

Point-of-Use/Point-of-Entry Treatment for Arsenic Removal: Operational Issues and Costs

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) has promulgated a new Maximum Contaminant Level (MCL) of 10 micrograms per liter ($\mu\text{g/L}$) for arsenic in drinking water. All community water systems will have to comply with this new MCL by early 2006. EPA estimates that 4,100 community water systems, 97 percent of which serve 10,000 or fewer people will have to take corrective measures to meet the new, more stringent arsenic limit. Centralized treatment is not always a feasible treatment alternative, especially in areas where each home has a private well or where the treatment costs are prohibitive. In such instances, point-of-use (POU) or point-of-entry (POE) treatment alternatives are more attractive and feasible. Even though POU/POE treatment systems are easy to install and operate, there is very little information currently available in terms of actual operational data. To fill this critical data gap, the Arsenic Research Partnership comprising of American Water Works Association Research Foundation (AwwaRF), USEPA and Association of California Water Agencies (ACWA) launched a national study to evaluate the feasibility of using POU/POE treatment systems for arsenic removal.

This study evaluated some of the most promising "under-the-sink" (POU) and POE treatment alternatives for arsenic removal including reverse osmosis (RO) and adsorption to iron activated alumina (Fe-AA) and granular ferric hydroxide (GFH). These technologies were evaluated at various locations, including at Stagecoach, NV; Sun City West, AZ and Metropolitan Water District, AZ over periods up to 12 months. The POU and POE units were operated under continuous and intermittent conditions. The intermittent operation was performed to simulate the actual use in homes. The units were also shut-off for one-week durations to simulate vacation periods. In addition to arsenic, the treated water was monitored for other parameters such as total dissolved solids, silica, hardness and heterotrophic plate counts (HPCs).

Consistent removal of arsenic and TDS was observed in the POU-RO treated water. No significant improvement was observed in the microbial quality after POU-RO treatment. Consistent fluxes were maintained even after operating for 8-12 weeks. The run lengths on the POU and POE adsorption systems were dependent on source water quality including pH and the presence of interfering ions such as silica.

The costs for POU-RO and POU-adsorption were developed by obtaining individual quotations for significant cost items such as housing for membrane/media, membrane elements or adsorption media, flow control/measuring devices and bladder or storage tanks. The replacement frequency for media and membranes was determined based on the findings of the field POU/POE tests, consultations with manufacturers and best professional judgment. The findings

of this study will be useful for systems that are impacted by the new arsenic MCL and are considering POU/POE treatment approach.

POU/POE EVALUATION

As part of this study, POU/POE arsenic treatment was evaluated at four of the five sites. Table 1 summarizes the technologies that were installed at each of the five sites.

Table 1
Summary of Technologies Evaluated at Field Sites

Location	POU/POE Arsenic Technology
Tucson, AZ	POU-RO POU-AA: 4.5-inches x 20-inches POE-GFH: 12-inch diameter column POE-Fe-AA: 12-inch diameter column
Stagecoach, NV	POE-GFH: 12-inch diameter column POE-Fe-AA: 12-inch diameter column
Sun City West, AZ	POU-RO POU-Mn-AA: 4.5 inches x 10 inches POU-AA: 4.5 inches x 10 inches POE-GFH: 12-inch diameter column POE-Fe-AA: 12-inch diameter column
Unity, ME	POU-RO POU-Mn-AA: 4.5 inches x 10 inches
Carson City, NV	POU-GFH: 4.5 inches x 10 inches POU-Mn-AA: 4.5 inches x 10 inches

Sun City West, AZ - At Sun City West, AZ, POU-RO, POU-Mn-AA, and POU-AA were installed and run on a timer. For the first two weeks of testing, the POU units were run continuously to establish a breakthrough curve for the smaller 10" columns and to achieve the maximum number of gallons treated through the RO. Following breakthrough of the two columns, the media cartridges were replaced and run for 40 minutes on and 40 minutes off cycles for 16 hours followed by 8 hours off under pressure to simulate home use. Two 12-inch diameter POE columns, one filled with GFH and the other filled with Fe-AA, were also installed at this site.

Metropolitan Water District, Tucson, AZ - A POU-RO system and a POU-AA system were installed at this site. Also, two 12-inch POE columns, one filled with GFH and one filled with Fe-AA, were installed at this site. The POE units were ran at flow rates of 3 gallons per minute (gpm) that resulted in an EBCT of 5 minutes.

Stagecoach, NV - At Stagecoach water is pumped from a storage tank through two, 12-inch POE adsorption columns. The adsorption media that were tested include GFH and Fe-AA.

Unity, ME - A POU-RO and a POU-Mn-AA were installed at this site. There is approximately 100 µg/L As (III) at this site. The POU-RO system was not effective in treating the As (III).

