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Arsenic Pilot Plant Operation and Results- Rio Rancho, 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 10µg/L (10 ppb) 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. The pilot tests described in this report was conducted in Rio Rancho New Mexico between September 2005 and October 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 Sandia National Laboratories pilot demonstrations at the Rio Rancho Well #21 site obtained arsenic removal data for six different commercially available sorption media and two reverse osmosis systems in Phase 1 and nine sorption media (including three novel technologies) in Phase 2. Well water at Rio Rancho has approximately 20 ppb arsenic in the oxidized (arsenate - As(V)) redox state with moderate amounts of silica, vanadium, sulfate and a slightly alkaline pH (7.8). This report will focus mainly on the Phase 2 study. The study provides estimates of the capacity (bed volumes until breakthrough at 10 ppb arsenic) of other adsorptive media in the same chlorinated water.

Acknowledgements

This project would not have been possible without the generous collaboration of the City of Rio Rancho and its Water Utility Department. Special thanks to Nik Rael, Zachary Satterfield, and Benjamin Chwirka from the University of New Mexico. We acknowledge the invaluable help of Alicia Aragon, Justin Marbury, Fotini Walton, Michelle Shedd, and Carolyn Kirby from Sandia National Laboratories.

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Table of Contents

Figures

Tables

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
RO	reverse osmosis
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

TFC	Thin Film Composite
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):

$$\equiv\overline{\text{M-OH}} + H^+ + H_2AsO_4^- \rightarrow \equiv\overline{\text{M-H}_2\text{AsO}_4} + H_2O \text{ (arsenate sorption)}$$

$$\equiv\overline{\text{M-OH}} + H_3AsO_3 \rightarrow \equiv\overline{\text{M-H}_2\text{AsO}_3} + H_2O \text{ (arsenite sorption)}$$

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).

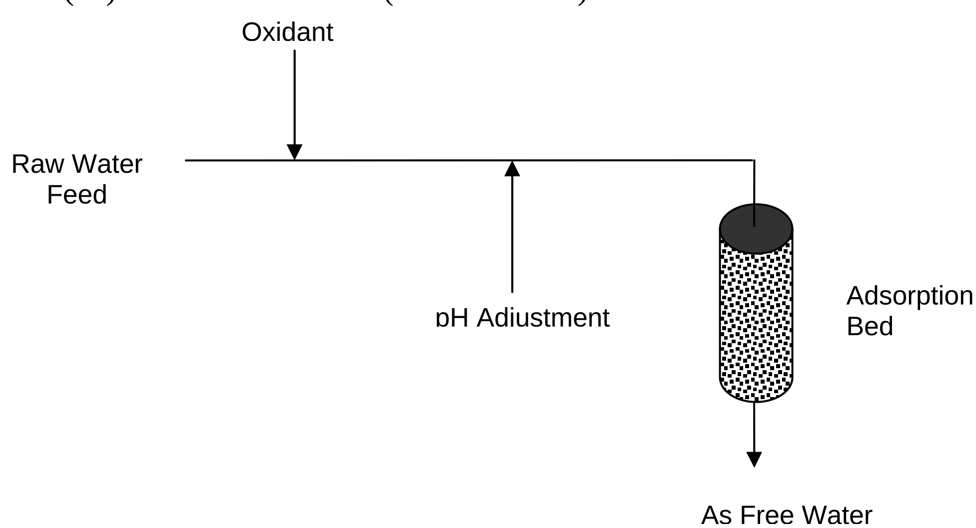

Figure 1-1. Diagram of the Sorption Process for Arsenic Removal

2. Objectives of the Rio Rancho 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 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. The pilot test described in this report was conducted in Rio Rancho, New Mexico between September 2005 and October of 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 Rio Rancho consisted of granular adsorption media packed in cylindrical columns. Water flow was distributed from the top of the columns. Phase 1 also evaluated two reverse osmosis systems. Technologies were considered based primarily on the results of the Vendor Forums held in October 2003, 2004, and 2005 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/arsenic.htm**. The media and reverse osmosis equipment used for these tests are listed in Table 2-1.

Table 2-1 Media and Systems Used at Rio Rancho

Type	Manufacturer	Product	Phase Used
Granular Ferric Oxide	Adedge	E-33	1, 2
Granular Ferric Oxide	Kemiron	CFH 10, CFH 12	1, 2
Granular Titanium Oxide	Dow	ADSORBSIA™GTO™	1, 2
Nanoparticle Zirconium Oxide	MEI	Isolux 302M	1, 2
Iron Impregnated Resin	Purolite	ArsenX^{np}	1, 2
Iron Coated Resin	Resin Tech	ASM-10HP	1, 2
Granular Iron/Copper Oxide	Sandia	SANS	2
Modified Silicate	ADA	Am. Si.	2
Modified Bone Char	Brimac	Bone Char	2
Reverse Osmosis	Watts Premiere	KP4 4-stage RO	1
Reverse Osmosis	Watts Premiere	Zero Waste RO	1

The objectives of the Rio Rancho Pilots included evaluation of:

- The comparative treatment performance of adsorptive media using chlorinated water from the Rio Rancho Well #21;
- The comparative treatment performance of point-of-use reverse osmosis systems;
- Comparison of media performance to predictions based on vendor data;
- Limited assessment of maintenance and operational requirements for all media.

In addition to the adsorption and reverse osmosis tests, a beta test of the Trace Detect Arsenic Guard online arsenic detection system was performed during Phase 2 operations. Also, a test of a different arsenic removal methodology called In-Tank Arsenic Removal was performed. These tests will have separate reports.

3. Description of Pilot Test

3.1 Site Description

The verification test site is the Rio Rancho, New Mexico (RRNM) Well Site #21, or simply the "Rio Rancho site", located just off Loma Colorado Drive in Rio Rancho, New Mexico. The city of Rio Rancho operates multiple wells to serve a growing population near 62,000. The well site is located on Loma Colorado St., near the city's high school. The well pumps directly into a distribution system nearby. The well pump's capacity is 2000 gpm.

During this pilot, a portion of the chlorinated Well #21 water was diverted to the arsenic adsorption media filters and reverse osmosis systems. The pilot equipment is housed within a metal storage transportainer. The transportainer, RRNM Well #21 building, power drop and the sanitary sewer connection are secured within a six foot chain link fence. The transportainer is heated by a small unit heater, and cooled by a small air conditioner. Temperatures were maintained between 50-80 ^{o}F, except in Phase 1, where freezing conditions were experienced. Chlorinated water was provided to the pilot test equipment at pressures from 70-80 psi.

The treated water from the arsenic adsorption filters and reverse osmosis systems and backwash wastewater from the arsenic adsorption media filters was discharged to the sanitary sewer via a 2-inch polyethylene pipe. The total discharge was limited to 3 gpm or less; none of the treated water was returned to the drinking water distribution system. The discharge was coordinated with the City of Rio Rancho Utility Department. The City of Rio Rancho water utility also assisted with on-site logistics and provided water, electricity, and site security.

Figure 3-1. Rio Rancho 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), the adsorptive capacity of all media to breakthrough (defined as 10 µg/L or 10 ppb) and the adsorptive capacity to approximately 80% of the influent concentration for several of the media. Pilot-scale operational parameters for each media are based upon full-scale operating conditions as provided by the respective vendors. Table 3-1 provides a summary of the basis for design of the pilot columns for all media. The RO systems are also summarized.

3.2.2 Pilot Equipment

The Rio Rancho pilot system is made up of the following modular components:

1. Raw water makeup system
    a. Tie-in to Rio Rancho Well #21 via hydrant,
    b. Pressure control and relief;
2. Column skid

The raw water at Rio Rancho is chlorinated by the utility in a building at the site. The chlorinated raw water was delivered to the pilot unit raw water makeup system after a pressure reducing valve provided by the Rio Rancho water system. The pilot unit ran continuously, except for occasional brief periods when the well was shut down for repairs. Pressure reducing valves were installed both on the main feed to the pilot unit and to each column to maintain proper pressure.

The Rio Rancho pilot had two phases: Phase 1 studied adsorptive media and two point-of-use reverse osmosis systems; Phase two studied adsorptive media only. Phase 2 included novel media, along with commercially available media.

The pilot test skids contained six or eight columns, each designed as independent arsenic adsorption media filters operating in parallel. Each column is modular in design consisting of the following components (Refer to Drawings RR-02, RR2-02, and RR-03 in Appendix A-3.):

- rotameter
- upgradient pressure gauge
- column with adsorptive media
- down gradient pressure gauge
- air vent
- sample tap
- totalizing flow meter
- check valve
- associated piping

The pilot system included a datalogger which recorded inlet pressure, all water meter flow rate readings and totalized water treated by each column or RO system, and the temperatures outside the transportainer, inside the transportainer, and inside the datalogger box. This datalogger was connected to a laptop, which provided the user with an interface to the datalogger data and controls.

All backwash waste went to the Rio Rancho sanitary sewer system. Columns are fully separated from each other and are able to be backwashed independently. This avoids mixing backwash water from different media. The backwash collection tank and backwash manifold will be drained prior to backwash of a different media.

Appendix A-1 gives a chronological log of pilot plant operation. Various operating changes are chronicled as well as descriptions of repairs and adjustments.

