Arsenic Treatment for Small Water Systems

Course No: C02-010

Credit: 2 PDH

Steven Liescheidt, P.E., CCS, CCPR

Continuing Education and Development, Inc.
9 Greyridge Farm Court
Stony Point, NY 10980

P: (877) 322-5800
F: (877) 322-4774

info@cedengineering.com

Guidance Document:

Arsenic Treatment for Small Water Systems

November 2005

Washington State Department of
Health
Environmental Health Programs
Division of Drinking Water

DOH PUB. #331-210
(updated)

Guidance Document:

Arsenic Treatment for Small Water Systems

November 2005

For more information or additional copies of this report contact:

Training and Outreach Section
Division of Drinking Water
Department of Health
PO Box 47828
Olympia, WA 98504-7828
(360) 236-3164
http://www.doh.wa.gov/ehp/dw/

Mary Selecky
Secretary of Health

Bill White
Assistant Secretary, Environmental Health

Gregg Grunenfelder
Director, Division of Drinking Water

The Department of Health is an equal opportunity agency. If you need this publication in an alternative format, please call 1-800-527-0127 (voice) or 1-800-833-6388 (TDD relay service). For additional copies of this publication, call 1-800-521-0323. This and other publications are available on the Internet: http://www.doh.wa.gov/ehp/dw

Table of Contents

List of Tables

List of Figures

Introduction and Scope

This guidance document is a resource for small water systems that have elevated levels of arsenic in one or more of their sources and need to comply with the final Arsenic Rule published by the U.S. Environmental Protection Agency (EPA) in January 2001 (January 22, 2001, Federal Register notice, Volume 66, Number 14).

In this document, small water systems are defined as those that generally serve less than 1,000 persons. The statewide data for arsenic indicates that systems under 1,000 population comprise over 80 percent of the Group A water systems with sources that have exceeded the new arsenic standard at some time in the past.

Included in this document are tools to help owners, operators, and board members of small water systems make informed decisions about arsenic compliance options, focused on selecting the most suitable treatment alternative. It is designed to be used by a small water system without the assistance of a licensed engineer.

Several steps can be taken by a small system to decide which treatment technology is best for their system. A licensed engineer would, however, be needed to prepare the design and construction documents for any project installation. On the following page is a checklist of the steps that can be followed by a system to make an appropriate treatment decision.

As with any water treatment process, there are often site-specific conditions that should be identified and factored into the final decision regarding treatment options. This guidance document provides a limited overview of what those specific elements might be.

Throughout this document the units of concentration for water quality parameters (analytical tests) will be given in terms of either “parts per billion” or “milligrams per liter.” Parts per billion, or ppb, will be used when the levels of significance for a water quality parameter are very small, and milligrams per liter will be used when the significant level is relatively much higher. A milligram per liter is one thousand times larger than a part per billion.

The reader should keep in mind the units of measurement that apply to the various water quality parameters that are presented. Below is a summary that describes the equivalency of the units of measurement used for substances in drinking water:

- **Part per billion = ppb = microgram per liter = ug/L**
- **Part per million = ppm = milligram per liter = mg/L**
- **1mg/l = 1000 ppb**

For example: 10 ppb = 10 ug/L = 0.010 mg/L = 0.010 ppm

Arsenic Project Checklist

1. Collect and analyze samples for arsenic from each source at the entry to system distribution.

2. Determine compliance status based on regulatory requirements.

3. Evaluate feasibility of non-treatment alternatives such as blending, inactivating existing sources, and/or developing a new source. If non-treatment is feasible, go to Item 10 below. If treatment is necessary, proceed to item 4.

4. Measure water quality parameters (such as pH, iron, phosphate, etc.) for use in determining appropriate treatment options.

5. Identify the needed treatment system capacity in gallons per minute for maximum day demands and for the average annual daily demand.

6. Select the most practical approach(es) using the decision diagrams provided in this guidance document.

7. If practical, pilot test the selected treatment option to confirm that it will perform as expected for the water being treated.

8. Develop preliminary capital and operations and maintenance (O&M) costs using the cost curves provided in Appendix B. Include other site-specific cost estimates that may be associated with the specific system and selected treatment option.

9. Develop project specific cost estimates for construction and initial implementation of the treatment method selected.

10. Seek funding options, such as a Drinking Water State Revolving Fund (DWSRF) loan, and secure funds to complete the project.

11. Implement the project (e.g., design, state approvals, construction, inspections, etc.).

12. Identify and document successful operating criteria and processes through piloting after initiating full-scale treatment.

13. Continuously operate the treatment plant with trained operators.

Note: Steps 1-6, 8, 10 and 13 can be performed without the assistance of a licensed engineer. A licensed engineer must be involved in the piloting, design, and construction of an arsenic mitigation project.

Background

The new federal Arsenic Rule lowered the arsenic maximum contaminant level (MCL) from 50 ppb to 10 ppb and requires existing sources to be in compliance with the new MCL by January 2006. The Arsenic Rule also requires that 2002 annual Consumer Confidence Reports (CCR) include information for arsenic. More information on arsenic related CCR requirements are included on the Washington State Department of Health (DOH) fact sheet (see Appendix A) or on the web at:
http://www.doh.wa.gov/ehp/dw/our_main_pages/arsenic.htm

Purveyors with sources that exceed the new MCL are strongly encouraged to start securing funding as soon as is possible, since it may take from two to three years to determine an appropriate compliance approach, secure the needed funds, and construct the project.

This guidance document was developed to assist purveyors to logically select an appropriate arsenic compliance approach. If treatment is required, the cost information provided in this document can be used in developing costs for use in a DWSRF application.

Information and guidance is provided on the following topics:

- Arsenic occurrence in Washington State;
- Arsenic compliance approaches for small systems (both treatment and non-treatment alternatives); and
- Capital and operations costs for treatment alternatives (including waste disposal considerations).

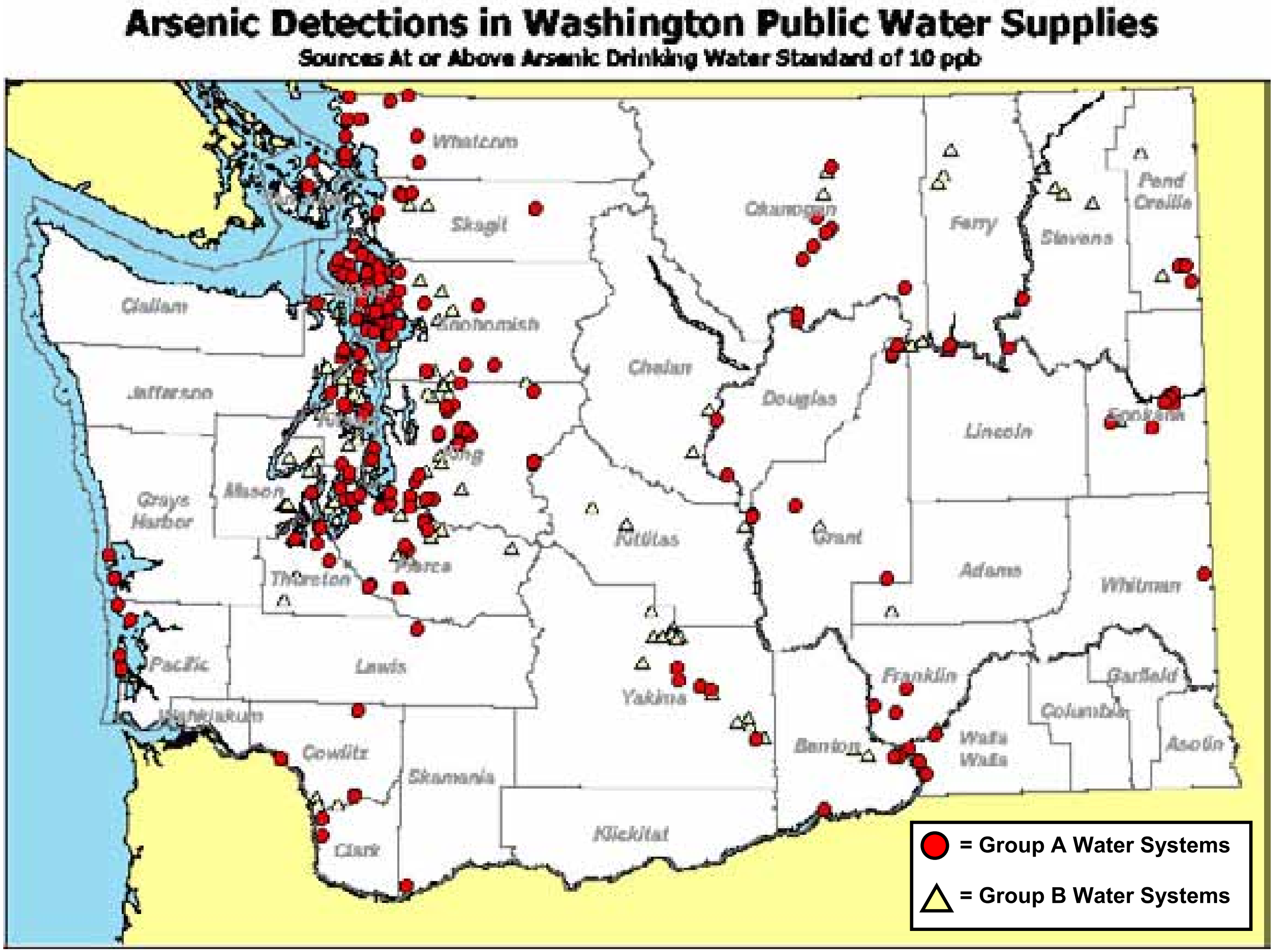
Arsenic Occurrence

Arsenic is a naturally occurring element in the Earth's crust. Most arsenic in drinking water comes from natural rock formations, especially those of volcanic origin. Arsenic is primarily a groundwater issue. There are no known surface water systems in the state that exceed the new arsenic MCL. The Puget Sound regional geology includes glacial and sedimentary deposits of volcanic material. Water that flows through these deposits tends to have greater concentrations of arsenic than other sources of water. As a result, sources in the Puget Sound region are more likely to exceed the new arsenic MCL than those in other parts of the state (Figure 1).

Arsenic has also been deposited in the environment from copper smelting and pre-1950 pesticide applications. However, this arsenic binds strongly to soil and typically remains within the top few feet of the surface. There is no evidence that man-made sources of arsenic have affected drinking water sources in the state.

High arsenic concentrations are not restricted to the Puget Sound Region. Arsenic above the 10 ppb MCL has been found in wells in 33 of the 39 counties in Washington State. The seven counties with the highest number of Group A water systems with arsenic above the MCL are identified in Table 1.

FIGURE 1: Arsenic Detections in Public Water Supplies



A colored version of this map is available at: http://www.doh.wa.gov/ehp/dw/our_main_pages/arseniclist.htm

Table 1:
Arsenic MCL Exceedances for Selected Counties

County	Group A Systems with As > 10 ppb
Island	48
King	21
Pierce	19
Whatcom	15
Snohomish	12
Kitsap	8
Yakima	7

Note: The above information was compiled from DOH source monitoring data for all Group A systems for the period 1993-2002.

Small systems comprise a significant majority of systems with sources that exceed the new arsenic MCL (Table 2). Of the 204 Group A water systems for which arsenic has been detected above the MCL, 85 percent serve less than 1,000 persons and more than 57 percent serve fewer than 100 persons.

Table 2:
Systems with at Least One Arsenic Detection Greater than 10 ppb

Water System Size	Number of Systems
Group A Water Systems serving populations:	
Greater than 10,000	9
Between 5,000 and 10,000	2
Between 1,000 and 5,000	23
Between 500 and 1,000	10
Between 100 and 500	47
Less than 100	117
Total Number of Group A Systems	208

Note: The above information was compiled from DOH source monitoring data for all Group A systems for the period 1993-2002.

Monitoring for Arsenic

If a sample from a source exceeds the arsenic MCL, quarterly sampling for arsenic must be performed to confirm that the running annual average is above the MCL. As summarized by EPA (2002), a water system will be required to provide treatment or to seek other options if any of the following is true for any of their sources of supply:

- A single sample > 40 ppb
- Average of two quarters > 20 ppb
- Running annual average (4 consecutive quarters) > 10 ppb

Arsenic Compliance Approaches

This guidance document addresses general approaches to comply with the Arsenic Rule. With any water treatment process, there are variables that are unique to a specific system. Water systems that encounter more complex or unusual situations are urged to seek the advice of water professionals early in the planning process. With any selected compliance approach, a project report must be completed in accordance with Washington Administrative Code (WAC) 246-290-110. The project report, as well as the design plans and specifications, must be prepared by a professional engineer licensed in the state of Washington.

A brief summary of compliance approaches appropriate for small systems is summarized below for use with the decision diagrams in this guidance document. Additional information on treatment technologies is provided following the decision diagrams.

