



**Arsenic Water Technology Partnership**

# Evaluation of Innovative Regenerable and Non-Regenerable Adsorption Media for Arsenic Removal



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# Evaluation of Innovative Regenerable and Non Regenerable Adsorption Media for Arsenic Removal

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## FOREWORD

The Water Research Foundation is a nonprofit corporation that is dedicated to the implementation of a research effort to help utilities respond to regulatory requirements and traditional high-priority concerns of the drinking water community.

The Arsenic Water Technology Partnership (AWTP) program is a partnership between Water Research Foundation, Sandia National Laboratories (SNL) and WERC, a Consortium for Environmental Education and Technology Development at New Mexico State University that is funded by DOE and the Water Research Foundation. The goal of the program is to provide drinking water utilities, particularly those serving small and rural communities, with cost-effective solutions for complying with the new 10 ppb arsenic MCL. This goal is being met by accomplishing three tasks: 1) bench-scale research to minimize operating, energy and waste disposal costs; 2) demonstration of technologies in a range of water chemistries, geographic locales, and system sizes; and 3) cost effectiveness evaluations of these technologies and education, training, and technology transfer.

The AWTP program is designed to bring new and innovative technologies developed at the laboratory and bench-scale to full-scale implementation and to provide performance and economic information under actual operating conditions. Technology transfer of research and demonstration results will provide stakeholders with the information necessary to make sound decisions on cost-effective arsenic treatment.

The Foundation participates in the overall management of the program, helps to facilitate the program's oversight committees, and administer the laboratory/bench-scale studies. SNL conducts the pilot-scale demonstrations and WERC oversees the education, training, economic analysis, and outreach activities associated with this program.

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## **EXECUTIVE SUMMARY**

On January 23, 2001, the U.S. Environmental Protection Agency (USEPA) reduced the drinking water maximum contaminant level (MCL) for arsenic from 50 parts per billion (ppb) to 10 ppb. The major issues associated with very small water supply systems adopting technologies for control of arsenic include lack of funds and other resources. There is a need to develop and implement technologies that are simpler to operate, employ centrally regenerable media and provide sufficient treatment between regenerations. Non-treatment options tend to be more economical and easier to implement and manage than the treatment options, however, in many small and rural areas, non-treatment options are generally not feasible or practical and treatment for arsenic will be necessary. Implementing a centralized arsenic treatment facility (ATF) or point-of-use (POU) type approach at these utilities will be challenging, given the lack of operator expertise, financial resources, and technical and management support. Whether a POU or centralized ATF approach is chosen, many of the least expensive arsenic treatment processes generate residual streams and, in some cases, hazardous wastes. Very small and rural systems have a great deal of difficulty in managing these wastes and complying with environmental disposal regulations.

### **PROJECT GOALS AND OBJECTIVES**

The primary goal of this project was to independently evaluate the efficacy of two innovative adsorption media — ArsenX<sup>np</sup> (AsX) and Adsorbsia GTO — under real world, full-scale conditions at two very small and rural drinking water systems, each serving a population of 80 to 100 persons. According to the manufacturer, AsX is a regenerable media, and this project developed data comparing the performance of a regenerated AsX media with the virgin media. The ability to regenerate on site or at an off-site facility is expected to reduce media and overall treatment costs but regeneration may pose additional burden for a very small water system. Adsorbsia GTO is a new adsorption media that has potential to be comparable with other commercially available adsorption media for arsenic removal. Both media are NSF 61 certified for drinking water use. Specific objectives of the project were to develop operational data for the selected media and compare the observed performance with other commercially available media, evaluate various hazardous properties of the exhausted media for its safe handling and disposal, compare performance of regenerated media with that of virgin media and determine the impact of water quality parameters (e.g., silica, pH, phosphorus and vanadium) that may hinder the treatment processes.

### **RESEARCH METHODS**

The adsorption media were tested at full-scale at two very small Public Water Systems (PWSs): the Triple G Dairy Water System (Triple G) and the Camp Verde Water System's (CVWS) Verde River Estate Site. Since the fixed bed adsorption columns provided full-scale treatment for the selected communities, proper approvals were obtained from the regulatory agencies. Triple G serves a residential area of 21 houses and utilized Adsorbsia GTO in a prefabricated, fiber-reinforced plastic vessel 30 inches in diameter and 72 inches in height capable of treating 30 gallons per minute (gpm). At an operational flowrate of 6.2 gpm/ft<sup>2</sup>, the empty bed contact time (EBCT) was 2.5 minutes. CVWS serves 45 customers, and the ATF

utilized AsX and consisted of steel adsorption vessel 24 inches in diameter and 72 inches in height, capable of treating 20 gpm. At an operational flowrate of 6.4 gpm/ft<sup>2</sup>, the EBCT was 2.5 minutes.

The samples collected at both testing sites were analyzed for field and laboratory water quality parameters using the Standard Methods for the Examination of Water and Wastewater (20<sup>th</sup> edition) procedures. To evaluate hazardous properties, the spent media were analyzed using the toxicity characteristics leaching procedure (TCLP) specified in USEPA method 1311. Spent AsX media was regenerated at an off-site facility, and its treatment performance was compared with the virgin media.

## **DISCUSSION OF RESULTS AND CONCLUSIONS**

The Triple G ATF with Adsorbsia GTO was operated for 125 days and treated 99,430 gallons (1,326 bed volumes) of water at variable flowrate. The influent arsenic ranged from 13 to 18 ppb with an average level of 16 ppb. The effluent arsenic level was below the detection limit of 1 ppb for up to 62 days of operation, or 558 bed volumes (BVs) treated. The observed performance of Adsorbsia GTO at Triple G was much lower than that observed in other studies. High source water pH (average of 9.2) and other water constituents such as vanadium may have contributed to observed treatment performance. Approaches such as reducing water pH to increase treatment performance using Adsorbsia GTO were described. Characterization of spent backwash water indicated it is not a hazardous waste and therefore may be discharged to an on site sewer or transported to a wastewater treatment facility. A prefilter installed upstream of the adsorption vessel to remove particulates lasted for 125 days without needing replacement. The pressure drop was minimal across the fixed bed media. Adsorbsia GTO effectively removed vanadium.

The average arsenic concentration in the source water at Camp Verde was 23 ppb. The ATF with the virgin AsX media treated 26,800 BVs at an effluent arsenic concentration of 10 ppb. In contrast to the Triple G ATF, the Camp Verde ATF operated at a relatively constant flow rate. Similar to Triple G, spent backwash water was not characterized as a hazardous waste and may be disposed of to an on site sewer or transported to a wastewater treatment facility. TCLP characterization of spent AsX extract showed an arsenic level below the method detection limit (0.2 mg/L). Hence the media would be eligible for disposal at a municipal landfill without resulting in additional costs. Similar to Triple G, the prefilter upstream of the adsorption vessel lasted for the entire 64 days without needing replacement. The pressure drops across the media were less than 1 psi.

Spent AsX media was removed from the adsorption vessel at Camp Verde and shipped back to the manufacturer for regeneration at an off-site location. The contactor with regenerated media was operated from 2/25/07 to 4/23/07, when an effluent arsenic level of 12 ppb was observed. The influent arsenic concentration during the evaluation of regenerated media ranged from 21 to 26 ppb, with an average of 24.2 ppb. The arsenic breakthrough for the regenerated and virgin media occurred at approximately 6,900 BVs. At an effluent arsenic level of 10 ppb, regenerated media treated 26 percent fewer BVs (19,900) when compared to virgin media (26,800 BVs). Based on the observed data from Camp Verde and the 26% loss of adsorption capacity, AsX may not be a cost effective adsorption media for Camp Verde.

Both ATFs could be operated without any major problems. Adsorption technology without pH adjustment appears to be a preferred choice for very small water systems. An

economic analysis and site-specific issues must be considered prior to selecting a final arsenic treatment technology.

# CHAPTER 1

## INTRODUCTION

### BACKGROUND

On January 23, 2001, the U.S. Environmental Protection Agency (USEPA) reduced the drinking water maximum contaminant level (MCL) for arsenic from 50 parts per billion (ppb) to 10 ppb. The Federal Arsenic Rule requires all community water systems (CWS) and non-transient non-community water systems (NTNCWS) to comply with the new MCL beginning with the compliance period five years within promulgation of the Federal Rule (January 23, 2001). The Rule allows water systems to apply for three- to nine-year extensions to the compliance date, based on the influent arsenic concentration and state discretion. This regulation represents one of the first rules under the 1996 Safe Drinking Water Act Amendments that significantly impact small and rural water supply systems. Given the lack of funding currently available and the high unit costs of smaller arsenic treatment plants, many small water supply systems have applied for extensions to construct arsenic treatment systems.

### Challenges to Small and Rural Utilities

The major issues associated with very small water supply systems adopting technologies for the control of arsenic include lack of funds and other resources. The cost per customer of centrally treating water can be significant, as the customer base is limited. Due to a limited number of operators in a very small system, a simple treatment system is desirable. The available adsorption and ion exchange media provide simple operation. However, disposal of single-use adsorption media and disposal of ion exchange regeneration solutions are major obstacles associated with the widespread application of these technologies. Therefore, there is a need to develop/implement technologies that are simpler to operate, employ centrally regenerable media and provide sufficient treatment between regenerations. The expansive small water supply system market has motivated technology developers to continue to develop media that meet the stated objectives.

The new arsenic MCL of 10 ppb has a potentially devastating impact on the small and rural water systems, particularly since NTNCWS are also required to comply with the new regulation. Systems serving fewer than 500 persons (<200 service connections) generally are simple groundwater systems with a single source, storage tank and hydropneumatic control system. Of the 4,000+ facilities impacted by the arsenic MCL, 72 percent of the utilities are in the size range of 25–500 (Federal Register, January 22, 2001). Some of these systems disinfect, which represents the most complex process currently utilized. In some cases, “non-treatment” options such as blending with water not contaminated with arsenic, modifying water sources (e.g., changing a well’s screen interval), consolidating water sources, replacing water sources with new sources, or becoming consecutive to another water system are potential methods to meet the new MCL. For the most part, non-treatment options tend to be more economical and easier to implement and manage than the treatment options described below. However, in many small and rural areas, non-treatment options are generally not feasible or practical and treatment for arsenic will be necessary.

Implementing a centralized arsenic treatment facility (ATF) or point-of-use (POU) type approach at these utilities will be challenging, given the lack of operator expertise, financial

resources, and technical and management support. USEPA has estimated that the cost to customers of small water systems (serving fewer than 3,300 people) would range from \$58 to \$327 per household per year (Federal Register, January 22, 2001). Estimates by Black et al. (1999) and Frey et al. (2000) are two to three times the USEPA estimates. Recent escalation in construction costs around the nation has further contributed to the inability of small and rural systems to install ATFs. Actual facility construction costs, documented by the research team, ranged between the USEPA estimated costs and those estimated by Black et al. (1999) and Frey et al. (2000). Based on eight facilities with water production capacities ranging from 20 gallons per minute (gpm) to 6 million gallons per day (MGD), the annualized construction costs ranged from \$37 to \$143 per consumer.