Figure 3-2. Rio Rancho Pilot Skid Unit (Phase 1 on left, Phase 2 on right)

Table 3-1 Summary of Pilot Operations, Phase 1

Pilot Scale Design Parameters	Adedge E33	Kemiron CFH 10	Purolite AsXnp	ResinTech ASM10 HP	MEI Isolux	Dow ADSORBSIA
Column # (RR-01)	1	2	3	4	5	6
Mesh Size	10 x 35	10 x 18	16 x 50	20 x 40	< 400	10 x 60
Bulk Density (g/mL)	0.48	1.2	0.81	0.74	0.896	0.8
Hydraulic Loading Rate (gpm/ft^2)	6.1	6.1	6.1	6.1	6.1	6.1
Design EBCT (min)	3	4.5	3	3	7.5	3
Actual EBCT (min)	4.0	4.8	2.9	3.1	9.0	4.7
Column Height (in)	50	50	50	50	Radial flow cartridge system 42" cartridge length	50
Column Diameter (in)	3	3	3	3		3
Media Depth (in)	32.25	38.5	25.25	26.5		34
Media Volume (L)	3.74	4.20	3.00	3.07	8.52	3.94
Media Mass (g)	1872	5671	2342	2495	7631	3908
Design Flowrate (gpm)	0.3	0.3	0.3	0.3	0.3	0.3
Average Flowrate (gpm)	0.25	0.24	0.27	0.26	0.25	0.22
Backwash Flowrate (gpm)	0.2-0.5	0.2-0.5	0.2-0.5	0.2-0.5	N/A	0.2-0.5
NSF 61 Certification?	Yes	Yes	Yes	Yes	Yes	Yes

Table 3-2 Summary of Design Basis, RO Systems, Phase 1

RO System	Capacity (gal/day)	Stages	Equipment Included
Watts Premiere KP-4	25	4	• 5 µm Sediment pre-filter • Chlorine removal pre-filter • Granular Activated Carbon post-filter • 3-gal storage tank • Automatic shut-off to minimize water consumption • High Production TFC Membrane • ANSI/NSF 58 Certified (entire system)
Watts Premiere Zero Waste RO	25	4	• 5 µm Sediment pre-filter • Chlorine removal pre-filter • Granular Activated Carbon post-filter • 3-gal storage tank • Automatic shut-off to minimize water consumption • High Production TFC Membrane • ANSI/NSF 58 Certified (entire system) • IAPMO Certified (meets plumbing codes) • Zero-waste by sending reject stream to hot water heater. Typical RO systems will create 4-12 gallons of waste per gallon of treated water

Table 3-3a Summary of Design Basis, Phase 2

Pilot Scale Design Parameters	Adedge E33	Kemiron CFH 12	Sandia SANS	Dow ADSORBS IA	MEI Isolux
Column # (RR2-01)	1	2	3	4	5
Mesh Size	10 x 35	18 x 20	10 x 60	10 x 60	< 400
Bulk Density (g/mL)	0.48	1.2	0.88	0.8	0.896
Design EBCT (min)	3	3	3	3	0.5
Actual EBCT (min)	3.9	4.2	4.0	3.8	0.6
Loading Rate (gpm/ft^2)	6	6	6	6	Radial flow cartridge system 20" cartridge length
Column Height (in)	50	50	50	50	
Column Diameter (in)	3	3	3	3	
Media Depth (in)	29.375	32	35.5	30.5	
Media Volume (L)	3.5	4.0	3.5	3.5	0.93
Media Mass (g)	1872	5671	3082	3908	833
Design Flowrate (gpm)	0.3	0.3	0.3	0.3	0.3
Average Flowrate (gpm)	0.23	0.23	0.27	0.25	0.24
Backwash Flowrate (gpm)	0.2-0.5	0.2-0.5	0.2-0.5	0.2-0.5	N/A
NSF 61 Certification?	Yes	Yes	No	Yes	Yes

Table 3-3b Summary of Design Basis, Phase 2

Pilot Scale Design Parameters	Purolite AsXnp	ResinTech ASM10 HP	ADA Am. Si.	Brimac Bone Char
Column # (RR2-01)	6	7	8a	8b
Mesh Size	16 x 50	20 x 40	10 x 40	20 x 60
Bulk Density (g/mL)	0.81	0.74	0.24	0.65
Design EBCT (min)	3	3	5	5
Actual EBCT (min)	3.4	2.9	5.6	7.6
Loading Rate (gpm/ft2)	6	6	2.3	2.3
Column Height (in)	50	50	50	50
Column Diameter (in)	3	3	4	4
Media Depth (in)	26.625	26	17.25	20
Media Volume (L)	3.5	3.5	3.6	3.6
Media Mass (g)	2342	2495	861	2298
Design Flowrate (gpm)	0.3	0.3	0.2	0.2
Average Flowrate (gpm)	0.24	0.27	0.16	0.16
Backwash Flowrate (gpm)	0.2-0.5	0.2-0.5	0.1-0.2	0.1-0.2
NSF 61 Certification	Yes	Yes	No	No

3.2.3 Adsorptive Treatment Process

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, one of which is surface area. The surface area is a function of the accessibility of the porosity of the media grains. 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. The time available for arsenic sorption is directly proportional to the EBCT. The design basis (manufacturers suggestions) for EBCT is shown in Tables 3-1 and 3-3 (a-b), and varies between 3 and 5 minutes. The actual EBCT values experienced during the pilot are larger than the design values because the pilot columns experienced lower flow rates than the design. This was primarily due to adjustments to the flow rate being based off of the rotameters instead of the electronic flow meters. The Isolux is a specialized cartridge type that is designed for 20-30 seconds EBCT (Phase 1 operations used a higher EBCT due to flow limitations from the City of Rio Rancho; Phase 2 operated at the manufacturer's recommendations.)

As water passes down through a filter vessel containing fixed bed media, the 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 a portion of the adsorptive capacity is used and arsenic breakthrough occurs (e.g. effluent arsenic is 10 ppb or greater). If the adsorbent media perform as expected, then 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). Eventually, as the adsorbent capacity of an adsorbent medium is decreased, 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.

3.2.4 Reverse Osmosis Treatment Process

Point-of-use (POU) arsenic treatment systems can be utilized under certain circumstances in some states. It is recommended that utilities consult with their primacy agency (e.g. state environmental department) for specifics in their region. These POU devices will treat water that is for drinking and cooking, instead of treating the entire household's water. They can be a lower cost option for small communities.

Reverse Osmosis is a process where water is passed through a semi-permeable membrane that mainly allows pure water molecules to pass. This pure water stream is called the permeate stream, and is nearly pure water with arsenic removed. Constituents in the raw water such as arsenic, calcium, magnesium, and others, along with water molecules are rejected and sent to a reject, or concentrate, stream. This concentrate stream has increased levels of the constituents in the influent water, and is typically sent to the sewer system. The Typical POU reverse osmosis systems are supplied with influent and effluent filtration systems, and the membranes can last up to 2-5 years, depending on water quality and water consumption.

3.3 Water Quality

Rio Rancho raw water quality is presented in Table 3-4. The water is generally of good quality except for arsenic, which exceeds the new MCL effective in January 2006. The water has moderate levels of silica, sulfate, and hardness and is near neutral in pH. The arsenic level is twice the January 2006 MCL of 10 µg/L (10 ppb). Since all arsenic is present as arsenate, only chlorinated water test results are summarized here. Phosphate was analyzed by ICP-MS only once, and the result was estimated due to the result being very near the detection limit.

Table 3-4 Rio Rancho Water Composition

Parameter	Chlorinated Feed Water
Conductivity (µS/cm)	620
Temperature (°C)	22
pH	7.6
Free Chlorine (ppm as Cl_2)	0.5
Turbidity (NTU)	0.1-3.9 (0.6 average)
Alkalinity (ppm)	160
Nitrate (ppm)	2.4
Phosphate (ppb)	43 (estimated)
Iron (ppb)	30
Particulate As (ppb)	ND (<1)
As (III) (ppb)	ND (<1)
As (V) (ppb)	19
Total Arsenic (ppb)	**19.8**
Titanium (ppb)	23
Zirconium (ppb)	ND (<3)
Vanadium (ppb)	16
Aluminum (ppb)	<5
Fluoride (ppm)	0.9
Chloride (ppm)	16
Sulfate (ppm)	101
Sodium (ppm)	116
Magnesium (ppm)	1.3
Calcium (ppm)	22
Silica (ppm)	26
TOC (ppm)	0.6

3.4 Media Description

The Rio Rancho pilots tested nine media and two RO systems. Adsorbent media included five metal oxides, two resins, an amended silicate product, and modified hydroxyapatite product

All vendors except MEI indicated that no pretreatment was required for their respective arsenic adsorption media; MEI utilizes a 5-µm, pleated pre-filter cartridge to minimize potential plugging of the Isolux media cartridge.

3.5 Sampling Plan

A detailed sampling plan has been previously published as SAND 2006-1324, but the essential analyses for the operation of the Rio Rancho Pilot Plant is summarized in Table 3-5. 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 Rio Rancho 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 3-5 Water Quality Sampling 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	Once	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	EPA 200.7 – SMOCL, AA Spectroscopy – WQL	
Titanium	Daily	Weekly	EPA 200.8	Analyses only for Hydroglobe columns
Zirconium	Daily	Weekly	EPA 200.8 – SMOCL AA Spectroscopy – WQL	Analyses only for MEI cartridges
Alkalinity	Daily	Weekly	Standard Method 2320 B	
Total Suspended Solids	Three times	Monthly	Standard Method 2540 B	SMOCL Only
Nitrate	Three times	Monthly	EPA 300.0	SMOCL Only
Metals	Daily	Weekly	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	Daily	Weekly	EPA 200.7 – SMOCL HACH 8185 – WQL	HACH method is the Silicomolybdate Method
Anions	Daily	Weekly	EPA 300.0	
Total Organic Carbon	Three times	Monthly	SW-46 9060	SMOCL Only

[1] Reference for the Standard Methods is APHA, 1998; Reference for EPA methods is USEPA, 2005.

