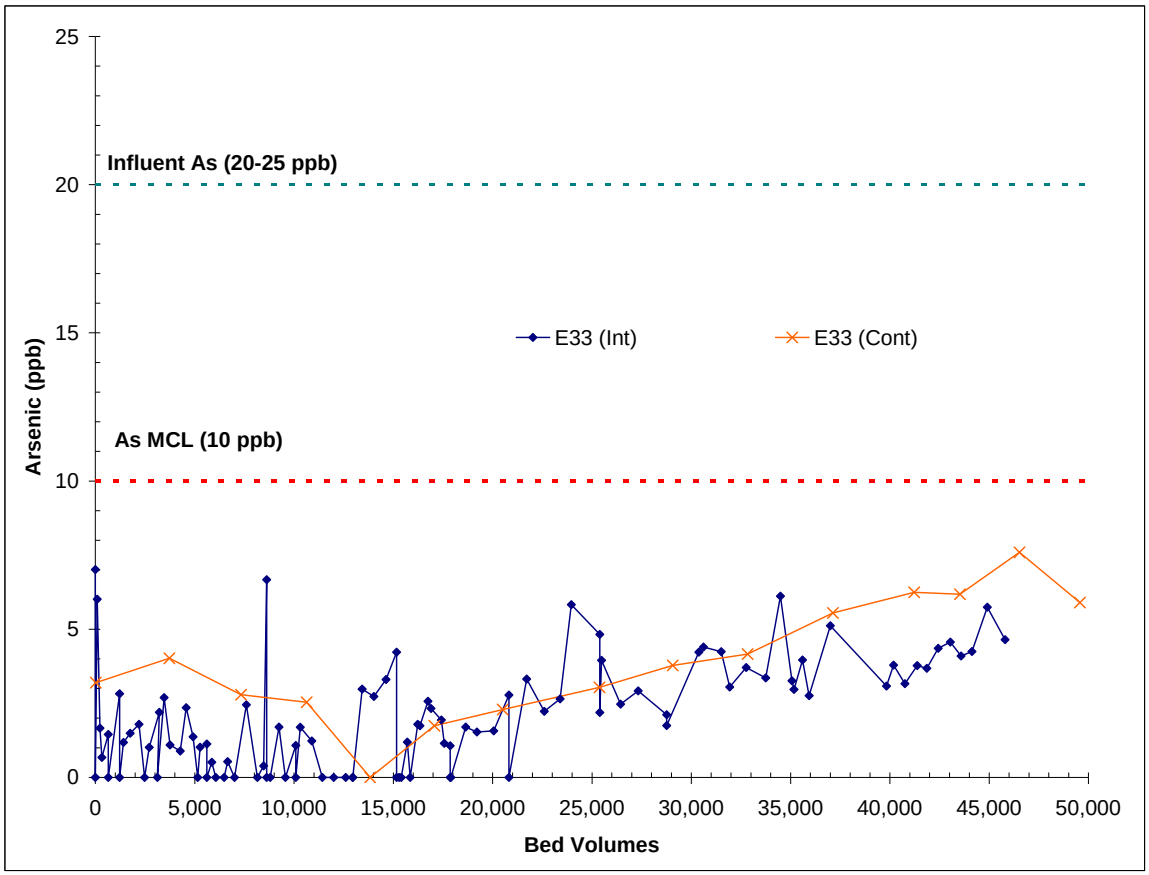

Figure 4-4. Effect of Continuous & Intermittent Operation (E33)

4.4. Spent Media Characterization

The spent arsenic adsorption media passed the TCLP (US EPA 1992) test with respect to all regulated metals. The ISOLUX material was not tested, as it was not in powder form; however, the amount of arsenic potentially adsorbed is significantly less than the TCLP limit (5 mg/L) and no other regulated metals would be present. All media can be disposed of in a non-hazardous landfill. Appendix F summarizes the TCLP results for each media. All results are in mg/L unless otherwise noted.

5. Discussion and Conclusions

5.1. Media Effectiveness

Of the fourteen media tested at the Desert Sands site, data is presented for all but AD26 in Table 5-1. AD26 data is not presented since the column was not operated properly for arsenic removal. The AD26 media is designed to be an arsenic and iron removal tool, and is supposed to be backwashed on a regular basis. It is supposed to also provide oxidation of arsenite to arsenate. The column was backwashed irregularly and effluent samples were not speciated to ascertain oxidation effectiveness. Italicized font indicates media that did not experience arsenic levels greater than 8 ppb; estimates of breakthrough were made for these media utilizing a curve fit of the data with extrapolation to arsenic values greater than 10 ppb. It should be noted that the actual BVs treated would depend on the future levels of influent arsenic and other competing contaminants. In addition, it is likely that the actual performance would be different (lower or higher) than the estimated BVs using the curve fit method.

Rank ordering the performance of the media was done using the obtained values for bed volumes to arsenic breakthrough. This rank ordering is also shown in Table 5-1, and is listed in order of ascending media performance. The media had EBCTs that were within the prescribed values from the media vendors. It is generally believed that a longer empty bed contact time will extend the life of the media, however, EBCTs longer than 5 minutes are rarely utilized in arsenic removal plant design due to the increase in cost and footprint required. With an estimated media life of 56,000-66,000 bed volumes of water treated to 10 ppb, E33 outperforms all other media.

Table 5-1. Summary of Media Performance (All Phases)

Column #	Phase	Media	BV to 8 ppb	BV to 10 ppb	Capacity @ 10 ppb (mg/g)
12	2	Bauxsol-GAC	<1000	<1000	0.43
12	3	Reddysorb	700	800	0.5
2	2	Amended Silicate	2,200	2,300	0.15
10	1	ASM-10HP	7,300	7,500	0.17
10	3	ARM200	11,000	13,000	0.37
6	1	ARM200	13,000	13,500	0.38
1	1	Isolux 302M	20,000	22,000	0.41
9	2	ArsenX^{np}	25,000	28,000	0.54
8	1	Metsorb	27,000	30,000	0.57
7	1	ADSORBSIA	30,000	34,000	0.4
3	2	SANS	31,000	34,000	0.63
11	3	*NXT-2*	*34,000*	*40,000*	*0.48*
4	1	CFH12	42,000	45,000	0.71
12	4	*E33 (cont)*	*50,000*	*56,000*	*1.93*
5	1	*E33 (int)*	*58,000*	*66,000*	*1.75*

The full scale pilot demonstration performed by the US EPA yielded slightly different results. Although the final report has not yet been published, results were presented (Sorg, 2006). The pilot tested two different versions of the E33 product: the first run was with a granular E33 media and the second was a pelletized E33 product. Breakthrough occurred at approximately

42,000 bed volumes for the granular media and at approximately 45,000 bed volumes for the pelletized product. The difference between the pilot and full scale could be explained by the inaccuracies in the calculation of bed volumes and/or from flow meters in either case. In the case of this pilot, the bed volume of media was calculated by measuring the height of the media after installation and initial backwash and calculating the volume. In the case of the full scale, bed volumes may be calculated from the weight and density of the media. Also, there are hydraulic differences between pilot and full scale operation.

5.2. Water Treatment Cost Estimates

The total cost of arsenic treatment consists of two parts: (1) Initial Capital Costs and (2) Annual Operations and Maintenance (O&M) Costs. Initial Capital Costs include the cost of a new or modified building, equipment costs for arsenic removal, and infrastructure improvements necessary for arsenic removal (e.g. pumps, piping, etc.). Annual O&M Costs include labor, electrical costs, media replacement costs, chemical pre-treatment and post-treatment (if applicable), and media disposal costs.

Arsenic treatment costs can have a wide range, due to the performance of the different kinds of media and the O&M costs associated with maintaining the system. In addition, each site will have its own specific water chemistry and site conditions which can contribute to unique costs.

