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Capital Costs of Arsenic Removal Technologies U.S. EPA Arsenic Removal Technology Demonstration Program Round 1

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FOREWORD

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Sally Gutierrez, Acting Director
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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, the 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). Since the inception of the project, 10 of 12 systems have been installed, with flowrates at all systems ranging from 37 to 640 gpm.

A key objective of the long-term demonstration project is to determine the cost-effectiveness of the technologies. This report provides a brief description of each of the 12 Round 1 demonstration sites and the respective technologies being evaluated. Capital costs were organized into three categories—equipment, engineering, and installation—and then summed to arrive at a total capital investment cost for each system. Operations and maintenance (O&M) costs associated with the treatment systems are not yet available; however, vendor-supplied estimates on media replacement costs also are provided in this report.

Excluding the cost for one system modification site, the total capital investment costs range from $90,757 to $305,000, and vary by flowrate, system design, material of construction, monitoring equipment, and specific site conditions. Based on a 3% interest rate and a 20-year return period, the unit costs of the total capital investment range from $0.03 to $0.79 per 1,000 gallons of water treated. In general, the unit cost decreases as the size of a treatment system increases. The equipment costs for the treatment systems range from $66,235 to $218,000, representing 54 to 80% of the total capital investment cost. Engineering costs for the treatment systems range from $4,907 to $50,659, accounting for 5 to 22% of the total capital investment with an average of 12%. Installation costs for the treatment systems range from $13,150 to $77,574, which accounts for 12 to 34% of the total capital investment with an average of 22%.

Finally, building cost information obtained from the host facilities also is provided in the report. Building costs range from $3,700 to $186,000, varying according to differences in location, size, design, material of construction, and choice of construction contractor.

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ABBREVIATIONS AND ACRONYMS

AA	activated alumina
ADEQ	Arizona Department of Environmental Quality
AM	adsorptive media (process)
APU	arsenic-package-unit
AWC	Arizona Water Company
C/F	coagulation/filtration (process)
CO_2	carbon dioxide
CRF	capital recovery factor
CS	carbon steel
EBCT	empty bed contact time
EPA	(United States) Environmental Protection Agency
FRP	fiberglass reinforced plastic
GFH	granular ferric hydroxide
GFO	granular ferric oxide
gpd	gallons per day
gpm	gallons per minute
HDPE	high-density polyethylene
HTA	Hoyle, Tanner, and Associates
IDEQ	Idaho Department of Environmental Quality
IHS	Indian Health Service
IX	ion exchange (process)
$KMnO_4$	potassium permanganate
MCL	maximum contaminant level
MDE	Maryland Department of Environment
MDEQ	Michigan Department of Environmental Quality
MDH	Minnesota Department of Health
MDWCA	(Desert Sands) Mutual Domestic Water Consumers Association
N/A	not available
NHDES	New Hampshire Department of Environmental Services
NSF	NSF International
O&M	operations and maintenance
ORD	Office of Research and Development
PE	Professional Engineer
P&ID	Piping and Instrumentation Diagram
PLC	programmable logic controller
psi(g)	pounds per square inch (gauge)

PVC	polyvinyl chloride
SDWA	Safe Drinking Water Act
SM	system modification
SS	stainless steel
STMGID	South Truckee Meadows General Improvement District
TCLP	Toxicity Characteristic Leaching Procedure
TO	Task Order
UST	underground storage tank

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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). One of the objectives of the studies is to determine the cost-effectiveness of the technologies using the cost information (including equipment, site engineering, installation, operation, and maintenance costs) provided by the vendors and/or obtained during the demonstration studies.

This report provides a brief description of each of the 12 demonstration sites and the respective technologies being evaluated and summarizes the capital investment made in the treatment systems. Building cost information obtained from the host facilities also is provided. The operations and maintenance (O&M) costs associated with the treatment systems will be reported in a separate document at the end of the demonstration project.

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, 2001). 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, 2003). 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.

In September 2002, EPA solicited proposals from engineering firms and vendors for commercially available cost-effective arsenic removal treatment technologies for the 17 potential host sites. The objective of this solicitation was to select treatment technologies for the demonstration project, which will evaluate 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 limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration project. 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 (sorted geographically from the Northeast to the Southwest), technologies, vendors, and key source water quality parameters (including arsenic, iron, and pH) of the 12 demonstration sites. Since the inception of the project, ten treatment systems have been installed and their performance is currently being evaluated. The systems for the Nambe Pueblo and STMGID sites are to be installed and expected to be operational before the end of 2004.

Table 1-1. Summary of Arsenic Removal Technologies and Source Water Quality Parameters

State	Demonstration Site	Technology	Vendor	Design Flowrate (gpm)	Source Water Quality As (µg/L)	Fe (µg/L)	pH
NH	Bow	AM (G2)	ADI	70[(a)]	39	<25	7.7
NH	Rollinsford	AM (E33)	AdEdge	100	36[(b)]	46	8.2
MD	Queen Anne's County	AM (E33)	Severn Trent	300	19[(b)]	270[(c)]	7.3
MI	Brown City	AM (E33)	Severn Trent	640	14[(b)]	127[(c)]	7.3
MN	Climax	C/F	Kinetico	140	39[(b)]	546[(c)]	7.4
ND	Lidgerwood	SM	Kinetico	250	146[(b)]	1,325[(c)]	7.2
NM	Desert Sands MDWCA	AM (E33)	Severn Trent	320	23[(b)]	39	7.7
NM	Nambe Pueblo	AM (E33)	AdEdge	145	33	<25	8.5
AZ	Rimrock	AM (E33)	AdEdge	90[(a)]	50	170	7.2
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 Consumer's 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).

2.0 ADSORPTIVE MEDIA PROCESSES

Nine of the 12 demonstration sites use adsorptive media (AM) processes in their arsenic removal treatment systems. These systems use four different adsorptive media: two of the media are iron products, either ferric oxide (E33) or ferric hydroxide (GFH), and the other two are iron-modified media (G2 and AAFS50). The key physical and chemical properties and costs of the four adsorptive media are presented in Table 2-1.

Because of varying site conditions and source water quality, the design and basic components of the AM systems vary among the demonstration sites. Three systems configure the AM vessels in series, whereas the other six in parallel. Also, some systems require pH adjustment because of high source water pH values. These variations in design have an impact on the total investment costs and must be taken into consideration when attempting to compare the costs of different systems. Table 2-2 summarizes the design and basic components of the AM systems.

Table 2-1. Physical and Chemical Properties and Costs of the Adsorptive Media

Parameter	G2	E33		AAFS50	GFH
Physical and Chemical Properties					
Matrix/Active Ingredient	Diatomaceous earth (Si-based) impregnated with a coating of ferric hydroxide	Iron oxide composite (90.1% FeOOH)		83% Al_2O_3 + proprietary additive	52-57% $Fe(OH)_3$ and β-FeOOH
Physical Form	Dry powder	Dry granular media		Dry granular media	Moist granular media
Color	Dark brown	Amber		Light amber	Dark brown
Bulk Density (g/cm^3)	0.75	0.45		0.91	1.22-1.29
Bulk Density (lb/ft^3)	47	28		57	76-81
BET Area (m^2/g)	27	142		220	127
Particle Size Distribution/ Effective Size (mm)	0.32	10 × 35 mesh		28 × 48 mesh	0.32-2
Media Cost					
Vendor	ADI	Severn Trent	AdEdge	Kinetico	USFilter
Cost ($/ft^3)	35	150	245	82	238
Cost ($/lb)	0.75	5.36	8.75	1.44	3.03
Media Replacement Cost (a)					
Vendor	ADI	Severn Trent	AdEdge	Kinetico	USFilter
Cost ($/ft^3)	40	167.5	295-329	252	244
Cost ($/lb)	0.85	5.98	10.54-11.75	4.42	3.12

(a) Cost includes material, freight, labor, travel expense, and media profiling and disposal fees, except for the cost of G2 which includes material and freight only.
N/A = not available.

Table 2-2. Summary of the Design and Components of the Adsorptive Media Systems

Media Type	Site	Media Vessels			Media Volume per Vessel (ft^3)	EBCT at Design Flow (min)	Pre/Post-Treatment			
		No.	Configu-ration	Material			Pre-Cl_2	Pre-pH Adjustment	Post-Cl_2	Post-pH Adjustment
G2	Bow, NH	2	Series	SS	85	18[(a)]	Yes	H_2SO_4	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_2	No	No
E33	Rimrock, AZ	2	Series	FRP	27	4.5[(a)]	Yes	No	No	No
E33	Rollinsford, NH	2	Parallel	FRP	27	4.0	Yes	CO_2	No	No
AAFS50	Valley Vista, AZ	2	Series	FRP	22	4.4[(a)]	Yes	H_2SO_4	No	No
GFH	STMGID, NV	3	Parallel	CS	80	5.1	No	No	Yes	No

EBCT = empty bed contact time; SS = stainless steel; FRP = fiberglass reinforced plastic; CS = carbon steel
(a) EBCT is for one vessel only.

2.1 G2 Adsorptive Media

The G2 media is an iron oxide-modified adsorptive media developed by ADI, Inc. specifically for arsenic adsorption. The media consists of a substrate of granular, calcined diatomite on which a ferric hydroxide coating is bonded. The physical and chemical properties of the G2 media are shown in Table 2-1. The media has NSF Standard 61 listing for use in drinking water. ADI markets G2 media for both As(V) and As(III) removal. As with most iron media products, G2 has a higher removal capacity for As(V) than As(III). Thus, a pre-chlorination step often is employed to oxidize As(III) in source water to As(V) prior to filtering the water through the G2 media.

The ADI G2 media process is being demonstrated at Bow, NH. The arsenic removal system is a fixed bed adsorption system consisting of two downflow pressure vessels in series. O&M of the system involves routine sampling and mechanical maintenance, monthly manual backwashing (to "fluff" media), and media replacement as necessary once the media reaches its adsorption capacity. Spent media, which is expected to pass the EPA's Toxicity Characteristic Leaching Procedure (TCLP) test, will be disposed of as non-hazardous waste. G2 media can be regenerated with 1% sodium hydroxide up to four times before the media needs to be replaced; however, for small systems, regeneration is generally not practiced because disposal of the regenerate (hazardous) is problematic.

2.1.1 Bow, NH Site Background. 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. 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 providing approximately 14,500 gpd.

Historically, the arsenic level in the source water ranges from 35 to 45 μg/L. An arsenic speciation test conducted on the source water in April 2004 found the arsenic (39.2 μg/L) to be predominately As(V) (38.7 μg/L). The iron level of the source water is relatively low, ranging from <25 to 60 μg/L. Based on the vendors' past experience, the level of iron in the source water is low enough that pretreatment for iron removal is not considered necessary. G2 media adsorbs arsenic most effectively at a pH value within the 5.5 to 7.5 range. Because the historic pH value of the source water ranges from 7.7 to 7.8, lowering the pH value to 6.5 is included as part of the demonstration study treatment system to extend the media life.

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 to control corrosion via pH adjustment. In addition, about 10 to 15% of the flow was treated through an activated alumina (AA) system that had been used at the site for several years.

2.1.2 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 decided to withdraw 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 ± 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^3 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 ± 0.2 before the water enters the distribution system for corrosion control.

2.1.3 Treatment System Operation. The G2 media system is operated in downflow mode through the SS adsorption vessels. Flow to each vessel is measured and totalized 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 from the storage tank. The purpose of the backwash is 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.

The 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 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. The estimated G2 media replacement cost is $6,800 per change-out (or $40/$ft^3$ for 170 ft^3 of media). This cost, however, does not include the cost for spent media off-loading and disposal or virgin media re-loading.

2.1.4 Capital Investment. The capital investment costs for equipment, site engineering, and installation at the Bow, NH Site are $154,700 (see Table 2-3). The equipment costs include the costs for two SS adsorption vessels, G2 media, a backwash booster pump, and associated piping, valving, and system instrumentation. The costs of the adsorption package unit are $76,100, which is approximately 74% of the total equipment costs or 49% of the total capital investment. The media cost (4,000 lb or 85 ft^3 in each vessel) is $6,000. The equipment costs also include $3,900 for a backwash booster pump and $16,600 for vendor's field services.

Table 2-3. Summary of Capital Investment for the Bow, NH Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
		Equipment Costs	
Adsorption System	1 unit	$76,100	–
G2 Media	170 ft^3	$6,000	–
Backwash Booster Pump	1	$3,900	–
Field Services (Vendor Labor and Travel)	–	$16,600	–
Equipment Total	–	**$102,600**	**66%**
		Engineering Costs	
Vendor Labor	–	$12,500	–
Engineering Total	–	**$12,500**	**8%**
		Installation Costs	
Subcontractor	–	$32,500	–
Vendor Labor	–	$3,550	–
Vendor Travel	–	$3,550	–
Installation Total	–	**$39,600**	**26%**
Total Capital Investment	–	**$154,700**	**100%**

The site engineering costs include the costs of preparing and submitting the required engineering plans to obtain system permits from the New Hampshire Department of Environmental Services (NHDES) Water Supply Engineering Bureau. The engineering plans include the process flow diagrams of the treatment system, system layout and footprint, mechanical and electrical tie-ins, and construction plan for the treatment building. Lewis Engineering, a local civil engineering firm, performed the site engineering design for the treatment system; C&C Water Services, the owner/operator of the water system, provided the construction plan for the treatment building. The engineering costs are $12,500, which is approximately 8% of the total capital investment.