Many very small groundwater systems without any previous treatment experience will be forced to install new centralized ATFs or multiple POU systems. Maintaining the operational integrity of either of these is essential in achieving any benefit from such a system. For small systems, up to 60 services connections (0.02 MGD or 13.8 gpm), a POU would cost between \$23 and \$28 per month per household (for membrane and adsorptive processes) (Narasimhan Consulting Services, Inc., 2005). A centralized throwaway adsorption media system (e.g., two contactors in series adsorptive process with 2.5 minute empty bed contact time [EBCT] per vessel) for all the 60 connections would cost approximately \$42 per month per household. For rural water utility customers with low and fixed incomes, the cost savings associated with a POU system may be significant. These costs must be weighed against the disadvantages of POU systems, including the management and maintenance required of several units within consumers' homes (i.e., to meet multiple treatment goals), process reliability, public perception, liability if a treatment system fails due to factors beyond the utility's control or lack of control of the operation.

Whether the POU or centralized ATF is chosen, many of the least expensive arsenic treatment processes generate residual streams and, in some cases, hazardous wastes. Very small and rural systems have a great deal of difficulty in managing these wastes and complying with environmental disposal regulations.

## **ARSENIC REMOVAL TECHNOLOGIES**

Arsenic can be present in the dissolved state as either As(III) in anaerobic/anoxic (reduced) systems or as As(V) in aerobic (oxidized) systems. In typical drinking water pH ranges of 6 to 9, the predominant arsenite species is neutral in charge ( $\text{H}_3\text{AsO}_3$ ), while arsenate species are present as  $\text{H}_2\text{AsO}_4^-$  and  $\text{HAsO}_4^{2-}$ . Although both organic and inorganic forms of arsenic have been detected, organic species (methylated arsenic) are generally not as common in drinking water as inorganic arsenic. In oxygenated waters, As(V) is dominant, existing in anionic forms of either  $\text{H}_2\text{AsO}_4^-$  or  $\text{HAsO}_4^{2-}$  over the pH range typically encountered in water treatment. Due to the differences in the ionic charge of the arsenate and arsenite particles in the pH 6–9 range, the neutrally charged arsenite compound ( $\text{H}_3\text{AsO}_3$ ) is difficult to remove when compared to the divalent ( $\text{HAsO}_4^{2-}$ ) and monovalent arsenate anions ( $\text{H}_2\text{AsO}_4^-$ ). The negative charges on the arsenate compounds make arsenic easy to remove by adsorptive, co-precipitative and chemical exchange processes. Therefore, arsenite is oxidized to arsenate before its removal.

Arsenic removal in drinking water systems is affected by other water quality constituents such as silica, phosphorus, pH, fluoride, sulfate, chloride, vanadium, total dissolved solids (TDS), iron and manganese. These parameters affect treatment efficiency by interfering with

arsenic removal during the adsorption process. Silica levels greater than 20 mg/L and fluoride levels greater than 2 mg/L adversely affect adsorption process using iron-based activated alumina (Fe-AA); pH values greater than 8.0 and phosphorus levels greater than 0.2 mg/L adversely affect adsorption using granular iron media. Similarly, sulfate in water may affect ion exchange (IX) treatment process effectiveness (Narasimhan Consulting Services 2005 and 2006).

There are a number of technologies available to remove arsenic to meet the 10 ppb MCL. These include IX, activated alumina and iron media adsorbents (used on a throwaway basis), nanofiltration/reverse osmosis, coagulation/filtration, lime softening and electrodialysis. In an ideal environment, an ATF would be simple to operate, without the use of chemicals, and reduce waste quantities and overall operating costs. The economics and complexity of operation and/or water quality issues limiting these technologies make them difficult and, in some cases, nearly impossible for small and rural systems to implement. Ion exchange has the disadvantage of interference from competing ions (e.g., sulfate), chromatographic dumping of arsenic if the IX media is run to exhaustion, and spent brine disposal issues. Reverse osmosis systems have very high capital, operating and maintenance (O&M) costs, and spent brine disposal issues. Lime softening systems are complex with significant waste handling issues. Electrodialysis requires significant process control, a high level of expertise and generates a large volume of reject water. Coagulation/filtration is an effective treatment but requires chemicals addition and residuals handling on a regular basis, and therefore, it may not be feasible for very small water systems. The adsorption media systems, while effective, require periodic media replacement, which creates a solid waste. For a very small water system, adsorption treatment systems are the easiest to operate and maintain, and therefore provide advantages over other treatment technologies. New adsorption media, some regenerable, with better adsorption characteristics are becoming commercially available on a regular basis.

## **ADSORPTION MEDIA EVALUATED**

Based on discussions held with a number of adsorption media manufacturers and extensive experience of the project team with arsenic treatment technologies, two media were selected for the project.

### **ArsenX<sup>np</sup>**

AsX is an iron-oxide coated resin developed by SolmeteX to remove arsenic from water. The media is certified to NSF International (NSF) Standard 61. For drinking water applications, the media can be handled in standard adsorption fixed bed columns. The media provides a combination of IX and adsorption and has superior flow characteristics compared to granular media. The particle size for AsX ranges from 0.3 to 0.6 mm and the media can withstand much higher head loss compared to other available media because of its cross-linked organic base material. Generally, no backwashing is required under normal operating conditions and a spherical bead design provides homogeneous flow through the media. As per the manufacturer, the optimal operating pH ranges are between 5 and 8. Pretreatment or post-treatment required would depend on site-specific conditions, including source water quality. Based on the information provided by the manufacturer, AsX is claimed to be regenerable up to 5–10 times before it requires replacement. This claim has not been verified independently and this study compared the performances of virgin and once-regenerated media for arsenic removal.

AsX is regenerated with sodium chloride and sodium hydroxide solutions and it is claimed that minimal capacity is lost after five regenerations.

### **Adsorbsia GTO**

Dow Chemical Company (Dow) has developed a granular titanium oxide media designed for single use adsorption operation. Adsorbsia GTO is claimed to have a strong affinity for arsenic, lead and other heavy metals. Its smaller particle size (16 × 60 mesh size) is expected to provide more homogeneous and less turbulent flow characteristics in comparison to larger granular media. The media is claimed to work over a wide pH range, including pH levels higher than 8.5.

## **PARTICIPATING WATER SYSTEMS**

As part of the project, arsenic treatment systems were operated at two very small water systems in Arizona. Each of these water systems is described below:

### **Triple G Dairy Water System**

The Triple G Dairy Public Water System (PWS ID 04-07-713) is located in Buckeye, Ariz. The 21-connection CWS serves a population of approximately 84 people. The peak hour water usage is approximately 20 gpm for the potable consumption. The system meets all the current requirements of the Safe Drinking Water Act. The historical water quality indicated an arsenic level of 17 ppb, a pH of 8.4, an iron level of 0.2 milligrams per liter (mg/L) and a manganese level below its detection limit.

### **Camp Verde Water System**

The Camp Verde Water System's Verde River Estate Site (PWS ID 04-13-072) is located in Camp Verde, Ariz. The 45-connection CWS serves approximately 100 people. The peak hour water usage is approximately 30 gpm for the potable consumption. The system meets all the current requirements of the Safe Drinking Water Act. The historic arsenic level is 24 ppb, with a pH of 7.5, and non detectable iron and manganese levels.

## **PROJECT GOALS AND OBJECTIVES**

The primary goal of this project was to independently evaluate the efficacy of two innovative adsorption media under real-world, full-scale conditions at two very small and rural drinking water systems. The selected media include a hybrid iron oxide-impregnated resin (ArsenX<sup>np</sup>) and a newly developed titanium-based media (Adsorbsia GTO). To evaluate manufacturer's claims of regenerability, ArsenX<sup>np</sup> (AsX) was regenerated and its performance compared before and after regeneration. These adsorption media were tested at two very small-scale water supply systems serving populations of 80 to 100 persons. Each of these media is described below:

Specific objectives of the project are to:

1. Develop operational data for the selected media and compare the observed performance with other commercially available media.
2. Evaluate various hazardous properties of the exhausted media for its safe handling and disposal.
3. Compare performance of regenerated AsX media with that of virgin media.
4. Determine the impact of water quality parameters such as silica, pH, phosphorus and vanadium that may hinder the treatment processes, and recommend a sampling plan to establish raw water quality.
5. Evaluate practical and operational issues associated with the two media products in day-to-day water system operation.

## **ORGANIZATION OF THE REPORT**

Chapter 2 summarizes the research methods and includes detailed descriptions of the participating public water systems, design of ATFs, process and site layouts for each system, sampling protocols and analytical procedures, as well as the regeneration method for AsX media. Chapter 3 presents a review of the existing studies to document performance of the study adsorption media for arsenic removal. Since the media are new, the majority of the presented information has been developed by the media manufacturers, research team and the Sandia National Laboratories. This chapter also provides the water quality and operational information for each existing study so that these data could be compared to the results from this study.

Chapter 4 documents the results from the two ATFs using the study media. Results for arsenic removal and possible impact of other water quality constituents, such as silica and vanadium, are also presented. The results are compared with existing studies documented in Chapter 3.



## **CHAPTER 2**

### **RESEARCH METHODS**

For this project, two adsorption media (AsX and Adsorbsia GTO) were selected for full-scale, fixed-bed studies to evaluate their effectiveness for arsenic treatment. Two very small Public Water Systems (PWSs), the Camp Verde Water System (CVWS) and Triple G Dairy Water System, were selected to conduct the adsorption studies. Since the adsorption treatment is a full-scale treatment for the selected communities, design memoranda (including detailed descriptions of ATFs), various drawings, construction and water permitting approvals were obtained from the Arizona Department of Environmental Quality (ADEQ) and Maricopa County Environmental Services Department (MCESD) prior to installation of the treatment systems.

Detailed experimental protocols, including design of adsorption vessels, operational flowrates, sampling, analytical and quality assurance/quality control protocols, roles and responsibilities of the research team and participating utilities were developed and followed throughout the study.

#### **DESCRIPTION OF SMALL PUBLIC WATER SYSTEMS**

##### **Triple G Dairy Public Water System**

The Triple G Dairy Public Water System (PWS ID 4-07-713) is located in Buckeye, Ariz. The system is served by a single 750-gpm well, but only a small fraction (approximately 30 gpm) of this flow is diverted to a residential area serving 21 houses. The site has a single 300,000 gallon storage tank, a 10,000 gallon hydropneumatic tank and eight booster pumps of varying sizes. Exact water consumption is unknown. Chlorination is performed at the booster station. The chlorine residual is maintained at 1 mg/L. A 4-inch diameter, schedule 40 polyvinyl chloride (PVC) pipeline connects the hydropneumatic tank to the housing units. The system has a pressure of 58 psi. The system meets all of the current Safe Drinking Water Act requirements except for the arsenic MCL.

