ARSENIC

CONTINUING EDUCATION PROFESSIONAL DEVELOPMENT COURSE

1st Edition

Technical Learning College

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Purpose of this Document

This document provides guidance to States, Tribes, and U.S. Environmental Protection Agency **(EPA)** Regions exercising primary enforcement responsibility under the Safe Drinking Water Act **(SDWA)**.

Throughout this document, the terms “State” or “States” are used to refer to all types of primacy agencies including U.S. territories, Indian tribes, and EPA regions. The SDWA provisions and EPA regulations described in this document contain legally binding requirements. This document does not substitute for those provisions or regulations, nor is it a regulation itself.

Thus, it does not impose legally binding requirements on the EPA, States, Tribes, or the regulated community, and may not apply to a particular situation based upon the circumstances.

The EPA, State, and Tribal decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance where appropriate. Any decisions regarding a particular facility will be made based on the applicable statutes and regulations.

Therefore, interested parties are free to raise questions and objections about the appropriateness of the application of this guidance to a particular situation, and the EPA will consider whether or not the recommendations or interpretations in the guidance are appropriate in that situation. The EPA may change this guidance in the future.

This course is intended to be used as a screening tool for arsenic treatment technologies. It provides descriptions of the theory, design, and operation of the technologies; information on commercial availability and use; performance and cost data, where available; and a discussion of factors affecting effectiveness and cost.

As a technology overview document, the information can serve as a starting point for identifying options for arsenic treatment. The feasibility of particular technologies will depend heavily on site-specific factors, and final treatment and remedy decisions will require further analysis, expertise, and possibly treatability studies.

Most of the information sources used for this report contain information about treatments of environmental media and drinking water. Only limited information was identified about the treatment of industrial waste and wastewater containing arsenic.

This does not necessarily indicate that treatment of industrial wastes and wastewater containing arsenic occurs less frequently, because data on industrial treatments may be published less frequently.

The authors and reviewers of this course identified these information sources based on their experience with arsenic treatment.

Important Information about this Manual

Disclaimer

This manual has been prepared to assist employees in the general awareness of the Arsenic treatment and remediation process including: water distribution systems and groundwater production systems, complex pumping ideas, dangerous excavation techniques, water regulatory sampling and dealing with often-complex procedures and requirements for safely handling hazardous and toxic materials.

The scope of the material is quite large, requiring a major effort to bring it under control. Employee health and safety, as well as that of the public, depend upon careful application of federal and state regulations and safe working procedures.

This manual will cover general laws, regulations, required procedures and work rules relating to water distribution and sampling. It should be noted, however, that the federal and state regulations are an ongoing process and subject to change over time. For this reason, a list of resources and hyperlinks is provided to assist in obtaining the most up-to-date information on various subjects. You can find these on our website or in this manual.

This manual is a guidance document for employees who are involved with Arsenic treatment, handling, water quality and pollution control. It is not designed to meet the full requirements of the United States Environmental Protection Agency (**EPA**) or the Department of Labor-Occupational Safety and Health Administration (**OSHA**) rules and regulations.

This course manual will provide general guidance and should not be used as a preliminary basis for developing general water/wastewater sampling plans or water distribution safety plans or procedures. This document is not a detailed water/wastewater textbook or a comprehensive source book on water/wastewater/safety rules and regulations.

Technical Learning College makes no warranty, guarantee or representation as to the absolute correctness or appropriateness of the information in this manual and assumes no responsibility in connection with the implementation of this information.

It cannot be assumed that this manual contains all measures and concepts required for specific conditions or circumstances. This document should be used for guidance and is not considered a legal document.

Individuals who are responsible for water distribution, production and/or sampling and the health and safety of workers at hazardous waste sites should obtain and comply with the most recent federal, state, and local regulations relevant to these sites and are urged to consult with OSHA, the EPA and other appropriate federal, state and local agencies.

Technical Learning College's Scope and Function

Welcome to the Program,

Technical Learning College (TLC) offers affordable continuing education for today's working professionals who need to maintain licenses or certifications. TLC holds several different governmental agency approvals for granting of continuing education credit.

TLC's delivery method of continuing education can include traditional types of classroom lectures and distance-based courses or independent study. TLC's distance based or independent study courses are offered in a print- based format and you are welcome to examine this material on your computer with no obligation. We will beat any other training competitor's price for the same CEU material or classroom training.

Our courses are designed to be flexible and for you do finish the material on your leisure. Students can also receive course materials through the mail. The CEU course or e-manual will contain all your lessons, activities and assignments. All of TLC's CEU courses allow students to submit assignments using e-mail or fax, or by postal mail. (See the course description for more information.)

Students have direct contact with their instructor—primarily by e-mail or telephone. TLC's CEU courses may use such technologies as the World Wide Web, e-mail, CD-ROMs, videotapes and hard copies. (See the course description.) Make sure you have access to the necessary equipment before enrolling, i.e., printer, Microsoft Word and/or Adobe Acrobat Reader. Some courses may require proctored closed-book exams depending upon your state or employer requirements.

Flexible Learning

At TLC, there are no scheduled online sessions or passwords you need contend with, nor are you required to participate in learning teams or groups designed for the "typical" younger campus based student. You will work at your own pace, completing assignments in time frames that work best for you. TLC's method of flexible individualized instruction is designed to provide each student the guidance and support needed for successful course completion.

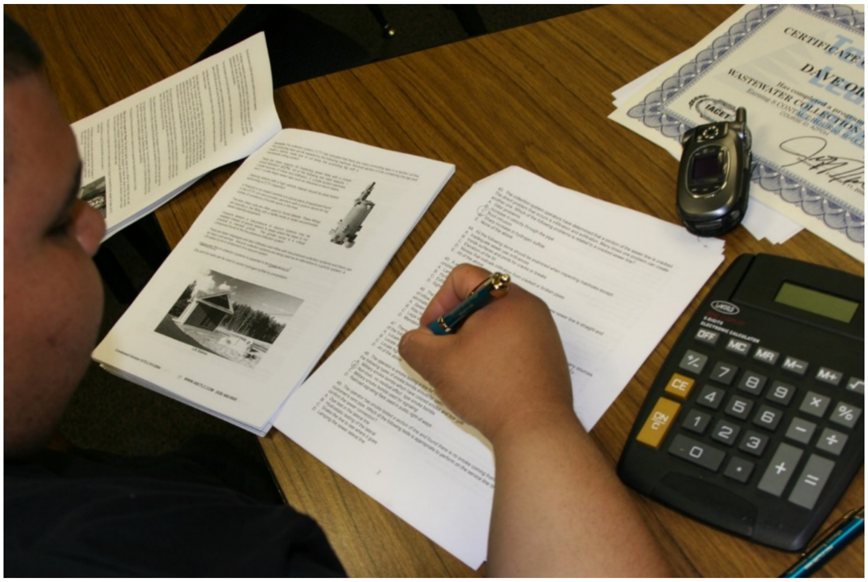
Course Structure

TLC's online courses combine the best of online delivery and traditional university textbooks. You can easily find the course syllabus, course content, assignments, and the post-exam (Assignment). This student friendly course design allows you the most flexibility in choosing when and where you will study.

Classroom of One

TLC offers you the best of both worlds. You learn on your own terms, on your own time, but you are never on your own. Once enrolled, you will be assigned a personal Student Service Representative who works with you on an individualized basis throughout your program of study. Course specific faculty members are assigned at the beginning of each course providing the academic support you need to successfully complete each course.

Satisfaction Guaranteed
We have many years of experience, dealing with thousands of students. We assure you, our customer satisfaction is second to none. This is one reason we have taught more than 20,000 students.



We welcome you to do the electronic version of the assignment and submit the answer key and registration to us either by fax or e-mail. If you need this assignment graded and a certificate of completion within a 48-hour turn around, prepare to pay an additional rush charge of $50.

Contact Numbers
Fax (928) 468-0675
Email Info@tlch2o.com
Telephone (866) 557-1746

Course Description

Arsenic CEU Training Course

The purpose of this CEU course is to provide a synopsis of the availability, performance, and cost of 13 various arsenic treatment technologies for soil, water, and wastewater. Its intended audience includes hazardous waste site managers; generators and treaters of arsenic-contaminated waste and wastewater; owners and operators of drinking water/wastewater treatment plants; regulators; and industrial waste/pretreatment inspectors.

General Course Objective

This course will review the EPA Arsenic Rule and different Arsenic removal devices and methods. This course will cover water and wastewater fundamentals/principles along with basic chemistry. This course is general in nature and not state specific. You will not need any other materials for this course.

Audience

Attention Pretreatment Operators, Laboratory Technicians, Water Distribution, Well Drillers, Pump Installers, and Water and Wastewater Treatment Operators. The target audience for this course is the person interested in working in a water treatment or distribution facility and wishing to maintain CEUs for certification license, meet education needs for promotion, or to learn how to do the job more safely and effectively.

Statement of Need

It is essential that all water and wastewater operators learn to deal with Arsenic. Arsenic is a priory pollutant being a threat to the wastewater treatment system. Water systems need to monitor for Arsenic to verify that the water they provide to the public meets all federal and state standards. Currently, the nation's community water systems (CWSs) and nontransient non-community water systems (NTNCWSs) must monitor for more than 83 contaminants including Arsenic.

This course will focus on the metalloids and related inorganic chemical (elemental) contaminates. You will learn the EPA rule concerning Arsenic and proper sampling techniques and various Arsenic treatment methods.

Inorganic Compounds (IOCs)

Inorganic compounds are rather simple chemicals present in ground water. These chemicals are generally described as mineral in nature and usually exist as ions (chemical substances with a positive or negative charge) when dissolved in water.

Typical examples include sodium, iron, calcium, magnesium, manganese, nitrate, chloride, sulfate, and zinc. Many of these chemicals are naturally occurring minerals that are dissolved from the rock/soil which make up the aquifer or water-bearing rock formations below the soil surface.

However, some of these compounds may be introduced into ground water by human activities. Nitrate (an agricultural fertilizer) and sodium chloride (road salt) are two examples. Water purveyors need to test for 30 different inorganic compounds including all arsenic, barium, cadmium, lead, mercury, selenium, and thallium

Metalloid Section
Arsenic, boron, silicon, germanium, antimony and tellurium are commonly classified as metalloids. One or more from among selenium, polonium or astatine are sometimes added to the list. Boron is sometimes excluded from the list, by itself or together with silicon. Tellurium is sometimes not regarded as a metalloid. The inclusion of antimony, polonium and astatine as metalloids has also been questioned. A metalloid is a chemical element with properties that are in-between or a mixture of those of metals and nonmetals, and which is considered to be difficult to classify unambiguously as either a metal or a nonmetal.

Prerequisites: None

Final Examination for Credit
Opportunity to pass the final comprehensive examination is limited to three attempts per course enrollment.

Course Procedures for Registration and Support
All of Technical Learning College's (TLC) correspondence courses have complete registration and support services offered. Delivery of services will include, e-mail, web site, telephone, fax and mail support. TLC will attempt immediate and prompt service. When students register for a distance or correspondence course, they'll be assigned a start date and an ending date.

It is the student's responsibility to note dates for assignments and keep up with the course work. If a student falls behind, he/she must contact TLC and request an ending date extension in order to complete the course. It is the prerogative of TLC to decide whether to grant the request. All students will be tracked by a unique number.

Student Verification
The student shall submit a driver's license for signature verification and track their time worked on the assignment. The student shall sign an affidavit verifying they have not cheated and worked alone on the assignment. All student attendance is tracked on the student attendance database.

Disclaimer and Security Notice
The student shall understand that it their responsibility to ensure that this CEU course is either approved or accepted in my State for CEU credit. The student shall understand and follow State laws and rules concerning distance learning courses and understand these rules change on a frequent basis and will not hold Technical Learning College responsible for any changes. The student shall understand that this type of study program deals with dangerous conditions and will not hold Technical Learning College, Technical Learning Consultants, Inc. (TLC) liable for any errors or omissions or advice contained in this CEU education training course or for any violation or injury caused by this CEU education training course material.

Student Assistance
The student shall contact TLC if they need help or assistance and double-check to ensure my registration page and assignment has been received and graded.

Educational Mission

The educational mission of TLC is:

To provide TLC students with comprehensive and ongoing training in the theory and skills needed for the environmental education field,

To provide TLC students opportunities to apply and understand the theory and skills needed for operator certification and environmental education,

To provide opportunities for TLC students to learn and practice environmental educational skills with members of the community for the purpose of sharing diverse perspectives and experience,

To provide a forum in which students can exchange experiences and ideas related to environmental education,

To provide a forum for the collection and dissemination of current information related to environmental education, and to maintain an environment that nurtures academic and personal growth.

You are required that the final exam to be proctored.

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Arsenic Check

Arsenic enters groundwater from the erosion of arsenic containing rocks and soil.

Groundwater contaminated with arsenic has been found in 49 of the 50 states in the U.S. Recent debate over changing the U.S. limit as well as the problems in India and Bangladesh have made arsenic a hot topic.

This arsenic test kit provides a safe, reliable and simplified method to test for the presence of arsenic in water from 5 ppb to over 800 ppb. Inorganic arsenic compounds in the water sample are converted to arsine ($\mathbf{AsH}^{3}$) gas by a reaction between zinc powder and a mild acid powder.

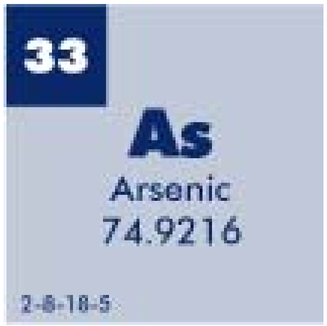
A test strip sensitive to the arsine gas is used to indicate the presence and concentration of arsenic in the water sample. A complete test requires about 30 minutes.

Two water samples can be tested simultaneously with the included test kit components.

- Tested by an independent laboratory to be accurate and reliable
- Non-hazardous reagents & easy to follow test procedure
- No Interference from H2S up to 2ppm
- No Iron or Sulfate interference
- Test detects both As+3 and As+5

Contact Lab Safety.
1-800-356-0783, www.labsafety.com

For our Arsenic test, reference the EPA website:
Verification report
http://www.epa.gov/etv/pdfs/vrvs/01_vr_quick.pdf
Verification Statement
http://www.epa.gov/etv/pdfs/vrvs/01_vs_quick.pdf



Definitions **Larger Glossary in the rear.**

As used in 40 CFR 141, the term:

Best available technology or *BAT* means the best technology, treatment techniques, or other means which the Administrator finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are available (taking cost into consideration). For the purposes of setting MCLs for synthetic organic chemicals, any BAT must be at least as effective as granular activated carbon.

Community water system means a public water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.

Compliance cycle means the nine-year calendar year cycle during which public water systems must monitor. Each compliance cycle consists of three three-year compliance periods. The first calendar year cycle begins January 1, 1993 and ends December 31, 2001; the second begins January 1, 2002 and ends December 31, 2010; the third begins January 1, 2011 and ends December 31, 2019.

Compliance period means a three-year calendar year period within a compliance cycle. Each compliance cycle has three three-year compliance periods. Within the first compliance cycle, the first compliance period runs from January 1, 1993 to December 31, 1995; the second from January 1, 1996 to December 31, 1998; the third from January 1, 1999 to December 31, 2001.

Contaminant means any physical, chemical, biological, or radiological substance or matter in water.

Maximum contaminant level means the maximum permissible level of a contaminant in water which is delivered to any user of a public water system.

Maximum contaminant level goal or *MCLG* means the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur, and which allows an adequate margin of safety. Maximum contaminant level goals are nonenforceable health goals.

Non-transient non-community water system or *NTNCWS* means a public water system that is not a community water system and that regularly serves at least 25 of the same persons over 6 months per year.

Point-of-entry treatment device (POE) is a treatment device applied to the drinking water entering a house or building for the purpose of reducing contaminants in the drinking water distributed throughout the house or building.

Point-of-use treatment device (POU) is a treatment device applied to a single tap used for the purpose of reducing contaminants in drinking water at that one tap.

Public water system means a system for the provision to the public of water for human consumption through pipes or, after August 5, 1998, other constructed conveyances, if such system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year. Such term includes: any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system; and any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system. Such term does not include any "*special irrigation district*."

A public water system is either a "community water system" or a "noncommunity water system."

State means the agency of the State or Tribal government which has jurisdiction over public water systems. During any period when a State or Tribal government does not have primary enforcement responsibility pursuant to section 1413 of the Act, the term "State" means the Regional Administrator, U.S. Environmental Protection Agency.

Surface water means all water which is open to the atmosphere and subject to surface runoff.

Ion Exchange Units

List of Acronyms and Abbreviation

AA Activated alumina
AC Activated carbon
ASR Annual Status Report
As(III) Trivalent arsenic, common inorganic form in water is arsenite, H3AsO3
As(V) Pentavalent arsenic, common inorganic form in water is arsenate, H2AsO4
BDAT best demonstrated available technology
BTEX Benzene, toluene, ethylbenzene, and xylene
CCA Chromated copper arsenate
CERCLA Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS 3 CERCLA Information System
CLU-IN EPA's CLeanUp INformation system
CWS Community Water System
cy Cubic yard
DDT Dichloro-diphenyl-trichloroethane
DI Deionized
DOC Dissolved organic carbon
DoD Department of Defense
DOE Department of Energy
EDTA Ethylenediaminetetraacetic acid
EPA U.S. Environmental Protection Agency
EPT Extraction Procedure Toxicity Test
FRTR Federal Remediation Technologies Roundtable
ft feet
GJO DOE's Grand Junction Office
gpd gallons per day
gpm gallons per minute
HTMR High temperature metals recovery
MCL Maximum Contaminant Level (enforceable drinking water standard)
MF Microfiltration
MHO Metallurgie-Hoboken-Overpelt
mgd million gallons per day
mg/kg milligrams per kilogram
mg/L milligrams per Liter
NF Nanofiltration
NPL National Priorities List
OCLC Online Computer Library Center
ORD EPA Office of Research and Development
OU Operable Unit
PAH Polycyclic aromatic hydrocarbons
PCB Polychlorinated biphenyls
POTW Publicly owned treatment works
PRB Permeable reactive barrier
RCRA Resource Conservation and Recovery Act
Redox Reduction/oxidation
RO Reverse osmosis
ROD Record of Decision
SDWA Safe Drinking Water Act
SMZ surfactant modified zeolite
SNAP Superfund NPL Assessment Program
S/S Solidification/Stabilization
SVOC Semivolatile organic compounds
TCLP Toxicity Characteristic Leaching Procedure
TNT 2,3,6-trinitrotoluene
TWA Total Waste Analysis
UF Ultrafiltration
VOC Volatile organic compounds
WET Waste Extraction Test
ZVI Zero valent iron

A PDF version of *Arsenic Treatment Technologies for Soil, Waste, and Water*, is available for viewing or downloading from the Hazardous Waste Cleanup Information (**CLU-IN**) system web site at *http://clu-in.org/arsenic*.

A limited number of printed copies are available free of charge, and may be ordered via the web site, by mail or by facsimile from:
U.S. EPA/National Service Center for Environmental Publications (**NSCEP**)
P.O. Box 42419 Cincinnati, OH 45242-2419
Telephone: (513) 489-8190 or (800) 490-9198 Fax: (513) 489-8695

Fact Sheet on the Arsenic Rule October 31, 2001

EPA ANNOUNCES ARSENIC STANDARD FOR DRINKING WATER OF 10 PARTS PER BILLION

What is the EPA announcing?

The EPA affirms the appropriateness of a maximum contaminant level (**MCL**) (or regulatory level) of 10 parts per billion (ppb) for arsenic in drinking water. Today's announcement will provide additional protection to at least 13 million Americans from cancer and other health problems.

Why did the EPA delay and review the 10ppb standard adopted in January 2001?

The EPA's responsibility is to establish protective health standards in which the public has confidence. Because of the debate surrounding the appropriateness and the cost of the 10 ppb standard (particularly for small water systems), the Administrator sought additional independent expert reviews of the January 2001 regulation.

What are the benefits of setting the standard at 10ppb?

Reducing arsenic from 50 ppb to 10ppb will prevent:

- more than 19-31 cases of bladder cancer per year, prevent 5-8 deaths each year from this cancer,
- more than19-25 cases of lung cancer, prevent 16-22 deaths from this cancer, and
- a number of cases of non-cancerous diseases, such as heart disease.

How many water systems are affected by this standard?

Of the 74,000 systems regulated by this MCL, approximately 4,000 systems will have to install treatment or take other steps to comply with the 10 ppb standard.

How much will it cost to implement this standard?

The EPA estimates that the average annual household water bill may increase by $32 per year, however, for households in systems that serve less than 3,300 people the cost will be substantially higher (ranging from $58 - $327 per household).

When must water systems meet the 10 ppb standard?

Water systems must meet this standard by January 23, 2006.

What is EPA doing to help smaller systems meet the 2006 compliance date?

The EPA plans to provide up to $20 million over the next two years for research and development of more cost-effective technologies to help small systems meet the more protective 10 ppb standard. The EPA also will provide technical assistance and training to operators of small systems, which will reduce their compliance costs.

Since 1996, states have provided more than $3.8 in loan assistance through the Drinking Water State Revolving Fund (**DWSRF**) to help water systems improve their infrastructure.

The EPA also provides funding to States for their drinking water programs (including assistance to small systems for control of arsenic) through the Public Water Systems Supervision grants program. Other federal funds are available through Housing and Urban Development's Community Development Block Grant Program, and the Rural Utilities Service of the U.S. Department of Agriculture.

Arsenic Guidance August 2002 Appendix N-3

What are the Consumer Confidence Report (CCR) requirements for arsenic after the effective date of this rule?

Community water systems are required to publish annual reports with information on water source, treatment, and any detected contaminants by July 1 of each year. Under the arsenic rule, systems that detect arsenic between 10 and 50 ppb must include health effects information in the CCR. Systems that detect arsenic between 5 and 10 ppb must include an educational statement in the CCR.

Systems with arsenic concentrations above 50 ppb (in violation of the existing standard) continue to be required to state they are in violation and must provide health effects information.

When are States required to update their programs for the new Arsenic standard?

Under the Safe Drinking Water Act, States have two years after promulgation to submit a complete and final primacy revision application to the EPA. States may request an extension of up to two additional years for program updates. The EPA will grant extensions on a case-by-case basis, depending on need.

For the arsenic standard, the initial two-year period ends January 22, 2003.

An extension for the entire two-year period would end January 22, 2005.

For More Information

For general information on arsenic in drinking water, contact the Safe Drinking Water Hotline, at (800) 426-4791, or visit the EPA Safewater website at http://www.epa.gov/safewater or the arsenic website at http://www.epa.gov/safewater/arsenic.html on the Internet.

Symptom of Arsenic poisoning from drinking water.

Arsenic Rule

EPA 815-F-00-016
January 2001

1. What are we announcing?

Today's final rule revises the current Maximum Contaminant Level (MCL) from 50 µg/L to 10 µg/L and sets a Maximum Contaminant Level Goal (**MCLG**) of zero for arsenic in drinking water. In addition, this final rule also clarifies how compliance is demonstrated for many inorganic and organic contaminants in drinking water.

2. What are the requirements of this final rule?

Both community water systems (**CWSs**) and non-transient, non-community water systems (**NTNCWSs**) will be required to reduce the arsenic concentration in their drinking water systems to 10 g/L.

A CWS is a public water system that serves at least 15 locations or 25 residents regularly year round (e.g., most cities and towns, apartments, and mobile home parks with their own water supplies). An NTNCWS is a public water system that is not a CWS and serves at least 25 of the same people more than 6 months of the year (e.g., schools, churches, nursing homes, and factories).

This final rule is also a vehicle for clarifying two compliance requirements for inorganic contaminants (**IOCs**), volatile organic contaminants (**VOCs**), and synthetic organic contaminants(**SOCs**). When a system fails to collect the required number of samples, compliance averages will be based on the actual number of samples collected. Also, new public water systems and systems using new sources of water must demonstrate compliance within State-specified time and sampling frequencies.

3. How soon after publishing the final rule will the changes take effect?

All CWSs and all NTNCWSs that exceed the MCL of 10 µg/L will be required to come into compliance 5 years after the promulgation of the final rule. Beginning with reports that are due by July 1, 2002, all CWSs will begin providing health information and arsenic concentrations in their annual consumer confidence report (**CCR**) for water that exceeds ½ the revised MCL.

4. Why is this rule significant?

In the 1996 amendments to the Safe Drinking Water Act (**SDWA**), Congress directed the EPA to propose a new arsenic regulation by January 1, 2000 and to issue the final rule by January 1, 2001 (Congress subsequently extended the final rule date to June 22, 2001). EPA published the proposed rule for arsenic on June 22, 2000. The rule proposed an MCL of 5 µg/L for arsenic and the EPA took comment on regulatory options of 3 µg/L (the feasible level), 10 µg/L and 20 µg/L.

The 1996 amendments to SDWA added discretionary authority for the EPA Administrator to adjust the maximum contaminant level (**MCL**) if the benefits would not justify the costs (1412(b)(6)). Today's rule is important because it is the second drinking water regulation in which the EPA will use the discretionary authority under SDWA Section 1412(b)(6). After careful consideration of the benefits and the costs, the EPA has decided to set the drinking water standard for arsenic higher than the technically feasible level of 3 µg/L because the EPA believes that the costs would not justify the benefits at this level.

The EPA believes that the final MCL of 10 µg/L maximizes health risk reduction at a cost justified by the benefits.

5. What health effects are associated with exposure to arsenic from drinking water?

In most drinking water sources, the inorganic form of arsenic tends to be more predominant than organic forms. Inorganic arsenic in drinking water can exert toxic effects after acute (short-term) or chronic (long-term) exposure. Although acute exposures to high doses of inorganic arsenic can cause adverse effects, such exposures do not occur from public water systems in the U.S. that are in compliance with the existing MCL of 50 µg/L.