4. Test Results

4.1 Operations

4.1.1 Phase 1

The pilot plant columns and reverse osmosis units shown in Figure 3-2 were installed and media was loaded in August 2005. Prior to loading into the columns, the media was sifted to a mesh size greater than 60 mesh. This was done to minimize the extended backwash times experienced in other pilots. The media was backwashed immediately to remove any fines present or produced during media installation. Each column was backwashed for 15 minutes, or 5 bed volumes, when the backwash effluent no longer had visible color. Table 4-1 summarizes initial backwash durations and volumes.

Table 4-1 Phase 1 Initial Backwash Summary

Column #	Manufacturer	Media	BW volume (gal)	BW volume (BV)
1	Adedge	E33	4.8	5
2	Kemiron	CHF 10	4.6	4
3	Purolite	AsXnp	4	5
4	ResinTech	ASM10 HP	3.9	5
6	DOW	ADSORBSIA GTO	3.9	4

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. Only columns 2 and 6 were backwashed after start-up; a summary is below in Table 4-2. The backwash on 9/28/05 was most likely due to inadequate initial backwashes. The water quality at Rio Rancho is fairly clean, in that there are minimal particulates to cause clogging of the media beds.

Table 4-2 Phase 1 CVT Backwash Summary

Date	Column	BW duration (min)	BW volume (gal)	ΔP before/after (psi)
9/28/05	2	10	3.4	12/0
	6	20	4.5	8/0
10/21/05	6	15	3.9	8.5/0.5

The reverse osmosis units were sized to produce approximately 25 gallons of clean water each day. Each system had a 3-gallon storage tank for the clean water. A solenoid valve was installed on the outlet of each tank and was controlled using the datalogger to simulate demand on the system. Each tank was automatically drained twice per day to the drain. Additional production occurred on days when sampling occurred. Samples were taken on the influent (same location as for the sorption columns), permeate water, and concentrate water streams on the same frequency as in Table 3-4.

Both the KP-4 and ZRO units had a water efficiency of approximately 10%, or for each gallon of product water, 9 gallons of water are sent to the drain. The ZRO unit is designed so that the reject water is not wasted and can be sent to the homeowner's hot water heater. The manufacturer, Watts-Premier (www.wattspremier.com/SDWA), indicates that higher supplied pressures can yield better water efficiencies. Both reverse osmosis units were provided with 50 psi feed pressure.

The intermittent operation of the RO systems and a winter storm caused freezing problems and the pilot was shut down in December 2005.

4.1.2 Phase 2

The pilot plant columns units shown in Figure 3-2 were installed and media loaded in April 2006. The media was backwashed immediately following installation. Media was not pre-sieved, as minimal improvement was seen in Phase 1. The reverse osmosis units were not installed a second time, as other groups were doing similar studies and the work was completed satisfactorily in Phase 1.

Each column was backwashed for 5-55 minutes. Backwashing occurred until the backwash effluent no longer had visible color. Table 4-3 summarizes initial backwash duration for each of the columns.

Table 4-3 Phase 2 Initial Backwash Summary

Column #	Manufacturer	Media	BW Duration	BW volume (gal)	BW volume (BV)
1	Adedge	AD33	15	4.5	5
2	Kemiron	CFH 12	17	7.5	8
3	SNL	SANS	10	2.8	3
4	DOW	ADSORBSIA	26	6.4	7
6	Purolite	AsXnp	10	2.5	3
7	Resin Tech	ASM-10HP	5	1.25	2
8a	ADA	Am Si	column not backwashed per manufacturer		
8b	Brimac	Bone Char	55	13.5	11

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. Only columns 1, 4, and 8b were backwashed after start-up; a summary is below in Table 4-2. The backwash on 4/11/06 was most likely due to inadequate initial backwash. Column 4 (Dow) had the most pressure drop increases, and therefore the most backwash events. Only at the end of the pilot did this column's pressure drop increase to significantly greater than 10 psi; this was due to column 4 not being backwashed for a long duration.

Table 4-4 Phase 2 CVT Backwash Summary

Date	Column	BW duration (min)	BW volume (gal)	ΔP before/after (psi)
4/11/06	4	35	5.25	9/0
6/13/06	1	10	3.4	10/0
	4	30	8.6	10/1
	8b	18	5	26/6
6/19/06	4	20	5	25/1
9/15/06	4	unk	unk	38/2

4.2 Water Chemistry Effects

Appendix A-2 presents the water chemistry measurements for the Rio Rancho pilot plant runs. Most analytes were unaffected by the adsorption media as attested by the low standard deviations noted for both feed and product water. Two exceptions, however are silica and vanadium in product water samples which owe their higher standard deviations to the fact that both vanadium and silica are adsorbed very rapidly in the early stages of testing.

4.3 Adsorption Media 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. The arsenic sorption capacity of the media was also 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.

The nine media that were part of the Rio Rancho tests are shown in breakthrough curves in Figures 4-1 and 4-2. For the pilot tests, the values of BV and capacity at 10 ppb (10 μg/L) arsenic show a fairly consistent relationship between the media. Since Phase 1 did not run to completion for all media, a comparison is made from the Phase 2 data only:

E33 ~ ADSORBSIA > SANS ~ AsX^{np} ~ CFH12 > MEI > ASM10HP > ADA > Bone Char

Many of the tests were continued after the 10 ppb breakthrough in order to look at complete exhaustion of the media bed. Figures 4-1 and 4-2 show that as the tests continue, the product water eventually approaches the feed water arsenic concentration.