Carson City, NV - A POU-Mn-AA system and POU-GFH system were installed at this site. The well was operated seasonally and was shut down for several months. The cartridges were operated for approximately 24 hours per day when the well was in operation.

RESULTS OF POU/POE EVALUATION

Metropolitan Water District, Tucson, AZ

Groundwater Quality

Summarized in Table 2 is the raw water quality for groundwater from Metropolitan Water District test well. The raw water was sampled once a week over the test period of 4 months. The data summarized in Table 2 are the averages of the values measured over that period. The average arsenic in the raw water was 11 µg/L. The source water had no iron, manganese or phosphate (competing ions that impact GFH breakthrough). The raw water had low levels of nitrate (2.1 mg-N/L), moderate levels of sulfate (35.1 mg/L), and high levels of silica (42.4 mg/L). The average pH of the raw water was 7.8.

Table 2
Water Quality Summary of Source Water From Metropolitan Water District

Parameter	Average	Standard deviation	Maximum value measured	Minimum value measured	Number of samples analyzed
pH	7.79	0.2	8.1	7.4	22
Chlorine residual, mg/L	0.79	0.39	2	0.5	23
Arsenic, mg/L	0.011	0.002	0.013	0.008	15
Alkalinity, mg/L	132.5	7.1	140.0	120.0	8
Fluoride, mg/L	1.5	0.2	1.8	1.1	8
Hardness as CaCO ₃ , mg/L	116.6	15.0	140.0	92.0	9
Iron, mg/L	<0.050	--	0.0	0.0	9
Manganese, mg/L	<0.010	--	0.0	0.0	9
Nitrate, mg/L	2.1	0.2	2.3	1.7	8
Orthophosphate, mg/L	<0.10	--	0.1	0.1	8
Sulfate, mg/L	37.6	5.2	43.0	28.0	11
Silica (as SiO ₂), mg/L	42.7	0.6	43.0	41.0	15
TDS, mg/L	305.7	35.5	350.0	260.0	7
HPCs, CFUs/mL	31.3	396.0	1160.0	1.0	8

POU-RO Results

Shown in Figure 1 are the arsenic and TDS levels in the POU-RO product water. After producing 780 gallons of product water the POU-RO treatment showed no detectable levels (< 0.002 mg/L) of arsenic. The POU-RO treatment also lowered the silica levels from 42.7 mg/L to <10 mg/L. Approximately 80-90% TDS removal was also observed. The TDS removal rates improved with operational time. The data for the rest of the parameters for RO product water are summarized in Table 3. The POU-RO treatment lowered alkalinity from 132.5 mg/L to 13.5 mg/L, hardness from 116 mg/L to <13 mg/L and fluoride from 1.5 mg/L to <0.4 mg/L. No significant changes were observed in the HPC levels of the POU-RO treated water compared to the feed water. It should be noted that the residual chlorine in the POU-RO feed water was removed by passing the water through a granular activated carbon filter.

Table 3
Water Quality Summary of POU-RO Product Water

Parameter	Average	Standard deviation	Maximum value measured	Minimum value measured	Number of samples analyzed
pH	7.63	0.66	8.8	6.7	26
Arsenic, mg/L	<0.002	0.00	<0.001	<0.001	17
Alkalinity, mg/L	15.0	2.1	18.0	12.0	6
Fluoride, mg/L	<0.40	0.0	<0.40	<0.40	6
Hardness as CaCO ₃ , mg/L	<13	0.0	0.0	0.0	8
Iron, mg/L	<0.050	0.0	0.0	0.0	6
Manganese, mg/L	<0.010	0.0	0.0	0.0	6
Nitrate, mg/L	<0.20	0.0	0.0	0.0	6
Orthophosphate, mg/L	<0.10	0.0	0.0	0.0	6
Sulfate, mg/L	<2.0	0.0	0.0	0.0	6
Silica (as SiO ₂), mg/L	6.5	0.7	7.7	4.8	22
TDS, mg/L	39.7	8.9	56.0	33.0	6
HPCs, CFUs/mL	40.2	66.8	143.0	1.0	5

POU-AA Results

The arsenic and silica concentrations in POU-AA unit are plotted as a function of bed volumes in Figure 2. The POU-AA system consistently removed arsenic to non-detect (<0.002 mg/L) levels until ~2,000 volumes (700 gallons of treated water). The AA media used in the POU-AA unit also removed silica quite appreciably, from 42.7 mg/L to <10 mg/L. A summary of POU-AA treated water is shown in Table 4. As expected, no TDS removal was observed in the POU-AA treated water. Some removal of fluoride was observed by POU-AA treatment. The HPC levels for the POU-AA treated water (average of 1.4 CFUs/mL) are lower than the raw water (average of 31 CFUs/mL) and POU-RO treated waters (40 CFUs/mL). The varying operational conditions (simulation of intermittent intensive use and vacation) did not affect the POU-AA performance.

