

**TECHNOLOGY SELECTION AND  
SYSTEM DESIGN  
U.S. EPA ARSENIC REMOVAL  
TECHNOLOGY DEMONSTRATION  
PROGRAM ROUND 1**

by

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## ABSTRACT

On January 18, 2001, the U.S. Environmental Protection Agency (EPA) finalized the maximum contaminant level (MCL) for arsenic at 0.01 mg/L. EPA subsequently revised the rule text to express the MCL as 0.010 mg/L (10 µg/L). The final rule requires all community and non-transient, non-community water systems to comply with the new standard by February 2006. In October 2001, EPA announced an initiative for additional research and development of cost-effective technologies to help small community water systems (<10,000 customers) meet the new arsenic standard, and to provide technical assistance to operators of small systems in order to reduce compliance costs.

As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, long-term, on-site demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems in order to evaluate the efficiency and effectiveness of arsenic removal systems at meeting the new arsenic MCL. For the Round 1 demonstration study, the selected arsenic treatment technologies include nine adsorptive media systems, one ion exchange system, one coagulation /filtration system, and one process modification. The adsorptive media systems use four different adsorptive media, including three iron-based media (i.e., ADI's G2, Severn Trent and AdEdge's E33, and USFilter's GFH), and one iron-modified activated alumina media (i.e., Kinetico's AAFS50, a product of Alcan). The flowrate of these systems ranges from 37 to 640 gallons per minute (gpm).

This report provides the source water quality characteristics at each of the 12 demonstration sites and the general rationale used to select the technologies for demonstration at each site. Information on the design and operation of each treatment system also is presented. The selection of the technologies for demonstration at each location was a cooperative decision made by the water system, state, and EPA. Many factors were considered in the selection process, including water quality, residual production and disposal, complexity of system operation, and costs. The selection of the adsorptive media and pretreatment methods depended on a number of factors that affect the system performance, including arsenic concentration and speciation, pH, and the presence of competing anions, as well as media-specific characteristics such as costs, media life, and empty-bed contact time (EBCT) requirements.

# CONTENTS

ABSTRACT.....	iv
FIGURES.....	vi
TABLES.....	vi
ABBREVIATIONS AND ACRONYMS.....	vii
ACKNOWLEDGEMENTS.....	viii
1.0 INTRODUCTION.....	1
1.1 Purpose and Scope.....	1
1.2 Background.....	1
1.3 Occurrence of Arsenic and Source Water Quality.....	2
2.0 TECHNOLOGY SELECTION.....	6
2.1 Technology Selection Factors.....	6
2.1.1 Water Quality.....	6
2.1.2 Residuals Generation and Disposal.....	7
2.1.3 Complexity of System Operation.....	8
2.1.4 Cost.....	9
2.1.5 Other Factors.....	9
2.2 Adsorptive Media Technologies.....	9
2.2.1 Technology Description.....	9
2.2.2 Adsorptive Media Selection Factors.....	12
2.2.2.1 Arsenic Concentration and Speciation.....	12
2.2.2.2 pH Value.....	12
2.2.2.3 Competing Anions.....	13
2.2.2.4 Media-Specific Characteristics.....	13
2.2.2.5 Media Costs.....	13
2.2.2.6 Regenerability.....	14
2.3 Ion Exchange Technology.....	14
2.4 Coagulation/Filtration and Iron Removal Technologies.....	15
2.4.1 Macrolite® Pressure Filtration.....	15
2.4.2 System Modification.....	16
3.0 Technology Design and Operation.....	17
3.1 Adsorptive Media.....	17
3.1.1 Bow, NH (G2 Media).....	17
3.1.1.1 Treatment System Description.....	17
3.1.1.2 Treatment System Operation.....	18
3.1.2 Desert Sands MDWCA, NM (E33 Media).....	18
3.1.2.1 Treatment System Description.....	18
3.1.2.2 Treatment System Operation.....	19
3.1.3 Brown City, MI (E33 Media).....	19
3.1.3.1 Treatment System Description.....	19
3.1.3.2 Treatment System Operation.....	19
3.1.4 Queen Anne’s County, MD (E33 Media).....	19
3.1.4.1 Treatment System Description.....	20
3.1.4.2 Treatment System Operation.....	20
3.1.5 Nambe Pueblo, NM (E33 Media).....	20
3.1.5.1 Treatment System Description.....	20
3.1.5.2 Treatment System Operation.....	20

3.1.6	Rimrock, AZ (E33 Media).....	21
3.1.6.1	Treatment System Description .....	21
3.1.6.2	Treatment System Operation .....	21
3.1.7	Rollinsford, NH (E33) .....	21
3.1.7.1	Treatment System Description .....	22
3.1.7.2	Treatment System Operation .....	22
3.1.8	STMGID, NV (GFH Media).....	22
3.1.8.1	Treatment System Description .....	22
3.1.8.2	Treatment System Operation .....	23
3.1.9	Valley Vista, AZ (AAFS50 Media).....	23
3.1.9.1	Treatment System Description .....	23
3.1.9.2	Treatment System Operation .....	23
3.2	Ion Exchange .....	23
3.2.1	Fruitland, ID (Purolite A-520E Resin).....	23
3.2.1.1	Treatment System Description .....	24
3.2.1.2	Treatment System Operation .....	24
3.3	Coagulation/Filtration.....	24
3.3.1	Climax, MN .....	24
3.3.1.1	Treatment System Description .....	24
3.3.1.2	Treatment System Operation .....	25
3.3.2	Lidgerwood, ND .....	25
3.3.2.1	Treatment System Description .....	25
3.3.2.2	Treatment System Operation .....	26
4.0	REFERENCES .....	27
Appendix A:	Photographs of Arsenic Removal Treatment Systems.....	A-1

## FIGURES

Figure 1-1.	Locations of EPA Round 1 Arsenic Removal Technology Demonstration Sites .....	3
Figure 2-1.	Arsenic Treatment Selection Guide as a Function of Initial Arsenic and Iron Content of Water .....	7

## TABLES

Table 1-1.	General Information of 12 Arsenic Removal Technology Demonstration Sites .....	2
Table 1-2.	Summary of Source Water Quality Data for the 12 Demonstration Sites .....	5
Table 2-1.	Major Decision Factors Considered in the Technology Selection Process .....	6
Table 2-2.	Summary of Residuals Generation and Disposal .....	8
Table 2-3.	Physical and Chemical Properties and Costs of the Adsorptive Media.....	10
Table 2-4.	Water Quality Impact on Pretreatment Requirements at E33 Demonstration Sites .....	11
Table 2-5.	Relative Effectiveness of Various Oxidants for Fe(II) and As(III) Oxidation .....	12
Table 2-6.	Physical and Chemical Properties of Purolite A-520E Resin.....	14
Table 2-7.	Properties of 40/60 Mesh Macrolite® Media .....	16
Table 3-1.	Summary of the Design and Components of the Adsorptive Media Systems.....	17

## ABBREVIATIONS AND ACRONYMS

AA	activated alumina
AM	adsorptive media (process)
APU	arsenic-package-unit
AWC	Arizona Water Company
C/F	coagulation/filtration (process)
CO <sub>2</sub>	carbon dioxide
CS	carbon steel
EBCT	empty bed contact time
EPA	United States Environmental Protection Agency
FRP	fiberglass reinforced plastic
GFH	granular ferric hydroxide
gpd	gallons per day
gpm	gallons per minute
HCl	hydrochloric acid
H <sub>2</sub> SO <sub>4</sub>	sulfuric acid
HDPE	high-density polyethylene
IX	ion exchange (process)
KMnO <sub>4</sub>	potassium permanganate
MCL	maximum contaminant level
MDWCA	Mutual Domestic Water Consumers Association
MnO <sub>2</sub>	manganese dioxide
N/A	not available
ORD	Office of Research and Development
PLC	programmable logic controller
PVC	polyvinyl chloride
SDWA	Safe Drinking Water Act
SM	system modification
SS	stainless steel
STMGID	South Truckee Meadows General Improvement District
TDS	total dissolved solids
TO	Task Order
ZPC	zero point charge

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## 1.0 INTRODUCTION

### 1.1 Purpose and Scope

Battelle, under a contract with the United States Environmental Protection Agency (EPA), is conducting full-scale demonstration studies on the removal of arsenic from drinking water supplies at 12 water treatment facilities throughout the United States. These demonstration studies evaluate the efficiency and effectiveness of the systems in meeting the new arsenic maximum contaminant level (MCL) of 0.010 mg/L (10 µg/L).

This report reviews the source water quality characteristics at each of the 12 demonstration sites and presents the rationale behind the selection of an arsenic removal technology for each site given its unique source water quality. The report also summarizes the design and operation of each of the technologies selected for the demonstration sites. The types of arsenic removal technologies demonstrated in this project include nine adsorptive media systems, one anion exchange system, one coagulation/filtration system, and one system modification to a MnO<sub>2</sub>-coated anthrasand filtration system. Other drinking water treatment technologies are available for arsenic removal, such as reverse osmosis and nanofiltration; however, the focus of this report is the technologies selected for the 12 full-scale demonstration studies.

### 1.2 Background

The Safe Drinking Water Act (SDWA) mandates that EPA identify and regulate drinking water contaminants that may have adverse human health effects and that are known or anticipated to occur in public water supply systems. In 1975 under the SDWA, EPA established an MCL for arsenic at 0.05 mg/L. The SDWA was amended in 1996 and required that EPA develop an arsenic research strategy and publish a proposal to revise the arsenic MCL by January 2000. On January 18, 2001, EPA finalized the arsenic MCL at 0.01 mg/L (EPA, 2001a). In order to clarify the implementation of the original rule, EPA revised the rule text on March 25, 2003 to express the MCL as 0.010 mg/L (10 µg/L) (EPA, 2003a). The final rule requires all community and non-transient, non-community water systems to comply with the new standard by February 2006.

In October 2001, EPA announced an initiative for additional research and development of cost-effective technologies to help small community water systems (<10,000 customers) meet the new arsenic standard, and to provide technical assistance to operators of small systems in order to reduce compliance costs. As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, on-site demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems. Shortly thereafter, an announcement was published in the *Federal Register* requesting water utilities interested in participating in the EPA-sponsored demonstration program to provide information on their water systems.

In June 2002, EPA selected 17 sites from a list of 115 sites to be the host sites for the demonstration studies. The selection of the sites was based on a number of factors; the three most significant factors were geographical location, arsenic concentration of the source water, and size of the system.

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the potential 17 host sites. The objective of this solicitation was to select treatment technologies for the demonstration project, which evaluates the efficiency and effectiveness of drinking water treatment technologies to meet the new MCL under varying source water

quality conditions. For the purposes of this solicitation, “treatment technologies” included process modifications and engineering approaches as well as new or add-on treatment technologies.

EPA received 70 technical proposals for the 17 host sites, with each site receiving from one to six proposals. In April 2003, an independent technical review panel reviewed the proposals and provided its recommendations to EPA on the technologies that it determined were acceptable for the demonstration at each site. Because of funding limitation and other technical reasons, only 12 of the 17 sites were selected for the demonstration project. A listing of the 12 sites showing the location (sorted geographically from the Northeast to the Southwest), arsenic concentration of the source water, and size of the water system to be demonstrated is presented in Table 1-1.