At the Desert Sands site, the average daily water production is 160,000 gallons per day. Economic calculations for this site are based on the following assumptions:

Design Basis:

- Bed volumes treated are from the E33 performance data in this pilot with a 3 minute EBCT for ambient pH
- Bed life for pH adjustment to 6.8 is assumed to be 120,000 bed volumes (based on performance at the Socorro pilot (Aragon, 2007; Siegel, 2007))
- No backwash reclaim tank, solids capturing equipment, or solids disposal are included
- No major infrastructure improvements are included
- Permitting, Engineering, and Installation cost estimates are included

Table 5-2 summarizes the input values used in the economic analysis using the pilot results. Results in Table 5-3 provide order of magnitude economic costs calculated by the utilizing the Cost Estimating Program for Arsenic Removal from Drinking Water Supplies by Adsorptive Media and Anion Exchange Processes ARCE model (US EPA, 2004) and an Excel spreadsheet for each of the pilot designs (5 minute EBCT). This spreadsheet adds in the cost of a building and recalculates the final cost estimates.

Table 5-3 summarizes the economic cost outputs and demonstrates that for this location the media costs heavily influence the total unit cost of water produced. The facility costs also influence the cost of water, but independently of media costs. With the estimated bed volumes obtained during this pilot, it is estimated that arsenic treatment costs would be $1.26 per 1000 gallons and $1.08 per 1000 gallons for ambient treatment and pH-adjusted treatment respectively. In the latter cost estimate, pH is lowered using hydrochloric acid to a pH of 6.8; the

treated water pH would be raised to near ambient levels using sodium hydroxide. Detailed tables are presented in Appendix G. Actual media performance of the E33 product will change the estimated costs, as this pilot was not run to arsenic values greater than 8 ppb.

Table 5-2. Capital Input Values for Economic Cost Calculations

Design Criteria	**pH 7.8**	**pH 6.8**
Vessel Flow Rate, gpm	379	379
Design Treatment Capacity, MGD	0.16	0.16
Configuration (series/parallel/unknown)	parallel	parallel
Unit Media Cost, $/cf	*$200.00*	*$200.00*
Building, sf	200	200
Building Unit Cost, $/sf	$200	$200
Annual Estimated Power Use, kWh/yr	14,334	14,334
Power Cost, $/kWh	0.08	0.08
Labor, Operations, hrs/yr	57.0	55.0
Unit Labor Cost, Operations, $/hr	$30	$30
Labor, Management, hrs/yr	12	12
Labor, Management, $/hr	$80	$80

Table 5-3. Capital and Annual O&M Costs for Arsenic Removal using Granular Media

Annual O&M Costs	**pH 7.8**	**pH 6.8**
Total Annual Media Costs, $/yr Based on Average Flow	$25,330	$15,198
Total Annual pH Adjustment Chemicals, $/yr	$0	$2,435
Annual Power Cost, $/yr	$1,147	$1,147
Spent Media Production, Tons/yr	n/a	n/a
Total Estimated Labor Costs, $/yr	$2,670	$2,610
Equipment Maintenance Costs, $/yr	$7,990	$8,025
Capital Cost Summary		
Media & Equipment	$298,828	$300,118
Building	$57,600	$57,600
Construction & 20% Contingency	$43,945	$44,135
Present Worth Analysis		
Net Interest Rate	4.0%	4.0%
Period, Years	20	20
Total Annual O&M Costs, $/yr	$37,137	$29,415
Present Worth of Annual O&M Costs	$504,701	$366,657
Total Estimated Facility Cost	$479,475	$481,296
Total Present Value of Facilities	$984,175	$847,953
Total Annual Amortized Cost (Capital + O&M)	$72,417	$62,394
Total Unit Cost of Water Produced, $/1,000 gal	$1.26	$1.08

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Appendix A. Desert Sands Arsenic Pilot Plant Logs

Table A-1a. Summary of Field Activities and Notes

8/15/05	**Phase 1 Pilot Starts.** Loaded media into columns and performed initial backwash.
8/16/05	Calibrated column electronic flow meters.
8/18/05	MEI 5-µm pre-filter is beginning to get dirty (reddish in color). Column 5 is not flowing well – will open rotameter all the way, so as to allow all flow possible to column (still flowing at 0.3 gpm).
8/23/05	Column 6 & 7 pressure gauges seem to be reading low (Later work recalibrated gauges.) Column 5 has very little flow, no pressure at bottom pressure gauge.
9/12/05	Noted that the supplied pressure/flow rate didn't allow for easy removal of fines and other particulate in the columns during backwashing. This required long durations for the backwash of the columns.
9/15/05	There is a fair amount of air in each of the columns, which is causing flow problems. Bled the air out of each column.
9/18/05	Changed MEI pre-filter.
9/23/05	Brown color noticed on top of column 7 media.
9/29/05	Noticed there were a lot of particulates and/or media fines during the backwash of column 9.
10/11/05	Noticed there were a lot of particulates and/or media fines during the backwash of columns 5 and 6.
10/14/05	Both titanium media have brown-red clumps forming at the top of the media (columns 7 and 8). Took samples of inlet/outlet of MEI pre-filter, then changed out the filter itself.
10/20/05	Fixed leak on column 10.
10/21/05	Speciation procedure not followed correctly before this date. Had been filtering twice the allowed amount through the speciation cartridge.
10/25/05	Noticed that column 1 was accidentally valved off (no flow) since previous visit. Opened valves & restored flow. Noted that the brown clumping layer on column 7 is smaller than column 8, but that both clumping layers appear to be causing the increased pressure drops across the media.
10/28/05	Noted fines were coming through the rotameter on column 4. Partially opened drain valve until water was clear in color. Noticed that column 6 had media clumping similar to the titanium media.
10/30/05	Can see what appears to be roots in the E33 media (column 5); these were also noticed in the full scale media. Noticed lots of fines and/or particulate matter when backwashing column 4.
11/1/05	High turbidity readings for columns 4 and 9. Column 4's results probably due to backwashing, column 9's results are unclear. Influent iron was slightly higher than average, and column 9 effluent had recently spiked with higher levels of iron.
11/4/05	Noticed fines and/or particulate matter when backwashing column 9. Noticed media clumping on columns 5 and 6.
11/8/05	Conductivity meter was not working properly. Did not record any conductivity results for this day's samples.

Table A-1b. Summary of Field Activities and Notes

11/11/05	Column 10 had air in column.
11/15/05	Conductivity meter was not working properly. Did not record any conductivity results for this day's samples.
11/17/05 11/18/05	Noted appearance of media fines and/or particulate matter in columns 9 and 4; Noted media clumping in columns 7 and 8. It appeared that a piece of the clump has moved to the bottom of column 7.
11/22/05	Had problems with the conductivity measurements for column 10.
12/4/05	Took totalized water meter readings from computer. Began overnight soak of ADA Amended Silicate media (used DI water).
12/5/05	**Phase 2 starts.** Modified skid to include 4" columns for column 2 and 12. Loaded media into columns 2 (ADA), 3 (SANS), 9 (new batch of ArsenX^{np}) , 12 (Bauxsol-GAC). Verified water meter calibration. Noted column 12 (Bauxsol-GAC) seemed to be losing its Bauxsol coating during backwash operation.
12/14/05	Column 12 has a lot of media fines at the top of the column and wasn't flowing well.
12/18/05	Changed MEI pre-filter.
1/1/06 1/3/06	Noticed significant amount of media fines in column 12.
1/4/06	High pressure drop and significant amount of media fines in column 12.
2/2/06	Noted high turbidity values; speculated that the cause was fibers from the drying cloths on the sample cells.
3/1/06	Removed media from columns 2, 10, 12. Added chlorine contact column upstream of all columns.
4/14/06	Noted the presence of particulates in the chlorine contact column
5/16/06	Sampled backwash water for column 3, 5, 6, 7, 8.
6/14/06	Removed media from columns 6, 7, 8; **Phase 3 starts.** Added new media to columns 10 (new batch of ARM200), 11 (NXT-2), and 12 (UTEP)
8/23/06	Flow meter on column 4 not working – replaced with column 6 meter.
9/13/06	Removed media from columns 11 and 12. **Phase 4 starts.** Modified skid piping to allow continuous flow to columns 2 & 12, along with pre-filtration for column 12. Added media to columns 2 (AD26) and 12 (E33).
10/1/06	Computer display not working.
10/5/06	Replaced column 12 pre-filter.
10/11/06	Removed columns 1, 3, 4, 9, and 10.
12/18/06	Pilot shut down; all equipment removed and treatment building was cleaned. Final water meter reading 550,300 gallons.