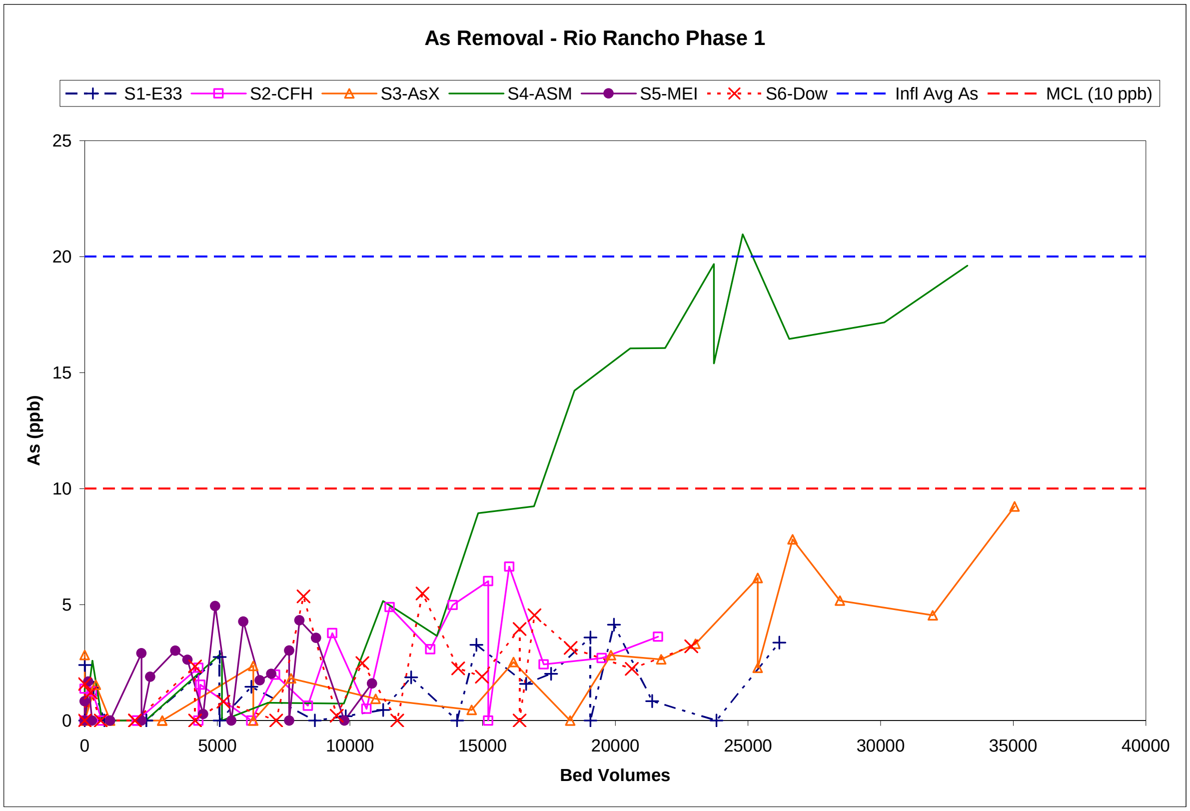

Figure 4-1. Rio Rancho Phase 1 Breakthrough Curves

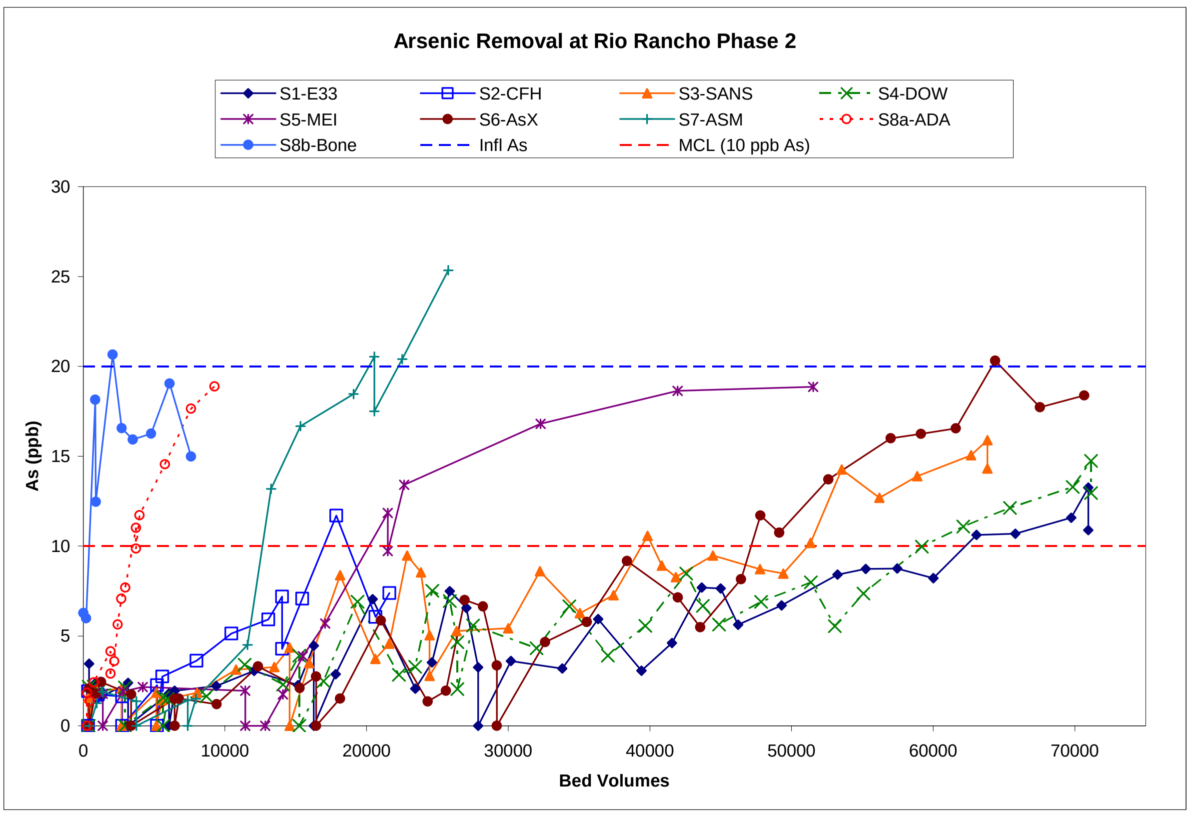

Figure 4-2. Rio Rancho Phase 2 Breakthrough Curves

4.4 Spent Media Characterization

The spent arsenic media passed the TCLP (US EPA 1992) test. The media can be disposed of in a regular landfill. Tables 4-5 and 4-6 summarize the TCLP results for each media.

Table 4-5 TCLP Analysis Results, Phase 1

Media	Unit	RCRA Limits	Detection Limits	E33	CFH0818	ASM-10HP	ADSORBSIA	ArsenXnp
Arsenic	mg/L	5	0.125	ND	ND	ND	ND	ND
Barium	mg/L	100	0.075	0.861	3.24	0.742	0.823	2.04
Cadmium	mg/L	1	0.125	ND	ND	ND	ND	ND
Chromium	mg/L	5	0.05	ND	ND	ND	ND	ND
Copper	mg/L	N/A	0.5	0.485	0.203	2.88	0.568	0.194
Lead	mg/L	5	0.125	ND	ND	ND	ND	ND
Mercury	μg/L	200	0.2	0.14	0.099	0.129	0.126	0.065
Nickel	mg/L	N/A	0.05	ND	ND	ND	ND	ND
Selenium	mg/L	1	2.5	ND	ND	ND	ND	ND
Silver	mg/L	5	0.125	ND	ND	ND	ND	ND
Zinc	mg/L	N/A	0.25	4	0.453	0.125	4.9	20.7

Table 4-6 TCLP Analysis Results, Phase 2

Media	Unit	RCRA Limits	Detection Limits	CFH12	ASM-10HP	ADA	SANS	ArsenXnp	ADSORBSIA
Arsenic	mg/L	5	0.125	ND	ND	ND	ND	ND	ND
Barium	mg/L	100	0.075	2.95	1.26	1.03	1.74	0.232	5.24
Cadmium	mg/L	1	0.125	ND	ND	ND	ND	ND	ND
Chromium	mg/L	5	0.05	ND	ND	ND	ND	ND	ND
Lead	mg/L	5	0.125	ND	ND	ND	0.217	ND	ND
Mercury	μg/L	200	0.2	ND	ND	ND	ND	ND	ND
Selenium	mg/L	1	2.5	ND	ND	ND	ND	ND	ND
Silver	mg/L	5	0.125	ND	ND	ND	ND	ND	ND

4.5 Reverse Osmosis Units

The point-of-use RO units tested in this pilot are designed to be installed beneath a user's kitchen sink, with the membranes lasting 2-5 years depending on the feed pressure and water chemistry. Therefore, with less than three months of usage during this pilot, arsenic never reached levels above the 10 ppb MCL. Table 4-7 summarizes the arsenic removal results during the Rio Rancho pilot.

Table 4-7 Reverse Osmosis Results Summary

	KP As (ppb)	ZRO As (ppb)
Avg	0.86	0.99
St Dev	0.92	1.31
Min	0	0
Max	3.28	2.81
# samples	23	23
Total Water Produced (Permeate) (gal)	307	263
Water Efficiency	~10%	~10%

5. Discussion and Conclusions

5.1 Media Effectiveness

The quantitative performance of the adsorptive media from pilot testing at the Rio Rancho Phase 2 pilot for arsenic removal have been tabulated in Tables 5-1 and 5-2. Although the data are presented here for Phase 1 operations, quantitation is difficult due to the short duration of the pilot. Most columns were not run to arsenic breakthrough. Row two of the tables lists number of bed volumes to breakthrough at 10 ppb, while row three of Table 5-2 shows the bed volumes to 80% (C/C_0=0.8) of exhaustion. This value is important for cases where a facility may choose to have two adsorptive media vessels in series in what is commonly referred to as a “lead-lag” design. The Phase 1 columns were not run to exhaustion, so only Phase 2 exhaustion numbers are presented here. Rows three through five of the tables present the capacity of the media for adsorbing arsenic and are reported as mg of arsenic per gram of media, (mg As/g media) normalized to 10,000 BV (Phase 1) and 35,000 BV (Phase 2) and the capacity at 80% exhaustion respectively. These values allow for comparison at a single point in time across all adsorption media.

Table 5-1 Breakthrough Bed Volumes and Media Capacity – Phase 1

Parameter	ASM-10HP	E33	CFH10	AsXnp	MEI	DOW
EBCT, min	3	3	3	3	0.5	3
BV to 10 ppb	17,000	>26,000	>22,000	>35,000	>11,000	>23,000
Capacity at 10 ppb, mg/g	0.41	>1.02	>0.32	>0.70	>0.23	>0.43
Capacity at 10,000 BV, mg/g	0.21	0.39	0.18	0.23	0.21	0.23

Table 5-2a Breakthrough Bed Volumes and Media Capacity – Phase 2

Parameter	MEI	CFH12	AsXnp	SANS	DOW	E33
EBCT, min	0.5	3	3	3	3	3
BV to 10 ppb	22,000	>22,000	47,000	51,000	60,000	63,000
BV at C/C_o = 0.8	32,000	>22,000	58,000	>64,000	>71,000	>71,000
Capacity at 10 ppb, mg/g	0.35	>0.27	0.95	0.79	0.85	1.81
Capacity at 35,000 BV, mg/g	0.34	>0.27	0.78	0.58	0.54	1.1
Capacity at C/C_o = 0.8, mg/g	0.39	>0.27	1.06	>0.88	>0.95	>1.95

The CFH12 column was inadvertently shut down prior to media breakthrough to 10 ppb. With the data available from this pilot and capacity data from other Sandia pilots, it is estimated that the CFH12 would have had a capacity of 40,000 bed volumes at 10 ppb. This estimate is made by extrapolating the data obtained in this pilot and assuming a profile for the data to 10 ppb.

Table 5-2b Breakthrough Bed Volumes and Media Capacity – Phase 2

Parameter	ASM-10HP	ADA	Brimac
EBCT, min	3	5	5
BV to 10 ppb	13,000	3,800	~800
BV at C/C_o = 0.8	15,000	5,800	2,600
Capacity at 10 ppb, mg/g	0.25	0.24	0.01
Capacity at 35,000 BV, mg/g	>0.28	>0.33	>0.03
Capacity at C/C_o = 0.8, mg/g	0.26	0.29	0.02

The Brimac column was operated at a typical flow rate and hydraulic loading rate for arsenic removal media. The vendor does recommend a higher empty bed contact time for better results, but didn't provide information at time of pilot start-up.