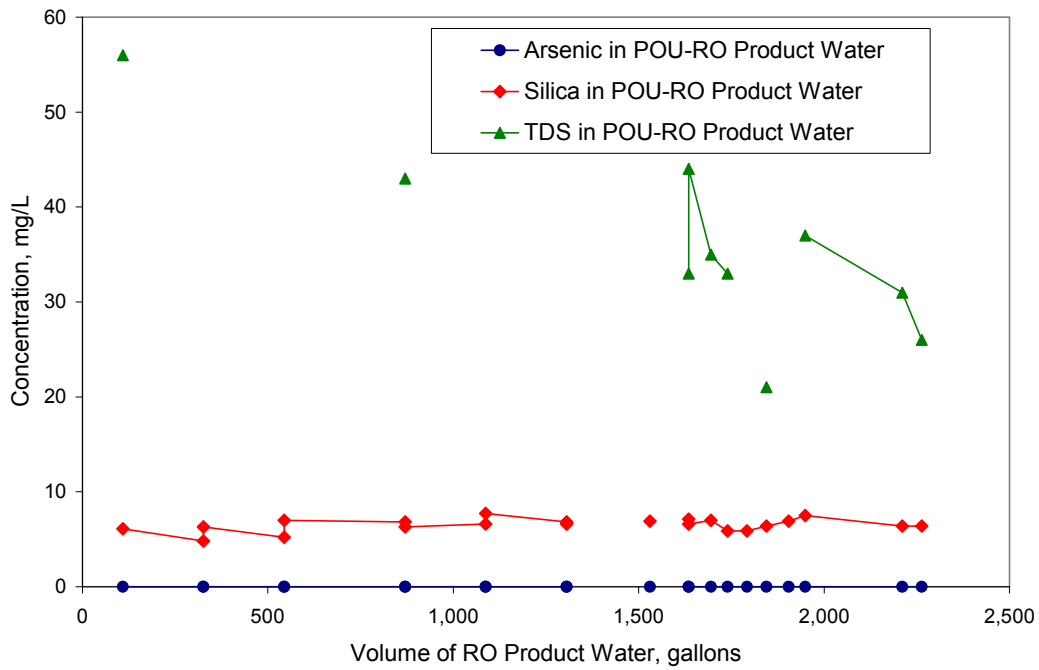


Figure 1. Arsenic, silica and TDS concentrations in POU-RO product water plotted as a function of cumulative volume of treated water

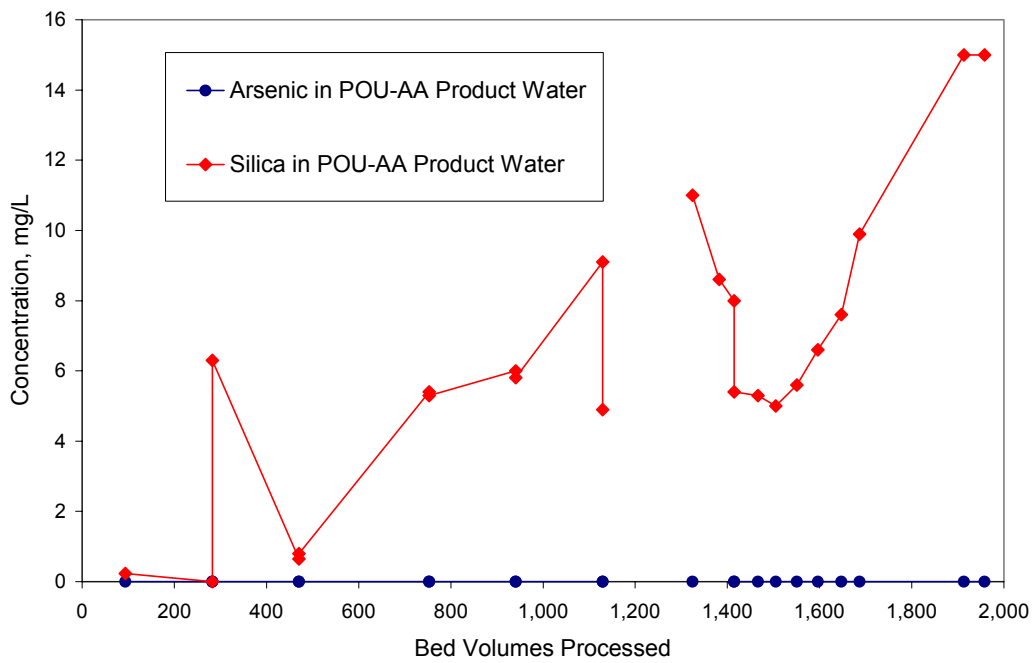


Figure 2. Arsenic and silica concentrations in POU-AA treated water plotted as a function of bed volumes processed