Installation costs are $39,600, including costs for equipment and labor to unload and install the adsorption unit, perform the piping tie-ins and electrical work, and load and condition the media. The installation was conducted by Lewis Engineering and C&C Water Services.

2.2 E33 Adsorptive Media

Bayoxide® E33 media is a granular ferric oxide (GFO) developed by Bayer AG for the removal of arsenic from drinking water supplies. The physical and chemical properties of E33 media are shown in Table 2-1. E33 media is provided in a dry crystalline form and has received NSF Standard 61 listing for use in drinking water applications. Severn Trent markets the media in the United States as Sorb-33, and offers several arsenic-package-units (APUs) with flowrates ranging from 150 to 300 gpm. Another company, AdEdge, Inc., provides similar systems using the same media (marketed as AD-33) with flowrates ranging from 5 to 150 gpm.

Each Severn Trent APU system consists of one or more fixed-bed pressure vessels, piping, instrumentation controls, and E33 media. The vessels are operated in downflow mode and can be configured in series or parallel. E33 media cannot be regenerated and the media is removed and disposed of after reaching its capacity. The media life depends on the influent arsenic concentration, water pH value, and concentrations of interfering ions that compete for the adsorption sites. Spend media is expected to pass the EPA's TCLP test and will be disposed of as non-hazardous waste. The APU system is designed to perform manual or automated backwash on a monthly or as-needed basis to remove iron oxide fines and to re-expand the compacted bed.

One of the Severn Trent treatment systems, APU-300, was installed at three demonstration sites: Desert Sands Mutual Domestic Water Consumer's Association (MDWCA) near Anthony, NM; Brown City, MI; and Queen Anne's County near Stevensville, MD. Raw water is pumped to the APU-300 system via 4-inch-diameter piping to two parallel 63-inch-diameter, 86-inch-tall fiberglass reinforced plastic (FRP) vessels. The system capacity is 150 gpm per vessel for a total rated capacity of 300 gpm.

Another similar, but smaller system, APU-100, was supplied by AdEdge and installed at three other demonstration sites: Nambe Pueblo, NM; Rimrock, AZ; and Rollinsford, NH. Raw water enters the APU-100 system via 2-inch-diameter piping to two parallel 36-inch-diameter and 72-inch-tall FRP vessels. The APU-100 system is designed for 50 gpm through each vessel. Each vessel has a dedicated instantaneous flow totalizer.

During the backwash cycle, raw water is directed to the laterals at the bottom of the FRP vessel via either the bottom opening of the APU-300 system or the top opening of the APU-100 system through a controller valve. The backwash water exits the top of the vessel and flows down to a discharge line, a clear sight tube (which allows for visual observation of the turbidity of the backwash water), and a backwash flow totalizer prior to discharge.

2.2.1 Desert Sands MDWCA (APU-300 System)

2.2.1.1 Site Background. 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.

Total arsenic concentrations in Well No. 3 source water range from 17.0 to 22.7 µg/L. An arsenic speciation test conducted on the water in August 2003 found the arsenic (22.7 µg/L) to be predominately As(III) (21.6 µg/L). A small amount of arsenic exists as As(V) (0.7 µg/L) and particulate As (0.4 µg/L). Prior to the installation of the APU-300 system, the well water was treated with sodium hypochlorite (0.4 to 0.5 mg/L as Cl_2) for disinfection and the oxidation of trace amounts of hydrogen sulfide. Source water pH values range from 7.6 to 7.7, so pH adjustment is not required. The concentrations of iron (38.9 to 73.0 µg/L) and other ions in the source water are sufficiently low as to not require any pretreatment other than chlorine.

2.2.1.2 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 FRP pressure vessels, each containing about 80 ft^3 of E33 media.

2.2.1.3 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. The estimated E33 media replacement cost is $26,800 per change-out (or $167.5/$ft^3$ for 160 ft^3 of media). This cost includes material, freight, labor, travel expense, and media profiling and disposal fee.

2.2.1.4 Capital Investment. The capital investment costs for equipment, site engineering, and installation are $153,000 (see Table 2-4). The equipment costs are $112,000 (or 73% of the total capital investment), which includes $72,000 for the APU-300 skid-mounted unit, $24,000 for E33 media (i.e., $150/$ft^3$ or $5.34/lb to fill two vessels), and vendor's labor and travel for the system shakedown and startup.

Table 2-4. Summary of Capital Investment for the Desert Sands MDWCA Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
APU-300 Skid-Mounted System	1 unit	$72,200	–
Sorb-33 Media	160 ft^3	$24,000	–
Miscellaneous Equipment and Materials	–	$2,500	–
Vendor Labor	–	$9,500	–
Vendor Travel	–	$3,800	–
Equipment Total	–	**$112,000**	**73%**
Engineering Costs			
Subcontractor	–	$16,300	–
Vendor Labor	–	$6,700	–
Engineering Total	–	**$23,000**	**15%**
Installation Cost			
Subcontractor	–	$9,000	–
Vendor Labor	–	$5,600	–
Vendor Travel	–	$3,400	–
Installation Total	–	**$18,000**	**12%**
Total Capital Investment	–	**$153,000**	**100%**

The engineering costs include the costs for the preparation of the system layout and footprint, design of the piping connections up to the distribution tie-in points, design of the electrical connections, and assembling and submission of the engineering plans for the permit application. The engineering costs are $23,000, which is 15% of the total capital investment.

The installation costs include the costs for the equipment and labor to unload and install the APU-300 system, perform the piping tie-ins and electrical work, and load and backwash the media. The installation was performed by Severn Trent and the Desert Sands MDWCA utility staff subcontracted to Severn Trent. A variety of elevated pressure and flow restriction issues caused the actual system start-up date to be delayed, and these problems forced Severn Trent to redesign the system's piping, valving, and instruments and controls. The costs for the system retrofitting are not included in this cost analysis. The installation costs are $18,000, or 12% of the total capital investment.

2.2.2 Brown City, MI (APU-300 System)

2.2.2.1 Site Background. 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.

Based on historic sampling results at the site, the total arsenic level in the groundwater ranges from 10 to 36 μg/L. An arsenic speciation test conducted on water from Well No. 4 in July 2003 indicated that the arsenic (14.2 μg/L) is primarily As(III) (11.2 μg/L). The ability of E33 media to remove both As(III) and As(V) is currently being tested. Chlorine for disinfection is added after water passes through the APU-300 treatment system. The level of iron in the source water ranges from 127 to 263 μg/L, which is low enough not to require any pretreatment for iron removal. Because the source water pH values range from 7.3 to 7.5, pH adjustment was determined to be unnecessary. Other water quality parameters also were determined to have no adverse impact on the E33 arsenic adsorption.

2.2.2.2 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^3 of E33 media.
- **Post-chlorination.** Sodium hypochlorite is added to treated water for disinfection. The target residual levels are 0.3 mg/L (as Cl_2) for free chlorine and 0.4 mg/L (as Cl_2) for total chlorine in the distribution system.

2.2.2.3 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. The estimated E33 media replacement cost for the Brown City system is $53,600 per change-out (or $167.5/$ft^3$ for a total of 320 ft^3 of media).

2.2.2.4 Capital Investment. The capital investment costs for the Brown City system are $305,000 (see Table 2-5). The equipment costs include the costs for the two skid-mounted APU-300 units ($144,400), Sorb-33 media ($150/$ft^3$ or $5.34/lb to fill four vessels with a total cost of $48,000),

Table 2-5. Summary of Capital Investment for the Brown City, MI Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
APU Skid-Mounted System	2	$144,400	–
Sorb-33 Media	320 ft^3	$48,000	–
Miscellaneous Equipment and Materials	–	$3,400	–
Vendor Labor	–	$17,500	–
Vendor Travel	–	$4,700	–
Equipment Total	–	**$218,000**	**71%**
Engineering Costs			
Subcontractor	–	$27,740	–
Vendor Labor	–	$6,680	–
Vendor Travel	–	$1,080	–
Engineering Total	–	**$35,500**	**12%**
Installation Costs			
Subcontractor	–	$42,000	–
Vendor Labor	–	$5,600	–
Vendor Travel	–	$3,900	–
Installation Total	–	**$51,500**	**17%**
Total Capital Investment	–	**$305,000**	**100%**

miscellaneous materials and supplies ($3,400), and vendor's labor and travel ($22,200) for the system shakedown and startup activities. The equipment costs are 71% of the total capital investment.

The engineering costs include the costs for the design work necessary to develop the final system layout and footprint within the building, design of the piping connections up to the distribution tie-in points in the building, and the design of the electrical connection and conduit plan. The engineering plans were prepared by Boss Engineering of Michigan and included an existing site conditions plan, a floor plan, a process flow diagram, and other site-specific details. The engineering costs also include the cost for the submission of the plans to the Michigan Department of Environmental Quality (MDEQ) for permit review and approval. Engineering costs amount to $35,500 or 12% of the total capital investment.

The installation costs include the cost for labor, equipment, and materials to unload and install the skid-mounted units, perform the piping tie-ins and electrical work, and load and backwash the media. All of the piping tie-ins were completed using ductile iron pipe, valves, and fittings. Installation costs are $51,500 or 17% of the total capital investment.

2.2.3 Queen Anne's County (APU-300 System)

2.2.3.1 Site Background. The Queen Anne's County facility supplies water to approximately 300 connections (900 people) 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.

The total arsenic concentrations in the groundwater range from 17 to 20 µg/L. An arsenic speciation test conducted in August 2003 indicated that arsenic (18.8 µg/L) exists predominately as As(III) (18.4 µg/L).

Historic source water sampling has shown that total iron levels range from 50 to 1,660 μg/L; however, the most recent data indicate that iron levels are below 300 μg/L. The iron level is low enough that pretreatment for iron removal would not be required. Moreover, because the pH values of the source water range from 7.0 to 7.5, pH adjustment also would not be necessary. No other water quality parameters have been found to have a potential adverse impact on the media performance.

Prior to the demonstration project, the only 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.

2.2.3.2 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.
- **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_2). 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.

2.2.3.3 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. The estimated media replacement cost for the Queen Anne's County system is identical to the cost for the Desert Sands MDWCA system, i.e., $26,800 per change-out.

2.2.3.4 Capital Investment. The capital investment for the Queen Anne's County system is $211,000 (see Table 2-6), which includes $129,500 for equipment, $36,700 for site engineering, and $44,800 for system installation. The equipment costs include the costs for a skid-mounted APU-300 system ($72,200), E33 media ($150/ft^3 or $5.36/lb for a total media cost of $24,000 to fill two vessels), miscellaneous materials and supplies ($19,800), and vendor's labor and travel for the system shakedown and startup ($13,500). The equipment costs are about 62% of the total capital investment.

The engineering costs include costs for the relevant process flow diagrams of the treatment system, system layout and footprint (supplied by Severn Trent), and mechanical details of the treatment equipment and piping connections. Stearns and Wheeler, LLC, a local engineering firm, performed the engineering design for the treatment system, as well as the design for the treatment building. The costs also cover the labor to compile the design package, including the system information and construction plans for the treatment building, for submission to the Maryland Department of the Environment (MDE) for review and approval. The engineering costs of $36,700 are 17% of the capital investment.

Table 2-6. Summary of Capital Investment for the Queen Anne's County Treatment System.

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
APU Skid-Mounted System	1 unit	$72,200	–
E33 Media	160 ft^3	$24,000	–
Misc. Equipment and Materials	1	$19,800	–
Vendor Labor	–	$10,000	–
Vendor Travel	–	$3,500	–
Equipment Total	–	**$129,500**	**62%**
Engineering Costs			
Subcontractor	–	28,940	–
Vendor Labor	–	$6,680	–
Vendor Travel	–	$1,080	–
Engineering Total	–	**$36,700**	**17%**
Installation Costs			
Subcontractor	–	$35,800	–
Vendor Labor	–	$5,600	–
Vendor Travel	–	$3,400	–
Installation Total	–	**$44,800**	**21%**
Total Capital Investment		**$211,000**	**100%**

The installation costs include costs for the equipment and labor to unload and install the skid-mounted units, perform the piping tie-ins and electrical work, and load and backwash the media. The installation work and the construction of the treatment building were conducted by Stearns and Wheeler and their construction subcontractor. Installation costs of $44,800 are 21% of the capital investment.

