Summary Report

Evaluation of Point of Use Treatment Technologies to Remove Arsenic from Private Wells in West Anchorage

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By

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Introduction

In 2001, the United States Environmental Protection Agency (EPA) lowered the maximum contaminant level (MCL) of arsenic in public drinking water systems from 50 to 10 parts per billion (ppb). Although private wells in Alaska are not regulated by the EPA, the publicity about arsenic in public water systems has increased awareness of private homeowners about the presence of arsenic in groundwater.

This study was conducted to provide information to Anchorage homeowners about the occurrence of arsenic in private water systems and to provide guidance on selecting in-home treatment systems for arsenic removal. The study was conducted by University of Alaska Anchorage (UAA) School of Engineering for the Municipality of Anchorage Department of Health and Human Services (DHHS).

West Anchorage, an area served primarily by private wells that can contain naturally occurring arsenic, was the study area selected for this project. The first phase consisted of a limited water quality and geologic analysis of the study area. In the second phase, three point-of-use (POU) treatment systems were evaluated for their ability to remove arsenic from private wells in West Anchorage. Guidance documents and presentation materials for distribution to homeowners were developed in the final project phase.

This document summarizes the project results in more detail than could be provided in the guidance documents. It contains a brief literature review that provides background on arsenic in groundwater, the results of the water quality and geologic investigations and a summary of the results of POU system testing.

Because it does not contain the complete data set collected during the study, this document should be viewed as an extended abstract of the project.   Individuals seeking more detailed data and information on materials and methods can request additional information from Professor Craig Woolard, Ph.D., P.E. of the UAA School of Engineering.

Literature Review

Arsenic can be ingested in either the organic or inorganic form. The organic form of arsenic has little to no consequences to the human body. However, the inorganic form can be more harmful. Acute exposure (defined as a large concentration of arsenic being ingested over a very short period of time) to inorganic arsenic can result in gastrointestinal irritation, low blood pressure and cardiovascular attacks. The lethal dose of arsenic for a human adult has been estimated at 1-4 mg As/kg (Pontius *et al,* 1994).

Ingestion of arsenic from drinking water is typically classified as a chronic exposure (i.e., the ingestion of small concentrations of arsenic over a longer period of time). Noncarcinogenic symptoms of chronic arsenic exposure include changes in skin pigmentation and skin ulcerations. Arsenic ingestion has also been linked to skin and other forms of cancer (Nriagu, 1994).

Sources of Arsenic

Arsenic can enter a drinking water from both man-made and natural sources. Nationwide, the most common man-made sources of arsenic are wood preservatives and agricultural chemicals (Welch and Westjohn *et al*, 2000). Arsenic can also be introduced to water sources through the exposure of arsenic containing ores during mining operations or the discharge of arsenic wastes from smelters (Chen *et al*, 1999). However, arsenic in West Anchorage groundwater appears to originate from natural sources. When the proper redox and pH conditions occur, arsenic can be released into the groundwater from natural arsenic bearing minerals such as arsenopyrite ($FeAsS$), scorodite ($FeAsO_42H_2O$), and pharmacosiderite ($Fe_3(AsO_4)_2(OH)_35H_2O$) (Smedly and Kinniburgh, 2002).
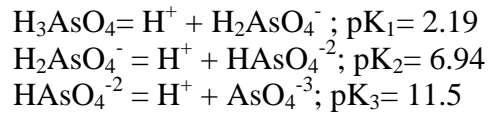
West Anchorage Geology

The majority of West Anchorage is located on glacial outwash deposits comprised of gravel, sand, silt and clay. There appears to be an upper and lower aquifer in the area, but the integrity of the confining layer separating the two aquifers has not been fully defined. A dominant geologic formation in West Anchorage is the Bootlegger Cove Formation. This formation was deposited over older sand, gravel, and glaciofluvial silt which were then subjected to a period of erosion before the deposition of the Bootlegger Cove Formation (Ulery and Updike, 1983). The cohesive facies of this formation have been referred to as the Bootlegger Cove clay or the "blue clay." This clay is suggested to be responsible for the ground failures during the earthquake in 1964 (Ulery and Updike, 1983). Research by Drew (1966) using x-ray diffraction showed that the Bootlegger Cove clay consists of chlorite, illite, quartz, and feldspar, with coarser fractions containing primarily quartz and feldspar, and chlorite and illite dominating the finer fraction
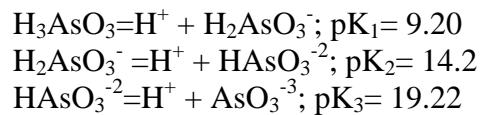
Arsenic Chemistry