**Table 1-1. General Information of 12 Arsenic Removal Technology Demonstration Sites**

State	Demonstration Site	Technology	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH
NH	Bow	AM (G2)	ADI	70 <sup>(a)</sup>	39	<25	7.7
NH	Rollinsford	AM (E33)	AdEdge	100	36 <sup>(b)</sup>	46	8.2
MD	Queen Anne’s County	AM (E33)	Severn Trent	300	19 <sup>(b)</sup>	270 <sup>(c)</sup>	7.3
MI	Brown City	AM (E33)	Severn Trent	640	14 <sup>(b)</sup>	127 <sup>(c)</sup>	7.3
MN	Climax	C/F	Kinetico	140	39 <sup>(b)</sup>	546 <sup>(c)</sup>	7.4
ND	Lidgerwood	SM	Kinetico	250	146 <sup>(b)</sup>	1,325 <sup>(c)</sup>	7.2
NM	Desert Sands MDWCA	AM (E33)	Severn Trent	320	23 <sup>(b)</sup>	39	7.7
NM	Nambe Pueblo	AM (E33)	AdEdge	145	33	<25	8.5
AZ	Rimrock	AM (E33)	AdEdge	90 <sup>(a)</sup>	50	170	7.1
AZ	Valley Vista	AM (AAFS50)	Kinetico	37	41	<25	7.8
ID	Fruitland	IX	Kinetico	250	44	<25	7.4
NV	STMGID	AM (GFH)	USFilter	350	39	<25	7.4

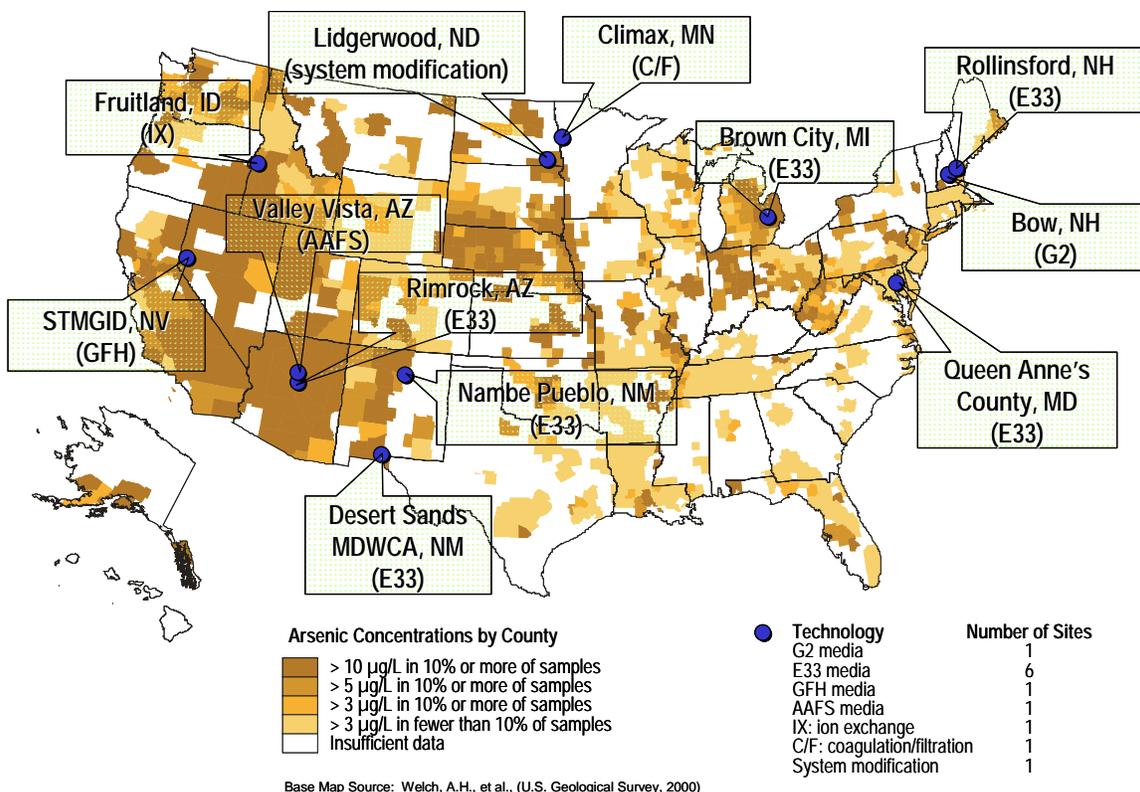
AM = adsorptive media process; C/F = coagulation/filtration process; IX = ion exchange process; SM = system modification; MDWCA = Mutual Domestic Water Consumers Association; STMGID = South Truckee Meadows General Improvement District

- (a) Due to system reconfiguration from parallel to series operation, the design flowrate is reduced by 50%.
- (b) Arsenic exists mostly as As(III).
- (c) Iron exists mostly as soluble Fe(II).

Using the information provided by the review panel, EPA in cooperation with the host sites and the drinking water programs of the respective states selected one technical proposal for each site. The technologies selected for evaluation include nine adsorptive media systems, one anion exchange system, one coagulation/filtration system, and one process modification with iron addition. The nine adsorptive media systems use four different media products, including ADI’s G2, Severn Trent’s and AdEdge’s E33, USFilter’s granular ferric hydroxide (GFH), and Kinetico’s AAFS50 (a product of Alcan). Table 1-1 summarizes the locations, technologies, vendors, and key source water quality parameters (including arsenic, iron, and pH) of the 12 demonstration sites. The locations and technologies also are shown in Figure 1-1.

### 1.3 Occurrence of Arsenic and Source Water Quality

Arsenic is a common, naturally-occurring drinking water contaminant that originates from the erosion and dissolution of arsenic-bearing rocks and soils into groundwater. As shown in Figure 1-1, the levels of arsenic in groundwater vary widely across the United States, with concentrations detected more frequently above the new MCL of 10 µg/L in the southwest and far west. In addition, certain parts



**Figure 1-1. Locations of EPA Round 1 Arsenic Removal Technology Demonstration Sites**

of the Midwest, Great Lakes, Interior Plains near North and South Dakota, and East to Northeast along the seacoast show pockets of elevated arsenic concentrations. Arsenic concentrations in groundwater appear to be generally lower in the Southeast with very infrequent detections above 10 µg/L, but less data is available in this region than in others (Welch et al., 2000).

Arsenic occurs in natural waters in both inorganic and organic forms. However, inorganic forms such as arsenite [As(III)] and arsenate [As(V)] are predominant in natural waters. The valence and species of inorganic arsenic are dependent on the oxidation-reduction condition and pH of the water. As a general rule of thumb, As(III), the reduced trivalent form, is found in groundwater (assuming anaerobic conditions); and As(V), the oxidized pentavalent form, is found in surface water (assuming aerobic conditions). This rule, however, does not always hold true for groundwater. Some groundwaters have been found to have only As(III), others with only As(V), and still others with the combination of both As(III) and As(V). Arsenite exists in five forms in aqueous solution, depending on pH:  $H_4AsO_3^+$ ,  $H_3AsO_3$ ,  $H_2AsO_3^-$ ,  $HAsO_3^{2-}$  and  $AsO_3^{3-}$ . Arsenate exists in four forms in aqueous solution, also depending on pH:  $H_3AsO_4$ ,  $H_2AsO_4^-$ ,  $HAsO_4^{2-}$ , and  $AsO_4^{3-}$  (EPA, 2003b).

Source water quality plays an important role in the technology selection and the design and operation of the treatment system. The source water quality at each of the 12 demonstration sites was characterized based on historic data and source water samples collected and analyzed by Battelle in 2003. The historic sampling results were obtained from individual facilities and respective state drinking water officials. The arsenic speciation samples were collected using an anion exchange resin method modified from Edwards (1998) by Battelle (EPA, 2000). Table 1-2 provides the range of several water quality parameters at each site and the one-time arsenic speciation sampling results.

Total arsenic concentrations at the 12 demonstration sites range from 14.2 to 146 µg/L. At six of 12 sites, As(III) is the most prevalent form of arsenic in groundwater with no distinct pattern noted by geographic region. Three sites (Lidgerwood, ND, Climax, MN, and Rollinsford, NH) have manganese levels above the secondary MCL of 50 µg/L. Lidgerwood, ND and Climax, MN also have consistently higher iron levels in groundwater above the secondary MCL of 300 µg/L (i.e., with a maximum total iron level of 1,620 µg/L and 850 µg/L, respectively). At both sites, iron is present predominantly in the Fe(II) soluble form. In general, iron levels are highest in the Great Lakes Region including Michigan and Minnesota, and Interior Plains including North Dakota. Iron levels are relatively lower in the Northeast and Southwest.

Because arsenic readily adsorbs onto iron, the concentration of iron in source water is one of the main factors considered in the arsenic removal technology selection process. Given various regional water quality parameters, therefore, the presence of iron plays a prominent role in the technology selection and the treatability of a given water source. The elevated iron levels in the Interior Plains of North Dakota and northwestern Minnesota also are associated with very hard water (hardness from 228 to 513 mg/L) and elevated manganese and sulfate concentrations. However, the high iron levels in Michigan are associated with softer water (hardness at 83.2 mg/L) and relatively lower levels of manganese and sulfate. Soft water with hardness of less than 102 mg/L is present in the Northeast to East (New Hampshire and Maryland) and southwest (New Mexico and Nevada). Hard water is noted at both sites in Arizona. Typical ranges for SiO<sub>2</sub> in the United States are reported at 10 to 30 mg/L (Freeze and Cherry, 1979), so only the STMGID, NV and Fruitland, ID sites have elevated SiO<sub>2</sub> concentrations. Phosphate is less than 0.1 mg/L at all 12 sites. Nitrate is detected above the 10-mg/L MCL only at the Fruitland, ID site, and antimony was detected above the 0.006 mg/L-MCL only at the STMGID, NV site. The pH values of the source waters range from 7.1 to 8.5, and four of 12 sites have relatively elevated pH levels at or above 7.7 and may require pH adjustment before treatment (Bow, NH; Rollinsford, NH; Nambe Pueblo, NM; and Valley Vista, AZ).

**Table 1-2. Summary of Source Water Quality Data for the 12 Demonstration Sites**

State	Facility	Technology	Total As	Soluble As	Particulate As	As(III)	As(V)	Total Fe	Soluble Fe	Total Mn	Soluble Mn	Sulfate	Orthophosphate	Silica (as SiO <sub>2</sub> )	Alkalinity	Hardness	pH
			µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg <sup>(a)</sup>	mg <sup>(a)</sup>
NH	Bow	AM (G2)	32.0-47.0	44.1	<0.1	0.5	43.6	<25-60	<25	2.1-25.0	1.5	12.0-15.5	<0.10	19.7	54	92.7	7.7
NH	Rollinsford	AM (E33)	33.8-55.9	33.9	2.3	20.1	13.9	46-206	<30	56.7-100	68.6	29.0-40.5	<0.10	13.1-14.3	171	50.9	8.2
MD	Queen Anne's County	AM (E33)	17.0-19.0	18.7	0.1	18.4	0.3	91-300	254	0.4-8.0	1.4	4.2-5.8	<0.10	13.3-14.5	168	102	7.3
MI	Brown City	AM (E33)	14.2-31.0	12.0	2.2	11.2	0.8	127-200	118	13.0-18.7	15.0	74.0-128	<0.10	7.4-8.1	235	83.2	7.3
MN	Climax	C/F	31.0-41.0	34.6	4.2	34.8	<0.1	546-850	540	128-170	130	100-120	<0.10	27.3-29.9	304	228	7.4
ND	Lidgerwood	SM	108-146	126	20.3	121	5.3	1,310-1,620	1,316	544-675	664	344-390	<0.10	27.8-29.4	344	513	7.2
NM	Desert Sands MDWCA	AM (E33)	17.0-22.7	22.3	0.4	21.6	0.7	39-73	<30	8.9-10.0	9.0	158-190	<0.10	34.6-35.1	188	84.0	7.7
NM	Nambe Pueblo	AM (E33)	29.0-33.2	31.4	1.8	0.2	31.2	<30-138	<30	1.3-22.9	1.3	<10-28.2	<0.10	14.1-15.1	168	5.4	8.5
AZ	Rimrock	AM (E33)	50.0-63.6	64.8	<0.1	<0.1	64.8	36-170	<25	<0.4-7.5	8.1	9.5-13.0	<0.10	24.8-27.8	378	335	7.1
AZ	Valley Vista	AM (AAFS50)	39.0-41.0	38.1	2.8	0.3	37.8	<30	<30	<0.1-50	<0.1	8.4-9.0	<0.10	18.5-21.4	154	172	7.8
ID	Fruitland <sup>(b)</sup>	IX	37.0-44.0	40.1	3.4	0.8	39.3	<30-744	<30	1.6-50.0	0.5	57.3-64.0	<0.10	54.3-57.8	381	233	7.4
NV	STMGID <sup>(c)</sup>	AM (GFH)	45.0-87.9	89.4	<0.1	0.3	89.1	<30	<30	0.1-3.0	<0.1	8.0-28.0	<0.10	52.5-68.6	100	17.1	7.4

(a) As CaCO<sub>3</sub>.