Table 4
Water Quality Summary of POU-AA Product Water

Parameter	Average	Standard deviation	Maximum value measured	Minimum value measured	Number of samples analyzed
pH	7.84	0.31	8.6	7.4	26
Arsenic, mg/L	<0.002	0.0	<0.001	<0.001	23
Alkalinity, mg/L	138.3	7.2	150.0	120.0	12
Fluoride, mg/L	0.54	0.17	0.79	0.45	4
Hardness as CaCO ₃ , mg/L	120	10.0	130.0	110.0	9
Iron, mg/L	<0.5	0.0	0.0	0.0	7
Manganese, mg/L	<0.01	0.0	0.0	0.0	7
Nitrate, mg/L	2.17	0.19	2.4	2.0	6
Orthophosphate, mg/L	<0.10	0.0	0.0	0.0	7
Sulfate, mg/L	38.5	2.2	41.0	35.0	6
Silica (as SiO ₂), mg/L	6.4	3.9	15.0	0.21	23
TDS, mg/L	273.3	15.1	290.0	250.0	6
HPCs, CFUs/mL	1.4	1.2	4.0	1.0	6

POE-Fe-AA and POE-GFH

The breakthrough curves for arsenic and silica in treated waters for POE-Fe-AA and POE-GFH are shown in Figures 3 and 4, respectively. The raw water has an average silica concentration of 42.7 mg/L (Table 2). For both Fe-AA and GFH, some decrease was observed in silica concentrations of the treated waters and this decrease is more predominant in the initial periods. The adsorption of silica, which is a function of source water pH, is expected to decrease the adsorption capacity of the media for arsenic. The initial breakthrough of arsenic in POE-Fe-AA and POE-GFH systems occurred after processing 60,000 and 75,000 gallons of water, respectively.

Shown in Figures 5 and 6 are the arsenic concentrations in the raw and treated waters for POE-Fe-AA and POE-GFH columns, respectively, plotted as a function of bed volumes. As shown by the data presented in Figure 5, the arsenic breakthrough (arsenic concentration > 0.010 mg/L) for Fe-AA occurred approximately at 25,000 bed volumes. The GFH system operated for 45,000 bed volumes with an arsenic concentration of 0.006 mg/L (Figure 6). The method detection limit for arsenic was 0.001 mg/L.

Summaries of the water qualities for POE-Fe-AA and POE-GFH treated water are shown in Tables 5 and 6, respectively. No significant removal of sulfates or fluoride was observed in the POE-Fe-AA system. The Fe-AA also did not leach out any aluminum into the treated water. There was no significant increase in iron or manganese concentrations in the GFH treated water.