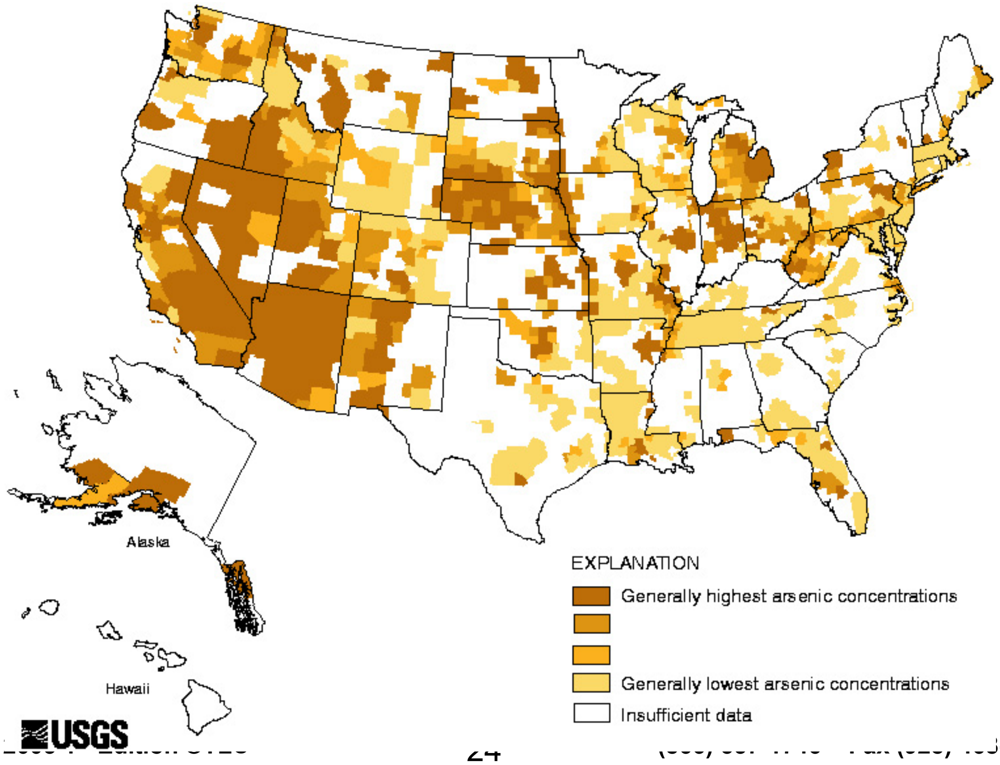
Today's final rule addresses the long-term, chronic effects of exposure to low concentrations of inorganic arsenic in drinking water. Studies link inorganic arsenic ingestion to a number of health effects. ***These health effects include:***

- **Cancerous Effects:** skin, bladder, lung, kidney, nasal passages, liver and prostate cancer; and
- **Non-cancerous effects**: cardiovascular, pulmonary, immunological, neurological and endocrine (e.g., diabetes) effects.

6. What are the sources of arsenic contamination in water?

The contamination of a drinking water source by arsenic can result from either natural or human activities. Arsenic is an element that occurs naturally in rocks and soil, water, air, plants, and animals.

Volcanic activity, the erosion of rocks and minerals, and forest fires are natural sources that can release arsenic into the environment. Although about 90 percent of the arsenic used by industry in the United States is currently used for wood preservative purposes, arsenic is also used in paints, drugs, dyes, soaps, metals and semi-conductors.



Agricultural applications, mining, and smelting also contribute to arsenic releases.

7. How many people and how many systems will be affected by this rule?
Higher levels of arsenic tend to be found more in ground water sources than in surface water sources (i.e., lakes and rivers) of drinking water. Compared to the rest of the United States, the Western states have more systems with arsenic levels greater than 10 µg/L.

Parts of the Midwest and New England have some systems whose current arsenic levels are greater than 10 µg/L, but more systems with arsenic levels that range from 2-10 µg/L of arsenic.

While many systems may not have detected arsenic in their drinking water above 10 µg/L, there may be geographic "***hot spots***" with systems that may have higher levels of arsenic than the predicted occurrence for that area.

About 3,000 (or 5.5 percent) of the nation's 54,000 CWSs and 1,100 (or 5.5 percent) of the 20,000 NTNCWSs will need to take measures to lower arsenic in their drinking water. Of the affected systems, 97 percent serve less than 10,000 people.
Arsenic Guidance August 2002 Appendix N-9

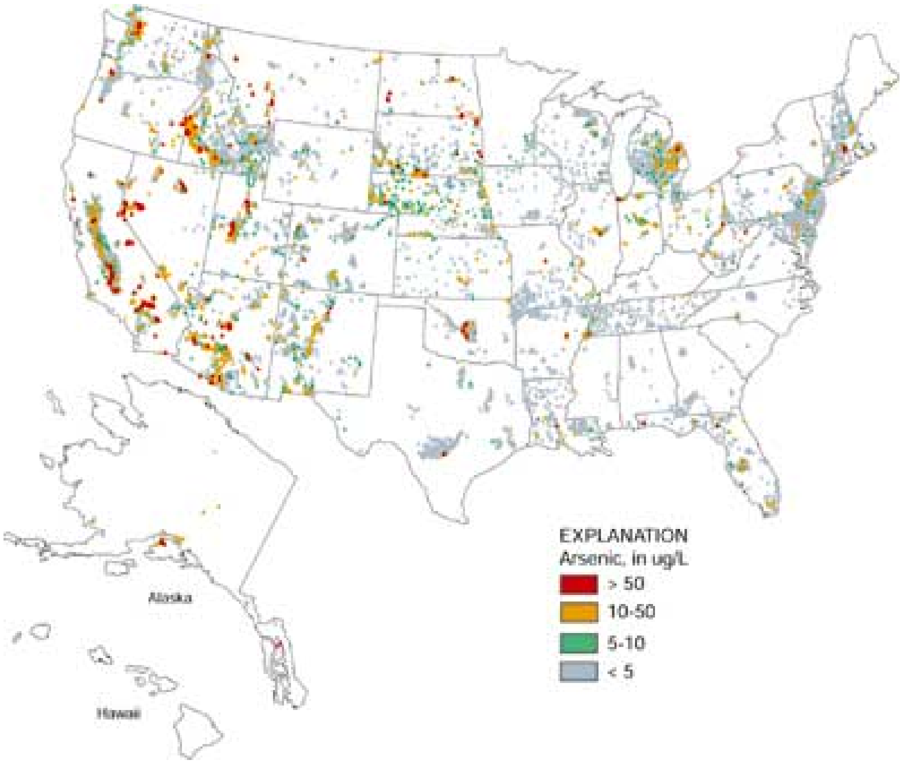


Table 1 below shows the estimated number of CWSs and NTNCWSs that would be affected by this rule and the estimated population served by these public water systems.

Table 1. Estimates of the Number of CWSs and NTNCWSs That Would Need to Treat and the Population Served by These Systems

Regulatory Action	Type of System and Total Number	Number Systems Affected	Total Population Served by the Affected System
10 µg/L	CWSs (54,000)	~ 3,000	~ 11 million
10 µg/L	NTNCWSs (20,000)	~ 1,100	~ 1.7 million

8. How much will this rule cost?

The EPA estimates the total national annualized costs of treatment, monitoring, reporting, recordkeeping, and administration for this rule to be approximately $181 million (using 1999dollars at a three percent discount rate - Table 2). Most of the cost is due to the cost of installing and operating the treatment technologies needed to reduce arsenic in public water systems (both CWSs and NTNCWS). The EPA estimates the total treatment cost to be approximately $177 million per year. Annual monitoring and administrative costs will be about $2.7 million and States' costs will be approximately $1 million.

August 2002 Arsenic Guidance Appendix N-10

Table 2. Annual National System and State Compliance Costs (3% Discount Rate, $millions)

	CWS	NTNCWS	Total
System Costs			
Treatment	$170	$7.0	$177
Monitoring/Administrative	$1.8	$0.9	$2.7
State Costs	$0.9	$0.1	$1.0
Total Cost	$173	$8.0	$181

The average annual household costs for the homes served by the approximately 2,387 CWSs that require treatment are expected to be approximately $32 per year. The average annual household costs are shown categorized by system size in Table 3. The disparity in household costs between system size is due to economies of scale. Larger systems are able to spread the costs they incur over a larger customer base.

Table 3. Total Annual Costs (Dollars) per Household for CWSs

System Size	25-500	501-3,300	3.3K-10K	10K-and above
Annual	$ 327-$162	$ 71-$58	$ 38	$32-$0.86

Household Costs

The estimated average annual costs for CWSs, which exceed the final MCL of 10 µg/L and are required to treat, are shown in Table 4 categorized by system size.

Table 4: Average Annual Costs per CWS (Dollars)

CWS System Size	Costs ($)
25-500	$6,494-$12,358
501-3,300	$22,100-$53,086
3,300-10,000	$111,646
10,000 and above	$531,584-$1,340,716

What are the benefits of this rule?

The rule will protect approximately 13 million Americans served by CWSs and NTNCWSs (this number is based on reducing arsenic from 50 to 10 µg/L). Reducing arsenic from 50 to 10 µg/L will prevent ~ 19-31 cases of bladder cancer and ~ 5-8 deaths due to bladder cancer per year.

The EPA estimates that reducing arsenic from 50 to 10 µg/L will prevent ~ 19-25 cases of lung cancer and ~ 16-22 deaths due to lung cancer per year. In addition to these quantified benefits, there are substantial non-quantified benefits of this rule, including reducing the incidences of non-cancerous effects summarized above.

The quantified annual benefits for the today's rule range from $140 to $198 million. The benefit range consists of both lower and upper bound estimates. These estimates reflect the upper and lower bound of the risk range addressed by this rule as well as different drinking water consumption distributions that were used in our analysis.

Is there funding associated with this rule?

Since 1996, the DWSRF has made over $3.2 billion available for loans to help water systems improve their infrastructure. The EPA also provides funding to States that have primary enforcement responsibility for their drinking water programs through the Public Water Systems Supervision (**PWSS**) grants program. Other federal funds are available through Housing and Urban Development's Community Development Block Grant Program, and the Rural Utilities Service of the U.S. Department of Agriculture. In the most recent year, 2000, the DWSRF and Rural Utilities Service combined made $1.7 billion available to States and public water systems for capital improvements and infrastructure needs.

How did EPA consult with stakeholders?

From 1997-1999, the EPA conducted a number of Agency workgroup meetings on arsenic as well as five stakeholder meetings across the country. Representatives of eight federal agencies, 19 State offices, 16 associations, 13 corporations, 14 consulting engineering companies, two environmental organizations, three members of the press, 37 public utilities and cities, four universities, and one Indian tribe attended the stakeholder meetings on arsenic.

Five States also provided written comments on implementation issues during the rule development process. The Office of Water staff presented an overview of the arsenic rulemaking to over 900 Tribal attendees in 1998 and provided more detailed information in 1999 to 25 Tribal council members and water utility operators from 12 Indian tribes.

As part of the Small Business Regulatory and Enforcement Flexibility Act (**SBREFA**) consultation process, the EPA also received substantial input from discussions with small entity representatives. The National Drinking Water Advisory Council (**NDWAC**) provided useful input, particularly on the benefits analysis and small systems affordability.

The EPA also posted discussion papers produced for our stakeholder interactions on the Office of Ground Water and Drinking Water (**OGWDW**) Internet site and sent them directly to participants at stakeholder meetings and others who expressed interest.

In addition, the EPA provided updates on rulemaking activities at national and regional meetings of various groups and trade associations.

Furthermore, the EPA participated in technical workgroup meetings held by the American Water Works Association (**AWWA**). The EPA received comments from over 1,100 commenters from the public on the proposed rule. The EPA has considered these comments carefully in developing today's final rule for arsenic.

Where can the public get more information about this final rule?
For general information on arsenic in drinking water, contact the Safe Drinking Water Hotline, at (800) 426-4791, or visit the EPA Safewater website at http://www.epa.gov/safewater or the arsenic website at http://www.epa.gov/safewater/arsenic.html.

In addition to this technical fact sheet, the following documents and fact sheets will be available to the public at the EPA's web site on arsenic in drinking water:

- Federal Register notice of the final arsenic regulation
- Detailed technical support documents on Arsenic in Drinking Water
- Consumer Fact Sheet on Arsenic in Drinking Water

A copy of the Federal Register notice of the final regulation or any of the technical and consumer facts sheets can be obtained by contacting the Safe Drinking Water Hotline at (800) 426-4791 and (703) 285-1093. The Safe Drinking Water Hotline is open Monday through Friday, excluding federal holidays, from 9:00 a.m. to 5:30 p.m. Eastern Time.

Lesion caused by high level of Arsenic in the drinking water.

Arsenic Sources

There are many small abandoned mines in the US which produce acid mine drainage effluent which contains up to 20ppm of arsenic and many heavy metals such as copper and zinc. This one on the right is in Montana.

The dissolved iron which occurs naturally in acid mine drainage streams will be activated by sunlight so that it can catalyze the oxidation of both arsenic and iron.

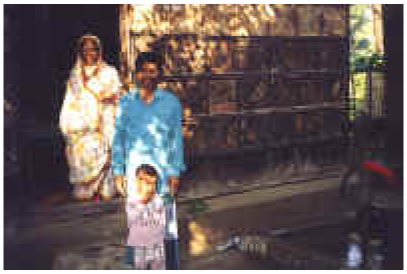
Alternatively, a commercially manufactured UV lamp reactor can be used to achieve faster oxidation of acid mine water and for the stabilization of flue dust. These demonstrations were conducted with MSE and funded by the USEPA.

Patent 2 Sulfite and Short Wavelength Ultraviolet light
Drinking Water Treatment in Small WTP for Rural Townships

This 10 gpm reactor is used to demonstrate the oxidation of arsenic in a small town's water supply in Northern California. After oxidation, the arsenic was removed with iron hydroxide to produce clean water which contained less arsenic than the new stringent health limits.

Applications in Bangladesh

Patent 1 Iron and Sunlight or UV light



Families across Bangladesh rely on hand dug water for drinking. The tubewell of this family, like many others (50-70 million people), has been painted red signifying that the water naturally contains a dangerous amount of arsenic. Many thousands of villagers who have drunk the water for several years have developed skin cancers from the water.

AusAID has funded a demonstration Project in Bangladesh. The first step of the process involves dissolving a few grams of iron salt into forty liters of tubewell water and leaving it exposed to sunlight for a few hours.

After solar oxidation the arsenic contaminated water is transferred into the CRC-ANSTO designed settling urn. After settling overnight the urn provides the convenience of 'clean drinking water on tap' to a Krishnapur villager.

No electricity is needed for this low-tech process which is planned for use in rural areas of Bangladesh.

Analysis in remote locations

The ANSTO team has overcome many difficulties to be able to determine trace arsenic concentrations immediately at our field sites.

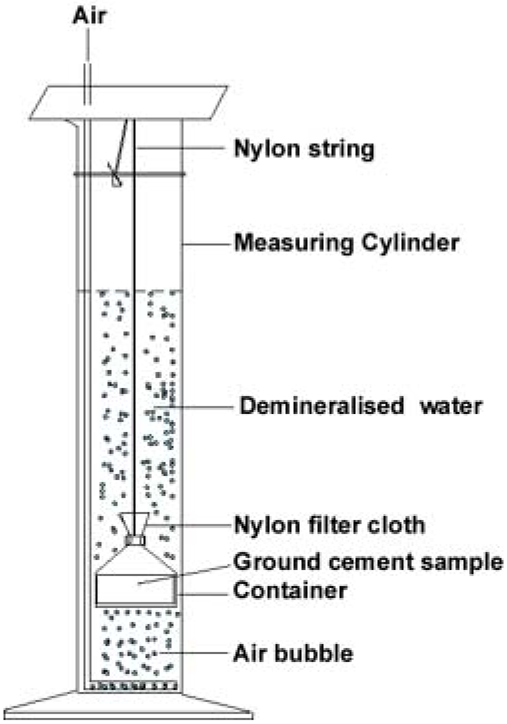
Solid Waste Stabilization

Iron hydroxide is the most effective adsorbent for arsenic known. However, it is very difficult to dewater and normally dries to be very dusty. The chunky solid in this photo was produced by carefully controlling the drying conditions. Further stability can be attained by incorporating the solid in cement.

The water treatment residues, with and without cement encapsulation, passed the standard US EPA TCLP leach test for landfill disposal.

Leachability Testing

ANSTO routinely conduct the regulatory leaching tests including the TCLP. When arsenic wastes are not properly stabilized they are prone to reaction with atmospheric carbon dioxide. In order to identify problem solids ANSTO has developed a simple long-term leach test in aerated water.



The ANSTO group has been working in this varied field of arsenic remediation and advanced oxidation technologies for a decade and welcomes new challenges.

ANSTO Environment
ANSTO Environment is the largest multidisciplinary environmental research organization in Australia and the largest research unit at ANSTO. Australian Nuclear Science and Technology Organization (**ANSTO**)

For more information contact:
Tae Passfield
ANSTO Environment (Bld 21a)
ANSTO
PMB 1 Menai, NSW 2234

Patent 1
Khoe G.H., Emett M.T. and Robins R.G.(1997)'Photo assisted oxidation of species in solution'. US Patent No. 5,688,378. Emett, M and Khoe, G. (2001) Photochemical oxidation of arsenic by oxygen and iron in acidic solutions. Water Research, 35, 649-656

Patent 2
Khoe, G. H., Zaw, M. Prasad, P. S. and Emett, M. T. (1999) Photo-assisted oxidation of inorganic species in aqueous solutions, International Patent Number: WO 99/05065, International Publication date: 4 February 1999.

Exemptions & the Arsenic Rule

The EPA's goal is to have all water systems comply with the 10 ppb arsenic maximum contaminant level (**MCL**) by January 23, 2006. The EPA understands, however, that additional time may be necessary for some systems to comply with the revised MCL, and believes that exemptions under §1416 of the Safe Drinking Water Act (**SDWA**) are an appropriate mechanism to provide this additional time.

Exemptions can help ensure that systems which are unable to comply with the revised arsenic MCL will have the opportunity to gain the resources or take the steps needed to comply with the rule in an appropriate period of time. The use of exemptions will also allow systems time to develop a plan for long-term capacity. States can act before the revised arsenic MCL goes into effect and move water systems more expeditiously toward compliance.

All public water systems (**PWSs**) that meet the minimum criteria outlined in the SDWA are eligible for an exemption of up to three years. For smaller water systems, exemptions can provide up to nine additional years beyond the compliance date of the MCL to achieve compliance. The EPA anticipates that States will grant systems only as much additional time as is needed to build capacity and come into compliance.

Without exemptions, water systems might not begin to move toward compliance until 2006. Exemptions encourage water systems to start down the path to compliance now, so that public health is better protected.

Exemptions are administrative tools that States can use in their long-term strategies to build capacity in drinking water systems. The use of exemptions gives eligible systems additional time to build capacity in order to achieve and maintain regulatory compliance, while continuing to provide acceptable levels of public health protection.

States can use exemptions during the implementation of the Arsenic Rule. The use of exemptions can help ensure that systems which are unable to comply with the arsenic MCL by January 23, 2006 will have the opportunity to gain the resources needed to comply with the rule in an appropriate period of time.

The EPA encourages the use of exemptions as a means of providing additional time to eligible systems. There are a number of criteria which systems must meet to be eligible for an exemption. First, the State must have adopted the August 14, 1998 Variance and Exemptions Regulation (63 FR 43835).

Since some States may choose not to allow exemptions, systems under their jurisdiction will not be able to obtain an exemption. For States with exemptions provisions, systems must meet certain eligibility criteria as outlined in SDWA §1416. Systems that meet these eligibility requirements may qualify for different exemption durations depending on system size, arsenic concentrations, system needs, and other State requirements, if any.

Finally, the State must provide notice and opportunity for a public hearing. If the exemption is approved, the State must prescribe a compliance schedule. This document shows how exemptions can be granted in a straightforward and streamlined manner. It is divided into 2 sections.

Section 1 explains in a question and answer (**Q&A**) format how the applicable laws and regulations can be translated into a workable set of exemption guidelines. Section 2 is a "***How To***" guide demonstrating how straightforward the granting of an exemption can be.

Section 2 also includes two forms that can simplify the exemption process. The first form is for systems to use when requesting an exemption. The second form is for States to use when determining whether to grant an exemption. Both forms are accompanied by line-by-line instructions that explain the information needed and the types of paperwork necessary to document an exemption.

SECTION 1: EXEMPTION Q&A

1. What is an exemption?

Exemptions are administrative tools that allow water systems additional time to acquire financial assistance and develop mechanisms necessary to ensure compliance with a drinking water standard.

PWSs are required to meet the revised arsenic MCL of 10 ppb by January 23, 2006 (40 CFR 141.6(j)). To avoid noncompliance, exemptions must be issued prior to this date. If granted an exemption, a PWS would have up to 3 additional years to comply (January 23, 2009). Eligible systems serving fewer than 3,300 persons may be granted up to 3 exemption extensions of 2 years each (SDWA §1416(b)(2) and 40 CFR 142.20(b)(2)), allowing up to 9 total years (14 years since the rule was published) to obtain financial assistance and implement a compliance strategy (January 23, 2015).

This Q & A document explains what States need to consider in granting exemptions and suggests a simple, straightforward, and effective manner in which States can document their decisions regarding exemptions.

2. Which systems are eligible for exemptions?

A system is eligible for an exemption from the arsenic MCL if, at a minimum, it meets all four of the following criteria (40 CFR 142.20(b) and SDWA §1416(a)):

1. "Due to **compelling factors**," (40 CFR 142.50) the PWS is unable to achieve compliance by January 23, 2006 through any means, including treatment or developing an alternative source of water supply.
2. The PWS **"was in operation" by January 23, 2006** or, if not in operation by January 23, 2006, the system has "no reasonable alternative source of drinking water" available to it.
3. The exemption "***will not result in an*** **unreasonable risk to health**."
4. The system cannot reasonably make **management and/or restructuring changes** that would result in compliance or improve the quality of the drinking water if compliance cannot be achieved. Section 2 provides a simple form that States can use to document system eligibility for an exemption and, if appropriate, the findings and conditions associated with granting an exemption.

3. How can a system indicate its interest in receiving an exemption?

Section 2 also provides a simple form that systems can use to request an exemption, if allowed by the State. States that choose to use the exemption provision can modify the form to fit their needs. Systems that need exemptions will generally have limited technical, financial, and managerial capacity. Therefore, States and technical assistance providers may want to make a special effort to alert systems to the potential availability of exemptions and to assist them in completing an application.

4. Under what minimum conditions may an eligible system receive an exemption from the arsenic MCL?

To receive an exemption from its State, an eligible PWS must, at a minimum, be "***taking all practicable steps to meet***" the MCL (40 CFR 142.20(b), 40 CFR 142.50(b), and SDWA §1416(b)(2)(B)). In addition, no exemption shall be granted by a State unless the PWS establishes that:

1. In order to meet the MCL, the system needs capital improvements that cannot be completed prior to January 23, 2006;
2. In the case of a system that needs financial assistance for the necessary improvements, the system has entered into an agreement to receive the necessary financial assistance or has demonstrated that such financial assistance, either from a federal or State program, is "***reasonably likely to be available within the period of the exemption***"; or,
3. The system has entered into an enforceable agreement to become part of a regional water system (SDWA §1416(b)(2)(B)).

For example, a PWS that needs capital improvements and requires financial assistance could provide written documentation showing its position on the Drinking Water State Revolving Fund (**DWSRF**) priority list. Alternatively, the PWS could document its loan agreement with a private lender, or provide a written and enforceable agreement to become a part of a regional PWS.

When reviewing a system's need for capital improvements that cannot be completed prior to January 23, 2006, the State should determine whether it is feasible for the system to design an appropriate treatment train, obtain sufficient funding, and install the treatment technology by January 23, 2006. Systems should consider installing a Best Available Technology (**BAT**), and small systems should consider installing a small system compliance technology (**SSCT**) listed in the Final Arsenic Rule (40 CFR 141.62(c) & (d)).

Systems and States should consider the possibility of upgrading the system's existing treatment capabilities and the installation of additional treatment technology. If modification or installation before January 23, 2006 is not feasible due to compelling circumstances, the system may be eligible for an exemption.

In addition, the State must consider whether the system can develop or gain access to an alternative water source by January 23, 2006 (40 CFR 142.20(b) and 40 CFR 142.50(a)). The feasibility of establishing a partnership to use a neighboring system's source must be considered along with the development of a new source (40 CFR 142.20(b)(1)(ii)). PWSs and States should consider whether the characteristics of the new source would require the system to treat for other contaminants and, consequently, make using the new source cost prohibitive.

If, due to compelling reasons, the system cannot implement measures to develop an alternative source before January 23, 2006, the system may be eligible for an exemption.

1For additional details, see Question 10.

5. Under what minimum conditions may an eligible system qualify for an exemption extension?

PWSs that receive exemptions and serve no more than 3,300 persons may be able to extend their exemptions by up to 6 years. These extensions can be considered and granted when the State grants the original 3-year exemption.[1] These extensions provide States the flexibility to develop compliance schedules longer than 3 years. A system is eligible to extend its exemption only if, at a minimum, it:

1. Proves that it is taking all practicable steps to meet the established schedule to achieve full compliance with the arsenic MCL.
2. Needs financial assistance for the necessary improvements and has entered into an agreement for, or is reasonably likely to obtain (from a federal or State program), financial assistance to make necessary capital improvements, or has entered into an enforceable agreement to become a part of a regional public water system (40 CFR 142.20(b) and SDWA §1416(b)(2)(C)).

States may grant up to three additional 2-year extensions during which systems are exempt from the MCL. The extensions should be based on how much time the system reasonably needs to come into compliance. A primacy State must document its findings when extending an exemption (40 CFR 142.20(b)(2)). Again, these findings can be based on easily acquired or readily available information and can be documented in a streamlined and straightforward manner.

Exemption Eligibility Issues

6. What are "compelling factors"?

As a minimum condition for receiving an exemption, a system must be unable to achieve compliance by January 23, 2006, due to compelling factors (40 CFR 142.20(b), 40 CFR 142.50(a)(1), and SDWA section 1416(a)(1)).

According to the SDWA, compelling factors may include economic factors, including qualification of the PWS as a system serving a disadvantaged community pursuant to SDWA section 1452(d). SDWA section 1452(d) defines a disadvantaged community as "the service area of a PWS that meets affordability criteria established after public review and comment by the State in which the public water system is located."

Among the factors a State may wish to consider in determining whether a system needs additional time to achieve compliance are the following:

1. The number and types of activities that should reasonably be undertaken, consistent with the size of the system and the financial consequences to its ratepayers, in order to choose and implement an appropriate technology. These activities may include pilot-testing or field-testing arsenic-removal technologies, selecting an engineering consultant, coordinating with State and local agencies, preparing plans and specifications, obtaining financing, obtaining bids for construction, obtaining permits, constructing the facilities, and testing the completed facilities.
2. The time appropriately allocated for each of the activities identified in (1), and the total time allocated for all activities.
3. The cost of performing the activities identified in (1), and any savings that might be obtained from additional time.
4. The benefits that may be obtained from additional time, including any improvements in cost-effectiveness that may be obtained from non-BAT technologies or from ascertaining which technology may be most appropriate for the raw water supplies available to the system.

Other compelling factors affecting a system's ability to comply may be identified by the State on a case by-case basis. The EPA recognizes many systems may have difficulty in achieving compliance by January 23, 2006. There will be a wide variety of circumstances the States will have to consider, and there may be sufficient variation so that ***"compelling circumstances***" cannot be strictly defined.

7. How can a PWS beginning operation after January 23, 2006 qualify for an exemption?

At a minimum, a PWS that begins operation after January 23, 2006 must show that it has "***no reasonable alternative source of drinking water***" in order to qualify for an exemption (40 CFR 142.20(b) and SDWA §1416(a)(2)). Such a system should show that it is not feasible to develop an alternative source of water which has a lower level of arsenic or to access a neighboring system's water source. A system that successfully demonstrates it has no reasonable alternative source of drinking water may be eligible for an exemption. To be eligible, new systems still must meet all other exemption eligibility criteria that apply, including:

1. The presence of a compelling factor which prohibits the system from complying by January 23, 2006.
2. The absence of unreasonable risk to health.
3. The lack of available management or restructuring changes that would result in compliance or, if compliance cannot be achieved, would improve water quality.

8. What constitutes an "Unreasonable Risk to Health"?

An exemption from the revised arsenic MCL requires, among other things, that the exemption will not result in an unreasonable risk to health. An exemption to an MCL allows a PWS to continue to provide water at some level above the MCL for a specified period of time, after which the system must come into compliance.