Adsorbsia GTO was used for the Triple G ATF, which consisted of a prefabricated skid with one steel adsorption vessel. To treat a flow of 30 gpm, an adsorption vessel 30-inches in diameter and 72-inches in height was constructed (Figure 2.1). The skid was mounted on a concrete pad. The vessel was equipped with an air release valve and a 2-inch media drain. System pressure was used to convey water to and through the adsorption vessel. The vessel was provided with a 4-inch by 6-inch access opening at the top for visual inspection. The treated flow was measured with a calibrated rotameter. To measure head loss through the media, two pressure gauges were installed at the inlet and outlet of the vessel. Sample taps for raw water and treated water were installed for collecting samples. The water system was piped to the adsorption vessel using a Schedule 80 PVC pipe and fittings. A pre-filter with a nominal pore size of 50 microns ( $\mu\text{m}$ ) was installed on the inlet of the ATF to avoid accumulation of any suspended solids within the adsorption media. A site plan and a process diagram are shown on Figures 2.2 and 2.3. The adsorption vessel contained 12 inches of gravel as a support layer for the 75 gallons (approximately  $10 \text{ ft}^3$ ) of adsorption media. At an operational flow rate of  $6.2 \text{ gpm/ft}^2$ , the empty bed contact time was 2.5 minutes. Prior to media installation, the vessel was filled with approximately three feet of water to ensure minimal void space formation upon loading of media. After the installation, the media was backwashed to remove fines before it was put into

service. Removal of fines took approximately 16 hours, a relatively long time compared to backwashing of other adsorption media. Water pH was not adjusted during the project. The spent backwash water was disposed to the on site dairy wastewater treatment facility.



**Figure 2.1 Triple G Dairy adsorption system**



## Camp Verde Water System

The CVWS (Verde River Estate Site) consists of a 65-gpm well, two storage tanks (10,000 gallons each), a 20-gpm booster pump and a hydropneumatic tank (2,000 gallons). One of the storage tanks is 11 feet in diameter and 16 feet in height, and the other tank is 12 feet in diameter and 15 feet in height. The system injects chlorine at the well head using a tablet feed system. A 4-inch diameter, schedule 40 PVC line goes from the hydropneumatic tank to supply water leading to various customer connections. The ATF was not installed at the well head, as the well flowrate (65 gpm) was much higher than that required (20gpm) for the treatment system. A skid mounted fiber-reinforced plastic adsorption vessel 24 inches in diameter and 72 inches in height was utilized at CVWS (Figure 2.4). The vessel was equipped with a pressure release valve and a 2-inch media drain. Two pressure gauges were installed at the inlet and outlet of the vessel to measure head loss through the media. Sample taps for raw and treated water were installed for sample collection. A pre-filter (25 $\mu$ m) was installed at the inlet of the treatment system to avoid accumulation of any suspended solids within the adsorption media. A site plan and a process diagram are shown on Figures 2.5 and 2.6.

The adsorption vessel contained 12 inches of gravel as a support layer for the 50 gallons (6.7 ft<sup>3</sup>) of adsorption media. At an operational flowrate of 6.4 gpm/ft<sup>2</sup>, the empty bed contact time was 2.5 minutes. Prior to media installation, the vessel was filled with approximately three feet of water to ensure minimal void space formation upon loading of media. After the installation, the media was backwashed to remove fines before it was put into service. The well water pH was not adjusted during the project. The spent backwash water was disposed to an off-site liquid waste disposal facility.

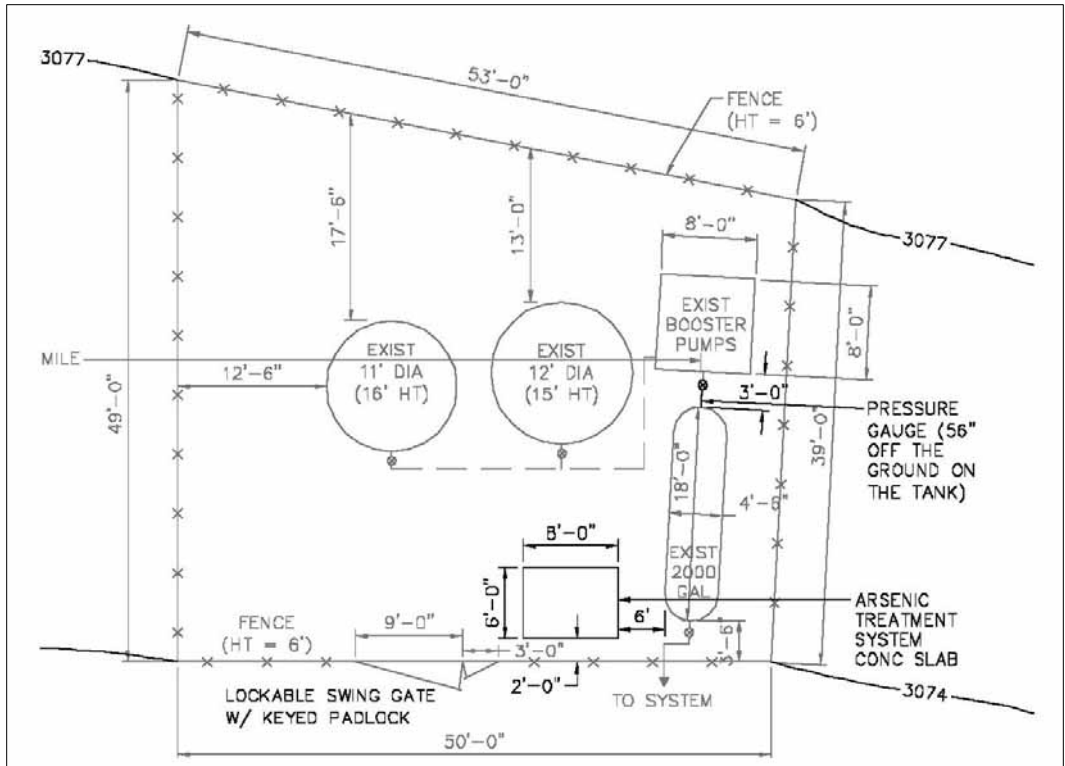
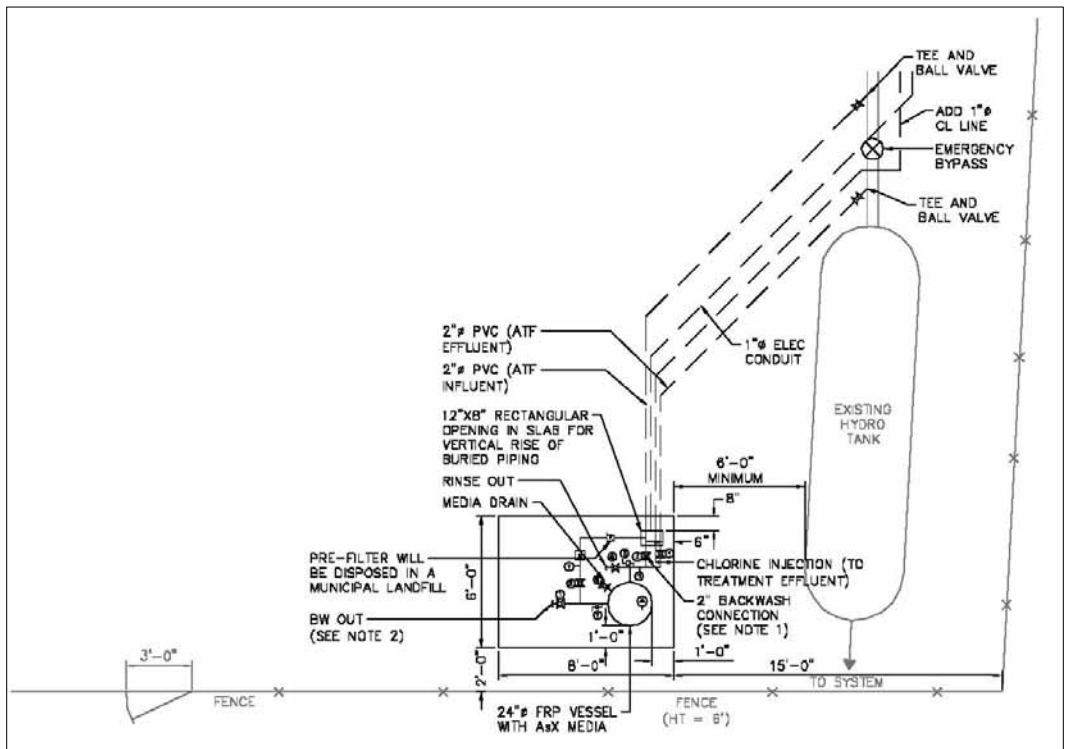


Figure 2.4 CVWS adsorption system





**Figure 2.6 CVWS ATF schematic**

## ANALYTICAL METHODS

The influent and effluent samples collected at both testing sites were analyzed for field and laboratory parameters. Procedures described in the Standard Methods for the Examination of Water and Wastewater (20th edition) were utilized for the project (Table 2.1). The monitored parameters and their frequency of analysis are summarized in Table 2.2. The field parameters, which were monitored once per week, consisted of flowrate, pressure readings, pH, free chlorine, temperature and turbidity. Samples for the laboratory parameters were collected as per the Standard Methods and were analyzed by a USEPA certified laboratory (Legend Technical Services of Arizona, Inc., Phoenix, Arizona). After the effluent arsenic level reached 10 ppb, the spent media were analyzed for arsenic, cadmium and selenium using the toxicity characteristics leaching procedure (TCLP) specified in USEPA Method 1311. An arsenic-containing waste whose TCLP extract exceeds 5.0 mg/L is considered a Resource Conservation and Recovery Act hazardous waste and must be properly treated and disposed of.

**Table 2.1**  
**Analytical procedures**

Parameter	Standard Method No.
Alkalinity	2320B (titration)
pH	4500-H (electrode)
Temperature	2550-B
Turbidity	2130-B (nephelometric)
TDS	2540-C (gravimetric)
Arsenic, Vanadium	3120-B (inductively coupled plasma)
Silica	3120-B (inductively coupled plasma)
Fluoride (F), Sulfate (SO <sub>4</sub> ), Phosphate (PO <sub>4</sub> )	4500-F <sup>-</sup> , 4500-SO <sub>4</sub> <sup>-2</sup> B, 4500-PO <sub>4</sub> <sup>-3</sup> C
Iron (Fe <sup>+2,+3</sup> ), Manganese (Mn <sup>+2</sup> )	3500-Fe B, 3500-Mn B

**Table 2.2**  
**Monitored field and laboratory parameters**

Water system	Field parameters		Lab parameters		
	Once a week	Once in two weeks	Once a week	Once in two weeks	Once a month
Camp Verde Water System	pH, chlorine, turbidity, temperature	Mn, Fe	Arsenic (As)	Silica (Si) alkalinity	F, TDS
Triple G Dairy Water System	pH, chlorine, turbidity, temperature	Mn, Fe	As	Vanadium (V), F, alkalinity	Si, TDS

**REGENERATION OF ARSENX<sup>NP</sup> MEDIA**

When the effluent reached an arsenic level of 10 ppb, the media was removed and shipped to the manufacturer’s regeneration facility. The media was removed from the vessel and packed in a suitable container, as per manufacturer’s recommended procedure. The media was regenerated using a procedure that meets the NSF 61 certification. SolmeteX provided the following general procedure that was used for regenerating AsX media:

1. The regeneration is performed by passing a fixed volume of a 2% caustic solution (NaOH) and 1% sodium chloride solution through the media at a designated flow rate to remove arsenic.
2. The arsenic solution is then passed through another proprietary solution that irreversibly binds arsenic and the solution is disposed of, as per federal and state regulations.
3. The media is thoroughly rinsed after this process with 500 parts per million (ppm) NaCl and then sparged with carbon dioxide until the pH of the column is 6.5 to 7 units.

