Maximum Contaminant Level Recommendations for Arsenic in Drinking Water

Basis and Background

New Jersey Drinking Water Quality Institute

March 10, 2003

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MEMORANDUM

To: Bradley M. Campbell, Commissioner

From: Bruce Chorba, Chair, Health Effects Subcommittee /s/

                    Stephen Jenniss, Chair, Testing Subcommittee /s/

                    Paul LaPierre, Chair, Treatment Subcommittee /s/

Subject: Recommendation for the Regulation of Arsenic in Drinking Water

Date: March 10, 2003

        The fifteen member New Jersey Drinking Water Quality Institute (Institute) was established by the 1983 amendments to the New Jersey Safe Drinking Water Act (N.J.S.A. 58:12A-1 et seq., P.L. 1983, c. 443). The Institute is responsible for developing maximum contaminant levels (MCL) or standards for hazardous contaminants in drinking water and recommending these standards to the Commissioner of the N.J. Department of Environmental Protection (NJDEP).

        Three subcommittees were established to address the main areas of concern for development of MCLs as outlined in the legislation. The Health Effects Subcommittee is responsible for recommending health-based levels for contaminants of concern, the Testing Subcommittee is responsible for evaluating and recommending appropriate analytical methods to measure levels as close to the health-based levels as possible and the Treatment Subcommittee is responsible for evaluating best available treatment technologies for removal of the contaminants of concern from drinking water.

        Arsenic is a known human carcinogen and is known to occur in New Jersey drinking water sources. The Institute reviewed health effects, analytical methods and New Jersey certified laboratory testing capabilities and treatment information for arsenic in drinking water at the request of NJDEP. The three Subcommittees met during 2001, 2002 and 2003 to review the most

recent literature on arsenic and to formulate recommendations to NJDEP based on the legislative direction in the 1983 amendments to the New Jersey Safe Drinking Water Act.

The Institute recognizes that the health-based goal for establishing a drinking water standard for carcinogenic substances in New Jersey, as stated in the 1983 amendments to the New Jersey Safe Drinking Water Act, is a one in one million excess cancer risk over a lifetime exposure period. The Institute determined that the drinking water concentration resulting in a one in one million excess cancer risk over a lifetime exposure for arsenic is 0.003 µg/L. The Institute has determined that 3 µg/L is the practical quantitation level that can be achieved by New Jersey certified drinking water laboratories using appropriate federally approved methods, and that arsenic can be removed from drinking water to a level of 3 µg/L based on treatment technologies that are currently available.

The 1983 amendments to the New Jersey Safe Drinking Water Act state that MCLs for carcinogens must be set, within the limits of medical, scientific and technological feasibility, at a level which would not permit cancer in more than one in one million persons ingesting the chemical for a lifetime. Since the health-based goal is not achievable within the limits of scientific and technological feasibility, the Institute recommends that NJDEP adopt a drinking water standard of 3 µg/L for New Jersey.

The Institute is recommending a 3 µg/L drinking water standard to NJDEP with the understanding that the technology for analyzing arsenic in drinking water is improving, as is the treatment technology for removing arsenic from drinking water. The Institute recommends that NJDEP periodically request that the Institute review the latest findings for arsenic testing and treatment in anticipation of future recommendations regarding this chemical.

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Basis and Background

New Jersey Drinking Water Quality Institute

March 10, 2003

Prepared by Sandra Krietzman, M.S.
Water Supply Administration, Bureau of Safe Drinking Water
New Jersey Department of Environmental Protection

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Maximum Contaminant Level Recommendations
For Arsenic in Drinking Water

Executive Summary

Arsenic is a known human carcinogen and is known to occur in New Jersey drinking water sources. The Commissioner of the New Jersey Department of Environmental Protection (NJDEP) requested that the New Jersey Drinking Water Quality Institute (Institute) review the most current literature on arsenic in drinking water and recommend a Maximum Contaminant Level (MCL) to NJDEP.

The health-based goal for establishing a drinking water standard for carcinogenic substances in New Jersey, as stated in the 1983 Amendments to the New Jersey Safe Drinking Water Act, is a one in one million excess cancer risk over a lifetime exposure period. The Institute determined that the drinking water concentration resulting in a one in one million excess cancer risk over a lifetime exposure for arsenic is 0.003 µg/L. The Institute has determined that 3 µg/L is the practical quantitation level that can be achieved by New Jersey certified drinking water laboratories using appropriate federally approved methods and that arsenic can be removed from drinking water to a level of 3 µg/L based on treatment technologies that are currently available.

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The Institute is recommending a 3 µg/L drinking water standard to NJDEP with the understanding that the technology for analyzing arsenic in drinking water is improving as is the treatment technology for removing arsenic from drinking water. The Institute recommends that NJDEP periodically request that the Institute review the latest findings for arsenic testing and treatment in anticipation of future recommendations regarding this chemical.

Purpose

The federal MCL for arsenic in drinking water that will take effect on January 23, 2006 is 0.10 milligrams per liter (mg/L or parts per million, "ppm") or 10 micrograms per liter (µg/L or parts per billion, "ppb"). The arsenic standard of 10 µg/L in drinking water was made more stringent by the United States Environmental Protection Agency (USEPA) on January 22, 2001, and after a series of delays in 2001, became effective on February 22, 2002. The Federal standard of 50 µg/L that is currently in effect has been the U.S. Public Health Service standard since 1942. New Jersey regulations adopt all federal primary drinking water standards into New Jersey regulations by reference. New Jersey can promulgate drinking water standards as long as these MCLs are at least as protective as the federal standards.