2.2.4 Nambe Pueblo, NM (APU-150 System)

2.2.4.1 Site Background. 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.

The total arsenic concentrations of the well water range from 29 to 33.2 μg/L. An arsenic speciation test conducted in August 2003 found arsenic (33.2 μg/L) to be primarily As(V) (31.2 μg/L) with 1.8 μg/L as particulate and 0.2 μg/L as As(III). The pH values of the raw water range from 8.5 to 8.8, so pH adjustment using carbon dioxide (CO_2) is recommended by AdEdge to lower the pH to approximately 7.0 upstream of the arsenic treatment system. The concentration of iron (<30 to 138 μg/L) and other ions in the source water are low enough not to interfere significantly with the adsorption of arsenic by the E33 media.

2.2.4.2 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_2 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_2).
- **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^3 of E33 media.

2.2.4.3 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_2 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. The estimated media replacement cost is $24,196 per change-out (or $295/$ft^3$ for 82 ft^3 of media to fill all three vessels).

2.2.4.4 Capital Investment. The capital investment for the APU-150 system is $139,251 (see Table 2-7). The equipment costs are $112,211, which includes the costs for one APU-100 and one APU-50 skid-mounted unit ($54,380), a CO_2 injection (i.e., pH adjustment) module ($16,250), 82 ft^3 of E33 media ($20,090), and vendor labor and shipping ($21,491). The equipment costs are 80% of the capital investment.

Table 2-7. Summary of Capital Investment for the Nambe Pueblo Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
APU-150 Skid-Mounted System	2 skids	$54,380	–
pH Adjustment Module	1 unit	$16,250	–
E33 Media	82 ft^3	$20,090	–
Vendor Labor	–	$19,230	–
Shipping	–	$2,261	–
Equipment Total	–	**$112,211**	**80%**
Engineering Costs			
Subcontractor	–	$6,300	–
Vendor Labor	–	$3,420	–
Vendor Travel	2 days	$993	–
Material	–	$75	–
Engineering Total	–	**$10,788**	**8%**
Installation Costs			
Subcontractor	–	$11,522	–
Vendor Labor	4 days	$3,040	–
Vendor Travel	4 days	$1,290	–
Material	–	$400	–
Installation Total	–	**$16,252**	**12%**
Total Capital Investment	–	**$139,251**	**100%**

The engineering cost includes costs for the preparation of a set of documents related to the process equipment, including specification sheets, mechanical drawings, equipment configurations, and piping and instrumentation diagrams (P&IDs). A formal engineering design package is not required for the Nambe Pueblo site, as the Pueblo's political status obviates the need for state permitting. The Indian Health Service (IHS) prepares the majority of the site engineering drawings. The engineering costs incurred by AdEdge are $10,788, or 8% of the capital investment.

The installation costs include the costs for the equipment, travel, and labor to unload and install the APU-150, perform the piping tie-ins and electrical work, and load and backwash the media. The installation will be performed by a local firm subcontracted to AdEdge. The installation costs are $16,252, or 12% of the capital investment.

2.2.5 Rimrock, AZ (APU-100 System)

2.2.5.1 Site Background. 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 µg/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.

Total arsenic concentrations in the blended well water range from 51 to 61 µg/L. An arsenic speciation test conducted on Well No. 2 water in October 2003 showed arsenic (64 µg/L) exists entirely as As(V). The iron level is 170 µg/L in the blended water and 36 µg/L in Well No. 2 water. At these levels, iron removal is not required. The pH is 7.1 to 7.2, which is within the effective removal pH range and, therefore, pH adjustment is not required. Concentrations of competing ions, such as silica (27.8 mg/L) and phosphate (<0.1 mg/L), are not high enough to significantly impact the arsenic adsorption on the media.

2.2.5.2 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 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 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. The recycling of the backwash water is accomplished by metering the water back to the APU-100 system at a rate of 0.5 gpm.

2.2.5.3 Treatment System Operation. For the purpose of the demonstration study, Well No. 2 is operated at about 30 gpm for 12 hours per day from 8:00 am to 8:00 pm 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. The tank is equipped with high- and low-level sensors, which control the recycle pump to recirculate the backwash water into the raw water feed.

The media replacement for this lead/lag-configured APU-100 system is similar to that of the Bow G2 system (see Section 2.1.3). 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. The estimated media replacement cost is \$17,780 per change-out (or \$329/ft^3 for 54 ft^3 of media).

2.2.5.4 Capital Investment. The total capital investment for the Rimrock system is \$90,757 (see Table 2-8), including \$66,235 for the equipment, \$11,372 for the site engineering, and \$13,150 for the system installation. The equipment costs accounted for 73% of the total capital investment, and include the costs for two FRP vessels, 54 ft^3 of E33 media, piping and valving, instrument and controls, field services (including operator training, technical support, and system shakedown), and miscellaneous materials and supplies. The media cost is \$245/ft^3 or \$8.73/lb with a total cost of \$13,230 to fill both vessels. In addition, a change order of \$4,840 is included for system reconfiguration from parallel to series operation.

The engineering costs include the costs for preparation and submission of engineering plans for obtaining necessary permits from the state and local regulatory agencies. Fann Environmental, LLC, a local engineering firm, provided support to AdEdge to prepare the engineering plans and submittals. The engineering plans include the system P&ID, control panel schematics, and drawings of a site plan, a treatment plan, and a piping plan. A design report and ancillary equipment cut sheets also are included in the permit submittal package. The submittals were certified by a State of Arizona-registered Professional Engineer (PE) and submitted to the Arizona Department of Environmental Quality (ADEQ) for review and approval. After the Certificate of Approval to Construct was received, a construction permit was applied to and approved by Yavapai County. Following the system reconfiguration, updated information was submitted to ADEQ for a second Approval of Construction. The engineering costs for the project were \$11,372, or 13% of the capital costs.

The installation costs include the costs for the labor for equipment unloading and plumbing, as well as mechanical and electrical connections. The activities include setting and anchoring the vessels, completing system plumbing and tie-ins to the distribution system, and performing vessel hydraulic testing and media loading. The installation activities were performed by AdEdge and Fann Environmental. System reconfiguration added \$2,070 to the installation cost, bringing the total cost for installation to \$13,150, or 14% of the capital investment.

The costs associated with the backwash recycle system are not reflected in the capital investment shown in Table 2-8. AWC contracted AdEdge to design and install the backwash recycle system for handling the backwash water. The total costs for the backwash recycle system is \$11,546, including material, engineering, and installation costs.

Table 2-8. Summary of Capital Investment for the Rimrock, AZ Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
Adsorptive Media Vessels	2	$21,800	–
E33 Media	54 ft^3	$13,230	–
Piping and Valves	1	$7,520	–
Instrumentation and Controls	1	$4,575	–
O&M Manual, Operator Training, Technical Support	1	$3,800	–
Procurement, Assembly, Labor, Shakedown	1	$12,575	–
Freight Costs	1	$1,855	–
Change Order for System Reconfiguration	1	$880	–
Equipment Total	–	**$66,235**	**73%**
Engineering Costs			
Materials, Submittals, FedEx, Postage, Supplies	1	$75	–
AdEdge PM Oversight, Specification Preparation	1	$3,420	–
Design, Drawings, Coordination	1	$4,970	–
Review Meeting, Airfare, Lodging and Meals	1	$1,017	–
Change Order for System Reconfiguration	–	$1,890	–
Engineering Total	–	**$11,372**	**13%**
Installation Costs			
Subcontractor	1	$6,750	–
Vendor Labor	4 days	$3,040	–
Vendor Travel	4 days	$1,290	–
Change order for System Reconfiguration	–	$2,070	–
Installation Total	–	**$13,150**	**14%**
Total Capital Investment(a)	–	**$90,757**	**100%**

(a) Estimated costs of $11,546 for a backwash recycle system not included.

2.2.6 Rollinsford, NH (APU-100 System)

2.2.6.1 Site Background. 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.

Historical water sampling test results show that total arsenic levels range from 34 to 56 µg/L. An arsenic speciation test conducted in August 2003 indicated that the arsenic (36.2 µg/L) exists mainly as As(III) (20.1 µg/L). The well water has total iron levels ranging from 46 to 206 µg/L, which is low enough not to require iron pretreatment. The pH values of raw water range from 7.4 to 8.4; therefore, pH adjustment to near 7.0 would increase the arsenic adsorption capacity. The presence of other ions in the source water is not likely to affect the arsenic adsorption by the E33 media.

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.

2.2.6.2 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 the 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 As(III) oxidation and improve arsenic adsorption.

- **Pre-pH adjustment.** After pre-chlorination, the water pH is adjusted to about 7.0 with CO_2 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^3 of E33 media.

2.2.6.3 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 schedule 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. The estimated media replacement cost for the Rollinsford system is similar to that for the Rimrock system, i.e., \$17,558 per change-out, or \$325/ft^3 for 54 ft^3 of media.

2.2.6.4 Capital Investment. The capital investment for the Rollinsford system is \$106,568 (see Table 2-9). The equipment costs include the costs for a skid-mounted APU-100 unit (\$23,781), a CO_2 injection module (\$16,600), E33 media (\$245/ft^3 or \$8.75/lb with a total cost of \$13,230 to fill two vessels), and miscellaneous materials, supplies, and labor (\$28,470). The equipment costs represent 77% of the total capital investment.

The engineering costs are \$4,907 (or 5% of the capital investment), which include the costs for preparing the required engineering plans for permit applications. The plans comprise process flow diagrams of the treatment system, mechanical drawings of the treatment equipment (supplied by AdEdge), and a schematic of the building footprint and equipment layout. As part of the site engineering work, Hoyle, Tanner, and Associates (HTA) designed a subsurface leach bed for disposal of the system backwash water. The design of this leach system was submitted along with an application to discharge to groundwater for review and approval by the NHDES Water Supply Engineering Bureau. This portion of the site engineering was provided by the facility and the cost for this work is not reflected in the engineering costs shown in Table 2-9.

Installation costs are \$19,580, or 18% of the capital investment. System installation was completed by Waterline Services, LLC, a local water and wastewater service firm. The installation costs include the equipment and labor to unload and install the skid-mounted unit and CO_2 injection loop and module, perform the piping tie-ins and electrical work, and load and backwash the media.

Table 2-9. Summary of Capital Investment for the Rollinsford, NH Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
APU Skid-Mounted System	1 unit	$23,781	–
E33 Media	54 ft^3	$13,230	–
Miscellaneous Equipment and Materials	–	$15,895	–
pH Adjustment Module	1	$16,600	–
Vendor Labor	–	$12,575	–
Equipment Total	–	**$82,081**	**77%**
Engineering Costs			
Material	–	$75	–
Vendor Labor	–	$3,800	–
Vendor Travel	–	$1,032	–
Engineering Total	–	**$4,907**	**5%**
Installation Costs			
Material	–	$400	–
Subcontractor	–	$14,850	–
Vendor Labor	–	$3,040	–
Vendor Travel	–	$1,290	–
Installation Total	–	**$19,580**	**18%**
Total Capital Investment	–	**$106,568**	**100%**

2.3 AAFS50 Adsorptive Media

Alcan's Actiguard AAFS50 media is an iron-modified AA media and is used in Kinetico's arsenic adsorption systems. AAS50 is engineered with a proprietary additive to enhance its arsenic adsorption performance over standard-grade AA media. The physical and chemical properties of the AAFS50 media are shown in Table 2-1. The AAFS50 media has NSF Standard 61 listing for use in drinking water. Kinetico recommends that the raw water pH be adjusted to less than 7.7 and that As(III) be oxidized to As(V) to maximize arsenic removal. The adsorption capacity of the AAFS50 media can be impacted by both high levels of phosphate (>1 mg/L) and silica (>40 mg/L as SiO_2).

The Kinetico AAFS50 system uses a single or multiple fixed bed pressure vessels, operating in downflow mode, to remove dissolved arsenic. The AAFS50 system is designed with a lead/lag tank configuration. Spent media is expected to pass the EPA's TCLP test, and will be disposed of as non-hazardous waste. The system backwash is initiated by an operator on a monthly or as-needed basis. The backwash water is stored in a 1,800-gallon holding tank, which is part of the AAFS50 package system. The stored backwash water can be reclaimed with a recycle pump after passing through a bag filter assembly.

2.3.1 Valley Vista, AZ Site Background. 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 a sodium hypochlorite feed to reach a target residual chlorine level at 0.6 mg/L (as Cl_2). 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.

Historically, total arsenic concentrations in the Well No. 2 water range from 34 to 47 μg/L. An arsenic speciation test conducted in July 2003 showed that of the 41.0 μg/L total arsenic measured, 92% is As(V) (37.8 μg/L). The historical pH values vary from 7.6 to 7.9. The July 2003 analysis of the Well No. 2 water found 0.2 mg/L of fluoride, 8.7 mg/L of sulfate, 18.5 mg/L of silica (as SiO_2), and less than 0.1

mg/L of orthophosphate. These concentrations appear to be low enough that the media life would not be affected by adsorption of these ions. The same analysis found 16.2 μg/L of vanadium, but less than detectable levels of iron, aluminum, manganese, molybdenum, and antimony. The adsorption of vanadium by AAFS50 has not been reported and is not expected to reduce the arsenic removal capacity of the media.