Because of the low volume of media and to comply with the NSF 61 certification requirements, the manufacturer had to construct special equipment. Therefore, it took approximately two months for regenerating the media. The regenerated media was shipped back to the site and loaded into the adsorption vessel similar to the virgin media.

## CHAPTER 3 REVIEW OF EXISTING INFORMATION

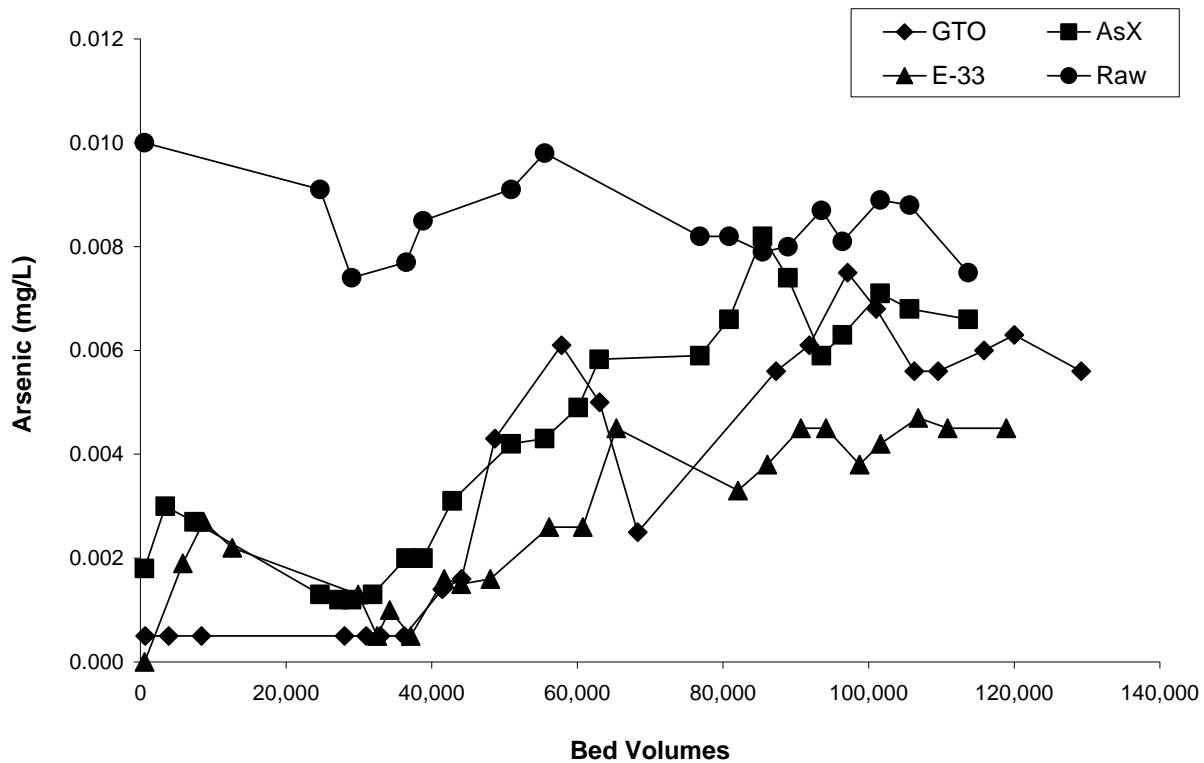
Both Adsorbsia GTO and AsX are relatively new adsorption media for arsenic control, and existing treatability information is not available in the peer-reviewed literature. Therefore, the majority of information was obtained from the non peer-reviewed bench and pilot scale treatability studies conducted by the research team and Sandia National Laboratories (SNL). Information from these sources is summarized in the following sections.

Narasimhan Consulting Services, Inc. (NCS) conducted a side-by-side comparison of three adsorption media (Adsorbsia GTO, AsX and E33) for an arsenic contaminated well for the City of Phoenix (Phoenix) Water Services Department, Arizona (NCS, 2006). The source water quality during the testing period (September 2004 to March 2005) is summarized in Table 3.1. All three media were evaluated at the ambient pH level and with an EBCT and hydraulic loading rate of 2.5 minutes and 8.0 gpm/ft<sup>2</sup>, respectively. Two 12-inch diameter contactors were used for Adsorbsia GTO and E-33, while a 1.5-inch diameter column was used for AsX. AsX was tested in a small contactor because of the amount of media available during the testing period.

The average arsenic level in the source water was 8.5 ppb and ranged from 7.4 to 10 ppb. Figure 3.1 compares arsenic breakthrough profiles for the three tested media. While there is variability in the data primarily attributed to variations in source water arsenic level, E33 and Adsorbsia GTO performed better than AsX media.

**Table 3.1**  
**Average source water quality parameters at the Phoenix Well**

Parameters	Units	Value
Arsenic	mg/L	0.085
pH	Standard <i>Units</i>	7.9
Silica	mg/L	40
Iron	mg/L	0.085
Fluoride	mg/L	0.45
Vanadium	mg/L	0.022
Turbidity	NTU	0.28
Nitrate-N	mg/L	1.4
Alkalinity	mg/L	174
TDS	mg/L	259



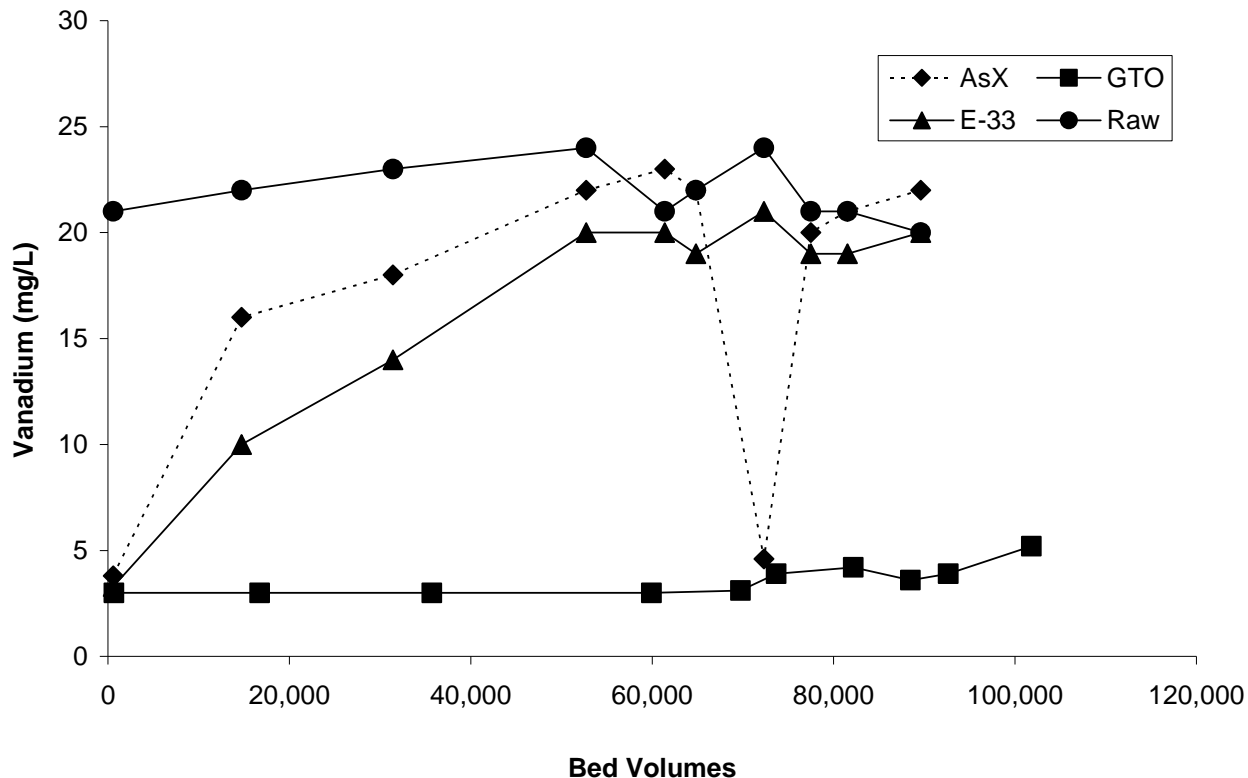
**Figure 3.1 Arsenic breakthrough profiles for three adsorption media at City of Phoenix pilot study**

Vanadium appears to compete with arsenic for adsorption sites on media. All three media removed vanadium. As shown on Figure 3.2, Adsorbisia GTO continued to remove vanadium beyond 102,000 BVs, while AsX and E33 were saturated with vanadium at approximately 60,000 and 89,000 BVs, respectively. Based on the data, vanadium appears to impact arsenic adsorption for all three media, however, Adsorbisia GTO was impacted more than AsX and E33.

Silica was removed by all three media for approximately 3,500 BVs at which point the media were saturated with silica. Silica does not appear to impact arsenic removal by the three media as the three media were exhausted for silica much sooner than either arsenic or vanadium.

Fluoride was not reduced by either AsX or E33 but was observed in the Adsorbisia GTO column effluent at 650 BVs and the column was saturated at 28,000 BVs. Due to lack of data, it is difficult to assess the adverse impacts of fluoride on arsenic adsorption.

As a member of the Arsenic Water Technology program, Sandia National Laboratories (SNL) has conducted demonstration scale studies for innovative, commercial technologies primarily for rural and small (serving less than 10,000 persons) public water systems. SNL has tested several adsorption media at three water systems – Socorro Springs, Anthony and the City of Rio Rancho in New Mexico (Aragon et al. 2007a, 2007b and 2007c). The source water quality for these studies is summarized in Table 3.2. The source water for Anthony was chlorinated to oxidize arsenite to arsenate.



**Figure 3.2 Vanadium breakthrough profiles for three adsorption media at City of Phoenix pilot study**

At Socorro Springs, five adsorption media including MEI Isolux 302M (zirconium oxide), Hydroglobe Metsorb (titanium oxide), BASF ARM200 (iron oxide), AsX and E 33, were tested by SNL (Aragon 2007a). Media EBCT ranged from 0.3 minutes for Isolux 302M to 5 minutes for E33. Based on BVs treated corresponding to an effluent arsenic concentration of 10 ppb, E33 (52,000 BVs at 5 minutes EBCT) performed the best, followed by Isolux 302M (32,000 BVs), AsX (27,000 BVs), Metsorb (13,000 BVs) and ARM200 (8,600 BVs). The inferior ARM200 performance was attributed to a preproduction batch.

At Anthony, thirteen adsorption media, including Virotec Buaxsol-GAC, UTEP Reddysorb (iron coated pumice), ADA Amended Silicate, Resin Tech ASM 10HP (iron coated resin), ARM200, Isolux 302M, AsX, Metsorb, Adsorbisia GTO, SNL SANS (granular ferric and cupric oxide), EP Minerals NXT-2 (iron and magnesium coated lanthanum) Kemira CFH12 (granular iron oxide) and E33 were tested by SNL(Aragon 2007b). Media EBCT ranged from 2.5 minutes for E33 to 10 minutes for Reddysorb. Based on BVs treated corresponding to an effluent arsenic concentration of 10 ppb, E33 (56,000 BVs) performed the best, followed by CFH12 (45,000 BVs), NXT-2 (40,000 BVs), SANS (34,000 BVs), Adsorbisia GTO (34,000 BVs), Metsorb (30,000), AsX(28,000 BVs), Isolux 302M (22,000 BVs), ARM200 (13,500 BVs), ASM-10HP (7,500 BVs), Amended Silicate (2,300 BVs), Reddysorb (800 BVs) and Bauxsol-GAC (<1,000 BVs).