Appendix B. Water Chemistry Measurements

Appendix B tables list relevant analyte concentrations for major ions as well as pH, TOC, conductivity, turbidity and free chlorine. We report the average (A), standard deviation (SD) and number of samples measured (N).

SA = Unchlorinated Feed Water
SB = Chlorinated Feed Water
NT = Not Tested

Table B-1a. Raw Water Chemistry Measurements

		Total As (ppb)	Part. As (ppb)	As III (ppb)	As V (ppb)	Ca (ppm)	Cu (ppm)	Fe (ppm)	Mg (ppm)	Mn (ppb)
SA	Avg	20.5	1.1	18.6	2.2	25.5	0.0	0.3	3.9	10.7
	SD	2.1	1.1	1.5	1.2	5.6	0.0	0.2	0.2	3.8
	N	98	76	78	76	64	43	86	52	91
SB	Avg	20.7	1.4	2.6	17.6	25.5	0.0	0.2	3.9	12.7
	SD	2.0	1.2	3.0	3.8	5.5	0.0	0.1	0.2	11.1
	N	119	77	80	59	81	55	106	69	108

Table B-1b. Raw Water Chemistry Measurements

		SiO2 (ppm)	Na (ppm)	V (ppb)	Alkalinity (ppm $CaCO_3$)	Cl (ppm)	F (ppm)	Nitrates (ppm)	Sulfate (ppm)
SA	Avg	36.9	247	4.0	178	172	0.5	0.0	181
	SD	2.9	35.7	1.3	4.4	7.6	0.0	0.0	7.9
	N	71	29	92	70	54	54	14	55
SB	Avg	36.5	246	4.2	182	174	0.5	0.0	182
	SD	3.0	27.5	0.9	5.2	7.0	0.0	0.0	6.4
	N	75	29	111	74	56	56	12	57

Table B-1c. Raw Water Chemistry Measurements

		TDS (ppm)	TSS (ppm)	TOC (ppm)	pH	Conductivity (µS/cm)	Temp °C	Free Cl_2 (ppm)	Turbidity (NTU)
SA	Avg	655	0.5	0.7	7.8	1310	30.6	0.0	1.4
	SD	4.1	1.0	0.2	0.1	262.3	1.2	0.1	1.3
	N	23	12	10	94	91	75	93	94
SB	Avg	657	0.3	0.8	7.8	1350	30.6	0.6	0.4
	SD	3.9	0.6	0.2	0.1	99.7	1.4	0.7	0.3
	N	23	10	11	100	94	82	99	97

Table B-2a. Effluent Water Chemistry Measurements

		Ca (ppm)	Fe (ppm)	Cu (ppm)	Mg (ppm)	Mn (ppb)	SiO_2 (ppm)	Na (ppm)	V (ppb)
Isolux	A	23.1	0.0	NT	3.7	< 3.0	30.0	244	2.9
	SD	11.6	0.1		0.6	N/A	13.3	25.2	2.1
	N	27	41		23	84	47	19	85
AD26	A	NT	0.0	NT	NT	< 3.0	34.1	NT	0.8
	SD		0.0			N/A	6.3		1.7
	N		23			23	13		23
SANS	A	27.2	0.0	0.2	3.9	< 3.0	34.5	221	3.2
	SD	1.1	0.0	0.1	0.3	N/A	3.1	19.0	2.6
	N	10		54	11	54	20	11	54
CFH12	A	27.2	0.0	NT	4.1	< 3.0	31.6	237	2.9
	SD	6.2	0.1		1.0	N/A	12.2	22.8	2.1
	N	25	83		23	85	47	20	86
E33 (cont)	A	28.6	0.0	NT	3.8	< 3.0	35.0	232	2.7
	SD	7.1	0.0		0.5	N/A	7.6	41.3	2.2
	N	27	90		23	92	47	20	93
E33 (int)	A	NT	0.0	NT	NT	< 3.0	29.2	NT	0.9
	SD		0.0			N/A	8.9		1.5
	N		15			15	13		15
ARM200 (1st)	A	26.9	0.0	NT	3.9	< 3.0	34.0	230	3.2
	SD	7.7	0.1		0.3	N/A	8.4	40.5	2.0
	N	25	67		24	68	45	21	69
ARM200 (2nd)	A	NT	0.0	NT	NT	< 3.0	22.3	NT	1.4
	SD		0.0			N/A	11.0		2.0
	N		22			22	7		22
ADSORBSIA	A	23.1	0.0	NT	3.8	< 3.0	33.8	239	3.1
	SD	10.1	0.1		0.6	N/A	9.5	23.5	2.1
	N	26	39		23	68	45	20	69
Metsorb	A	23.4	0.0	NT	3.8	< 3.0	34.4	238	3.2
	SD	9.9	0.1		0.5	N/A	8.7	20.7	2.0
	N	24	38		23	68	45	20	69
$ArsenX^{np}$ (1st batch)	A	28.1	0.2	NT	3.7	< 3.0	36.5	267	2.6
	SD	8.1	0.6		0.5	N/A	9.0	26.2	2.1
	N	16	32		12	33	26	9	33
$ArsenX^{np}$ (2nd batch)	A	27.2	0.0	NT	3.9	< 3.0	36.2	232	2.6
	SD	1.0	0.0		0.3	N/A	4.9	17.6	2.1
	N	9	55		10	51	20	10	51
ASM-10HP	A	29.2	0.0	NT	4.0	< 3.0	34.1	257	2.7
	SD	9.5	0.0		0.2	N/A	7.5	17.9	2.0
	N	16	40		15	41	30	12	41
NXT2 (2nd batch)	A	NT	0.1	NT	NT	< 3.0	25.4	NT	1.4
	SD		0.3			N/A	11.9		1.9
	N		32			32	7		32

Table B-2b. Effluent Water Chemistry Measurements

		Alkalinity (ppm $CaCO_3$)	Cl (ppm)	Fl (ppm)	Nitrates (ppm)	Sulfate (ppm)	TDS (ppm)	TSS (ppm)
Isolux	A	174	179	0.5	0.0	172	662	0.0
	SD	36.9	30.4	0.2	0.1	44.9	18.4	0.0
	N	49	31	32	11	32	23	9
AD26	A	179	172	0.5	NT	178	NT	NT
	SD	8.7	6.0	0.0		5.3		
	N	14	14	14		14		
SANS	A	168	177	0.5	0.0	190	660	0.0
	SD	34.6	7.2	0.0	0.0	25.9	3.6	0.0
	N	27	24	24	5	24	17	5
CFH12	A	174	174	0.6	0.0	195	660	0.0
	SD	36.0	7.9	0.4	0.0	41.3	10.7	0.0
	N	49	32	32	11	32	23	9
E33 (cont)	A	182	173	0.5	0.0	182	658	0.0
	SD	5.3	8.0	0.0	0.0	6.9	4.6	0.0
	N	49	32	32	11	32	23	9
E33 (int)	A	183	173	0.5	NT	179	NT	NT
	SD	8.3	6.6	0.0		5.8		
	N	14	14	14		14		
ARM200 (1st)	A	180	173	0.5	0.0	185	656	0.1
	SD	15.2	7.9	0.0	0.0	8.2	8.4	0.2
	N	47	30	30	10	30	23	9
ARM200 (2nd)	A	177	177	0.5	NT	185	NT	NT
	SD	5.5	3.3	0.0		2.7		
	N	7	7	7		7		
ADSORBSIA	A	175	173	0.5	0.0	193	645	0.0
	SD	34.0	8.4	0.1	0.0	38.5	64.6	0.0
	N	47	30	30	11	30	23	9
Metsorb	A	174	174	0.5	0.0	187	656	0.0
	SD	34.5	9.4	0.1	0.0	20.7	10.4	0.0
	N	47	30	30	11	30	23	9
$ArsenX^{np}$ (1st batch)	A	167	170	0.5	0.0	201	682	0.1
	SD	42.2	10.2	0.2	0.0	60.2	76.5	0.2
	N	24	12	12	8	11	6	6
$ArsenX^{np}$ (2nd batch)	A	179	175	0.5	0.1	182	661	0.0
	SD	5.6	5.9	0.0	0.2	6.4	3.1	0.0
	N	27	23	23	5	22	16	5
ASM-10HP	A	175	187	0.5	0.0	156	660	0.0
	SD	22.0	52.1	0.0	0.0	65.3	15.8	0.0
	N	30	13	14	9	14	10	6
NXT2 (2nd batch)	A	165	176	0.3	NT	194	NT	NT
	SD	63.9	3.4	0.2		28.6		
	N	7	7	7		7		