Non-Treatment Alternatives – include the blending of sources prior to the distribution system, inactivating the problem source, connecting to an adjacent water system, and developing a new source. When feasible, non-treatment alternatives are typically less burdensome and less costly than treatment.

Iron Oxidation/Filtration – involves the oxidation of naturally occurring iron, which binds to arsenic and is then removed by filtration. Iron can be added to increase the amount of arsenic removed by filtration. The process is most effective when pH is less than 7.5 and the concentration of iron to arsenic is 20:1, or greater.

Ion Exchange – involves the exchange of chloride ions for arsenic ions and periodic regeneration of the ion exchange resin with a salt solution. Health concerns associated with system operations and brine disposal limit the applicability of this technology for most small systems.

Sorbents – adsorb arsenic from the water. Well water is passed through a pressure vessel containing a sorbent, which is periodically replaced. The frequency of replacement will vary depending upon the sorbent used, pH, and other water quality parameters. All sorbents need to be National Sanitation Foundation (NSF) 61 approved.

Point-of-use/Point-of-entry (POU/POE) – also referred to as under-the-sink and whole-house treatment units have limited applicability. The 1996 amendments to the Safe Drinking Water Act (SDWA) outline the conditions under which POU/POE devices may be used as a compliance option. Based on a review of the issues involved with POU/POE treatment requirements, DOH will not allow POU/POE treatment for arsenic removal.

Water Quality Information

Water systems considering the installation of arsenic treatment should have adequate water quality information. Certain water quality parameters can interfere with arsenic treatment, while some treatment technologies require specific water quality conditions to be most effective. The water quality parameters in Table 3 will be referenced in decision diagrams that help a water purveyor identify an appropriate treatment technology for further evaluation.

Table 3:
Water Quality Parameters Useful for
Arsenic Treatment Determinations

Water Quality Parameters	
Standard IOCs	**Recommended**
Arsenic (Total)	pH
Chloride	Alkalinity
Iron	Total Organic Carbon
Manganese	Phosphate
Sulfate	Silica
	Arsenic (III)
	Arsenic (V)
	Hardness (Ca, Mg)
	Total Dissolved Solids

Many of these water quality parameters are analyzed during routine regulatory inorganic chemical (IOC) analysis, generally required every three years. Some parameters, such as calcium, magnesium, silica, phosphate, pH, alkalinity, and total organic carbon (TOC), are not routinely analyzed, and determination of their concentrations will require additional monitoring. Speciation testing for arsenic is also recommended to determine if oxidation of As(III) to As(V) will be required.

Figures 2 through 6 present decision pathways that are intended to aid water purveyors in the selection of an arsenic removal process. It is possible that more than one arsenic removal process will be technically suitable. In this case, other factors, such as costs, ease of operation, local service availability, etc., will be important to the final selection of a treatment method.

Note: It is important that the decision matrix process be used prior to any cost analysis for the selection of an arsenic removal process. The technical feasibility of the treatment alternative must be established before costs become a consideration.