In this guidance, the EPA is suggesting an approach to determine what does **not** constitute an unreasonable risk to health with respect to arsenic. This approach bases the length of an exemption on the level of arsenic in the water. States may use an alternate method to the following approach.

The EPA's approach is based on the fact that Congress included exemption provisions in the SDWA with the clear intention that they be used to address the needs of economically challenged systems by providing additional time to achieve compliance. Congress necessarily contemplated that the customers of these systems would be exposed to drinking water above the MCL for the period of the exemption.

The limitation that Congress imposed on this excess exposure is that it not constitute an unreasonable risk to health. The EPA is suggesting one possible approach to determining what does not pose an unreasonable risk to health with respect to arsenic, rather than addressing the much more complex issue of what **does** constitute an unreasonable risk to health.

In reauthorizing the SDWA, Congress established a time frame for implementation that allows systems up to 5 years to comply with new or revised regulatory requirements. Under the revised MCL of 10 ppb, water systems are allowed to continue to operate at levels between 10 ppb and 50 ppb for up to 5 years.

Through the time frame allowed in SDWA, Congress made the tacit determination that these exposures will pose an acceptable, and therefore not "***unreasonable***" risk of adverse health effects to the affected population. Based on that determination and on information suggesting a linear relationship between the arsenic dose and cancer risk, the EPA is suggesting concentration levels that should not generally pose an unreasonable risk to health for exemptions of various durations.

The previous arsenic MCL was 50 ppb. Systems must begin complying with the revised MCL of 10 ppb by January 23, 2006, five years from the date the Arsenic Rule was published (January 22, 2001). Thus, in principle, a system could be providing water with an arsenic level of 50 ppb until January 23, 2006 and be in full compliance with the SDWA and EPA regulations. The system would remain in compliance if it reduced its arsenic level to 10 ppb or less by January 23, 2006.

Exemptions could extend the compliance date by up to 3 years or up to 9 years, depending on system size and number of extensions granted. The longest period a system could have to achieve compliance would be 14 years (the 5-year base of January 22, 2001-January 23, 2006, plus a 3-year exemption and three 2-year extensions). As a matter of congressional policy, exposure at 50 ppb for the 5 years from January 22, 2001 to January 23, 2006 should **not** pose an unreasonable risk to health. This represents 40 ppb above the revised MCL of 10 ppb (50 ppb-10 ppb = 40 ppb).

The total exposure above the revised MCL for those 5 years is 40 ppb × 5 years = 200 ppb × years.

This 200 ppb × years may be thought of as the "***excess compliance-period exposure.***" That is, it represents the exposure above what would have occurred if water systems had instantaneously complied with the revised MCL on January 22, 2001. It represents "***excess exposure***" that, as a matter of law and policy, should not pose an unreasonable risk to health.

The EPA's policy is to assume a linear relationship between adverse health effects of a chemical and exposure unless there are sufficient data to decide otherwise. In its review of the Arsenic Rule extending into fall 2001, the scientific community again endorsed the EPA's decision to use a linear approach for estimating arsenic risks.

Exemptions and any subsequent extensions cannot be granted for more than 9 years and for concentrations higher than 50 ppb. Thus, for an exemption, the determination of what concentration level and duration does not pose an unreasonable risk to health can be conservatively determined by limiting "***excess compliance-period exposure***" to #200ppb × years for the total compliance period including the full duration of an exemption.

The following calculations clarify the application of this concept:
(5 years) × (40 ppb) = 200 ppb × years
(8 years) × (C8) = 200 ppb × years; (C8) = (200ppb × years)/(8 years) = 25 ppb

Thus, for an initial 3-year exemption (which provides a total compliance period of 8 years), a concentration of 25 ppb above the MCL of 10 ppb (a total concentration of 35 ppb) would not generally pose an unreasonable risk to health.

(10 years) × (C10) = 200 ppb × years; (C10) = (200 ppb × years)/(10 years) = 20 ppb
Thus, for a 2-year extension to the initial 3-year exemption (which provides a total compliance period of 10 years), a concentration of 20 ppb above the MCL of 10 ppb (a total concentration of 30 ppb) would not generally pose an unreasonable risk to health.

(12 years) × (C12) = 200 ppb × years; (C12) = (200 ppb × years)/(12 years) = 17 ppb
Thus, for two 2-year extensions to the initial 3-year exemption (which provides a total compliance period of 12 years), a concentration of 17 ppb above the MCL of 10 ppb (or a total concentration of 27 ppb) would not generally pose an unreasonable risk to health.

(14 years) × (C14) = 200 ppb × years; (C14) = (200 ppb × years)/(14 years) = 14 ppb
Thus, for three 2-year extensions to the initial 3-year exemption (which provides a total compliance period of 14 years), a concentration of 14 ppb above the MCL of 10 ppb (or a total concentration of 24 ppb) would not generally pose an unreasonable risk to health.

Based on these calculations, the EPA believes the values in Table 1 offer a conservative and appropriate framework for determining the duration of an exemption that should not generally pose an unreasonable risk to health for systems with various historical arsenic concentrations. As a result, States may wish to consider exemptions for the indicated arsenic concentrations over the indicated time periods.

Table 1: Exemption Eligibility Based on "Unreasonable Risk to Health" Criteria

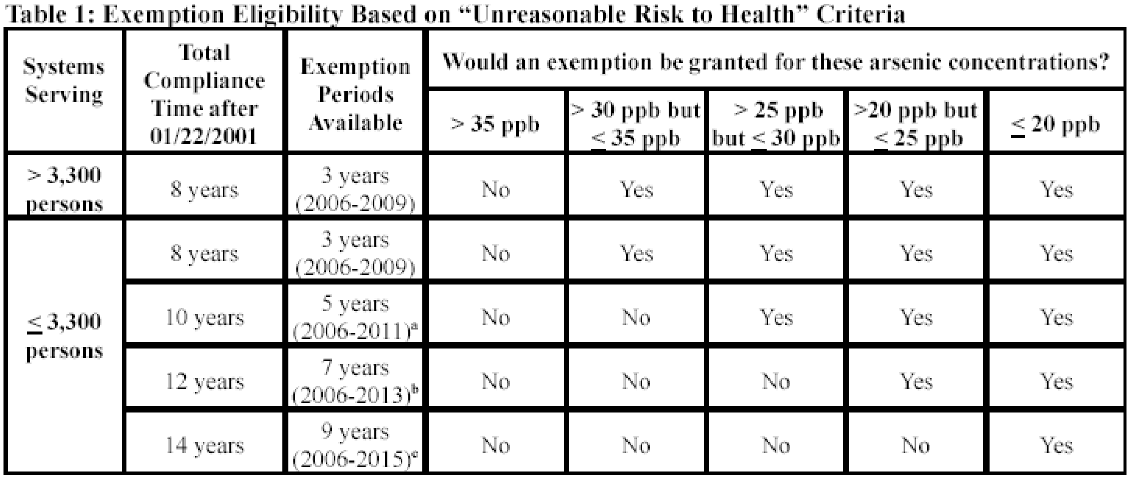


Table 1: Exemption Eligibility Based on "Unreasonable Risk to Health" Criteria

Systems Serving	Total Compliance Time after 01/22/2001	Exemption Periods Available	Would an exemption be granted for these arsenic concentrations?				
			> 35 ppb	> 30 ppb but ≤ 35 ppb	> 25 ppb but ≤ 30 ppb	>20 ppb but ≤ 25 ppb	≤ 20 ppb
> 3,300 persons	8 years	3 years (2006-2009)	No	Yes	Yes	Yes	Yes
≤ 3,300 persons	8 years	3 years (2006-2009)	No	Yes	Yes	Yes	Yes
	10 years	5 years (2006-2011)[a]	No	No	Yes	Yes	Yes
	12 years	7 years (2006-2013)[b]	No	No	No	Yes	Yes
	14 years	9 years (2006-2015)[c]	No	No	No	No	Yes

a Includes the initial 3-year exemption available to all systems and the first of three 2-year small system extensions.
b Includes the initial 3-year exemption available to all systems and two of three 2-year small system extensions.
c Includes the initial 3-year exemption available to all systems and all three 2-year small system extensions.

Note that, in determining the arsenic concentrations allowable in small systems that receive the second and third extensions available to them, the EPA suggests that States round down the allowable concentrations relative to the values shown in the calculations discussed above.

This rounding down provides an additional margin of safety, given the relatively long durations of elevated exposures that would be experienced by the individuals served by these systems.

This analysis is predicated on the assumption that a system will seek an exemption based on the historical concentration of arsenic in its source water. In other words, under this approach exemptions would not be available for systems that historically have had arsenic concentrations above 35 ppb, even if those systems have recently taken steps to reduce their concentrations to 35 ppb or less.

Furthermore, under this approach, exemptions would not offer a stair-step path to compliance. Systems could not obtain a 3-year exemption with a concentration of 35 ppb, and then seek an extension to that exemption by blending or otherwise reducing their concentrations to 30 ppb. Under this approach, the total length of the exemption for which a system is eligible is determined by the historical concentration of arsenic in the system's source water at the time of application for an exemption.

9. What must the State consider to conclude that management or restructuring changes cannot reasonably be made to achieve compliance or improve the drinking water quality by January 23, 2006?

The regulation (40 CFR 142.20(b)(1)) defines the measures a State must consider before determining that management or restructuring changes cannot reasonably be made by a system to achieve compliance or, if compliance cannot be achieved, improve the quality of its drinking water. This task need not be onerous or time consuming.

Rather, the State can use information from existing files, site visits, and telephone conversations with system managers to make determinations, and can quickly and briefly document such determinations.

The State determination form in Section 2 is an example of such streamlined documentation.

In making the determination, the State must consider what a system could reasonably accomplish through all of the following (40 CFR 142.20(b)(1)(i)):

1. Rate increases.
2. Accounting changes.
3. Appointment of a State-certified operator (under the State's Operator Certification program).
4. Joint operation with one or more PWSs (through a contractual agreement).
5. Activities consistent with the State's Capacity Development Strategy (to help the PWS acquire and maintain technical, financial, and managerial capacity).
6. Ownership changes.
7. "Consolidation (physical or otherwise) with another PWS."

In addition, the State must consider whether the DWSRF or other forms of federal or State assistance are "***reasonably likely to be available within the period of the exemption***" to implement the appropriate measures (40 CFR 142.20(b)(1)(i)). If none of these measures is feasible by January 23, 2006, the system may be eligible for an exemption if the other three criteria listed above in the answer to Question 2 are met.

A State must document its findings when determining that appropriate management or restructuring changes cannot reasonably be made by January 23, 2006 (40 CFR 142.20(b)(1)). Such documentation may conveniently be prepared using a form such as that suggested in Section 2.

2Excludes EPA Regions responsible for direct implementation.

Granting an Exemption

10. What must States document in granting an exemption to a system?
When a State grants an exemption to a PWS, it "***must document all findings required under SDWA section 1416***," including management and restructuring changes (40 CFR 142.20(b)(1)). States must document financial assistance needs when granting an extension (40 CFR 142.20(b)(2)).

States must provide the reasons for granting each exemption, including documenting the need for the exemption and providing the reason that the exemption will not result in unreasonable risk to health (40 CFR 142.15(a)(3)). The documentation process does not need to be onerous or time consuming. The State determination form in Section 2 suggests a streamlined approach to State documentation.

11. What else is expected from States during the exemption process?
The EPA encourages States to have systems request an exemption as soon as possible after determining that January 2006 compliance is not feasible. By beginning the exemption process early, States and systems have more time to conduct public hearings, identify the solutions necessary to bring systems into compliance, and set compliance schedules.

A State must decide whether to grant an exemption within 90 days (or less as prescribed by State rules) of receiving the exemption request (40 CFR 142.21 and 40 CFR 142.52).

The State should use the information it has about the system, as well as supplementary information provided by the system, to determine whether the system is eligible.

States will have to exercise their discretion in granting exemptions. The EPA will review the decisions made by a primacy State in accordance with 40 CFR 142 Subpart C (which provides that the EPA will review a State's exemptions to determine whether the State has abused its discretion or failed to establish a compliance schedule as required by SDWA §1416(b)(1)).

Section 2 offers an example of an "***Exemption Request Form***" for systems seeking an exemption. The EPA suggests that States and technical assistance providers work with systems most likely to need exemptions to help them complete such a form.

When a State grants an exemption, it must at the same time set a compliance schedule for the system, including increments of progress, or milestones (40 CFR 142.20(b), 40 CFR 142.53, and SDWA §1416(b)(1)). The schedule should require compliance as "***expeditiously as practicable***" (SDWA §1416(b)(2)(A)).

In addition, the State must prescribe a schedule for the system to implement control measures for arsenic during the period of the exemption (40 CFR 142.20(b), 40 CFR 142.53(c) and SDWA §1416(b)(1)). Before the schedules for compliance and control measures take effect, the State must notify and give the public an opportunity to comment on the schedules (40 CFR 142.20(b), 40 CFR 142.54, and SDWA §1416(b)(1)).

Public participation is a key component of the new flexibilities (i.e., exemptions) to SDWA, allowing impacted consumers to participate in making key decisions. None of these tasks need be overly burdensome. For example, States can hold joint hearings on groups of exemptions within a geographic area to minimize the administrative burden without compromising consumer participation.

Other efficiencies can be developed by States to streamline the process and make exemptions a viable and effective option for ensuring long-term compliance.

During the deliberation process, the State can also determine whether an extension will be necessary for an otherwise eligible system to implement its compliance strategy (including securing financial assistance).

"***The Agency interprets the extension provisions for public water systems serving less than 3,300 persons to allow the primacy agency to grant the additional two-year periods at the time of initial issuance of the exemption for those small systems that need financial assistance for the necessary improvements***"
(63 FR 43843).

These extensions provide States the flexibility to develop feasible compliance schedules (i.e., longer than 3 years). In order to grant extensions beyond the initial exemption/extension period, the State must conduct a review to ensure that the system is taking all practicable steps to comply with the MCL and the exemption compliance schedule provided by the State (40 CFR 142.20(b)(2)).

If the State determines that a PWS is not taking all practicable steps to comply with the requirements, the exemption should not be extended. The PWS should be subject to enforcement to address violations of the established schedule and the Arsenic Rule requirements.

If the exemption is extended, the PWS should be in full compliance with the Arsenic Rule at the end of the extension period.

Figure 1, below, summarizes the arsenic exemption process.

PWS determines it won't be able to comply with revised arsenic MCL by January 23, 2006 & requests an exemption from the State. State and PWS work together to determine if the system is eligible for an exemption and hold public hearing.

State informs PWS of exemption decision.

State sets a compliance schedule for the PWS (taking into account extensions) & appropriate control measures.

PWS implements compliance strategy, meeting all State milestones and informing customers as required.

State must decide whether to extend exemption (if applicable) by determining whether PWS is taking all practicable steps to stay on compliance schedule.

PWS continues to implement compliance strategy, meeting all State milestones and informing customers as directed.

PWS COMPLIES WITH MCL
PWS must comply with MCL by January 23, 2006.
Granted
Denied

PWS must comply with MCL.
Denied
Extended

DEADLINE
STATE MUST ACT WITHIN 90 DAYS AFTER REQUEST AS DETERMINED BY STATE
NO LATER THAN 1/23/09*
AS DETERMINED BY STATE
NO LATER THAN 1/23/15*
*Last feasible date. The EPA suggests taking action as early as possible.

12. What additional conditions may States impose on eligible systems for them to qualify for an exemption?
In addition to the compliance schedule, States may add conditions to the exemption to further reduce the health risk. For example, States may require systems to use bottled water, point-of-use devices, or point of entry devices as a condition of granting an exemption (40 CFR 142.57(a)). Under this condition, bottled water must meet the requirements in 40 CFR 142.62(g) and point-of-use or point-of-entry devices must meet the requirements in 40 CFR 142.62(h).

13. What should a system do once an exemption is granted?
When granted an exemption by its State, a PWS should follow the compliance schedule and meet all milestones. The system should understand how it will need to show progress and meet all other requirements of the exemption.

14. What are the system's reporting and public notification requirements?
In addition to the reporting and notification requirements outlined in the Arsenic Implementation Guidance Section I-A.7.d and I-A.7.e, systems operating under an exemption must include the following information in their consumer confidence report and public notice (40 CFR 141.153(g) and 40 CFR 141.205(b)):

1. An explanation of the reasons for the exemption.
2. The date on which the exemption was issued.
3. A brief status report on the steps the system is taking to install treatment, find alternative sources of water, or otherwise comply with the terms and schedules of the exemption.
4. A notice of any opportunity for public input in the review or extension of the exemption.

Systems operating under an exemption are required to issue a Tier 3 public notice and to notify their consumers within one year of receiving an exemption and repeat the notice annually for as long as the exemption applies to the system.

In addition, if the notice is posted, it must remain in place for as long as the exemption exists (40 CFR 141.204(b)(1)).

A system that violates the conditions of an exemption is required to issue a Tier 2 public notice (40 CFR141.203(a) containing the ten elements specified in 40 CFR 141.205(b).

HOW DO EXEMPTIONS FIT WITH OTHER PROGRAMS?

15. How can the DWSRF provisions and exemption provisions be used together?

Given the many competing demands placed on the DWSRF and other financial assistance programs, the flexibility to extend the period of time available for a system to receive financial assistance is important for States and systems. Exemptions help ensure that DWSRF assistance goes to PWSs most in need of such aid. Exemptions also allow systems that receive DWSRF assistance to be able to use it in a way that produces full compliance with an MCL.

The State must consider whether DWSRF assistance will likely be available within the time period of the exemption to implement necessary changes (40 CFR 142.20(b)(1)(i)). This requirement to consider the DWSRF as a possible funding source does not mean that the State must provide DWSRF assistance to a system seeking an exemption. States retain full authority to allocate SRF funds.

Another major source of federal financial assistance for water systems is the Rural Utility Service Water and Environmental Programs (**WEP**). WEP provides loans, grants, and loan guarantees for drinking water in rural areas and towns of up to 10,000 persons. Public bodies, non-profit organizations, and federally recognized Indian tribes are eligible for assistance.

Over $1.5 billion in financial assistance was available from WEP in fiscal year 2001.

16. Can the variance and the exemption provisions be used together?

PWSs that receive a small system variance for arsenic are not eligible for exemptions (SDWA §1416(b)(2)(D)).

A State may grant a variance to a PWS after an exemption has been granted. Generally, this would be appropriate only if unforeseen changes in circumstances during the exemption period make compliance unaffordable for the system.

For instance, if a system installs a BAT during the exemption period, but still cannot comply with the MCL due to source water characteristics, the State may grant the system a general variance.

For more information, please refer to the document *Revision of Existing Variance and Exemption Regulations to Comply With Requirements of the Safe Drinking Water Act; Final Rule* (63 FR 43835 (August 14, 1998)).

Other Tools

17. How should States deal with systems that fail to meet the terms of their exemptions and come into compliance?

With appropriate State support and oversight, systems receiving exemptions should be able to achieve compliance by the time their exemptions expire. But in some States, systems may violate the terms of their exemptions or fail to be in compliance when their exemptions expire.

In such situations, States may wish to consider the use of Administrative Orders (**AOs**) to direct these systems to take positive steps toward compliance.

Often, States issue AOs to noncompliant systems after exhausting other administrative compliance options and instead of pursuing more formal civil or criminal relief.

Depending on the state authority, an AO may include, among other things, a finding of violation, a compliance schedule with milestones, and a provision for assessing stipulated penalties for any violation of the AO's terms. In most States, systems have the right to appeal the terms of the AO in the administrative arena (such as during an administrative hearing) or in the judicial system; depending upon State authority, a State may be able to commence contempt proceedings in a civil court, collection actions, receivership proceedings, or termination of service proceedings for violation of the AO's terms.

States can use an AO to describe the conditions under which the system would be allowed to continue to operate after the violation or expiration of the exemption, while acknowledging that the system is in violation of the revised MCL. The terms of the AO should ensure that the system is taking the steps needed to come into compliance in accordance with a State-prescribed schedule.

In addition to unilateral AOs, States may have the option of entering into Administrative Consent Orders (i.e., stipulated agreements) with noncompliant PWSs.

An Administrative Consent Order is a legal agreement between the State and the PWS in which the system agrees to pay for correction of violations and to take the required corrective action within an agreed-upon period of time.

Stipulated agreements generally have the same force and effect as AOs and are effective when a system wants to comply and has committed to a compliance schedule.

However, stipulated agreements, AOs, and other enforcement tools should not be viewed as alternatives to exemptions. Exemptions are the statutory tool of choice for helping eligible systems achieve compliance. Enforcement tools should be used only after non-compliance has occurred.

Congress explicitly created the exemption provisions to address the needs of systems facing difficult, "***compelling***" circumstances that preclude their being able to achieve compliance in the normal time frame. Exemptions can help systems from ever being in non-compliance.

SECTION 2: HOW TO GRANT EXEMPTIONS

Granting an exemption can be simple and straightforward. For each exemption granted, it is important that the State work closely with the system to ensure that the exemption will result in compliance without jeopardizing the health of the system's customers. EPA encourages States to have systems request exemptions as soon as possible after determining that compliance is not feasible.

This gives States and systems more time to identify solutions and set appropriate compliance schedules to attain compliance as quickly as possible.

This Section provides two sample forms:

FORM #1: EXAMPLE SYSTEM REQUEST FORM. States can consider using this kind of form to collect important information from systems requesting exemptions.

FORM #2: EXAMPLE STATE DETERMINATION FORM. States can consider using this kind of form to determine whether a system should be granted an exemption.

Each form is presented with step-by-step instructions. States should modify these forms to fit their needs.

States can use the **EXAMPLE SYSTEM REQUEST FORM** to gather information from each water system requesting an exemption. Systems needing exemptions will generally have limited technical, financial, and managerial capacity.

Therefore, States and technical assistance providers may wish to make a special effort to alert systems to the potential availability of exemptions and to assist them in completing applications such as the one discussed below.

States can use the **EXAMPLE STATE DETERMINATION FORM** to determine whether a system should be granted an exemption (and if necessary, an extension). The form allows the State to quickly document each eligibility assessment.

FORM #1: EXAMPLE SYSTEM REQUEST FORM PAGE 1 OF 2

1 System Name:	**2 PWSID:**
3 Contact Person:	**4 Phone Number:**

5 Address:
6 Date System Began Operating:
7 Have you received a variance for arsenic? YES NO
8 What is the range of arsenic levels in your finished water? High: Low:
9 Summarize your treatment process:
10 Arsenic treatment options considered:
11 Current water rate structure:
12 Does the system have a certified operator? YES NO
13 What steps have you taken to meet the MCL?
14 What capital improvements are needed?
15 Why can't these improvements be made before 1/23/06?
16 If financial assistance is needed, which of the following describes your system (include documentation):

- **You have entered into an agreement to get the financial assistance**

YES
NO

- **You are reasonably likely to get financial assistance from a Federal or State source**

YES
NO

17 Assistance Source: DWSRF RUS Other:

Date Applied: **Contact:**

18 Have you entered into an enforceable agreement to become part of a regional PWS?
YES
NO
19 How much time do you need to:

- secure funding
- finish the capital improvement(s)
- begin operating in compliance with the revised MCL

Total time needed to come into compliance

20 If you will begin operation after 1/23/06, why can't your system use another source of drinking water with lower arsenic levels?

Submitted by: ______________________________ Date: ________________________

Please use the space below to provide any other information that you would like the State to know when considering your request:
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System Request Form Instruction & Notes

Although the State should have system contact information on file, it is useful to have the most current information possible. This is particularly beneficial if someone besides the normal system contact is handling the exemption request.

Although the State will likely know when every system began operating, it is useful to verify this date. Systems that begin operations after January 23, 2002 must meet an additional eligibility requirement to receive an exemption.

Systems that have received a small system variance for arsenic are not eligible for an exemption. Currently, such variances cannot be granted.

Most systems should be able to provide a range of arsenic levels in their finished water from monitoring results for the current MCL. Systems that lack arsenic data should conduct sampling before applying for an exemption. The State will use these data to make its unreasonable risk to health determination.

The State can use the information about a system's treatment process and finished water arsenic levels to understand the treatment options available to a system. Using this information, the State may be able to suggest a low-cost strategy for modifying the treatment process or may determine that treatment modifications by January 23, 2006 are not feasible and affordable.

The State can use this information to ensure that systems have considered all reasonable arsenic compliance options. The State may be able to suggest strategies the system did not consider.

Information about the system's current water rate structure allows the State to determine whether there are feasible water rate changes that would result in compliance or improve water quality.

The State can use this information to determine whether the system is in compliance with the State's operator certification requirements, and to determine whether the appointment of a certified operator would result in compliance or improve water quality.

States can use this information to verify that the system is taking all practicable steps to comply with the revised MCL by January 23, 2006.

This information helps the State identify whether capital improvements are required.

The State must determine that these capital improvements cannot be completed before January 23, 2006 for the system to be eligible for an exemption.

If a system needs financial assistance to complete the necessary capital improvements, it must either have entered into an agreement (public or private) to get the assistance, or it must be reasonably likely to get the assistance from a federal or State source during the period of the exemption. The Drinking Water State Revolving Fund (**DWSRF**) and the Rural Utilities Service (**RUS**) are major sources of financial assistance.
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Other sources include Community Block Grants through Housing and Urban Development Assistance and other State programs.

The system should include documentation that supports its claim, such as a letter from the State identifying the system's position on the DWSRF priority list.

If financial assistance is needed, the system should identify the source of assistance, the date the system applied for assistance, and the system's contact in the assistance organization. This information will allow the State to determine whether the system is eligible for receiving an exemption.

Alternatively, a system may choose to enter into an "***enforceable agreement***" to become part of a regional PWS.

States should work with each system receiving an exemption to develop realistic compliance schedules that require compliance as "***expeditiously as practicable***."

Systems should provide an estimate of the time they need to secure funding, finish the needed capital improvement(s), and begin operating in compliance with the revised MCL. States can use these estimates, along with their understanding of similar capital improvement projects, to develop realistic compliance schedules for the systems.

The State can use this information as a basis for determining whether a system that began operating after January 23, 2006 is eligible for an exemption. These systems are eligible for an exemption only if they can demonstrate that another source of drinking water with lower arsenic levels cannot reasonably be found.

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FORM #2: Example State Determination Form PAGE 1 OF 3

1 SYSTEM NAME	**6 DATE BEGAN OPERATING**
2 POP. SERVED PWSID	**7 REQUEST DATE**
3 SYSTEM CONTACT	**8 DATE GRANTED**
4 PHONE NUMBER	**9 PUBLIC HEARING DATE**
5 CONTACT ADDRESS	**10 EXEMPTION COMPLIANCE DATE**

ELIGIBILITY DETERMINATION
CRITERIA INFORMATION SOURCE

11 Are there compelling factors that will prevent the system from complying by 1/23/06?
YES NO* Sanitary Survey DWSRF Application Capacity Assessment Exemption Request Other:
12 Did the system begin operating before 2/22/02? YES NO
(see 12a)
Sanitary Survey DWSRF Application Capacity Assessment
Exemption Request Other:
12a. If the system began operating after 2/22/02, does the system have a reasonable alternative source of drinking water?
YES* NO Sanitary Survey DWSRF Application Capacity Assessment
Exemption Request Other:
13 What is the system's high value for arsenic in finished water (in pb)?
Sanitary Survey DWSRF Application Capacity Assessment
Exemption Request Other:
How many years will it take the system to achieve compliance(from 1/2001)?
Sanitary Survey DWSRF Application Capacity Assessment
Exemption Request Other:
What is the product of the high arsenic value minus 10 and the years until compliance (in ppb x years)?