In water, arsenic is commonly found as arsenate (As (V)) or the reduced arsenite ion (As (III)). The presence of oxidizing or reducing conditions in water bodies determines the oxidation state of arsenic. Sixteen to 46% of the groundwater sources in the country exceed arsenic concentrations of greater than 5 ppb whereas surface water sources seldom exceed this concentration (Chwirka, J.D. *et al*, 2000). Arsenite is present in water

as the oxyanion AsO_3^{-3} whereas arsenate exists as the oxyanion AsO_4^{-3}. Arsenate and arsenite oxyanions behave as acids in water. Arsenic acid (H_3AsO_4) will undergo the following dissociations:

$$H_3AsO_4 = H^+ + H_2AsO_4^- \; ; \; pK_1 = 2.19$$
$$H_2AsO_4^- = H^+ + HAsO_4^{-2}; \; pK_2 = 6.94$$
$$HAsO_4^{-2} = H^+ + AsO_4^{-3}; \; pK_3 = 11.5$$

Whereas, arsenous acid (H_3AsO_3) behaves as follows:

$$H_3AsO_3 = H^+ + H_2AsO_3^-; \; pK_1 = 9.20$$
$$H_2AsO_3^- = H^+ + HAsO_3^{-2}; \; pK_2 = 14.2$$
$$HAsO_3^{-2} = H^+ + AsO_3^{-3}; \; pK_3 = 19.22$$

At pH values common in ground water, arsenite is in the neutral form making species in the +3 oxidation state more mobile and generally more toxic. Arsenate is negatively charged at most drinking water pH levels, and as a result, it is often more easily removed by treatment systems.

Treatment Systems

In-home treatment devices come in two sizes. Point of use (POU) devices are small treatment units that are commonly located under one or more sinks within a home. These devices treat only the water used at the tap and typically produce only a few gallons of potable water per day. Water used for non-potable uses such as washing and bathing are not treated by POU systems. Point of entry (POE) devices are larger systems designed to treat all of the water used within the home. Because the negative health effects of arsenic are caused by ingestion, a POU device will reduce the majority of the health risk associated with arsenic contaminated water. These devices are also generally less expensive and easier to maintain than a POE devices and as a result, many homeowners opt to install POU devices.

There are two main types of POU systems commonly available today. Both adsorptive media and reverse osmosis systems are capable of removing arsenic from drinking water. However, the effectiveness of the treatment process depends primarily on raw water quality and water use (US EPA, 2001).

In activated alumina adsorptive media processes, arsenic is adsorbed onto the surface of an aluminum based media as the water passes through the device. When all of the adsorption sites are filled, the media is spent and must be replaced. Factors that effect the

efficiency of activated alumina processes include pH (optimal is 5.5-6.0) and arsenic speciation (As (III) is often not efficiently removed). Particulates and colloids can cause media fouling (Chwirka, 2000; US EPA, 2001).

Ferric hydroxide based media are also used in adsorptive media systems. As with activated alumina, arsenic ions are adsorbs to the media and once all the adsorption sites are filled, the media must be replaced. Water quality parameters can affect the efficiency of a ferric hydroxide adsorptive media system. Particulates or colloids in the water can also lead to a fouling of the media. Advanced adsorptive media processes are able to operate over a wide range of water qualities and they can remove both As (III) and As (V). In addition to removing arsenic, adsorptive media processes also reduce heavy metal concentrations and improve taste and odor (Giles *et al.*, 2002).

Initial costs for POU adsorption units range from $150 to over $500. The majority of the devices cost $200 to $300. Costs of replacement filters vary from $40 to $500, with the majority in the $100 to $200 range. These costs do not include installation, shipping or sampling.

In reverse osmosis (RO) treatment, untreated water flows under pressure past a semipermeable membrane. The membrane allows treated water to flow through while arsenic and other contaminants are retained and disposed of as a concentrated solution. RO systems are capable of effectively removing As (V), but do not typically have the same efficiency with respect to As (III) (Giles *et al.*, 2002). Turbidity, iron and manganese can adversely impact RO systems. Typical production rates for POU RO systems are 5 – 15 gallons per day (EPA, 2002).