(b) Nitrate was detected at 13.9 mg/L in Fruitland, ID.

(c) Antimony was detected at 15.8 µg/L in STMGID, NV.

Data range reported for total As, total Fe, total Mn, SO<sub>4</sub>, and SiO<sub>2</sub> only.

## 2.0 TECHNOLOGY SELECTION

Of the 70 technology proposals submitted to EPA by 19 different vendors for consideration for demonstration, 41 proposals (10 vendors) received either a recommended or highly recommended rating by the EPA peer review panel. The technologies selected for the 12 demonstration sites consist of four types of technologies: adsorptive media, ion exchange, coagulation/filtration, and a system modification using iron addition.

### 2.1 Technology Selection Factors

The selection of the technologies to be demonstrated at the 12 locations was a cooperative decision made by the water system, state, and EPA. Many factors were considered in the selection process with the primary considerations listed in Table 2-1.

**Table 2-1. Major Decision Factors Considered in the Technology Selection Process**

Decision Factor	Issues
Water Quality	Impact of water quality on performance and pretreatment requirements
Residuals Generation	Quantity and characteristics
Residuals Disposal	Available disposal methods; state requirements
Complexity of System Operation	Operational complexity or level of operator oversight
Cost	Capital and operational costs (excluding residual disposal)
Other	Adaptability for expansion or new technology conversion

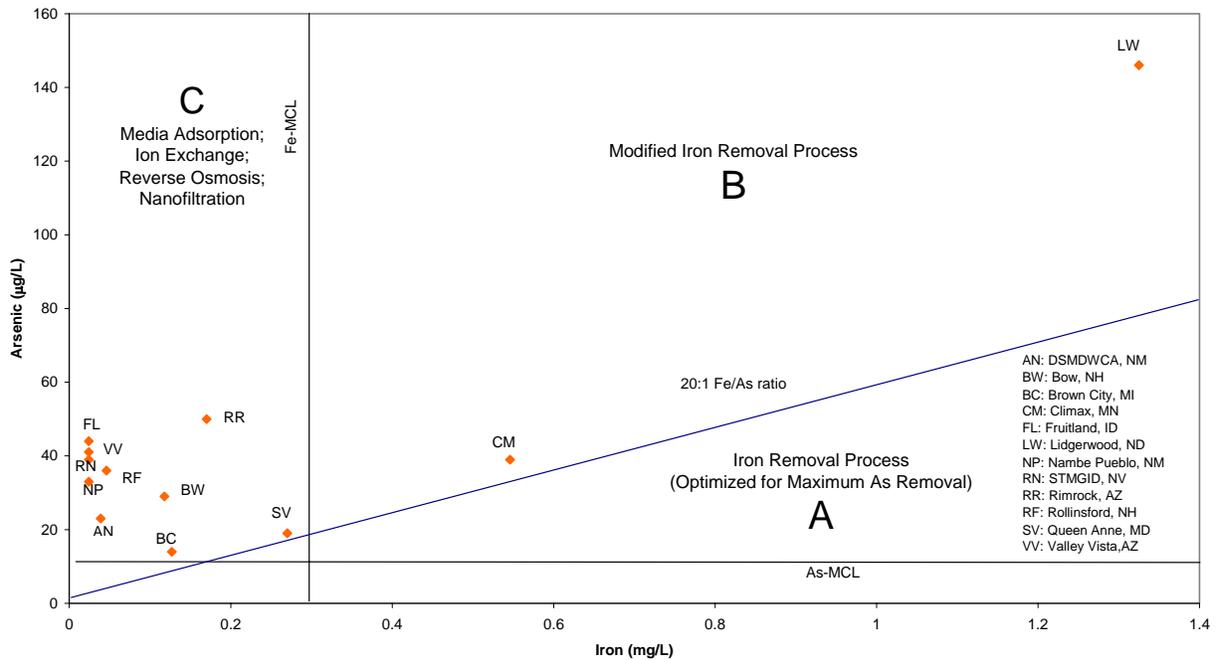
**2.1.1 Water Quality.** A number of drinking water treatment technologies are available to reduce arsenic concentrations in source water to below the new MCL of 10 µg/L, including adsorption, ion exchange, membrane processes such as reverse osmosis and nanofiltration, and coagulation/filtration-related processes. Many of the most effective arsenic removal processes available are iron-based treatment technologies such as chemical coagulation/filtration with iron salts, and adsorptive media with iron-based products. These processes are particularly effective at removing arsenic from aqueous systems because iron surfaces have a strong affinity for adsorbing arsenic.

Because of the unique role that iron plays in facilitating arsenic removal, the level of iron in the source water is a major consideration in the selection of an optimal treatment technology. Figure 2-1 illustrates how technology selection was strongly influenced by the initial arsenic and iron concentrations in source water. This figure breaks down technology selection into the following three categories:

- **High Iron Levels.** Iron removal processes can be used to facilitate arsenic removal from drinking water supplies via adsorption and co-precipitation. Iron removal treatment is best suited to source water with relatively high natural iron levels at an iron to arsenic ratio of 20:1 or greater (EPA, 2001b and 2002). Therefore, source water with this ratio would be a potential candidate for arsenic removal by iron removal (refer to Region A in Figure 2-1). Converting this ratio into a removal guideline indicates that 1 mg/L iron should be capable of removing up to 50 µg/L arsenic. This removal capacity is a “rule of thumb” and will only be achieved under optimum adsorptive and process operational conditions.

- **Moderate Iron Levels.** If the iron to arsenic ratio in source water is less than 20:1, then a modified treatment process such as coagulation/filtration with the addition of an iron salt may be selected (refer to Region B in Figure 2-1).
- **Low Iron Levels.** Technologies such as adsorptive media, ion exchange, and membrane processes are best suited to sites with relatively low iron levels in their source water at less than 300 µg/L, the secondary MCL for iron (refer to Region C in Figure 2-1). Above this level, taste odor, and color problems can occur in treated water, along with an increased potential for fouling of system components with iron particulates. In addition, ion exchange resins cannot effectively remove Fe(III)-arsenic complexes (EPA, 2000).

As shown in Figure 2-1, 10 of the 12 sites for this demonstration project are considered low-level iron sites and only two of the 12 sites have sufficiently high iron levels to be considered for a modified iron removal process.



**Figure 2-1. Arsenic Treatment Selection Guide as a Function of Initial Arsenic and Iron Content of Water (Sorg, 2002)**

**2.1.2 Residuals Generation and Disposal.** All arsenic removal technologies produce some residuals that must be disposed of. Table 2-2 summarizes the type and quantity of residuals that will be generated from each of the 12 demonstration sites, as well as disposal methods. The residuals may be either a solid material, such as a spent adsorptive media; or a liquid waste, such as backwash water and/or spent brine from an adsorptive media, an iron removal, or an ion exchange process. The quantity and characteristics of the residuals often affect technology selection, especially in western states such as Arizona and New Mexico, where water conservation is a key issue. The quantity of solid residuals generated is primarily a function of media life. Spent media most likely will pass the Toxicity Characteristic Leaching Procedure (TCLP) test for disposal at sanitary landfills. The quantity of liquid waste generated is a function of backwash/regeneration flowrate and frequency. In general, adsorptive

media systems are backwashed once to twice per month, producing from 10 to 15 bed volumes of wastewater with each backwashing. Other technologies such as coagulation/filtration may require more frequent backwashing to prevent excess pressure buildup or filter leakage and are typically backwashed on a daily to weekly schedule. The characteristics of the backwash water often are determined by analytes such as turbidity, total dissolved solids (TDS), arsenic, iron, and manganese. Availability or non-availability of an on-site method, such as a leach field, a holding pond, or a sanitary sewer, was important in selecting the best treatment option for a demonstration site. Off-site disposal also might be an option, such as for the Queen Anne’s County, MD site. Recycling of backwash water may be required at some locations, especially if the treatment system does not have access to an on-site disposal option or if reclamation of backwash water is economically attractive. State disposal regulations always are a major concern.

**Table 2-2. Summary of Residuals Generation and Disposal**

<b>Technology</b>	<b>Site</b>	<b>Design Flowrate (gpm)</b>	<b>Spent Media per Changeout (ft<sup>3</sup>)</b>	<b>Backwash Water (gal) (Bed Volume)<sup>(a)</sup></b>	<b>Backwash Water Disposal</b>
AM (G2)	Bow, NH	70	170	2,260 – 3,390 (2 – 3 BV)	Surface leach field
AM (E33)	Desert Sands MDWCA, NM	320	160	12,000 – 18,000 (10 – 15 BV)	Holding pond
AM (E33)	Brown City, MI	640	320	24,000 – 36,000 (10 – 15 BV)	Ditch
AM (E33)	Queen Anne’s County, MD	300	160	12,000 – 18,000 (10 – 15 BV)	Off-site disposal
AM (E33)	Nambe Pueblo, NM	145	81	6,060 – 9,090 (10 – 15 BV)	Holding pond
AM (E33)	Rimrock, AZ	90	54	4,040 – 6,060 (10 – 15 BV)	Recycling of liquid fraction
AM (E33)	Rollinsford, NH	100	54	4,040 – 6,060 (10 – 15 BV)	Subsurface septic system
AM (GFH)	STMGID, NV	350	240	12,800 – 17,100 (7 – 10 BV)	Sanitary sewer
AM (AAFS50)	Valley Vista, AZ	37	44	1,100 – 1,440 (3 – 4 BV)	Recycling of liquid fraction
C/F	Climax, MN	140	N/A	1,650 – 1,980	Sanitary sewer
IX	Fruitland, ID	250	N/A	7,000 – 10,500 <sup>(b)</sup>	Sanitary sewer
SM	Lidgerwood, ND	250	N/A	9,600	Recycling of liquid fraction

(a) Applicable to adsorptive media system only.

(b) Including 1,500 gallons of spent brine.

BV = bed volume

**2.1.3 Complexity of System Operation.** For small systems, complexity of system operation is always a concern. Complex systems often require more experienced and skilled operators to operate the systems. During technology selection, questions often raised by system operators include the frequency of backwashing, chemical addition requirements (pH adjustment, chlorine addition, etc.), and the frequency of media replacement. The level of automation available for system operation and data collection can significantly decrease the complexity, and thus can save time.