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). 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. Costs were not calculated for the POU reverse osmosis systems tested in Phase 1.

At the Rio Rancho Well 21 site, the average daily water production is 1 million gallons per day (MGD). Economic calculations for this site are based on the following assumptions:

Design Basis:

- Bed Volumes are from the E33 performance in this pilot with a 3 minute EBCT
- 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
- NOTE: pH adjustment will undoubtedly affect media capacity and treatment cost estimates, however is not included in this report

Table 5-3 summarizes the input values used in the economic analysis using the pilot results. Results in Table 5-4 provide order of magnitude economic costs calculated by the ARCE model (US EPA, 2004) for each of the pilot designs (3 minute EBCT). This table demonstrates that for this location the media costs heavily influence the total unit cost of water produced. The facility costs however, also influence the cost of water, but independently of media costs (baseline construction costs are the same).

Table 5-3 Economic Input Variables Used in ARCE Model (E33 media)

Design Criteria	**Q=0.86 mgd**
Vessel Flow Rate, gpm	1600
Design Treatment Capacity, MGD	0.86
Configuration (series/parallel/unknown)	parallel
Unit Media Cost, $/cf	$200.00
Building, sf	484
Building Unit Cost, $/sf	$200
Annual Estimated Power Use, kWh/yr	38,084
Power Cost, $/kWh	0.10
Labor, Operations, hrs/yr	127.0
Unit Labor Cost, Operations, $/hr	$30
Labor, Management, hrs/yr	12
Labor, Management, $/hr	$80

Table 5-4 Capital and Annual O&M Costs for Arsenic Removal (E33 media)

Annual O&M Costs	
Total Annual Media Costs, $/yr Based on Average Flow	$51,240
Annual Power Cost, $/yr	$3,808
Spent Media Production, Tons/yr	n/a
Total Estimated Labor Costs, $/yr	$2,640
Equipment Maintenance Costs, $/yr	$19,005
Capital Cost Summary	
Media & Equipment	$116,920
Building	$40,000
Construction & 20% Contingency	$48,143
Present Worth Analysis	
Net Interest Rate	4.0%
Period, Years	20
Total Annual O&M Costs, $/yr	$76,693
Present Worth of Annual O&M Costs, $	$1,042,283
Total Estimated Facility Cost	$807,572
Total Present Value of Facitlities, $	$1,849,855
Total Annual Amortized Cost (Capital + O&M)	$136,116
Total Unit Cost of Water Produced, $/1,000 gals	$0.43

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Appendix A-1 Rio Rancho Arsenic Pilot Plant Logs

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

Date	Activity
9/24/05	Installed media & performed initial backwash on columns
9/25/05	Installed Reverse Osmosis (RO) tubing
9/26/05	Performed Calibration of all pressure gauges, pressure reducing valves, and adsorption columns' water meters
9/28/05	Backwashed columns 2 and 6 (Kemiron CFH10 and ADSORBSIA GTO™)
9/30/05	MEI pre-filter is already red.
10/3/05	Noticed that RO water meters may be reading inaccurately. The calculated totalized readings seemed too high.
10/6/05	Verified RO water meter calibration
10/7/05	Rio Rancho Utilities GFCI tripped. This outlet supplies our datalogger and computer. Reset GFCI & will monitor.
10/9/05	Product ZRO (S8P) had high conductivity in initial sample. Re-sampled and all was normal. Ran out of SA sample water, no samples for TSS, Ra226/228 this time.
10/14/05	GFCI tripped again. Will use a non-GFCI outlet for the computer/datalogger circuit.
10/18/05	Installed new cord cap on outlet box to allow for use of the non-GFCI outlet (couldn't close old one); Installed plastic around and on top of outlet assembly to minimize water intrusion; Added more silicone to the electrical box on outside of Sandia transportainer.
10/21/05	Backwashed column 6.
10/25/05	SB is slightly colored & has high turbidity
10/28/05	Installed insulation on drain line; Modified piping to accept temperature sensor. Totalized gallons for entire pilot seems too be incorrect.
11/11/05	Installed insulation on the rest of the outside piping
11/29/05	Totalized gallons for entire pilot stuck at 99999.
12/6/05	Outside temperature unexpectedly dropped to 10 ^{o}F. Reverse Osmosis systems are intermittent, which caused the influent line to freeze, then break. The pilot was shut down until the transportainer could be weatherized.

Table A-1b. Summary of Field Activities and Notes, Phase 2

Date	Activity
4/2/06	Installed media and performed initial backwash of all columns.
4/4/06	Battery needs to be replaced on datalogger; Replaced on 4/5/06
4/5/06	GFCI for lights tripping now. Will use a different outlet.
4/6/06	Turned on heater, overnight temperature to be near freezing.
4/10/06	Totalizer readings now correct; corrected for power outages when battery failed.
4/11/06	Backwashed column 4 (ADSORBSIA GTO™)
4/12/06	Internet access available at pilot site; for Trace Detect beta test
4/13/06	Turbidity readings are strange; Tried re-calibrating & no improvement.
4/15/06	Turbidity meter is operating fine; Used silicone oil on outside of sample cells, there may be scratches which affect the meter readings.
4/21/06	Rio Rancho Utilities performed maintenance in their well house. SNL pilot shut down for less than half an hour, but bled air out of system once flow re-established.
4/28/06	All samples had 0 ppm free chlorine; Verified readings with second test.
5/2/06	MEI pressure gauge leaking. Fixed.
5/8/06	Trace Detect system installed.
5/26/06	High SB turbidity.
5/31/06	Removed ADA media and started Bone Char soaking period. Ending water meter reading: 14,165 gallons.
6/1/06	Installed Bone Char media & performed initial backwash.
6/2/06	High pressure drop on column 7; Never backwashed.
6/7/06	Columns 2 & 7 removed (Kemiron and Resin Tech)
6/13/06	Backwashed columns 1, 4, and 8 (E33, ADSORBSIA GTO™, Bone Char)
6/16/06	High pressure drop on column 4
6/19/06	Backwashed column 4 for 20 minutes.
6/30/06	Column #4 had high turbidity.
7/31/06	Column #4 had higher pressure drop, and continued to increase. Wasn't backwashed until 9/12/06.
10/17/06	Removed columns #1, 3, 4, 5 (E33, MEI, SANS, ADSORBSIA GTO™)
10/25/06	Removed column #6. Installed 1.5 L of SolmeteX npRIO for Trace Detect study.
11/10/06	SB brown and turbid
11/16/06	Final sample of column #6 for this run. Removed media & installed new 1.5 liters of npRIO.
11/29/06	High SB free chlorine.
11/30/06	Inside temperature is 32 ^{o}F – someone turned off heater. Turned it back on. Removed column #6 media and disconnected all influent and effluent piping outside transportainer.
12/7/06	All pilot equipment removed – transportainer ready for pick up.

Appendix A-2 Water Chemistry Measurements

Appendix A-2 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). All are in units of mg/L (ppm) unless otherwise stated. SB is the chlorinated feed water.

Table A-2a. Phase 1 – Water Chemistry Measurements, Adsorption Columns

Sample Point		pH	Ca (ppm)	Mg (ppm)	Na (ppm)	Cl (ppm)	F (ppm)	Sulfate (ppm)	V (ppb)
SB Chlorinated Feed	A	7.6	22.1	1.3	116.1	16.0	0.9	101.2	15.6
	SD	0.4	3.6	0.1	13.6	0.3	0.0	2.2	2.0
	N	17	14	14	12	4	4	4	19
S1 E33	A	7.6	21.0	1.3	116.4	16.0	0.9	100.7	0.0
	SD	0.3	6.0	0.1	10.8	0.4	0.0	2.1	0.1
	N	17	15	14	11	4	4	4	19
s2 CFH10	A	7.4	19.7	1.3	114.8	16.1	0.7	135.4	0.0
	SD	0.6	5.6	0.1	10.6	0.4	0.4	65.8	0.2
	N	17	15	14	12	4	4	4	19
s3 ArsenX^{np}	A	7.7	22.1	1.3	115.2	16.0	0.9	102.3	0.3
	SD	0.2	3.7	0.1	11.2	0.3	0.1	4.3	1.1
	N	16	13	14	12	4	4	4	19
s4 ASM-10HP	A	7.7	22.3	2.1	115.5	48.0	0.9	76.7	0.2
	SD	0.3	3.5	2.9	10.4	64.0	0.1	50.8	0.7
	N	17	13	14	12	4	4	4	19
s5 Isolux	A	7.8	16.9	1.1	104.4	34.7	0.8	91.0	0.0
	SD	0.5	10.2	0.5	34.7	37.4	0.5	20.2	0.0
	N	17	14	13	12	4	4	4	19
s6 Adsorbsia™ GTO™	A	7.5	17.2	1.1	117.8	16.1	0.7	128.2	0.0
	SD	0.5	9.6	0.4	13.6	0.4	0.5	52.0	0.0
	N	18	13	14	12	4	4	4	20