Most POU RO units are equipped with pre and post filtration units. Prefiltration serves to reduce solids loading and extend the life of the membrane while post filtration is used as a final polishing step. The most common membranes used in RO processes are cellulose acetate, thin-film polyamide composites, and sulfonated polysulfone (EPA, 2002).

A review of product literature for POU RO units revealed that initial costs range from $360 to over $1100. The majority of the devices cost $300 to $500. Costs of replacement filters vary from $40 to $250, with the majority in the $100 to $200 price range. These costs do not include installation, shipping and handling, or sampling.

Water Quality and Geologic Investigations

The first project phase consisted of a limited water quality and geologic analysis of West Anchorage. A complete analysis, including arsenic speciation, was conducted on water samples collected from 9 homes in West Anchorage in 2003. Information from existing well logs and data collected from the analysis of cuttings from a well drilled in the study area were also compiled during 2003. Figure 1 shows the location of the sampled wells and the well log data used in the analysis. Water quality, well log and drill cuttings data were then analyzed to determine if any trends or patterns were apparent that could help homeowners evaluate the potential for arsenic contamination.

Well Water Quality

Table 1 separates wells in West Anchorage into shallow depth (< 50 ft), moderate depth (50-150 ft), and deep (>150 ft) wells and lists total arsenic concentrations as well as the percent of the total arsenic present as As (V). Concentrations of iron, manganese and vanadium are also provided as a function of depth because these metals can impact the operation of in-home treatment systems. No correlation between the depth of the well and arsenic concentration was apparent from the data. Higher iron concentrations of iron and manganese were found the shallow and moderate depth wells than in the deep wells. These data do not show a correlation between iron and arsenic which suggests that a wide variety of geological materials could act a as source of arsenic in West Anchorage groundwater.

Table 2 lists the concentrations of As (III) and As (V) in the sampled wells. All of the wells sampled contained more As (III) than As (V). No clear trend in the distribution of arsenic species as a function of depth was observed.
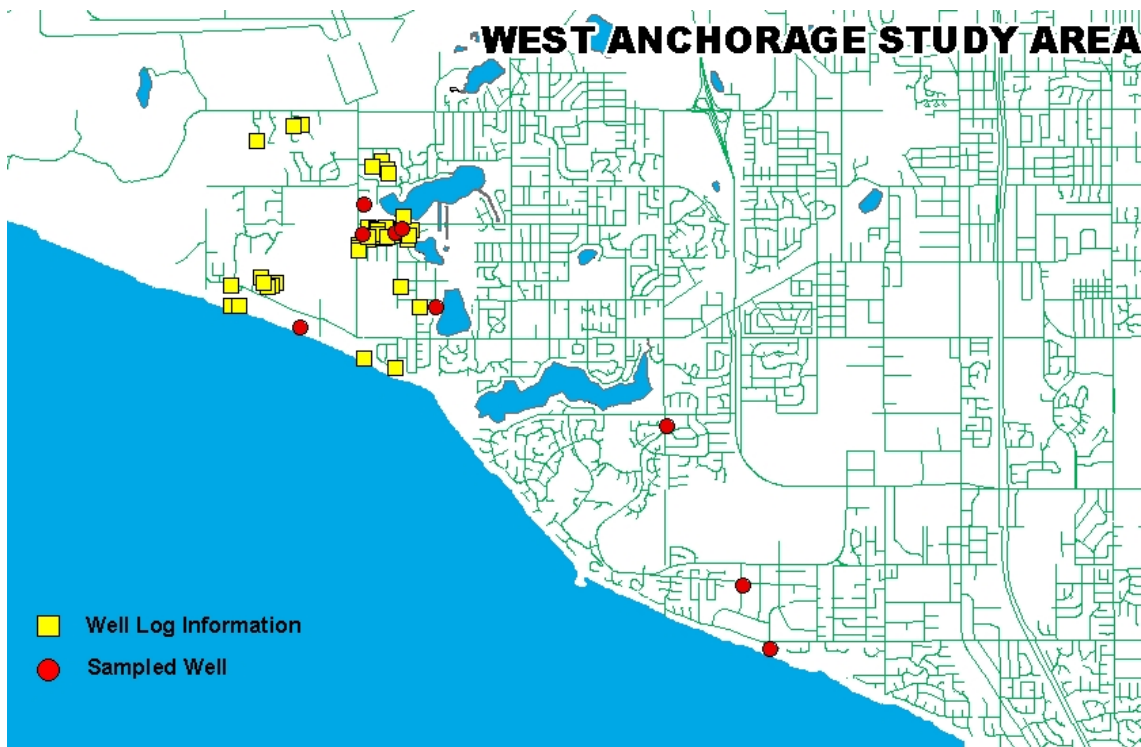
Figure 1 – Locations of the sampled wells and well logs evaluated in Phase 1.