FIGURE 2: Decision Diagram 1 - Non-Treatment Alternatives

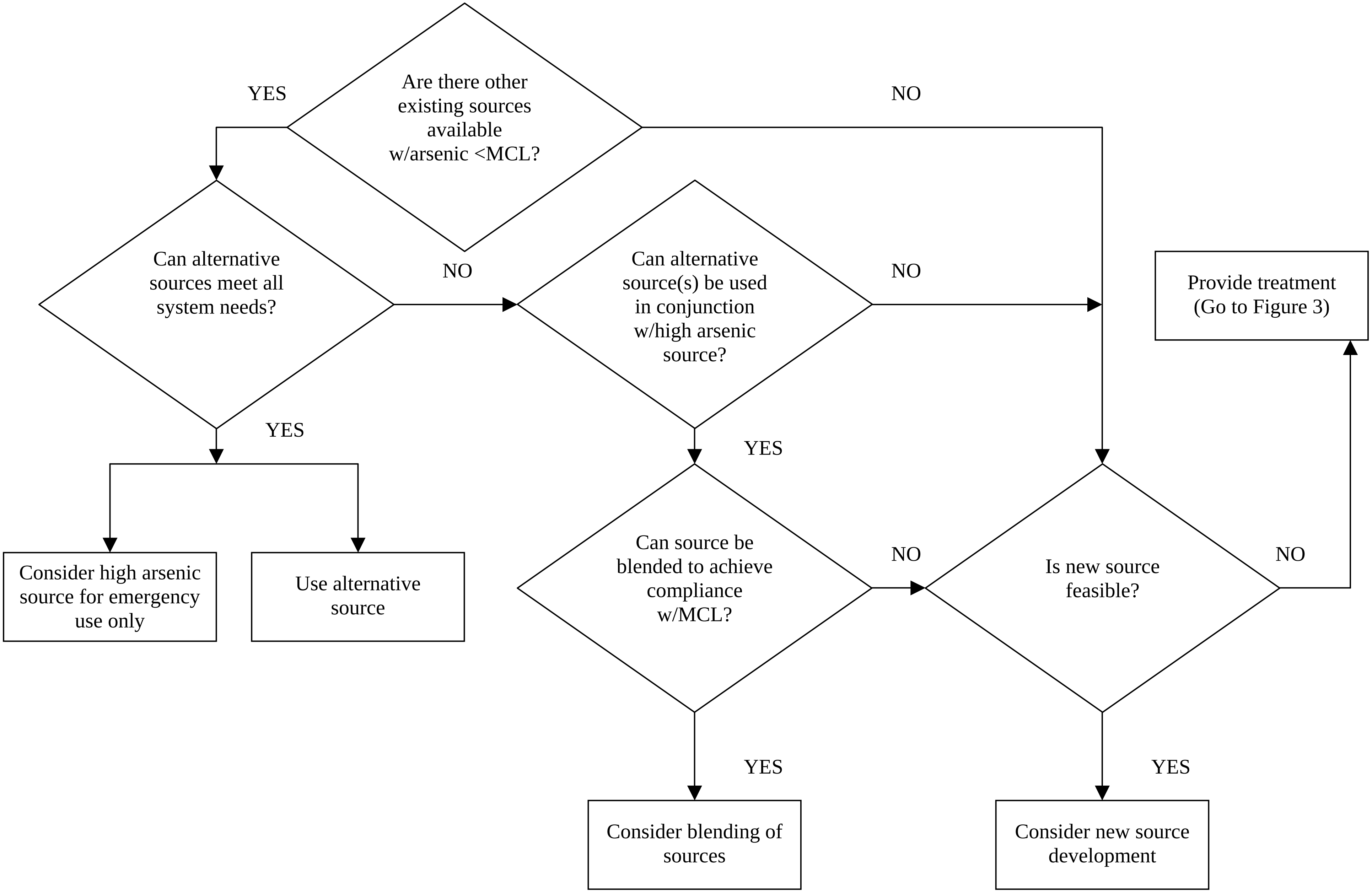


FIGURE 3: Decision Diagram 2 - Iron Oxidation/Filtration Alternative

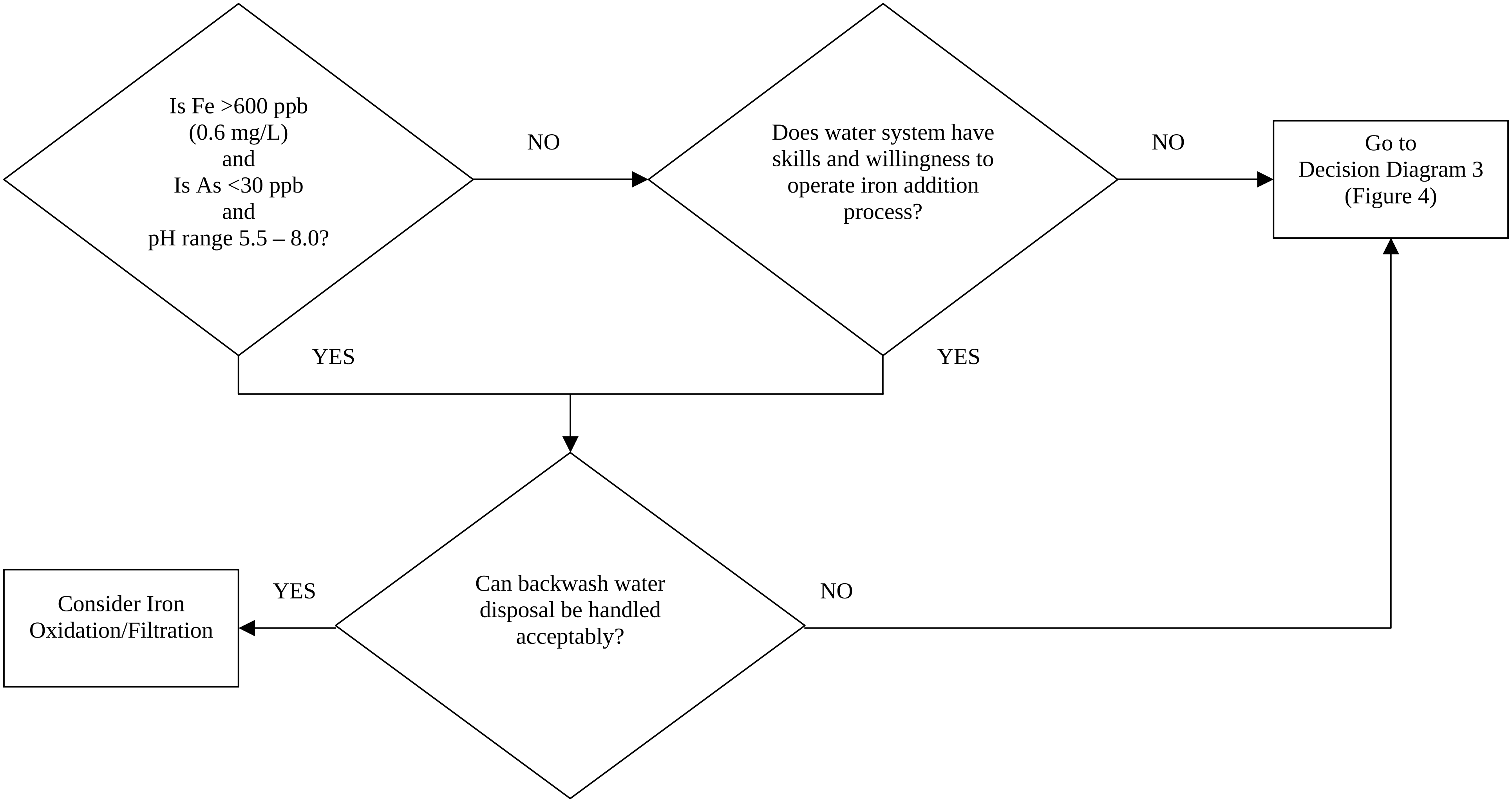


FIGURE 4: Decision Diagram 3 – Ion Exchange Alternative

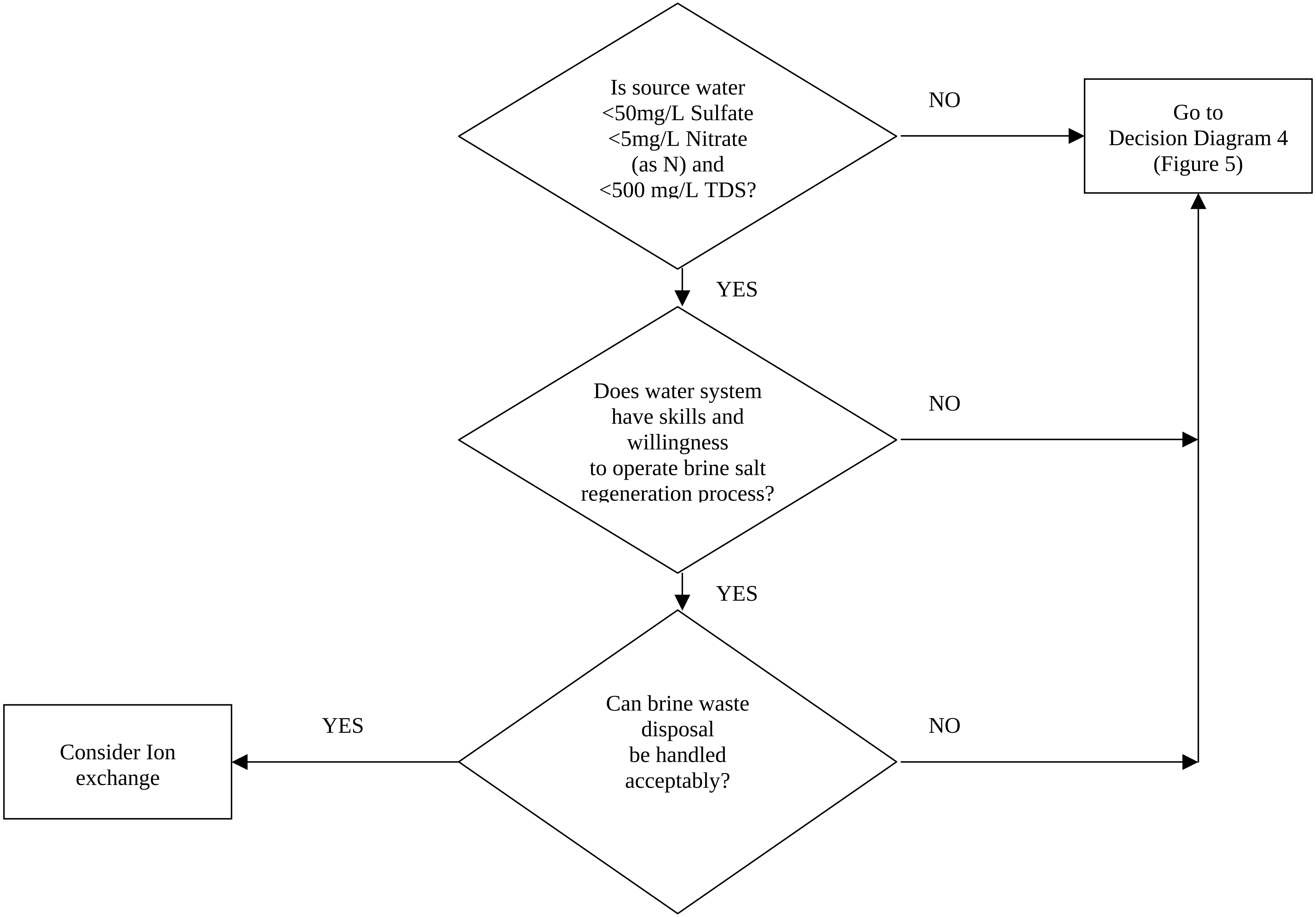
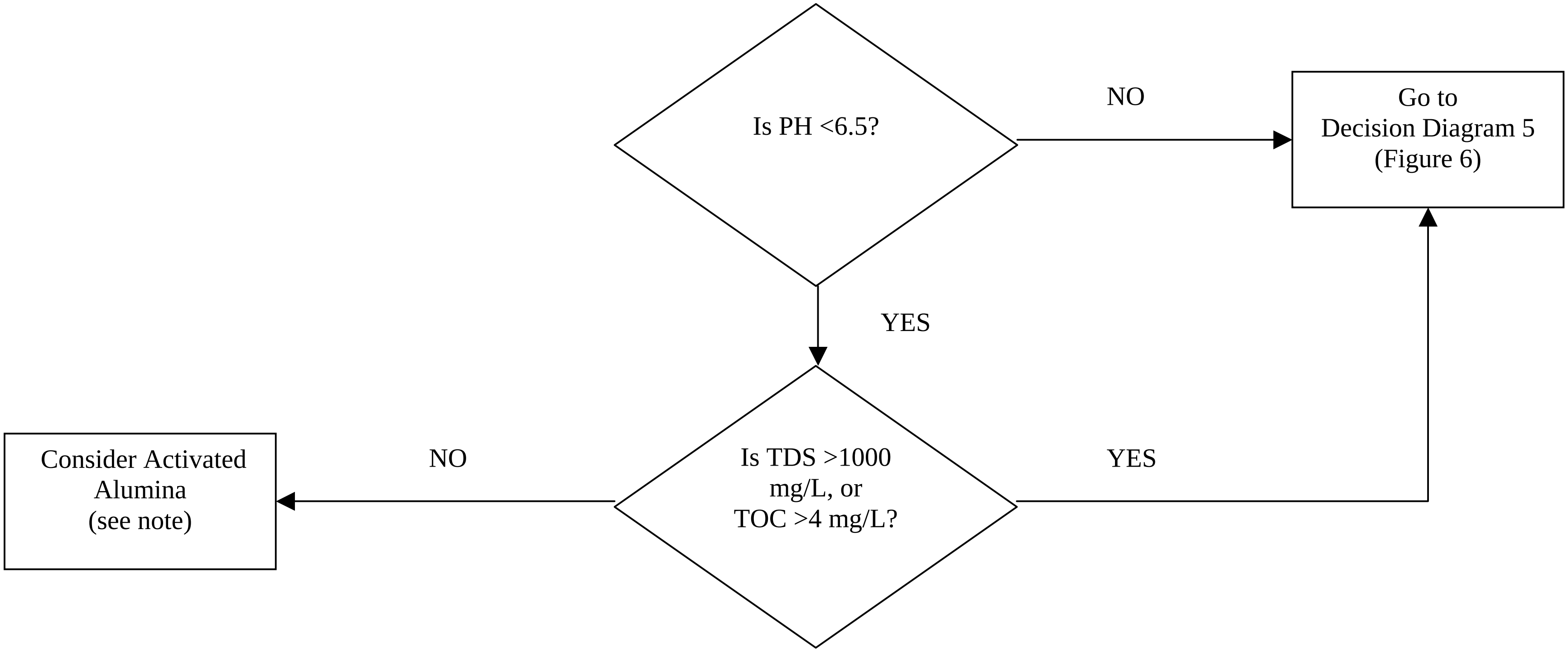


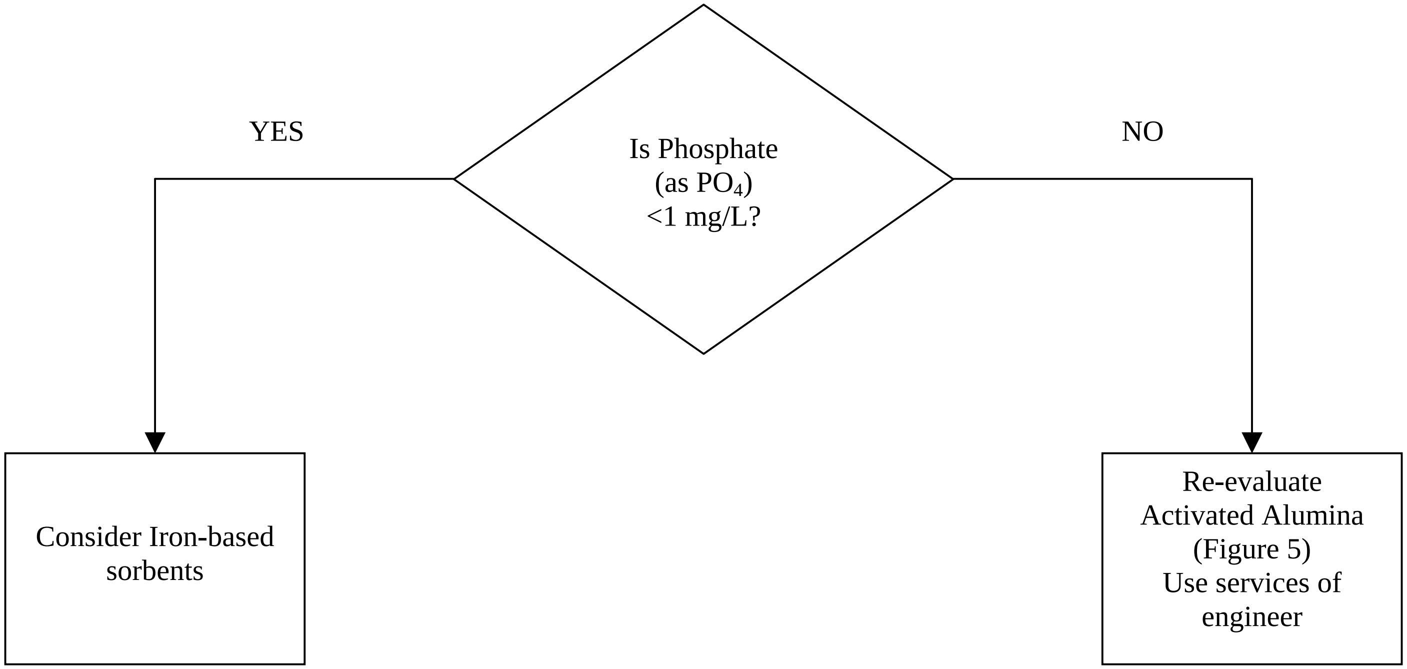
FIGURE 5: Decision Diagram 4 – Activated Alumina Alternative



Note: If water quality levels are <u>greater than</u> any of the following, then consulting with an engineer to determine possible interference limitations would be appropriate.

1 mg/L Phosphate
250 mg/L Chloride
360 mg/L Silica
0.5 mg/L Iron
0.05 mg/L Manganese

FIGURE 6: Decision Diagram 5 – Iron-Based Sorbent Alternative



Basic Arsenic Treatment Design

Arsenic in water is commonly present in water as dissolved ions. It is present in two different oxidation states: arsenite [AsO_3^{-3}] and arsenate [AsO_4^{-3}]. Arsenite, commonly written as As(III), is the reduced form of arsenic and is more difficult to remove from water than arsenate, As(V), the oxidized form of arsenic. Consequently, most treatment techniques will incorporate chemical oxidation, such as chlorination or ozonation, as an initial step to convert As(III) to As(V).

There are several types of treatment that are available for arsenic. EPA has identified the following "Best Available Technologies" (BATs) for arsenic removal:

- Oxidation/Filtration
- Ion Exchange
- Activated Alumina Adsorption
- Enhanced Coagulation/Filtration
- Enhanced Lime Softening
- Reverse Osmosis
- Electrodialysis Reversal

Only some of the technologies listed above are generally recognized as being suitable for small systems. Enhanced coagulation/filtration and enhanced lime softening apply only to systems currently treating surface water with those technologies. Electrodialysis reversal and reverse osmosis require expensive equipment and are complex to properly operate. They are also not likely to be suitable for small system source treatment.

Of the available technologies, the most appropriate for small systems include:

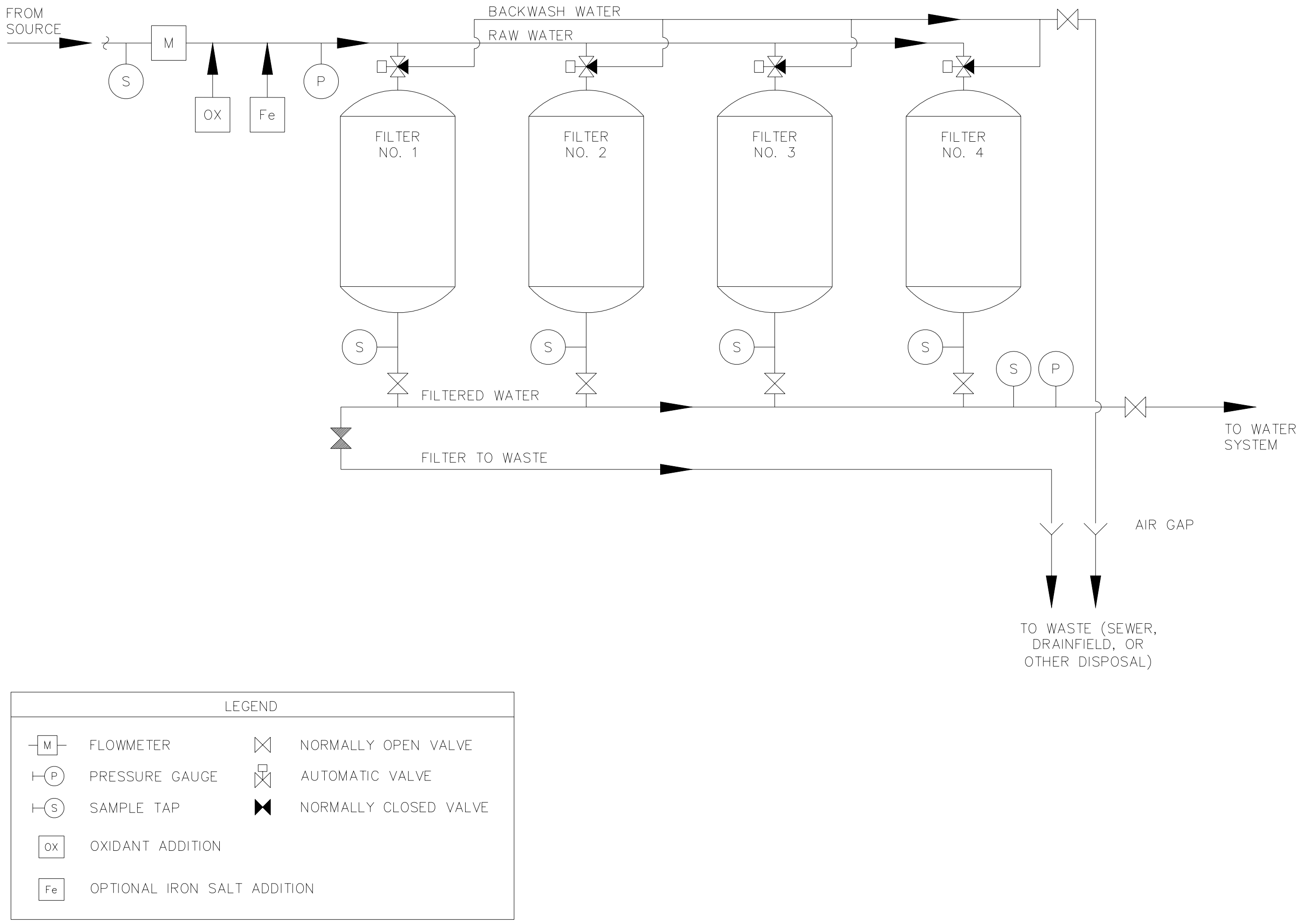
- Oxidation/Filtration;
- Ion Exchange; and
- Sorption (including Activated Alumina and Iron-based Sorbents).