14 Can the system reasonably make any of the following changes with the result being compliance or improved water quality?**
YES* NO Sanitary Survey DWSRF Application Capacity Assessment
Exemption Request Other:

- Rate Increases
- Accounting Changes
- Appointment of State-certified Operator
- Joint Operation
- Capacity Development Activities
- Ownership Changes
- Consolidation

15 DETERMINATION
YES – SYSTEM IS ELIGIBLE
NO – SYSTEM IS NOT ELIGIBLE
* System is not eligible for an exemption. **Given the potential availability of federal and State financial assistance.

APPROVAL DETERMINATION CRITERIA INFORMATION SOURCE PAGE 2 OF 3

16 Has the system received a small system variance for the arsenic standard?
YES* NO Sanitary Survey WSRF Application Capacity Assessment
Exemption Request Other:

17 Is the system taking all practicable steps to meet the MCL?
YES NO* Sanitary Survey DWSRF Application Capacity Assessment
Exemption Request Other:

18a Does the system need to make capital improvements that cannot be completed before /23/06?
YES NO* Sanitary Survey DWSRF Application Capacity Assessment
Exemption Request Other:

18b Does the system need financial assistance for capital improvements?
YES (see 18c)
NO (skip to 20)

18c Is one of the following true:
- The system agreed to become part of a regional PWS?
- The system is reasonably likely to get financial assistance during the exemption?

YES (see 19)
NO* Sanitary Survey DWSRF Application Capacity Assessment
Exemption Request Other:

19 Financial assistance information. Source: DWSRF RUS Other:

Date Applied: **Source Contact:**

20 DETERMINATION YES – EXEMPTION GRANTED NO – EXEMPTION DENIED
* System is not eligible for an exemption.

Approved by: ____________________________________ Date: _________________

FORM #2: Example State Determination Form PAGE 3 OF 3

EXEMPTION EXTENSION
CRITERIA INFORMATION SOURCE

21 Has the system qualified for a 3 year exemption? YES NO***

22 Does the system serve fewer than 3,300 people? YES NO***

23 Does the system need financial assistance? YES NO***

24 Has the system agreed to become part of a regional PWS? YES*** NO

25 DETERMINATION YES – EXTENSION APPROVED NO – EXTENSION DENIED

If yes, how many extensions and for how many total years
(not to exceed 6): Extensions Years
*** System is not eligible for an extension.

Approved by: ____________________________________ **Date:** _________________
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Arsenic Treatment Methods

Brake Fern
A Phytoremediation method.

Hyperaccumulating ferns have been used in the remediation of arsenic-contaminated soil, waste, and water. The fern can tolerate as much as 1,500 parts per million (ppm) of arsenic in soil, and can have a bioconcentration factor up to 265. The arsenic concentration in the plant can be as high as 2 percent (dry weight) (Ref. 15.3, 15.6).

Who Needs to Know about Arsenic Treatment Technologies?

This course was prepared to provide information on the current state of arsenic treatment for soil, waste, and water.

The course may be used to:

- Identify proven and effective arsenic treatment technologies.
- Screen those technologies based on effectiveness, treatment goals, application-specific characteristics, and cost.
- Apply experience from sites with similar treatment challenges.
- Find more detailed arsenic treatment information.

This course may be used by remediation site managers, hazardous waste generators (for example, wood treaters, herbicide manufacturers, mine and landfill operators), drinking water treatment plant designers and operators, and the general public to help screen arsenic treatment options.

Arsenic is a common inorganic element found widely in the environment. It is in many industrial products, wastes, and wastewaters, and is a contaminant of concern at many remediation sites.

Arsenic contaminated soil, waste, and water must be treated by removing the arsenic or immobilizing it.

Because arsenic readily changes valence states and reacts to form species with varying toxicity and mobility, effective, long-term treatment of arsenic can be difficult.

In some disposal environments arsenic has leached from arsenic-bearing wastes at high concentrations (Ref. 2.11). Recently, the EPA reduced the maximum contaminant level (**MCL**) for arsenic in drinking water from 0.050 mg/L to 0.010 mg/L, effective in 2006 (Ref. 2.9).

Drinking water suppliers may need to add new treatment processes or retrofit existing treatment systems to meet the revised MCL. In addition, it may affect Superfund remediation sites and other sites that base cleanup goals on the arsenic drinking water MCL.

This course provides information needed to help meet the challenges of arsenic treatment.

2.2 Background

Where Does Arsenic Come From?

Arsenic occurs naturally in rocks, soil, water, air, plants, and animals.

Natural activities such as volcanic action, erosion of rocks, and forest fires, can release arsenic into the environment. Industrial products containing arsenic include wood preservatives, paints, environment include mining and smelting operations; agricultural applications; burning of fossil fuels and wastes; pulp and paper production; cement manufacturing; and former agricultural uses of arsenic(Ref. 2.1).

What Are the Health Effects of Arsenic?

Many studies document the adverse health effects in humans exposed to inorganic arsenic compounds. A discussion of those effects is available in the following documents:

- National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring (66 FR 6976 /January 22, 2001) (Ref. 2.1)
- The Agency for Toxic Substances and Disease Registry (**ATSDR**) ToxFAQsTM for Arsenic (Ref.2.13).

How Does Arsenic Chemistry Affect Treatment?

Arsenic is a metalloid or inorganic semiconductor that can form inorganic and organic compounds. It occurs with valence states of -3, 0, +3 (arsenite), and +5 (arsenate).

However, the valence states of -3 and 0 occur only rarely in nature. This discussion of arsenic chemistry focuses on inorganic species of As(III) and As(V).

Inorganic compounds of arsenic include hydrides (e.g., arsine), halides, oxides, acids, and sulfides (Ref. 2.4).

The toxicity and mobility of arsenic varies with its valence state and chemical form. Arsenite and arsenate are the dominant species in surface water and sea water, and organic arsenic species can be found in natural gas and shale oil (Ref. 2.12).

Different chemical compounds containing arsenic exhibit varying degrees of toxicity and solubility.

Arsenic readily changes its valence state and chemical form in the environment. Some conditions that may affect arsenic valence and speciation include (Ref. 2.7):

- pH - in the pH range of 4 to 10, As(V) species are negatively charged in water, and the predominant As(III) species is neutral in charge
- redox potential
- the presence of complexing ions, such as ions of sulfur, iron, and calcium
- microbial activity

Adsorption-desorption reactions can also affect the mobility of arsenic in the environment. Clays, carbonaceous materials, and oxides of iron, aluminum, and manganese are soil components that may participate in adsorptive reactions with arsenic (Ref. 2.7).The unstable nature of arsenic species may make it difficult to treat or result in treated wastes whose toxicity and mobility can change under some environmental conditions. Therefore, the successful treatment and long-term disposal of arsenic requires an understanding of arsenic chemistry and the disposal environment.

How Often Does Arsenic Occur in Drinking Water?

Arsenic is a fairly common environmental contaminant.

Both groundwater (e.g., aquifers) and surface water (e.g., lakes and rivers) sources of drinking water can contain arsenic. The levels of arsenic are typically higher in groundwater sources.

Arsenic levels in groundwater tend to vary geographically. In the U.S., Western states (AK, AZ, CA, ID, NV, OR, UT, and WA) tend to have the highest concentrations (>0.010 mg/L), while states in the North Central (MT, ND, SD, WY), Midwest Central (IL, IN, IA, MI, MN, OH, and WI), and New England (CT, MA, ME, NH, NJ, NY, RI, and VT) regions tend to have low to moderate concentrations (0.002 to 0.010 mg/L).

However, some portions of these areas may have no detected arsenic in drinking water.

Other regions of the U.S. may have isolated areas of high concentration. The EPA estimates that 4,000 drinking water treatment systems may require additional treatment technologies, a retrofit of existing treatment technologies, or other measures to achieve the revised MCL for arsenic.

An estimated 5.4% of community water systems (**CWSs**) using groundwater as a drinking water source and 0.7% of CWSs using surface water have average arsenic levels above 0.010 mg/L. (Ref. 2.1)

How Often Does Arsenic Occur at Hazardous Waste Sites?

Hazardous waste sites fall under several clean-up programs, such as Superfund, Resource Conservation and Recovery Act (**RCRA**) corrective actions, and state cleanup programs.

This section contains information on the occurrence and treatment of arsenic at National Priorities List (**NPL**) sites, known as Superfund sites. Information on arsenic occurrence and treatment at Superfund sites was complied from the CERCLIS 3 database (Ref. 2.3), the Superfund NPL Assessment Program (**SNAP**) database, and the database supporting the document "***Treatment Technologies for Site Cleanup: Annual Status Course (Tenth Edition)***" (Ref.2.8).

The information sources identified for this course does not contain information on arsenic occurrence and treatment at RCRA corrective action and state cleanup program sites.

Table 2.1 lists the number of Superfund sites with arsenic as a contaminant of concern by media.

Groundwater and soil were the most common media contaminated with arsenic at 380 and 372 sites, respectively.

The number of sites in Table 2.1 exceeds the number of total sites with arsenic contamination (568) because each site may have more than one type of media contaminated with arsenic.

Table 2.1
Number of Superfund Sites with Arsenic as a Contaminant of Concern by Media

Media Type	Number of Sites
Groundwater	380
Soil	372
Sediment	154
Surface Water	86
Debris	77
Sludge	45
Solid Waste	30
Leachate	24
Other	21
Liquid Waste	12
Air	8
Residuals	1

Source: Ref. 2.3

Arsenic occurs frequently at NPL sites. Figure 2.1 shows the most common contaminants of concern present at Superfund sites for which a Record of Decision (**ROD**) has been signed, through FY 1999, the most recent year for which such information is available.

Arsenic is the second most common contaminant of concern (after lead), occurring at 568 sites (47% of all sites on the NPL with RODs).

Table 2.2
Number of Superfund Sites with Arsenic as a Contaminant of Concern by Site

Landfills and Other Disposal	209
Chemicals and Allied Products	42
Lumber and Wood Products	33
Groundwater Plume Site	26
Metal Fabrication and Finishing	20
Batteries and Scrap Metal	18
Military and Other Ordnance	18
Transportation Equipment	15
Primary Metals Processing	14
Chemicals and Chemical Waste	12
Ordnance Production	12
Electrical Equipment	11
Radioactive Products	9
Product Storage and Distribution	8
Waste Oil and Used Oil	8
Metals	6
Drums and Tanks	6
Transportation	5
Research and Development	5
Other a	104

Sources: Ref. 2.3, 2.15

a Includes site types with fewer than 5 sites, sites whose site types were identified as "other" or "multiple", and unspecified industrial waste facilities.
b Some sites have more than one site type.

Different Arsenic Treatment Technologies

- Phytoremediation
- Electrokinetics
- Biological Treatment
- Permeable Reactive Barriers
- Ion Exchange
- Adsorption
- Membrane Filtration
- Precipitation/Coprecipitation
- In Situ Soil Flushing
- Pyrometallurgical Recovery
- Soil Washing/Acid Extraction
- Vitrification
- Solidification/Stabilization

Number of Applications of Arsenic Treatment Technologies at Superfund Sites
Information on the application of groundwater pumps and treatment technologies, including precipitation/coprecipitation, membrane filtration, adsorption, and ion exchange, is based on available data and is not comprehensive.

Methodology
This Introduction describes the purpose of the report, presents background information, and summarizes the methodology used to gather and analyze data.

Each technology described includes a brief description of the technology, information about how it is used to treat arsenic, its status and scale, and available cost and performance data, including the amount and type of soil, waste, and water treated and a summary of the results of analyses of untreated soil, waste, and water and treatment residuals for total and leachable arsenic concentrations.

The technology summaries are organized as follows: the technologies typically used to treat soil and waste appear first, in the order of their frequency of full-scale applications, followed by those typically used for water in the same order, and then by those used to treat soil, waste, and water.

These technologies have been used at full scale for the treatment of arsenic in soil, waste, and water. For the purposes of this report, the term "***soil***" includes soil, debris, sludge, sediments, and other solid-phase environmental media.

Waste includes nonhazardous and hazardous solid waste generated by industry. Water includes groundwater, drinking water, non-hazardous and hazardous industrial wastewater, surface water, mine drainage, and leachate.

Treatment Trains
Treatment trains consist of two or more technologies used together, either integrated into a single process or operated as a series of treatments in sequence.

The technologies in a train may treat the same contaminant. The information gathered for this report included many projects that used treatment trains.

A common treatment train used for arsenic in water includes an oxidation step to change arsenic from As(III) to its less soluble As(V) state, followed by precipitation/ coprecipitation and filtration to remove the precipitate.

Some trains are employed when one technology alone is not capable of treating all of the contaminants. For example, at the Baird and McGuire Superfund Site (Table 9.1), an above-ground system consisting of air stripping, metals precipitation, and activated carbon adsorption was used to treat groundwater contaminated with volatile organic compounds (**VOCs**), arsenic, and semivolatile organic compounds (**SVOCs**). In this treatment train the air stripping was intended to treat VOCs; the precipitation, arsenic; and the activated carbon adsorption, SVOCs and any remaining VOCs.

In many cases, the available information does not specify the technologies within the train that are intended to treat arsenic. Influent and effluent concentrations, where available, often were provided for the entire train, and not the individual components.

In such cases, engineering judgment was used to identify the technology that treated arsenic.

For example, at the Greenwood Chemical Superfund site a treatment train consisting of metals precipitation, filtration, UV oxidation and carbon adsorption was used to treat groundwater contaminated with arsenic, VOCs, halogenated VOCs, and SVOCs.

The precipitation and filtration were assumed to remove arsenic, and the UV oxidation and carbon adsorption were assumed to have only a negligible effect on the arsenic concentration.

Where a train included more than one potential arsenic treatment technology, all arsenic treatment technologies were assumed to contribute to arsenic treatment, unless available information indicated otherwise.

For example, at the Higgins Farm Superfund site, arsenic contaminated groundwater was treated with precipitation and ion exchange.

Activated carbon adsorption is most commonly used to treat organic contaminants.

This technology is generally ineffective on As(III) (Ref. 2.14). Where treatment trains included activated carbon adsorption and another arsenic treatment technology, it was assumed that activated carbon adsorption did not contribute to the arsenic treatment, unless the available information indicated otherwise.

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Comparison of Arsenic Treatment Technologies

What Technologies Are Used to Treat Arsenic?

This section identifies 13 technologies applicable to arsenic-contaminated soil, waste, and water. Technologies are considered applicable if they have been used at full scale to treat arsenic.

The media treated by these technologies can be grouped into two general categories: soil and waste; and water.

Technologies applicable to one type of soil and waste are typically applicable to other types. For example, solidification/stabilization has been used to effectively treat industrial waste, soil, sludge, and sediment.

Similarly, technologies applicable to one type of water are generally applicable to other types. For example, precipitation/coprecipitation has been used to effectively treat industrial wastewaters, groundwater, and drinking water.

Arsenic Treatment Technologies

Soil and Waste Treatment Technologies

- Solidification/Stabilization
- Vitrification
- Soil Washing/Acid Extraction
- Pyrometallurgical Recovery
- In Situ Soil Flushing

Water Treatment Technologies

- Precipitation/Coprecipitation
- Membrane Filtration
- Adsorption
- Ion Exchange
- Permeable Reactive Barriers

Soil, Waste, and Water Treatment Technologies

- Electrokinetics
- Phytoremediation
- Biological Treatment

What Technologies Are Used Most Often to Treat Arsenic?

This section provides information on the number of treatment projects identified for each technology and estimates of the relative frequency of their application.

The most frequently used technology for soil and waste containing arsenic is solidification/stabilization. The available data show that this technology can effectively meet regulatory cleanup levels, is commercially available to treat both soil and waste, is usually less expensive, and generates a residual that typically does not require further treatment prior to disposal.

Other arsenic treatment technologies for soil and waste are typically used for specific applications.

Vitrification may be used when a combination of contaminants are present that cannot be effectively treated using solidification/stabilization. It has also been used when the vitrification residual could be sold as a commercial product.

However, vitrification typically requires large amounts of energy, can be more expensive than S/S, and may generate off-gasses containing arsenic.

Soil washing/acid extraction is used primarily to treat soil. However, it is not applicable to all types of soil or to waste.

Pyrometallurgical treatment has been used primarily to recycle arsenic from industrial wastes containing high concentrations of arsenic from metals refining and smelting operations. These technologies may not be applicable to soil and waste containing low concentrations of arsenic. In situ soil flushing treats soil in place, eliminating the need to excavate soil.

However, no performance data were identified for the limited number of full-scale applications of this technology to arsenic.

For water containing arsenic, the most frequently used technology is precipitation/coprecipitation. Based on the information gathered for this report, precipitation/coprecipitation is frequently used to treat arsenic contaminated water, and is capable of treating a wide range of influent concentrations to the revised MCL for arsenic.

The effectiveness of this technology is less likely to be reduced by characteristics and contaminants other than arsenic, compared to other water treatment technologies. It is also capable of treating water characteristics or contaminants other than arsenic, such as hardness or heavy metals.

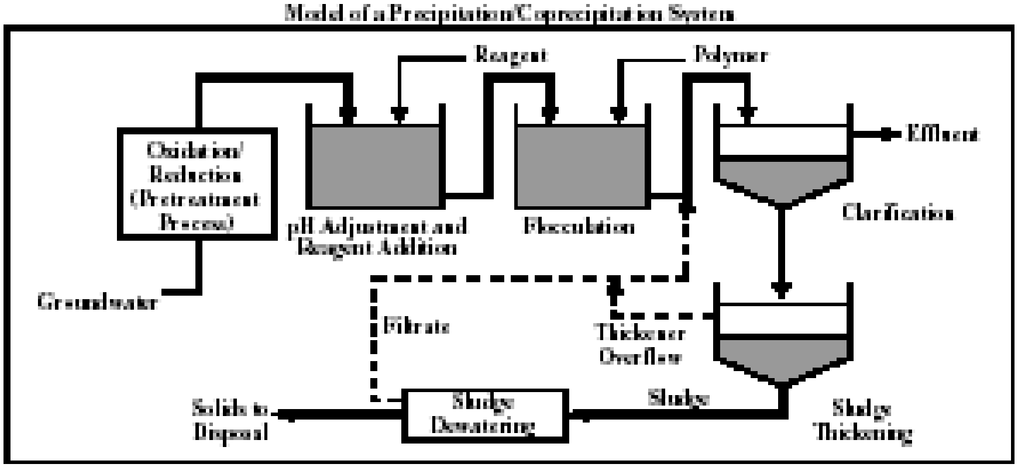
Systems using this technology generally require skilled operators; therefore, precipitation/ coprecipitation is more cost effective at a large scale where labor costs can be spread over a larger amount of treated water produced.

The effectiveness of adsorption and ion exchange for arsenic treatment is more likely than precipitation/coprecipitation to be affected by characteristics and contaminants other than arsenic.

Precipitation/Coprecipitation Process

- **Oxidation/Reduction**
- **(Pretreatment Process)**
- **Groundwater Solids to**
- **Disposal**
- **Sludge**
- **Dewatering**
- **Filtrate**
- **Sludge Sludge**
- **Thickening**
- **Thickener**
- **Overflow**
- **Flocculation pH Adjustment and**
- **Reagent Addition**
- **Polymer Reagent**
- **Effluent**
- **Clarification**

Model of a Precipitation/Coprecipitation System



Precipitation/coprecipitation has been the most frequently used method to treat arsenic contaminated water, including groundwater, surface water, leachate, mine drainage, drinking water, and wastewater in numerous pilot- and full-scale applications. Based on the information collected to prepare this report, this technology typically can reduce arsenic concentrations to less than 0.050 mg/L and in some cases has reduced arsenic concentrations to below 0.010 mg/L.

Technology Description: Precipitation uses chemicals to transform dissolved contaminants into an insoluble solid. In coprecipitation, the target contaminant may be dissolved or in a colloidal or suspended form.

Dissolved contaminants do not precipitate, but are adsorbed onto another species that is precipitated.

Colloidal or suspended contaminants become enmeshed with other precipitated species, or are removed through processes such as coagulation and flocculation.

Many processes to remove arsenic from water involve a combination of precipitation and coprecipitation. The precipitated/coprecipitated solid is then removed from the liquid phase by clarification or filtration. Arsenic precipitation/coprecipitation can use combinations of the chemicals and methods listed below.

Media Treated:
- Drinking water
- Groundwater
- Wastewater
- Surface water
- Leachate
- Mine drainage

Chemicals and Methods Used for Arsenic Precipitation/Coprecipitation:
- Ferric salts, (e.g., ferric chloride), ferric sulfate, ferric hydroxide
- Ammonium sulfate
- Alum (aluminum hydroxide)
- pH adjustment
- Lime softening, limestone, calcium hydroxide
- Manganese sulfate
- Copper sulfate
- Sulfide

Technology Description and Principles
For this report, technologies were considered precipitation/coprecipitation if they involved the following steps:
- Mixing of treatment chemicals into the water
- Formation of a solid matrix through precipitation, coprecipitation, or a combination of these processes, and
- Separation of the solid matrix from the water

Technologies that remove arsenic by passing it through a fixed bed of media, where the arsenic may be removed through adsorption, precipitation/coprecipitation, or a combination of these processes, are discussed in the adsorption treatment section.

Precipitation/coprecipitation usually involves pH adjustment and addition of a chemical precipitant or coagulant; it can also include addition of a chemical oxidant. Oxidation of arsenic to its less soluble As(V) state can increase the effectiveness of precipitation/coprecipitation processes, and can be done as a separate pretreatment step or as part of the precipitation process. Some pretreatment processes that oxidize As(III) to As(V) include ozonation, photo oxidation, or the addition of oxidizing chemicals such as potassium permanganate, sodium hypochlorite, or hydrogen peroxide.

Clarification or filtration is commonly used to remove the solid precipitate. Precipitation/coprecipitation is frequently used to treat water contaminated with metals.

The references identified for this report contained information on its application to industrial wastewater, groundwater, surface water, leachate, and mine drainage.

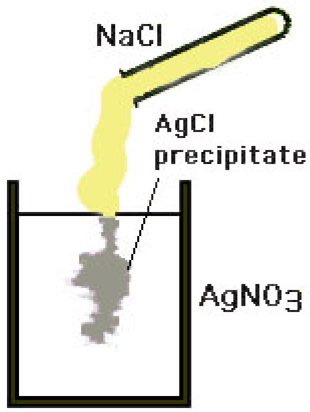
Precipitation/Coprecipitation Chemistry

Precipitation Reactions

A **precipitate** is a solid that forms out of solution.

A common example of a precipitation reaction happens when mixing the following two clear solutions:

(1) silver nitrate ($AgNO_3$)
and
(2) sodium chloride (NaCl)



The chemical equation for this reaction is ...

$$AgNO_3 + NaCl \longrightarrow AgCl + NaNO_3$$

The precipitate forms because the solid product of the reaction (**AgCl**) is ***insoluble*** in water.

That is true for all precipitates - the solids are insoluble in aqueous solutions.

Precipitation reactions occur all around us. For example, sometimes the pipes in our homes get clogged because precipitates of magnesium and calcium oxides have deposited themselves within the pipes. This can happen with "***hard***" water.

Another example is a kidney stone. A kidney stone is nothing more than a precipitate - often of calcium ions (from cheese) and oxalates. It is often suggested that a good way to avoid kidney stones is to drink a lot of water. This helps because the solubility of the precipitate increases with the amount of water - thus avoiding the formation of the kidney stone to begin with.

Complex

The chemistry of precipitation/coprecipitation is often complex, and depends upon a variety of factors, including the speciation of arsenic, the chemical precipitants used and their concentrations, the pH of the water, and the presence of other chemicals in the water to be treated. As a result, the particular mechanism that results in the removal of arsenic through precipitation/coprecipitation treatment is process-specific, and in some cases is not completely understood.

For example, the removal mechanism in the treatment of As(V) with Fe(III) has been debated in the technical literature.

It is beyond the scope of this course to provide all possible chemical reactions and mechanisms for precipitation/coprecipitation processes that are used to remove arsenic. More detailed information on the chemistry involved in specific processes can be found in the references listed at the end of this section.

The effectiveness of this technology can be evaluated by comparing influent and effluent contaminant concentrations. All of the 12 environmental media projects for which both influent and effluent arsenic concentration data were available had influent concentrations greater than 0.050 mg/L.

The treatments achieved effluent concentrations of less than 0.050 mg/L in eight of the projects and less than 0.010 mg/L in four of the projects. Information on the leachability of arsenic from the precipitates and sludges was available for three projects. For all of these projects, the concentration of leachable arsenic as measured by the toxicity characteristic leaching procedure (**TCLP**) (the RCRA regulatory threshold for identifying a waste that is hazardous because it exhibits the characteristic of toxicity for arsenic) was below 5.0 mg/L.

Factors Affecting Precipitation/Coprecipitation Performance

• **Valence state of arsenic** - The presence of the more soluble trivalent state of arsenic may reduce the removal efficiency. The solubility of arsenic depends upon its valence state, pH, the specific arsenic compound, and the presence of other chemicals with which arsenic might react (Ref. 9.12). Oxidation to As(V) could improve arsenic removal through precipitation/coprecipitation (Ref. 9.7).

• **pH** - In general, arsenic removal will be maximized at the pH at which the precipitated species is least soluble. The optimal pH range for precipitation/coprecipitation depends upon the waste treated and the specific treatment process (Ref. 9.7).

• **Presence of other compounds** - The presence of other metals or contaminants may impact the effectiveness of precipitation/coprecipitation. For example, sulfate could decrease arsenic removal in processes using ferric chloride as a coagulant, while the presence of calcium or iron may increase the removal of arsenic in these processes (Ref. 9.7).

A Bangladeshi shows the lesions from arsenicosis
(photo by WPI/M. Smith-Nilson)

Case Study: Winthrop Landfill Site

The Winthrop Landfill Site, located in Winthrop, Maine, is a former dump site that accepted municipal and industrial wastes. Groundwater at the site was contaminated with arsenic and chlorinated and nonchlorinated VOCs.

A pump-and-treat system for the groundwater has been in operation at the site since 1995.

Organic compounds have been remediated to below action levels, and the pump and-treat system is currently being operated for the removal of arsenic alone. The treatment train consists of equalization/pH adjustment to pH 3, chemical oxidation with hydrogen peroxide, precipitation/coprecipitation via pH adjustment to PH 7,flocculation/clarification, and sand bed filtration.

It treats 65 gallons per minute of groundwater containing average arsenic concentrations of 0.3 mg/L to below 0.005 mg/L.

Through May, 2001, 359 pounds of arsenic had been removed from groundwater at the Winthrop Landfill Site using this above ground treatment system. Capital costs for the system were about $2 million, and O&M costs are approximately $250,000 per year (Ref. 9.29, cost year not provided).