Table B-2c. Effluent Water Chemistry Measurements

		pH	Conductivity. (µS/cm)	Temp °C	Free Cl_2 (ppm)	Turbidity (NTU)
Isolux	A	7.5	1280	30.3	0.1	0.3
	SD	1.0	289	1.3	0.1	0.2
	N	91	90	74	92	90
AD26	A	7.1	1310	29.4	NT	NT
	SD	N/A	N/A	N/A		
	N	1	1	1		
SANS	A	7.7	1500	30.2	0.1	0.3
	SD	1.0	1610	1.6	0.1	0.1
	N	57	55	47	55	52
CFH12	A	7.6	1280	30.4	0.4	0.4
	SD	0.9	289	1.1	0.2	0.7
	N	91	90	73	90	89
E33 (cont)	A	7.7	1280	33.7	0.5	0.3
	SD	0.8	284	31.0	0.2	0.1
	N	93	92	76	91	90
E33 (int)	A	7.7	1310	28.3	NT	NT
	SD	N/A	N/A	N/A		
	N	1	1	1		
ARM200 (1st)	A	7.7	1280	30.2	0.5	0.3
	SD	0.9	300	1.1	0.2	0.3
	N	84	83	63	83	82
ARM200 (2nd)	A	7.7	1240	107	0.4	0.3
	SD	0.1	311	311	0.2	0.1
	N	17	17	17	16	16
ADSORBSIA	A	7.6	1280	30.2	0.5	0.3
	SD	1.0	305	1.2	0.2	0.2
	N	81	80	64	80	79
Metsorb	A	7.6	1280	30.2	0.2	0.4
	SD	1.0	305	1.2	0.1	0.5
	N	81	80	64	80	78
$ArsenX^{np}$ (1st batch)	A	7.6	1290	30.4	0.0	0.4
	SD	0.8	402	1.1	0.1	0.4
	N	37	37	30	37	37
$ArsenX^{np}$ (2nd batch)	A	7.7	1280	29.5	0.0	0.3
	SD	1.1	180	4.7	0.1	0.1
	N	56	53	46	56	55
ASM-10HP	A	7.6	1230	30.2	0.0	0.2
	SD	1.2	454	1.5	0.0	0.1
	N	45	44	30	45	45
NXT2 (2nd batch)	A	8.2	1310	31.1	0.5	0.6
	SD	0.6	13.2	0.9	0.1	0.8
	N	17	17	17	16	16

Table B-3a. Effluent Water Chemistry Measurements

		Ca (ppm)	Fe (ppm)	Cu (ppm)	Mg (ppm)	Mn (ppb)	SiO_2 (ppm)	Na (ppm)	V (ppb)
ADA	A	26.5	0.0	NT	3.9	< 3.0	37.4	225	4.6
	SD	1.5	0.1		0.4	N/A	1.3	15.0	1.1
	N	10	20		10	14	10	9	14
Bauxsol/GAC	A	26.9	0.1	NT	4.2	< 3.0	38.4	229	12.6
	SD	1.5	0.1		0.0	N/A	0.8	15.5	6.3
	N	3	12		3	7	3	3	7
UTEP	A	NT	0.0	NT	NT	< 3.0	30.1	NT	2.3
	SD		0.0			N/A	9.7		2.1
	N		17			17	7		17

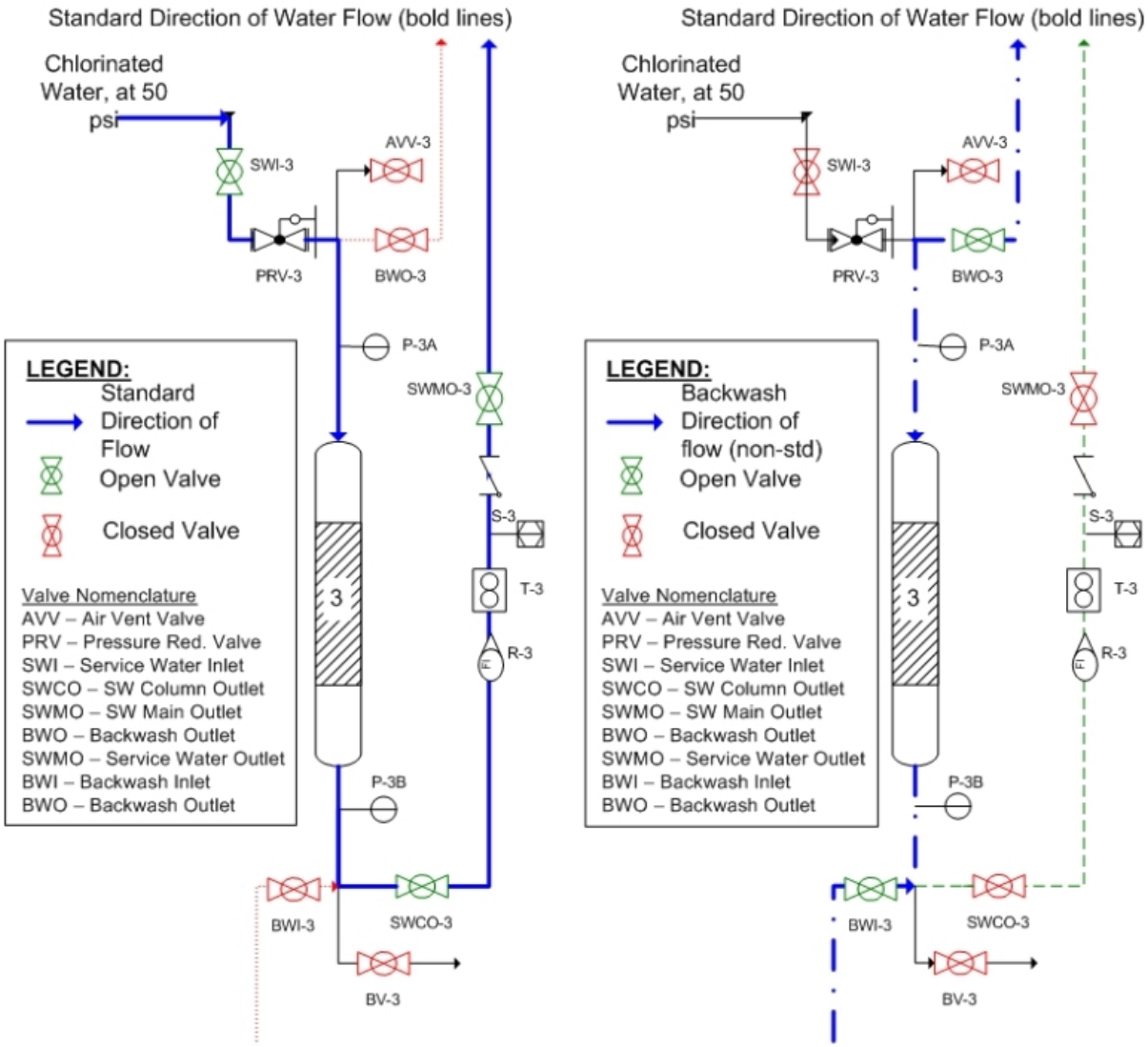
Table B-3b. Effluent Water Chemistry Measurements