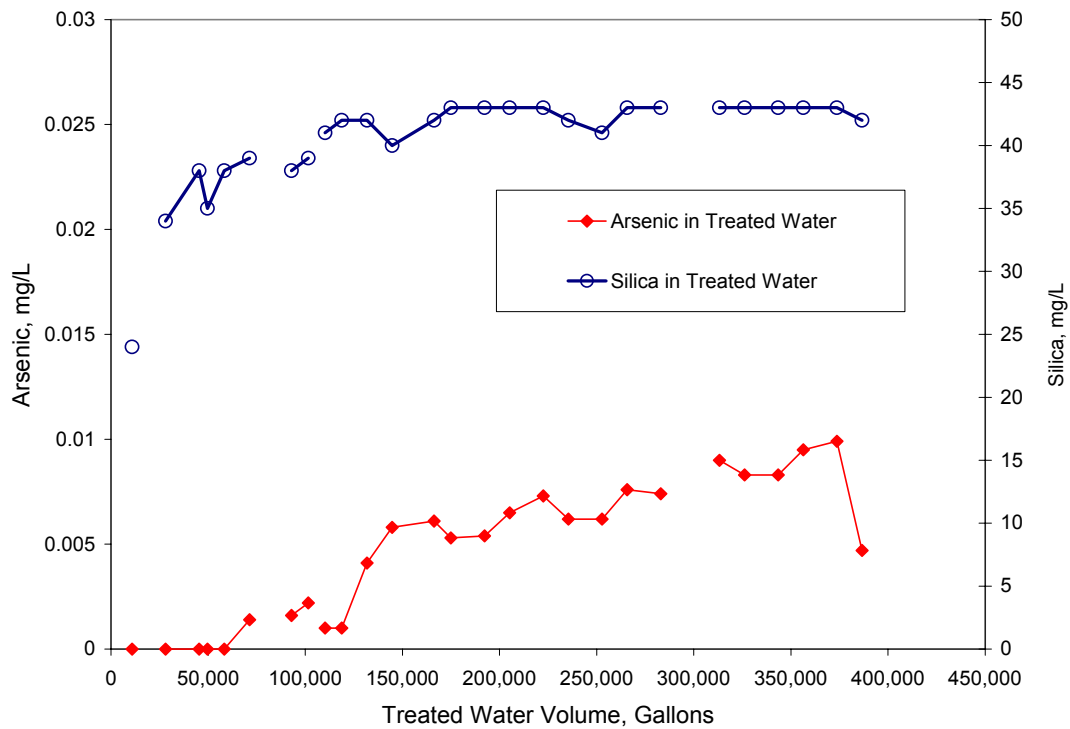


Figure 3. Arsenic and silica concentrations plotted as a function of treated water volume for POE-Fe-AA treatment

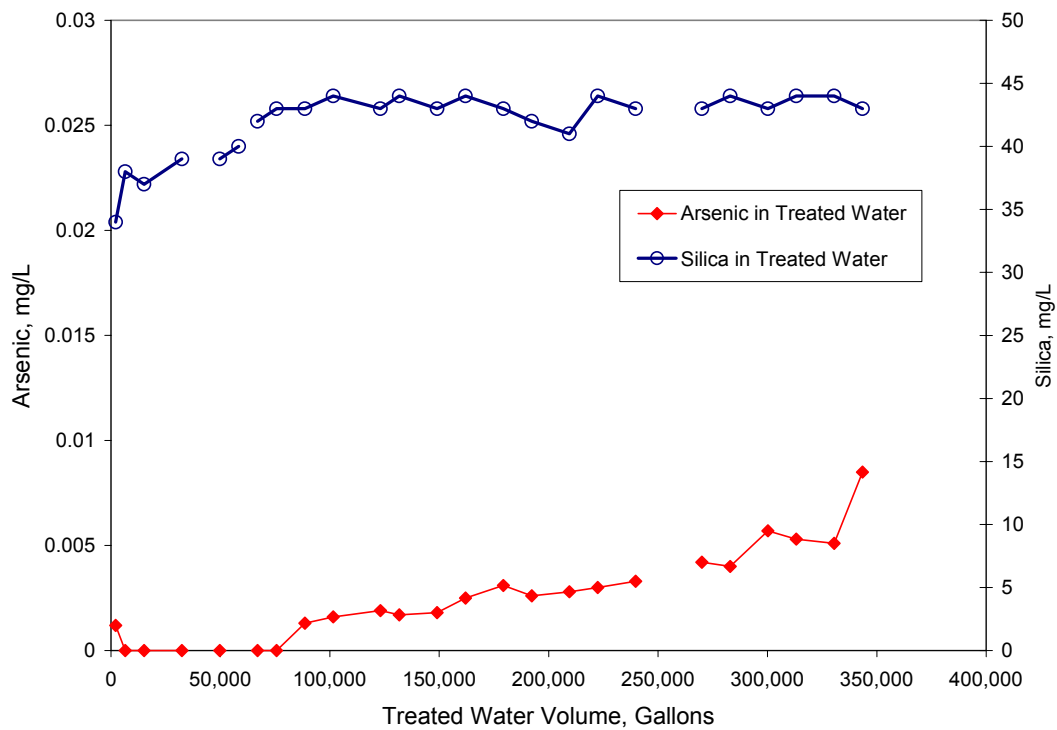


Figure 4. Arsenic and silica concentrations plotted as a function of treated water volume for POE-GFH treatment