These three technologies are described in greater detail in this document.

Oxidation/Filtration

The oxidation/filtration process involves the oxidation of iron and arsenic, followed by filtration (Figure 7). During the oxidation step, arsenic binds to the iron oxides that are formed. These iron oxides are then removed by filtration. In general, the process is the same as treatment to remove iron and manganese. The key criterion is that there is sufficient iron to bind the arsenic.

FIGURE 7: Iron Oxidation/Filtration Process Schematic



Chlorine, ozone, or permanganate can be used to oxidize As(III) to As(V). The oxidant is injected prior to the filters with sufficient time to allow for the oxidation of the iron and arsenic. The filters then remove the arsenic and iron together. A number of different filter media can be used, including sand, greensand, solid manganese dioxide such as pyrolucite, and manganese dioxide coated sand such as BIRM™. Typical iron and manganese removal equipment is shown in Figure 8.

FIGURE 8: Typical Oxidation/Filtration System Composed of Pressure Vessels and Pyrolucite Media for 200 gpm (ATEC Technologies, Hollister, CA)

Over time, the filter media accumulates the filtered solid material. This causes increased headloss through the filter to a point where it is necessary to backwash the filter to remove the accumulated material. During backwashing, the flow rate is increased and its direction is reversed. This causes the media to be disturbed, allowing the filtered material to be dislodged from the media into the backwash flow. The backwash water with the associated filtered material is directed to waste.

The water quality parameters that most strongly affect this treatment process are the concentration of naturally occurring iron in the raw water and the raw water pH. Ideally, the ratio of iron to arsenic will be greater than 20:1 and the pH between 6.0 and 8.0. The process effectiveness decreases significantly when the pH is greater than 7.5. The addition of iron in the form of ferric chloride ($FeCl_3$) can be used to provide additional iron, as well as decrease the raw water pH. This benefit from iron addition should be weighed against the potential for decreased filter run times, increased backwash water disposal, and process complexity concerns for very small systems.

Typical design parameters for oxidation/filtration systems are included in Table 4 and cost information is provided in Appendix B.

Table 4:
Iron Oxidation/Filtration Design Parameters

Parameter	Value
Media loading rate	3-12 gpm/sq. ft.
Empty bed contact time	3 minutes
Oxidant	Chlorine, ozone, permanganate
Media depth	20-48 inches
Backwash rates	15-30 gpm/sq. ft
Approximate backwash volume	4-10% of production

Iron Oxidation/Filtration Wastes

The main waste stream from iron oxidation and filtration is the backwash water that contains particulate iron oxides. The iron oxides tightly bind arsenic. Previous studies have indicated that the concentration of arsenic in the solids is well below the threshold for being considered a hazardous waste (MacPhee 2000, Chiwirka 2001). The Washington State Department of Ecology (Ecology) has indicated that the filter backwash water is conditionally exempt from the state-based permit requirements, if discharged to the ground and proper management practices are employed.

Ion Exchange

In the ion exchange process, arsenic ions bind to an ion exchange resin and, in the process, displace chloride ions. The resin is contained within a pressure vessel (Figure 9) and periodically regenerated with a concentrated salt solution. Water softeners function similarly, removing calcium and magnesium from water in exchange for sodium.

FIGURE 9: Typical Ion Exchange System Composed of Pressure Vessels Filled with Anion Exchange Resin Capable of Treating 75 gpm (Kinetico, Newbury, Ohio)

Other ions compete with As(V) for binding sites on the ion exchange resin. The most important of these ions is sulfate. Since sulfate binds more strongly to the resin than As(V), the amount of water that can be treated prior to regeneration is proportional to sulfate concentration (Figure 10). If the resin is not regenerated often enough, all the arsenic that is bound to the resin will be dislodged from the column over a very short period of time. This phenomenon, known as chromatographic peaking, can result in treated water with arsenic concentrations several times that of the untreated water.

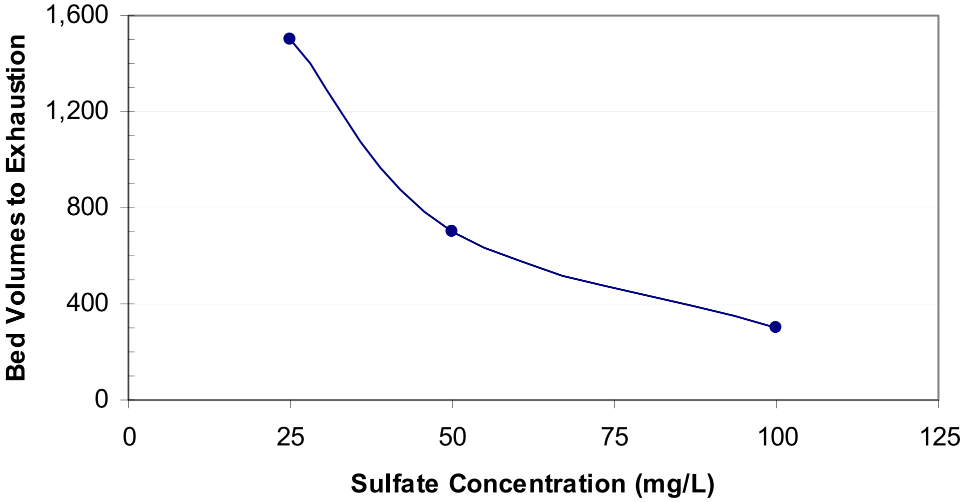


FIGURE 10: Effect of Sulfate on Ion Exchange Performance (Clifford, 1999).

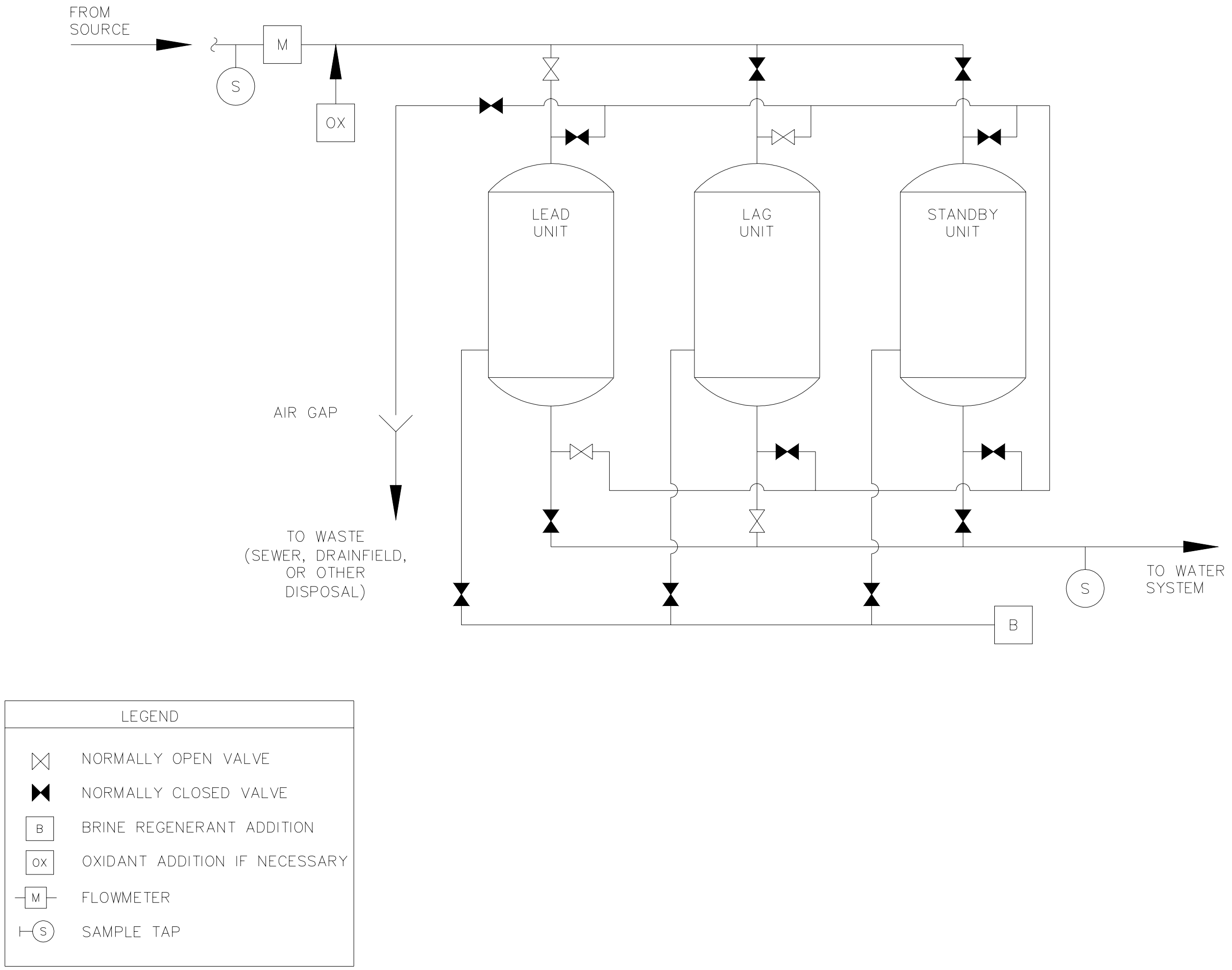
As shown on Figure 11, preoxidation of As(III) to As(V) is required prior to the ion exchange column, since only As(V) can be effectively removed by ion exchange. Following treatment, pH adjustment of the treated water may be required since carbonate ions bind to the resin decreasing the pH of the treated water following startup of a freshly regenerated ion exchange column.

Typical design parameters for ion exchange systems are included in Table 5 and cost information is provided in Appendix B.

Table 5:
Ion Exchange Design Parameters

Parameter	Value
Media Loading Rate	2-24 gpm/sq. ft.
Empty Bed Contact Time	1-10 minutes
Oxidant	Chlorine, ozone – may require dechlorination or deozonation to protect resin
Media depth	24-40 inches
Regeneration Loading	2-6 gpm/sq. ft (downflow) 0.4-4 gpm/sq. ft (upflow)
Regenerant Brine Strength	1-5 moles/liter (60 – 300 grams/liter NaCl)

FIGURE 11: Ion Exchange Process Schematic



Ion Exchange Wastes

The waste products from ion exchange are the liquid backwash stream and the spent regenerant stream. The backwash stream consists of water with particulate matter that has been filtered onto the resin, while the regenerate stream is a brine solution of high salinity that can also have high levels of arsenic. In most cases, Ecology will require a State Wastewater Discharge Permit for public water systems that employ ion exchange for arsenic removal.

Sorption

The sorption process involves passing untreated water through a pressure vessel containing an aluminum or iron-based material that adsorbs the arsenic. When the sorbent is exhausted, typically after a few months to more than a year, the spent media is replaced.

Activated alumina has been used for arsenic sorption for many years. There are several considerations involved with use of activated alumina. Activated alumina is most effective at pH 5.5-6.0. For most applications, acid addition is required to optimize the process. Subsequent base addition is also usually required to return the water to a pH suitable for potable use after arsenic treatment. High levels of silica and other contaminants can affect the removal efficiency of arsenic and the life of the sorptive media.

Iron-based media systems, such as that shown in Figure 12, have been developed in the past decade specifically for arsenic removal. These systems can remove arsenic at pH levels normally found in drinking water systems. However, the amount of water that can be treated between change-outs is strongly affected by the pH of the water as well as the concentration of phosphate. Phosphate in excess of 0.2 mg/l can affect arsenic removal, with each additional 0.5 mg/l above 0.2 mg/l reducing arsenic removal by 30 percent (EPA, 2002). Similarly, a change in the pH from 7.0 to 8.5 would cause a 400% decrease in the volume of water that can be treated prior to breakthrough.

FIGURE 12: Typical Sorption System Composed of Pressure Vessels with Iron-based Sorption Media Capable of Treating 100 gpm (AdEdge Technologies, Inc., Norcross, Georgia)

As with the other technologies, the sorbent media accumulates solid material, which requires backwashing for removal. The backwash flow with the associated solids is directed to waste. Figure 13 shows a process schematic of a typical sorption process.