2.3.2 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 purposes. 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 the biological growth. The chlorine residual is maintained at 0.4 to 0.6 mg/L (as Cl_2) 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^3 of the AAFS50 media. The empty bed contact time (EBCT) is 4.4 minute per vessel.

2.3.3 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. For the purposes of the demonstration study, the system operates for 24 hours a day without pH adjustment. Under these conditions, the media in the lead tank will last for only 56 days before change-out is necessary. The estimated media replacement cost for two vessels is \$11,073 per change-out, including \$7,447 for subcontractor and \$3,626 for media. The unit cost is \$252/ft^3, two times higher than the unit media cost (i.e., \$82/ft^3, see Table 2-1).

2.3.4 Capital Investment. The capital investment for the Valley Vista, AZ system is \$228,309 (see Table 2-10). The equipment costs include the costs for two skid-mounted pressure vessels, 44 ft^3 of AAFS50 media, instrumentation and controls, a backwash recycle system, a chemical injection system, labor (for operator training, technical support, and system shakedown), warranty, and miscellaneous supplies. The total equipment costs are \$122,544, or 54% of the capital investment.

The engineering costs include the costs to prepare and submit the engineering plans to obtain necessary permits from the relevant state and local regulatory agencies. Kinetico and its subcontractor, Fann Environmental, LLC, prepared the engineering plans, which include general arrangement and process and instrumentation diagrams of the AAFS50 system, a site plan, a treatment plan, and a piping plan. A process design report and ancillary equipment cut sheets also are included in the submittal package. The PE-certified submittal package was sent to ADEQ for review and approval. After the Certificate of Approval to Construct was received, a construction permit was submitted to Yavapai County for approval. After the system was installed, another package was submitted to ADEQ for an Approval of Construction. The engineering costs for the project are $50,659 or 22% of the total capital investment.

The installation costs include the costs to unload and setup the equipment and to perform mechanical and electrical connections. The activities involve setting and anchoring the adsorption vessels, completing system plumbing and tie-ins to the distribution system, performing vessel hydraulic testing, and loading media. The installation activities were performed by Kinetico and Fann Environmental. The installation costs total $55,106 or 24% of the total capital investment.

2.4 GFH Adsorptive Media

GFH is a granular ferric hydroxide media produced by GEH Wasserchemie Gmbh of Germany and marketed by USFilter under an exclusive marketing agreement. The physical and chemical properties of the GFH media are shown in Table 2-1. The GFH media that has received NSF Standard 61 listing for use in drinking water applications is capable of removing both As(V) and As(III) and has a pH operating range of 5.5 to 9.0 with the removal capacity increasing with decreasing pH. Competing ions such as silica and phosphate are known to adsorb onto the GFH media and reduce the arsenic removal capacity of the media.

Table 2-10. Summary of Capital Investment for the Valley Vista, AZ Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
Media Skid and Tanks	1	$30,134	–
Air Compressors	1	$2,602	–
Instrumentation and Controls	1	$13,211	–
Backwash Recycle System	1	$13,486	–
Media Educator Kit	1	$943	–
Chemical Injection	1	$11,197	–
Labor	1	$39,736	–
Warranty	1	$10,610	–
Change Order for Adding a Flow Totalizer	1	$625	–
Equipment Total	–	**$122,544**	**54%**
Engineering Costs			
Material	–	–	–
Labor	–	$40,021	–
Travel	–	–	–
Subcontractor	–	$10,638	–
Engineering Total	–	**$50,659**	**22%**
Installation Costs			
Material	–	–	–
Labor	–	$15,213	–
Travel	–	$10,319	–
Subcontractor	–	$29,574	–
Installation Total	–	**$55,106**	**24%**
Total Capital Investment	–	**$228,309**	**100%**

The USFilter GFH arsenic removal system consists of pressure vessels in parallel, piping, instrumentation and controls, and the GFH media. The GFH media cannot be regenerated and the spent media must be removed and disposed of. The media life depends on the influent arsenic concentration, pH, and operating hours per day. According to USFilter, the spent GFH media will pass EPA's TCLP test and be classified as a non-hazardous waste. Backwash of the system may be triggered automatically based on differential headloss through the pressure vessels or on a set time period. The system also may be backwashed manually.

2.4.1 STMGID Site Background. 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_2). 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 about November 1 every year.

The total arsenic concentrations of the source water range from 18 to 93 µg/L. An arsenic speciation test conducted on August 20, 2003 showed arsenic (87.9 µg/L) to be almost entirely As(V) (i.e., 99.7%). The pH of the source water ranges from 6.9 to 7.9. The test results also found less than 0.1 mg/L of orthophosphate, 68.6 mg/L of silica (as SiO_2), and 8.0 mg/L of sulfate. Antimony ranges from 7 to 18 µg/L (MCL is 6 µg/L), and the concentrations of iron, aluminum, manganese, and molybdenum are at less than detectable levels. Removal of antimony by GFH media will be monitored during the demonstration study.

2.4.2 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^3 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 chlorine residual of 1.0 mg/L.

2.4.3 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 upon 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. The estimated media replacement cost is \$58,500/ft^3 per change-out (or \$244/ft^3 for 240 ft^3 of media).

2.4.4 Capital Investment. The total capital investment for the STMGID system is \$232,147 (see Table 2-11). The total capital investment includes \$157,647 for equipment (68%), \$16,000 for engineering (7%), and \$58,500 (25%) for installation. The equipment costs include the costs for three skid-mounted CS pressure vessels ($45,500), 240 ft^3 of GFH media ($238/$ft^3$ or $3.03/lb for a total cost of $57,000), process piping and valving ($11,000), instrumentation and controls ($9,500), and field services, labor, and travel ($27,000). The equipment costs also include a change order of $7,647 for three flow meters and three differential pressure gauges.

STMGID prepared engineering plans and permit submittals for the project using input, such as system specifications and P&IDs, from USFilter. The plans include site engineering drawings, equipment tie-ins, and site plans. The submittals were certified by a State of Nevada-registered PE and sent to the Washoe County Department of Health for review and approval; costs incurred by STMGID for the plans preparation and submittals are not included in the $16,000 charged by USFilter (see Table 2-11).

The installation costs include labor and material costs for equipment off-loading, and mechanical and electrical connections. The installation activities include off-loading the equipment at the site, placement of the equipment on an existing concrete pad, field assembly of the equipment, media loading, completion of system plumbing and tie-ins to the raw water line and the distribution line, and painting of the exterior. The installation activities will be performed by USFilter. The installation cost of $58,500 is 25% of the total capital investment.

Table 2-11. Summary of Capital Investment for the STMGID Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
GFH Media	240 ft^3	$57,000	–
Tanks	3 tanks	$45,500	–
Process Valves and Piping	–	$11,000	–
Instrumentation and Controls	–	$9,500	–
Field Services and Misc.	–	$12,000	–
Labor	–	$10,000	–
Travel	–	$5,000	–
Change Order for Adding Three Flow Meters and Three Differential Pressure Gauges	–	$7,647	–
Equipment Total	–	**$157,647**	**68%**
Engineering Costs			
Material	–	–	–
Labor	–	$16,000	–
Travel	–	–	–
Subcontractor	–	–	–
Engineering Total	–	**$16,000**	**7%**
Installation Costs			
Material	–	$13,500	–
Labor	–	$30,000	–
Travel	–	$10,000	–
Subcontractor	–	$5,000	–
Installation Total	–	**$58,500**	**25%**
Total Capital Investment	–	**$232,147**	**100%**

3.0 COAGULATION/FILTRATION PROCESS

Kinetico's Macrolite® arsenic removal system uses coagulation and pressure filtration to remove arsenic-bearing iron solids with a ceramic filtration media called Macrolite®. This low-density, spherical media is manufactured by Kinetico, and is designed to allow for higher filtration rates (i.e., up to 10 gpm/ft^2) than those commonly used for conventional filtration processes. Macrolite® is chemically inert and compatible with chemicals such as acids, caustics, oxidants, and coagulant chemicals such as ferric chloride. Macrolite® media is listed under NSF Standard 61 for drinking water applications. The physical properties of the media are summarized in Table 3-1.

Table 3-1. Physical Properties of 40/60 Mesh Macrolite® Media

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

(a) Data not available for 40/60 mesh

3.1 Climax, MN Site Background

The City of Climax supplies drinking water to 264 people. 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.

The total arsenic concentrations range from 31 to 41 µg/L. An arsenic speciation test conducted in July 2003 showed that arsenic (38.7 µg/L) is present predominately as As(III) (34.8 µg/L). Iron levels in source water range from 546 to 850 µg/L, and pH values range from 7.4 to 7.9. The iron levels are 13 to 27 times higher than the arsenic levels.

3.2 Treatment System Description

The 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^3) of 40/60 mesh Macrolite® media, which is underlained 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 Treatment System Operation

The system is fully automated with an operator interface, programmable logic controller (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^2 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 accomplished through 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.

3.4 Capital Investment

The capital investment for the Climax system is $249,081 (Table 3-2), which includes $137,970 for equipment, $39,344 for engineering, and $71,767 for installation. The equipment costs include the costs for the Macrolite® media, contact tanks, filtration skid, instrumentation and controls, labor (including activities for the system shakedown), and system warranty. The equipment costs are 55% of the total capital investment.

The engineering cost include the costs for preparing a process design report and the required engineering plans, which include a general arrangement drawing, P&IDs, interconnecting piping layouts, tank fill details, a schematic of the PLC panel, an electrical on-line diagram, and other associated drawings. After certified by a Minnesota-registered PE, the plans were submitted to the Minnesota Department of Health (MDH) for permit review and approval. The engineering costs are 16% of the total capital investment.

As discussed above, the installation costs include the costs for equipment and labor for system unloading and setup, plumbing, and mechanical and electrical connections. The installation costs are 29% of the total capital investment.

Table 3-2. Summary of Capital Investment for the Climax, MN Treatment System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
Media, Filter Skid, and Tanks	1	$66,210	–
Air Compressor	1	$2,346	–
Control Panel	1	$11,837	–
Additional Flow Meter/Totalizers	1	$2,622	–
Labor	–	$43,005	–
Warranty	–	$11,950	–
Equipment Total	–	**$137,970**	**55%**
Engineering Costs			
Labor	–	$38,094	–
Subcontractor	–	$1,250	–
Engineering Total	–	**$39,344**	**16%**
Installation Costs			
Labor	–	$12,914	–
Travel	–	$6,163	–
Subcontractor	–	$52,690	–
Installation Total	–	**$71,767**	**29%**
Total Capital Investment	–	**$249,081**	**100%**

4.0 ION EXCHANGE PROCESS

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 is listed 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 4-1.

The anion exchange process is a fixed-bed process using an anion exchange resin in the chloride form to remove arsenic from drinking water by exchanging arsenic for chloride. The process also removes nitrate, sulfate, uranium, and bicarbonate. The efficiency of the IX process for arsenic and nitrate removal is strongly affected by sulfate that is preferred over both arsenic and nitrate. Unlike adsorptive media processes, IX resins are not sensitive to the pH value of raw water. Once it reaches its capacity, the resin is regenerated with a sodium chloride brine solution. The regeneration process produces a liquid waste that is high in sulfate, nitrate, and arsenic.

Table 4-1. Physical and Chemical Properties of Purolite A-520E Resin

Parameter	Value
Polymer Matrix Structure	Macroporous styrene-divinylbenzene
Physical Form and Appearance	Opaque cream-colored spherical beads
Whole Bead Count	95% minimum
Functional Groups	Quaternary ammonium
Ionic Form, as Shipped	Cl^-
Shipping Weight (approximate)	680 g/L (42.5 lb/ft^3)
Screen Size Range (U.S. Standard Screen)	16 to 50 mesh, wet
Particle Size Range	+1200 mm <5%, -300 mm <1%
Moisture Retention, Cl^- form	50 to 56%
Reversible Swelling, Cl^- to SO_4^{2-}/NO_3^-	Negligible
Total Exchange Capacity, Cl^- form	
Wet, volumetric	0.9 meq/mL min.
Dry, weight	2.8 meq/g min.
Operating Temperature, Cl^- form	100^{o}C (212^{o}F) max.
pH Range, Stability	0 to 14
pH Range, Operating	4.5 to 8.5

4.1 Fruitland, ID Site Background

The Fruitland water system supplies drinking water to approximately 4,000 people. Well No. 6 has a flow capacity of 250 gpm and high arsenic and nitrate concentrations, and 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 a replacement. The new well also operates at 250 gpm and has the same high levels of arsenic and nitrates as the abandoned well.