**2.1.4 Cost.** With limited resources available, operational cost is always an issue for most small systems, and thus is a major consideration in technology selection. For this demonstration study, the capital costs were generally less emphasized by the 12 water systems because the capital investment for the treatment systems is funded by EPA. However, the capital costs of treatment systems will be a major concern for most utilities when selecting technologies in the future. Information on the capital costs of the 12 treatment systems is reported in an EPA report, entitled *Capital Costs of Arsenic Removal Technologies: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1* (EPA, 2004b).

**2.1.5 Other Factors.** Other factors that influenced technology selection for the 12 demonstration sites included the adaptability of a selected process for future expansion and the ability to make changes to a selected process to take advantages of improvement in technology in the future. For example, for the adsorptive media processes, it was important to consider whether the technology being put in place could be easily adaptable to using new and possibly less costly adsorptive media that may become available in the future.

## **2.2 Adsorptive Media Technologies**

**2.2.1 Technology Description.** The adsorptive media process is a fixed-bed process by which ions in solution, such as arsenic, are removed by available adsorptive sites on an adsorptive media. When the available adsorptive sites are filled, spent media may be regenerated or simply thrown away and replaced with new media. Granular activated alumina (AA) was the first adsorptive media successfully applied for the removal of arsenic from water supplies. More recently, other adsorptive media have been developed and marketed for arsenic removal.

The adsorptive media process has many advantages for small systems. The process is relatively easy to operate, has low maintenance requirements and low costs, and typically generates residuals that can easily be disposed of. Nine of the 12 sites selected an adsorptive media process for demonstration, and all of them fall under the category of being a low-iron site, with iron levels in the source water at less than 300 µg/L. Only four different adsorptive media were selected for use at the nine sites: G2 (ADI), E33 (Severn Trent and AdEdge), GFH (USFilter) and AAFS50 (Kinetic).

The key physical and chemical properties and unit costs of the four adsorptive media are presented in Table 2-3. All of these media have been widely evaluated in laboratory and pilot tests and have received listing under the NSF Standard 61 for use in drinking water applications. These materials are either iron based or alumina-based media. Differences in their overall composition, valence state of the iron, crystalline structure, available surface area, and other physicochemical characteristics may result in different arsenic adsorption capacities and kinetics. In addition, it has been demonstrated that iron-based media typically have higher arsenic removal capacities compared to alumina-based media (EPA, 2003b).

Other emerging adsorptive media types are currently available, but are not being tested as part of the Round 1 Arsenic Removal Technology Demonstration Program. These materials include iron-based media such as Engelhard's ARM 200; titanium-based media such as Hydroglobe's MetSorb and Dow Chemical's XUR; zeolite-based media such as WRT's Z-33, and iron-modified resin such as Solomex's As:X<sup>mp</sup>. Some of these media are expected to be evaluated in the Round 2 Program. The four media types to be evaluated as part of Round 1 are further described below:

**G2 Media.** The ADI system at Bow, NH, uses the G2 adsorptive media. G2 is an iron oxide-modified adsorptive media developed by ADI specifically for arsenic adsorption. It consists of a diatomaceous earth substrate coated with ferric hydroxide as the primary constituent and active ingredient. ADI markets G2 media for both As(V) and As(III) removal. Because it preferentially removes As(V) and the source water at Bow contains primarily As(V), G2 media should be effective at treating the source water

**Table 2-3. Physical and Chemical Properties and Costs of the Adsorptive Media**

Parameter	G2	E33	GFH	AAFS50	
<i>Physical and Chemical Properties</i>					
Matrix/Active Ingredient	Diatomaceous earth (Si-based) impregnated with a coating of ferric hydroxide	Iron oxide composite (90.1% FeOOH)	52-57% Fe(OH) <sub>3</sub> and β-FeOOH	83% Al <sub>2</sub> O <sub>3</sub> + proprietary additive	
Physical Form	Dry powder	Dry granular media	Moist granular media	Dry granular media	
Color	Dark brown	Amber	Dark brown	Light amber	
Bulk Density (g/cm <sup>3</sup> )	0.75	0.45	1.22-1.29	0.91	
Bulk Density (lb/ft <sup>3</sup> )	47	28	76-81	57	
BET Area (m <sup>2</sup> /g)	27	142	127	220	
Particle Size Distribution/ Effective Size (mm)	0.32	10 × 35 mesh	0.32-2	28 × 48 mesh	
Zero Point Charge <sup>(a)</sup>	N/A	8.3	7.6	7.3	
Operating pH Range	5.5 to 7.5	6.0 to 8.0	5.5 to 9.0	<7.7	
EBCT (min)	10	5	5	5	
Regenerability	Yes	No	No	No	
<i>Media Cost</i>					
Vendor	ADI	Severn Trent	AdEdge	USFilter	Kinetico
Cost (\$/ft <sup>3</sup> )	35	150	245	238	82
Cost (\$/lb)	0.75	5.36	8.75	3.03	1.44

(a) Amy et al. (2004).

N/A = not available.

EBCT = empty bed contact time.

at Bow. The level of iron in the source water is low enough that pretreatment for iron removal is not necessary prior to adsorption.

G2 media adsorbs arsenic most effectively at a pH value within the 5.5 to 7.5 range, and less effectively at a higher pH value. Historic pH measurements indicate that the pH values are in the range of 7.7 to 7.8; therefore, acid addition for lowering the pH is included as part of the treatment system to extend the media life. The presence of other ions in the source water is not expected to impede the arsenic adsorption because of their relatively low concentrations and because arsenic is more preferred than other ions by G2 media.

**E33 Media.** The Bayoxide® E33 media was developed by Bayer AG for the removal of arsenic from drinking water supplies. It is a granular ferric oxide media designed to remove dissolved arsenic via adsorption onto its ferric oxide surface. Severn Trent markets the media in the United States for As III and As V removal as Sorb-33, and offers several arsenic package units (APUs) with flowrates ranging from 150 to 300 gallons per minute (gpm). Another company, AdEdge, Inc., provides similar systems using the same media (marketed as AD-33) with flowrates ranging from 5 to 150 gpm. The Sorb-33 demonstration sites are located at Desert Sands Mutual Domestic Water Consumers Association (MDWCA), NM; Brown City, MI; and Queen Anne’s County, MD. The AD-33 demonstration sites are located at Nambe Pueblo, NM; Rimrock, AZ; and Rollinsford, NH.

E33 adsorbs arsenic and other ions, such as antimony, cadmium, chromate, lead, molybdenum, selenium, and vanadium. The adsorption is effective at pH values ranging between 6.0 and 9.0. At pH values

greater than 8.0 to 8.5, pH adjustment is recommended to maintain its adsorption capacity. Two competing ions that can reduce the adsorption capacity are silica (at levels greater than 40 mg/L) and phosphate (at levels greater than 1 mg/L). In general, water with an iron content of less than 300 µg/L can be treated with E33 media without any pretreatment. Table 2-4 summarizes the impact of water quality at the six E33 sites on the need for pretreatment, including pre-oxidation of As(III) to As(V) and raw water pH adjustment. Pre-chlorination also is used for disinfection with the media having only a slight chlorine demand for only a short period of time, such as one or two week s.

**Table 2-4. Water Quality Impact on Pretreatment Requirements at E33 Demonstration Sites**

Site	Pre-Chlorination	pH Adjustment	Water Quality
<i>Severn Trent Systems</i>			
Desert Sands MDWCA, NM	Yes [As(III) = 21.6 µg/L]	No [pH = 7.7]	Sulfate 158 to 190 mg/L
Brown City, MI	No [As(III) = 11.2 µg/L]	No [pH = 7.3]	Iron up to 200 µg/L
Queen Anne’s County, MD	No [As(III) = 18.4 µg/L]	No [pH =7.3]	Not Significant
<i>AdEdge Systems</i>			
Nambe Pueblo, NM	No [As(III) = 0.2 µg/L]	Yes [pH =8.5]	Not Significant
Rimrock, AZ	No [As(III) = <0.1 µg/L]	No [pH = 7.1]	Not Significant
Rollinsford, NH	Yes [As(III) = 20.1 µg/L]	Yes [pH = 8.2]	Manganese up to 100 µg/L

**GFH Media.** GFH is a granular ferric hydroxide media produced by GEH Wasserchemie GmbH of Germany and marketed by USFilter under an exclusive marketing agreement. GFH is capable of adsorbing both As(V) and As(III). GFH media adsorbs arsenic within a pH range of 5.5 to 9.0, but less effectively at the upper end of this range. Arsenic in the source water at the STMGID, NV site is predominately As(V). With a moderate pH of 6.9 to 7.9 for the source water, pH adjustment is not recommended. Competing ions such as silica and phosphate in source water can adsorb onto GFH media, thus reducing the arsenic removal capacity of the media. Source water at STMGID, NV contains less than 0.1 mg/L of orthophosphate and 28.0 mg/L of sulfate. Only silica concentrations (68.6 mg/L as SiO<sub>2</sub>) appear to be high enough to potentially impact the arsenic adsorption capacity.

**AAFS50 Media.** The Kinetico arsenic adsorption system at Valley Vista, AZ, uses Alcan’s Actiguard AAFS50 media. AAFS50 media is different from conventional AA because it is engineered with a proprietary additive to enhance its arsenic adsorption performance. Standard grade AA was the first adsorptive media successfully applied for the removal of arsenic from water supplies. However, it often requires pH adjustment to 5.5 in order to achieve optimal arsenic removal. The AAFS50 product is modified with an iron-based additive to improve its performance and to increase the pH range within which it can achieve effective removal.

Based on vendor’s recommendations, As(III) should be oxidized to As(V) in order to maximize arsenic removal with this media. Based on the results of the field arsenic speciation at the Valley Vista site, 37.8 µg/L exists as As(V) and only 0.3 µg/L exists as As(III). For this reason, pre-chlorination at this site was determined to be unnecessary. Optimal arsenic removal efficiency is achieved with a pH of the feed water less than 7.7. The pH value of the source water ranges from 7.7 to 8.0, thus, pH adjustment equipment is used. Competing ions such as fluoride, sulfate, silica, and phosphate can adsorb onto AAFS50 media, and potentially can reduce its arsenic removal capacity. The source water contained 0.2 mg/L of fluoride, 8.7 mg/L of sulfate, 18.5 mg/L of silica (as SiO<sub>2</sub>), and less than 0.1 mg/L of orthophosphate. These concentrations appear to be low enough that the operating capacity should not be greatly affected. The adsorption capacity of AAFS50 can be impacted by both high levels of silica (>40

mg/L SiO<sub>2</sub>) and phosphate (>1 mg/L). In addition, the vendor recommended that the system be operated in a series configuration to minimize the chance for arsenic breakthrough to impact drinking water quality.

**2.2.2 Adsorptive Media Selection Factors.** The performance of arsenic adsorption treatments systems depends on several factors including arsenic concentration and speciation, pH, presence of competing anions, and media-specific characteristics such as media life and empty-bed contact time (EBCT) requirements. Other factors to consider in media selection include the unit and life-cycle costs of the media and whether it can be regenerated on site.

**2.2.2.1 Arsenic Concentration and Speciation.** Both arsenic concentration and speciation play a role in the effectiveness of arsenic removal in an adsorption system. Total arsenic concentration has an impact on the life-cycle costs for media replacement, as higher initial arsenic concentrations will exhaust the media more rapidly. The proportion of As(III) and As(V) in source water also influences the need for pretreatment because of the potential impact of As(III) on the overall life of the media. In general, As(V) is more readily adsorbed within the pH range of typical drinking water applications. For this reason, it may be preferable to oxidize As(III) to As(V) in order to increase the effectiveness of an arsenic removal system. Oxidation of As(III) often is accomplished using a pre-chlorination step to oxidize As(III) to As(V) prior to entering adsorption vessels. Table 2-5 summarizes the options available for the effective oxidation of As(III), including the addition of chlorine and potassium permanganate (often used in conjunction with manganese greensand systems). The effectiveness of the oxidants for oxidizing Fe(II), commonly found with As III, also is shown in Table 2-5.