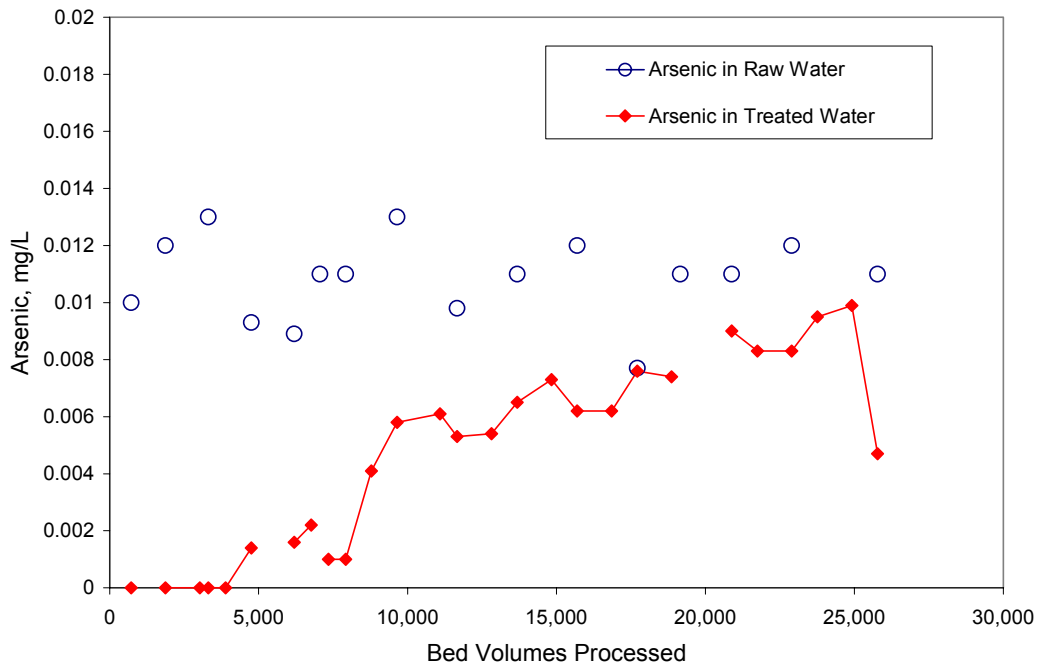


Figure 5. Arsenic concentrations in the source water and POE-Fe-AA treated water plotted as a function of bed volumes processed

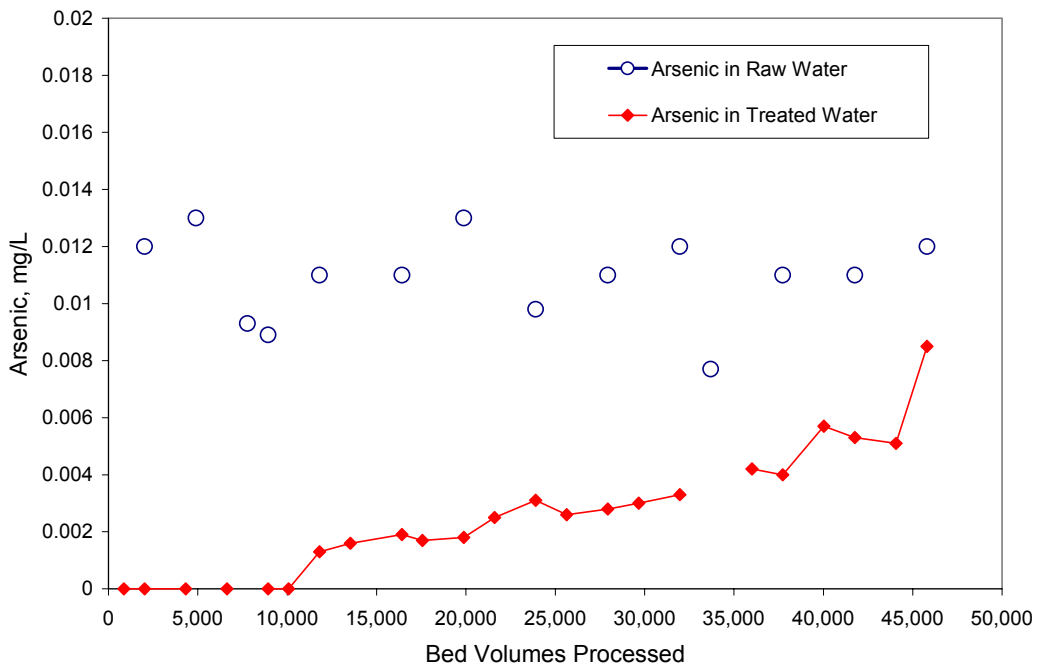


Figure 6. Arsenic concentrations in the source water and POE-GFH treated water plotted as a function of bed volumes processed

Table 5
Water Quality Summary of POE - Fe-AA Product Water

Parameter	Average	Standard deviation	Maximum value measured	Minimum value measured	Number of samples analyzed
Arsenic, mg/L	0.0065	0.002	0.0099	0.001	19
Aluminum, mg/L	< 0.1	--	<0.01	<0.01	9
Fluoride, mg/L	1.4	0.1	1.6	1.3	9
Sulfate, mg/L	42	3.3	48	36	9
Silica as SiO ₂ , mg/L	42	0.8	43	40	19

Table 6
Water Quality Summary of POE - GFH Product Water

Parameter	Average	Standard deviation	Maximum value measured	Minimum value measured	Number of samples analyzed
Arsenic, mg/L	0.003	0.002	0.006	0.001	24
Iron, mg/L	< 0.05	0.004	0.061	<0.05	9
Manganese, mg/L	< 0.01	--	< 0.01	< 0.01	2
Sulfate, mg/L	42	3.3	47	36	9
Silica as SiO ₂ , mg/L	42	2.1	44	37	24