		Alkalinity (ppm $CaCO_3$)	Cl (ppm)	Fl (ppm)	Nitrates (ppm)	Sulfate (ppm)	TDS (ppm)	TSS (ppm)
ADA	A	179	174	0.5	0.0	179	659	0.0
	SD	10.1	6.0	0.1	0.0	7.1	2.8	0.0
	N	17	14	14	5	14	10	5
Bauxsol/GAC	A	180	177	0.6	0.0	172	659	0.2
	SD	4.1	5.0	0.0	0.0	2.1	0.6	0.4
	N	8	5	5	3	5	3	3
UTEP	A	176	176	0.5	NT	184	NT	NT
	SD	9.3	3.6	0.0		2.2		
	N	7	7	7		7		

Table B-3c. Effluent Water Chemistry Measurements

		pH	Conductivity (µS/cm)	Temp °C	Free Cl_2(ppm)	Turbidity(NTU)
ADA	A	7.8	1310	26.5	0.4	0.4
	SD	0.1	6.8	2.3	0.2	0.6
	N	16	13	4	15	16
Bauxsol/GAC	A	8.0	1310	25.1	0.0	0.7
	SD	0.2	1.6	N/A	0.0	0.9
	N	9	5	1	9	9
UTEP	A	7.9	1310	30.8	0.5	0.3
	SD	0.1	10.9	1.0	0.2	0.1
	N	16	16	16	16	16

Appendix C. Pilot Flow Diagrams



NOTES:
All AVVs (e.g. AVV-3) are air vents that will be used to bleed air bubbles out of the system. Normal mode of operation is to be closed.

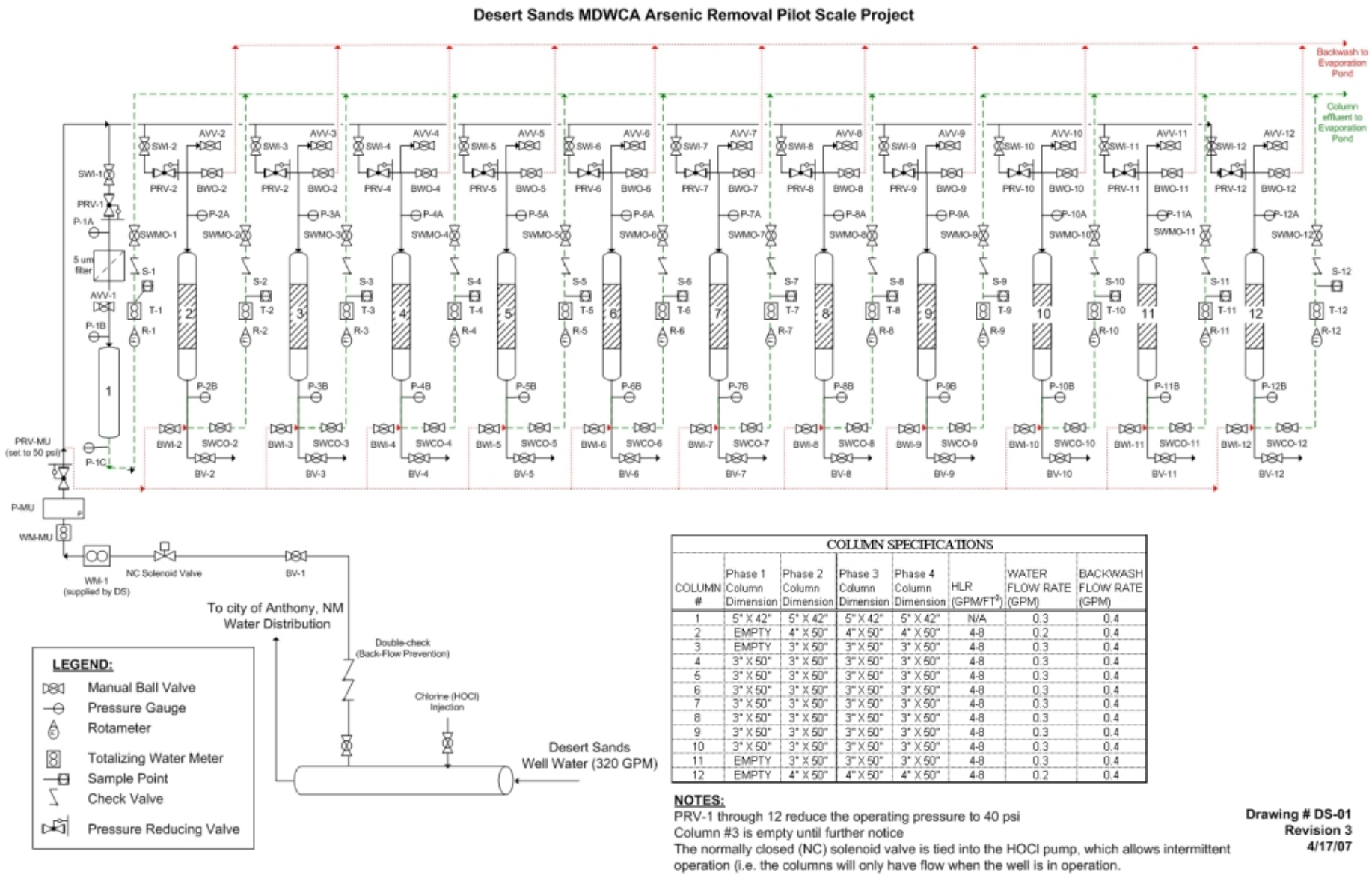
All BVs (e.g. BV-3) are drain valves that will be used to drain the system. Normal mode of operation is to be closed.

Backwashing will only occur when the pressure drop across each column is at or greater than 10 psi.

All PRVs (e.g. PRV-3) will reduce the operating pressure to 40 psi for column operation.

Drawing # DS-02
Revision 2
4/17/07

Figure C-1. Single Column Flow Diagram



COLUMN SPECIFICATIONS							
COLUMN #	Phase 1 Column Dimension	Phase 2 Column Dimension	Phase 3 Column Dimension	Phase 4 Column Dimension	HLR (GPM/FT^2)	WATER FLOW RATE (GPM)	BACKWASH FLOW RATE (GPM)
1	5" X 42"	5" X 42"	5" X 42"	5" X 42"	N/A	0.3	0.4
2	EMPTY	4" X 50"	4" X 50"	4" X 50"	4-8	0.2	0.4
3	EMPTY	3" X 50"	3" X 50"	3" X 50"	4-8	0.3	0.4
4	3" X 50"	3" X 50"	3" X 50"	3" X 50"	4-8	0.3	0.4
5	3" X 50"	3" X 50"	3" X 50"	3" X 50"	4-8	0.3	0.4
6	3" X 50"	3" X 50"	3" X 50"	3" X 50"	4-8	0.3	0.4
7	3" X 50"	3" X 50"	3" X 50"	3" X 50"	4-8	0.3	0.4
8	3" X 50"	3" X 50"	3" X 50"	3" X 50"	4-8	0.3	0.4
9	3" X 50"	3" X 50"	3" X 50"	3" X 50"	4-8	0.3	0.4
10	3" X 50"	3" X 50"	3" X 50"	3" X 50"	4-8	0.3	0.4
11	EMPTY	3" X 50"	3" X 50"	3" X 50"	4-8	0.3	0.4
12	EMPTY	4" X 50"	4" X 50"	4" X 50"	4-8	0.2	0.4

NOTES:
PRV-1 through 12 reduce the operating pressure to 40 psi
Column #3 is empty until further notice
The normally closed (NC) solenoid valve is tied into the HOCl pump, which allows intermittent operation (i.e. the columns will only have flow when the well is in operation.