Typical design parameters for iron- and aluminum-based sorbent systems are included in Table 6 and cost information is provided in Appendix B.

Table 6:
Sorption Process Design Parameters

Parameter	Value
Activated Alumina:	
Media Loading Rate	2-10 gpm/sq. ft.
Empty Bed Contact Time	0.5-5 minutes
Media Depth	24 inches
Iron Based Sorbents:	
Media Loading Rate	5-8 gpm/sq. ft.
Empty Bed Contact Time	3-5 minutes
Media Depth	32-45 inches
Backwash Rates	5-6 gpm/sq. ft
Approximate Backwash Volume	< 1% of production
Estimated Media Life	6-36 months

Sorption Wastes

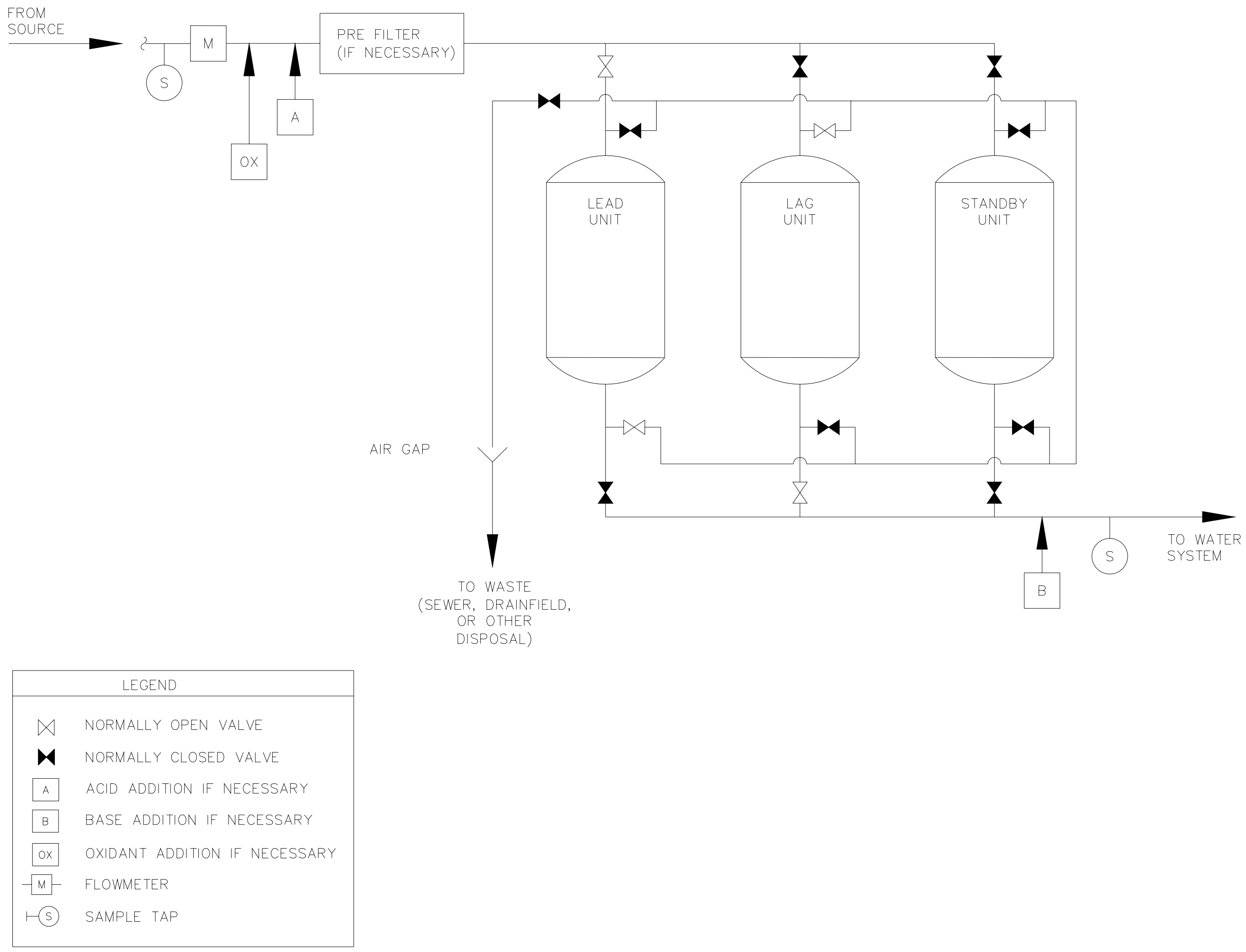
The waste product from sorption treatment is the liquid stream from the backwash of the filtration system and spent media. Previous research has indicated that the spent media is well below the threshold for being considered a hazardous waste. The liquid waste stream generally accounts for less than one percent of the total system production and similarly does not meet the threshold for being considered a hazardous waste. A more thorough discussion of waste disposal is included later in this document.

Waste disposal

Waste disposal must be considered as part of treatment process selection. Arsenic bearing wastes have the potential to be considered a hazardous waste and, as such, are subject to stringent disposal regulations. All operations and cost estimates in this guidance document assume nonhazardous waste disposal. This section provides a brief overview of the water disposal considerations and options for the two general types of wastes that are generated: liquid and solid.

The hazardous waste threshold is called the Toxicity Characteristic (TC), which is 5 mg/L for arsenic. If liquid wastes, such as ion exchange brines, exceed the TC, they are considered a hazardous waste. For solids, the waste is put through a process called the Toxicity Characteristic Leaching Procedure (TCLP). If the liquid extract from the TCLP test exceeds 5 mg/L of arsenic, the solid would be considered a hazardous waste.

FIGURE 13: Sorption Process Schematic



The Ecology publication “Fact Sheet for NPDES General Permit: Wastewater Treatment Plants - Wastewater Discharge” explains how permit conditions were developed, presents the legal basis for permit conditions, and provides background information on water treatment facilities. Ecology should be contacted for additional information or if discharge permit requirements are unclear. You can call the Water Quality Program at 360-407-6400.

Liquid Waste Disposal

The disposal options for liquid wastes include sewer discharge, land application, and surface water discharge. Practical disposal options for ion exchange brines are limited. Both land and surface water disposal of brines requires a permit from Ecology. Sewer disposal is possible only if the waste does not exceed the TC and meets the requirements of the sewer agency.

Backwash disposal from oxidation/filtration and sorbent processes is less restricted than ion exchange brines. Discharge to a surface water would require a National Pollutant Discharge Elimination System (NPDES) permit that meets water quality criteria defined by Ecology. However, land disposal of backwash waters from oxidation/filtration and sorbent processes are conditionally exempt from requiring a discharge permit as long as the following conditions are met:

1. Discharge must be free of additives that have the potential to reach waters of the state;
2. Infiltration ponds/trenches must have sufficient free board to prevent over-topping and be managed so there is no reasonable potential for discharge to surface water;
3. Discharge must not result in unmanaged soil erosion or deterioration of land features;
4. Residual solids that accumulate in infiltration ponds/trenches must be disposed of as necessary to avoid a build up and concentration of these materials; and
5. Disposal of solids must be consistent with requirements of the local health department.

Solid Waste Disposal

Solids that pass a TCLP test can generally be disposed of in a non-hazardous waste landfill. Research by the EPA and other organizations indicates that spent sorbents and the solids from oxidation/filtration backwash water pass the TCLP test.

Pilot testing

The best overall alternative should be pilot tested to verify suitability of the technology given the assumptions used in the alternatives analysis. Pilot testing consists of setting up and operating a small-scale system to determine its performance using the actual field conditions and raw water that will be treated at full-scale. Pilot testing is required by the Department of Health (DOH) for most treatment applications.

In some cases, where the cost of pilot testing would approach the cost of installing the full-scale equipment, the pilot-testing phase may be included in the start-up process for the technology. An engineer should be involved with the pilot testing and can contact DOH if the piloting will be complicated or overly expensive compared to the overall project costs. In these cases, data from operating the full-scale equipment is evaluated as pilot data useful for treatment process modifications and for specification of operational procedures.

Properly conducted pilot testing can provide valuable data that can help avoid significant mistakes in the application and design of filtration facilities. For a pilot study to be useful, the pilot study should be conducted for long enough to obtain meaningful data. The length of time will vary depending upon the process selected, raw water quality, seasonal changes, and the length of filter runs.

Proposed pilot study protocols prepared by a licensed engineer must be reviewed and approved by DOH. Upon completion of the pilot study fieldwork, a report summarizing the data and results must be submitted to DOH.

Design

Once the pilot study has been completed, the detailed design can be completed. As part of the detailed design, a project report must be completed in accordance with WAC 246-290-110 (Project Report). The project report, as well as the design plans and specifications, must be prepared by a professional engineer licensed in the state of Washington. The project report must include the following information:

- Project Description
- Planning Information
- Analysis of Alternatives
- Water Quality Data
- Water Quantity and Water Rights
- Design Criteria
- Engineering Calculations
- Legal Considerations
- Operation and Maintenance Considerations

Once the project report is completed, design plans and specifications can be completed. These plans and specifications must be reviewed and approved by DOH in accordance with WAC 246-290-120 (Construction Documents) prior to beginning construction. Upon completion of construction, a Certification of Construction Completion form, signed by the project engineer, must be submitted to DOH.

Bibliography

Chowdhury, Z., et al. Adsorption Treatment For Arsenic Removal: Design, Operation and Costs. Proceedings of the AWWA WQTC Conference, 2002.

Chwirka, J.D., et al. Removing arsenic from groundwater. *Jour. AWWA*, 93:3:79 (March 2000).

Clifford, D. Presentation to the Arsenic Technical Work Group. Washington, D.C. (1999)

Edwards, M. Chemistry of arsenic removal during coagulation and Fe-Mn oxidation. *Jour. AWWA*, 86:9:64 (September 1994).

EPA, 2002. *Arsenic Treatment Technology Design Manual for Small Systems*, prepared by Economic and Engineering Services for The Cadmus Group under contract No. 68-C-99-245 for EPA 2002.

EPA, 2000. *Technologies and Costs for Removal of Arsenic from Drinking Water*, prepared by International Consultants, Inc., Malcolm Pirnie, Inc., and The Cadmus Group under contract No. 68-C6-0039 for EPA 2000.

MacPhee, M.J., et al. Arsenic in Water Plant Residuals: When Will the Other Shoe Drop? Proceedings of the AWWA WQTC Conference, 2000

Selvin, N., et al. Arsenic Treatment – Latest Developments with Granular Ferric Media, Proceedings of the AWWA WQTC Conference, 2001.

Sorg, T.J. Modifying Iron Removal Processes to Increase Arsenic Removal, Proceedings of AWWA WQTC Conference, 2001.

Wang, L., et al. As Removal by IX and AA. Jour. AWWA, 94:4:161 (April 2002).

Appendix A:
Arsenic Publications

Fact Sheet: Guidelines for Water Purveyors
Arsenic in Drinking Water

Questions and Answers: Arsenic in Drinking Water

Arsenic and Clarifications to Compliance and New Source Monitoring Rule:
A Quick Reference Guide (EPA)

Fact Sheet

November 2005

DOH PUB. #331-166
(updated)

Guidelines for Water Systems

Arsenic in Drinking Water

Requirements for Water Systems

In January 2001, the Environmental Protection Agency (EPA) lowered the Maximum Contaminant Level (MCL) for arsenic from 50 parts per billion (ppb) to 10 ppb. The lower federal standard becomes effective in January 2006 for existing Group A Community (serving more than 25 people) and Non-Transient, Non-Community (NTNC) public water systems.

On February 22, 2002, the arsenic reporting requirements for the annual Consumer Confidence Reports (CCR) were changed. After this date, depending upon the level of arsenic detected, community water systems must include the concentration of arsenic reported by the laboratory and possibly an educational or health effects information statement about arsenic in their CCRs.

Consumer Confidence Reports

CCR reporting requirements depend upon the concentration of arsenic reported by a laboratory. Arsenic concentrations within the three ranges described below have distinct reporting requirements. If a laboratory reports an arsenic value of "<10" or "less than 10 ppb" contact DOH for specific information.

Arsenic reported below 5 ppb:
Any arsenic value reported by a laboratory above the method detection limit and below 5 ppb must be included in the CCR water quality data table. There are no additional reporting requirements for results below 5 ppb.

Arsenic reported between 5-10 ppb: (use EPA or DOH's suggested language)

> **EPA's educational statement – in federal rule:**
> While your drinking water meets EPA's standard for arsenic, it does contain low levels of arsenic. EPA's standard balances the current understanding of arsenic's possible health effects against the costs of removing arsenic from drinking water. EPA continues to research the health effects of low levels of arsenic, which is a mineral known to cause cancer in humans at high concentrations and is linked to other health effects such as skin damage and circulatory problems.
>
> **Department of Health's recommended educational statement:**
> Your drinking water currently meets EPA's revised drinking water standard for arsenic. However, it does contain low levels of arsenic. There is a small chance that some people who drink water containing low levels of arsenic for many years could develop circulatory disease, cancer, or other health problems. Most types of cancer and circulatory diseases are due to factors other than exposure to arsenic. EPA's standard balances the current understanding of arsenic's health effects against the costs of removing arsenic from drinking water.