SUMMARY OF POU/POE EVALUATION

Data similar to the Metropolitan Water District study were collected for other locations. Summaries of the POU/POE evaluation results from the different locations are shown in Table 7. As shown by the data presented in this table, except for POU-RO on Unity, ME water, all the other POU systems that were evaluated produced more than 1,000 gallons of treated water. Assuming a per capita consumption of 2.5 L of potable water per day, a 1,000 gallon POU system should last for one-year for a home of 4 family members. All of the POU- adsorption units that were tested at the Metropolitan Water District and Sun City West sites met the criteria of treating more than >1,000 gallons of water prior to 10 µg/L arsenic breakthrough. The POU-RO system at the Metropolitan Water District site did not treat up to 1,000 gallons due to the low product water flux through the RO membrane. However, the POU-RO systems at the Metropolitan Water District and Sun City sites treated water to below detection limits for flows up to 750 gallons.

The two POU-adsorption units at the Sun City West site were smaller in height (10" compared to 20") than the Metropolitan Water District therefore faster adsorption breakthrough was achieved (in the smaller units compared to the larger units). The POU-AA and the POU-Mn-AA units performed similarly by treating approximately 2,600 gallons for 10 µg/L breakthrough. The breakthrough for POU-adsorption systems at Sun City West occurred three days after the samples showed an arsenic value of <0.001 µg/L. The POU at Carson City, NV showed better

performance in terms of run length compared to other sites. Trace levels of iron in the raw water might have enhanced performance at this site.

Table 7
POU/POE Performance Summary

Location	Technology	Effluent Si, as SiO ₂ , mg/L	Effluent pH	Effluent arsenic, mg/L	Gallons treated to 10 µg/L breakthrough	Can the process produce 1000 gallons?*
Metropolitan Water District, AZ	POU-RO	4.8-7.7	6.7-8.8	<0.002	> 780	Yes
	POU-AA	0.23-11.0	7.4-8.6	<0.002	700	Yes
	POE-Fe-AA	24-39	7.0-7.7	<0.001-0.010	386,500	Yes
	POE-GFH	34-39	7.2-7.7	<0.001-0.006	337,500	Yes
Sun City West, AZ	POU-RO	2.1-4.9	7.1-7.8	<0.002	>1,300	Yes
	POU-AA	0.2-27.7	7.7-8.3	<0.002-0.021	2,600	Yes
	POU-Mn-AA	0.2-28.3	7.9-8.3	<0.002-0.024	2,600	Yes
	POE-Fe-AA	5.8-40.9	7.2-8.1	<0.002-0.010	63,000	Yes
	POE-GFH	0.5-50.7	7.2-8.3	<0.002-0.010	368,000	Yes
Stagecoach, NV	POE-Fe-AA	1.2-26	8.0-8.3	<0.001-0.014	54,700	Yes
	POE-GFH	18-29	8.0-8.3	<0.001-0.009	109,440	Yes
Unity, ME	POU-RO	<0.1	8.2	0.053-0.081	0	No
	POU-Mn-AA	--	--	In progress	--	--
Carson City, NV	POU-GFH	1.3-23	7.7-8.3	<0.002-0.012	17,000	Yes
	POU-Mn-AA	1-21	8.0-9.0	<0.002-0.016	13,000	Yes

* 1000 gallons of POU treated water would be sufficient to cater to the needs of a 4-person home for one year assuming that one person requires about 2.5 L per day

IN-HOME POU TESTING

In-house POU testing is being conducted at three locations. This testing program consists of installing POU units and monitoring their performance over a 12-month period. The three sites where this evaluation is being performed include Sandy Stream Park, Unity, Maine; Stagecoach General Improvement District, Nevada; and Marana, Tucson, Arizona. The Maine site has approximately 30 service connections (or homes), 20 of which are participating. The Nevada site has 50 service connections, 20 of which are participating in this study. In Marana, 20 of the 75 service connections are participating. The in-house POU evaluation is in progress. Preliminary results will be presented at the conference.

POU TREATMENT COSTS

The costs for POU-RO treatment were developed assuming a 3-stage system consisting of a pre-filter (5-micron particle filter or GAC filter), an RO membrane and a post-filter (GAC for taste enhancement). The POU-RO system costs also include the costs for bladder tank and an additional faucet. A picture of a typical 3-stage RO system is shown in Figure 7. To develop operation and maintenance (O&M) costs, it was assumed that the RO membrane, pre-filter and

post-filter would be replaced on an annual basis (once a year). For some POU-RO systems, a different manufacturer than the POU supplier could provide the RO membranes. Note that As(III) removal by RO membranes is poor and is still under evaluation.