Of the 12 drinking water projects having both influent and effluent arsenic concentration data, eight had influent concentrations greater than 0.050 mg/L. The treatments achieved effluent concentrations of less than 0.050 mg/L in all eight of these projects, and less than 0.010 mg/L in two projects. Information on the leachability of arsenic from the precipitates and sludges was available for six projects. For these projects the leachable concentration of arsenic was below 5.0 mg/L.

All of the 28 wastewater projects having both influent and effluent arsenic concentration data had influent concentrations greater than 0.050 mg/L. The treatments achieved effluent concentrations of less than 0.050 mg/L in 16 of these projects, and less than 0.010 mg/L in 11 projects. Information on the leachability of arsenic from the precipitates and sludges was available for four projects.

Only one of these projects had a leachable concentration of arsenic below 5.0 mg/L. Projects that did not reduce effluent arsenic concentrations to below 0.050 or 0.010 mg/L do not necessarily indicate that precipitation/coprecipitation cannot achieve these levels. The treatment goal for some applications could have been above these concentrations, and the technology may have been designed and operated to meet a higher concentration.

Some projects will include treatment trains, the most common being precipitation/coprecipitation followed by activated carbon adsorption or membrane filtration. In those cases, the performance data listed are for the entire treatment train, not just the precipitation/coprecipitation step. The case study in this section discusses in greater detail the removal of arsenic from groundwater using an aboveground treatment system at the Winthrop Landfill Superfund site.

Applicability, Advantages, and Potential Limitations

Precipitation/coprecipitation is an active ex situ treatment technology designed to function with routine chemical addition and sludge removal. It usually generates a sludge residual, which typically requires treatment such as dewatering and subsequent disposal.

Some sludge from the precipitation/coprecipitation of arsenic can be a hazardous waste and require additional treatment such as solidification/stabilization prior to disposal. In the presence of other metals or contaminants, arsenic precipitation/coprecipitation processes may also cause other compounds to precipitate, which can render the resulting sludge hazardous (Ref. 9.7). The effluent may also require further treatment, such as pH adjustment, prior to discharge or reuse.

Factors Affecting Precipitation/Coprecipitation Costs

- **Type of chemical addition** - The chemical added will affect costs. For example, calcium hypochlorite, is a less expensive oxidant than potassium permanganate (Ref. 9.16).
- **Chemical dosage** - The cost generally increases with increased chemical addition.

Larger amounts of chemicals added usually results in a larger amount of sludge requiring additional treatment or disposal (Ref. 9.7, 9.12).

- **Treatment goal** - Application could require additional treatment to meet stringent cleanup goals and/or effluent and disposal standards(Ref. 9.7)
- **Sludge disposal** - Sludge produced from the precipitation/coprecipitation process could be considered a hazardous waste and require additional treatment before disposal, or disposal as hazardous waste (Ref. 9.7).

More detailed information on selection and design of arsenic treatment systems for small drinking water systems is available in the document "***Arsenic Treatment Technology Design Manual for Small Systems*** " (Ref. 9.36).

Summary of Cost Data

Limited cost data are currently available for precipitation/coprecipitation treatment of arsenic. At the Winthrop Landfill Site (Project 1), groundwater containing arsenic, 1,1-dichloroethane, and vinyl chloride is being pumped and treated above ground through a treatment train that includes precipitation.

The total capital cost of this treatment system was $2 million ($1.8 million for construction and $0.2 million for design). O&M costs were about $350,000 per year for the first few years and are now approximately $250,000 per year. The treatment system has a capacity of 65 gpm.

However, these costs are for the entire treatment train (Ref. 9.29, cost year not provided). At the power substation in Fort Walton, Florida, the reported O&M cost was $0.006 per gallon (for the entire treatment train, Ref 9.32, cost year not provided). Capital cost information was not provided.

A low-cost, point-of-use precipitation/coprecipitation treatment designed for use in developing nations with arsenic-contaminated drinking water was pilot-tested in four areas of Bangladesh (Project 31). This simple treatment process consists of a two-bucket system that uses potassium permanganate and alum to precipitate arsenic, followed by sedimentation and filtration.

The equipment cost of the project was approximately $6, and treatment of 40 liters of water daily would require a monthly chemical cost of $0.20 (Ref. 9.22, cost year not provided).

The document "***Technologies and Costs for Removal of Arsenic From Drinking Water*"** (Ref. 9.7) contains more information on the cost of systems to treat arsenic in drinking water to below the revised MCL of 0.010 mg/L.

The document includes capital and O&M cost curves for three precipitation/coprecipitation processes:

- Enhanced coagulation/filtration
- Enhanced lime softening
- Coagulation assisted microfiltration

These cost curves are based on computer cost models for drinking water treatment systems. The cost information available for enhanced coagulation/ filtration and enhanced lime softening are for retrofitting existing precipitation/coprecipitation systems at drinking water treatment plants to meet the revised MCL.

Therefore, the cost information could not be used to estimate the cost of a new precipitation/coprecipitation treatment system.

The first step in water treatment is softening. Lime is added to the water, resulting in an exothermic reaction and a pH increase to 11.

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Membrane Filtration for Arsenic

Membrane filtration can remove a wide range of contaminants from water. Based on the information collected to prepare this report, this technology typically can reduce arsenic concentrations to less than 0.050 mg/L and in some cases has reduced arsenic concentrations to below 0.010 mg/L.

However, its effectiveness is sensitive to a variety of untreated water contaminants and characteristics. It also produces a larger volume of residuals and tends to be more expensive than other arsenic treatment technologies.

Therefore, it is used less frequently than precipitation/coprecipitation, adsorption, and ion exchange. It is most commonly used to treat groundwater and drinking water, or as a polishing step for precipitation processes. Only two full-scale projects using membrane filtration to treat arsenic were identified in the sources researched for this course.

Technology Description: Membrane filtration separates contaminants from water by passing it through a semi-permeable barrier or membrane. The membrane allows some constituents to pass through, while blocking others (Ref. 10.2, 10.3).

Media Treated:
- Drinking water
- Groundwater
- Surface water
- Industrial wastewater

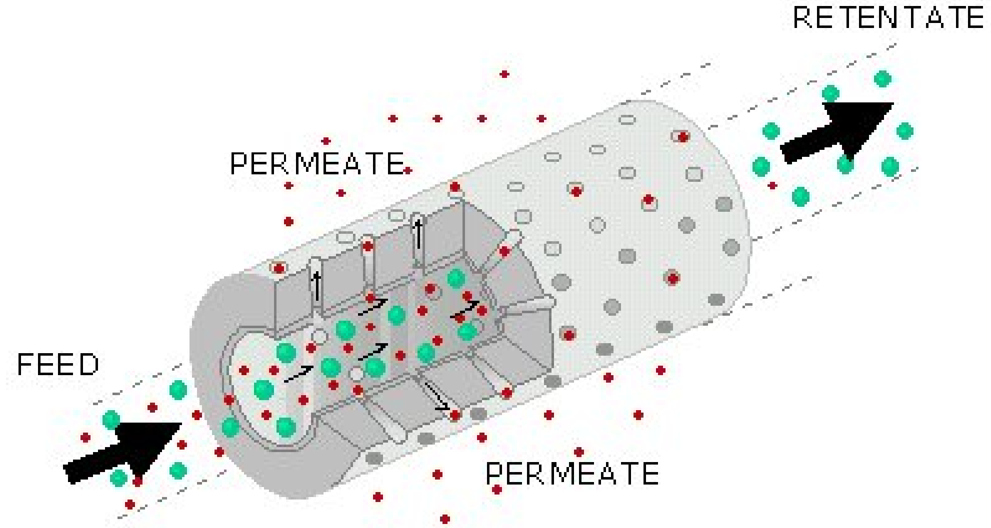
Types of Membrane Processes:
- Microfiltration
- Ultrafiltration
- Nanofiltration
- Reverse osmosis

Technology Description and Principles

There are four types of membrane processes: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). All four of these processes are pressure-driven and are categorized by the size of the particles that can pass through the membranes or by the molecular weight cut off (i.e., pore size) of the membrane (Ref. 10.2). The force required to drive fluid across the membrane depends on the pore size; NF and RO require a relatively high pressure (50 to 150 pounds per square inch [psi]), while MF and UF require lower pressure (5 to 100 psi) (Ref.10.4). The low pressure processes primarily remove contaminants through physical sieving, and the high pressure processes through chemical diffusion across the permeable membrane (Ref. 10.4).

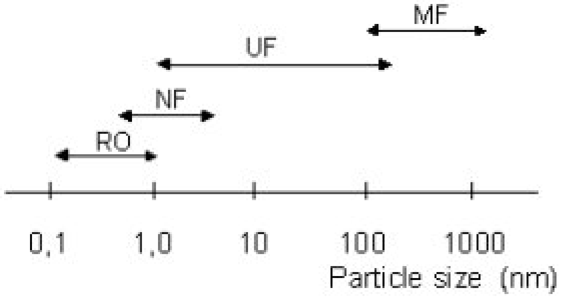
Because arsenic species dissolved in water tend to have relatively low molecular weights, only NF and RO membrane processes are likely to effectively treat dissolved arsenic (Ref. 10.4). MF has been used with precipitation/coprecipitation to remove solids containing arsenic. The sources used for this report did not contain any information on the use of UF to remove arsenic; therefore, UF is not discussed in this technology summary.

Membrane filtration processes
A membrane process is a separating process, in which a feed flow is divided into two flows, either gaseous or liquid. The flow containing the components retained by the membrane is the retentate flow, while the components passing through the membrane form the permeate flow. If the two phases are fluid, then we speak of membrane filtration.



Transport through the membrane is performed by a pressure difference, a concentration difference, a chemical or electrical potential difference as a driving force. The membrane itself forms a semi-permeable barrier through which some particles are transported faster than others, so that a separation occurs.

The pressure driven membrane filtration processes are: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). They differ primarily in the size of the particles to separate and the membranes needed for it.



The smaller the pore size of the membranes, the higher the pressure needed to achieve separation. In the case of microfiltration and ultrafiltration we speak of low pressure processes, while nanofiltration and reverse osmosis are high pressure processes.

The following table gives a summary of the different processes, including pevaporation.

Process	Driving force	Separation principle	Applications
Microfiltration	Pressure difference (0.1 - 1 bar)	filtration	bacteria filter
Ultrafiltration	Pressure difference (0.5 – 10 bar)	filtration	concentrating macromolecular solutions
Nanofiltration	Pressure difference (5 – 20 bar)	filtration/ electrostatic interaction	partial water softening
Reverse osmosis	Pressure difference (8 – 100 bar)	Solution diffusion mechanism	water desalination
Pervaporation	Concentration gradient	Solution diffusion mechanism	separating organic solvents

MF generates two treatment residuals from the influent waste stream: a treated effluent (permeate) and a rejected waste stream of concentrated contaminants (reject).

RO is a high pressure process that primarily removes smaller ions typically associated with total dissolved solids. The molecular weight cut off for RO membranes ranges from 1 to 20,000, which is a significantly lower cut off than for NF membranes. The molecular weight cut off for NF membranes ranges from approximately 150 to 20,000. NF is a high-pressure process that primarily removes larger divalent ions associated with hardness (for example, calcium [Ca], and magnesium [Mg] but not monovalent salts (for example, sodium [Na] and chlorine [Cl]).

NF is slightly less efficient than RO in removing dissolved arsenic from water (Ref. 10.4).

Factors Affecting Membrane Filtration Performance

• **Suspended solids, high molecular weight, dissolved solids, organic compounds, and colloids** - The presence of these constituents in the feed stream may cause membrane fouling.

• **Oxidation state of arsenic -** Prior oxidation of the influent stream to convert As(III) to As(V) will increase arsenic removal; As(V) is generally larger and is captured by the membrane more effectively than As(III).

• **pH -** pH may affect the adsorption of arsenic on the membrane by creating an electrostatic charge on the membrane surface.

• **Temperature** - Low influent stream temperatures decreases membrane flux. Increasing system pressure or increasing the membrane surface area may compensate for low influent stream temperature.

MF is a low-pressure process that primarily removes particles with a molecular weight above 50,000 or a particle size greater than 0.050 micrometers. The pore size of MF membranes is too large to effectively remove dissolved arsenic species, but MF can remove particulates containing arsenic and solids produced by precipitation/ coprecipitation (Ref. 10.4).

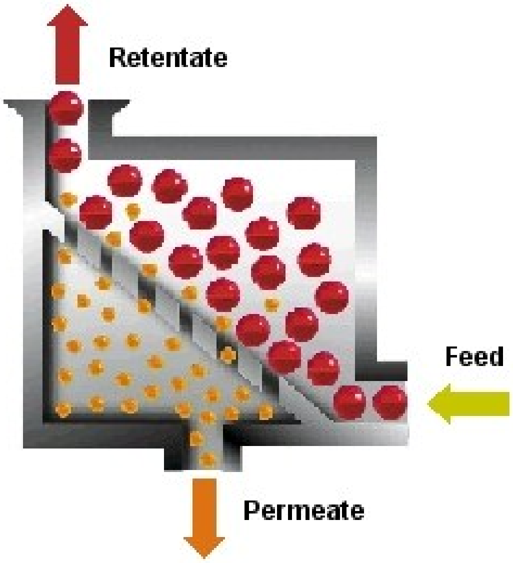
Media and Contaminants Treated
Drinking water, surface water, groundwater, and industrial wastewater can be treated with this technology. Membrane filtration can treat dissolved salts and other dissolved materials (Ref. 10.12).

Summary of Performance Data
Table 10.1 presents the performance data found for this technology. Performance results for membrane filtration are typically reported as percent removal, (i.e., the percentage of arsenic, by mass, in the influent that is removed or rejected from the influent wastewater stream). A higher percentage indicates greater removal of arsenic, and therefore, more effective treatment.

Although many of the projects listed in Table 10.1 may have reduced arsenic concentrations to below 0.05 mg/L or 0.01 mg/L, data on the concentration of arsenic in the effluent and reject streams were not available for most projects.

For two RO projects, the arsenic concentration in the reject stream was available, allowing the concentration in permeate to be calculated.

For both projects, the concentration of arsenic prior to treatment was greater than 0.050 mg/L, and was reduced to less than 0.010 mg/L in the treated water.



For two projects involving removal of solids from precipitation/coprecipitation treatment of arsenic with MF, the arsenic concentration in the permeate was available. The concentration prior to precipitation/coprecipitation treatment was greater than 0.050 mg/L for one project, and ranged from 0.005 to 3.8 mg/L for the other.

For both projects, the concentration in the treated water was less than 0.005 mg/L.

The case study at the end of this section further discusses the use of membrane filtration to remove arsenic from groundwater used as a drinking water source.

Case Study: Park City Spiro Tunnel Water Filtration Plant

The Park City Spiro Tunnel Water Filtration Plant in Park City, Utah treats groundwater from waterbearing fissures that collect in a tunnel of an abandoned silver mine to generate drinking water. A pilot-scale RO unit treated contaminated water at a flow rate of 0.77 gallons per minute (gpm) from the Spiro tunnel for 34 days. The total and dissolved arsenic in the feedwater averaged 0.065 and 0.042 mg/L, respectively. The total and dissolved arsenic concentrations in the permeate averaged <0.0005 and <0.0008 mg/L, respectively.

The RO process reduced As (V) from 0.035 to 0.0005 mg/L and As (III) from 0.007 to 0.0005 mg/L. The membrane achieved 99% total As removal and 98% As (V) removal (Ref. 10.12).

Factors Affecting Membrane Filtration Costs

- Type of membrane filtration - The type of membrane selected may affect the cost of the treatment (Ref. 10.1, 10.2).
- Initial waste stream - Certain waste streams may require pretreatment, which would increase costs (Ref. 10.4).
- Rejected waste stream - Based on concentrations of the removed contaminant, further treatment may be required prior to disposal or discharge (Ref. 10.4).

Applicability, Advantages, and Potential Limitations

Membrane technologies are capable of removing a wide range of dissolved contaminants and suspended solids from water (Ref. 10.12). RO and NF technologies require no chemical addition to ensure adequate separation. This type of treatment may be run in either batch or continuous mode.

This technology's effectiveness is sensitive to a variety of contaminants and characteristics in the untreated water. Suspended solids, organics, colloids, and other contaminants can cause membrane fouling.

Therefore, it is typically applied to groundwater and drinking water, which are less likely to contain fouling contaminants. It is also applied to remove solids from precipitation processes and as a polishing step for other water treatment technologies when lower concentrations must be achieved.

More detailed information on selection and design of arsenic treatment systems for small drinking water systems is available in the document "***Arsenic Treatment Technology Design Manual for Small Systems*** " (Ref. 10.15).

Summary of Cost Data

The research conducted in support of this report did not document any cost data for specific membrane filtration projects to treat for arsenic. The document "***Technologies and Costs for Removal of Arsenic From Drinking Water***" (Ref. 10.4) contains additional information on the cost of point-of-use reverse osmosis systems to treat arsenic in drinking water to levels below the revised MCL of 0.010 mg/L. The document includes capital and O&M cost curves for this technology. These cost curves are based on computer cost models for drinking water treatment systems.

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Adsorption Treatment for Arsenic

Adsorption has been used to treat groundwater and drinking water containing arsenic.

Based on the information collected for this course, this technology typically can reduce arsenic concentrations to less than 0.050 mg/L and in some cases has reduced arsenic concentrations to below 0.010 mg/L. Its effectiveness is sensitive to a variety of untreated water contaminants and characteristics. It is used less frequently than precipitation/coprecipitation, and is most commonly used to treat groundwater and drinking water, or as a polishing step for other water treatment processes.

Technology Description: In adsorption, solutes (contaminants) concentrate at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase. The adsorption media is usually packed into a column. As contaminated water is passed through the column, contaminants are adsorbed. When adsorption sites become filled, the column must be regenerated or disposed of and replaced with new media.

Media Treated:
- Groundwater
- Drinking water

Types of Sorbent Used in Adsorption to Treat Arsenic:
- Activated alumina (AA)
- Activated carbon (AC)
- Copper-zinc granules
- Granular ferric hydroxide, ferric hydroxide coated newspaper pulp, iron oxide coated sand, iron filings mixed with sand
- Greensand filtration ($KMnO_4$ coated glauconite)
- Proprietary media
- Surfactant-modified zeolite

Technology Description and Principles
This section discusses arsenic removal processes that use a fixed bed of media through which water is passed. Some of the processes described in this section rely on a combination of adsorption, precipitation/coprecipitation, ion exchange, and filtration.

However, the primary removal mechanism in each process is adsorption. For example, greensand is made from glauconite, a green, iron-rich, clay-like mineral that usually occurs as small pellets mixed with other sand particles. The glauconite-containing sand is treated with potassium permanganate (**KMnO4**), forming a layer of manganese oxides on the sand.

As water passes through a greensand filtration bed, the KMnO4 oxidizes As(III) to As(V), and As(V) adsorbs onto the greensand surface. In addition, arsenic is removed by ion exchange, displacing species from the manganese oxide (presumably hydroxide ion [OH-] and water [H2O]). When the KMnO4 is exhausted, the greensand media must be regenerated or replaced.

Greensand media is regenerated with a solution of excess KMnO4.Greensand filtration is also known as oxidation/filtration (Ref. 11.3).

Activated alumina (**AA**) is the sorbent most commonly used to remove arsenic from drinking water (Ref. 11.1), and has also been used for groundwater (Ref. 11.4).

The reported adsorption capacity of AA ranges from 0.003 to 0.112 grams of arsenic per gram of AA (Ref. 11.4). It is available in different mesh sizes and its particle size affects contaminant removal efficiency.

Up to 23,400 bed volumes of wastewater can be treated before AA requires regeneration or disposal and replacement with new media (Ref. 11.3). Regeneration is a four-step process:

- Backwashing
- Regeneration
- Neutralization
- Rinsing

The regeneration process desorbs the arsenic. The regeneration fluid most commonly used for AA treatment systems is a solution of sodium hydroxide.

The most commonly used neutralization fluid is a solution of sulfuric acid. The regeneration and neutralization steps for AA adsorption systems might produce a sludge because the alumina can be dissolved by the strong acids and bases used in these processes, forming an aluminum hydroxide precipitate in the spent regeneration and neutralization fluids. This sludge typically contains a high concentration of arsenic (Ref. 11.1).

Activated carbon (**AC**) is an organic sorbent that is commonly used to remove organic and metal contaminants from drinking water, groundwater, and wastewater (Ref. 11.4).

AC media are normally regenerated using thermal techniques to desorb and volatilize contaminants (Ref. 11.6). However, regeneration of AC media used for the removal of arsenic from water might not be feasible (Ref. 11.4).

The arsenic might not volatilize at the temperatures typically used in AC regeneration. In addition, off-gas containing arsenic from the regeneration process may be difficult or expensive to manage.

The reported adsorption capacity of AC is 0.020 grams of As(V) per gram of AC. As(III) is not effectively removed by AC. AC impregnated with metals such as copper and ferrous iron has a higher reported adsorption capacity for arsenic. The reported adsorption capacity for As(III) is 0.048 grams per gram of copper impregnated carbon and for As(V) is 0.2 grams per gram of ferrous iron-impregnated carbon (Ref. 11.4).

Iron-based adsorption media include granular ferric hydroxide, ferric hydroxide-coated newspaper pulp, ferric oxide, iron oxide-coated sand, sulfur-modified iron, and iron filings mixed with sand. These media have been used primarily to remove arsenic from drinking water. Processes that use these media typically remove arsenic using adsorption in combination with oxidation, precipitation/coprecipitation, ion exchange, or filtration.

For example, iron oxide-coated sand uses adsorption and ion exchange with surface hydroxides to selectively remove arsenic from water.

The media requires periodic regeneration or disposal and replacement with new media. The regeneration process is similar to that used for AA, and consists of rinsing the media with a regenerating solution containing excess sodium hydroxide, flushing with water, and neutralizing with a strong acid, such as sulfuric acid (Ref. 11.3).

The sources used for this report contained information on the use of surfactant-modified zeolite (SMZ) at bench scale, but no pilot- or full-scale applications were identified. SMZ is prepared by treating zeolite with a solution of surfactant, such as hexadecyltrimethylammonium bromide (HDTMA-Br).

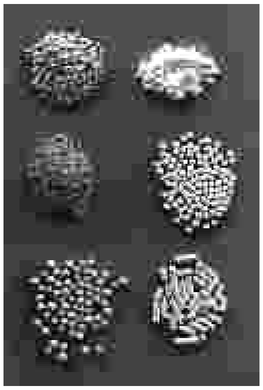
This process forms a stable coating on the zeolite surface. The reported adsorption capacity of SMZ is 0.0055 grams of As(V) per gram of SMZ at 250C. SMZ must be periodically regenerated with surfactant solution or disposed and replaced with new SMZ (Ref. 11.17).

Zeolite

The name zeolite is a general term for a stonelike material which consist of crystalline metal-alumo-silicates with a large internal surface area of up to 1000 m^2/g, strong electrostatic fields in the crystal lattice and with a volumetric density of about 0.8 kg/dm^3.

The word zeolite is of Greek origin and means – directly translated – ***"boiling rock"*** which describes the effect which is to be seen if water is poured over dry zeolite. In 1925 the process of water and methanol separation using zeolites was observed for the first time. And due to this separation action (sieve action) the name "***molecular sieve***" was later attributed to zeolites.

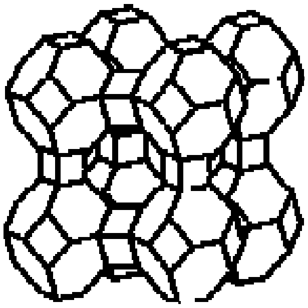
Zeolites are non-poisonous, inflammable, are naturally available in abundance and are therefore compatible with the environment. More than 40 natural and 100 synthetic zeolites are known.



The most important property of a number of zeolites is their ability for reversible adsorption of water. Even after several thousand adsorption/desorption cycles, the structural changes of the crystal lattice are insignificant if the process parameters pressure and temperature do not exceed certain limits. The application diversity of zeolites is tremendous: they are applied as molecular sieves, as adsorbents, as catalysts in cracking of hydrocarbons in the pretrochemical industry, as filler components in paper production and as ion exchange material in detergents

Currently the chemical industry produces more than 1.4 million tons of synthetic zeolite annually and it can be expected that the world wide demand (and consequently the production) will further increase. The price, e.g. for laundry detergent zeolite is between 1.00 and 8.00 DM/kg, depending on the type and consistency of material delivered. The price for specialized zeolites is higher.

Zeolite Structures



Structure of A-Zeolite

The basic building blocks of zeolites are tetrahedral consisting of four oxygen anions and one centrally positioned silicon or aluminum cation. Zeolites are classified according to the various tetrahedral frameworks formed by these basic building blocks. The structure of the synthetic zeolites of types A, X and Y which have gained importance in industrial processes, are shown in the figure.

The aluminum and silicon atoms are positioned at the junctions while the oxygen atoms form the bridges between the tetrahedral. The difference in electro-chemical charges between the aluminum and silicon atoms per one aluminum atom results in a non-compensated negative charge. The balance is restored by metal cations which occupy preferred positions.

Because of the strong local electrical dipole movement in the lattice framework, zeolites adsorb all polar and non-polar molecules that will fit into their specific framework. This adsorption process is accompanied by release of heat--the ***"heat of adsorption"***. Theoretical and experimental studies have determined quantitative heat of adsorption values for zeolite based thermal processes.

Media and Contaminants Treated

Adsorption is frequently used to remove organic contaminants and metals from industrial wastewater. It has been used to remove arsenic from groundwater and drinking water.

Summary of Performance Data

Adsorption treatment effectiveness can be evaluated by comparing influent and effluent contaminant concentrations.

Factors Affecting Adsorption Performance

- Fouling - The presence of suspended solids, organics, solids, silica, or mica, can cause fouling of adsorption media (Ref. 11.1, 11.4).
- Arsenic oxidation state - Adsorption is more effective in removing As(V) than As(III) (Ref. 11.12).
- Flow rate - Increasing the rate of flow through the adsorption unit can decrease the adsorption of contaminants (Ref. 11.1).
- Wastewater pH - The optimal pH to maximize adsorption of arsenic by activated alumina is acidic (pH 6).

Therefore, pretreatment and post-treatment of the water could be required (Ref. 11.4) achieved in both of the projects. In the other two groundwater and surface water projects the influent arsenic concentration was between 0.010 mg/L and 0.050 mg/L, and the effluent concentration was less than 0.010 mg/L.

Of the ten drinking water projects (eight full and two pilot scale) having both influent and effluent arsenic concentration data, eight had influent concentrations greater than 0.050 mg/L. Effluent concentrations of less than 0.050 mg/L were achieved in seven of these projects. For two drinking water projects the influent arsenic concentration was between 0.010 mg/L and 0.050 mg/L, and the effluent concentration was less than 0.010 mg/L.

Projects that did not reduce arsenic concentrations to below 0.050 or 0.010 mg/L do not necessarily indicate that adsorption cannot achieve these levels. The treatment goal for some applications may have been above these levels and the technology may have been designed and operated to meet a higher arsenic concentration.

Information on treatment goals was not collected for this course.

Pilot-scale Studies

Two pilot-scale studies were performed to compare the effectiveness of AA adsorption on As(III) and As(V).