Table A-2b. Phase 1 – Water Chemistry Measurements, Adsorption Columns

Sample Point		Nitrates (ppm as NO_3-N)	SiO_2 (ppm)	Alkalinity (ppm)	TOC (ppm)	Conductivity (μs/cm)	Temp °C	Free Cl_2 (ppm)	Turbidity (NTU)
SB Chlorinated Feed	A	2.4	26.1	160.3	0.6	617.2	21.7	0.5	0.6
	SD	0.1	1.2	7.7	0.2	5.1	4.1	0.1	0.8
	N	4	15	17	3	17	16	17	17
S1 E33	A	2.4	23.0	161.0	NT	617.1	21.4	0.4	0.2
	SD	0.0	8.5	8.1		4.7	4.1	0.2	0.3
	N	4	15	17		17	17	17	17
s2 CFH10	A	2.4	17.2	135.8	NT	619.9	21.6	0.3	0.1
	SD	0.1	9.0	52.0		16.4	3.9	0.2	0.1
	N	4	15	17		17	17	17	17
s3 ArsenX^{np}	A	2.1	24.0	159.1	NT	616.1	21.5	0.0	0.1
	SD	0.8	5.6	8.2		4.3	4.2	0.0	0.0
	N	4	15	17		16	16	16	16
s4 ASM-10HP	A	1.8	23.4	153.6	NT	619.4	21.8	0.0	0.1
	SD	1.2	5.5	35.5		19.9	4.0	0.1	0.1
	N	4	15	16		17	16	17	17
s5 Isolux	A	3.2	13.8	138.1	NT	607.0	21.8	0.2	0.2
	SD	1.3	11.3	51.8		20.0	4.0	0.1	0.1
	N	3	15	17		17	16	17	17
s6 Adsorbsia™ GTO™	A	2.4	19.8	141.7	NT	611.0	21.5	0.4	0.8
	SD	0.0	11.1	47.6		19.3	3.9	0.2	2.9
	N	4	15	17		18	18	18	18

Table A-2c. Phase 1 – Water Chemistry Measurements, Reverse Osmosis Units

Sample Point		pH	Ca (ppm)	Mgm (ppm)	Na (ppm)	Cl (ppm)	F (ppm)	Sulfate (ppm)	Nitrates (ppm as NO3-N)
KP4 Product	**A**	7.8	0.4	0.0	1.5	1.8	0.1	0.8	0.5
	SD	0.5	0.7	0.1	2.1	1.3	0.0	0.5	0.1
	N	17	14	13	12	4	4	4	4
KP4 Reject	**A**	7.8	26.2	1.5	136.5	18.3	1.1	120.3	2.4
	SD	0.3	9.5	0.1	16.6	0.7	0.1	4.6	0.7
	N	16	14	14	12	4	4	4	4
ZRO Product	**A**	8.0	5.2	0.3	45.0	6.5	0.4	35.9	1.1
	SD	0.3	7.2	0.5	46.5	5.7	0.3	41.2	0.9
	N	17	14	13	12	4	4	4	4
ZRO Reject	**A**	7.8	25.1	1.5	136.1	17.9	1.0	116.3	2.5
	SD	0.2	4.2	0.1	18.3	1.0	0.1	3.6	0.2
	N	15	14	14	12	4	4	4	4

Table A-2d. Phase 1 – Water Chemistry Measurements, Reverse Osmosis Units

Sample Point		V (ppb)	SiO2 (ppm)	Alkalinity (ppm)	Conductivity (µs/cm)	Temp °C	Free Cl2 (ppm)	Turbidity (NTU)
KP4 Product	**A**	0.0	4.9	7.4	22.9	19.7	0.0	0.2
	SD	0.0	4.8	2.6	4.4	5.0	0.0	0.2
	N	19	14	16	17	17	17	17
KP4 Reject	**A**	16.4	31.2	190.1	718.5	21.0	0.0	0.2
	SD	3.2	1.9	9.6	25.9	4.4	0.0	0.1
	N	18	13	15	16	16	16	16
ZRO Product	**A**	0.0	8.3	35.0	17.8	19.5	0.1	0.1
	SD	0.0	8.8	46.2	4.0	4.9	0.1	0.1
	N	19	14	16	15	17	17	17
ZRO Reject	A	16.1	30.7	183.0	691.3	20.7	0.1	0.2
	SD	2.2	1.4	7.9	24.6	4.4	0.1	0.1
	N	18	13	15	15	15	15	15

Table A-2e. Phase 2 – Water Chemistry Measurements, Adsorption Columns

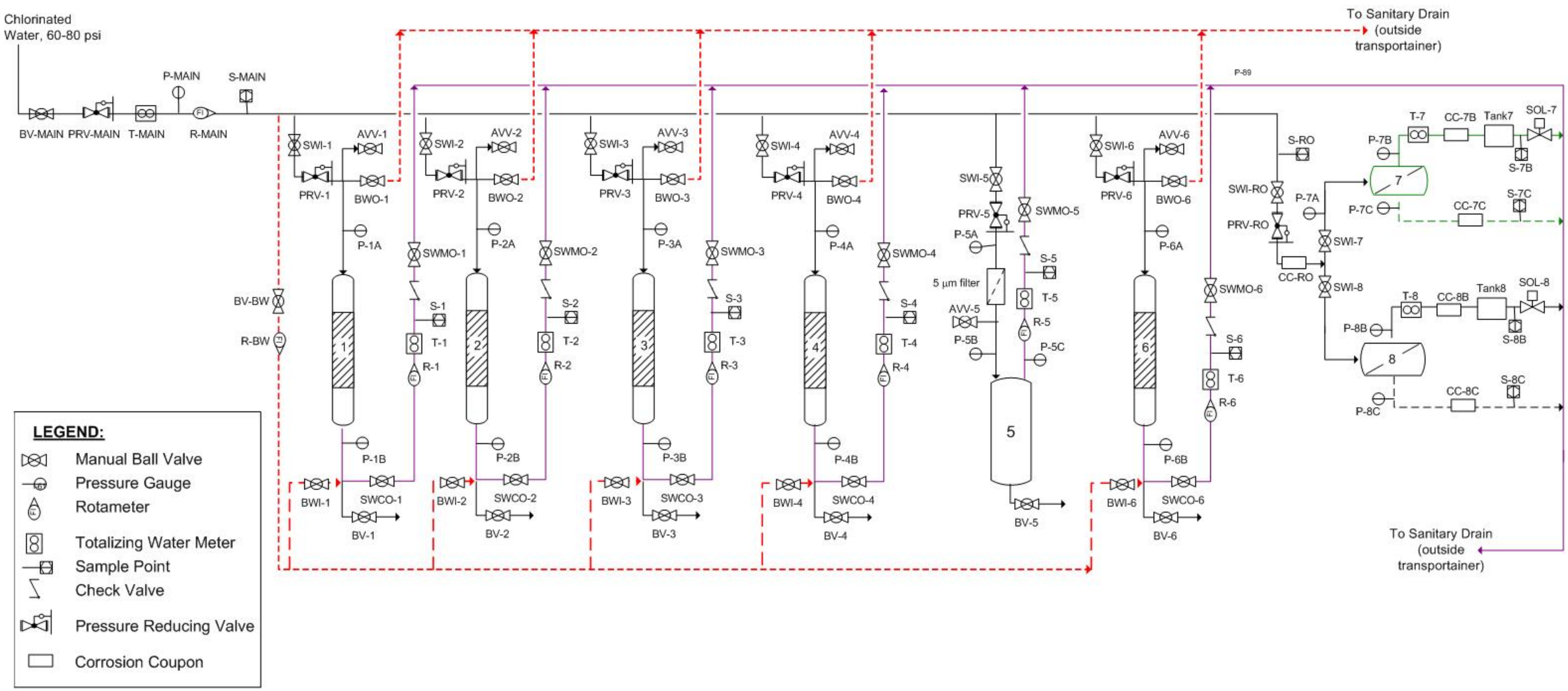
		pH	Ca (ppm)	Mg (ppm)	Cu (ppm)	V (ppb)	SiO2 (ppm)	Alkalinity (ppm $CaCO_3$)	Cl (ppm)	F (ppm)
SB	A	7.3	17.1	1.2	0.0	15.6	25.4	164.3	17.0	0.9
	SD	0.3	3.5	0.2	0.0	3.1	2.7	5.8	1.7	0.2
	N	62	37	30	34	43	33	36	35	35
S1 E33	A	7.4	NT	NT	NT	5.5	22.9	163.3	17.8	0.9
	SD	0.3	NT	NT	NT	5.4	7.2	2.8	2.9	0.0
	N	61	NT	NT	NT	35	15	18	18	18
s2 CFH12	A	7.6	NT	NT	NT	1.2	19.4	139.0	17.9	0.8
	SD	0.2	NT	NT	NT	2.0	8.0	51.0	2.5	0.2
	N	30	NT	NT	NT	14	13	16	16	15
S3 SANS	A	7.5	NT	NT	0.2	0.6	21.1	147.3	20.7	0.9
	SD	0.2	NT	NT	0.1	1.4	7.8	38.3	10.2	0.0
	N	61	NT	NT	36	35	15	18	18	18
S6 Adsorbsia™ GTO™	A	7.6	NT	NT	NT	0.2	21.6	143.9	17.2	0.8
	SD	0.4	NT	NT	NT	0.8	8.9	46.1	2.0	0.3
	N	33	NT	NT	NT	35	15	18	18	18
s5 Isolux	A	7.7	NT	NT	NT	3.0	18.2	155.9	17.9	0.8
	SD	0.3	NT	NT	NT	5.1	10.2	15.9	3.0	0.4
	N	12	NT	NT	NT	9	9	12	12	12
S6 ArsenX^{np}	A	7.7	NT	NT	NT	6.8	22.7	170.4	18.7	0.9
	SD	0.2	NT	NT	NT	7.6	7.5	31.5	5.4	0.0
	N	30	NT	NT	NT	32	16	18	19	19
S7 ASM-10HP	A	7.8	NT	NT	NT	0.0	20.3	140.0	43.2	0.9
	SD	0.2	NT	NT	NT	0.0	7.7	52.8	67.1	0.0
	N	12	NT	NT	NT	13	12	15	15	15
S8a Am. Si.	A	7.8	NT	NT	NT	3.2	21.5	159.7	17.9	0.9
	SD	0.2	NT	NT	NT	4.3	6.2	8.9	2.5	0.1
	N	12	NT	NT	NT	9	9	12	12	12
S8a Bone Char	A	7.7	NT	NT	NT	12.6	22.7	162.7	16.3	0.7
	SD	0.3	NT	NT	NT	3.9	5.4	4.2	0.3	0.5
	N	9	NT	NT	NT	10	4	3	3	3