Drawing # DS-01
Revision 3
4/17/07

Figure C-2. Pilot Skid Flow Diagram

Appendix D. pH and Silica Data

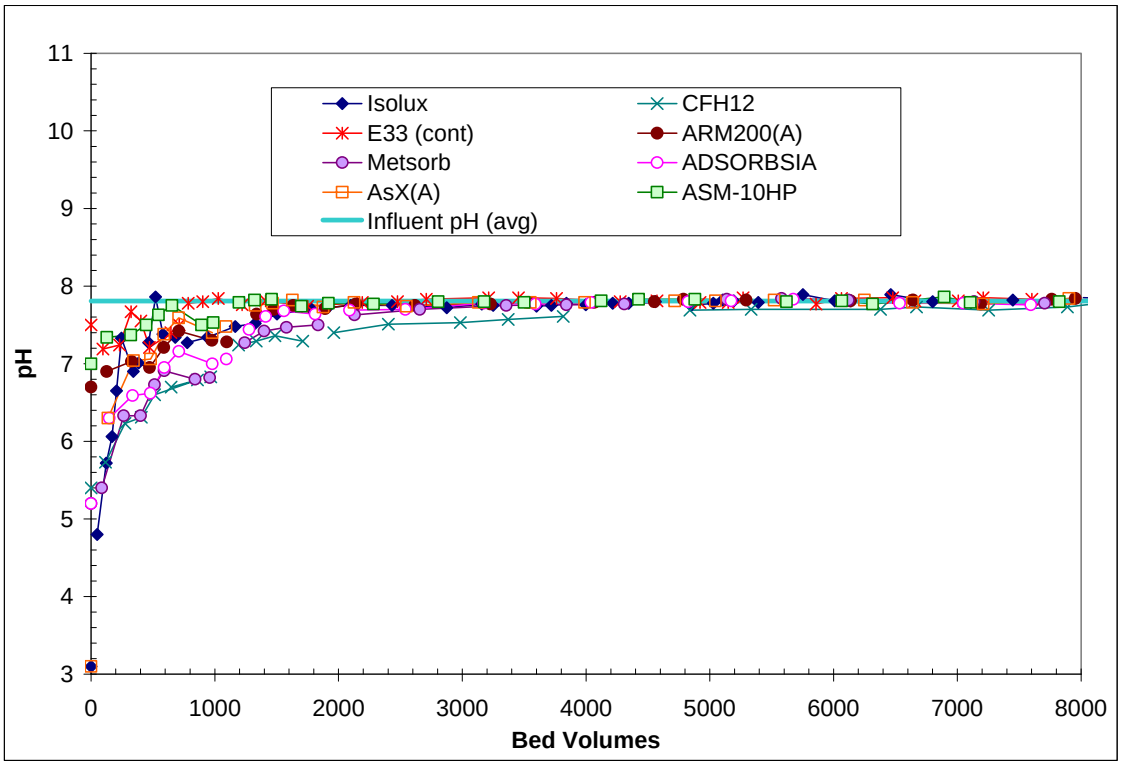


Figure D-1. Phase 1 Initial pH Effects from Adsorptive Media

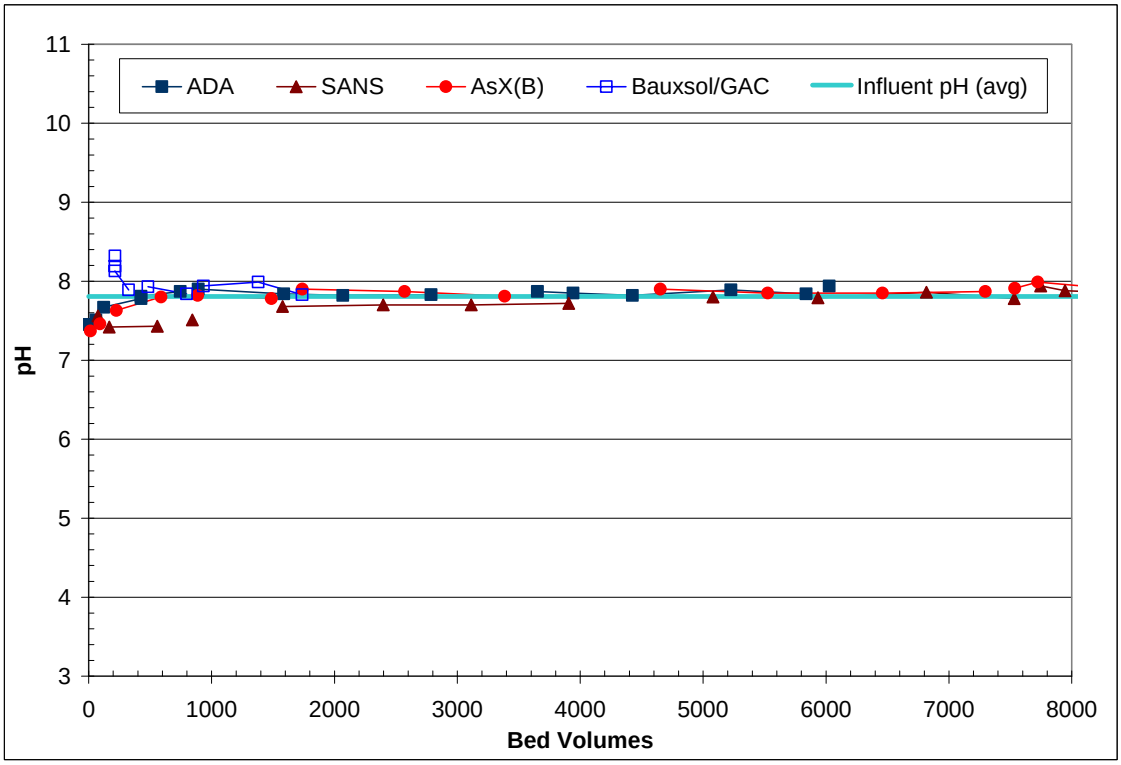


Figure D-2. Phase 2 Initial pH Effects by Adsorptive Media

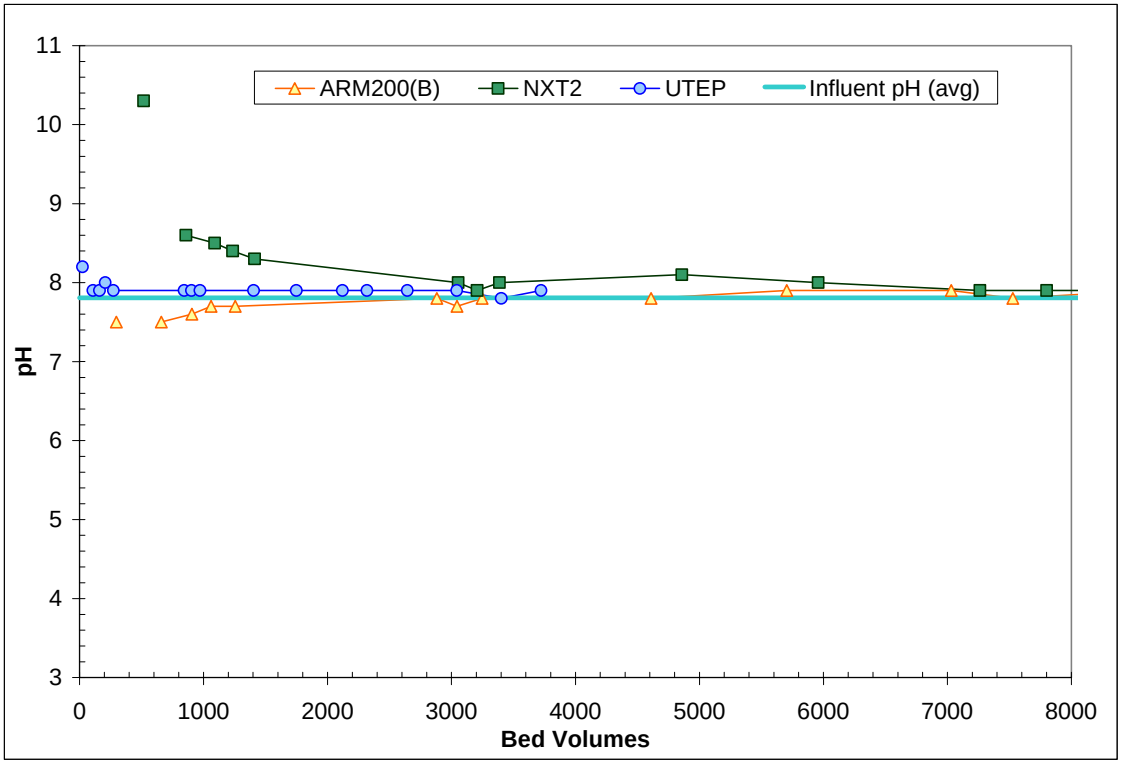


Figure D-3. Phase 3 Initial pH Effects From Adsorptive Media

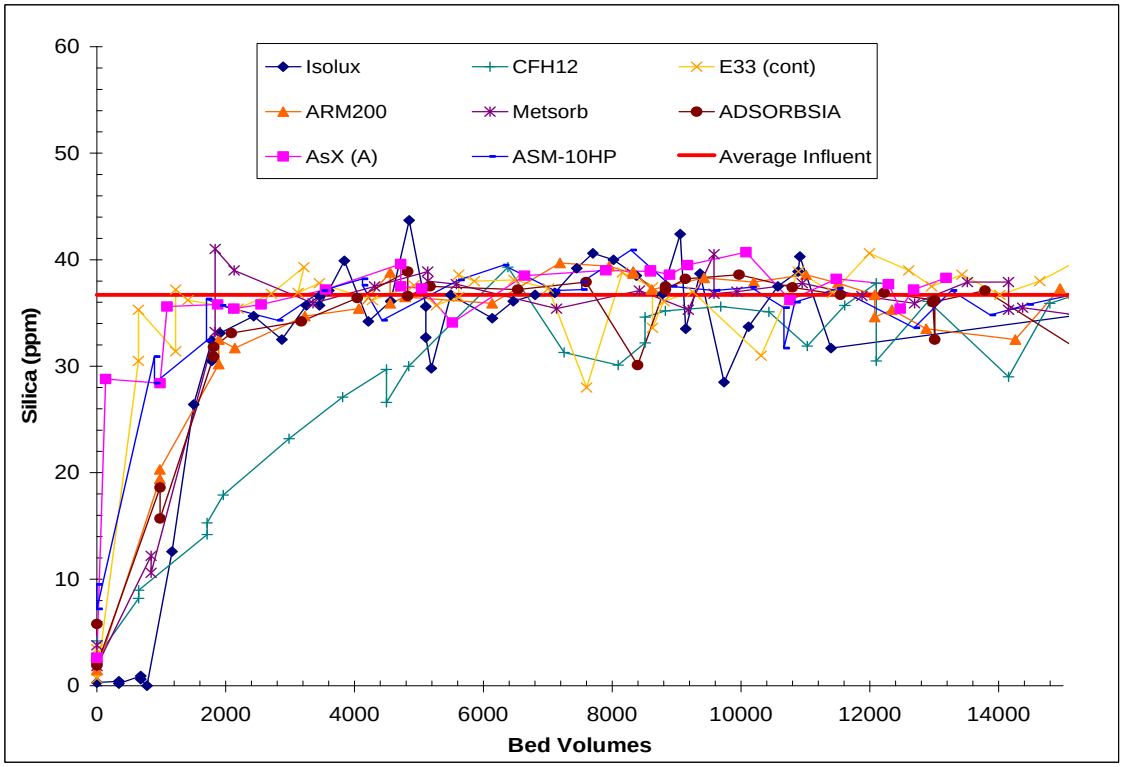


Figure D-4. Phase 1 Initial Silica Removal By Adsorptive Media

Appendix E. Detailed Backwash Information

Table E-1. Phase 1 Column Backwash Data

		Initial Backwash		CVT Backwash Information		
Column #	Media	BW Duration, min	BW Volume, gal	Avg days between BW	Avg # BW/month	Total # BW
1	Isolux 302M	No Backwash necessary		No Backwash necessary		
4	CFH-12	30	6.08	25	1.2	16
5	E33	39	6.78	34	0.9	14
6	ARM200	44	9.58	17	1.8	16
7	ADSORBSIA	31.5	13.79	18	1.6	16
8	Metsorb	89	32.54	21	1.4	14
9	ArsenX^{np}	20	1.75	47	0.7	2
10	ASM-10HP	10	2.10	N/A	N/A	0

Table E-2. Phase 2 Column Backwash Data

		Initial Backwash		CVT Backwash Information		
Column #	Media	BW Duration, min	BW Volume, gal	Avg days between BW	Avg # BW/month	Total BW
2	Amended Silicate	35		73		
3	SANS	20	9.12	62	0.5	5
9	ArsenX^{np}	9	3.74	98	0.3	2
12	Bauxsol - GAC	No BW Performed		14	5.6	5

Table E-3. Phase 3 Column Backwash Data

		Initial Backwash		CVT Backwash Information		
Column #	Media	BW Duration, min	BW Volume, gal	Avg days between BW	Avg # BW/month	Total # BW
10	ARM200	No Data Collected		12	2.6	6
11	NXT-2	No Data Collected		22	1.4	8
12	Reddysorb	No Data Collected		N/A	N/A	0

Table E-4. Phase 4 Column Backwash Data

		Initial Backwash		CVT Backwash Information		
Column #	Media	BW Duration, min	BW Volume, gal	Avg days between BW	Avg # BW/month	Total # BW
2	AD26	16	14	17	1.7	5
12	E33	26	20.34	N/A	N/A	0

Dow Loading and Backwash Procedure

Tech Fact

ADSORBSIA™ GTO™ Arsenic Removal Media

Loading and Start Up Procedures

ADSORBSIA™ GTO™ media is a single use media that is typically operated in down-flow configuration. Systems using ADSORBSIA GTO media should be loaded according to these procedures.

Procedure

Before loading the media, make a detailed inspection of the empty vessel:

- Remove all debris from previous materials or foreign material.