For As(III), 300 bed volumes were treated before arsenic concentrations in the effluent exceeded 0.050 mg/L, whereas 23,400 bed volumes were treated for As(V) before reaching the same concentration in the effluent. The results of these studies indicate that the adsorption capacity of AA is much greater for As(V).

The case study at the end of this section discusses in greater detail the use of AA to remove arsenic from drinking water.

Applicability, Advantages, and Potential Limitations

For AA adsorption media, the spent regenerating solution might contain a high concentration of arsenic and other sorbed contaminants, and can be corrosive (Ref. 11.3).

Spent AA is produced when the AA can no longer be regenerated (Ref. 11.3). The spent AA may require treatment prior to disposal (Ref. 11.4).

Because regeneration of AA requires the use of strong acids and bases, some of the AA media becomes dissolved during the regeneration process. This can reduce the adsorptive capacity of the AA and cause the AA packing to become "***cemented***."

Regeneration of AC media involves the use of thermal energy, which could release volatile arsenic compounds. Use of air pollution control equipment may be necessary to remove arsenic from the off-gas produced (Ref. 11.6).

Competition for adsorption sites could reduce the effectiveness of adsorption because other constituents may be preferentially adsorbed, resulting in a need for more frequent bed regeneration or replacement. The presence of sulfate, chloride, and organic compounds has reportedly reduced the adsorption capacity of AA for arsenic (Ref. 11.3).

The order for adsorption preference for AA is provided below, with the constituents with the greatest adsorption (Ref. 11.3):

OH- > H2AsO4- > Si(OH)3O- > F- > HSeO3- > SO42-> H3AsO3

This technology's effectiveness is also sensitive to a variety of contaminants and characteristics in the untreated water, and suspended solids, organics, silica, or mica can cause fouling.

Therefore, it is typically applied to groundwater and drinking water, which are less likely to contain fouling contaminants. It may also be used as a polishing step for other water treatment technologies.

More detailed information on selection and design of arsenic treatment systems for small drinking water systems is available in the document "***Arsenic Treatment Technology Design Manual for Small Systems "*** (Ref. 11.20).

Summary of Cost Data

One source reported that the cost of removing arsenic from drinking water using AA ranged from \$0.003 to\$0.76 per 1,000 gallons (Ref. 11.4, cost year not provided).

Factors Affecting Adsorption Costs

- Contaminant concentration - Very high concentrations of competing contaminants may require frequent replacement or regeneration of adsorbent (Ref. 11.2). The capacity of the adsorption media increases with increasing contaminant concentration (Ref. 11.1, 11.4).

- High arsenic concentrations can exhaust the adsorption media quickly, resulting in the need for frequent regeneration or replacement.

- Spent media - Spent media that can no longer be regenerated might require treatment or disposal (Ref. 11.4).

Case Study:
Treatment of Drinking Water by an Activated Alumina Plant

A drinking water treatment plant using AA installed in February 1996 has an average flow rate of 3,000 gallons per day.

The arsenic treatment system consists of two parallel treatment trains, with two AA columns in series in each train. For each of the trains, the AA media in one column is exhausted and replaced every 1 to 1.5 years after treating approximately 5,260 bed volumes.

Water samples for a long-term evaluation were collected weekly for a year. Pretreatment arsenic concentrations at the inlet ranged from 0.053 to 0.087 mg/L with an average of 0.063 mg/L. The untreated water contained primarily As(V) with only minor concentrations of As(III) and particulate arsenic. During the entire study, the arsenic concentration in the treated drinking water was below 0.003 mg/L.

Spent AA from the system had leachable arsenic concentrations of less than 0.05 mg/L, as measured by the TCLP, and therefore, could be disposed of as nonhazardous waste.

The document "***Technologies and Costs for Removal of Arsenic From Drinking Water***" (Ref. 11.3) contains detailed information on the cost of adsorption systems to treat arsenic in drinking water to below the revised MCL of 0.010 mg/L.

The document includes capital and operating and maintenance (O&M) cost curves for four adsorption processes:

- AA (at various influent pH levels)
- Granular ferric hydroxide
- Greensand filtration (KMNO4 coated sand)
- AA point-of-use systems

Many of the technologies used to treat drinking water are applicable to treatment of other types of water, and may have similar costs.

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Changing the membrane filter on a RO unit.

Ion Exchange Treatment for Arsenic

Ion exchange has been used to treat groundwater and drinking water containing arsenic.

Based on the information collected to prepare this course, this technology typically can reduce arsenic concentrations to less than 0.050 mg/L and in some cases has reduced arsenic concentrations to below 0.010 mg/L. Its effectiveness is sensitive to a variety of untreated water contaminants and characteristics. It is used less frequently than precipitation/coprecipitation, and is most commonly used to treat groundwater and drinking water, or as a polishing step for other water treatment processes.

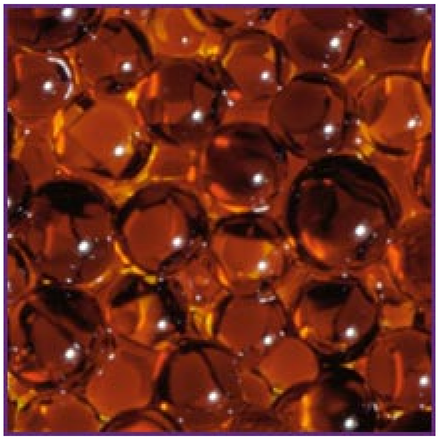
Technology Description: Ion exchange is a physical/chemical process in which ions held electrostatically on the surface of a solid are exchanged for ions of similar charge in a solution.

It removes ions from the aqueous phase by the exchange of cations or anions between the contaminants and the exchange medium (Ref. 12.1,12.4, 12.8).

Media Treated:
- Groundwater
- Surface water
- Drinking water

Exchange Media Used in Ion Exchange to Treat Arsenic:
- Strong base anion exchange resins

Technology Description and Principles
The medium used for ion exchange is typically a resin made from synthetic organic materials, inorganic materials, or natural polymeric materials that contain ionic functional groups to which exchangeable ions are attached (Ref. 12.3). Four types of ion exchange media have been used (Ref. 12.1):
- Strong acid
- Weak acid
- Strong base
- Weak base



Strong and weak acid resins exchange cations while strong and weak base resins exchange anions. Because dissolved arsenic is usually in an anionic form, and weak base resins tend to be effective over a smaller pH range, strong base resins are typically used for arsenic treatment (Ref. 12.1).

Resins may also be categorized by the ion that is exchanged with the one in solution.

For example, resins that exchange a chloride ion are referred to as chloride-form resins.

Another way of categorizing resins is by the type of ion in solution that the resin preferentially exchanges. For example, resins that preferentially exchange sulfate ions are referred to as sulfate-selective. Both sulfate-selective and nitrate-selective resins have been used for arsenic removal (Ref. 12.1).

The resin is usually packed into a column, and as contaminated water is passed through the column, contaminant ions are exchanged for other ions such as chloride or hydroxide in the resin (Ref. 12.4). Ion exchange is often preceded by treatments such as filtration and oil-water separation to remove organics, suspended solids, and other contaminants that can foul the resins and reduce their effectiveness.

Ion exchange resins must be periodically regenerated to remove the adsorbed contaminants and replenish the exchanged ions (Ref. 12.4).

Regeneration of a resin occurs in three steps:
- Backwashing
- Regeneration with a solution of ions
- Final rinsing to remove the regenerating solution

The regeneration process results in a backwash solution, a waste regenerating solution, and a waste rinse water. The volume of spent regeneration solution ranges from 1.5 to 10 percent of the treated water volume depending on the feed water quality and type of ion exchange unit (Ref. 12.4). The number of ion exchange bed volumes that can be treated before regeneration is needed can range from 300 to 60,000 (Ref. 12.1).

The regenerating solution may be used up to 25 times before treatment or disposal is required.

Factors Affecting Ion Exchange Performance
- **Valence state** - As(III) is generally not removed by ion exchange (Ref. 12.4).
- **Presence of competing ions** - Competition for the exchange ion can reduce the effectiveness of ion exchange if ions in the resin are replaced by ions other than arsenic, resulting in a need for more frequent bed regeneration (Ref. 12.1, 12.9).
- **Fouling** - The presence of organics, suspended solids, calcium, or iron, can cause fouling of ion exchange resins (Ref. 12.4).
- **Presence of trivalent iron** - The presence of Fe (III) could cause arsenic to form complexes with the iron that are not removed by ion exchange (Ref. 12.1).
- **pH** - For chloride-form, strong-base resins and a pH in the range of 6.5 to 9 is optimal. Outside of this range, arsenic removal effectiveness decreases quickly (Ref. 12.1).

Final Rinsing Step
The final rinsing step usually requires only a few bed volumes of water (Ref. 12.4).

Ion exchange can be operated using multiple beds in series to reduce the need for bed regeneration; beds first in the series will require regeneration first, and fresh beds can be added at the end of the series. Multiple beds can also allow for continuous operation because some of the beds can be regenerated while others continue to treat water. Ion exchange beds are typically operated as a fixed bed, in which the water to be treated is passed over an immobile ion exchange resin.

One variation on this approach is to operate the bed in a nonfixed, countercurrent fashion in which water is applied in one direction, usually downward, while spent ion exchange resin is removed from the top of the bed.

Regenerated resin is added to the bottom of the bed. This method may reduce the frequency of resin regeneration (Ref. 12.4).

Media and Contaminants Treated

Anion exchange resins are used to remove soluble forms of arsenic from wastewater, groundwater, and drinking water (Ref. 12.1, 12.4). Ion exchange treatment is generally not applicable to soil and waste.

It is commonly used in drinking water treatment for softening, removal of calcium, magnesium, and other cations in exchange for sodium, as well as removing nitrate, arsenate, chromate, and selenate (Ref. 12.9).

Type, Number, and Scale of Identified Projects Treating Water Containing Arsenic

Ion exchange of arsenic and groundwater, surface water, and drinking water is commercially available.

Information is available on seven full-scale applications, including three applications to groundwater and surface water, and four applications to drinking water. No pilot-scale applications or applications to industrial wastewater were found in the sources researched.

Summary of Performance Data

Ion exchange treatment effectiveness can be evaluated by comparing influent and effluent contaminant concentrations. The single surface water project with both influent and effluent arsenic concentration data had an influent concentration of 0.0394 mg/L, and an effluent concentration of 0.0229 mg/L.

Of the three drinking water projects with both influent and effluent concentration data, all had influent concentrations greater than 0.010 mg/L. Effluent concentrations of less than 0.010 mg/L were consistently achieved in only one of these projects.

Projects that did not reduce arsenic concentrations to below 0.050 or 0.010 mg/L do not necessarily indicate that ion exchange cannot achieve these levels. The treatment goal for some applications could have been above these levels and the technology may have been designed and operated to meet a higher arsenic concentration. Information on treatment goals was not collected for this report.

Factors Affecting Ion Exchange Costs

- **Bed regeneration** - Regenerating ion exchange beds reduces the amount of waste for disposal and the cost of operation (Ref. 12.1).
- **Sulfate** - Sulfate (SO4) can compete with arsenic for ion exchange sites, thus reducing the exchange capacity of the ion exchange media for arsenic. This can result in a need for more frequent media regeneration or replacement and associated higher costs (Ref. 12.1).

Case Study:
National Risk Management Research Laboratory Study

A study by the EPA ORD's National Risk Management Research Laboratory tested an ion exchange system at a drinking water treatment plant. Weekly sampling for one year showed that the plant achieved an average of 97 percent arsenic removal.

The resin columns were frequently regenerated (every 6 days). Influent arsenic concentrations ranged from 0.045 to 0.065 mg/L and effluent concentrations ranged from 0.0008 to 0.0045 mg/L (Ref. 12.9).

The case study at the end of this section further discusses the use of ion exchange to remove arsenic from drinking water.

Applicability, Advantages, and Potential Limitations

For ion exchange systems using chloride-form resins, the treated water could contain increased levels of chloride ions and as a result be corrosive. Chlorides can also increase the redox potential of iron, thus increasing the potential for water discoloration if the iron is oxidized.

The ion exchange process can also lower the pH of treated waters (Ref. 12.4).

For ion exchange resins used to remove arsenic from water, the spent regenerating solution might contain a high concentration of arsenic and other sorbed contaminants, and could be corrosive. Spent resin is produced when the resin can no longer be regenerated.

The spent resin may require treatment prior to reuse or disposal (Ref. 12.8).

The effectiveness of ion exchange is also sensitive to a variety of contaminants and characteristics in the untreated water, and organics, suspended solids, calcium, or iron can cause fouling. Therefore, it is typically applied to groundwater and drinking water, which are less likely to contain fouling contaminants. It may also be used as a polishing step for other water treatment technologies.

More detailed information on selection and design of arsenic treatment systems for small drinking water systems is available in the document "***Arsenic Treatment Technology Design Manual for Small Systems*** " (Ref. 12.10).

Summary of Cost Data

One project reported a capital cost for an ion exchange system of $6,886 with an additional $2,000 installation fee (Ref. 12.9, cost year not provided). The capacity of the system and O&M costs were not reported. Cost data for other projects using ion exchange were not found.

The document "***Technologies and Costs for Removal of Arsenic From Drinking Water***" (Ref. 12.1) contains additional information on the cost of ion exchange systems to treat arsenic in drinking water to levels below the revised MCL of 0.010 mg/L. The document includes capital and O&M cost curves for ion exchange at various influent sulfate (SO4) concentrations.

These cost curves are based on computer cost models for drinking water treatment systems. The curves estimate the costs for ion exchange treatment systems with different design flow rates. The document also contains information on the disposal cost for residuals from ion exchange. Many of the technologies used to treat drinking water are applicable to treatment of other types of water, and may have similar costs.

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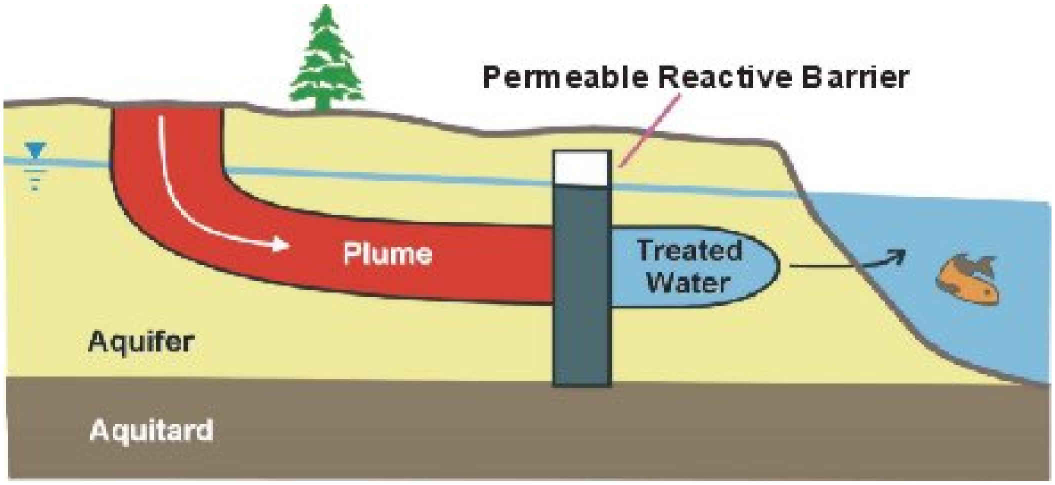
Permeable Reactive Barriers for Arsenic

Permeable reactive barriers (**PRBs**) are being used to treat arsenic in groundwater at full scale at only a few sites. Although many candidate materials for the reactive portion of the barrier have been tested at bench scale, only zero valent iron and limestone have been used at full scale.

The installation techniques for PRBs are established for depths less than 30 feet, and require innovative installation techniques for deeper installations.



Technology Description and Principles
PRBs are applicable to the treatment of both organic and inorganic contaminants. The former usually are broken down into carbon dioxide and water, while the latter are converted to species that are less toxic or less mobile.

The most frequent applications of PRBs is the in situ treatment of groundwater contaminated with chlorinated solvents. A number of different treatment media have been used, the most common being zerovalent iron (**ZVI**). Other media include hydrated lime, slag from steelmaking processes that use a basic oxygen furnace, calcium oxides, chelators (ligands selected for their specificity for a given metal), iron oxides, sorbents, substitution agents (e.g., ion exchange resins) and microbes (Ref. 13.6, 13.8, 13. 18).

The cost of the reactive media will impact the overall cost of PRB remedies. The information sources used for this report included information about PRB applications using ZVI, basic oxygen furnace slag, limestone, surfactant modified zeolite, and ion exchange resin to treat arsenic.

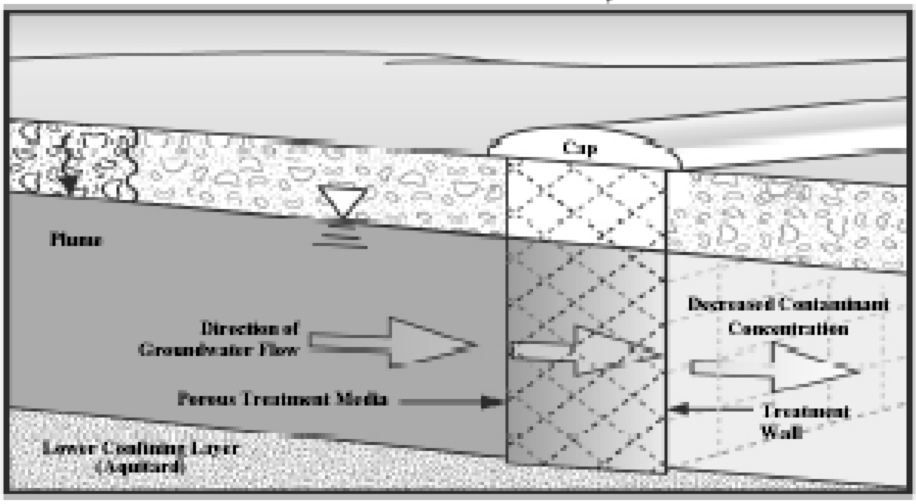
Technology Description: Permeable reactive barriers (**PRBs**) are walls containing reactive media that are installed across the path of a contaminated groundwater plume to intercept the plume. The barrier allows water to pass through while the media remove the contaminants by precipitation, degradation, adsorption, or ion exchange.

Media Treated:
- Groundwater (in situ)

Chemicals and Reactive Media Used in PRBs to Treat Arsenic:
- Zero valent iron (**ZVI**)
- Limestone
- Basic oxygen furnace slag
- Surfactant modified zeolite
- Ion exchange resin

Installation Depth:
- Up to 30 feet deep using established techniques
- Innovative techniques required for depths greater than 30 feet

Model of a Permeable Reactive Barrier System



For the PRB projects identified for this course, ZVI was the most commonly used reactive media. As groundwater reacts with ZVI, pH increases, Eh decreases, and the concentration of dissolved hydrogen increases. These basic chemical changes promote a variety of processes that impact contaminant concentrations. Increases in pH favor the precipitation of carbonates of calcium and iron as well as insoluble metal hydroxides.

Decreases in Eh drive reduction of metals and metalloids with multiple oxidation states.

Finally, an increase in the partial pressure of hydrogen in subsurface systems supports the activity of various chemotrophic organisms that use hydrogen as an energy source, especially sulfate-reducing bacteria and iron-reducing bacteria (Ref. 13.15).

Arsenate [As (V)] ions bind tightly to the iron filings, causing the ZVI to be oxidized to ferrous iron, aerobically or anaerobically in the presence of water, as shown by the following reactions:

(anaerobic) $Fe^0 + 2H_2O \quad Fe^{+2} + H_2 + 2OH^-$
(aerobic) $2Fe^0 + 2H_2O + O_2 \quad 2Fe^{+2} + 4OH$

The process results in a positively charged iron surface that sorbs the arsenate species by electrostatic interactions (Ref. 13.5, 13.17).

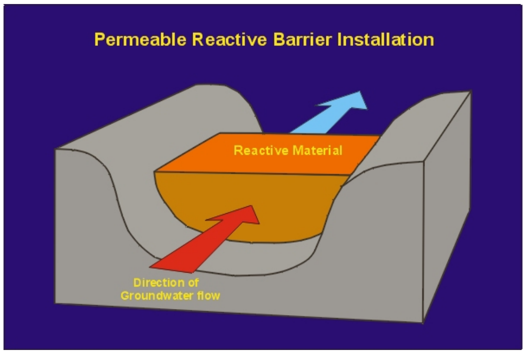
In systems where dissolved sulfate is reduced to sulfide by sulfate-reducing bacteria, arsenic may be removed by the precipitation of insoluble arsenic sulfide (As2S3) or co-precipitated with iron sulfides (FeS) (Ref. 13.15).PRBs can be constructed by excavating a trench of the appropriate width and backfilling it with a reactive medium.

Commercial PRBs are built in two basic configurations: the funnel-and-gate and the continuous wall. The funnel-and-gate uses impermeable walls, for example, sheet pilings or slurry walls, as a "***funnel***" to direct the contaminant plume to a "***gate(s)***" containing the reactive media, while the continuous wall transects the flow path of the plume with reactive media (Ref. 13.6). Most PRBs installed to date have had depths of 50 feet (ft) or less.

Those having depths of 30 ft or less can be installed with a continuous trencher, while depths between 30 and 70 ft require a more innovative installation method, such as biopolymers. Installation of PRBs at depths greater than 70 ft is more challenging (Ref. 13.13).

Media and Contaminants Treated

This technology can treat both organic and inorganic contaminants. Organic contaminants are broken down into less toxic elements and compounds, such as carbon dioxide and water. Inorganic contaminants are converted to species that are less toxic or less mobile.



Inorganic contaminants that can be treated by PRBs include, but are not limited to, chromium (Cr), nickel (Ni), lead (Pb), uranium (U), technetium (Tc), iron (Fe), manganese (Mn), selenium (Se), cobalt (Co), copper (Cu), cadmium (Cd), zinc (Zn), arsenic (As), nitrate (NO3-), sulfate (SO42-), and phosphate (PO43-).

The characteristics that these elements have in common is that they can undergo redox reactions and can form solid precipitates with common groundwater constituents, such as carbonate (CO3 2-), sulfide (S2-),and hydroxide (OH-). Some common sources of these contaminants are mine tailings, septic systems, and battery recycling/disposal facilities (Ref. 13.5, 13.6, 13.14).

PRBs are designed to treat groundwater in situ. This technology is not applicable to other contaminated media such as soil, debris, or industrial wastes.

Type, Number, and Scale of Identified Projects Treating Water Containing Arsenic

PRBs are commercially available and are being used to treat groundwater containing arsenic at a full scale at two Superfund sites, the Monticello Mill Tailings and Tonolli Corporation sites, although arsenic is not the primary target contaminant for treatment by the technology at either site (Ref. 13.1).

At a third Superfund site, the Asarco East Helena site, this technology has been tested at a bench scale, and implementation at a full scale to treat arsenic is currently planned (Ref. 13.15).

In 1999, a pilot-scale treatment was conducted at Bodo Canyon Disposal Cell Mill Tailings Site, Durango, Colorado, to remediate groundwater contaminated with arsenic (Ref. 13.12).

In addition, PRBs have been used in two bench-scale treatability studies by the U.S. Department of Energy's Grand Junction Office (GJO) to evaluate their application to the Monticello Mill Tailings site and a former uranium ore processing site (Ref. 13.3).

Additional bench-scale studies of the treatment of arsenic using PRBs that contain various reactive media are listed below (Ref. 13.8, 13.11). These studies were not conducted to evaluate the application of PRBs to specific sites.

Factors Affecting PRB Performance

Fractured rock - The presence of fractured rock in contact with the PRB may allow groundwater to flow around, rather than through, the PRB (Ref. 13.6).
Deep aquifers and contaminant plumes - PRBs may be difficult to install for deep aquifers and contaminant plumes (>70 ft deep) (Ref. 13.13).
High aquifer hydraulic conductivity – The hydraulic conductivity of the barrier must be greater than that of the aquifer to prevent preferential flow around the barrier (Ref. 13.13).
Stratigraphy - Site stratigraphy may affect PRB installation. For example, clay layers might be "***smeared***" during installation, reducing hydraulic conductivity near the PRB (Ref. 13.6).
Barrier plugging - Permeability and reactivity of the barrier may be reduced by precipitation products and microbial growth (Ref. 13.6).

Other Bench-Scale Studies Using Adsorption or Ion Exchange Barriers

. Activated alumina (Dupont)
. Bauxite (Dupont)
. Ferric oxides and oxyhydroxides (Dupont, University of Waterloo),
. Peat, humate, lignite, coal (Dupont)
. Surfactant-modified zeolite (New Mexico Institute of Mining and Technology)

Other Bench-Scale Studies Using Precipitation Barriers

. Ferrous hydroxide, ferrous carbonate, ferrous sulfide (Dupont)
. Limestone (Dupont)
. Zero-Valent Metals (DOE GJO)

Applicability, Advantages, and Potential Limitations

PRBs are a passive treatment technology, designed to function for a long time with little or no energy input.

They produce less waste than active remediation (for example, extraction systems like pump and treat), as the contaminants are immobilized or altered in the subsurface (Ref. 13.14).

PRBs can treat groundwater with multiple contaminants and can be effective over a range of concentrations. PRBs require no aboveground equipment, except monitoring devices, allowing return of the property to economic use during remediation (Ref. 13.5, 13.14).

PRBs are best applied to shallow, unconfined aquifer systems in unconsolidated deposits, as long as the reactive material is more conductive than the aquifer. (Ref. 13.13). PRBs rely on the natural movement of groundwater; therefore, aquifers with low hydraulic conductivity can require relatively long periods of time to be remediated.

In addition, PRBs do not remediate the entire plume, but only the portion of the plume that has passed through the PRB. Because cleanup of groundwater contaminated with arsenic has been conducted at only two Superfund sites and these barriers have been recently installed (Tonolli in 1998 and Monticello in 1999), the long-term effectiveness of PRBs for arsenic treatment has not been demonstrated (Ref. 13.13).

Case Study: Monticello Mill Tailings Site

Permeable Reactive Barrier

The Monticello Mill Tailings in Southeastern Utah is a former uranium/vanadium processing mill and mill tailings impoundment (disposal pit). In January 1998, the U.S. Department of Energy completed an interim investigation to determine the nature and extent of contamination in the surface water and groundwater in operable unit 3 of the site.

Arsenic was one of several contaminants in the groundwater, and was found at concentrations ranging from 0.010 to 0.013 mg/L. A PRB containing ZVI was constructed in June 1999 to treat heavy metal and metalloid contaminants in the groundwater. Five rounds of groundwater sampling occurred between June 1999 and April 2000, and sampling was expected to continue on a quarterly basis until July 2001. The average concentration of arsenic entering the PRB, as measured from September to November 1999 was 0.010 mg/L, and the effluent concentration, measured in April 2000, was less than 0.0002 mg/L (Ref. 13.1, 13.2, 13.14)

Factors Affecting PRB Costs

. **PRB depth** - PRBs at depths greater than 30 feet may be more expensive to install, requiring special excavation equipment and construction materials (Ref. 13.13).
. **Reactive media** - Reactive media vary in cost, therefore the reactive media selected can affect PRB cost.