At the City of Rio Rancho, nine adsorption media were, including Brimac Bone Char, Amended Silicate, ASM 10HP, Isolux 302M, AsX, Adsorbsia GTO, SANS, Kemira CFH 12 (granular iron oxide) and E33 were tested during Phase 2 of the project (Aragon 2007c). Additional media were tested during Phase 1 but sufficient breakthrough profiles were not generated for proper comparison. Media EBCT ranged from 0.5 minutes for Isolux 302M to 5 minutes for ASM 10HP and Bone Char. Based on BVs treated corresponding to an effluent arsenic concentration of 10 ppb, E33 (63,000 BVs) performed the best, followed by Adsorbsia GTO (60,000 BVs), SANS (51,000 BVs), AsX(47,000 BVs), CFH12 (estimated at 40,000 BVs), Isolux 302M (22,000 BVs), ASM-10HP (13,000 BVs), Amended Silicate (3,800 BVs), and Bone Char (~800 BVs).

**Table 3.2**  
**Water quality parameters for SNL pilot studies using different adsorption media**

Parameters	Units	Value		
		Socorro	Anthony	Rio Rancho
Arsenic (V)	mg/L	0.042	0.02	0.019
Arsenic (III)	mg/L	<0.002	0.018	<0.001
pH	SU	8.0/6.81	7.7	7.6
Silica	mg/L	25	37	50
Iron	mg/L	0.04	0.5	0.15
Fluoride	mg/L	0.5	0.5	0.9
Vanadium	mg/L	0.011	0.002	0.015
Nitrate-N	mg/L	0.2	ND*	2.0
Alkalinity	mg/L as CaCO <sub>3</sub>	130	180	160
Sulfate	mg/L	29	180	100

\*non detect.

Under a contract with SNL, NCS conducted a pilot study that compared four adsorption media including E33, npRio (a modified version of AsX), Adsorbsia GTO and Kemira CFH0818 at the City of Weatherford, OK water system (Arora et al. 2007). The adsorption pilot units consisted of a 6-inch diameter, fiber-reinforced plastic columns with an EBCT of 2.5 minutes. The column was operated at 6 gpm/ft<sup>2</sup>. Arsenic in the source water ranged from 15.7 to 29.7 ppb, with an average of 20 ppb. The water was neutral to slightly basic, as pH ranged from 6.9 to 7.6 with an average value of 7.3. Sulfate (75 to 119 mg/L), chloride (33 to 43 mg/L), calcium (64 to 73 mg/L), magnesium (12 to 15 mg/L) and conductivity (450 to 610 µm/cm) levels indicated high total dissolved solids in groundwater. Nitrate levels (18.9 - 25 mg/L as NO<sub>3</sub>) were moderate in Weatherford groundwater. Vanadium in well water ranged from 0.02 to 0.03 mg/L. Well water was chlorinated (around 1 mg/L) to ensure that arsenic was present arsenate. Based on BVs treated corresponding to an effluent arsenic concentration of 10 ppb, E33 (estimated at 73,100 BVs) performed the best, followed by Adsorbsia GTO (44,100 BVs), Kemira CFH0818 (44,100 BVs) and npRio (22,500 BVs). Vanadium was also reduced by all adsorption media with

the earliest breakthrough (effluent level greater than the detection limit of 1.5 ppb) observed for Kemira CFH0818 (19,700 BVs), followed by E33 (29,400 BVs), npRio (40,500 BVs) and then by Adsorbsia GTO(>47,100 BVs). Silica was marginally removed. Based on comparative results from different studies, E33 appears to perform the best under a variety of different source water conditions. Adsorbsia GTO performs better than AsX in reviewed studies. Difference observed performances for a media at different locations may be attributed to difference in source water quality.

## **COMPARISSON OF STUDY MEDIA WITH OTHER COMMERCIAL MEDIA**

A number of adsorption media are available for arsenic removal. New media are being developed and will be available in the future. Based on a study conducted by NCS, Table 3.3 qualitatively compare Adsorbsia GTO and AsX with other adsorption media (NCS 2001). Based on the information, source water quality is an important criterion in the selection of an adsorption media. Silica levels greater than 20 mg/L and fluoride levels greater than 2 mg/L affect adsorption for iron-based activated alumina; pH values greater than 8.0 and phosphorus levels greater than 0.2 mg/L affect adsorption using granular iron media (GIM). Vanadium levels greater than 30 ppb and silica levels greater than 40 mg/L can compete for adsorption sites on iron- and titanium-based adsorption media. Similarly, sulfate levels greater than 50 mg/L affect IX treatment processes. At water pH above 8.0, most ferric-based adsorption media lose their positive charge because the point of zero charge of ferric hydroxide is pH 8.2 and more silicate ions are present, both significantly reducing adsorption capacity. High levels of sulfate may impact the run length of a granular media adsorption column, while very low sulfate levels can impact IX processes since sulfate is preferably removed over arsenic. Nitrate may pose a significant problem in ion exchange systems for arsenic removal due to nitrate peaking.

**Table 3.3**  
**Comparison of arsenic adsorption media**

<b>Treatment technology</b>	<b>pH effect</b>	<b>Phosphate interference</b>	<b>Fluoride interference</b>	<b>Iron interference</b>	<b>Sulfate interference</b>	<b>TDS interference</b>
IX	Effective in broad pH range (6.5 - 9)*	Minimal§§	Minimal§§	Significant†	Significant§	Significant*
AA	Effective in 5.5-6 range‡	Significant‡‡	Significant‡‡	High‡‡	Less** to significant‡‡	Minimal†
GFH	Wide Range up to 8.5‡‡‡	Significant***	Minimal	High	Moderate	Minimal

NOTES:

- \* Clifford and Lin (1995)
- † Clifford et al. (1998)
- ‡ Rosenblum and Clifford (1984)
- § Pontius (1990)
- \*\* Benjamin et al. (1998)
- †† Clifford and Lin (1990)
- ‡‡ Saha et al. (2001)
- §§ Clifford (1999)
- \*\*\* USEPA (2004)
- ††† USEPA (2000)

## **CHAPTER 4**

### **RESULTS AND DISCUSSIONS**

Fixed-bed adsorption testing of Adsorbsia GTO and AsX were studied on full-scale ATFs for two very small community water systems CWSs - Triple G and Camp Verde public water systems. This chapter provides the results of the arsenic removal testing, including characterization of residuals for the two CWSs.

#### **TRIPLE G WATER SYSTEM**

The Triple G ATF with Adsorbsia GTO was operated from 2/22/06 to 6/26/06 and treated 99,431 gallons of water. As expected for a very small CWS, the water flow rate at Triple G varied from zero to 30 gpm. The historical water consumption pattern is not available. The ATF could not be operated at a constant flowrate because Triple G did not wish to waste a large volume of water. Once a week, the water system operator recorded the instantaneous water consumption, which ranged from 3.6 to 13 gpm. The weekly instantaneous water consumption readings were taken between 7:00 a.m. and 2:00 p.m., and the maximum flow rate was not recorded during the time of data collection. Based on these flow rates, the calculated EBCT ranged from 5.8 to 20.8 minutes.

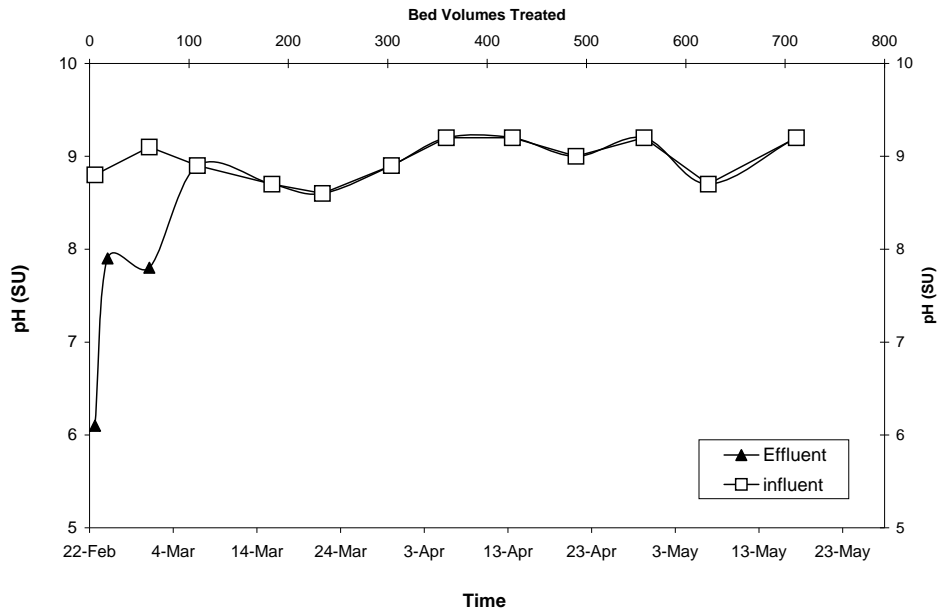
Water temperature, pH, turbidity and chlorine levels in the influent and effluent water from the ATF were monitored on weekly basis. Samples for arsenic were taken on a weekly basis and shipped overnight to a commercial laboratory for analysis. Samples for alkalinity, vanadium, phosphorus and fluoride were collected biweekly and shipped to the analytical laboratory for analysis. Samples for silica and total dissolved solids (TDS) were collected once every four weeks. Table 4.1 summarizes the source water quality observed during the testing period. As described in Chapter 3, water pH plays an important role in arsenic adsorption. The historical source water pH was reported at 8.4. However, during the testing period, the water pH ranged from 8.6 to 9.9 with an average value of 9.2. Figure 4.1 summarizes the observed influent and effluent water pH. A depression in effluent pH was observed for the first two weeks of water treatment, after which the effluent pH equaled the influent pH. The pH depression has also been observed by the manufacturer and is attributed to acidic functional groups from the media. The effluent pH equilibrated with influent pH after two weeks, during which 3,500 gallons of water were treated. Figure 4.2 shows the influent and effluent chlorine levels. The media consumed chlorine for the first two weeks. Similar chlorine consumption has also been observed for iron based adsorption media (NCS 2006). After initial chlorine consumption, the effluent chlorine levels were the same as the influent levels.