The total arsenic concentrations of the raw water sampled from the old well range from 32 to 46 μg/L. An arsenic speciation test conducted on the August 2003 shows arsenic (43.4 μg/L) to be present predominately as As(V) (39.2 µg/L). The water also contains 3.4 µg/L of particulate arsenic and 0.8 µg/L of As(III). Nitrate concentrations show an increasing trend from 5.2 mg/L in July 1986 to 13.9 mg/L in November 2001. When the nitrate level began to exceed the MCL of 10 mg/L, the well was shut down and not used. Sulfate concentrations range from 57 to 64 mg/L. Total iron concentrations range from less than detection to 744 µg/L, which is present mostly as Fe(III). The uranium concentration measured on December 6, 2002 was 22.4 µg/L, which is below the new U.S. EPA MCL of 30 µg/L. Because the IX 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 water range from 7.4 to 7.6.

4.2 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-µm bag filters. This filtration step prevents the resin bed from being fouled by particulates.
- **Ion exchange system**. The Kinetico ion exchange arsenic/nitrate removal system consists of two parallel 48-inch-diameter, 72-inch-tall FRP pressure vessels. Each vessel contains 50 ft^3 (in 4-ft depth) of Purolite A-520E strong base anion exchange resin, 3 ft^3 of flint gravel support media, and 3 ft^3 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 2-hp, 60-gallon vertical air compressor also is provided with the system.

4.3 Treatment System Operation

The Kinetico arsenic/nitrate removal system is a fully automated system that has an operator interface, 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 IX 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. A brine saturator is included with the system. 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.

4.4 Capital Investment

The total capital investment for the Fruitland, ID system is $290,521 (see Table 4-2). The primary equipment costs include the costs for a Purolite A-520E resin, ion exchange vessel skid ($63,673), a brine system ($35,388) and initial salt fill ($4,133 for 15 tons of salt), a bag filter unit ($3,540), air compressor ($1,295), and a PLC control panel ($11,524). The equipment costs also include $32,870 for the system fabrication, shakedown, and startup, operator's training, and technical services. The total equipment costs for the package treatment system are $177,328, or 61% of the total capital investment.

The engineering costs include the costs for the preparation and submission of an engineering submittal package, including a general arrangement drawing, P&IDs, tank fill details, control panel schematics, piping tie-in drawings, and other associated drawings. The engineering submittal was prepared by Holladay Engineering, a local firm subcontracted to Kinetico. The engineering package was reviewed and approved by the Idaho Department of Environmental Quality (IDEQ). The total engineering costs are $35,619, or 12% of the total capital investment.

The installation costs include the costs for equipment and labor for system unloading, setup, and plumbing, as well as mechanical and electrical connections. The activities include setting and anchoring the vessels, completing system plumbing and tie-in to the distribution system, performing vessel hydraulic testing, and loading resins. The installation activities were performed by Kinetico and its subcontractor. System installation began on March 8, 2004, and was nearly complete when the failure of Well No. 6 was discovered. The delay caused by the replacement of the well necessitated an unscheduled trip by Kinetico that was covered by a change order. The change order also includes a sand filter to be installed downstream of the salt saturator tank. The installation costs are $77,574, or 27% of the total capital investment.

Table 4-2. Summary of Capital Investment for the Fruitland, ID System

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
Resin, IX Skid, and Tanks	1	$63,673	–
Pretreatment Filter Unit	1	$3,540	–
Brine System	1	$35,388	–
Initial Salt Fill	15 tons	$4,133	–
Air Compressor	1	$1,295	–
Instrumentation and Controls	1	$11,524	–
Engineering Subcontractor	–	$8,000	–
Labor	–	$32,870	–
Warranty	–	$16,905	–
Equipment Total	–	**$177,328**	**61%**
Engineering Costs			
Labor	1	$35,619	–
Engineering Total	–	**$35,619**	**12%**
Installation Costs			
Labor	–	$11,524	–
Travel	–	$4,095	–
Subcontractor	–	$61,955	–
Installation Total	–	**$77,574**	**27%**
Total Capital Investment	–	**$290,521**	**100%**

5.0 SYSTEM MODIFICATION

In many Midwestern states, it is common to have high levels of arsenic in water supplies along with high levels of iron and manganese. Many drinking water systems have installed iron/manganese removal processes to remove arsenic along with iron and manganese. In some cases, depending on the iron-to-arsenic ratio of the raw water, the iron removal process can reduce arsenic to below the 10 μg/L MCL. However, it is also common to find that the iron/manganese removal process does not reduce arsenic to below the MCL, probably because of a low iron-to-arsenic ratio or the presence of As(III) in the source water. In such cases, low-cost system modifications may be made to the process to increase arsenic removal by adding a pre-oxidation step to convert As(III) to As(V), adding iron to the feed water, or a combination of both. If carried out properly, these modifications can reduce arsenic concentrations to below the MCL, thereby eliminating the need for adding new and possibly expensive treatment steps to the existing processes.

The Lidgerwood, ND facility, unlike the other 11 demonstration sites, has a coagulation/filtration treatment system in place for the removal of elevated levels of iron, manganese, and arsenic in groundwater. The existing system reduces the arsenic concentration from approximately 140 to 30 μg/L. The system was selected for the arsenic demonstration project to evaluate the performance of a low-cost system modification to further remove arsenic to below 10 μg/L. The system modification is being undertaken using a phased approach: Phase I involves the installation and testing of an iron addition system. Depending on the performance of the filtration system to handle the increased iron load onto the filters, a Phase II modification may be included to retrofit the existing gravity filtration cells with Kinetico's Macrolite® media.

5.1 Lidgerwood, ND Site Background

The Lidgerwood water treatment system supplies drinking water to approximately 750 people. 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, 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.

5.2 Treatment System Description

The Lidgerwood treatment system consists of pre-chlorination, forced-draft aeration, potassium permanganate ($KMnO_4$) 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_2. 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 to oxidize iron and manganese.

- **$KMnO_4$ oxidation.** A supplementary oxidation step is provided by the addition of $KMnO_4$, 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_2-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^2 that are filled with 20 × 40 mesh MnO_2-coated anthrasand. The hydraulic loading to the filters is approximately 2 gpm/ft^2. 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.

5.3 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 the 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.

5.4 Capital Investment

The system modification is planned in two phases. Phase I involves the installation of an iron addition system where ferric chloride is added at approximately 1.0 mg/L to enhance arsenic removal. Phase II with the Macrolite® retrofit will only be implemented if the Phase I system modifications are not sufficient to reach the 10 μg/L arsenic MCL in the plant effluent. The Phase I capital investment for the iron chemical feed system and monitoring equipment is $55,740 (see Table 5-1). The Phase II capital investment costs will be provided in a final summary report for the project if the Phase II work is implemented at a later date.

The primary equipment for the iron addition system includes a 60-gallon chemical day tank with secondary containment skid, a tank mixer, a chemical metering pump, and associated materials such as tubing and fasteners. In addition, supplemental on-line instrumentation was installed at the plant to track filtration cell performance under baseline conditions and after the start-up of iron addition. This instrumentation included a Scaletron low-profile drum scale, four Hach 1720D low-range turbidimeters, a Foxboro differential pressure cell, and a Telog data logging system. The equipment costs are $31,154, or 56% of the total capital investment.

The engineering cost ($5,786, or 10% of the total capital cost) includes the costs for labor for the preparation of a process design report and the system plans including a P&ID, assembly drawing, control panel layout, turbidity meter interconnect, and an interconnect schematic.

The installation costs include the costs for equipment and labor to ship, install, and shakedown the ferric chloride addition system. The primary installation activities include placing the ferric chloride tank on the drum scale and spill containment deck, mounting the tank mixer and pump to a wall bracket, and connecting the tubing from the chemical metering pump to the injection point at the rapid mix tank. The installation labor also includes all electrical connections, and connection and calibration of the associated instrumentation including the drum scale, turbidimeters, and differential pressure cell. The installation costs are $18,800, or 34% of the total capital cost.

Table 5-1. Summary of Capital Investment for the Lidgerwood, ND System Modification

Description	Quantity	Cost	% of Capital Investment Cost
Equipment Costs			
Chemical Feed System	1	$5,570	–
Turbidimeter	4	$9,567	–
dP Transmitter	1	$1,894	–
Data Logger	1	$3,703	–
Drum Scale	1	$3,940	–
Other Miscellaneous	–	$1,177	–
Labor	–	$2,020	–
Warranty	–	$3,283	–
Equipment Total	–	**$31,154**	**56%**
Engineering Costs			
Engineering Total	–	**$5,786**	**10%**
Installation Costs			
Material	–	$1,493	–
Labor	–	$12,307	–
Travel	–	$5,000	–
Installation Total	–	**$18,800**	**34%**
Total Capital Investment	–	**$55,740**	**100%**

6.0 COST SUMMARY

Section 6 begins with a review of the total capital investment costs, and then breaks the discussion down into three cost categories: equipment, engineering, and installation. Building construction costs provided by host facilities also are tabulated and described at the end of the section. However, the building cost information does not have any direct bearing on the cost analysis presented in this section.

6.1 Total Capital Investment

Total capital investment costs for the 12 arsenic demonstration systems are summarized in Table 6-1; this total cost is the sum of the costs for equipment, engineering, and installation. Capital investment costs range from $90,757 for the Rimrock system to $305,000 for the Brown City system (excluding the Lidgerwood system modification cost, which is $55,740). Annualized costs for the 12 systems also were calculated using a capital recovery factor (CRF) of 0.06722 based on a 3% interest rate and a 20-year return period, and are presented in Table 6-2.

Throughout this analysis, cost data for all 12 systems were plotted against system flowrate data for all systems, and curve fitting was performed on the results. Separate plots also were generated for just those systems that involve iron-based adsorptive media. Figure 6-1 shows total capital cost plotted against flowrate data for all 12 arsenic treatment systems. These data were fitted with a linear regression curve (R^2 of 0.2300), and resulted in a poor correlation; this result was not unexpected, and is likely due to the wide variety of technologies evaluated by the EPA demonstration study. A much stronger correlation resulted when cost and flowrate data for just the iron-based adsorptive media treatment systems were plotted (R^2 of 0.8247; see Figure 6-2); this result was expected due to the similarity of the technologies evaluated.

The water industry often uses the unit cost to compare water treatment system costs, so for this analysis, unit cost for the total capital investment of each treatment system, as expressed as cost per 1,000 gallons of water treated, was calculated by dividing the annualized cost by the annual water production at the system design flowrate. The calculation assumed that the system was operated 24 hours a day, 7 days a week. The unit costs of the 12 systems range from $0.06 per 1,000 gallons for the Desert Sands MDWCA and Brown City systems, to $0.79 per 1,000 gallons for the Valley Vista system (excluding the Lidgerwood system modification; see Table 6-2).

Unit cost data also were plotted against system flowrate data; Figure 6-3 shows the curve for all 12 treatment systems, and Figure 6-4 shows the curve for just the iron-based systems. The results indicate that the unit cost decreases as the size of a system increases.

Based on the fits of all four cost curves, a strong correlation seems to exist between total capital cost and size of the arsenic treatment system, but just for iron-based media systems. Also, results generally indicate that the E33 adsorptive systems are the lowest cost systems; however, this conclusion may not be a valid one because the wide variations in system designs, materials of construction, monitoring equipment, and site-specific conditions also may impact the costs of the treatment systems. The full results of the curve fitting are summarized in Table 6-3.

Table 6-1. Capital Investment Costs of the 12 Round 1 Arsenic Demonstration Systems

Facility	System Design Flowrate (gpm)	Total Capital Investment	Equipment		Engineering		Installation	
			Cost	% of Total Capital Investment	Cost	% of Total Capital Investment	Cost	% of Total Capital Investment
G2 Media System								
Bow, NH	70	$154,700	$102,600	66%	$12,500	8%	$39,000	26%
E33 Media Systems								
Desert Sands MDWCA, NM	320	$153,000	$112,000	73%	$23,000	15%	$18,000	12%
Brown City, MI	640	$305,000	$218,000	71%	$35,500	12%	$51,500	17%
Queen Anne's County, MD	300	$211,000	$129,500	62%	$36,700	17%	$44,800	21%
Nambe Pueblo, NM	145	$139,251	$112,211	80%	$10,788	8%	$16,252	12%
Rimrock, AZ	90	$90,757	$66,235	73%	$11,372	13%	$13,150	14%
Rollinsford, NH	100	$106,568	$82,081	77%	$4,907	5%	$19,580	18%
AAFS50 Media System								
Valley Vista, AZ	37	$228,309	$122,544	54%	$50,659	22%	$55,106	24%
GFH Media System								
STMGID, NV	350	$232,147	$157,647	68%	$16,000[b]	7%[b]	$58,500	25%
Coagulation/Filtration System								
Climax, MN	140	$249,081	$137,970	55%	$39,344	16%	$71,767	29%
Anion Exchange System								
Fruitland, ID	250	$290,521	$177,328	61%	$35,619	12%	$77,574	27%
System Modification								
Lidgerwood, ND	250	$55,740	$31,154	56%	$5,786	10%	$18,800	34%
Statistics								
Minimum	37	$90,757[a]	$66,235[a]	54%	$4,907	5%	$13,150	12%
Maximum	640	$305,000	$218,000	80%	$50,659	22%	$77,574	34%
Average	–	–	–	66%	–	12%	–	22%

(a) Excluding the Lidgerwood, ND system.
(b) Engineering work performed by STMGID and its costs not reflected herein.