Well Logs and Subsurface Geology

Well logs were collected from the Department of Health and Human Services and the Alaska Department of Natural Resources. Approximately 50 well logs were collected from the West Anchorage study area. The well logs collected were divided into "usable" and "unusable" data based on the detail of the lithologic observations and precision of the descriptions. Figure 2 is an example of a "usable" well log. Twenty-three well logs were selected and entered into Rockworks™ , a software package which uses the lithology and coordinates of the wells to develop a fence diagram of the area. Figure 3 is a typical fence diagram generated from the West Anchorage well log data. A clay layer that separates the subsurface material into an upper and lower area is apparent. These areas may be an upper and lower aquifer, but there is insufficient data in this analysis to verify the continuity of the subsurface formations.

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USES SITE ID (7089) 14750D601
DAILY DRILLING LOG   16

SYREN BROS. DRILLING, INC

2701 Eagle Street   Anchorage, Alaska 99503   274-6437

OWNER OF LAND....Rick Fuxjager...........
ADDRESS....... Lot 9B, Blk 2, Sundi Lake Sub....
WELL - SITE.... same
DATE - STARTED.. 9/9/82
DATE - ENDED... 9/18/82

DEPTH OF WELL...512'
STATIC LEVEL OF WATER FT......
DRAW DOWN FT......
GALS. PER HR/MN...... 60 gal/min.
KIND OF CASING...... 6' A53 250&280 wall) Grd.B steel

KIND OF FORMATION:

FROM....0....FT. TO....30....FT. silt/sand
FROM....30....FT. TO....35....FT. clay layer
FROM....35....FT. TO....80....FT. dry sand
FROM....80....FT. TO....92....FT. damp sand
FROM....92....FT. TO....155....FT. wet sand (begin)
FROM....155....FT. TO....175....FT. water/sand (heaving)
FROM....175....FT. TO....210....FT. clay
FROM....210....FT. TO....240....FT. clay/gravel
FROM....240....FT. TO....275....FT. silt/clay/hardpan slip
FROM....275....FT. TO....300....FT. clay/gravel
FROM....300....FT. TO....355....FT. clay/gravel
FROM....355....FT. TO....368....FT. clay/gravel

FROM....368....FT. TO....376....FT. sand/water
FROM....376....FT. TO....450....FT. clay
FROM....450....FT. TO....465....FT. clay/gravel/silty water
FROM....465....FT. TO....497....FT. clay
FROM....497....FT. TO....501....FT. rock shelf
FROM....501....FT. TO....507....FT. gravel
FROM....507....FT. TO....512....FT. sand/gravel/water
FROM........FT. TO........FT.
FROM........FT. TO........FT.
FROM........FT. TO........FT.
FROM........FT. TO........FT.

MISCL. INFORMATION:
set pump at bottom of well, to keep sand from heaving
during pump operation.

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1 1982

DRILLER'S NAME................ Stephen D. Syren

12-4-10 BD BC13 (lot is divided ...)

Figure 2 – An example of a well log with acceptable data quality

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Table 1 - Arsenic levels and various metals concentrations for wells in West Anchorage at various depths.

Shallow Depth Wells						
Well	Depth	Total As (ug/L) [% As(V)]	Total Iron (ug/L)	Total Mn (ug/L)	Total Vanadium (ug/L)	Material
A	49	36.8 [16.0%]	20210	1382	1.78	Gravel with Water
B	44	19.0 [ND]	13050	688.8	1.32	Sand and Gravel
Moderate Depth Wells						
Well	Depth	Total As (ug/L) [% As(V)]	Total Iron (ug/L)	Total Mn (ug/L)	Total Vanadium (ug/L)	Material
C	102	26.4 [41.0%]	5994	593.3	ND	Gravelly silt, cemented
Deep Wells						
Well	Depth	Total As (ug/L) [% As(V)]	Total Iron (ug/L)	Total Mn (ug/L)	Total Vanadium (ug/L)	Material
C	199	74.2 [13.9%]	318.6	116.9	ND	Sand and Gravel
E	261	15.4 [2.1%]	4849	438.1*	ND	Gravel, slight sand
F	318	10.3 [19.0%]	59.6	2.7	ND	Sand and Gravel
G	330	59.1 [13.2%]	113.2	25.4	ND	Gravel and Water