- Clean up distributors and collectors, and inspect all laterals and splash-plates for damage or plugging.
- Inspect the nozzles, check that they are in good shape, clean and tight, and gaskets are intact and in place. Whenever possible, replace with new ones if older than 5 years.
- Whenever possible, check the pressure loss of the empty vessel at nominal flow rate and observe the flow patterns for uniformity.

Loading of the media:

- Dow recommends using an underlayment covering the bottom lateral to a depth of 1 - 2 inches above the bottom laterals. Any particle size between 50 mesh (300 micron) and 8 mesh (2,000 micron) is acceptable. A high density underlayment (>75#/ft³), such as garnet, sand or stone should be used.
- Fill the vessel with water to at least six inches above the height of the subfill before loading the underlayment. Other standard methods for loading underlayment may be acceptable.
- After loading the underlayment, drain the vessel.
- Load the dry media into the vessel by dumping from the top of the vessel or physically transferring the media.
- Use appropriate personal protective equipment while loading the media. A particulate filter (respirator or dust mask), safety glasses, and body covering clothing are specified for use while transferring the dry media. (Refer to MSDS for detailed safety information.)

Vessel Start-up:

- Begin backwashing at slow flow rate (1 - 2 gpm/ft²) for 15 minutes.
- Increase backwash flow rate until bed is expanded by 25 - 50%. This should require a rate of 6 - 10 gpm/ft². Be careful to avoid excessive backwash flow rates resulting in media loss.
- Check the drain for evidence of full size media particles (10 - 60 mesh). The presence of fine particles (-60 mesh) in the drain is normal.
- Continue this backwash for 75 - 90 bed volumes or until the water runs visibly clearer (<100 NTU). Some cloudiness may still be present.
- Begin service flow to drain for 5 - 10 bed volumes at the maximum designed service flow rate.
- When water is running clear, reduce to normal service flow rate and bring vessel into service.
- Note the pressure through the vessel under normal flow rates in order to benchmark your system. At normal service flows (6 - 14 gpm/ft²) the pressure drop should be about 1 - 4 psi/ft of media depth.