Table 6-2. Annualized and Unit Costs of Total Capital Investment for the 12 Round 1 Arsenic Demonstration Systems

Facility	System Flowrate (gpm)	Annualized Cost [(a)]				Unit Cost ($/1,000 gal)	
		Total	Equipment	Engineering	Installation	Total	Equipment
G2 Media System							
Bow, NH	70	$10,398	$6,896	$840	$2,662	$0.28	$0.19
E33 Media Systems							
Desert Sands MDWCA, NM	320	$10,284	$7,528	$1,546	$1,210	$0.06	$0.04
Brown City, MI	640	$20,501	$14,653	$2,386	$ 3,462	$0.06	$0.04
Queen Anne's County, MD	300	$14,183	$8,704	$2,467	$3,011	$0.09	$0.06
Nambe Pueblo, NM	145	$9,360	$7,542	$725	$1,092	$0.12	$0.10
Rimrock, AZ	90	$6,100	$4,452	$764	$884	$0.13	$0.09
Rollinsford, NH	100	$7,163	$5,517	$330	$1,316	$0.14	$0.10
AAFS50 Media System							
Valley Vista, AZ	37	$15,346	$8,237	$3,405	$3,704	$0.79	$0.42
GFH Media System							
South Truckee Meadows GID, NV	350	$15,604	$10,596	$1,075	$3,932	$0.08	$0.06
Coagulation/Filtration System							
Climax, MN	140	$16,742	$9,274	$2,645	$4,824	$0.23	$0.13
Ion Exchange System							
Fruitland, ID	250	$19,528	$11,919	$2,394	$5,214	$0.15	$0.09
System Modification							
Lidgerwood, ND	250	$3,747	$2,094	$389	$1,264	$0.03	$0.02

MDWCA = Mutual Domestic Water Consumer's Association.
STMGID = South Truckee Meadows General Improvement District.
(a) Based on an interest rate of 3% and a 20-year return period.

Table 6-3. Summary of Cost Equations

Cost Variable Y	Data Source	Regression Equation[(a)]	R^2
Total Capital Investment Cost ($)	All 12 systems	Y = 227.63X + 133,933	0.2300
	8 Iron-based AM systems	Y = 333.84X + 90,455	0.8247
Unit Cost of Total Capital Investment ($/1,000 gal)	All 12 systems	$Y = 10.001X^{-0.8532}$	0.6541
	8 Iron-based AM systems	$Y = 2.2543X^{-0.578}$	0.8022
Equipment Cost ($)	All 12 systems	Y = 186.29X + 78,982	0.3938
	8 Iron-based AM systems	Y = 230.28X + 64,533	0.8751
Unit Equipment Cost ($/1,000 gal)	All 12 systems	$Y = 5.5075X^{-0.8189}$	0.6470
	8 Iron-based AM systems	$Y = 1.768X^{-0.5972}$	0.8633

(a) X denotes system flowrate in gpm.

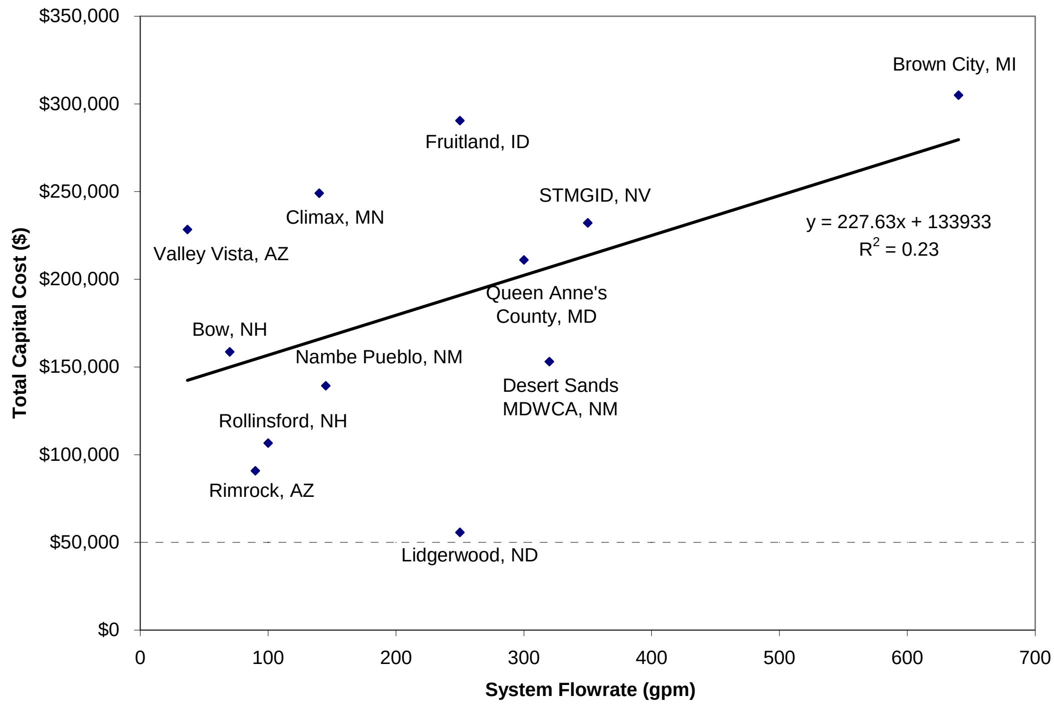

Figure 6-1. Total Capital Investment Cost vs. System Flowrate (All Systems)

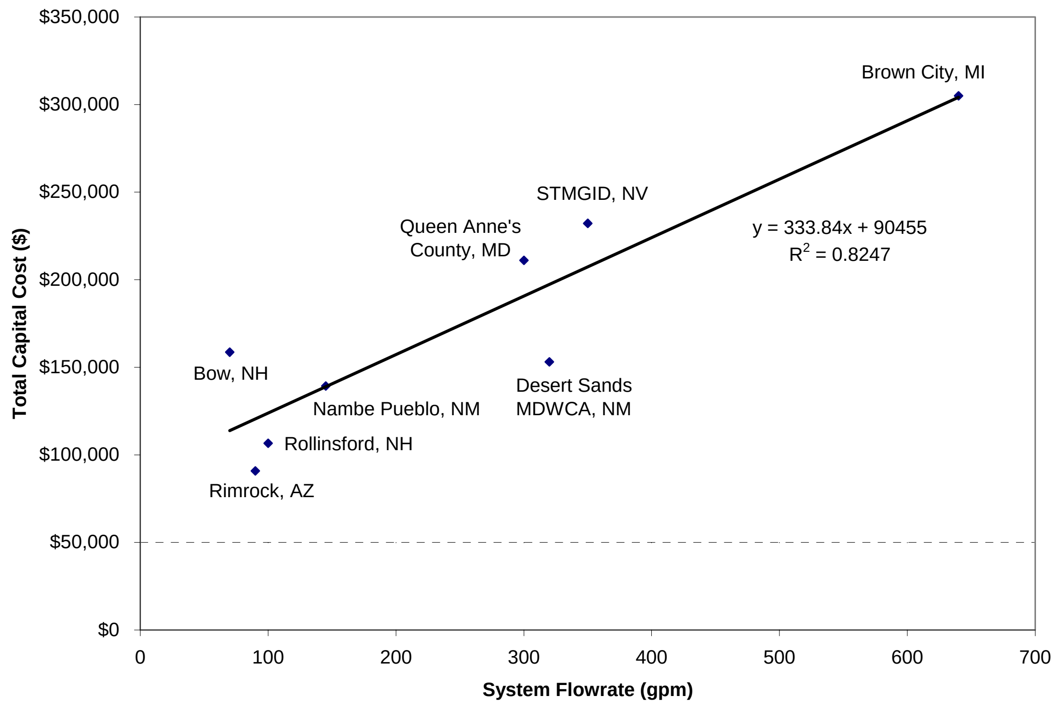

Figure 6-2. Total Capital Investment Cost vs. System Flowrate (Iron-Based Adsorptive Media Systems Only)

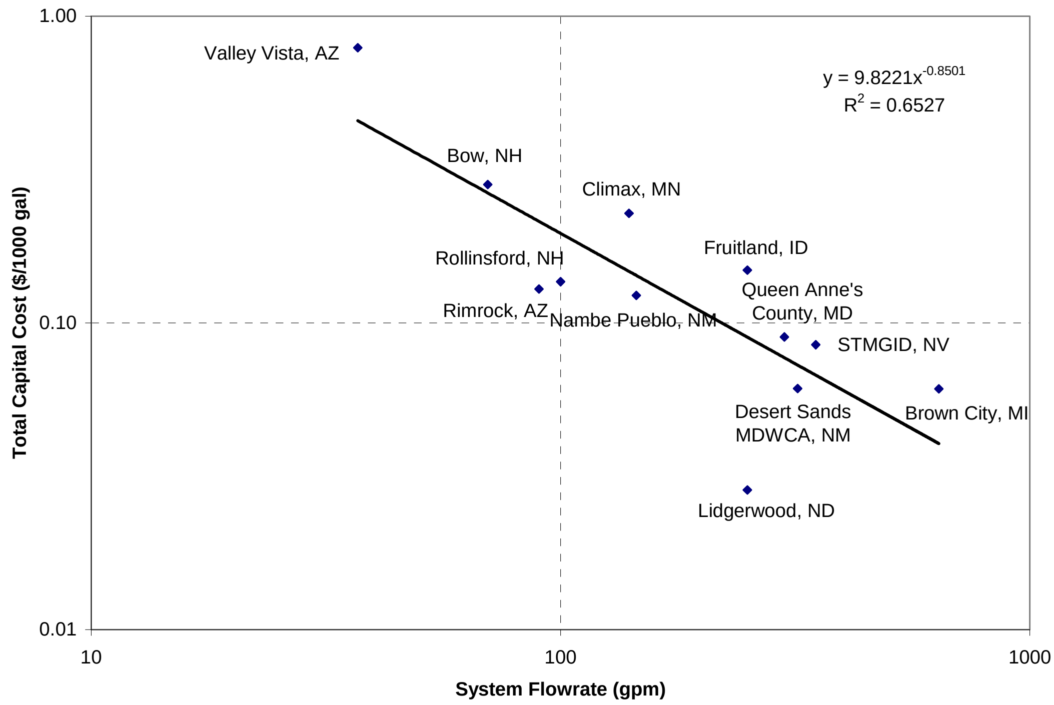

Figure 6-3. Unit Cost of Total Capital Investment vs. System Flowrate (All Systems)

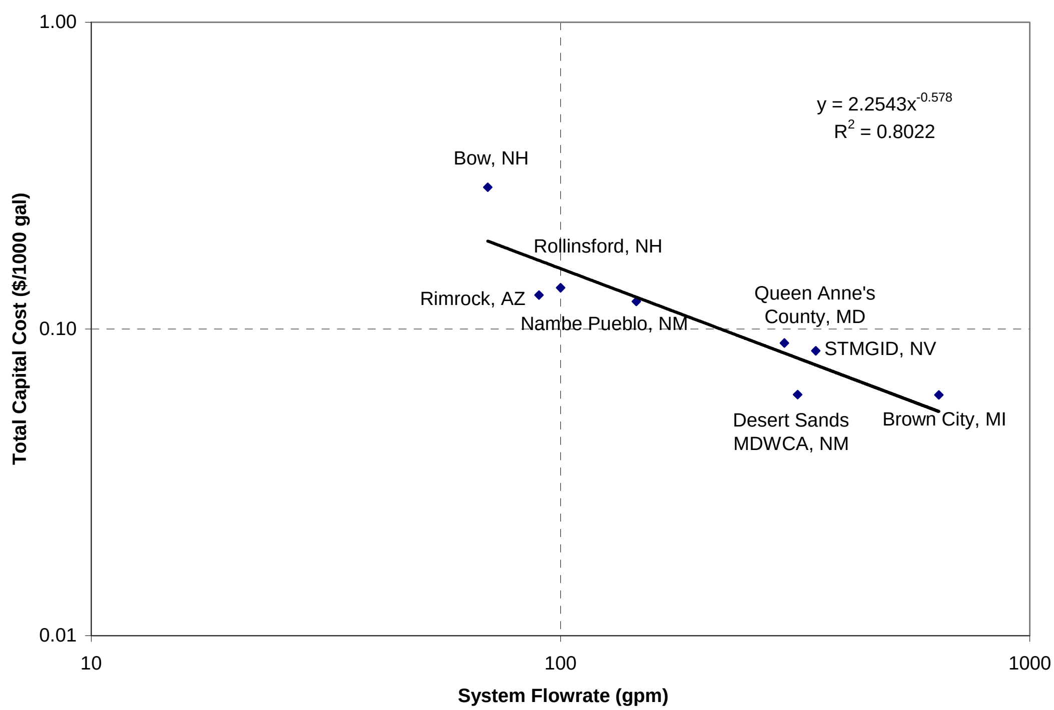

Figure 6-4. Unit Cost of Total Capital Investment vs. System Flowrate (Iron-Based Adsorptive Media Systems Only)

6.2 Equipment Costs

Equipment costs for the treatment systems range from $66,235 for the Rimrock system to $218,000 for the Brown City system (excluding the Lidgerwood system modification equipment cost, which is $31,154), as shown in Table 6-1. Figure 6-5 shows equipment cost plotted against flowrate data for all 12 arsenic treatment systems. These data were fitted with a linear regression curve (R^2 of 0.3938), and resulted in a poor correlation; like the capital investment cost analysis, this result is likely due to the wide variety of technologies evaluated for the EPA demonstration study. A much stronger correlation again resulted when cost and flowrate data for just the iron-based adsorptive media treatment systems were plotted (R^2 of 0.8751; see Figure 6-6). Also, because equipment cost makes up the highest percentage of the total capital investment cost (i.e., 54 to 80%), the curves on the equipment cost plots were expected to be similar to those on the capital investment plots.