Table 2 - Arsenic speciation of West Anchorage wells

Shallow Depth Wells			
Well	Depth	As(III) ppb	As(V) ppb
A	49	28.7	5.9
B	44	15.2	ND
Moderate Depth Wells			
Well	Depth	As(III) ppb	As(V) ppb
C	102	13.8	10.8
Deep Wells			
Well	Depth	As(III) ppb	As(V) ppb
D	199	66.1	10.4
E	261	13.0	0.3
F	318	8.3	2.0
G	330	51.5	7.8
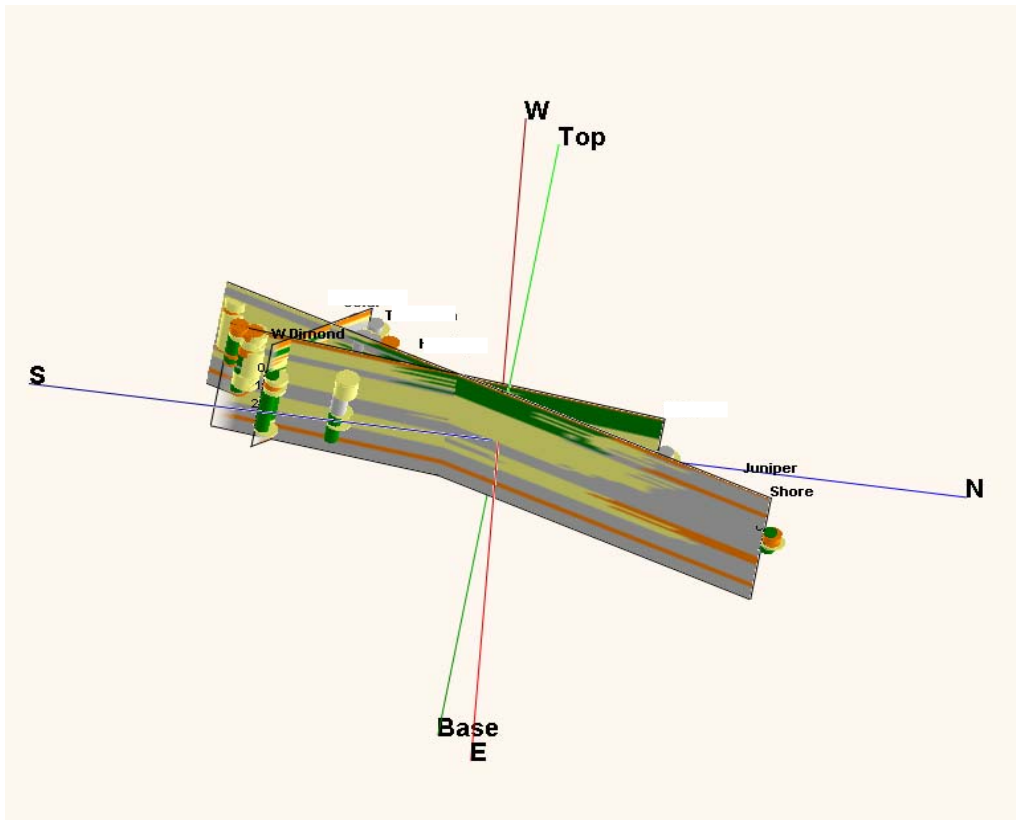
**Figure 3 - Typical fence diagram of West Anchorage created using Rockworks™.
(Yellow = sand, orange = gravel, gray = clay, green = silt).**

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Analysis of Soils Collected from a Drinking Water Well

On August 4 and 5, 2003 M-W Drilling installed a drinking water well at a new private residence on Wilcox Street in West Anchorage. The well was drilled to a depth of approximately 300 ft and developed at 295 ft. Soil samples were collected and described every 5 ft by UAA and DHHS staff. The soils were then dried, placed in 2M HCl for leaching, and the leachate analyzed to determine metal concentrations.