Washington State Department of
Health
Division of Environmental Health
Office of Drinking Water

HELPING TO ENSURE SAFE AND RELIABLE DRINKING WATER

Arsenic reported above 10 ppb:

EPA's health effects statement – in federal rule:
Some people who drink water that contains arsenic in excess of the MCL over many years could experience skin damage or problems with their circulatory system, and may have an increased risk of getting cancer.

Financial Assistance for Water Systems

The Drinking Water State Revolving Fund, administered by the Department of Health and the Public Works Board, may be able to help systems move toward compliance with this new standard by offering low interest loans. Information on the State Revolving Fund can be accessed at: http://www.doh.wa.gov/ehp/dw/Our_Main_Pages/dwsrf.htm

In addition, EPA plans to provide funding for the research and development of more cost-effective technologies to help bring all systems into compliance with the new standard. The agency will also work with small communities to maximize grants and loans.

Water Treatment

These treatment technologies are available to remove arsenic from water:

- **Coagulation/filtration:** This method uses conventional treatment processes to coagulate the arsenic. The treated water is then filtered.
- **Activated alumina:** This method removes arsenic from water by adsorption onto alumina.
- **Reverse osmosis:** This technology uses pressure to force water through a membrane filter, leaving arsenic behind.
- **Anion exchange:** Arsenic is adsorbed onto a resin, and the resin is periodically regenerated with sodium chloride solution.
- **Oxidation/filtration:** This technology oxidizes naturally occurring iron, which binds to arsenic followed by filtration.

For More Information

Washington State Department of Health:

Drinking Water Southwest Regional Office	360-664-0768
Drinking Water Northwest Regional Office	253-395-6750
Drinking Water Eastern Regional Office	509-456-3115
Drinking Water Data & Source Monitoring: Jimmy Weber	360-236-3097
Treatment Technology Options: Sam Perry	253-395-6755
Arsenic Health Effects: Jim W. White	360-236-3192

Office of Drinking Water: http://www.doh.wa.gov/ehp/dw
EPA Arsenic Information: http://www.epa.gov/OGWDW/arsenic.html
Agency for Toxic Substances and Disease Registry (U.S. Centers for Disease Control and Prevention): http://www.atsdr.cdc.gov/tfacts2.html

PUBLIC HEALTH
ALWAYS WORKING FOR A SAFER AND
HEALTHIER WASHINGTON

Questions & Answers

Arsenic in Drinking Water

November 2005

DOH PUB. #331-167
(updated)

What is arsenic and where does it come from?

Arsenic is a naturally occurring element in the earth's crust. Arsenic can be released into the environment through natural processes such as volcanic action, erosion of rock, or by human activities such as mining or smelting of arsenic-containing ores, and orchard spraying. It has been used commercially in wood preservatives, agricultural chemicals, and the manufacture of semi-conductors.

How does arsenic get into drinking water?

Most arsenic in drinking water comes from natural rock formations. Water that encounters these rock formations can dissolve arsenic and carry it into underground aquifers, streams, and rivers that may be used as drinking water supplies. Arsenic deposited on the ground from industrial or agricultural uses tends to remain in the top few feet of soil for a long time and is not likely to have a significant impact on most aquifers. When dissolved in water, arsenic has no smell, taste, or color, even at high concentrations.

How can arsenic affect human health?

Arsenic has been reported to cause more than 30 different adverse health effects including cardiovascular disease, diabetes mellitus, skin changes, nervous system damage, and various forms of cancer. The odds that one or more of these could occur depends upon the amount of arsenic a person consumes, and how sensitive they are to the effects of arsenic. Getting arsenic on the skin when bathing or washing is not considered a major contributor to health risk. There is a small chance that some people who drink water containing low levels of arsenic for many years could develop circulatory disease, cancer, or other health problems. Most cancers and circulatory diseases are due to factors other than exposure to arsenic.

Why was the drinking water standard for arsenic tightened?

For many years, the drinking water standard for arsenic was 50 parts per billion (ppb). The federal Environmental Protection Agency (EPA) established the standard to reduce the amount of arsenic allowed in public drinking water supplies. EPA tightened the standard from 50 ppb to 10 ppb in February 2002. The reason EPA tightened the standard was to lessen people's long-term exposure to arsenic in drinking water to reduce the risk of adverse health effects.

Washington State Department of
Health
Division of Environmental Health
Office of Drinking Water

HELPING TO ENSURE SAFE AND RELIABLE DRINKING WATER

Are some parts of Washington more affected than others?

Elevated levels of naturally occurring arsenic are present in some central and northern Puget Sound counties. These levels of arsenic in groundwater are thought to be attributed to geologic formations rather than human activities.

How does the new standard affect water systems?

EPA's standard of 10 ppb balances the current understanding of arsenic's health effects against the costs of removing arsenic from drinking water. Increased safety comes at a cost; the new arsenic standard will be the most costly of new EPA rules to meet. Affected systems may be able to use an alternative source of water, or design and install new water treatment methods to remove arsenic from water. The new drinking water standard becomes effective in January 2006. In the meantime, customers will receive a Consumer Confidence Report from their water utility each year with information on the level of arsenic (if any) detected in their drinking water.

Is my health at risk if I drink water with arsenic higher than the new standard?

Arsenic present in drinking water, soil, air, and food does pose health risks. The more you are exposed to arsenic over time, the higher the risk becomes for experiencing health effects. Different people may have different responses to the same exposure to arsenic, so there is no way to know exactly what may happen in any given case. Reducing the amount of arsenic allowed in drinking water will lessen people's exposure and reduce risk of adverse health effects.

Can water from private wells also be contaminated with arsenic?

Yes, it can. Local health departments can advise people about how to get private well water tested for arsenic and other possible contaminants.

Are there ways to remove arsenic from water at the tap?

Yes. NSF International is an independent non-profit organization that certifies treatment products and methods. Such certification is not a guarantee of safety, but it may help you make decisions. Call 1-800-NSF-MARK or go to their web site at: http://www.nsf.org/

For more information:

Washington State Department of Health:

- Drinking Water Southwest Regional Office: 360-664-0768
- Drinking Water Northwest Regional Office: 253-395-6750
- Drinking Water Eastern Regional Office: 509-456-3115
- Drinking Water Data & Source Monitoring: Jimmy Weber, 360-236-3097
- Treatment Technology Options: Sam Perry, 253-395-6755
- Arsenic Health Effects: Jim W. White, 360-236-3192
- Office of Drinking Water: http://www.doh.wa.gov/ehp/dw

EPA Arsenic Information: http://www.epa.gov/OGWDW/arsenic.html

Agency for Toxic Substances and Disease Registry (U.S. Centers for Disease Control and Prevention): http://www.atsdr.cdc.gov/tfacts2.html

United States
Environmental Protection
Agency

Office of Water
(4606)

EPA 816-F-01-004
January 2001

Arsenic and Clarifications to Compliance and New Source Monitoring Rule: A Quick Reference Guide

Overview of the Rule

Title	Arsenic and Clarifications to Compliance and New Source Monitoring Rule 66 FR 6976 (January 22, 2001)
Purpose	To improve public health by reducing exposure to arsenic in drinking water.
General Description	Changes the arsenic MCL from 50 µg/L to 10 µg/L; Sets arsenic MCLG at 0; Requires monitoring for new systems and new drinking water sources; Clarifies the procedures for determining compliance with the MCLs for IOCs, SOCs, and VOCs.
Utilities Covered	All community water systems (CWSs) and nontransient, noncommunity water systems (NTNCWSs) must comply with the arsenic requirements. EPA estimates that 3,024 CWSs and 1,080 NTNCWSs will have to install treatment to comply with the revised MCL.

Public Health Benefits

Implementation of the Arsenic Rule will result in . . .	• Avoidance of 16 to 26 non-fatal bladder and lung cancers per year. • Avoidance of 21 to 30 fatal bladder and lung cancers per year. • Reduction in the frequency of non-carcinogenic diseases.

Critical Deadlines & Requirements

Consumer Confidence Report Requirements *

Report Due	*Report Requirements*
July 1, 2001	For the report covering calendar year 2000, systems that detect arsenic between 25 µg/L and 50 µg/L must include an educational statement in the consumer confidence reports (CCRs).
July 1, 2002 and beyond	For reports covering calendar years 2001 and beyond, systems that detect arsenic between 5 µg/L and 10 µg/L must include an educational statement in the CCRs.
July 1, 2002 - July 1, 2006	For reports covering calendar years 2001 to 2005, systems that detect arsenic between 10 µg/L and 50 µg/L must include a health effects statement in their CCRs.
July 1, 2007 and beyond	For reports covering calendar year 2006 and beyond, systems that are in violation of the arsenic MLC (10 µg/L) must include a health effects statement in their CCRs.

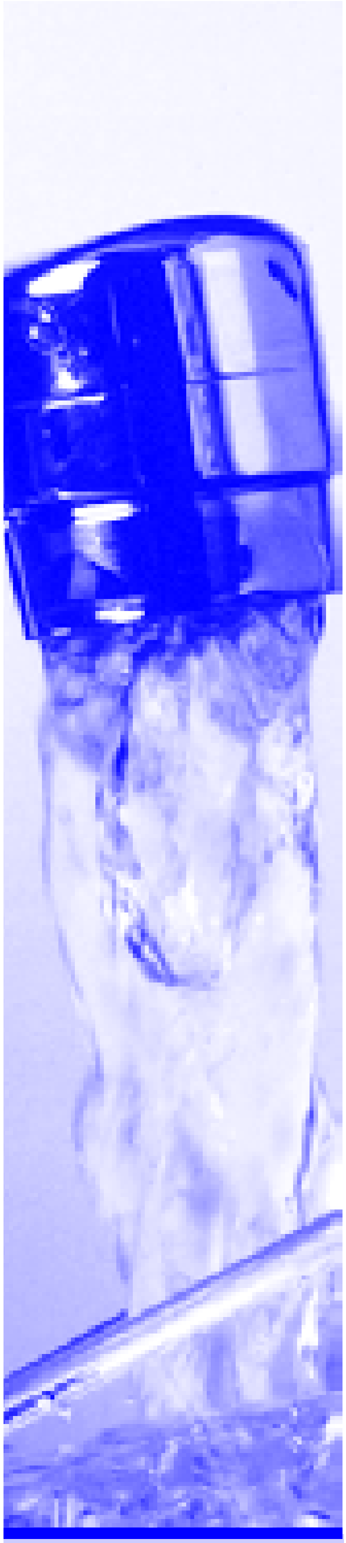
For Drinking Water Systems

Jan. 22, 2004	All *NEW* systems/sources must collect initial monitoring samples for all IOCs, SOCs, and VOCs within a period and frequency determined by the State.
Jan. 1, 2005	When allowed by the State, systems may grandfather data collected after this date.
Jan. 23, 2006	The new arsenic MCL of 10 µg/L becomes effective. All systems must begin monitoring or when allowed by the State, submit data that meets grandfathering requirements.
Dec. 31, 2006	Surface water systems must complete initial monitoring or have a State approved waiver.
Dec. 31, 2007	Ground water systems must complete initial monitoring or have a State approved waiver.

For States

Spring 2001	EPA meets and works with States to explain new rules and requirements and to initiate adoption and implementation activities.
Jan. 22, 2003	State primacy revision applications due.
Jan. 22, 2005	State primacy revision applications due from States that received 2-year extensions.

* For required educational and health effects statements, please see 40 CFR 141.154.



Compliance Determination (IOCs, VOCs, and SOCs)

1. Calculate compliance based on a running annual average at each sampling point.
2. Systems will not be in violation until 1 year of quarterly samples have been collected (unless fewer samples would cause the running annual average to be exceeded.)
3. If a system does not collect all required samples, compliance will be based on the running annual average of the samples collected.

Monitoring Requirements for Total Arsenic (1)

Initial Monitoring

One sample after the effective date of the MCL (January 23, 2006). Surface water systems must take annual samples. Ground water systems must take one sample between 2005 and 2007.