Unit equipment costs for the treatment systems range from $0.04 to $0.42 per 1,000 gallons of water treated (excluding the Lidgerwood system modification; see Table 6-2). In general, the unit equipment cost increases as the size of a system decreases. The treatment systems with the lowest unit equipment costs are the E33 media systems with higher flowrates; for example, both the 640-gpm Brown City system and the 320-gpm Desert Sands MDWCA system have a unit cost of $0.04 per 1,000 gallons. Conversely, the most expensive treatment option based on the unit equipment cost is the 37-gpm Valley Vista system, which has a unit equipment cost of $0.42 per 1,000 gallons. However, the Valley Vista system is equipped with a backwash recycle system and extra monitoring and control devices, which are not included in the other systems.

Unit equipment cost data also were plotted against system flowrate data; Figure 6-7 shows the curve for all 12 treatment systems (R^2 of 0.647), and Figure 6-8 shows the curve for just the iron-based systems (R^2 of 0.8633). Results are similar to those for unit total capital investment, and show a stronger correlation for the iron-based systems between equipment cost and size of system.

6.3 Engineering Costs

Engineering costs for the treatment systems range from $4,907 for the Rollinsford system to $50,659 for the Valley Vista system. These engineering costs represent from 5 to 22% of the total capital investment costs, with an average percentage of 12% (see Table 6-1). Engineering cost data for all 12 systems are plotted against system flowrate data on Figure 6-9. The lowest engineering-related costs were associated with the 100-gpm E33 media system at Rollinsford, NH, followed closely by the system modification at Lidgerwood, ND. Annualized engineering costs for all 12 systems were calculated using a CRF value of 0.06722, and range from $330 to $3,405 (Table 6-2).

6.4 Installation Costs

Installation costs for the treatment systems range from $13,150 for the Rimrock system to $77,574 for the Fruitland system. These installation costs represent from 12 to 34% of the total capital investment costs, with an average percentage of 22% (see Table 6-1). Installation cost data for all 12 systems are plotted against system flowrate data on Figure 6-10. Relatively low installation costs were associated with all three sites using E33 media systems (Nambe Pueblo, NM; Rimrock, AZ; and Rollinsford, NH). Annualized installation costs for all 12 systems were calculated using a CRF value of 0.06722, and range from $884 to $5,214 (Table 6-2).

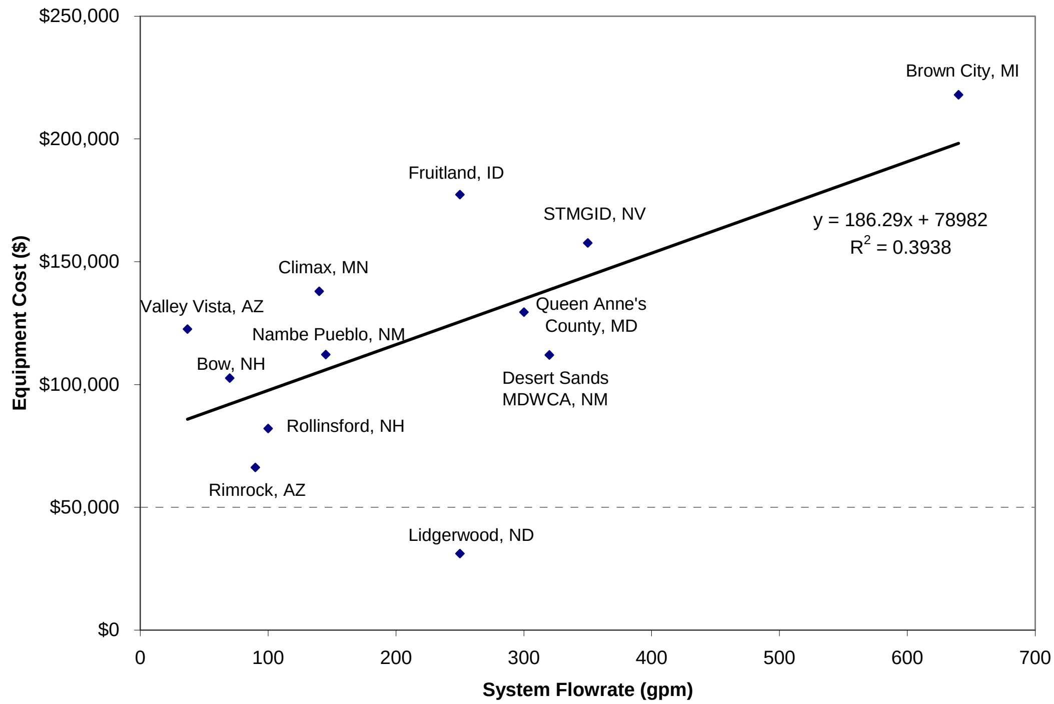

Figure 6-5. Equipment Cost vs. System Flowrate (All Systems)

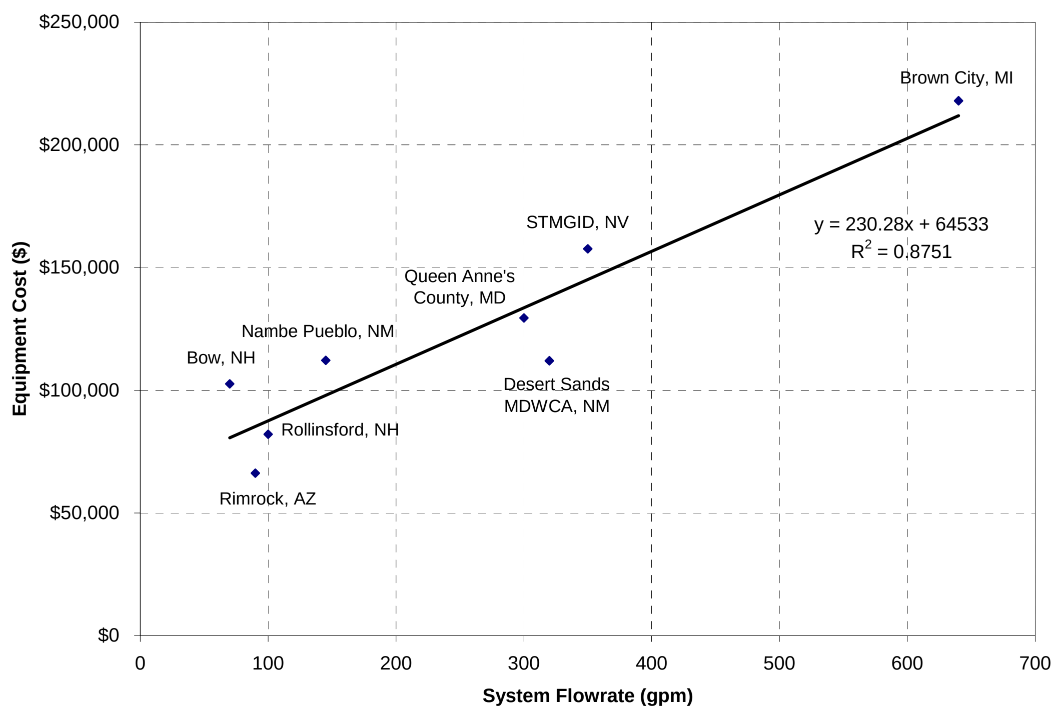

Figure 6-6. Equipment Cost vs. System Flowrate (Iron-Based Adsorptive Media Systems Only)

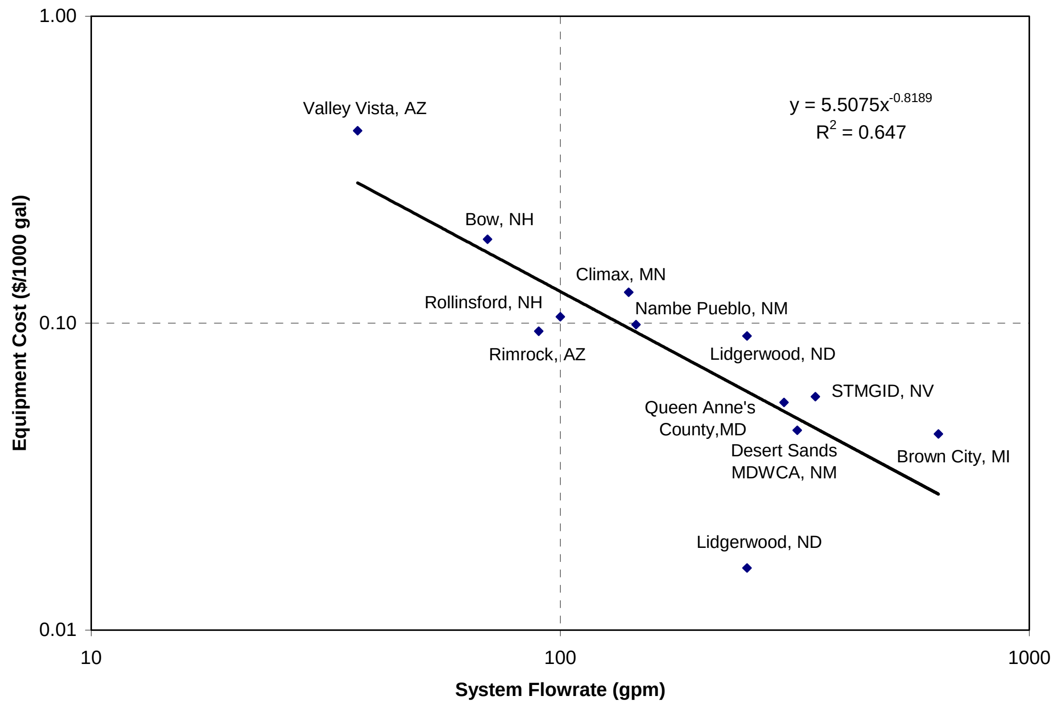

Figure 6-7. Unit Equipment Cost vs. System Flowrate (All Systems)

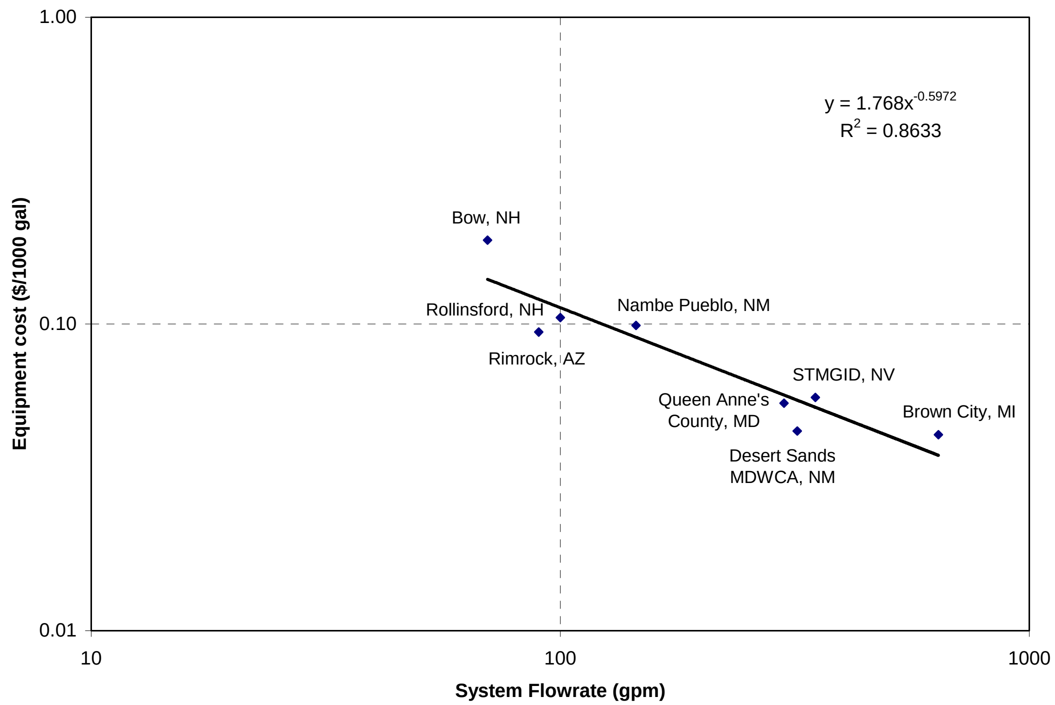

Figure 6-8. Unit Equipment Cost vs. System Flowrate (Iron Based Adsorptive Media Systems Only)