A thick clay layer was observed between 120 ft to 235 ft. Large amount of sand and clay with gravel were observed at the bottom of the well. A marginal correlation between leachable iron and vanadium, manganese, nickel, chromium and aluminum was observed. However, no strong correlation between arsenic and the other metals was apparent.

Treatment System Testing

Three POU systems were evaluated for 7 months to 1 year in four homes in West Anchorage. The Multi-Pure system uses an ferric hydroxide based adsorptive media specifically designed to remove arsenic from water. The Multi-Pure system consists of a single filter element that contains a pre-filter to remove suspended and colloidal material followed by a porous carbon block impregnated with sorptive media specific for arsenic removal.   The filter element is contained in a stainless steel housing which is connected to the cold water line. Water passing through the filter element is dispensed through a dedicated drinking water tap. Additional information on this POU system can be found at www.multipure.com.

The Kinetico Reverse Osmosis system consists of a four step process.   Untreated water is first passed through a 5 micron pre-filter to remove suspended solids. After filtration water is forced through a semipermeable reverse osmosis membrane. Permeate from the RO membrane is directed to a pressurized storage tank. A unique feature of the Kinetico system is that treated water is continually circulated through the storage tank. Permeate is passed through an activated carbon filter as the final step in the treatment process. This system is also installed under the sink and a separate tap is installed for dispensing drinking water.   Additional information on the Kinetico system can be found at www.kinetico.com.

The Culligan Good Water Machine® is a reverse osmosis POU system also utilizes a semipermeable membrane to remove impurities from raw water. Prior to going through the RO filter, the raw water is passed through a 5 micron sediment filter. After the water has passed through the RO filter, it is passed through a carbon filter. The water is then stored in a simple small pressure tank before being passed through a second carbon filter and dispensed from a dedicated faucet. More information on the Culligan Good Water Machine® can be found at www.culligan.com.

The POU treatment systems were installed in private homes in West Anchorage in the Fall of 2003. Samples were regularly collected from these systems and analyzed for arsenic concentration and other basic water quality parameters such as pH and conductivity. These systems were evaluated for efficacy in arsenic removal as well as ease of installation and use.

Table 3 summarizes basic untreated well water quality parameters at each test site. The average total arsenic concentrations range from 7.56 ppb to 49.36 ppb. At all three sites, the majority of the arsenic found is soluble As (III) ranging from an average of 6.21 ppb to an average of 41.66 ppb. The average pH of the untreated water at the three sample sites ranged from 7.61 – 8.38 with an average conductivity range from 302.1 – 578.5 µS/cm. The average total iron concentration of the untreated water ranged from 47.89 – 154.6 ppb.

Table 3 – Untreated Well Water Quality at Each Test Site

Parameter Average	MultiPure POU	Kinetico POU	Culligan POU
pH	8.38	7.66	7.61
Cond (uS\cm)	302.1	522.2	578.5
Total As (ppb)	49.36	26.99	7.56
Sol As (ppb)	47.26	27.44	6.6
As (III) (ppb)	41.66	20.66	6.21
As (V) (ppb)	5.6	6.78	0.97
Total Mg (ppb)	4343	226.73	62.57
Total Mn (ppb)	25.5	10.7	1.81
Total Ca (ppb)	13225	914.87	281.47
Total Fe (ppb)	154.6	140.25	47.89
Total V (ppb)	0.4	1.06	0.2

Figure 4 plots the performance of a Multi-Pure (Model Plus-As-SB-PID-PA) POU system. The Multi-Pure system reduced the total arsenic concentration from an average of 46.5 ppb to typically less than 1 ppb (99% removal of total arsenic). Treated water arsenic levels were consistently low throughout the study period regardless of variations in untreated water arsenic concentration. The Multi-Pure system was capable of removing both the As (III) and As(V) present in the well water from the test location. At the end of the study period, a slight increase in treated water arsenic concentration was apparent suggesting that the effective cartridge life for this site was approximately 1 year.