Reduced Monitoring

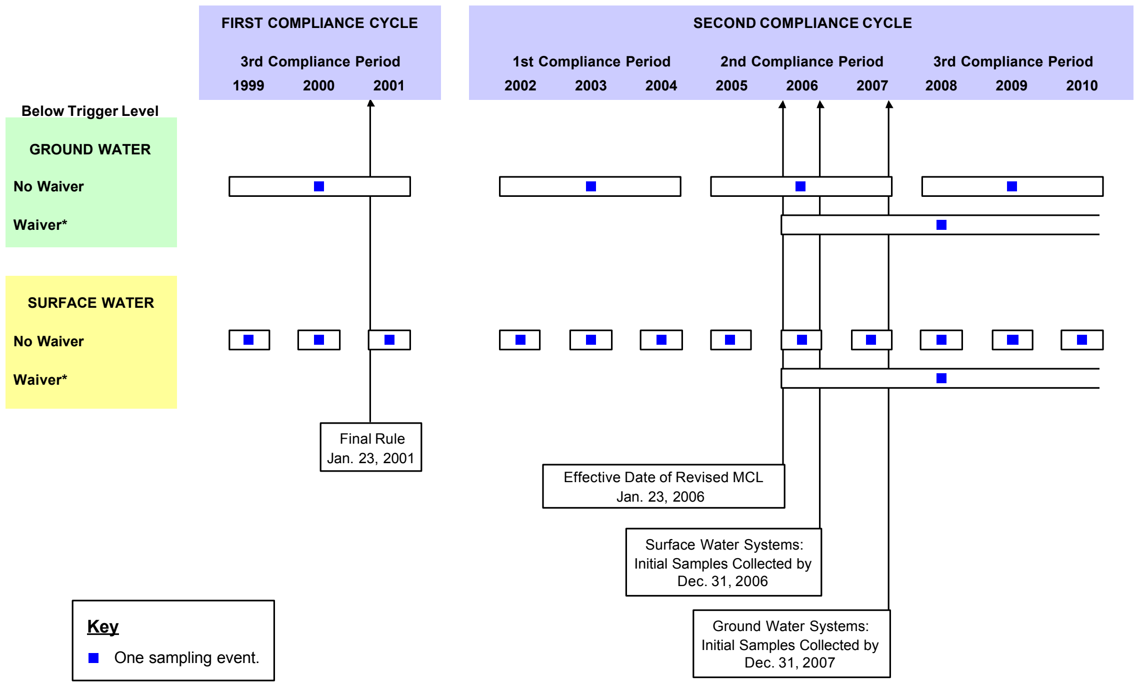
If the initial monitoring result for arsenic is less than the MCL . . .	Ground water systems must collect one sample every 3 years. Surface water systems must collect annual samples.

Increased Monitoring

A system with a sampling point result above the MCL must collect quarterly samples at that sampling point, until the system is reliably and consistently below the MCL.

(1) All samples must be collected at each entry point to the distribution system, unless otherwise specified by the State.

Applicability of the Standardized Monitoring Framework to Arsenic



*Waivers are not permitted under the current arsenic requirements. States may issue 9 year monitoring waivers under the revised final arsenic rule. To be eligible for a waiver, surface water systems must have monitored annually for at least 3 years. Ground water systems must conduct a minimum of 3 rounds of monitoring with detection limits below 10 µg/L.

For additional information on the Arsenic Rule

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA Web site at www.epa.gov/safewater; or contact your State drinking water representative. EPA will provide arsenic training over the next year.

Appendix B:
Arsenic Treatment Cost Curves and Information

Project Cost Estimation

General

Part of the evaluation process for assessing arsenic removal systems includes estimating costs. Cost estimation must include both capital costs and operations and maintenance costs to accurately reflect the overall or true costs. For example, a relatively inexpensive process to purchase and install may have substantial operations costs that increase the life-cycle cost of using the technology. In other instances an expensive process to buy and install may have such low operations costs that the technology would be less expensive over its operational lifespan.

Capital costs can vary significantly from facility to facility based upon the location, site constraints, system hydraulics, and raw water quality. Capital cost estimates obtained from the cost curves contained in this document are helpful for planning, but they should be refined in light of other variable project costs and updated as soon as adequate data are available. Table B-1 details several of the factors that should be included in the estimated capital cost of a facility.

Table B-1:
Capital Cost Considerations

Item	Includes
Mobilization	Contractor’s overhead and profit and costs for bringing equipment to site. Typically 5 - 15% of total construction cost.
Treatment Equipment	Vendor quote with delivery, start-up, training, Operations and Maintenance (O&M) manual, and spare parts.
Pumping Equipment	Cost to modify/add pumping systems to bring raw water to the treatment facility and pump treated water into the distribution system. Vendor quote with delivery, start-up, training, O&M manual, and spare parts.
Installation	Cost for contractor to order, handle, store, install and test equipment. Typically 10 - 50% of the cost of the equipment.
Water Transmission Lines	Cost to construct water lines to bring water to and from the new facility. This cost may be substantial if the site is distant from existing water transmission facilities.
Sitework	Excavation, backfill, compaction, and site grading. Also includes gravel materials required.
Building	Building to house mechanical and electrical equipment. Building should also have space for laboratory and office facilities, chemical feed equipment, and storage.

Item	Includes
Piping	Piping and valves required to interconnect filtration equipment with existing piping and pumping equipment. Typically 10 - 20% of total construction cost.
Electrical, Telemetry and Controls	Electrical wiring and controls required to operate the pumps and filtration equipment. May include new power service and emergency generator. Typically 10 - 20% of total construction cost.
HVAC	Fans, heaters, and exhausters required to keep a building from freezing and minimize condensation.
Sales Tax	Washington State Sales Tax on construction cost.
Engineering Design	Costs to develop plans and specifications for the treatment facility. Even projects to be completed by the owner must have plans and specifications approved by the Department of Health. Typically 10 - 15% of construction cost.
Inspection and Construction Management	Costs to administer a construction contract and inspect the work completed by the contractor. May be reduced or omitted if the Owner has qualified personnel available to perform. Typically 10 - 15% of construction cost.
Land Acquisition	If land must be purchased or leased for the project.
Contingency	Accounts for items and detail not contemplated at the alternatives analysis level. Typically 20 - 30% of construction cost.

O & M cost estimates should also be carefully evaluated for each alternative. Some operations and maintenance cost information is available from equipment vendors including estimated power consumption, chemical usage, and component replacement frequency. These estimates from equipment suppliers should be verified by contacting operators of similar facilities. Labor and power costs can generally be estimated from local conditions. Table B-2 provides some operations and maintenance factors to consider in evaluation of alternatives.

Table B-2:
Operations and Maintenance Cost Considerations

Item	Includes
Labor	The cost of labor to operate and maintain a facility.
Power Consumption	Cost to operate pumps and electrical and mechanical equipment in the facility.
Chemicals	Costs for chemicals used for filtration.
Maintenance	Costs to keep equipment in proper working order including frequently replaced parts.

Capital Cost Information for Arsenic Treatment Systems

The capital costs presented in this section for iron oxidation/filtration and ion exchange were adapted from *Technologies and Costs for Removal of Arsenic from Drinking Water* prepared for EPA in 2000 by International Consultants, Inc., Malcolm Pirnie, Inc., and The Cadmus Group. These capital costs were adjusted for inflation using the Engineering News Record Construction Cost Index (ENR CCI) of 7560.

The capital costs for activated alumina and iron based sorbents were extracted from "Adsorption Treatment For Arsenic Removal: Design, Operation and Cost," a technical article prepared by Malcolm Pirnie Inc., and HDR Inc. in 2002.

The cost estimating curves in this document are presented in 2002 dollars. To adjust for inflation, the following equation, taken from the EPA 2002 *Arsenic Treatment Technology Design Manual for Small Systems,* should be used.

$$P_{current} = P_{2002}(1+i)^{(Y-2002)}$$

Where:

$P_{current}$ = Current Cost
P_{2002} = Year 2002 Cost
i = Annual rate of inflation (~2.5% to 3%)
Y = Current Year

Operations and Maintenance Assumptions

O & M costs for iron oxidation/filtration and ion exchange were adapted from *Technologies and Costs for Removal of Arsenic from Drinking Water* prepared for EPA in 2000 by International Consultants, Inc., Malcolm Pirnie, Inc., and The Cadmus Group. The O&M costs assume the cost parameters shown in Table B-3 below.

Table B-3:
Operations and Maintenance
Cost Assumptions

Parameter	Cost
Electricity	\$0.08/kWh
Diesel Fuel	\$1.25/gallon
Natural Gas	\$0.006/scf
Labor	Large systems: \$40/hr Small systems: \$28/hr
Building Energy Use	102.6 $kWh/ft^2/yr$

O & M costs for activated alumina and iron based sorbents were extracted from "Adsorption Treatment For Arsenic Removal: Design, Operation and Cost," a technical article prepared by Malcolm Pirnie Inc., and HDR Inc. in 2002.

All O & M costs assume that none of the waste products will be considered hazardous. Hazardous waste disposal costs could significantly impact the final operations and maintenance costs.

Cost Estimation Curves

Cost estimating curves can be used to develop initial planning level estimates of capital and O&M costs. The capital cost curves include costs for equipment, building, sitework, electrical, piping, and engineering. The cost for a typical system can be found by inserting the system design capacity, in gallons per minute, into the equation shown on the figure.

O & M cost curves can be developed similarly. On an O&M cost curve, find the average annual water system flow in gpm (gallons per minute), then find the correlating annual operations and maintenance costs from the curve. As an alternative, the average annual flow, in gpm capacity, can be entered into the equation on the chart.

Iron Oxidation and Filtration

Capital costs can be estimated from Figure B-1 and O&M costs can be estimated from Figure B-2. The information contained in these figures should be used only as an initial estimate. The actual cost for a specific installation can vary depending on other project specifics.

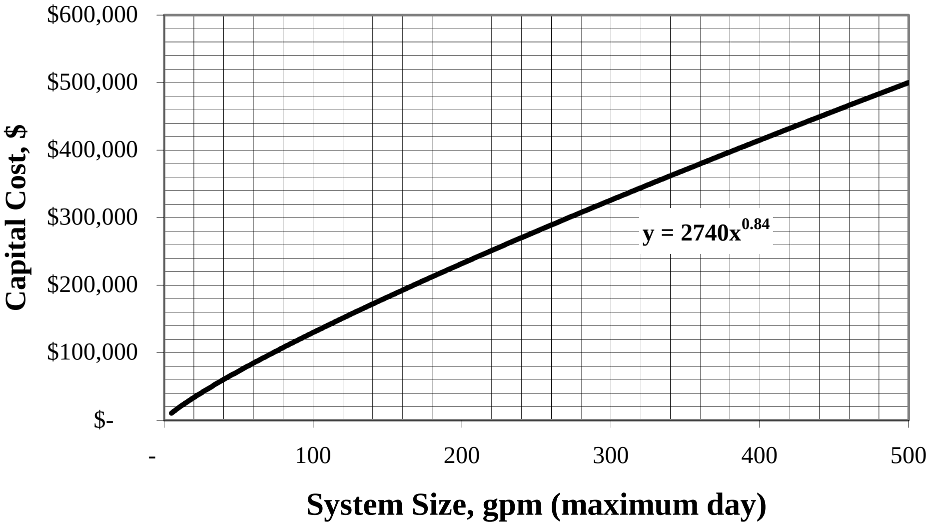


FIGURE B-1: Iron Oxidation/Filtration Capital Costs

(Curve adapted from EPA *Technologies and Costs for Removal of Arsenic from Drinking Water*, 2000 with costs adjusted to 2002 dollars.)

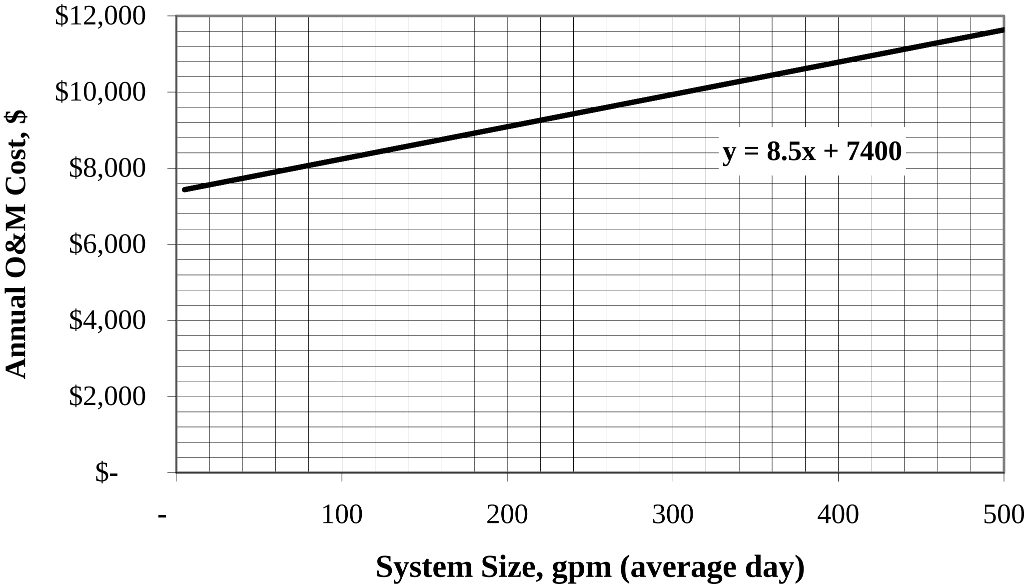


FIGURE B-2: Iron Oxidation/Filtration O&M Costs

(Curve adapted from EPA *Technologies and Costs for Removal of Arsenic from Drinking Water*.)