#### **Arsenic Removal**

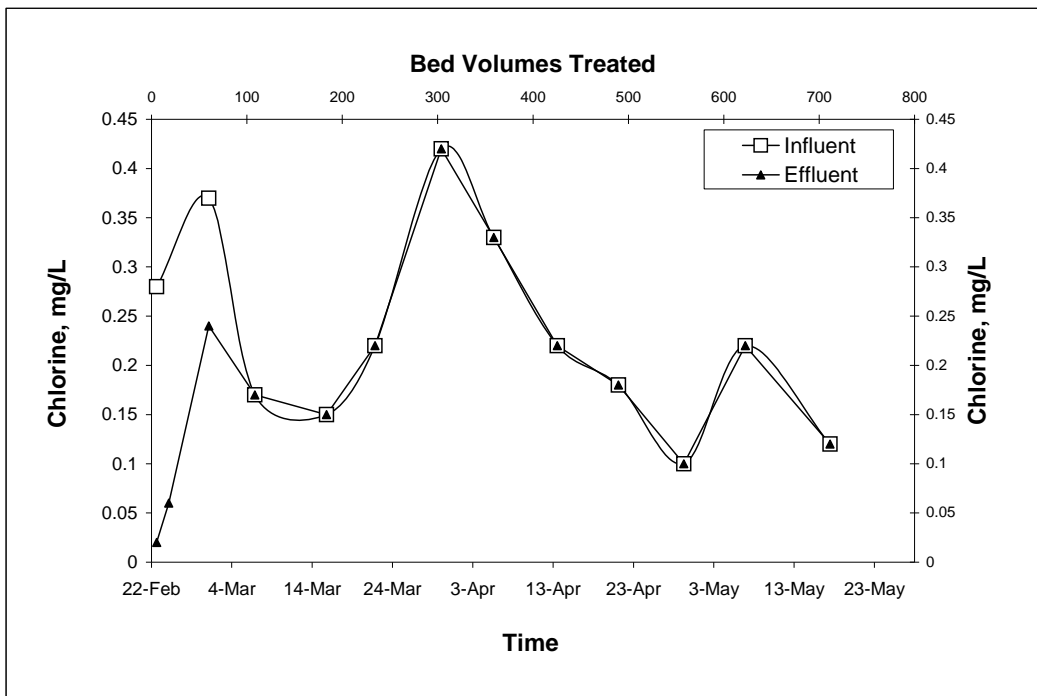
Figure 4.3 displays the arsenic breakthrough profile for Adsorbsia GTO media. The influent arsenic ranged from 13 to 18 ppb, with an average level of 16 ppb. The effluent arsenic level was below the detection limit of 1 ppb for up to 62 days of operation, or 558 BVs treated. The effluent arsenic level reached 11 ppb in 125 days of operation, or 1,325 BVs treated.

**Table 4.1**  
**Source water quality for Triple G ATF**

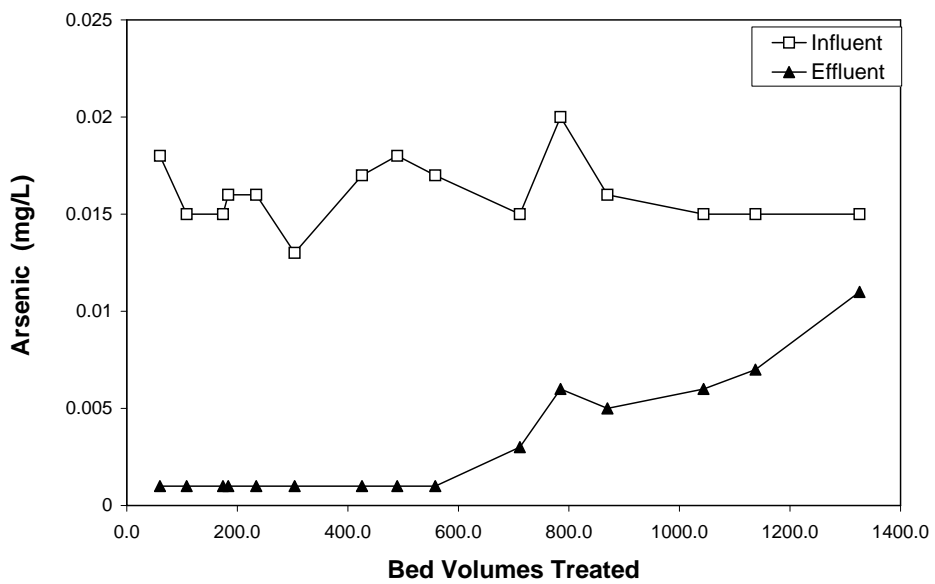
<b>Parameter</b>	<b>Value</b>	<b>No. of samples</b>
As(V), ppb	16	12
pH, Standard Units	9.2 (8.6 – 9.9)	20
Sulfate, mg/L	31	1
Iron, mg/L	<0.01	1
Silica (SiO <sub>2</sub> ), mg/L	20.5	4
Manganese, mg/L	<0.005	1
Vanadium, mg/L	0.036	8
Chlorine, mg/L	0.21	20
Turbidity, NTU	0.17	18
Temperature, °C	29	20
ORP	210	1
Total alkalinity, mg/L as CaCO <sub>3</sub>	67	8
Fluoride, mg/L	2.2	8
TDS, mg/L	265	4



**Figure 4.1 Observed influent and effluent pH behavior for Adsorbisia media at Triple G ATF**



**Figure 4.2 Observed influent and effluent chlorine behavior for Adsorbsia media at Triple G ATF**



**Figure 4.3 Arsenic breakthrough profile for Adsorbsia media at Triple G ATF**

The number of BVs treated at Triple G (1,325) was much lower than that observed at the City of Phoenix pilot testing (see Chapter 3). The average source water arsenic for the Phoenix pilot testing was 7.4 ppb, which is less than half of that at Triple G. The vanadium level was higher at Triple G than at Phoenix and may have impacted the observed treatment performance at Triple G. The water quality parameters that impacted the arsenic removal performance are pH and fluoride. pH impacts arsenic adsorption and much lower adsorption run lengths can be expected at a pH greater than 9.0. Even at high pH values, the ATF provided treatment for 125 continuous days. This performance can be enhanced at pH less than 8.0. None of the commercially available adsorbents treat arsenic effectively at pH values greater than 8.5. Further, adding pH reduction facilities can complicate the operation for a very small system but can also significantly decrease the adsorbent replacement frequency. Therefore, pH adjustment may result in better adsorption media treatment performance at Triple G and a reduction in overall treatment costs. It should be noted that if Triple G adopts pH adjustment prior to an adsorption process, the same treatment goal may be achieved at a lower cost by using other adsorption media such as E33.

Compliance of a public water system with the arsenic rule depends on the source of water and the population served. A public water system exceeding a regulatory limit generally takes quarterly samples unless the primacy agency reduces the monitoring requirements based on the reported compliance data. The compliance is based on running annual average (RAA) of quarterly samples. Since the compliance is based on an average, the arsenic concentration in the distributed water can exceed the MCL as long as the water system complies with the MCL on a RAA basis every quarter. For an adsorption treatment system, arsenic is not observed in the effluent and the breakthrough profile occurs slowly over a period of time. Therefore, compliance samples taken at different intervals along the breakthrough profile can be averaged to comply with the quarterly RAA. Samples with effluent arsenic levels below the detection limit, or MCL, can be averaged with samples with arsenic levels higher than MCL as long as the quarterly RAA values are below the MCL. In this manner, the overall treatment period can be extended, resulting in reduced costs. For the Triple G arsenic breakthrough profile, the effluent arsenic level in the first quarter is below the detection limit. The effluent arsenic levels can be assumed to be 0.006, 0.014 and 0.016 (average influent level) mg/L in the second, third and fourth quarters, respectively. Although, the effluent arsenic level is 0.016 mg/L (higher than MCL of 0.01 mg/L), the quarterly RAA of 0.009 mg/L is below MCL.

Parallel, staggered operation of fixed bed adsorbents can also result in improved process performance. In this manner, effluent from different adsorbents at different saturation levels can be combined to meet the MCL. However, this strategy may not be practical for a very small water system. Another approach to increase process performance is to increase the EBCT, or bed depth. Generally, an increase in bed depth results in an increased process performance because the ratio of mass transfer zone to bed depth decreases with increased bed depth. For arsenic adsorption, an EBCT of three to four minutes is adequate, and an increase in performance is not realized with a further increase in EBCT.

## **Other Water Constituents**

Silica, vanadium, fluoride and other competing water constituents can compete for sites on adsorption media. Silica was removed by Adsorbisia GTO for up to 350 BVs, as shown on

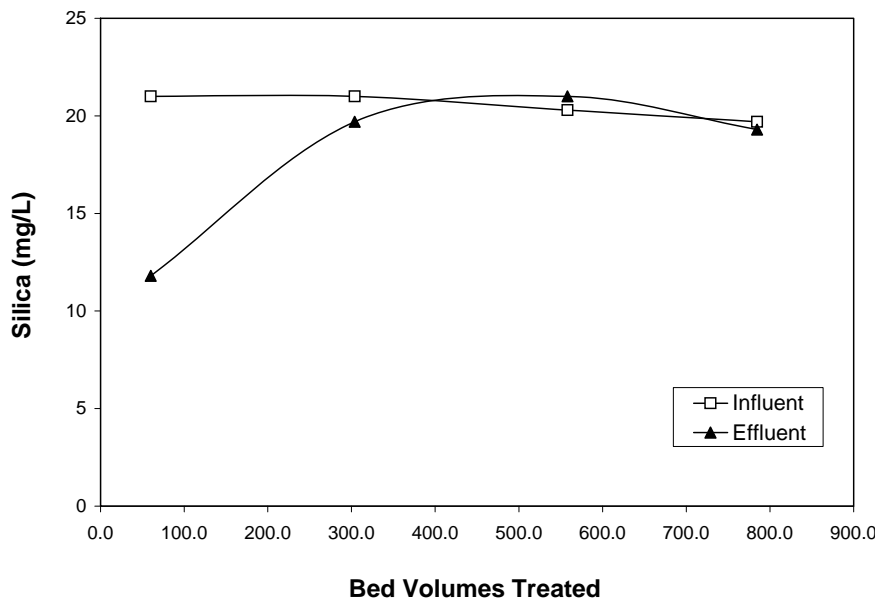
Figure 4.4. Removal of silica may have impacted arsenic removal. For the Phoenix pilot testing, silica was removed up to 3,500 BVs compared to the Triple G study. Although, the silica level at Phoenix (40 mg/L) was higher than at Triple G (20.5 mg/L), higher pH at Triple G, may have impacted the observed silica removal.

Vanadium removal at Triple G is displayed in Figure 4.5. Similar to Phoenix and Weatherford, Adsorbsia GTO continues to remove vanadium and this may have competitively impacted arsenic removal. While vanadium is not currently regulated in drinking water, it is on the list of contaminants for future regulation. Adsorbsia GTO appears to be an effective treatment technology for the control of vanadium in water, however, additional treatability studies would be required to identify the impact of other water quality constituents on its removal.