The homeowners were generally happy with the performance of the unit. The system produced enough volume for their drinking water needs and they logged no complaints pertaining to the taste or odor of the treated water. The Multi-Pure system was easily installed under the sink. Total installation time was less than 30 minutes.
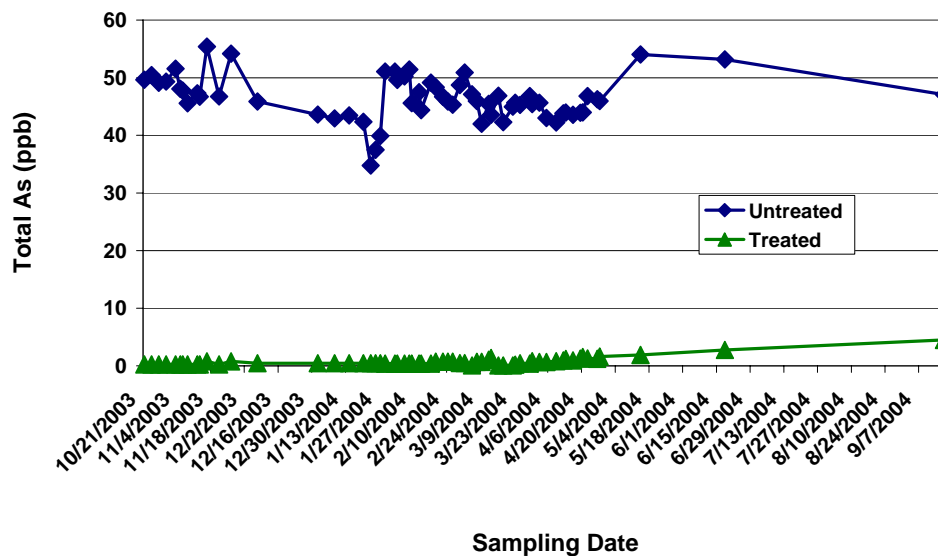
Figure 4 - Total As removal performance with the Multi-Pure adsorptive media system

The arsenic removal performance of the Kinetico reverse osmosis system over a 7 month sampling period is graphed in Figure 5. The Kinetico system removed 39% of the total arsenic reducing the average total arsenic concentration from 24.2 to 14.7 ppb. The water at this test site contained primarily soluble As (III) which can be difficult to remove by RO treatment. No complaints were made by homeowner regarding the taste or the smell of the treated water. Although it was not difficult, the installation of the Kinetico RO unit was significantly more complex than the Multi-Pure unit. A homeowner with no prior experience installing this unit could expect to spend several hours installing the system.

On May 5, 2004 the Kinetic RO unit was replaced by a Multi-Pure AS-SB-SV adsorption unit. Limited testing of this unit indicated that the Multi-Pure system was able to reduce the arsenic concentration at this site from approximately 29 ppb to less than 1 ppb.
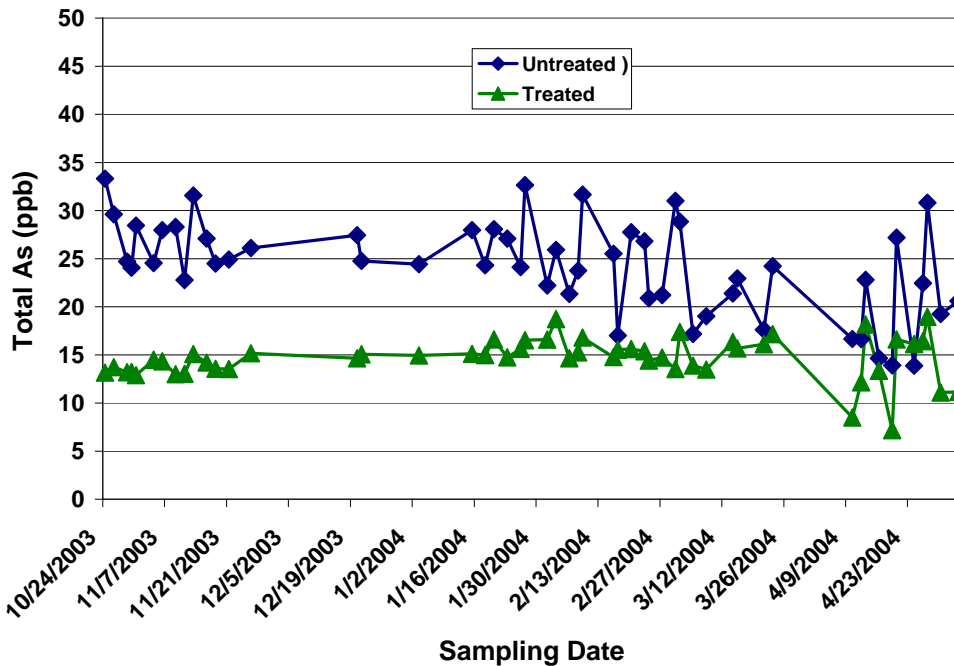
Figure 5 - Total As removal performance with the Kinetico RO System