**Table 2-5. Relative Effectiveness of Various Oxidants for Fe(II) and As(III) Oxidation**

Oxidant	Fe(II) Oxidation	As (III) Oxidation
Air (aeration)	Effective	Not effective
Chlorine	Effective	Effective
Chloramine	Not effective	Not effective
Ozone	Effective	Effective
Chlorine dioxide	Effective	Not effective
Potassium permanganate	Effective	Effective

Note: Adapted from EPA (2004a).

**2.2.2.2 pH Value.** The arsenic removal capacity for both alumina-based and iron-based adsorptive media can be enhanced by pH adjustment. The lowering of pH can be accomplished using hydrochloric acid (HCl), sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), or carbon dioxide (CO<sub>2</sub>). A one-time capital cost increase is required for chemical feed and storage equipment as well as increased operating cost for consumable acid or caustic. However, the pH adjustment method may be cost-effective given the potential for a significantly increased media life. A discussion of the impact of pH on arsenic adsorption for both alumina-based and iron-based media is provided below.

Alumina-based media can remove mainly As(V). The optimal arsenic removal capacity with standard grade AA is achieved at a pH value of 5.5. For example, process demonstrations showed that arsenic removal capacity was reduced by more than 15% at pH 6.0 compared to that of pH 5.5 (Rubel, 1984). Therefore, adjusting the pH of source water can provide removal capacity advantages. The alumina-based AAFS50 product used in this study has been modified with an iron-based additive to expand the operational pH range up to 7.7 for effective arsenic removal.

Iron-based media has an affinity to adsorb both As(III) and As(V). The predominant mechanism in arsenic adsorption onto the iron oxide or hydroxide surface appears to be electrostatic attraction. However, the adsorption of As(III) versus As(V) is impacted very differently by source water pH. The adsorption of As(V) decreases with increasing pH values in the 3 to 10 range because, as the pH increases, the surface charge of the media becomes less positive and there is less attraction to the negatively charged As(V) species of  $\text{H}_2\text{AsO}_4^-$  and  $\text{HAsO}_4^{2-}$ . The As(V) species of  $\text{H}_2\text{AsO}_4^-$  dominates at a pH value between 2.0 and 7.0, and  $\text{HAsO}_4^{2-}$  dominates at a pH value between 7.0 and 11.0. On the other hand, As(III) adsorption is shown to increase with an increase in pH value with a maximum adsorption at pH 9.0. This is likely because the uncharged species,  $\text{H}_3\text{AsO}_3$ , predominates for As(III) in the pH range of natural waters, and at pH 9.0, the  $\text{H}_2\text{AsO}_3^-$  form occurs, thus increasing the affinity for the positively-charged iron solid surface. The range of effective adsorption of both As(III) and As(V) overlaps within the pH range of 6.0 to 7.5, with more As(V) adsorbed at a low value pH and more As(III) adsorbed at a high pH value (Jain and Loeppert, 2000). The optimal pH range for arsenic removal is specific to each media type; vendor-reported optimal pH ranges are 5.5 to 7.5 for G2, 6.0 to 8.0 for E33, and 5.5 to 9.0 for GFH.

**2.2.2.3 Competing Anions.** The adsorption of arsenic is influenced by the presence of other competing anions in source water such as fluoride, bicarbonate, sulfate, silica, and phosphate. Anions compete directly for available binding sites on the surface of the media and also can alter the electrostatic charge at the media surface. This competition has the potential to reduce the overall effectiveness of arsenic removal from source water. In order for a competing ion to have an effect, it must be present in sufficient concentration and/or have a stronger affinity for adsorption onto the media than arsenic. Competing ions such as silica, phosphate, fluoride, and sulfate may adsorb onto AAFS50 and reduce its removal capacity for arsenic (Kinetic, 2003). For example, the vendor reports that AAFS50 media is impacted by both high levels of phosphate (>1 mg/L) and silica (>40 mg/L  $\text{SiO}_2$ ). E33 is reported to be affected by silica at levels greater than 40 mg/L, sulfate at levels greater than 150 mg/L, and phosphate at levels greater than 1 mg/L. G2 is reported to be unaffected by sulfate concentrations up to 250 mg/L. GFH also experiences effects from competing ions such as silica, phosphate, and sulfate, but no threshold values were provided by the vendor.

**2.2.2.4 Media-Specific Characteristics.** Each media has unique characteristics related to its arsenic adsorption capacity and the kinetics or rate at which arsenic is adsorbed onto the media. These factors play a role in its overall cost-effectiveness for technology selection and are related to the chemical composition of the media, its mesh size and surface area, its pore structure, and other physicochemical properties (such as zero point charge [ZPC]) that impact adsorption processes. Table 2-3 presents the vendor-reported data for the four media used in this project, including media surface area and mesh size and recommended EBCT. The adsorption capacity of the media will impact the overall life-cycle cost for media replacement, and the EBCT primarily impacts the size of the adsorption vessels and the capital cost of the equipment.

**2.2.2.5 Media Costs.** The unit costs of the four media used in this study are provided in Table 2-3. For the alumina-based media AAFS50, the unit cost is relatively low at \$1.44/lb compared to the unit cost of the iron-based media, which ranges from \$0.75/lb to \$8.75/lb. Although the unit cost may be a factor, the technology selection should rely on an estimate of the life-cycle cost of the media, which is a function of the media's arsenic adsorption capacity, its expected media life given influent arsenic and water quality, the size of the vessels, and other site-specific factors. In general, the alumina-based media have lower arsenic adsorption capacities compared to the iron-based media. Therefore, the iron-based media would be more cost-competitive because they would need to be replaced less frequently, which would decrease the overall life-cycle cost. At the end of the one-year evaluation period, the life cycle costs associated with these four media will be reported as part of a Final Performance Evaluation Report for each demonstration site.

**2.2.2.6 Regenerability.** Some of the commercially available arsenic adsorptive media can be regenerated by chemical pH adjustment upon exhaustion of the arsenic removal capacity. Chemical regeneration of adsorptive media is economically sound for large systems with high arsenic concentrations. As the size of the system decreases and/or the raw water arsenic concentration decreases, the economic benefit compared to the capital and operating cost is diminished. For very small systems, it may be more cost-effective to use disposable media. G2 media used at the Bow, NH site can be regenerated using a caustic solution. The vendor reports that the media can be regenerated 4 to 5 times, with each regeneration resulting in a 10% decrease in the media's capacity for arsenic adsorption. However, due to the small size of the system at Bow (40 gpm), it was determined that on-site regeneration would not be cost-effective.

### 2.3 Ion Exchange Technology

Ion exchange is a fixed-bed process that involves exchanging ions from solution onto a resin. For arsenic removal, an anion resin in the chloride form is used to remove As(V). Anion exchange resins also remove other anions such as sulfate, nitrate, and uranium. Because As(III) occurs in water below pH 9 with no ionic charge, As(III) is not removed by the anion exchange process. When the resin eventually becomes saturated with arsenate and other anions such as nitrate and sulfate, the resin must be regenerated. In the regeneration step, a sodium chloride brine solution is passed through the spent resin where the adsorbed arsenate and other anions are replaced with chloride ions. Because of high concentrations of arsenic in the spent brine, it likely will be classified as a hazardous waste. The advantages of the anion exchange technology for arsenic removal is simplicity of operation, long resin life, ease of regeneration, and lack of impact of pH on the exchange capacity.

A Kinetico IX-248-AS/N Ion Exchange Arsenic-Nitrate Removal System was selected for the Fruitland, ID demonstration site. The system uses a macroporous strong base resin, Purolite A-520E, to remove arsenic and nitrate from water. Purolite A-520E resin is approved for use in drinking water applications under NSF Standard 61. The Purolite resin is formed in a matrix of opaque, cream-colored spherical beads. The physical properties of this resin are summarized in Table 2-6.

**Table 2-6. Physical and Chemical Properties of Purolite A-520E Resin**

Parameter	Value
Polymer Matrix Structure	Macroporous styrene-divinylbenzene
Physical Form and Appearance	Opaque cream spherical beads
Whole Bead Count	95% minimum
Functional Groups	Quaternary ammonium
Ionic Form as Shipped	Cl <sup>-</sup>
Shipping Weight	680 g/L (42.5 lb/ft <sup>3</sup> )
Screen Size Range (U.S. Standard Screen)	16 – 50 mesh, wet
Particle Size Range	+1200 mm <5%, -300 mm <1%
Moisture Retention, Cl <sup>-</sup> Form	50-56%
Reversible Swelling, Cl <sup>-</sup> to SO <sub>4</sub> <sup>2-</sup> /NO <sub>3</sub> <sup>-</sup>	Negligible
Total Exchange Capacity, Cl <sup>-</sup> Form	
Wet, Volumetric	0.9 meq/mL minimum
Dry, Weight	2.8 meq/g minimum
Operating Temperature, Cl <sup>-</sup> Form	100°C (212°F) maximum
pH Range, Stability	0-14
pH Range, Operating	4.5-8.5

Total arsenic concentrations of the source water at the Fruitland, ID site range from 37 to 44 µg/L. Based on the speciation sampling event, arsenic exists predominantly as As(V) (39.3 µg/L). A small amount of arsenic also exists as As(III) (0.8 µg/L) and particulate As (3.4 µg/L). Because arsenic is present primarily as As(V), pre-chlorination is not required at the site.

The efficiency of the ion exchange process for arsenic removal is strongly affected by competing ions, such as sulfate, nitrate, and TDS. In general, the ion exchange process is not economically attractive if source water contains high levels of TDS (>500 mg/L) and sulfate (>250 mg/L). Sulfate concentrations in the Fruitland raw water range from 57.3 to 64.0 mg/L. Sulfate is more preferred by the ion exchange resin than arsenate (i.e., H<sub>2</sub>AsO<sub>4</sub><sup>-</sup>). Nitrate concentrations showed an increasing trend from 5.2 mg/L in July 1986 to 13.90 mg/L in November 2001. In addition to arsenic, nitrate will be monitored during the one-year performance evaluation study to ensure that it will not exceed the 10 mg/L MCL.

Total iron concentrations in the source water range from the detection limit to 744 µg/L. No pretreatment for iron is planned before the ion exchange process. The uranium concentration was measured at 22.4 µg/L, but does not exceed the EPA MCL of 30 µg/L. Because the ion exchange process can remove uranium (Clifford, 1999), samples will be collected for uranium analyses during the one-year performance evaluation study. The pH values of the raw source water range from 7.4 to 7.6. To protect the ion exchange beds from particulates in the groundwater, bag filters have been installed upstream of the anion exchange system.

## **2.4 Coagulation/Filtration and Iron Removal Technologies**

Iron removal processes can be used to remove arsenic from drinking water supplies. Iron removal processes involve the oxidation of soluble iron and As(III), adsorption and/or co-precipitation of As(V) onto iron hydroxides, and filtration. The actual capacity to remove arsenic during iron removal processes depends on a number of factors, including the amount of arsenic present, arsenic speciation, pH, amount and form of iron present, and existence of competing ions, such as phosphate, silicate, and natural organic matter (EPA, 2004a). The coagulation/filtration system selected for the demonstration study is one that employs an engineered ceramic filtration media, Macrolite<sup>®</sup>, to remove arsenic-bearing iron solids. In addition, a process modification is being implemented to provide supplemental iron addition to source water to enhance the arsenic removal efficiency of a MnO<sub>2</sub>-coated anthrasand filtration system. The main advantage of the process is that it uses the natural iron to remove arsenic. Thus, sites with high iron concentrations requiring an iron removal process can use one process to remove both iron and arsenic.