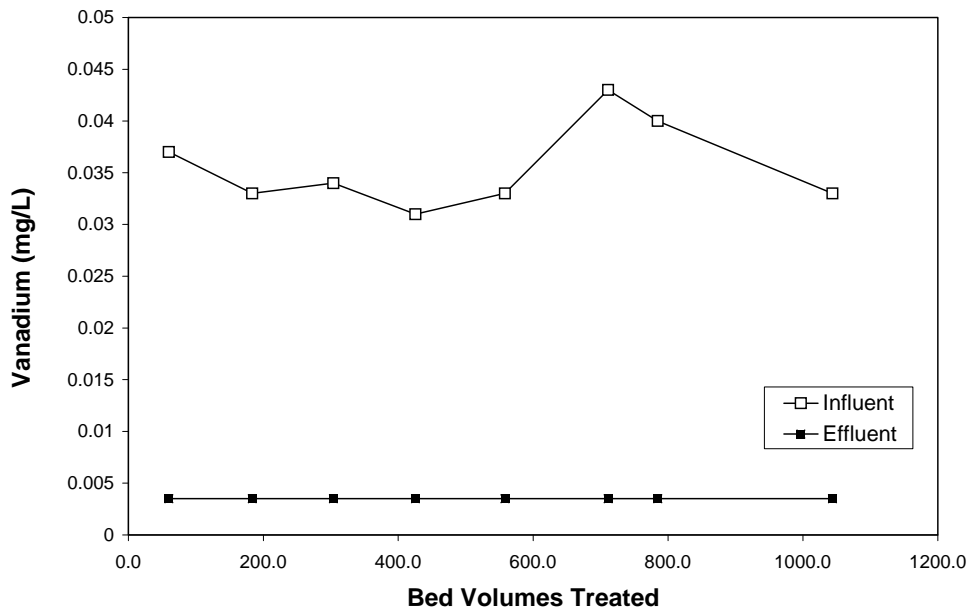
Based on the observed removal of arsenic and other constituents, water pH greater than 9.0 appears to negatively impact the arsenic removal capacity at Triple G. Strategies to improve adsorption performance at Triple G are discussed above.

### Residuals Characterization

For an adsorption treatment process, spent backwash water and spent media are the residuals which need to be characterized to ensure proper disposal. The adsorption media is backwashed after its installation to remove any fines. The media is also backwashed periodically (once every three to six months) if the head loss increases beyond the media specifications.



**Figure 4.4 Silica breakthrough profile for Adsorbsia media at Triple G ATF**



**Figure 4.5 Vanadium breakthrough for Adsorbisia media at Triple G ATF**

### *Spent Backwash Water*

At Triple G, media was backwashed after its installation in the adsorption vessel. A composite sample of spent backwash water was collected and analyzed for various water quality parameters, as shown in Table 4.2.

**Table 4.2**  
**Water quality characteristics of spent backwash water at Triple G**

Parameter	Units	Values
pH	S.U	6.1
Arsenic	mg/L	<0.008
TDS	mg/L	2,200
Alkalinity	mg/L as CaCO <sub>3</sub>	22
Phosphorous, Total	mg/L	<0.02
Silica as SiO <sub>2</sub>	mg/L	10
Fluoride	mg/L	0.31
Vanadium	mg/L	<0.02
Iron	mg/L	0.28

Arsenic was completely removed by the virgin media and, therefore, was below its detection limit in the spent backwash water. pH was also reduced by virgin media, as also shown in Figure 4.1. TDS at 2,200 mg/L increased by eight times compared to source water, probably due to release of acidic constituents responsible for pH reduction in the spent backwash water. A decrease in alkalinity in spent backwash water also verifies the presence of acidic constituents on the virgin media. Since there is no iron in the source water, the presence of iron in the spent backwash water may be attributed to the media. Based on the observed water constituents and their concentrations, disposal of spent backwash water appears not to violate any regulatory requirements. However, it may not be disposed of to a receiving stream or Water of the U.S., or recharged into an aquifer, depending on local or state regulations. Since the spent backwash water is not a hazardous waste, it may be discharged to an on-site sewer or transported to a wastewater treatment facility.

### ***Spent Adsorbisia GTO***

A representative sample of spent Adsorbisia GTO media was taken from the adsorption vessel and was analyzed for arsenic elution using TCLP. The results indicated that arsenic (method detection limit of 0.2 mg/L) did not leach from the media. In addition to arsenic, leaching of cadmium and selenium from the spent Adsorbisia GTO media was also analyzed, although these parameters were not analyzed in the source water. Both cadmium (method detection limit of 0.005 mg/L) and selenium (method detection limit of 0.2 mg/L) did not leach from the spent Adsorbisia media. Based on the results, the media would be eligible for disposal at a municipal landfill without resulting in additional costs associated with disposal of hazardous wastes.

### **Other Operational Observations**

A prefilter was installed upstream of the adsorption vessel to remove particulate matter that may increase head loss through the fixed bed media. The installed prefilter lasted for 125 days without replacement. Therefore, a prefilter can provide the necessary particulate removal at Triple G.

Pressure was monitored at the influent and effluent sides of the pressure vessel to evaluate pressure drop through the media. The influent pressure increased from 28 psi to approximately 40 psi in one week of operation. The effluent pressure drop mirrored the influent pressure, indicating that Adsorbisia GTO did not induce any headloss. Low head loss development may be attributed to low particulate matter, absence of iron and manganese, and relatively low hydraulic loading rate. The observation also indicates that the media may not require any additional backwashing and would not result in any additional operational costs.

### **CAMP VERDE WATER SYSTEM**

The Camp Verde ATF consisted of an adsorption treatment system using AsX media. The start-up of the Camp Verde ATF began on April 7, 2006, and reached an effluent arsenic level of 12 ppb in approximately two months. After installation, the media was backwashed to remove any fines and a composite spent backwash water sample was taken to evaluate its

characteristics. The Camp Verde ATF treated 1.6 million gallons of water resulting in 31,800 BVs at effluent arsenic level of 12 ppb. In contrast to the Triple G ATF, the Camp Verde ATF operated at a relatively constant flow rate. Demands were sufficient to maintain flow through the ATF.

The Camp Verde ATF was operated at a flow rate of 20 gpm for two weeks and treated approximately 6,900 BVs. The flow rate was increased to 25 gpm (a 25% increase in flow rate) due to an increase in water demand. The flow rate remained constant at 25 gpm until the media was exhausted. Similar to the Triple G ATF, temperature, pH and chlorine levels in the influent and effluent water were observed weekly. Samples for arsenic were taken on a weekly basis and shipped overnight to an analytical laboratory for testing. Samples for alkalinity, vanadium, phosphorus and fluoride are collected biweekly and shipped to the commercial laboratory for analysis. Samples for silica and total dissolved solids are collected once every four weeks. Table 4.3 summarizes the source water quality observed during the testing period. Arsenic concentration in Camp Verde water averaged 21 ppb, while pH averaged 7.3. TDS averaged 466 mg/L and total alkalinity averaged 367 mg/L, as CaCO<sub>3</sub> were somewhat higher than those in the Triple G source water.

**Table 4.3**  
**Influent water quality for Camp Verde ATF**

Parameter	Value	No. of samples
Arsenic (V), ppb	23	8
pH, Standard Units	7.3 (7.3 – 7.4)	11
Iron, mg/L	<0.01	1
Silica (SiO <sub>2</sub> ), mg/L	44	5
Manganese, mg/L	<0.002	1
Vanadium, mg/L	<0.007	1
Chlorine, mg/L	0.15	11
Temperature, °C	29	8
Total alkalinity, mg/L as CaCO <sub>3</sub>	367	4
Fluoride, mg/L	0.28	2
TDS, mg/L	466	2

A comparison of influent and effluent water pH levels at Camp Verde indicated that treatment with AsX media did not appear to impact treated water pH.

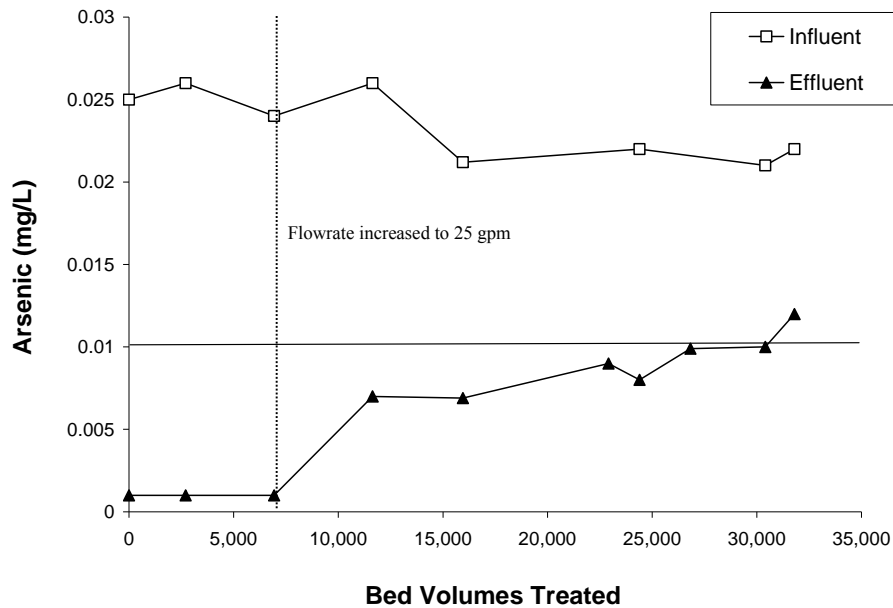
### **Arsenic Removal**

Figure 4.6 displays the arsenic breakthrough profile for AsX media at the Camp Verde system. The influent arsenic level ranged from 21 to 26 ppb. A sharp breakthrough was observed between 6,900 (14 days) and 11,600 BVs (21 days). The increase in effluent arsenic level was related to an increase in flowrate from 20 gpm to 25 gpm. Due to a decrease in influent arsenic concentration, the effluent arsenic concentration did not increase as rapidly, and reached an

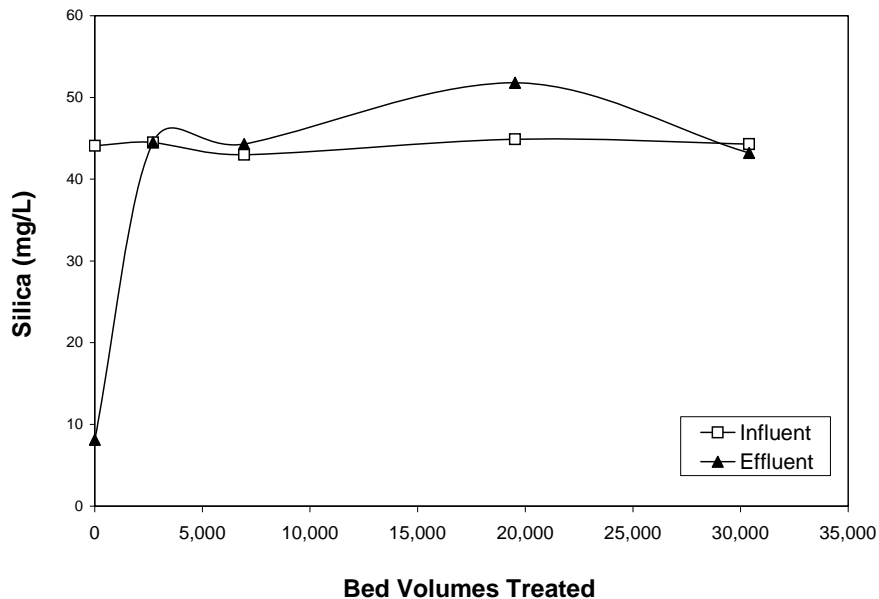
arsenic level of 10 ppb around 26,800 BVs (50 days). The operation of the ATF was stopped at approximately 31,800 BVs (64 days) and the media was removed and shipped for regeneration.