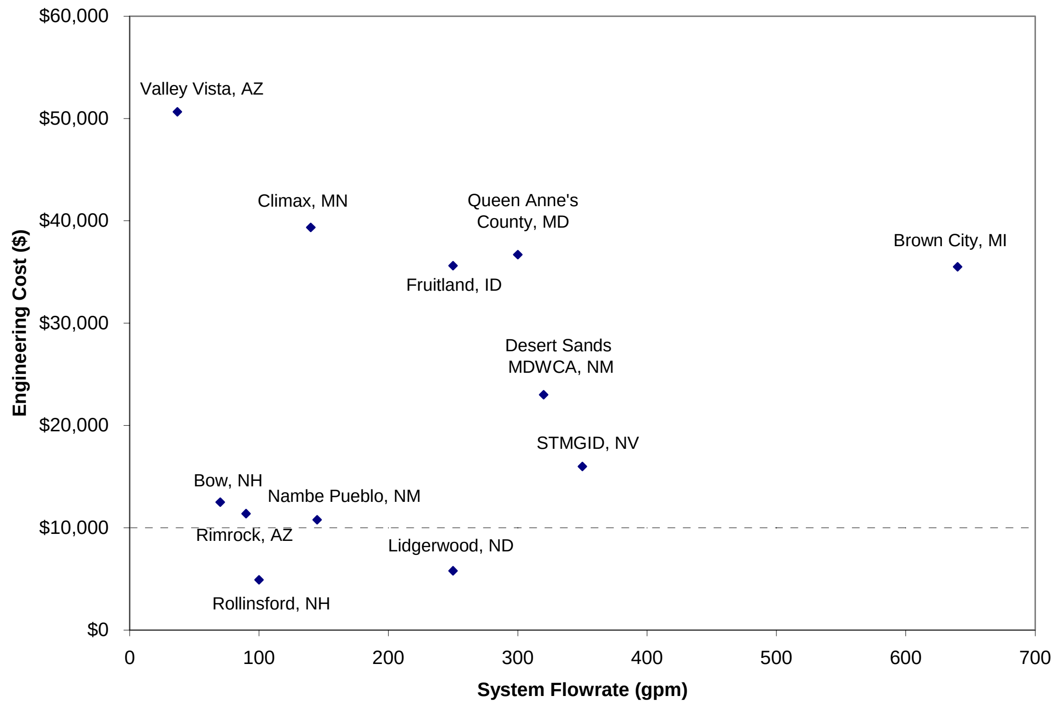

Figure 6-9. Engineering Cost vs. System Flowrate

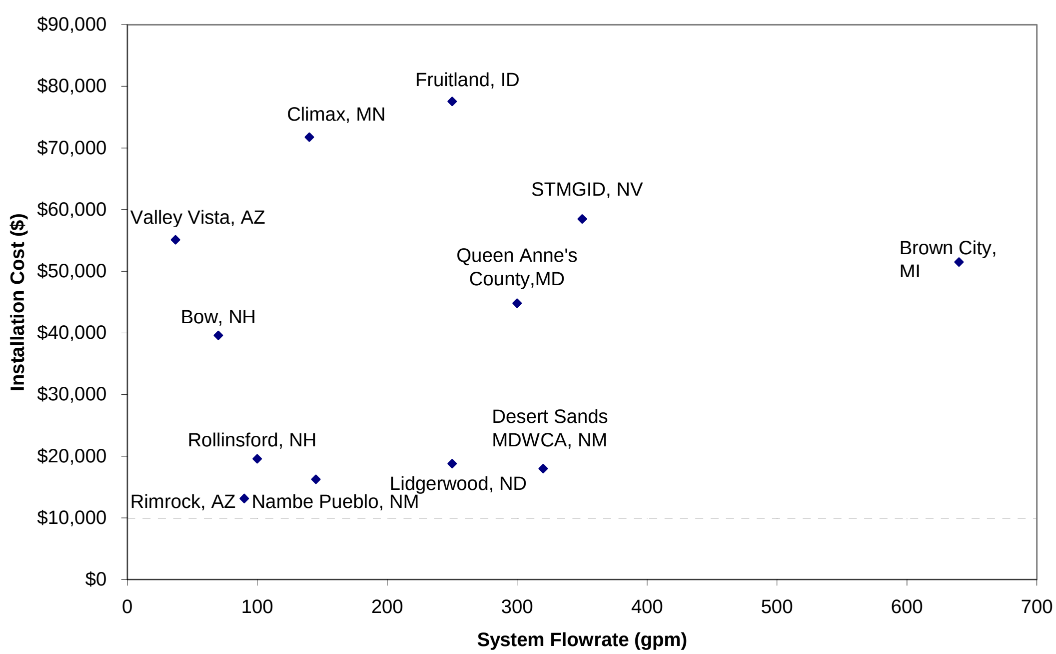

Figure 6-10. Installation Cost vs. System Flowrate

6.5 Building Costs

All buildings and building modifications are paid for by the water systems. Building costs range from a low of $3,700 (the Desert Sands MDWCA site) to a high of near $186,000 (the STMGID site). Costs vary according to differences in building design (size and materials of construction) and choice of construction contractor. A summary of the building costs associated with each facility is provided in Table 6-4; details on the building construction for each site are provided in the following subsections.

Table 6-4. Summary of Building Costs

Facility	Type of Building/Material of Construction	Building Size	Building Cost ($)
Bow, NH	Concrete foundation/wood frame	20 ft × 22 ft	~$25,000
Desert Sands MDWCA, NM	Concrete foundation/steel frame	15 ft × 15.5 ft	$3,700
Brown City, MI	Concrete block	28 ft × 28 ft	$62,602
Queen Anne's County, MD	Concrete block with brick siding	16 ft × 23 ft	$92,630
Nambe Pueblo, NM[(a)]	Concrete block	28 ft × 36 ft	~$150,000
Rimrock, AZ	Sun shade with steel frame	12 ft × 15 ft	$25,223
Rollinsford, NH	Concrete foundation and floor/ wood frame with vinyl siding	33 ft × 13 ft	$57,000
Valley Vista, AZ	Sun shade with steel frame	12 ft × 25 ft	$22,078
STMGID, NV[(a)]	Concrete block	32 ft × 18 ft	$186,000
Climax, MN	Concrete foundation and floor/ wood frame with metal wall panels	22 ft × 24 ft	$88,256
Fruitland, ID	Concrete foundation and floor/ wood frame, steel siding and roof	360 ft^2	$18,000
Lidgerwood, ND	Building already exists, a new building not needed		

(a) Building not yet completed.

6.5.1 Bow, NH. The cost of building an addition on the existing structure at this site was approximately $25,000. Construction included placement of a steel support on top of the existing concrete structure, and construction of a wooden frame building on this steel support to house the ADI G2 arsenic adsorption system. The new building is roughly the same size as the existing concrete structure, with a footprint of 20 ft × 22 ft.

6.5.2 Desert Sands MDWCA, NM. The Desert Sands MDWCA in Anthony, NM built an addition onto their existing pump house in order to shelter the APU-300 treatment system equipment and inlet/outlet plumbing. The structure was built by MDWCA staff, with the exception of the electrical tie-in. The total cost for the building was $3,700, with $2,700 for material and $1,000 for labor. The addition measures 15 ft × 15.5 ft at the base (232.5 ft^2), with a total height of 12 ft, and consists of a concrete floor, steel frame, and insulated steel siding and roofing, with a walk-through door.

6.5.3 Brown City, MI. The total cost for the addition to the existing concrete block well house at the Brown City Site was $62,602. The addition is a 28 ft × 28 ft concrete block structure with a 10-ft-wide roll-top metal door and access hatches in the roof for media loading. The primary construction costs totaled $41,468, and included excavation, masonry, carpentry, and concrete floor pouring. The overhead door cost was $1,400. The building costs also included $13,048 for the roof deck work and roofing including the overhead roof hatches. The building was finished with a wood and aluminum trim and painted white. The cost for painting was $2,135, and the heating and electrical work for the building totaled $4,550.

6.5.4 Queen Anne's County, MD. Total construction cost for the Queen Anne's County addition was $92,630, including about $18,000 for the building design and $75,000 for construction. The 16 ft × 23 ft treatment area is an addition to the original 8 ft × 16 ft well house. The building was constructed using concrete block and has brick siding. Construction took approximately one month to complete including placement and setting of the vessels within the building, which were put into place before the roof was installed.

6.5.5 Nambe Pueblo, NM. The IHS plans to construct a free-standing building to house the APU-150 treatment system, near the existing well pump house. The concrete block building will be 28 ft × 36 ft (1,008 ft^2), with a wall height of 14 ft, and a corrugated steel roof. The building will have both a walk-through door and a 12 ft × 12 ft roll-up door. The building will be constructed by a contractor known to the HIS, and the estimated cost for labor and materials, including grading and utilities, is approximately $150,000.

6.5.6 Rimrock, AZ. Total construction cost for the Rimrock building was $25,223, including design and installation of a 12 ft × 15 ft concrete pad, a sunshade structure, and a backwash recycle system. The sunshade structure is 12 ft × 15 ft with a height of 9.5 ft, and is manufactured by Versa-Tube. The sunshade is constructed with a galvanized steel frame anchored to the concrete pad and sheeted with a 29-gauge steel that has a specially coated surface. The shades are pre-engineered with a 90-mph wind load and a 30-lb/ft^2 snow loading capacity. This sunshade structure can be completely closed to resemble a metal building if the building needs to be heated in the winter. The cost for materials and labor to assemble the shade is approximately $3,500.

6.5.7 Rollinsford, NH. The Rollinsford building cost approximately $57,000, including design and construction of the subsurface leach field directly adjacent to the building which is used for disposing of the backwash water from the system. The building itself measures 33 ft × 13 ft. It has a wood frame with vinyl siding and a concrete foundation and floor. It includes two 10-ft roll-up doors on the front side allowing access to the treatment equipment and one walk-through door on the end of the building.

6.5.8 Valley Vista, AZ. The Valley Vista building cost was $22,078, including design and installation of a 12 ft × 25 ft concrete pad and a sunshade structure. The sunshade structure is similar to the one at the Rimrock site but larger, at 12 ft × 25 ft, with a height of 11.5 ft. Manufactured by Versa-Tube, the sunshade is constructed with a galvanized steel frame anchored to the concrete pad and sheeted with a 29-gauge steel that has a specially coated surface. The shades are pre-engineered with a 90-mph wind load and a 30-lb/ft^2 snow loading capacity. This structure can be completely closed to resemble a metal building if the building needs to be heated in the winter. The cost for materials and labor to assemble the shade is approximately $4,500.

6.5.9 STMGID, NV. STMGID plans to construct a free-standing building to house the GFH system. The CMU block building will measure 32 ft × 18 ft, with an interior wall height of 12 ft and a 3 tab asphalt shingle roof. The building will have one walk-through door and an 8-ft × 11-ft roll-up door. The estimated cost of the building, water system improvements (i.e., system connection and backwash line), utilities, landscaping, and labor is $186,000.

6.5.10 Climax, MN. A 22-ft × 24-ft building was built as an addition onto the existing concrete block well house, and cost $88,256. The building walls are constructed with a wood stud frame and 24 gauge pre-fabricated metal wall panels and set on a 6-inch-thick concrete slab floor with footings. The building also is equipped with an insulated, 10-ft-wide overhead door. The building construction cost includes all of the required insulation, mechanical, and electrical work. The building is heated with a 60,000 BTUH heater. The connection to the existing water main requires 16 linear ft of 6-inch-diameter C900 pipe and costs $4,650. The initial budget called for $6,730 for connection to the sanitary sewer with 145 ft of 6-inch-diameter PVC pipe. However, after plan review by the MDH, a code requirement was identified to complete the sanitary sewer connection at a distance greater than 50 ft from the wellhead. An underground storage tank was placed at a distance of 50 ft from the well house to hold the backwash water prior to pumping to the sewer. The cost estimate for this change order was approximately $12,000.

6.5.11 Fruitland, ID. The City of Fruitland constructed an addition to their existing pump house to house the anion exchange system. The addition covers 360 ft^2 of floor space, and is 17 ft high, with a wood frame and steel siding and roofing, and a roll-up door. The total cost for the material and electrical is approximately $18,000.

6.5.12 Lidgerwood, ND. There are no building costs for the Lidgerwood site because the system modification does not require any modifications to the existing building that houses the existing coagulation/filtration system.

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