Table A-2f. Phase 2 – Water Chemistry Measurements, Adsorption Columns

		Nitrates (ppm NO_3-N)	Sulfate (ppm)	TOC (ppm)	Conductivity (µS/cm)	Temp °C	Free Cl_2 (ppm)	Turbidity (NTU)
SB Chlorinated Feed	A	2.6	104.6	0.3	538.2	23.1	0.5	0.9
	SD	0.4	3.9	0.3	99.4	1.7	0.6	1.0
	N	2	34	3	62	62	63	62
S1 E33	A	2.3	102.6	0.4	536.9	23.2	0.4	0.2
	SD	0.0	5.2	0.0	99.6	1.6	0.5	0.2
	N	3	18	3	61	61	62	61
s2 CFH12	A	2.3	130.3	0.4	608.4	22.3	0.5	0.2
	SD	0.0	51.3	0.4	55.2	1.6	0.6	0.1
	N	3	16	3	30	30	30	30
S3 SANS	A	2.3	107.6	0.2	537.7	23.2	0.0	0.2
	SD	0.0	35.1	0.2	101.9	1.6	0.1	0.2
	N	3	18	3	61	61	62	61
S6 Adsorbsia™ GTO™	A	2.3	117.6	0.5	529.1	23.6	0.3	0.3
	SD	0.0	41.9	0.4	104.1	1.3	0.4	0.4
	N	3	18	3	33	33	33	33
s5 Isolux	A	2.3	101.1	2.3	594.0	22.4	0.6	0.2
	SD	0.0	6.1	3.7	57.7	1.5	0.4	0.1
	N	3	12	3	12	12	12	12
S6 ArsenX^{np}	A	1.6	92.4	1.9	513.7	23.6	0.0	0.2
	SD	1.3	29.8	2.2	98.4	1.3	0.0	0.2
	N	3	19	3	29	29	30	30
S7 ASM-10HP	A	1.5	87.3	0.6	608.0	23.0	0.0	0.1
	SD	1.3	35.9	0.2	69.4	1.4	0.0	0.1
	N	3	15	3	12	12	12	12
S8a Am. Si.	A	2.3	102.3	0.6	596.8	23.0	0.6	0.2
	SD	0.0	6.5	0.2	57.2	1.3	0.5	0.1
	N	3	12	3	12	12	12	12
S8a Bone Char	A	NT	105.7	NT	544.0	24.6	0.0	0.2
	SD	NT	4.9	NT	102.4	0.9	0.0	0.1
	N	NT	3	NT	9	9	9	9

Appendix A-3 Pilot Flow Diagrams

Rio Rancho Arsenic Removal Pilot Scale Project



COLUMN SPECIFICATIONS									
COL #	MANUFACTURER	MEDIA	COLUMN DIMENSION	HLR (GPM/FT2)	WATER (GPM)	BACKWASH (GPM)	MEDIA HEIGHT (IN)	MEDIA WEIGHT (G)	EBCT
1	ADEDGE	AD33	3" X 55.5"	6	0.3	0.4	29	2243	3
2	KEMIRON	CFH-12	3" X 55.5"	5	0.3	0.4	29	3969	3
3	DOW	ADSORBSIA	3" X 55.5"	6	0.3	0.4	29	4655	3
4	RESINTECH	ASM-10 HP	3" X 55.5"	6	0.3	0.4	29	3457	3
5	MEI	ISOLUX	5" X 42"	N/A	0.3	N/A	N/A	N/A	0.5
6	SANDIA	SANS	3" X 55.5"						
7	WATTS PREMIER	KP 4	4-STAGE RO WITH CARBON FILTER PRE-TREATMENT, STORAGE TANK, 25 GPD						
8	WATTS PREMIER	Z RO	ZERO WASTE RO WITH CARBON FILTER PRE-TREATMENT, STORAGE TANK, 25 GPD						

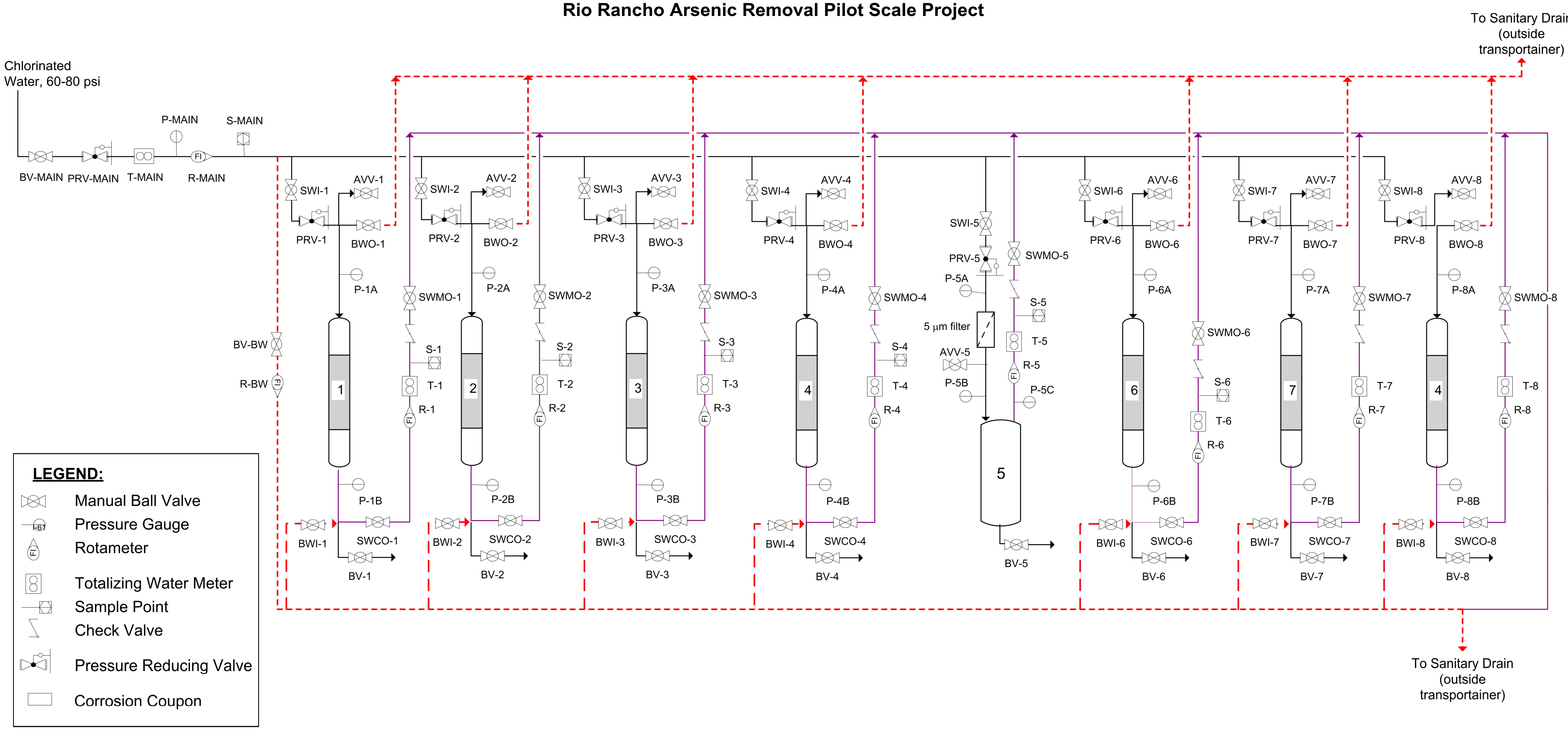
NOTES:

1. PRV-MAIN reduces the operating pressure to 50-80 psi. PRV-1 through 7 and P-RO reduce the operating pressure to 40-60 psi
2. The KP-4 RO system (unit 7) has a booster pump capable of operating up to 125 psi
3. Each RO is capable of producing 25 gallons per day (GPD)
4. Both RO systems (units 7 & 8) have storage tanks that will be drained using a timer, which is connected to the solenoid valves (SOL-7 and SOL-8). This will simulate consumption by a home owner.
5. Corrosion coupons are installed on all parts of the RO system to determine general corrosion rates.