### Other Water Constituents

Similar to Triple G, the presence of other water constituents can impact arsenic adsorption at the Camp Verde system. Silica in the Camp Verde system source water ranged from 43 to 45 mg/L, and its breakthrough profile is shown in Figure 4.7. While silica is adsorbed by AsX, its adsorption capacity could not be determined, since the sample taken at 2,700 BVs showed that the media was saturated with silica. Therefore, the impact of silica on arsenic adsorption by AsX media cannot be conclusively stated. Due to limited data collected for vanadium and fluoride, it is difficult to assess their adsorption behavior.



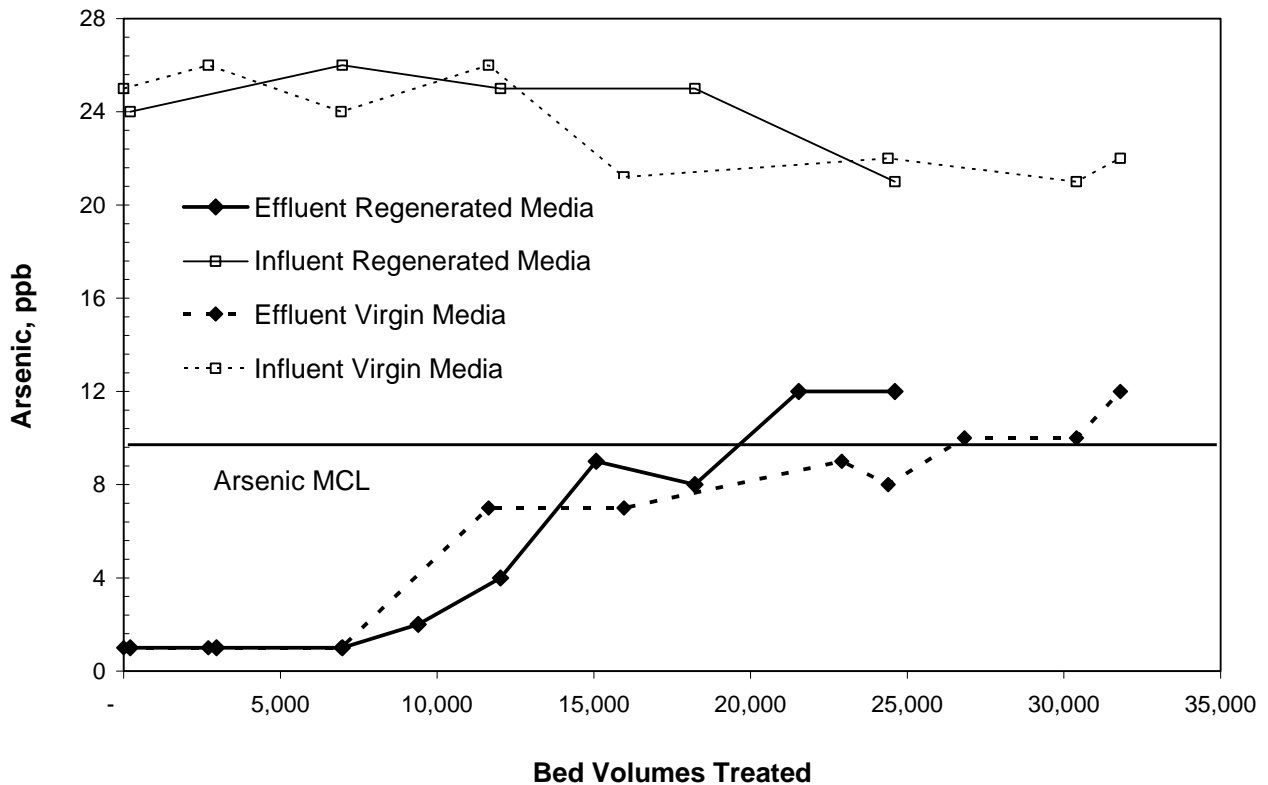
**Figure 4.6 Arsenic breakthrough profile for AsX media at Camp Verde ATF**



**Figure 4.7 Silica breakthrough for AsX media at Camp Verde ATF**

### **Comparison of Performance Between Virgin and Regenerated AsX Media**

Spent AsX media was removed from the adsorption vessel and shipped back to the manufacturer for regeneration. The media was regenerated by the manufacturer, as per NSF specifications, and shipped back to Camp Verde. The media was loaded into the contactor in the same manner as the virgin media (see Chapter 2). The regenerated media was backwashed to remove any fines prior to treating water. Figure 4.8 compares the arsenic breakthrough profiles for the regenerated and virgin media. The contactor with regenerated media was operated from 2/25/07 to 4/23/07, when an effluent arsenic level of 12 ppb was observed. The influent arsenic concentration during evaluation of regenerated media ranged from 21 to 26 ppb, with an average of 24.2 ppb. The influent arsenic concentration during the virgin media evaluation ranged from 21 to 26 ppb, with an average of 23.4 ppb. The arsenic breakthrough for the regenerated and virgin media occurred at approximately 6,900 BVs. Regenerated media showed more capacity for arsenic up to an effluent arsenic level of 7 ppb, however, beyond this level the virgin media showed more capacity for arsenic. The effluent arsenic levels of 10 ppb for the regenerated and virgin media were estimated at 19,900 and 26,800 BVs, respectively. At an effluent arsenic level of 10 ppb, regenerated media treated 26 percent less BVs when compared to virgin media. Besides differences in adsorption capacities, a comparison of the breakthrough curves also indicated different adsorption kinetics: virgin media showed a slower uptake of arsenic. Based on one regeneration of the AsX media, the media capacity and kinetics were impacted.



**Figure 4.8 Comparison of arsenic breakthrough profiles for virgin and regenerated AsX at CVWS**

Based on the observed data from Camp Verde, it appears that AsX media may not be cost effective as there was an arsenic adsorption capacity was reduced by 26% after one single regeneration. It should, however, be noted that loss of adsorption capacity may be site-specific.

### Residuals Characterization

Similar to Triple G ATF, spent backwash water and spent media were characterized to evaluate their proper disposal.

#### *Spent Backwash Water*

At the Camp Verde system, media was backwashed after its installation in the adsorption vessel. A composite sample of spent backwash water was collected and analyzed for various water quality parameters, as shown in Table 4.4.

Arsenic was completely removed by the virgin media, and therefore, was below its detection limit in the spent backwash water. An increase in pH was observed, while the alkalinity decreased in the spent backwash water. The data is likely anomalous. TDS in spent backwash

water compared well with the raw water. Removal of silica by AsX is also evidenced by its lower level (12 mg/L) in spent backwash water compared to the source water level (44 mg/L). Based on the observed water constituents and their concentration, disposal of spent backwash water appears not to violate any regulatory requirements. However, local and state regulations may preclude its discharge into a receiving stream or Water of the U.S. or recharge into an aquifer, depending on local or state regulations. Since the spent backwash water is not a hazardous waste, it may be discharged to an on-site sewer or transported to a wastewater treatment facility.

**Table 4.4**  
**Spent backwash water quality for the Camp Verde system**

Parameter	Units	Values
pH	S.U	7.8
Arsenic	mg/L	<0.002
TDS	mg/L	483
Alkalinity	mg/L as CaCO <sub>3</sub>	191
Phosphorous, Total	mg/L	<0.02
Silica as SiO <sub>2</sub>	mg/L	12
Fluoride	mg/L	<0.1
Vanadium	mg/L	<0.02
Iron	mg/L	0.83

### ***Spent AsX Media***

A representative sample of spent AsX media was taken from the adsorption vessel and was analyzed for arsenic elution using TCLP. The results indicated that arsenic (method detection limit of 0.2 mg/L) did not leach from the media. In addition to arsenic, leaching of cadmium and selenium from the spent AsX media was also analyzed, although these parameters were not analyzed in the source water. Both cadmium (method detection limit of 0.005 mg/L) and selenium (method detection limit of 0.2 mg/L) did not leach from the spent AsX media. Based on the results, the media would be eligible for disposal at a municipal landfill without additional costs associated with disposal of hazardous wastes.

### **Other Operational Observations**

A prefilter was installed upstream of the adsorption vessel to remove particulate matter that may increase head loss through the fixed bed media. The installed prefilter lasted for 64 days without replacement. Therefore, a prefilter can provide the necessary particulate removal at the Camp Verde system.

Pressure was monitored at the influent and effluent sides of the pressure vessel to evaluate pressure drop through the media. The influent and effluent pressure values were recorded at 60 psi, indicating that the media had very low head loss development during the testing period. The observation also indicates that the media may not require any additional backwashing and would not result in any additional operational costs.

## **OPERATIONAL CONSIDERATIONS**

Very small public water systems do not have adequate resources for operation of complex treatment systems. Both ATFs operated without any major problems. At both ATFs, an operator observed the proper operations of each ATF and took required samples. It is estimated that an average of two to four hours per week would be adequate for normal operation of these ATFs. Backwashing of Adsorbisia GTO required 16 hours, which can be a significant effort for a very small system. The estimated level of effort would include recording logs for ATFs, taking samples on a monthly basis and maintenance related issues such as the replacement of prefilters. For media replacement and its disposal, an additional eight to 12 hours were used. Both utilities continue to use the systems installed during this demonstration as their permanent arsenic systems. They are bidding media supply contracts competitively after the media exhausted. For both ATFs, backwashing was not required, except for one associated with initial media installation. For a full-scale operation, it is recommended that either two adsorption vessels or a finished water storage tank be utilized during periods of media changeout. In this manner, an uninterrupted supply of water can be assured. Provision of an additional adsorption vessel also provides redundancy and reliable operations and is preferred.

For compliance purposes, additional effluent samples are recommended. In this manner, the effluent arsenic level may be averaged along the breakthrough profile, and the media may not have to be replaced at an effluent arsenic level of 10 ppb. If an additional adsorption vessel is available, staggered parallel operation would also result in reduced effluent arsenic levels and potentially lower operational costs.

Based on the operation of two ATFs at very small public water systems, adsorption technology without pH adjustment appears to be a preferred choice. Economics and site-specific issues must be considered prior to the selection of a final arsenic treatment technology.



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## ABBREVIATIONS

ADEQ	Arizona Department of Environmental Quality
AsX	ArsenX <sup>np</sup>
ATF	arsenic treatment facility
AWWA	American Water Works Association
BV	bed volume
COP	City of Phoenix
CVWS	Camp Verde Water System
CWS	community water system
EBCT	empty bed contact time
Fe-AA	iron-based activated alumina
GIM	granular iron media
gpm	gallons per minute
IX	ion exchange
L/min	liters per minute
MCESD	Maricopa County Environmental Services Department
MCL	maximum contaminant level
MGD	million gallons per day
mg/L	milligram per liter
NCS	Narasimhan Consulting Services, Inc.
NSF	NSF International
NTNCWS	non-transient non-community water system
NTU	nephelometric turbidity units
O&M	operations and maintenance
ppb	parts per billion
POU	point-of-use
psi	pounds per square inch
PVC	poly vinyl chloride
PWS	public water system
RAA	running annual average
SNL	Sandia National Laboratories

TCLP	toxicity containment leachate procedure
TDS	total dissolved solids
USEPA	United States Environmental Protection Agency