Figure 6 plots the reduction of total arsenic concentration using a Culligan POU RO system. The Culligan system had an arsenic removal efficiency of approximately 40%, reducing the average total arsenic concentration from 11 ppb to 6.5 ppb. The well water arsenic concentration at this site was highly variable. Just as with the Kinetico RO test site, the majority of the arsenic was present as As (III) which may have compromised the ability of the RO system to remove arsenic. No complaints were made by homeowner regarding the taste or the smell of the treated water. Installation of the Culligan RO unit was slightly less complex than installation of the Kinetico unit.

On July 8, 2004 the Culligan RO unit was replaced by a Multi-Pure AS-SB-SV adsorption unit. Limited testing of the Multi-Pure system indicated that it was able to reduce the arsenic concentration at this site from approximately 24 ppb to less than 1 ppb.
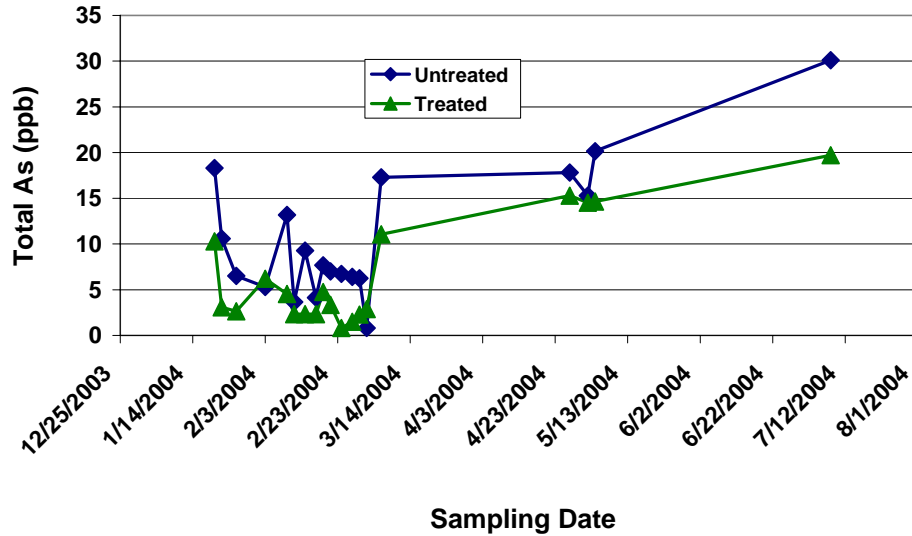
Figure 6 - Total As removal performance with the Culligan RO System

Conclusions

The arsenic in Anchorage drinking water wells appears to be released from naturally occurring arsenic bearing minerals. Even though it is derived from natural sources, this arsenic can pose a health threat if present in high enough concentration. Our study indicated that elevated arsenic, greater than 10 parts per billion (ppb), is present in many wells in West Anchorage and that a large fraction of the arsenic is present as As (III). Unfortunately, there are insufficient data at this time to predict whether a specific well has high arsenic levels.

There are two primary methods of treatment used in POU systems on the market today. Adsorptive media systems use an iron or aluminum based material specifically designed to chemically bind with arsenic to remove it from water. In reverse osmosis (RO) treatment, untreated water flows under pressure past a membrane. The membrane selectively rejects arsenic and other contaminants and allows treated water to pass through.

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Both adsorptive media and RO systems are capable of providing excellent arsenic removal, but their effectiveness is highly dependent upon the type of the water being treated.

The two RO systems tested as part of this study did not consistently achieve high levels of arsenic removal.   These results suggest that West Anchorage groundwater quality is such that RO systems may not be effective in every case. Homeowners should carefully evaluate system performance claims of these popular units and evaluate actual performance to ensure that arsenic can be consistently removed.

More consistent performance was obtained with the adsorptive media system. The iron based system evaluated in this project was particularly robust and effective over a wide range of water qualities. These systems had effective cartridge lives of over 10 months in the UAA/DHHS study, although results will vary from site to site depending on water quality and usage rates.

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