Drawing # RR-02
Revision 1
9/15/05

Figure A-3a. Phase 1 Flow Diagram

Rio Rancho Arsenic Removal Pilot Scale Project



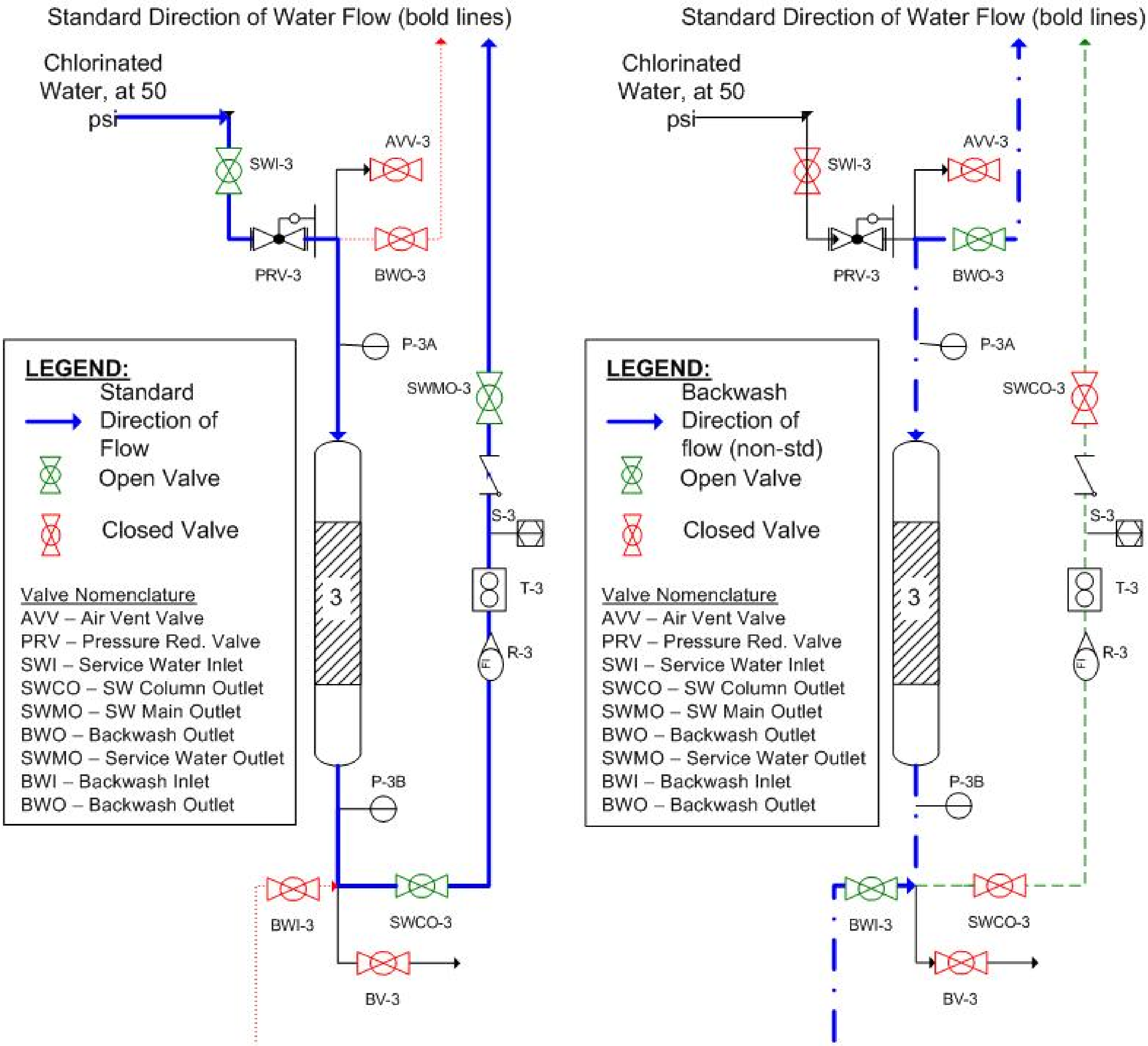
COLUMN SPECIFICATIONS									
COL #	MANUFACTURER	MEDIA	COLUMN DIMENSION	HLR (GPM/FT2)	WATER (GPM)	BACKWASH (GPM)	MEDIA HEIGHT (IN)	MEDIA WEIGHT (G)	EBCT
1	ADEDGE	AD33	3" X 55.5"	6	0.3	0.4	30.3	1872	3
2	KEMIRON	CFH-12	3" X 55.5"	6	0.3	0.4	45.0	5671	4.5
3	PUROLITE	ARSENX^{NP}	3" X 55.5"	6	0.3	0.3	30.3	3082	3
4	DOW	ADSORBSIA	3" X 55.5"	6	0.3	0.3	28.9	3908	3
5	MEI	ISOLUX	2.5" X 20"	N/A	0.3	N/A		N/A	0.72
6	PUROLITE	ARSENX^{NP}	3" X 55.5"	6	0.3	0.3	30.3	2342	3
7	RESINTECH	ASM-10 HP	3" X 55.5"	6	0.3	0.3	30.3	2495	3
8A	ADA	AM SI	3" X 55.5"	6	0.3	0.3	30.3	861	3
8B	BRIMAC	BONE CHAR	3" X 55.5"	6	0.3	0.3	30.3	2298	3

NOTES:

1. PRV-MAIN reduces the operating pressure to 50-80 psi. PRV-1 through 7 and P-RO reduce the operating pressure to 40-60 psi
2. The KP-4 RO system (unit 7) has a booster pump capable of operating up to 125 psi
3. Each RO is capable of producing 25 gallons per day (GPD)
4. Both RO systems (units 7 & 8) have storage tanks that will be drained using a timer, which is connected to the solenoid valves (SOL-7 and SOL-8). This will simulate consumption by a home owner.
5. Corrosion coupons are installed on all parts of the RO system to determine general corrosion rates.

Drawing # RR2-02
Revision 1
12/7/06

Figure A-3b. Phase 2 Flow Diagram



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 greater than 3 times the initial operating pressure drop.

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

Drawing # RR-03
Revision 1
9/15/05

Figure A-3c. Detailed Column Operation

Appendix A-4 Summary of Economic Calculations, ARCE model

Table A-4a. Detailed Economic Calculation Input Parameters

Design Criteria	**Q=0.86 mgd**
Vessel Flow Rate (gpm)	1600
Design Treatment Capacity. MGD	0.86
Configuration (series/parallel/unknown)	parallel
Number of Trains	2
Number of Vessels per Train	2
Bed Depth, ft	4.0
Vessel Diameter, ft	5.0
Total Facility Media Volume, cf	1,281.0
Media Bulk Density, PCF	*32*
Unit Media Cost, $/cf	*$200.00*
System Equipment Cost Summary	
Equipment Installation Cost, %	10%
Interior Piping Allowance,%	10%
I&C Allowance, %	3%
Electrical Allowance, %	2%
Yard Piping Allowance,%	10%
Building Facilities	
Building, sf	200
Building Unit Cost, $/sf	$200
Contractor & Engineering Cost Summary	
Engineering/Contractor Cost, %	30%
Permitting Cost, %	15%
Working Capital	$0
Start-up	$0
Contingency, %	25%
Annual O&M Costs	
Media Use Per Year, CF/Yr Based on Average Flow	708
Equipment Maintenance Costs, % of Capital Costs	5%
Annual Estimated Power Use, kWh/yr	38,084
Power Cost, $/kWh	0.10
Spent Media Production, Tons/yr	n/a
Labor, Operations, hrs/yr	56.0
Unit Labor Cost, Operations, $/hr	$30
Labor, Management, hrs/yr	12
Labor, Management, $/hr	$80
Equipment Maintenance Costs, % of Capital Costs	5%

Table A-4b. Detailed Economic Calculation Output Information

Total GIM System Equipment Cost Summary	**Q=0.86 mgd**
Total Vessel Cost including Valves, $	$123,892
Subtotal System Costs, $ (System Direct Capital Cost)	$418,101
Building Facilities	
Building, sf	484
Building Unit Cost, $/sf	$200
Building Cost, $	$96,800
Contractor & Engineering Cost Summary	
Subtotal Estimated Facility Cost, $	$418,101
Engineering/Contractor Cost, $	$125,430
Permitting Cost, $	$62,715
Working Capital	$0
Start-up	$0
Contingency, $	$104,525
Total Indirect Cost, $	$292,671
Annual O&M Costs	
Total Annual Media Costs, $/yr Based on Average Flow	$51,240
Annual Power Cost, $/yr	$3,808
Spent Media Production, Tons/yr	n/a
Total Estimated Labor Costs, $/yr	$1,680.0
Equipment Maintenance Costs, $/yr	$19,005.0
Capital Cost Summary	
Media & Equipment	$710,772
Building	$96,800
Engineering/Contractor Cost, $	$125,430
Permitting Cost, $	$62,715
Working Capital	$0
Start-up	$0
Contingency, $	$104,525
Present Worth Analysis	
Net Interest Rate	4.0%
Period, Years	20
Total Annual O&M Costs, $/yr	$76,693
Present Worth of Annual O&M Costs, $	$1,042,283
Total Estimated Facility Cost	$807,572
Total Present Value of Facitlities, $	$1,849,855
Total Annual Amortized Cost (Capital + O&M)	$136,116
Total Unit Cost of Water Produced, $/1,000 gals	$0.43

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
7	MS 0754	M. Aragon, 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 0892	R. Kottenstette, 01716
1	MS 0899	Tech Library, 9536 (electronic copy)