Summary of Cost Data

The EPA compared the costs of pump-and-treat systems at 32 sites to the costs of PRBs at 16 sites. Although the sites selected were not a statistically representative sample of groundwater remediation projects, the capital costs for PRBs were generally lower than those for pump and treat systems (Ref. 13.13).

However, at the Monticello site, estimates showed that capital costs for a PRB were greater than those for a pump-and-treat system, but lower operations and maintenance costs would result in a lower life-cycle cost to achieve similar cleanup goals. For the PRB at the Monticello site, total capital cost was $1,196,000, comprised of $1,052,000 for construction and $144,000 for the reactive PRB media. Construction costs are assumed to include actual construction costs and not design activities or treatability studies (Ref. 13.14, cost year not provided). Cost data for the other projects described in this section are not available.

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Electrokinetic Treatment of Arsenic

Electrokinetic treatment is an emerging remediation technology designed to remove heavy metal contaminants from soil and groundwater. The technology is most applicable to soil with small particle sizes, such as clay.

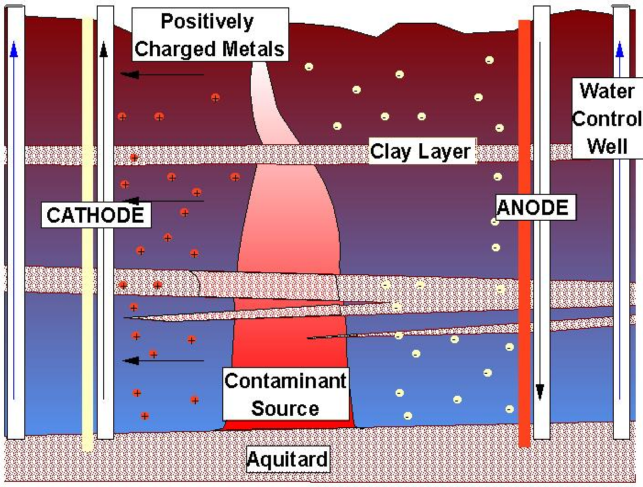
However, its effectiveness may be limited by a variety of contaminants and soil and water characteristics.

Information sources researched for this report identified a limited number of applications of the technology to arsenic.

Technology Description: Electrokinetic remediation is based on the theory that a low-density current will mobilize contaminants in the form of charged species. A current passed between electrodes is intended to cause water, ions, and particulates to move through the soil, waste, and water (Ref. 14.8).

Contaminants arriving at the electrodes can be removed by means of electroplating or electrodeposition, precipitation or coprecipitation, adsorption, complexing with ion exchange resins, or by pumping of water (or other fluid) near the electrode (Ref. 14.10).

Electrokinetics to Remediate Water Soluble Metals



Electrical Current - Electrical resistance heating and electrokinetics can move metals, mobilize NAPLS, or heat the soil as high as 250 °F to vaporize NAPLS. Both technologies work because moist soil conducts electric current.

Thus, it can either be heated, and vaporized NAPLS can be collected at wells or electrodes, or ions can move with the current and be collected at other types of electrodes.

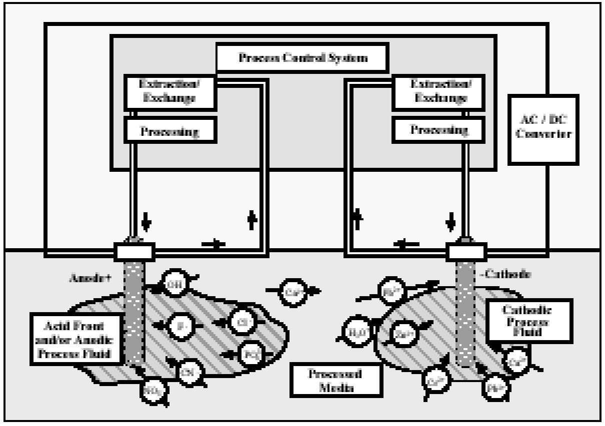
The resistance of the soil and mobility of fluids are controlled by the soil moisture, so this must be controlled, sometimes by injecting water.

The wells must be closely spaced, so capital cost for a project is higher. While heating is a fast process, moving ions with a current is much slower since the current must change the charge on the soil in order to mobilize ions.

However, electrokinetics is one of the few technologies for recovering metals, and resistance heating works well in clay layers.

Media Treated:
- Soil
- Groundwater
- Industrial wastes

Chemicals Used in Electrokinetic Process to Treat Arsenic:
- Sulfuric Acid
- Phosphoric Acid
- Oxalic Acid



Model of an Electrokinetic Treatment System

Technology Description and Principles

In situ electrokinetic treatment of arsenic uses the natural conductivity of the soil (created by pore water and dissolved salts) to affect movement of water, ions, and particulates through the soil (Ref. 14.8). Water and/or chemical solutions can also be added to enhance the recovery of metals by electrokinetics.

Factors Affecting Electrokinetic Treatment Performance

• **Contaminant properties** - The applicability of electrokinetics to soil and water containing arsenic depends on the solubility of the particular arsenic species.

Electrokinetic treatment is applicable to acid-soluble polar compounds, but not to insoluble metals (Ref. 14.6).

• **Salinity and cation exchange capacity** – The technology is most efficient when these parameters are low (Ref. 14.14). Chemical reduction of chloride ions at the anode by the electrokinetic process may also produce chlorine gas (Ref. 14.6).

• **Soil moisture** - Electrokinetic treatment requires adequate soil moisture; therefore addition of a conducting pore fluid may be required (Ref. 14.7). Electrokinetic treatment is most applicable to saturated soils (Ref. 14.9). However, adding fluid to allow treatment of soils without sufficient moisture may flush contaminants out of the targeted treatment area.

• **Polarity and magnitude of the ionic charge** - These factors affect the direction and rate of contaminant movement (Ref. 14.11).

- **Soil type** - Electrokinetic treatment is most applicable to homogenous soils (Ref. 14.9). Fine-grained soils are more amenable to electrokinetic treatment due to their large surface area, which provides numerous sites for reactions necessary for electrokinetic processes (Ref. 14.13).

- **pH** - The pH can affect process electrochemistry and cause precipitation of contaminants or other species, reducing soil permeability and inhibiting recovery. The deposition of precipitation solids may be prevented by flushing the cathode with water or a dilute acid (Ref. 14.14).

This technology can also be applied ex situ to groundwater by passing the water between electrodes. The current causes arsenic to migrate toward the electrodes, and also alters the pH and oxidation-reduction potential of the water, causing arsenic to precipitate/coprecipitate. The solids are then removed from the water using clarification and filtration (Ref.14.21).

Media and Contaminants Treated

Electrokinetic treatment is an in situ treatment process that has had limited use to treat soil, groundwater, and industrial wastes containing arsenic. It has also been used to treat other heavy metals such as zinc, cadmium, mercury, chromium, and copper (Ref. 14.1, 14.4, 14.20).

Electrokinetic treatment may be capable of removing contaminants from both saturated and unsaturated soil zones, and may be able to perform without the addition of chemical or biological agents to the site. This technology also may be applicable to low-permeability soils, such as clay (Ref. 14.1, 14.4, 14.9).

Applicability, Advantages, and Potential Limitations

Electrokinetics is an emerging technology with relatively few applications for arsenic treatment. It is an in situ treatment technology, and therefore does not require excavation of contaminated soil or pumping of contaminated groundwater. Its effectiveness may be limited by a variety of soil and contaminant characteristics.

Charged metal or metalloid cations, such as As (V) and As (III) migrate to the negatively-charged electrode (cathode), while metal or metalloid anions migrate to the positively charged electrode (anode) (Ref. 14.9).

Extraction may occur at the electrodes or in an external fluid cycling/extraction system (Ref. 14.11). Alternately, the metals can be stabilized in situ by injecting stabilizing agents that react with and immobilize the contaminants (Ref. 14.12).

Arsenic has been removed from soils treated by electrokinetics using an external fluid cycling/ extraction system (Ref. 14.2, 14.18).

Case Study: The Overpelt Project

A pilot-scale test of electrokinetic remediation of arsenic in groundwater was conducted in Belgium in 1997. This ex situ application involved pumping groundwater contaminated with zinc, arsenic, and cadmium and treating it in an electrokinetic remediation system with a capacity of 6,600 gpm.

The treatment system precipitated the contaminants, and the precipitated solids were removed using clarification and filtration. The electrokinetic treatment system did not use additives or chemicals. The treatment reduced arsenic concentrations in groundwater from 0.6 mg/L to 0.013 mg/L. The reported costs of the treatment were $0.004 per gallon for total cost, and $0.002 per gallon for O&M. (Ref. 14.21)

Factors Affecting Electrokinetic Treatment Costs

- **Contaminant extraction system –** Some electrokinetic systems remove the contaminant from the subsurface using an extraction fluid. In such systems, the extraction fluid may require further treatment, which can increase the cost (Ref. 14.4).

Scale of Electrokinetic Projects for Arsenic Treatment

Summary of Cost Data

Estimated costs of in situ electrokinetic treatment of soils containing arsenic range from $50 - $270 per cycle. (Ref. 14.2, 14.4, cost year not provided). The reported costs for one pilot-scale, ex situ treatment of groundwater of the treatment were $0.004 per gallon for total cost, and $0.002 per gallon for O&M. (Ref. 14.21)

In Situ Electrokinetic Remediation for Metal Contaminated Soils

Primary Contributors

Military activities are one of the primary contributors to metals contaminated soil problems. Military operations such as small arms training, electroplating and metal finishing operations, explosive and propellant manufacturing and use, and the use of lead based paint at military facilities, have resulted in vast tracts of land being contaminated with metals. As a result, there is a military need to develop cost-effective methods for cleaning up metal contaminated soils. Electrokinetic remediation was identified as a possible method of performing an in situ extraction of the metal contaminants from soils.

Electrokinetic remediation is an in-situ process in which an electrical field is created in a soil matrix by applying a low-voltage direct current (**DC**) to electrodes placed in the soil. As a result of the application of this electric field, heavy metal contaminants may be mobilized, concentrated at the electrodes, and extracted from the soil.

Many vendors have marketed the potential of electrokinetic remediation for metals contaminated soils, however, no large scale field demonstrations had been conducted. Issues such as control of contaminant movement, ability to achieve cleanup goals, byproduct formation, treatment effects on the soil matrix, etc. had not been addressed. Interest in electrokinetic remediation has been driven by the demand for technologies that are cost effective and will eliminate the long-term liability that is incurred by landfilling of contaminants.

Approach

The US Army Environmental Center (**USAEC**) and the Engineer Research and Development Center (**ERDC**) conducted a field demonstration of electrokinetic remediation to assess the performance and cost of the technology. This demonstration, sponsored by the Environmental Security Technology Certification Program and the Southwest Division, Naval Facilities Engineering Command, was conducted at a metals contaminated site at Naval Air Weapons Station (**NAWS**) Point Mugu, California.

Results

The bench tests conducted prior to field operations did not accurately reflect the effects that site conditions would have on the technology, specifically the retarding effects that competing ions would have on pH front development and contaminant mobility. Contaminant mobility and pH effects were ultimately observed in the field, however, the duration required for treatment in the field will be much longer than anticipated by the bench tests.

Also, the bench tests did not reflect the by-product formation that was encountered in the field, specifically the hydrogen sulfide gas and trihalomethane formation. As currently designed, the bench tests do not provide an adequate means of predicting performance, duration, and efficiency or the formation of potentially hazardous by-products as a result of the technology's reaction with site specific constituents. At best, it provided an indication that contaminants would ultimately be mobilized when the technology is applied.

The performance goal for the technology was to reduce contaminant levels to California State TTLC and STLC levels as well as to established Modified Region 9 Preliminary Remediation Goals. No contaminants were extracted during the demonstration period. The technology had an impact on organic contaminants at the site. An increase in organic contaminants was detected. This was primarily a result of the trihalomethane production resulting from the chlorine buildup in the anode wells. The VOC data also indicated that there was an increase in the vinyl chloride concentrations in some of the wells. The increase in the vinyl chloride concentration is attributed to acceleration of the naturally occurring dehalogenation of PCE and TCE as a result of the electrokinetic remediation system operation.

The site characteristic that most affected the treatment performance was the high chloride concentration of the groundwater. The chloride reactions at the anode act to retard the development of the pH front, which in turn lengthens the time required to extract the contaminants from the soil.

Conclusions

Electrokinetic remediation heavy metal extraction rate and efficiency is dependent upon many subsurface characteristics such as soil type and grain size, contaminant concentration, ionic mobility, total ionic concentration, types of contaminant species and their solubility, etc.

Additional complications with the application of electrokinetic remediation can arise from the presence of organic contaminants and possibly the organic material in the soil.

The soil's physical, chemical, and biological characteristics can individually and cumulatively impact the extraction rate and efficiency of the technology. As a result of the numerous factors affecting performance, the following technology application issues and performance concerns have been identified:

- There is a lack of understanding of the technology's effects on naturally occurring ions and how these effects impact mobilization and removal of the target contaminants. The field demonstration at NAWS Point Mugu identified many discrepancies between the laboratory testing and the performance observed in the field test. The retarding effects created by the naturally occurring ions cannot be accurately quantified in the laboratory tests and their effects on the type of metal species formed under the electric field influence cannot be accurately predicted. The metals species observed in the laboratory testing differed from those observed in the field. The species development will affect migration rate and extraction efficiency.

- The presence of naturally occurring ions and organic material as well as organic contaminants can result in the development of potentially hazardous by-products (i.e. chlorine, trihalomethanes, acetone, etc.) when an electric field is applied to the soil.

- The addition of ions to the soil as a result of the amendment addition to the cathode well may also result in the formation of hazardous by-products during operation of the technology. Laboratory treatability testing as currently designed cannot identify the potential for by-product production.

- The ability of the electric field to control the movement of mobilized contaminant ions in treatment zones affected by groundwater flow or tidal influences has not been validated.

- The soil chemical and biological factors that may limit the application of electrokinetic remediation have yet to be adequately quantified. As a result, site screening using readily measurable soil characteristics cannot be performed. Also as previously stated, laboratory treatability testing may give a false indication of the applicability of electrokinetic remediation to a specific site.

- The impact that electrokinetic extraction will have on the soil's physical, chemical, and biological characteristics has not been addressed. Application of an electric field has not produced any measurable adverse impacts; however, changes to the soil (and their potential ecological impacts) after cleanup target levels have been reached have not been assessed.

- There is a lack of understanding of the impact that electrode shape and electrode placement will have on the electric field shape and intensity formed within the soil matrix. The electric field shape and intensity will effect the formation of and movement of mobile heavy metal species. If complete coverage of the treatment area is not achieved, then all of the contaminants may not be extracted.

- Determination of the appropriate current density to the treatment area appears to be more of an art than a science. Current density or voltage application to the treatment area cannot be correlated to any specific measurable site parameter(s). Considering that electric field intensity can affect the types of contaminant species developed as well as impact the soil's physical, chemical, and biological properties, this parameter and the effects that varying this parameter has requires investigation and quantification.

- Those marketing the technology have not accurately represented the cost of applying electrokinetic remediation for heavy metals extraction. Typically, only power and chemical costs are referred to, thus giving the impression that this is a low-cost technology. Equipment costs, installation, maintenance, removal, and contaminant disposal significantly increase the turnkey cost of applying electrokinetic remediation. Depending on the site conditions and system design, treatment costs may vary from $150 to $1,200 per cubic yard.

Full-scale application of this technology for remediation of metals contaminated soil is limited at best until the issues and concerns stated above can be resolved.

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United States Army Environmental Center

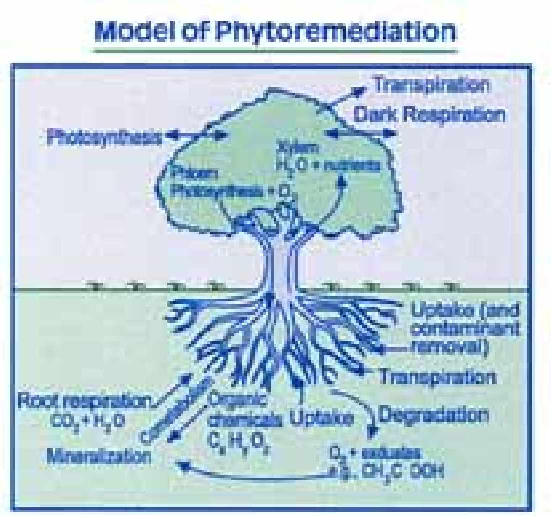
Phytoremediation Treatment of Arsenic

Phytoremediation is an emerging technology.

What is phytoremediation?

Phytoremediation is the use of plants to clean up pollution in the environment, especially at hazardous waste sites. Plants can take up and accumulate toxic metals in their leaves where they can be disposed of easily. Organic pollutants can be taken up by plants and degraded by plant metabolic activities. The action of bacteria associated with plant roots may be useful in the control of pollutants.

Research into phytoremediation has intensified since the early 1990s.



Studies at the University of Washington have led the way in understanding plant activities against important toxic compounds such as trichloroethylene (number one on the Superfund list of prevalent groundwater pollutants) and carbon tetrachloride.

Recently we have begun work in the use of plants to destroy toxic compounds in munitions wastes. We continue to study the mechanisms that are responsible for pollutant degradation by plants and to develop ways to increase the usefulness of plants for phytoremediation.

Applications

Phytoremediation has been applied to or proposed for cleanup of many types of hazardous wastes, including toxic metals and man-made organic compounds.

Metals

Certain plants can take up large amounts of some toxic heavy metals from the soil. For example, some trees adapted to growth on serpentine soils in the South Pacific, which are naturally high in nickel, take up the metal and concentrate it in their tissues, so much that the sap of the trees is a bright blue.

This phenomenon has inspired scientists and engineers to propose to develop plants that can "***hyperaccumulate***" heavy metals in their above-ground tissues so that, by harvesting them, the metals can be economically removed in an ecologically friendly manner.

Organics

Soluble compounds

The most important and widespread of groundwater pollutants are the chlorinated hydrocarbons, such as trichloroethylene. Plants can take up these carcinogens and break them down to harmless products such as chloride and carbon dioxide.

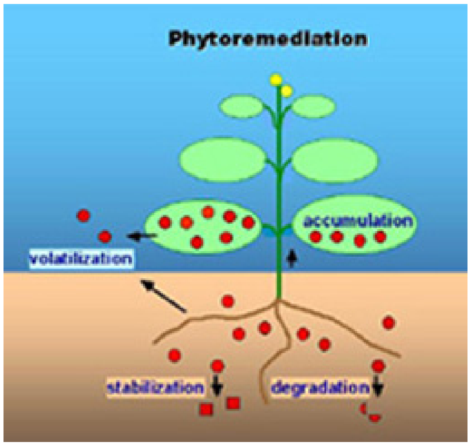
Pioneering work in the UW phytoremediation labs has demonstrated biochemical pathways for plant transformations of trichloroethylene and carbon tetrachloride. We are also developing transgenic plants for the enhanced breakdown of chlorinated hydrocarbons.

Another class of soluble compounds are some of the chemicals found in munitions, especially triazines such as RDX. We are also engineering plants to degrade these dangerous pollutants.

Insoluble compounds (hydrophobic)
Less soluble organic pollutants include polyaromatic hydrocarbons (**PAHs**) and polychlorinated biphenyls, as well as the munitions compound, TNT. Plants have a limited capability to take up these pollutants, but bacteria associated with their roots play a role in the degradation of many of these chemicals.

The data sources used for this report contain information on only one applications of phytoremediation to treat arsenic at full scale and two at pilot scale. Experimental research into identifying appropriate plant species for phytoremediation is ongoing. It is generally applicable only to shallow soil or relatively shallow groundwater that can be reached by plant roots. In addition, the phytoremediating plants may accumulate high levels of arsenic during the phytoremediation process, and may require additional treatment prior to disposal.

Technology Description: Phytoremediation is designed to use plants to degrade, extract, contain, or immobilize contaminants in soil, sediment, or groundwater (Ref. 15.6). Typically, trees with deep roots are applied to groundwater and other plants are used for shallow soil contamination.



Media Treated:
. Soil
. Groundwater

Types of Plants Used in Phytoremediation to Treat Arsenic:
. Poplar
. Cottonwood
. Sunflower
. Indian mustard
. Corn

Technology Description and Principles
Phytoremediation is an emerging technology generally applicable only to shallow contamination that can be reached by plant roots.

Phytoremediation applies to all biological, chemical, and physical processes that are influenced by plants and the rhizosphere, and that aid in cleanup of the contaminated substances.

Phytoremediation may be applied in situ or ex situ, to soils, sludges, sediments, other solids, or groundwater (Ref. 15.1, 15.4, 15.5, 15.7). The mechanisms of phytoremediation include phytoextraction (also known as phytoaccumulation, the uptake of contaminants by plant roots and the translocation/accumulation of contaminants into plant shoots and leaves), enhanced rhizosphere biodegradation (takes place in soil or groundwater immediately surrounding plant roots), phytodegradation (metabolism of contaminants within plant tissues), and phytostabilization (production of chemical compounds by plants to immobilize contaminants at the interface of roots and soil).

The data sources used for this course identified phytoremediation applications for arsenic using phytoextraction and phytostabilization.

The selection of the phytoremediating species depends upon the species ability to treat the contaminants and the depth of contamination. Plants with shallow roots (for example, grasses, corn) are appropriate only for contamination near the surface, typically in shallow soil.

Plants with deeper roots, (for example, trees) may be capable of remediating deeper contaminants in soil or groundwater plumes.

Examples of vegetation used in phytoremediation include sunflower, Indian mustard, corn, and grasses (such as ryegrass and prairie grasses) (Ref. 15.1). Some plant species, known as hyperaccumulators, absorb and concentrate contaminants within the plant at levels greater than the concentration in the surrounding soil or groundwater. The ratio of contaminant concentration in the plant to that in the surrounding soil or groundwater is known as the bioconcentration factor.

A hyperaccumulating fern (***Pteris vittata***) has been used in the remediation of arsenic-contaminated soil, waste, and water. The fern can tolerate as much as 1,500 parts per million (ppm) of arsenic in soil, and can have a bioconcentration factor up to 265. The arsenic concentration in the plant can be as high as 2 percent (dry weight) (Ref. 15.3, 15.6).

Factors Affecting Phytoremediation Performance

Contaminant depth - The treatment depth is limited to the depth of the plant root system (Ref. 15.5).

Contaminant concentration - Sites with low to medium level contamination within the root zone are the best candidates for phytoremediation processes (Ref. 15.4, 15.5).
High contaminant concentrations may be toxic to the remediating flora.

Climatic or seasonal conditions – Climatic conditions may interfere or inhibit plant growth, slow remediation efforts, or increase the length of the treatment period (Ref. 15.4).

Contaminant form - In phytoaccumulation processes, contaminants are removed from the aqueous or dissolved phase.
Phytoaccumulation is generally not effective on contaminants that are insoluble or strongly bound to soil particles.

Agricultural factors - Factors that affect plant growth and health, such as the presence of weeds and pests, and the availability of sufficient water and nutrients will affect phytoremediation processes.

Media and Contaminants Treated

Phytoremediation has been applied to contaminants from soil, surface water, groundwater, leachate, and municipal and industrial wastewater (Ref. 15.4). In addition to arsenic, examples of pollutants it can potentially address include petroleum hydrocarbons such as benzene, toluene, ethylbenzene, and xylenes (BTEX), polycyclic aromatic hydrocarbons (PAHs), pentachlorophenol, polychlorinated biphenyls (PCBs), chlorinated aliphatics (trichloroethylene, tetrachloroethylene, and 1,1,2,2-tetrachloroethane), ammunition wastes (2,4,6- trinitrotoluene or TNT, and RDX), metals (lead, cadmium, zinc, arsenic, chromium, selenium), pesticide wastes and runoff (atrazine, cyanazine, alachlor), radionuclides (cesium-137, strontium-90, and uranium), and nutrient wastes (ammonia, phosphate, and nitrate) (Ref. 15.7).

Treating Soil, Waste, and Water Containing Arsenic
The data sources used for this report contain information on phytoremediation of arsenic contaminated soil at full scale at one Superfund site (Ref. 15.7). Two pilot-scale applications and four bench-scale tests were also identified (Ref. 15.2, 15.3, 15.7-11).

Scale of Identified Phytoremediation Projects for Arsenic Treatment
Data on the effect of phytoremediation on the leachability of arsenic from soil were not identified. No projects with arsenic concentrations in the treated soil, waste, and water both prior to and after treatment were identified. Bioconcentration factors were available for one pilot- and two bench-scale studies, and ranged from 8 to 320.

Applicability, Advantages, and Potential Limitations
Phytoremediation is conducted in situ and therefore does not require soil excavation. In addition, revegetation for the purpose of phytoremediation also can enhance restoration of an ecosystem (Ref. 15.5).

This technology is best applied at sites with shallow contamination. If phytostabilization is used, the vegetation and soil may require long-term maintenance to prevent re-release of the contaminants. Plant uptake and translocation of metals to the aboveground portions of the plant may introduce them into the food chain if the plants are consumed (Ref. 15.5).

Products could bioaccumulate in animals that ingest the plants (Ref. 15.4). In addition, the toxicity and bioavailability of contaminants absorbed by plants and phytodegradation products is not always known. Concentrations of contaminants in hyperaccumulating plants are limited to a maximum of about 3% of the plant weight on a dry weight basis. Based on this limitation, for fast-growing plants, the maximum annual contaminant removal is about 400 kg/hectare/year.

However, many hyperaccumulating species do not achieve contaminant concentrations of 3%, and are slow growing. (Ref. 15.12) The case study at the end of this section further discusses an application of phytoremediation to the treatment to arsenic-contaminated soil.

Factors Affecting Phytoremediation Costs
Number of crops grown - A greater number of crops may decrease the time taken for contaminants to be remediated to specified goals, thereby decreasing costs (Ref. 15.2).

However, the number of crops grown will be limited by the length of the growing season, the time needed for crops to reach maturity, the potential for multiple crops to deplete the soil of nutrients, climatic conditions, and other factors.

Summary of Cost Data

Cost data specific to phytoremediation of arsenic were not identified. The estimated 30-year costs (1998 dollars) for remediating a 12-acre lead site were $200,000 for phytoextraction (Ref. 15.15). Costs were estimated to be $60,000 to $100,000 using phytoextraction for remediation of one acre of 20-inch-thick sandy loam (Ref. 15.14).

The cost of removing radionuclides from water with sun-flowers has been estimated to be $2 to $6 per thousand gallons of water (Ref. 15.16). Phytostabilization system costs have been estimated at $200 to $10,000 per hectare, equivalent to $0.02 to $1.00 per cubic meter of soil, assuming a 1-meter root depth (Ref. 15.17).

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Biological Treatment for Arsenic

Biological treatment designed to remove arsenic from soil, waste, and water is an emerging remediation technology. The information sources used for this report identified a limited number of projects treating arsenic biologically. Arsenic was reduced to below 0.050 mg/L in one pilot-scale application.

This technology promotes precipitation/coprecipitation of arsenic in water or leaching of arsenic in soil and waste. The leachate from bioleaching requires additional treatment for arsenic prior to disposal.

Technology Description: Biological treatment of arsenic is based on the theory that microorganisms that act directly on arsenic species or create ambient conditions that cause arsenic to precipitate/coprecipitate from water and leach from soil and waste.