**2.4.1 Macrolite<sup>®</sup> Pressure Filtration.** A Macrolite<sup>®</sup> arsenic removal system that uses coagulation/filtration to remove arsenic-bearing iron solids from source water was selected for the Climax, MN site. Macrolite<sup>®</sup> is a low-density, spherical media and is designed to allow for filtration rates up to 10 gpm/ft<sup>2</sup>, which is a higher loading rate than commonly used for conventional filtration media. Macrolite<sup>®</sup> is manufactured by Kinetico and is listed for use in drinking water applications under NSF Standard 61. Kinetico attributes Macrolite's<sup>®</sup> increased capacity for flow, while maintaining filtering capacity, to its uniform, rounded physical shape and rough surface texture compared to the irregular angular shapes of conventional granular media. The physical properties of this media are summarized in Table 2-7. Macrolite<sup>®</sup> also is chemically inert and compatible with chemicals such as acids, caustics, oxidants, and coagulant chemicals such as ferric chloride.

Total arsenic concentrations range from 31 to 41 µg/L in Climax source water. Based on the source water sampling result, up to 90% of the total arsenic (38.7 µg/L) is present as As(III). The proposed treatment process relies on the oxidation of As(III) to As(V) via chlorination, the adsorption of As(V), and the filtration of As(V)-bearing iron solids. The source water has iron levels that range from 546 to 850 µg/L.

As shown in Figure 2-1, the iron concentration should be 20 times the arsenic concentration to effectively co-precipitate the arsenic onto the iron solids. The iron analytical results indicate that iron levels are 13 to 27 times higher than the arsenic levels in the source water. There is no plan at this time to supplement the natural iron levels. In addition, the pH range of 7.4 to 7.9 is within the target range of 5.5 to 8.5 for arsenic removal by iron oxides.

**Table 2-7. Properties of 40/60 Mesh Macrolite® Media**

Property	Value
Color	Taupe, Brown to Grey
Thermal Stability	2,000°F
Sphere Size Range	0.014 – 0.009 inch
Bulk Density	0.86 g/cm <sup>3</sup> or 54 lb/ft <sup>3</sup>
Specific Gravity	2.05 g/cm <sup>3</sup> or 129 lb/ft <sup>3</sup>
Collapse Strength (for 30/50 mesh) <sup>(a)</sup>	7,000 to 8,000 psi

(a) Data not available for 40/60 mesh.

**2.4.2 System Modification.** The facility at Lidgerwood, ND, unlike the other demonstration sites, has a treatment system in place: a coagulation/filtration treatment system for the removal of elevated levels of iron, manganese, and arsenic in groundwater. Total arsenic concentrations of source water range from 108 to 146 µg/L and total iron concentrations range from 1,310 to 1,620 µg/L. The existing treatment system consists of pre-chlorination, forced draft aeration, potassium permanganate (KMnO<sub>4</sub>) oxidation, polymer coagulant addition, detention, gravity filtration, post-chlorination, and fluoridation. Although the existing system normally reduces the iron level to less than 25 µg/L, the system reduces the arsenic to only 26 to 31 µg/L. The purpose of the demonstration project is, therefore, to evaluate a treatment modification that can achieve an arsenic level below the 10-µg/L arsenic MCL. The modification selected consists of adding supplemental iron (i.e., ferric chloride) to increase the overall arsenic removal efficiency of the treatment system.

### 3.0 TECHNOLOGY DESIGN AND OPERATION

This section discusses the design and operation of the technology selected for each demonstration site. The technologies consist of nine adsorptive systems, one anion exchange system, one coagulation/filtration system, and one system modification. Photographs of the systems on-line at this time are shown in Appendix A.

#### 3.1 Adsorptive Media Systems

Nine adsorptive media systems using four different adsorptive media were selected for demonstration. Six systems use E33 media, one uses G2 media, one uses GFH media, and one uses AAFS50 media. A summary of the major aspects of the adsorptive treatment systems installed is provided in Table 3-1.

**Table 3-1. Summary of the Design and Components of the Adsorptive Media Systems**

Media Type	Site	Media Vessels			Media Volume per Vessel (ft <sup>3</sup> )	EBCT at Design Flow (min)	Pre/Post-Treatment			
		No.	Configuration	Material			Pre-Cl <sub>2</sub>	Pre-pH Adjust	Post-Cl <sub>2</sub>	Post-pH Adjust
G2	Bow, NH	2	Series	SS	85	18 <sup>(a)</sup>	Yes	H <sub>2</sub> SO <sub>4</sub>	No	NaOH
E33	Desert Sands MDWCA, NM	2	Parallel	FRP	80	3.7	Yes	No	No	No
E33	Brown City, MI	4	Parallel	FRP	80	3.7	No	No	Yes	No
E33	Queen Anne's County, MD	2	Parallel	FRP	80	4.0	No	No	Yes	No
E33	Nambe Pueblo, NM	3	Parallel	FRP	27	4.2	Yes	CO <sub>2</sub>	No	No
E33	Rimrock, AZ	2	Series	FRP	27	4.5 <sup>(a)</sup>	Yes	No	No	No
E33	Rollinsford, NH	2	Parallel	FRP	27	4.0	Yes	CO <sub>2</sub>	No	No
GFH	STMGID, NV	3	Parallel	CS	80	5.1	No	No	Yes	No
AAFS50	Valley Vista, AZ	2	Series	FRP	22	4.4 <sup>(a)</sup>	Yes	H <sub>2</sub> SO <sub>4</sub>	No	No

SS = stainless steel; FRP = fiberglass reinforced plastic; CS = carbon steel

(a) EBCT is for one vessel only.

**3.1.1 Bow, NH (G2 Media).** The 40-gpm Bow, NH water treatment system is owned and operated by C&C Water Services. The system supplies water to 96 homes in the community of Village Shore Estates. The source water is groundwater drawn from three on-site wells (No. 1, 2, and 3). The well pumps are controlled by the water levels in two 15,000-gallon storage tanks. Based on the water demand, the system runs approximately 6 hours per day.

Prior to the installation of the G2 system, the treatment at Bow included addition of a dilute sodium hypochlorite solution for disinfection, and of sodium hydroxide for pH adjustment. In addition, about 10 to 15% of the flow was treated through an AA system that had been used at the site for several years.

**3.1.1.1 Treatment System Description.** The G2 adsorption system was originally designed for the Allenstown, NH site at a flowrate of 70 gpm with two vessels operating in parallel. The system was subsequently reconfigured for series operation at the Bow, NH site after the Allenstown, NH site had

withdrawn from the demonstration study. The major components of the G2 treatment system are described as follows:

- **Pre-chlorination.** Injection of sodium hypochlorite was previously employed for disinfection at the site and is continued for both disinfection and As(III) oxidation, although arsenic in the source water exists predominately as As(V).
- **Pre-pH adjustment.** The pH of the source water is adjusted to approximately  $6.5 \pm 0.2$  using a 50% sulfuric acid solution.
- **G2 media adsorption.** The G2 media system consists of two 72-inch-diameter, 72-inch-tall, 304 stainless steel (SS) pressure vessels in series, each containing about 85 ft<sup>3</sup> of G2 media. The filter vessels are rated for 50 psi working pressure and can be reversed in the lead/lag positions manually using a series of valves.
- **Post-pH adjustment.** After adsorption, the pH of the treated water is adjusted with sodium hydroxide to approximately  $7.5 \pm 0.2$  before the water enters the distribution system for corrosion control.

**3.1.1.2 Treatment System Operation.** The G2 media system is operated in downflow mode through the SS adsorption vessels. Flow to each vessel is measured and totaled to record the volume of water treated. Pressure differential through each vessel also is monitored to track the pressure loss. Based on a set time or a set pressure differential, the adsorption vessels are taken off-line and backwashed one at a time using treated water to remove media fines built up in the beds and to “fluff” the compacted media bed. The backwash water is discharged to an on-site surface drainage field for disposal.

G2 media in the lead vessel is replaced when the effluent arsenic concentration from the lead vessel reaches the influent concentration or when the effluent concentration from the lag vessel reaches 10 µg/L. After the spent media in the lead vessel is replaced, this vessel becomes the lag vessel. Based on the average daily use rate of 15,000 gallons per day (gpd), the size of adsorption vessels, and the chemistry of the source water, it is expected that the G2 media in the lead vessel has an estimated working capacity of 10,300 bed volumes and will last for more than 14 months before change-out is necessary.

**3.1.2 Desert Sands MDWCA, NM (E33 Media).** The Desert Sands MDWCA serves 1,886 community members near Anthony, NM using an existing supply, storage, and distribution network that covers an area of approximately four square miles of unincorporated area in southern Dona Ana County. The water system consists of two production wells (Wells No. 2 and 3 with a combined capacity of 320 gpm), two steel water storage tanks with capacities of 99,000 and 240,000 gallons, and approximately 30 miles of distribution piping. The water production and consumption have fluctuated over the past several years with the peak production occurring in 1998 at 63.5 million gallons.

**3.1.2.1 Treatment System Description.** The Severn Trent APU-300 system has a design flowrate of 320 gpm, but can be operated at 350 gpm. The major components of the treatment system are as follows:

- **Pre-chlorination.** Sodium hypochlorite is added to raw water for disinfection, hydrogen sulfide control, and As(III) oxidation. The target chlorine level in treated water is 0.3 mg/L.

- **E33 media adsorption.** The system consists of two parallel 63-inch-diameter, 86-inch-tall fiberglass reinforced plastic (FRP) pressure vessels, each containing about 80 ft<sup>3</sup> of E33 media.

**3.1.2.2 Treatment System Operation.** The APU-300 system is programmed to perform an automated backwash every 45 days or on a pressure differential of 10 psi, using untreated well water. The vessels are taken off-line one at a time for backwash. While one vessel is backwashed, the other remains in service.

Based on an average daily use rate of about 345,600 gpd, the size of adsorption vessels, and the chemistry of the source water, it is expected that E33 media has an estimated working capacity of 132,000 bed volumes, and will last for approximately 15 months before change-out is necessary.

**3.1.3 Brown City, MI (E33 Media).** Brown City supplies water to approximately 1,334 people and has 630 service connections. The water source is groundwater from wells at three locations. Prior to the installation of the APU-300 system, the only treatment provided to the groundwater was chlorination for disinfection. Two wells (Wells No. 3 and 4) are located at the demonstration site. The water from Well No. 4 is treated by the APU-300 system and currently is operated on an intermittent basis for approximately 4-8 hours per day.

**3.1.3.1 Treatment System Description.** The Severn Trent APU-300 system has a design flowrate of 300 gpm, but can be operated at 350 gpm. Because the Brown City water supply wells are rated at 640 gpm, two APU-300 units were installed. The major components of the treatment system are as follows:

- **E33 media adsorption.** The units consist of four parallel 63-inch-diameter, 86-inch-tall FRP pressure vessels, each containing about 80 ft<sup>3</sup> of E33 media.
- **Post-chlorination.** Sodium hypochlorite is added for a target residual level of 0.3 mg/L (as Cl<sub>2</sub>) for free chlorine and 0.4 mg/L (as Cl<sub>2</sub>) for total chlorine in the distribution system.