Ion Exchange

Capital costs can be estimated from Figure B-3. O&M costs can be estimated from Figure B-4. The information contained in these figures should be used only as an initial estimate. The actual cost for a specific installation can vary depending on other project specifics.

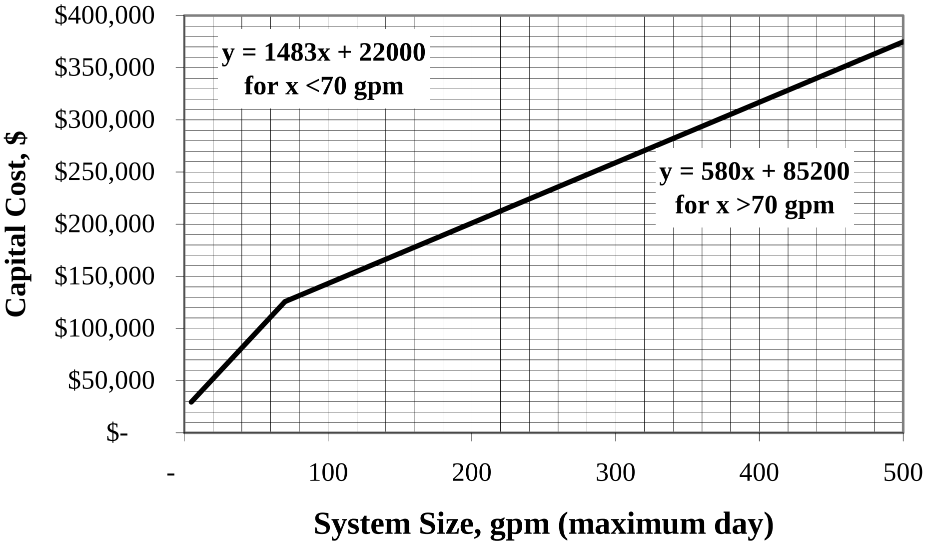


FIGURE B-3: Ion Exchange Capital Costs

(Curve adapted from EPA *Technologies and Costs for Removal of Arsenic from Drinking Water*, 2000 with costs adjusted to 2002 dollars.)

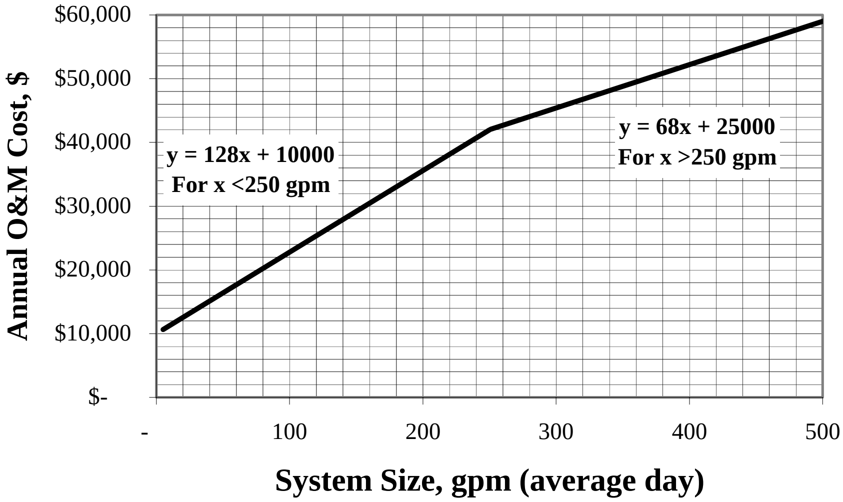


FIGURE B-4: Ion Exchange Annual O&M Costs

(Curve adapted from EPA *Technologies and Costs for Removal of Arsenic from Drinking Water*.)

Sorption

Capital costs for iron-based sorbent systems and activated alumina can be estimated from Figure B-5 and Figure B-6 respectively. O&M costs can be estimated from Figure B-7 and B-8. The information contained in these figures should be used only as an initial estimate. The actual cost for a specific installation can vary depending on other project specifics.

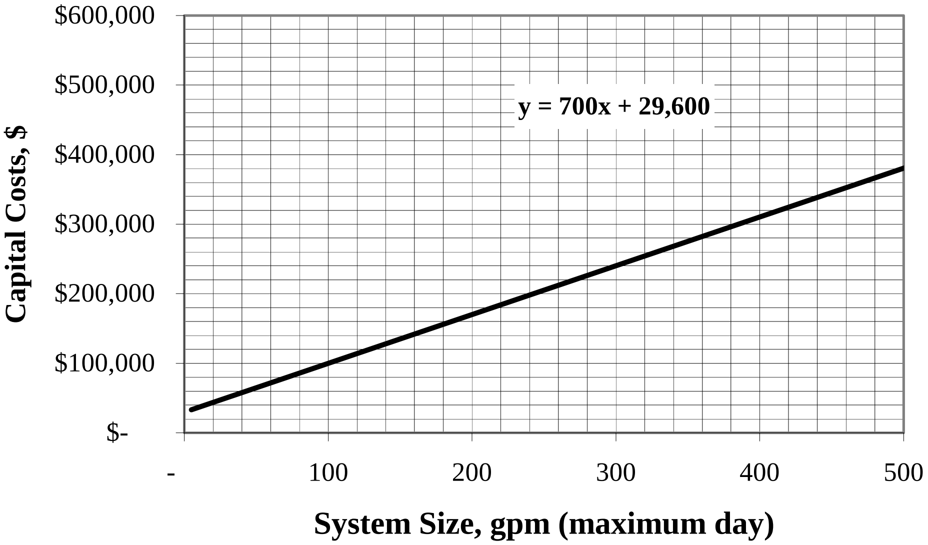


FIGURE B-5: Iron-based Sorbents Capital Costs – Natural pH 7.5
(Curve adapted from *Adsorption Treatment For Arsenic Removal: Design, Operation and Costs*. Costs in 2002 dollars.)

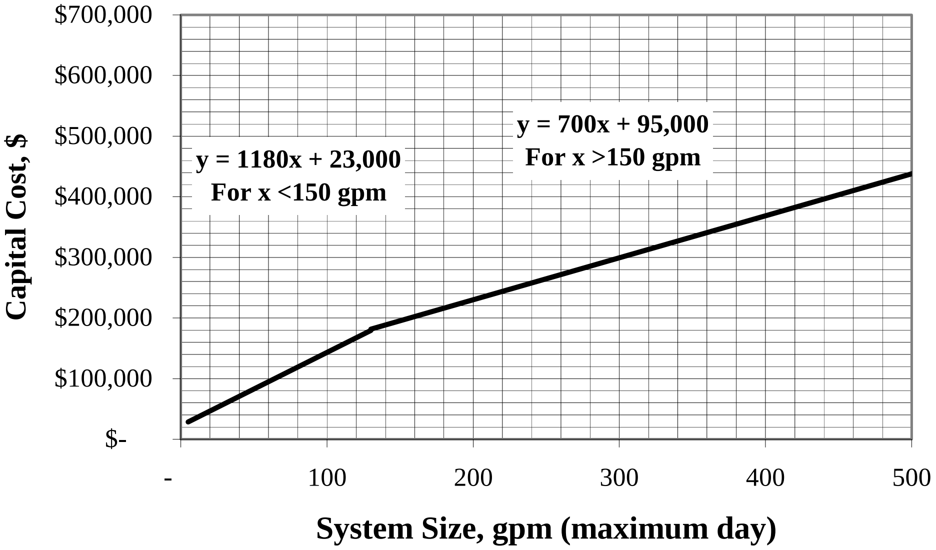


FIGURE B-6: Activated Alumina Capital Costs – Natural pH 7-8 with Equipment Sized for Quarterly Media Replacement
(Curve adapted from *Adsorption Treatment For Arsenic Removal: Design, Operation and Costs*. Costs in 2002 dollars.)

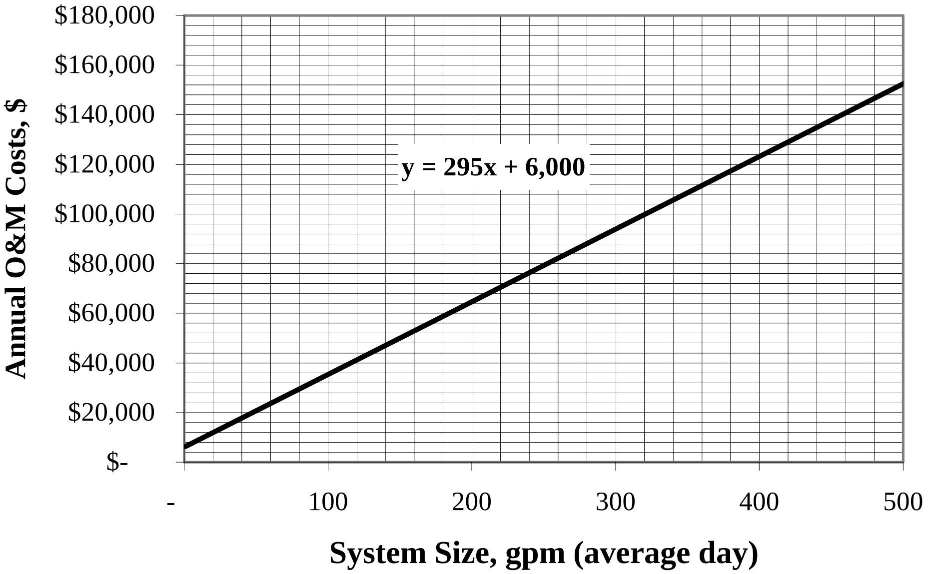


FIGURE B-7: Iron-Based Sorbents Annual O&M Costs - Natural pH 7.5
(Curve adapted from *Adsorption Treatment For Arsenic Removal: Design, Operation and Costs*. Costs in 2002 dollars.)

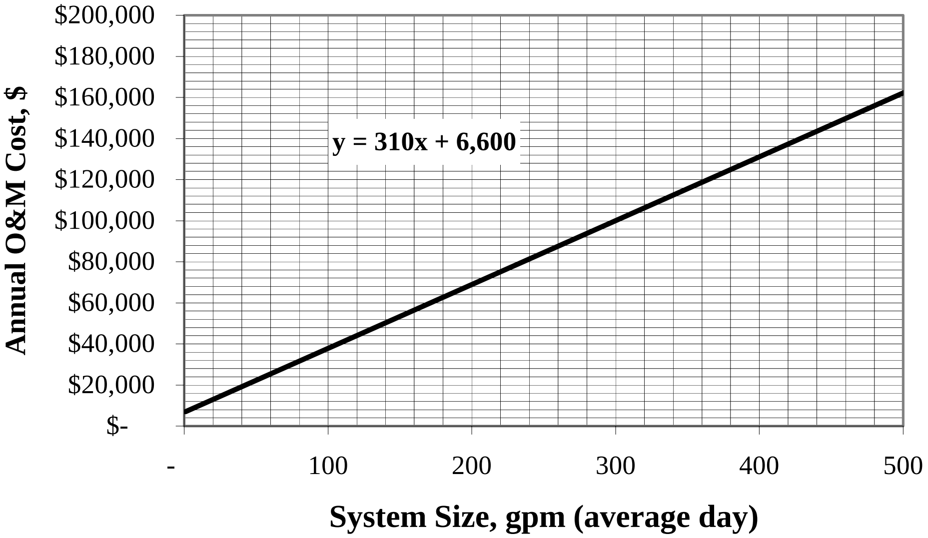


FIGURE B-8: Activated Alumina Annual O&M Costs - Natural pH 7-8 with Equipment Sized for Quarterly Media Replacement
(Curve adapted from *Adsorption Treatment For Arsenic Removal: Design, Operation and Costs*. Costs in 2002 dollars.)

Appendix C:
Iron and Aluminum Based Sorbent Manufacturers

List of Manufacturers

Iron-based Sorbents

AdEdge Technologies, Inc.
50 Technology Parkway South
Norcross, GA 30092
(678) 221-2034

ADI International, Inc.
1133 Regent Street, Suite 300
Fredericton, NB E3B 3Z2 Canada
(506) 452-9000

US Filter
600 Arrasmith Trail
Ames, IA 50010
(515) 232-4121

Activated Alumina

Alcan Chemicals
3690 Orange Place
Cleveland, OH 44122-4438
(800) 321-3864

Kinetico
10845 Kinsman Road
P.O. Box 193
Newbury, OH 44065
(800) 944-9283