Media Treated:
- Soil
- Waste
- Water

Microbes Used:
- Sulfate-reducing bacteria
- Arsenic-reducing bacteria

Technology Description and Principles

Although biological treatments have usually been applied to the degradation of organic contaminants, some innovative techniques have applied biological remediation to the treatment of arsenic. This technology involves biological activity that promotes precipitation/coprecipitation of arsenic from water and leaching of arsenic in soil and waste.

Biological precipitation/coprecipitation processes for water create ambient conditions intended to cause arsenic to precipitate/coprecipitate or act directly on arsenic species to transform them into species that are more amenable to precipitation/coprecipitation. The microbes may be suspended in the water or attached to a submerged solid substrate. Iron or hydrogen sulfide may also be added (Ref. 16.2, 16.3, 16.4, 16.4).

One water treatment process depends upon biological activity to produce and deposit iron oxides within a filter media, which provides a large surface area over which the arsenic can contact the iron oxides. The aqueous solution is passed through the filter, where arsenic is removed from solution through coprecipitation or adsorption to the iron oxides. An arsenic sludge is continuously produced (Ref. 16.3).

Another process uses anaerobic sulfate-reducing bacteria and other direct arsenic-reducing bacteria to precipitate arsenic from solution as insoluble arsenic sulfide complexes (Ref. 16.2). The water containing arsenic is typically pumped through a packed-bed column reactor, where precipitates accumulate until the column becomes saturated (Ref. 16.5). The arsenic is then stripped and the column is biologically regenerated(Ref. 16.2).

Hydrogen sulfide has also been used in suspended reactors to biologically precipitate arsenic out of solution (Ref. 16.2, 16.4).

These reactors require conventional solid/liquid separation techniques for removing precipitates.

Removal of arsenic from soil biologically via "***accelerated bioleaching***" has also been tested on a bench scale. The microbes in this system produce nitric, sulfuric, and organic acids which are intended to mobilize and remove arsenic from ores and sediments (Ref. 16.4). This biological activity also produces surfactants, which can enhance metal leaching (Ref.16.4).

Types of Fixed Bioreactors

(these diagrams copied from: John T. Cookson, Jr., 1995. <u>Bioremediation Engineering: Design and Application</u>. McGraw-Hill, Inc, New York, New York.)

Fluidized Bed Bioreactor System

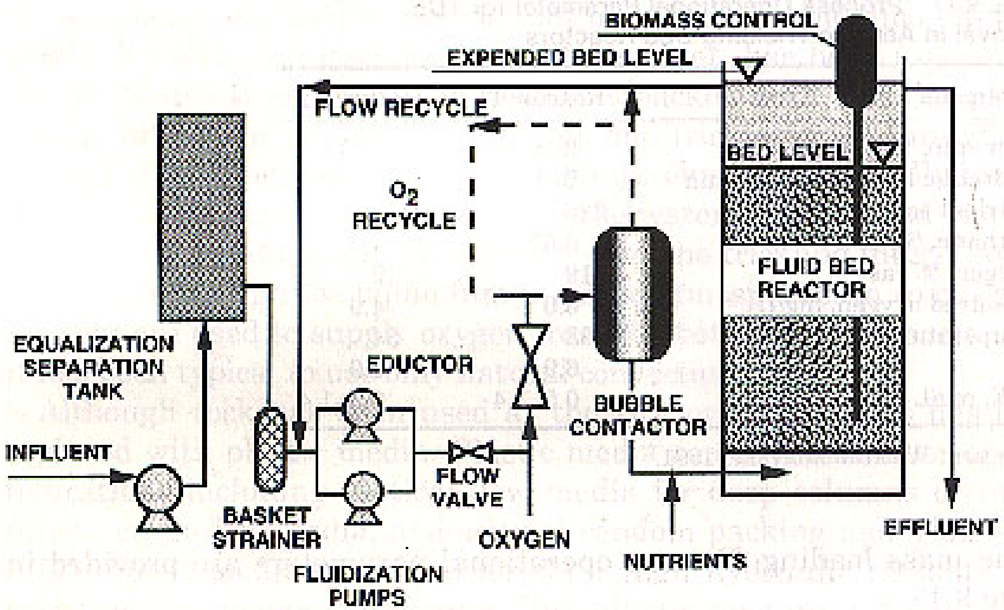

Figure 9.21 Skid-mounted fluidized-bed process flow diagram.

Packed Bed Reactor

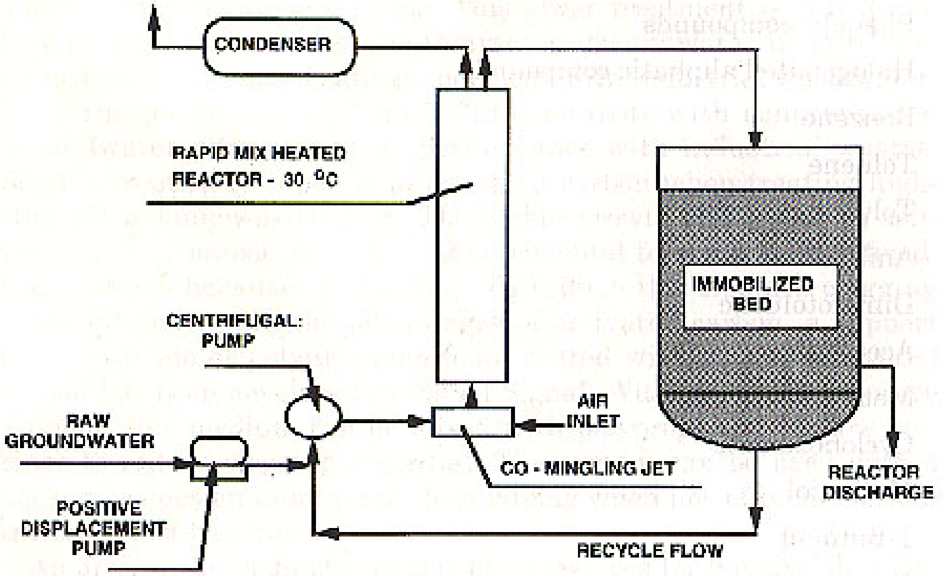

Figure 9.19 Packed-bed reactor for treating groundwater contaminated with halogenated aliphatic hydrocarbons.

Air Sparged Fixed-Bed Reactor

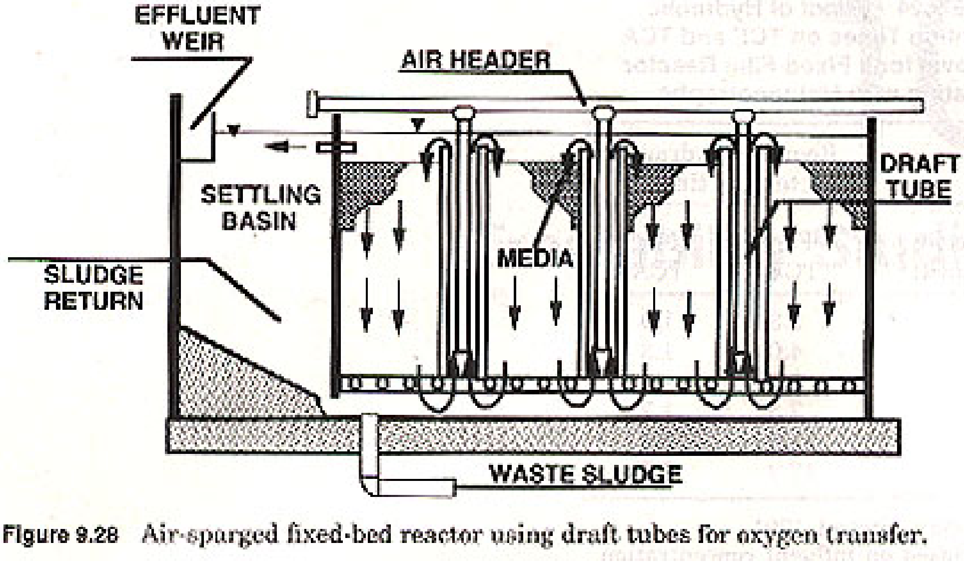

Figure 9.28 Air-sparged fixed-bed reactor using draft tubes for oxygen transfer.

Rotating Media Reactor

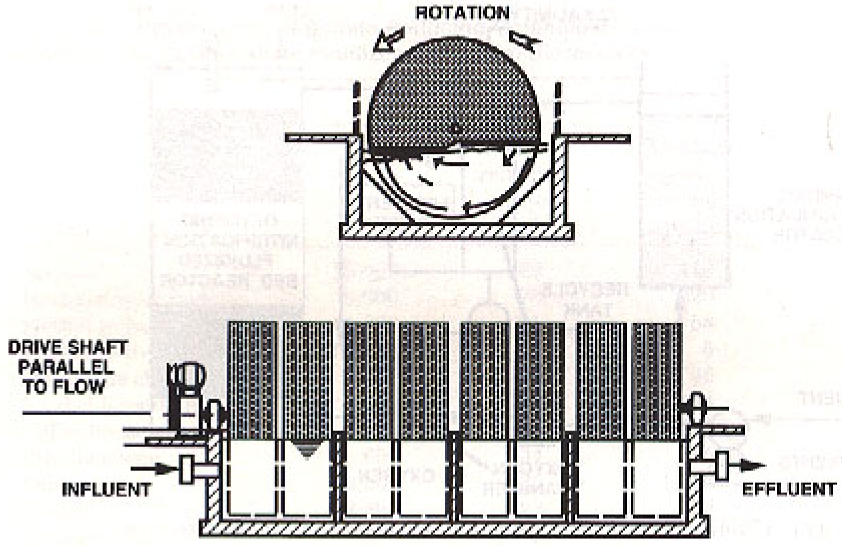

Figure 9.24 Rotating biological contactor.

Media and Contaminants Treated

Biological treatment typically uses microorganisms to degrade organic contaminants in soil, sludge, solids groundwater, and wastewaters.

Factors Affecting Biological Treatment Performance

- **pH** - pH levels can inhibit microbial growth. For example, sulfate-reducing bacteria perform optimally in a pH range of 6.5 to 8.0 (Ref. 16.5).
- **Contaminant concentration** - High arsenic concentrations may be toxic to microorganisms used in biological treatment (Ref. 16.1).
- **Available nutrients** - An adequate nutrient supply should be available to the microbes to enhance and stimulate growth. If the initial solution is nutrient deficient, nutrient addition may be necessary.
- **Temperature** - Lower temperatures decrease biodegradation rates. Heating may be required to maintain biological activity (Ref. 16.1).
- **Iron concentration** - For biologically enhanced iron precipitation, iron must be present in the water to be treated. The optimal iron level depends primarily on the arsenic concentration. (Ref. 16.3).

Factors Affecting Biological Treatment Costs

- **Pretreatment requirements** – Pretreatment may be required to encourage the growth of key microorganisms. Pretreatment can include pH adjustment and removal of contaminants that may inhibit microbial growth.
- **Nutrient addition** - If nutrient addition is required, costs may increase.

Treating Soil, Waste, and Water Containing Arsenic

The data sources used for this report contain information on biological treatment of arsenic at full scale at one facility, at pilot scale at three facilities, and at bench scale for one project. In addition, a biological treatment system using hydrogen sulfide has been used in a bio-slurry reactor to treat arsenic at bench and pilot scales (Ref. 16.4).

Applicability, Advantages, and Potential Limitations

A variety of arsenic-contaminated soil, waste, and water can be treated using biological processes. Biological treatment of arsenic may produce less sludge than conventional ferric arsenic precipitation (Ref. 16.2). A high concentration of arsenic could inhibit biological activity (Ref. 16.1, 16.2).

Case Study: Sodium Arsenite Spiked

Groundwater, Forest Row, Sussex, United Kingdom

Groundwater with naturally-occurring iron between 8 and 12 mg/L was extracted in Forest Row, Sussex, England and spiked with sodium arsenite.

The arsenic concentration before treatment ranged from 0.075 to 0.400 mg/L in the untreated water. The spiked groundwater was passed through a pilot biological filtration unit, 3 m high with a 15 cm diameter and filled to 1 m with silica sand. The arsenic concentration was reduced to <0.04 mg/L (Ref. 16.3)

Summary of Cost Data

The reported costs for biological treatment of arsenic contaminated soil, waste, and water range from less than $0.50 to $2.00 per 1,000 gallons (Ref. 16.2, 16.4, cost year not provided).

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GLOSSARY

AIR GAP SEPARATION: A physical separation space that is present between the discharge vessel and the receiving vessel, for an example, a kitchen faucet.

AIR BREAK: A physical separation which may be a low inlet into the indirect waste receptor from the fixture, or device that is indirectly connected. You will most likely find an air break on waste fixtures or on non-potable lines. You should never allow an air break on an ice machine.

ALTERNATIVE DISINFECTANTS: Disinfectants - other than chlorination (halogens) - used to treat water, e.g. ozone, ultraviolet radiation, chlorine dioxide, and chloramine. There is limited experience and scientific knowledge about the by-products and risks associated with the use of alternatives.

AMMONIA: A chemical made with Nitrogen and Hydrogen and used with chlorine to disinfect water.

AQUIFER: An underground geologic formation capable of storing significant amounts of water.

BACKFLOW: To reverse the natural and normal directional flow of liquids, gases, or solid substances back in to the public potable (drinking) water supply. This is normally an undesirable effect.

BACKFLOW PREVENTION: To stop or prevent the occurrence of, the unnatural act of reversing the normal direction of the flow of liquids, gases, or solid substances back in to the public potable (drinking) water supply. See Cross-connection control.

BACKSIPHONAGE: A liquid substance that is carried over a higher point. It is the method by which the liquid substance may be forced by excess pressure over or into a higher point.

BENCHING - A method of protecting employees from cave-ins by excavating the sides of an excavation to form one or a series of horizontal levels or steps, usually with vertical or near vertical surfaces between levels.

BREAK POINT CHLORINATION: The process of chlorinating the water with significant quantities of chlorine to oxidize all contaminants and organic wastes and leave all remaining chlorine as free chlorine.

BROMINE: Chemical disinfectant (HALOGEN) that kills bacteria and algae.

BUFFER: Chemical that resists pH change, e.g. sodium bicarbonate

CALCIUM HARDNESS: A measure of the calcium salts dissolved in water.

CAUSTIC SODA: Also known as sodium hydroxide and is used to raise pH.

CENTRIFUGAL PUMP: A pump consisting of an impeller fixed on a rotating shaft and enclosed in a casing, having an inlet and a discharge connection. The rotating impeller creates pressure in the liquid by the velocity derived from centrifugal force.

CHLORAMINES: A group of chlorine ammonia compounds formed when chlorine combines with organic wastes in the water. Chloramines are not effective as disinfectants and are responsible for eye and skin irritation as well as strong chlorine odors (also known as Combined Chlorine).

CHLORINE: Chemical disinfectant that kills bacteria and algae.

COMBINED CHLORINE: The reaction product of chlorine with ammonia or other pollutants, also known as chloramines.

CHLORINE DEMAND: Amount of chlorine required to react on various water impurities before a residual is obtained. Also, means the amount of chlorine required to produce a free chlorine residual of 0.1 mg/l after a contact time of fifteen minutes as measured by iodmetic method of a sample at a temperature of twenty degrees in conformance with Standard methods.

CHLORINE, FREE: Chlorine available to kill bacteria or algae. The amount of chlorine available for sanitization after the chlorine demand has been met. Also known as chlorine residual.

CHLORAMINATION: Treating drinking water by applying chlorine before or after ammonia. This creates a persistent disinfectant residual.

CHLORINATION: The process in water treatment of adding chlorine (gas or solid hypochlorite) for purposes of disinfection.

CHLORINE: A chemical which destroys small organisms in water.

COLIFORM: A group of bacteria commonly found in the environment. They are an indicator of potential contamination of water. Adequate and appropriate disinfection effectively destroys coliform bacteria.

CONTAMINANT: Any natural or man-made physical, chemical, biological, or radiological substance or matter in water, which is at a level that may have an adverse effect on public health, and which is known, or anticipated, to occur in public water systems.

CONTAMINATION: To make something bad. To pollute or infect something. To reduce the quality of the potable (drinking) water and create an actual hazard to the water supply by poisoning or through spread of diseases.

CORROSION: The removal of metal from copper, other metal surfaces and concrete surfaces in a destructive manner. Corrosion is caused by improperly balanced water or excessive water velocity through piping or heat exchangers.

CROSS-CONTAMINATION: The mixing of two unlike qualities of water. For example, the mixing of good water with a polluting substance like a chemical.

CRYPTOSPORIDIUM: A disease-causing parasite, resistant to chlorine disinfection. It may be found in fecal matter or contaminated drinking water.

DISINFECT: To kill and inhibit growth of harmful bacterial and viruses in drinking water.

DISINFECTION: The treatment of water to inactivate, destroy, and/or remove pathogenic bacteria, viruses, protozoa, and other parasites.

DISINFECTION BY-PRODUCTS (**DBPs**): The products created due to the reaction of chlorine with organic materials (e.g. leaves, soil) present in raw water during the water treatment process. The EPA has determined that these DBPs can cause cancer.

E. COLI, *Escherichia coli* : A bacterium commonly found in the human intestine. For water quality analyses purposes, it is considered an indicator organism. These are considered evidence of water contamination. Indicator organisms may be accompanied by pathogens, but do not necessarily cause disease themselves.

ELEVATION HEAD: The energy possessed per unit weight of a fluid because of its elevation. 1 foot of water will produce .433 pounds of pressure head.

ENERGY: The ability to do work. Energy can exist in one of several forms, such as heat, light, mechanical, electrical, or chemical. Energy can be transferred to different forms. It also can exist in one of two states, either potential or kinetic.

ENHANCED COAGULATION: The process of joining together particles in water to help remove organic matter.

ENTEROVIRUS: A virus whose presence may indicate contaminated water; a virus which may infect the gastrointestinal tract of humans.

FECAL COLIFORM: A group of bacteria that may indicate the presence of human or animal fecal matter in water.

FILTRATION: A series of processes that physically removes particles from water.

FINISHED WATER: Treated drinking water that meets state and federal drinking water regulations.

FLOCCULATION: The process of bringing together destabilized or coagulated particles to form larger masses which can be settled and/or filtered out of the water being treated.

FLOOD RIM: The point of an object where the water would run over the edge of something and begin to cause a flood. See Air Break.

GIARDIA LAMBLIA: A pathogenic parasite which may be found in contaminated water.

HAZARDOUS ATMOSPHERE - An atmosphere which by reason of being explosive, flammable, poisonous, corrosive, oxidizing, irritating, oxygen deficient, toxic, or otherwise harmful, may cause death, illness, or injury.

HEAD: The measure of the pressure of water expressed in feet of height of water. 1 psi = 2.31 feet of water. There are various types of heads of water depending upon what is being measured; for example, Static (water at rest) and Residual (water at flow conditions).

HEADWORKS: The facility at the "**head**" of the water source where water is first treated and routed into the distribution system.

HETEROTROPHIC PLATE COUNT BACTERIA: A broad group of bacteria including nonpathogens, pathogens, and opportunistic pathogens; they may be an indicator of poor general biological quality of drinking water. Often referred to as **HPC**.

INFECTIOUS PATHOGENS/ MICROBES/GERMS: Disease-producing bacteria, viruses and other microorganisms.

IRRIGATION: Water that is specially furnished to help provide and sustain the life of growing plants. It comes from ditches, and is sometimes treated with herbicides and pesticides to prevent the growth of weeds and the development of bugs in a lawn or garden.

KINETIC ENERGY: The ability of an object to do work by virtue of its motion. The energy terms that are used to describe the operation of a pump are pressure and head.

LANGELIER INDEX: A mathematically derived factor obtained from the values of calcium hardness, total alkalinity, and pH at a given temperature. A Langelier index of zero indicates perfect water balance (i.e., neither corroding nor scaling).

MAXIMUM CONTAMINANT LEVELS (MCLs): The maximum allowable level of a contaminant that federal or state regulations allow in a public water system. If the MCL is exceeded, the water system must treat the water so that it meets the MCL, or provide adequate backflow protection.

MECHANICAL SEAL: A mechanical device used to control leakage from the stuffing box of a pump. Usually made of two flat surfaces, one of which rotates on the shaft. The two flat surfaces are of such tolerances as to prevent the passage of water between them.

Mg/L: milligrams per liter

MICROBE, MICROBIAL: Any minute, simple, single-celled form of life, especially one that causes disease.

MICROBIAL CONTAMINANTS: Microscopic organisms present in untreated water that can cause waterborne diseases.

ML: milliliter

NON-CHLORINE SHOCK: An oxygen based shocking compound. Non Chlorine shock is fast dissolving so it allows swimming just 15 minutes after use.

NTU (nephelometric turbidity unit): A measure of the clarity of water.

OXIDIZING: The process of breaking down organic wastes into simpler elemental forms or by products. Also used to separate combined chlorine and convert it into free chlorine.

pH: A measure of the acidity of water. The pH scale runs from 0 to 14 with 7 being the mid point or neutral.. A pH of less than 7 is on the acid side of the scale with 0 as the point of greatest acid activity. A pH of more than 7 is on the basic (alkaline) side of the scale with 14 as the point of greatest basic activity. pH (Power of Hydroxyl Ion Activity).

pH OF SATURATION: The ideal pH for perfect water balance in relation to a particular total alkalinity level and a particular calcium hardness level, at a particular temperature. The pH where the Langelier Index equals zero.

PHENOL RED: Chemical reagent used for testing pH in the range of 6.8 - 8.4.

POLLUTION: To make something unclean or impure. Some states will have a definition of pollution that relates to non-health related water problems, like taste and odors. See Contaminated.

PATHOGENS: Disease-causing pathogens; waterborne pathogens. A pathogen is a bacterium, virus or parasite that causes or is capable of causing disease. Pathogens may contaminate water and cause waterborne disease.

pCi/L: picocuries per liter A curie is the amount of radiation released by a set amount of a certain compound. A picocurie is one quadrillionth of a curie.

PIPELINE APPURTENANCE: Pressure reducers, bends, valves, regulators (which are a type of valve), etc.

POTABLE: Good water which is safe for drinking or cooking purposes. Non-Potable: A liquid or water that is not approved for drinking.

POTENTIAL ENERGY: The energy that a body has by virtue of its position or state enabling it to do work.

ppm: Abbreviation for parts per million.

PRE-CHLORINATION: The addition of chlorine to the water prior to any other plant treatment processes.

PRESSURE HEAD: The height to which liquid can be raised by a given pressure.

PROGRAMMATIC CONSERVATION: Conservation that results from public education efforts that influence consumer behavior. Examples include turning off the water when brushing your teeth, washing only full loads of laundry, fixing leaks, etc.

RAW WATER: Water that has not been treated in any way; it is generally considered to be unsafe to drink. Sometimes referred to as Auxiliary Water.

RESERVOIR: An impoundment used to store water.

RESIDUAL DISINFECTION/ PROTECTION: A required level of disinfectant that remains in treated water to ensure disinfection protection and prevent recontamination throughout the distribution system (i.e., pipes).

SANITIZER: A chemical which disinfects (kills bacteria), kills algae and oxidizes organic matter.

SCALE: Crust of calcium carbonate, the result of unbalanced pool water. Hard insoluble minerals deposited (usually calcium bicarbonate) which forms on pool and spa surfaces and clog filters, heaters and pumps. Scale is caused by high calcium hardness and/or high pH. You will often find major scale deposits inside a backflow prevention assembly.

SEDIMENTATION: The process of suspended solid particles settling out (going to the bottom of the vessel) in water. The use of a strainer before the backflow assembly can help remove some of the course sedimentation.

SLOPING - A method of protecting workers from cave-ins by excavating to form sides of an excavation that are inclined away from the excavation to prevent cave-ins. The angle of incline required to prevent a cave-in varies with differences such as soil type, length of exposure, and application of surcharge loads.

SOLDER: A fusible alloy used to join metallic parts. Solder for potable water pipes shall be lead-free.

SHOCK: Also known as superchlorination or break point chlorination. Ridding a pool of organic waste through oxidization by the addition of significant quantities of a halogen. Often the best cure for ridding a water line of contamination after a backflow incident.

SURFACE WATER: Water which is open to the atmosphere and subject to surface runoff; generally, lakes, streams, rivers.

SUPERCHLORINATION: Application of large dosages of chlorine to destroy buildup of undesirable compounds in water.

STANDPIPE: A water tank that is taller than it is wide.

STUFFING BOX: That portion of the pump which houses the packing or mechanical seal.

SUMMERGED: To cover with water or liquid substance.

TCE, *trichloroethylene* : A solvent and degreaser used for many purposes; for example, dry cleaning is a common groundwater contaminant.

TITRATION: method of testing by adding a reagent of known strength to a water sample until a specific color change indicates the completion of the reaction.

TOTAL ALKALINITY: A measure of the acid-neutralizing capacity of water which indicates its buffering ability, i.e. measure of its resistance to a change in pH. Generally, the higher the total alkalinity, the greater the resistance to pH change.

TOTAL DISSOLVED SOLIDS (**TDS**) The accumulated total of all solids that might be dissolved in water.

TREATED WATER: Disinfected and/or filtered water served to water system customers. It must meet or surpass all drinking water standards to be considered safe to drink.

TRIHALOMETHANES (**THM**): Four separate compounds including chloroform, dichlorobromomethane, dibromochloromethane, and bromoform. The most common class of disinfection by-products created when chemical disinfectants react with organic matter in water during the disinfection process. See Disinfectant Byproducts.

TURBIDITY: A measure of the cloudiness of water caused by suspended particles.

VALVE: A device that opens and closes to regulate the flow of liquids. Faucets, hose bibs, and ball are examples of valves.

VANE: That portion of an impeller which throws the water toward the volute.

VELOCITY HEAD: The vertical distance a liquid must fall to acquire the velocity with which it flows through the piping system. For a given quantity of flow, the velocity head will vary indirectly as the pipe diameter varies.

VENTURI: If water flows through a pipeline at a high velocity, the pressure in the pipeline is reduced. Velocities can be increased to a point that a partial vacuum is created.

WATERBORNE DISEASES: A disease, caused by a virus, bacterium, protozoan, or other microorganism, capable of being transmitted by water (e.g., typhoid fever, cholera, amoebic dysentery, gastroenteritis).

WATERSHED: An area which drains all of its water to a particular water course or body of water.

WATER PURVEYOR: The individual or organization responsible to help provide, supply, and furnish quality water to a community.

WATER WORKS: All of the pipes, pumps, reservoirs, dams and buildings that make up a water system.

Conversion Factors

1 PSI = 2.31 Feet of Water
1 Foot of Water = .433 PSI
1.13 Feet of Water = 1 Inch of Mercury
454 Grams = 1 Pound
1 Gallon of Water = 8.34 lbs/gallon
1 mg/L = 1 PPM
17.1 mg/L = 1 Grain/Gallon
1% = 10,000 mg/L
694 Gallons per Minute = MGD

<u>LENGTH</u>
12 Inches = 1 Foot
3 Feet = 1 Yard
5280 Feet = 1 Mile
<u>AREA</u>
144 Square Inches = 1 Square Foot
43,560 Square Feet – 1 Acre
<u>VOLUME</u>
1000 Milliliters = 1 Liter

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