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Form No. 177-02127-0606

ADSORBSIA™ Titanium-based Media
For more information about ADSORBSIA, call the Dow Liquid Separations business:

North America:	1-800-447-4369
Latin America:	(+55) 11-5188-9222
Europe:	(+32) 3-450-2240
Pacific:	+60 3 7958 3392
Japan:	+813 5460 2100
China:	+86 21 2301 9000

http://www.adsorbsia.com

Notice: No freedom from any patent owned by Seller or others is to be inferred. Spent media from arsenic loading tests have been shown to pass both the TCLP and CA WET extraction protocols. These test results indicate that spent media can meet the criteria for disposal in a landfill as non-hazardous waste. However, use conditions can vary and Customers must confirm that spent media meets their local landfill requirements for disposal as non-hazardous waste. NO WARRANTIES ARE GIVEN; ALL IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE ARE EXPRESSLY EXCLUDED.

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Form No. 177-02127-0606

Appendix F TCLP Results

Table F-1. TCLP Analysis Results

	As	Ba	Cd	Cr	Cu	Pb	Hg	Ni	Se	Ag	Zn
Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	□g/L	mg/L	mg/L	mg/L	mg/L
Detection Limit	0.125	0.075	0.125	0.05	0.5	0.125	0.20	0.05	2.5	0.125	0.25
RCRA Limit	5	100	1	5	N/A	5	200	N/A	1	5	N/A
Amended Silica	<0.125	1.070	<0.125	<0.05	0.130	0.125	<0.20	0.034	<0.25	<0.125	5.730
SANS	<0.125	0.908	<0.125	<0.05	NT	0.204	<0.20	NT	<0.25	<0.125	NT
CFH12	<0.125	1.240	<0.125	<0.05	NT	0.126	<0.20	NT	<0.25	<0.125	NT
E33 (intermittent)	<0.125	0.548	<0.125	<0.05	NT	<0.125	<0.20	NT	<0.25	<0.125	NT
ARM200 (Phase 1)	<0.125	2.390	<0.125	<0.05	0.463	0.125	<0.20	0.060	<0.25	<0.125	6.420
ADSORBSIA	<0.125	3.450	0.125	<0.05	0.229	0.125	<0.20	0.024	<0.25	<0.125	25.100
Metsorb	<0.125	3.720	<0.125	<0.05	0.191	0.125	<0.20	0.042	<0.25	<0.125	1.890
ArsenXnp	<0.125	0.383	<0.125	<0.05	0.117	0.125	<0.20	<0.05	<0.25	<0.125	<0.25
ASM-10HP	<0.125	0.560	<0.125	<0.05	0.468	0.125	<0.20	<0.05	<0.25	<0.125	12.800
ARM200 (Phase 2)	0.141	1.900	<0.125	<0.05	NT	0.125	<0.20	NT	<0.25	<0.125	NT
NXT-2	<0.125	2.360	<0.125	<0.05	NT	0.125	<0.20	NT	<0.25	<0.125	NT
Bauxsol-GAC	<0.125	0.159	<0.125	<0.05	0.069	0.125	<0.20	<0.05	<0.25	<0.125	4.520
Redisorb	<0.125	0.968	<0.125	<0.05	NT	<0.125	<0.20	NT	<0.25	<0.125	NT
E33 (continuous)	<0.125	0.47	<0.125	<0.05	NT	<0.125	<0.20	NT	<0.25	<0.125	NT

NT = Not tested

Appendix G. Summary of Detailed Economic Calculations

Table G-1. Economic Calculation Input Details

Design Criteria	**pH 7.8**	**pH 6.8**
Vessel Flow Rate, gpm	379	379
Design Treatment Capacity, MGD	0.16	0.16
Configuration (series/parallel/unknown)	parallel	parallel
Number of Trains	1	1
Number of Vessels per Train	2	2
Bed Depth, ft	4.0	4.0
Vessel Diameter, ft	6.0	6.0
Total Facility Media Volume, cf	506.6	506.6
Media Bulk Density, lb/cf	32	32
Unit Media Cost, $/cf	$200.00	$200.00
Total Arsenic Removal System Equipment Cost Summary		
Equipment Installation Cost, %	10%	10%
Interior Piping Allowance,%	10%	10%
Instrumentation & Controls Allowance, %	3%	3%
Electrical Allowance, %	2%	2%
Yard Piping Allowance,%	10%	10%
Building Facilities		
Building, sf	288	288
Building Unit Cost, $/sf	$200	$200
Contractor & Engineering Cost Summary		
Engineering/Contractor Cost, %	30%	30%
Permitting Cost, %	15%	15%
Working Capital	$0	$0
Start-up	$0	$0
Contingency, %	25%	25%
Arsenic Removal Facilities Annual Costs		
Media Use Per Year, cf/Yr Based on Average Flow	127	76
Estimated pH adjustment chemicals, $/yr	$0	$2,435
Annual Estimated Power Use, kWh/yr	14,334	14,334
Power Cost, $/kWh	0.08	0.08
Spent Media Production, Tons/yr	n/a	n/a
Labor, Operations, hrs/yr	57.0	55.0
Labor, Management, hrs/yr	12	12
Labor Rate, Operations, $/hr	$30	$30
Labor Rate, Management, $/hr	$80	$80
Equipment Maintenance Costs, % of Capital Costs	5%	5%

[1] E33 cost is typical average, per EPA Pilot Demonstrations (www.arsenictradeshow.org) and personal communications with AdEdge
[2] Bldg size calculated by allowing 3 additional feet on each side of vessel (see diagram below)
[3] Bldg cost based on average price in EPA Cost report #600r06083
[4] Power consumption is estimated in ARCE model, and is comprised of "System Pressure Loss" and "Miscellaneous" power consumption

Table G-2. Economic Calculation Output Details

Total Arsenic Removal System Equipment Cost Summary	**pH 7.8**	**pH 6.8**
Total Vessel Cost including Valves	$58,481	$58,481
Subtotal System Costs (System Direct Capital Cost)	$175,781	$176,540
Building Facilities		
Building, sf	288	288
Building Unit Cost, $/sf	$200	$200
Building Cost	$57,600	$57,600
Contractor & Engineering Cost Summary		
Subtotal Estimated Facility Cost	$175,781	$176,540
Engineering/Contractor Cost	$52,734	$52,962
Permitting Cost	$26,367	$26,481
Working Capital	$0	$0
Start-up	$0	$0
Contingency	$43,945	$44,135
Total Indirect Cost	$123,047	$123,578
Annual O&M Costs		
Total Annual Media Costs, $/yr Based on Average Flow	$25,330	$15,198
Estimated pH adjustment chemicals, $/yr	$0	$2,435
Annual Power Cost, $/yr	$1,147	$1,147
Spent Media Production, Tons/yr	n/a	n/a
Total Estimated Labor Costs, $/yr	$2,670.0	$2,610.0
Equipment Maintenance Costs, $/yr	$7,990.1	$8,024.6
Capital Cost Summary		
Media & Equipment	$298,828	$300,118
Building	$57,600	$57,600
Construction & Contingency	$123,047	$123,578
Present Worth Analysis		
Net Interest Rate	4.0%	4.0%
Period, Years	20	20
Total Annual O&M Costs, $/yr	$37,137	$29,414
Present Worth of Annual O&M Costs	$504,701	$399,749
Total Estimated Facility Cost	$479,475	$481,296
Total Present Value of Facilities	$984,175	$881,046
Total Annual Amortized Cost (Capital + O&M)	$72,417	$64,829
Total Unit Cost of Water Produced, $/1,000 gal	$1.26	$1.12

Distribution:

1	MS 1002	S. Roehrig, 06300
1	MS 0735	J. Merson, 06310
1	MS 0754	M. Rigali, 06316
1	MS 0754	P. Brady, 06316
1	MS 0754	R. Kottenstette, 06316
6	MS 0754	M. Aragon, 06316
1	MS 0754	A. Aragon, 06316
1	MS 0754	B. Dwyer, 06316
1	MS 0754	R. Everett, 06316
1	MS 0754	W. Holub, 06316
1	MS 0754	J. Wright, 06313
1	MS 0750	C. Kirby, 06314
1	MS 0779	M. Siegel, 06772
2	MS 9018	Central Tech. Files, 8944
2	MS 0899	Tech Library, 9536