**3.1.3.2 Treatment System Operation.** Similar to the Desert Sands MDWCA system, the Brown City system is backwashed automatically every 45 days using untreated source water. The backwash also can be initiated manually by the operator. The vessels are taken off-line one at a time for backwash. While one vessel is backwashed, the other three remain in service.

Based on the average daily use rate of about 192,000 gpd, the size of adsorption vessels, and the source water chemistry, E33 media has an estimated working capacity of 80,000 bed volumes and will last for approximately 33 months before change-out is necessary.

**3.1.4 Queen Anne's County, MD (E33 Media).** The Queen Anne's County facility supplies water to approximately 300 connections in the community of Prospect Bay. The source water is extracted from two wells that alternate operation for 3-4 hours every other day. However, for the purpose of the demonstration study, Well No. 1, which is connected to the APU-300 system, operates for about 7 hours every day at a rate of 300 gpm.

Prior to the demonstration project, the treatment included chlorination using chlorine gas and the addition of a corrosion inhibitor (polyphosphate). Treated water was sent to a 300,000-gallon storage tank before the distribution system.

**3.1.4.1 Treatment System Description.** The major components of the Queen Anne’s County’s APU-300 treatment system are described as follows:

- **E33 media adsorption.** The APU-300 system is identical to that installed at Desert Sands MDWCA, NM.
- **Post-polyphosphate addition.** A polyphosphate chemical is added to treated water for corrosion control.
- **Post-chlorination.** Chlorine gas is added to the treated water for disinfection. The target total chlorine level in distributed water is 0.5 mg/L (as Cl<sub>2</sub>). The APU-300 system is monitored closely during the course of the study to determine if chlorination should be moved upstream of the E33 vessels in order to oxidize As(III) to improve the removal efficiency and the life of E33 media.

**3.1.4.2 Treatment System Operation.** Backwash of the E33 vessels follows the same procedures as performed at the Desert Sands MDWCA and Brown City.

According to Severn Trent, the estimated working capacity of the media is 114,000 bed volumes, which is equivalent to 63 months of useful media life when operating the system on an average use rate of 72,000 gpd. As mentioned above, the system will be closely monitored to determine if E33 media is effective for As(III) removal.

**3.1.5 Nambe Pueblo, NM (E33 Media).** The existing water system at Nambe Pueblo, NM supplies drinking water to approximately 500 community members with 150 service connections. The system consists of a 145-gpm well in a pump house containing a chlorine feed system and a 17-ft-diameter, 24-ft-high, 40,000-gallon water storage tank. The well pump is operated for 3 to 4 hours per day and produces approximately 34,000 gpd. A peristaltic pump injects chlorine into the water upstream of the water storage tank to maintain a residual chlorine level of 0.2 mg/L in distributed water. Water in the storage tank is gravity-fed through the distribution system to the community.

**3.1.5.1 Treatment System Description.** The AdEdge APU-150 system has a design flowrate of 145 gpm, and consists of an APU-100 and an APU-50 unit, with the components programmed to run cooperatively. The major components of the complete water treatment system are as follows:

- **Pre-pH adjustment.** The pH will be adjusted from above 8 to 7.0 by adding CO<sub>2</sub> to the water upstream of the APU-150 treatment system.
- **Pre-chlorination.** The existing chlorine addition system will continue to be used to achieve a target residual chlorine level of 0.2 mg/L (as Cl<sub>2</sub>).
- **E33 media adsorption.** The adsorptive media system consists of three parallel 36-inch-diameter, 72-inch-tall FRP pressure vessels, each containing about 27 ft<sup>3</sup> of E33 media.

**3.1.5.2 Treatment System Operation.** The APU-150 system will be programmed to perform an automated backwash with untreated well water either once a month or when the pressure drop across each vessel reaches 10 psi. The vessels will be taken off-line one at a time for backwash. While one vessel is backwashed, the other two will remain in service. CO<sub>2</sub> will be added to the water upstream of the APU-150 to lower the pH to approximately 7.0.

Based on the average daily use rate of about 34,000 gpd, the size of adsorption vessels, and the raw water chemistry, the E33 media has a working capacity of approximately 76,000 bed volume, and will last approximately 35 months before change-out is necessary

**3.1.6 Rimrock, AZ (E33 Media).** The Rimrock, AZ water system is owned and operated by the Arizona Water Company (AWC). The source water is extracted from Montezuma Haven Wells No. 1 and No. 2 that have a combined capacity of 90 gpm. In the summer of 2003, both wells were taken out of service due to exceedance of the arsenic levels over the old 50- $\mu\text{g/L}$  MCL. A new well, Well No. 3, was drilled nearby Wells No. 1 and No. 2 with a production capacity of 315 gpm. During the site cleanup in September 2003, Wells No. 1 and No. 2 were refurbished and developed for the demonstration study. Later, it was discovered that Well No. 1 went dry and that Well No. 2 only produced about 40 gpm.

**3.1.6.1 Treatment System Description.** The AdEdge APU-100 system was originally designed for a flowrate of 90 gpm, having two E33 vessels arranged in parallel. The system design was later modified to a lead/lag configuration because of the loss of Well No. 1, thus resulting in a reduced system capacity to 45 gpm. The major components of the treatment system are as follows:

- **Bag filter.** A bag filter is installed before the APU-100 system to remove any sediment from the well water.
- **Pre-chlorination.** A sodium hypochlorite solution is added to raw water to prevent biological growth and for disinfection. The target residual chlorine level is 0.4 mg/L (as  $\text{Cl}_2$ ) for free chlorine.
- **E33 media adsorption.** The APU-100 system consists of two 36-inch-diameter, 72-inch-tall FRP pressure vessels in series, each containing about 27  $\text{ft}^3$  of E33 media.
- **Backwash recycling.** Because of a lack of a sewer system for the backwash water discharge, a 3,000-gallon high-density polyethylene (HDPE) holding tank was installed to store the backwash water for recycling, which is accomplished by metering the water back to the APU-100 system at a rate of 0.5 gpm.

**3.1.6.2 Treatment System Operation.** For the purpose of the demonstration study, Well No. 2 is operated at about 30 gpm for 12 hours per day and is controlled by a timer. The system operates at about 30 gpm. During the system operation, the E33 vessels are backwashed automatically every 28 to 29 days using raw water. The backwash water is filtered through a set of dual bag filters to remove particulates and filtered water is stored in the 3,000-gallon holding tank equipped with high- and low-level sensors to control the recycle pump.

The media replacement for this lead/lag-configured APU-100 system is similar to that of the Bow G2 system. After the spent media in the lead vessel is replaced, the vessel is moved to the lag position. Based on the average daily use rate of 23,760 gpd, the size of adsorption vessels, and the raw water chemistry, the E33 media has an estimated working capacity of 66,000 bed volumes, and will last for about 19 months in the lead vessel before change-out is necessary.

**3.1.7 Rollinsford, NH (E33).** The Rollinsford, NH water system services about 450 connections. The source water is supplied by three bedrock wells, two of which, Wells No. 3 and No. 4, are located at Porter well house. Water from these two wells is combined before passing through the distribution system and is used for the demonstration study. Both wells are operated at near 50 gpm for about 8 to 10 hours per day, depending on the water demand.

The existing treatment system consists of disinfection using a dilute sodium hypochlorite solution fed at a rate of approximately 1.3 gpd. Treated water is sent directly to the looped distribution system and stored in a nearby storage tank.

**3.1.7.1 Treatment System Description.** The AdEdge APU-100 system has a design flowrate of 100 gpm. The major components of the complete water treatment system are described as follows:

- **Pre-chlorination.** Chlorination was initially applied as a post-chlorination process for disinfection purposes. After approximately one month of system operation, a rise in arsenic concentration in treated water was noted and, therefore, the chlorine injection point was moved to upstream of the adsorption vessels to facilitate the oxidation of As(III) and improve arsenic adsorption.
- **Pre-pH adjustment.** After pre-chlorination, the water pH value is adjusted to about 7.0 with CO<sub>2</sub> via a controlled injection loop located upstream of the E33 vessels.
- **E33 media adsorption.** The adsorption media system consists of two parallel 36-inch-diameter, 72-inch-tall FRP pressure vessels, each containing about 27 ft<sup>3</sup> of E33 media.

**3.1.7.2 Treatment System Operation.** Since the startup of the APU-100 system in January 2004, high pressure differential readings (over 30 psi at times) have been observed across the adsorption vessels. Several courses of actions, including retrofitting of some system piping and valving and aggressive backwashing, have been taken by AdEdge to address the problems. Backwash is performed manually by the operator using untreated well water with a frequency ranging from a few days to a couple of weeks.

Based on the source water chemistry and the average daily use rate of about 72,000 gpd, the E33 media has an estimated working capacity of 74,000 bed volumes, which will allow the media to last for 14 months before media change-out is necessary.

**3.1.8 STMGID, NV (GFH Media).** The STMGID water system is operated by the Washoe County Department of Water Resources to supply water to a population of 8,285 in Washoe County (Reno), NV. The demonstration project was selected for treating the groundwater from its 350-gpm Well No. 9. The existing treatment system consists of only sodium hypochlorite to provide a free chlorine residual level of 1.0 mg/L (as Cl<sub>2</sub>). The chlorinated water from this well is blended with other source waters with lower arsenic concentrations prior to supplying the distribution system. Well No. 9 is normally operated between March 1 and October 31 during periods of high demand. It is usually turned off by November 1 every year.

**3.1.8.1 Treatment System Description.** The USFilter GFH system has a design flow of 350 gpm and consists of three pressure vessels in parallel configuration. The major components of the treatment process include the following:

- **GFH media adsorption.** The GFH arsenic removal system is composed of three 66-inch-diameter and 72-inch-tall vertical carbon steel (CS) pressure vessels, each containing 80 ft<sup>3</sup> of GFH media. The skid-mounted filter vessels are rated for 100 psi of working pressure.
- **Post-chlorination.** Post-chlorination with sodium hypochlorite will be used for disinfection to provide a residual chlorine level of 1.0 mg/L.

**3.1.8.2 Treatment System Operation.** GFH media is backwashed on a headloss or elapsed time basis. The vessels will be taken off-line one at a time for backwash with treated water from the other two vessels. The backwash water produced will be discharged to a sanitary sewer.

When the GFH media adsorption capacity is exhausted, the spent media will be removed and replaced with virgin media. Based on the water quality characteristics and a 75% usage rate, USFilter projects that the media change-out will take place once every 182 days. The actual run length of the media will be determined based on the results of the one-year performance evaluation study.

**3.1.9 Valley Vista, AZ (AAFS50 Media).** The Valley Vista water system is privately owned by AWC. Raw water is supplied by Well No. 2 with a capacity of 37 gpm. Prior to this demonstration project, the treatment consisted of only sodium hypochlorite feed to reach a target residual chlorine level at 0.6 mg/L (as Cl<sub>2</sub>). The operation of the well is controlled by water levels in two 20,000-gallon storage tanks. On average, Well No. 2 is operated for approximately 8 hours per day.

**3.1.9.1 Treatment System Description.** The Kinetico AAFS50 system has a design flowrate of 37 gpm and consists of two pressure vessels configured in series. The major components of the complete treatment process include the following:

- **Pre-chlorination.** Sodium hypochlorite was initially applied after the adsorption vessels for disinfection. After approximately one month of the system operation, algae growth on the vessel view glass was noted. Therefore, the chlorine injection point was moved to before the adsorption vessels to control biological growth. The chlorine residual is maintained at 0.4 to 0.6 mg/L (as Cl<sub>2</sub>) throughout the treatment train.
- **pH adjustment.** The system has the capability to adjust the pH of the feed water to pH 7.0 using a 37% sulfuric acid. The pH control system consists of a solenoid-driven chemical metering pump, a 2-inch-diameter inline static mixer, an acid draw assembly with a low-level float, a pH meter, and a 55-gallon drum containing 37% sulfuric acid.
- **Adsorptive media vessels.** The treatment system consists of two 36-inch-diameter, 72-inch-tall FRP vessels, each containing 22 ft<sup>3</sup> of the AAFS50 media. The EBCT is 4.4 minute per vessel.