Figure 7. A 3-stage POU-RO system

The costs for POU-adsorption treatment were developed assuming a 1 or 2-stage adsorption system. A 1-stage adsorption system would just have an adsorbent media filter. A 2-stage adsorption system would have a pre-filter (for particle removal) and an adsorbent media filter. Pictures of 1-stage and 2-stage adsorption systems are shown in Figures 8 and 9, respectively. For costing purposes, it was assumed that both GFH and Fe-AA were effective for removing arsenic. An annual replacement of media was assumed based on the findings of the field evaluations, consultations with manufacturers and best professional judgment.

For both POU-RO and POU-adsorption systems, the O&M costs included the costs for monitoring and maintenance. The monitoring was assumed to consist of sampling and measuring arsenic in 25 percent of the homes every quarter. This monitoring would result in arsenic measurement at least once a year for all the homes. A unit cost \$15 per analysis was used for arsenic analysis. This unit cost is based on nationwide quotations that were obtained from EPA-certified laboratories.

The costs for POU-RO and POU-adsorption treatment for arsenic removal were developed by obtaining individual quotations for significant cost items such as housings for RO membrane/media/pre- and post-filters, membrane elements or adsorption media, flow control/measuring devices and bladder or storage tanks. Cost quotations from regional and national vendors were also obtained for installation and replacement of media or membranes on a regular basis. The installation costs include labor hours for making the necessary plumbing changes (e.g., adding an additional faucet) to retrofit the POU system. A summary of the costs that were developed using individual component and service quotations are shown in Table 8.



Figure 8. 1-stage POU adsorption system



Figure 9. 2-stage POU adsorption system

Table 8
Itemized Costs for POU-RO and POU-Adsorption

Cost Item	POU-RO	POU-Adsorption
Installation (one-time cost)	\$100	\$100
POU Purchase (one-time cost)	\$400	\$150
RO Membrane (once-a-year cost)	\$65	--
Pre-Filter (once-a-year cost)	\$20	--
Post-Filter (once-a-year cost)	\$20	--
Adsorption Cartridge (once-a-year cost)	--	\$50
Arsenic Analysis (one sample a year)	\$15	\$15
Maintenance, Sampling & Reporting (\$/year)*	\$300	\$300
Monthly Cost per Home (\$/month-home)**	\$50	\$38

* Cost per year for maintenance/sampling/reporting was developed assuming 8 hours of a technician time and 2 hours of a manager time. Assumed unit rates for technician and manager are \$25 and \$50 per hour, respectively

**Amortized the one-time installation and purchase costs using 6% interest rate over the period of 3 years and added them to the annual costs for maintenance and replacement

COMPARING CENTRALIZED TREATMENT AND POU COSTS

Assuming a residential water usage rate of 200 gallons per capita per day, a home of 4 family members would consume about 800 gallons of water per day. If centralized treatment is considered for 20 homes that receive water from an impacted source then this central system should be able to handle about 16,000 gallons per day (0.016 million gallons per day). Previously, unit treatment costs were developed for arsenic removal using adsorption processes (GFH or AA) at a wellhead or central location (Chowdhury et al., 2002). A comparison of the centralized and POU treatment costs for arsenic removal for different system sizes are shown in Table 9. These costs were developed assuming GFH as the adsorbent media.

Table 9
Comparison of Centralized and POU Adsorption Treatment Costs

Number of Homes or Service Connections	Central System Size (gallons per day)*	Centralized Adsorption Treatment Costs** (\$/month-home)	POU-Adsorption Treatment Costs*** (\$/month-home)
20	16,000	\$120	\$38
40	32,000	\$85	\$36
60	48,000	\$75	\$34
80	64,000	\$50	\$32
200	160,000	\$29	\$30

Note: *Assuming 200 gallons per capita per day and 4-member homes

**Using cost curves for POE-GFH treatment at natural pH, Chowdhury et al., 2002

***Assuming 5% discount in the POU costs for every additional 20 systems/homes

As shown in Table 9, the POU treatment costs are lower than the central treatment costs for small systems of service connections up to 80 homes. As the number of service connections approach 200, the costs for POU and centralized treatment are similar, indicating that the centralized treatment is probably more favorable. At 200 or more connections, the costs for administration, monitoring and reporting for POU treatment will be substantially more than those for a centralized treatment.

SUMMARY

The POU treatment for arsenic removal for small systems appears to be promising. Water quality will play a key role in determining the success of POU-adsorption and POU-RO treatment processes. The costs presented in this paper should only be used for planning purposes. The costs for POE/POU treatment will be governed by water quality and local factors.

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