**3.1.9.2 Treatment System Operation.** AAFS50 media is normally backwashed with treated water once a month. While one vessel is backwashed, the other is temporarily out of service. Backwash is semi-automatic and needs to be initiated by an operator. The backwash water produced is stored in a 1,800-gallon holding tank equipped with high/low level sensors. After solids are settled in the tank for a preset time period, the recycle pump is turned on and the water in the holding tank is filtered through a bag filter before being blended with the raw water at a maximum ratio of 10%.

When the arsenic removal capacity of the AAFS50 media in the lead tank is exhausted, the spent media will be removed and virgin media will be loaded into the vessel. Based on the water quality of Well No. 2, Kinetico estimates that the AAFS50 media has a capacity of 18,680 bed volumes, which will last for 173 days, assuming that the system operates 8 hours a day and that the pH of the raw water is adjusted to pH 7.0. When the system operates for 24 hours a day without pH adjustment, the media in the lead tank will last for only 56 days before change-out is necessary.

## **3.2 Ion Exchange**

**3.2.1 Fruitland, ID (Purolite A-520E Resin).** The Fruitland water system supplies drinking water to approximately 4,000 citizens. Well No. 6 that has a flow capacity of 250 gpm and high arsenic and

nitrate concentrations was selected for the demonstration project. Because of the high nitrate level, this well was taken off-line several years ago. During the hydraulic testing of the new anion exchange system, the well produced a large quantity of sediment due to a damaged casing. Because of the problem, a new well, Well No. 6-2004, was drilled near Well No. 6 as replacement. The new well also operates at 250 gpm and contains the same high levels of arsenic and nitrates as the abandoned well.

**3.2.1.1 Treatment System Description.** The Kinetico IX-248-AS/N ion exchange arsenic and nitrate removal system consists of the following components:

- **Pre-filtration.** The source water passes through a skid-mounted cartridge filtration system equipped with five 20- $\mu$ m bag filters. This filtration step prevents the resin bed from being fouled by particulates.
- **Ion exchange system.** The ion exchange system consists of two parallel 48-inch-diameter, 72-inch-tall FRP pressure vessels, each contains 50 ft<sup>3</sup> (in 4-ft depth) of Purolite A-520E strong base anion exchange resin, 3 ft<sup>3</sup> of flint gravel support media, and 3 ft<sup>3</sup> of polypropylene filler beads. The skid-mounted vessels are rated for 150 psi working pressure, and piped to a valve rack mounted on a welded steel frame. Each vessel is equipped with a 125-gpm flow-limiting device. A brine saturator and a 2-hp, 60-gallon vertical air compressor also are included with the system.

**3.2.1.2 Treatment System Operation.** The Kinetico arsenic/nitrate removal system is a fully automated system that has an operator interface, programmable logic controller (PLC), and a modem housed in a control panel. The control panel is connected to various instruments used to track the system performance, including flowrate and the volume of water treated since the last regeneration.

The system is regenerated based upon nitrate breakthrough, which is estimated to be at 400 to 500 bed volumes of water treated. Regeneration occurs one vessel at a time, thus temporarily reducing the service flowrate to 125 gpm. Regeneration is performed in a co-current mode using a NaCl brine solution stored in a nearby holding tank. The regeneration process is controlled by the system PLC, which is programmed to initiate the regeneration sequence after a given volume throughput (this volume is determined by sampling the process effluent during the system startup). The regeneration process includes three consecutive steps: brine draw, slow rinse, and fast rinse. The salt usage rate is estimated to be 3.19 lb/1,000 gallons of water treated.

### 3.3 Coagulation/Filtration

**3.3.1 Climax, MN.** The City of Climax supplies drinking water to 264 community members. The source water is supplied by two 141 ft-deep wells, each having a flow capacity of 160 and 140 gpm. However, only one well is in use at any one time with the two wells alternating on a monthly basis. Both wells can be used during fire emergencies with a full capacity of 300 gpm. Prior to this demonstration project, the treatment system consisted of only a chlorine gas feed to reach a target residual chlorine level of 0.6 mg/L. The water also is fluoridated to a target level of 1.8 mg/L.

**3.3.1.1 Treatment System Description.** Kinetico's coagulation/filtration system is a skid-mounted system consisting of two coagulation contact tanks and two pressure filtration tanks. The major components are described as follows:

- **Pre-chlorination.** The existing chlorine gas system is used to provide disinfection and oxidation of As(III) and Fe(II).

- **Coagulation.** Two 345-gallon, 42-inch-diameter, 72-inch-tall FRP contact tanks arranged in parallel provide 5 minutes of contact time each to facilitate the formation of iron flocs prior to filtration.
- **Macrolite® filtration.** Two pressure filtration vessels are arranged in parallel. Both FRP filtration vessels are 36 inches in diameter and 72 inches in height with 6-inch top and bottom flanges, and are mounted on a polyurethane coated, steel frame. Each vessel is filled with approximately 24 inches (14 ft<sup>3</sup>) of 40/60 mesh Macrolite® media, which is underlain with a fine garnet fill layered 1 inch above the 0.006-inch slotted SS wedge-wire underdrain. The flow through each vessel is regulated to 70 gpm using a flow-limiting device to prevent filter overrun or damage to the system. The normal system operation with both tanks on-line provides a total system flow of 140 gpm.

**3.3.1.2 Treatment System Operation.** The system is fully automated with an operator interface, PLC, and a modem housed in a central NEMA 4 control panel. The control panel is connected to various instruments used to track system performance including inlet and outlet pressure after each filter, system flowrate, backwash flowrate, and backwash turbidity.

At a 10 gpm/ft<sup>2</sup> loading rate and 24 inches of depth, the pressure drop across a clean Macrolite® filter bed is usually about 15 psi. The filters are automatically backwashed in upflow mode when the pressure drop across the bed reaches 25 to 30 psi. The backwash process involves multiple steps: the water is first drained from the filtration vessel and the filter is then sparged with air at 100 psig. After a brief settling period, the filtration vessel is backwashed with treated water at a flowrate of approximately 55 gpm. The backwash is performed one vessel at a time and the resulting wastewater is sent to the sanitary sewer through a 2-inch-diameter polyvinyl chloride (PVC) line. After backwash, the filtration vessel undergoes a filter-to-waste cycle before returning to feed service.

**3.3.2 Lidgerwood, ND.** The Lidgerwood water treatment system supplies drinking water to approximately 750 community members. The system capacity is 250 gpm for a peak daily demand of 180,000 gpd. The source water is pumped from two wells with the wells alternating every month. The total arsenic concentrations of the source water range from 38 to 146 µg/L. An arsenic speciation test performed in July 2003 found arsenic (146.2 µg/L) to be predominately As(III) (82%). The current treatment process relies on the oxidation of As(III) to As(V) and the adsorption and co-precipitation of As(V) onto iron solids. The source water has iron levels ranging from 1,310 to 1,620 µg/L. Historic analytical results indicate that iron levels typically are 9 to 11 times higher than the arsenic levels in the source water. The treated water results confirm that incomplete arsenic removal is occurring, with arsenic concentrations in the gravity filtration cell effluent being measured at 25 to 31 µg/L.

Treated water is stored in a clearwell before distribution. Two clearwells are located underneath the treatment building, including the original 16,000-gallon clearwell installed in 1984 and used as a source of clean backwash water, and the second 30,000-gallon clearwell installed in 1989 and used for distribution water. A 50,000-gallon water tower is included as part of the distribution for water storage.

**3.3.2.1 Treatment System Description.** The Lidgerwood treatment system consists of pre-chlorination, forced-draft aeration, KMnO<sub>4</sub> oxidation, polymer coagulant addition, detention, gravity filtration, post-chlorination, and fluoridation. A brief description of each treatment step is provided below:

- **Pre-chlorination.** A chlorine gas feed system is used for pre-chlorination of the source water to 1.8 mg/L as Cl<sub>2</sub>. Pre-chlorination helps prevent biological

growth in the filters and other system components. Chlorine also oxidizes iron, manganese, and arsenic in the groundwater.

- **Aeration.** Forced-draft aeration is used to promote the transfer of oxygen in air to the extracted groundwater in order to oxidize iron and manganese.
- **KMnO<sub>4</sub> oxidation.** A supplementary oxidation step is provided by the addition of KMnO<sub>4</sub>, which is stored in a 50-gallon tank and added at a dosage of approximately 0.6 to 0.7 mg/L. The potassium permanganate is used to continuously regenerate the MnO<sub>2</sub>-coated anthrasand in the filter cells.
- **Mixing and detention.** Polymer coagulant is stored in a 50-gallon tank and added to the rapid mix tank just prior to the baffled detention tank. The baffled detention tank has a capacity of 15,000 gallons, allowing for about 60 minutes of contact time before gravity filtration.
- **Filtration.** The particulate matter in the water is removed using four gravity filter cells with a total cross-sectional area of 120 ft<sup>2</sup> that are filled with 20 × 40 mesh MnO<sub>2</sub>-coated anthrasand. The hydraulic loading to the filters is approximately 2 gpm/ft<sup>2</sup>. The anthrasand was most recently changed out in October 2002.
- **Post-chlorination and fluoridation.** For post-chlorination, the free chlorine is targeted at 0.08 mg/L and the total chlorine residual is targeted at 1.9 mg/L. In addition, fluoride also is added to treated water prior to distribution.

**3.3.2.2 Treatment System Operation.** The treatment system operates 5 to 6 hours per day depending on water usage, and backwashing of the filters is performed on a regular schedule every Monday, Wednesday, and Friday or more frequently as needed. The system is equipped with a backwash recycling system. The backwash flowrate is about 240 gpm with an air scour pressure of 3.5 lb. Each backwash cycle usually lasts for 15 minutes per cell with 5 minutes of air and water supply and 10 minutes of water supply only. The backwash water produced from each backwash cycle is allowed to settle in a 18,000-gallon backwash recovery basin for about 6 hours before the supernatant is reclaimed to the mixing tank at a flowrate of 50 gpm. The sludge accumulated in the bottom of the backwash tank is pumped to a 20-ft-diameter by 9-ft, 5-inch-tall sludge holding tank and then collected for landfill disposal once every other year.

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## **Appendix A**

### **Photographs of Arsenic Removal Treatment Systems**



**Figure A-1. Bow, NH Treatment System**



**Figure A-2. Desert Sands MDWCA, NM Treatment System**



**Figure A-3. Brown City, MI Treatment System**



**Figure A-4. Queen Anne's County, MD Treatment System**



**Figure A-5. Nambe Pueblo, NM Treatment System  
(Photograph Taken before Shipment)**



**Figure A-6. Rimrock, AZ Treatment System**



**Figure A-7. Rollinsford, NH Treatment System**



**Figure A-8. Valley Vista, AZ Treatment System**



**Figure A-9. STMGID, NV Treatment System  
(Photograph Taken in the Shop)**



**Figure A-10. Climax, MN Treatment System**



**Figure A-11. Fruitland, ID Treatment System**



**Figure A-12. Lidgerwood, ND System Modification (Iron Addition System)**