At the request of NJDEP, the Institute began the work of reviewing the most current information regarding the health effects, analytical capability and treatment removal technologies available for the removal of arsenic from drinking water. The Institute also reviewed occurrence and levels of arsenic found in New Jersey drinking water. The Institute adopted the recommendations presented in this Basis and Background document and the attachments. The members of the Institute are listed in Appendix A. The reports prepared by the three Subcommittees are attached to this document as Appendices B, C, and D and provide much in depth information summarized briefly herein.

1983 New Jersey Safe Drinking Water Act Amendments and the New Jersey Drinking Water Quality Institute

The 1983 Amendments to the New Jersey Safe Drinking Water Act, also known as the "A-280 Amendments" (N.J.S.A. 58:12A-1 et seq.), require that MCLs be adopted for a given list of 22 organic contaminants. Furthermore, these amendments direct the development of MCLs for additional drinking water contaminants selected due to their health effects and occurrence in New Jersey waters, such as metals, base/neutrals, and pesticides.

The 1983 Amendments provide for the establishment of the Institute, consisting of six ex officio and nine appointed members, to advise NJDEP on drinking water issues. These members represent the public, the academic community, the water purveyors, NJDEP, the New Jersey Department of Health and Senior Services (NJDHSS), and the Water Supply Advisory Council.

In 1987, the Institute provided MCL recommendations for the list of contaminants in the 1983 amendments, and in 1994, it updated these recommendations and provided recommendations for six additional organic contaminants of concern. The recommendations have been adopted by NJDEP to form the basis for enforceable MCLs for most of these contaminants. The Institute also developed recommendations for modifications of the requirements of the existing radium MCL to reduce risk from exposure to radium-224. The Institute concluded that the USEPA MCL of a gross alpha limit of 15 picocuries per liter (pCi/L), excluding uranium and radon, is protective to the public for unacceptably high exposure to radium-224 in drinking water, provided that a requirement for rapid (within 48 hour) gross alpha-particle analysis is incorporated. NJDEP adopted a rapid (within 48 hours) gross alpha-particle analysis on September 16, 2002.

Factors Considered in Maximum Contaminant Level Development

The 1983 Amendments specify that MCLs for carcinogenic compounds are to be developed which "…permit cancer in no more than one in one million persons ingesting that chemical for a lifetime…" "…. within the limits of medical, scientific and technological feasibility." The Institute has interpreted technical feasibility to include the levels at which contaminants can be reliably quantitated by analytical methods (practical quantitation limits or PQLs) as well as the capability of treatment methods to remove the contaminants to specified levels. Cost is not a direct consideration in MCL derivation for carcinogens.

In contrast, for noncarcinogens, MCLs are to be derived which eliminate "…all adverse physiological effects from ingestion…" "…within the limits of practicability and feasibility…". Practicability has been interpreted by the Institute as permitting the consideration of cost for MCLs for noncarcinogens.

In order to develop MCL recommendations, the Institute established three Subcommittees to address the factors of health effects, analytical limitations, and treatment. The Health Effects Subcommittee (formerly known as the Lists and Levels Subcommittee) evaluates relevant health effects information and uses risk assessment approaches to derive the health based level, known as the Health-based Maximum Contaminant Level, which becomes the MCL if technological considerations allow. The Testing Subcommittee evaluates available analytical methods and derives the PQL, the level where quantitation can be achieved with acceptable uncertainty by most laboratories. The Treatment Subcommittee evaluates the capabilities of drinking water treatment methods to remove the contaminants to the Health-based MCL. The final MCL is set at the Health-based MCL if analytical and treatment considerations allow. If the analytical or treatment limits are higher than the health-based level, the MCL is set as close to the Health-based MCL as these considerations allow.

Occurrence of Arsenic in New Jersey Water

Arsenic in drinking water occurs from either natural or man-made sources. In ground water, natural rock materials comprising the aquifer can contain large reservoirs of arsenic and are usually the major source of aqueous arsenic (Welsh and others, 2000). Before synthetic organic pesticides were available, arsenic-based pesticides were widely used throughout New Jersey to protect crops from various infestations. However, arsenic from pesticides is strongly bound to near surface soil particles and is rarely a major source of arsenic in ground water unless a competing ion such as phosphate is subsequently applied. In that case, a slug of arsenic may locally impact ground water.

Black organic-rich fine-grained sedimentary rocks in the Newark Basin, in the Piedmont Physiographic Province in New Jersey, can contain over 100 mg/L arsenic, and the mineral pyrite (FeS_2) found in those rocks can contain up to 40,000 mg/L arsenic (Serfes, 2001). Data compiled by the New Jersey Geological Survey (NJGS) from public water supplies and the State's ambient ground water quality network reveal that arsenic concentrations in ground water are highest (up to 57 µg/L) in the Piedmont. Recent sampling in the Piedmont has revealed several wells with concentrations exceeding that value, one with up to 200 µg/L arsenic. Aquifers in the Piedmont are mainly comprised of red, gray and black shale and sandstone. Sampling by the NJGS (Serfes and others, 2000, 2001) of domestic wells in a 200 square mile study area in the western part of the Piedmont in New Jersey, indicate that 15 percent of the wells have arsenic concentrations exceeding 10 µg/L and approximately 50 percent are over 3 µg/L. Well water with arsenic concentrations greater than 10 µg/L, have low dissolved oxygen concentrations (DO < 3 mg/L) and pH values range from 7.5 to 8.0.

Arsenic exists in drinking water primarily in the inorganic state, and arsenite (+3) and arsenate (+5) are the prevalent toxic species found in drinking water (NRC, 1999). Oxidation-reduction, pH, and chemical and biological factors control the speciation of arsenic in ground water. In

New Jersey ground water, testing by NJGS showed that both arsenic species are present (As3+ or As5+) however As5+ generally dominates. The mineral pyrite is usually unstable in the oxidizing conditions found at or near the ground surface. Therefore, the mobilization and transport of arsenic likely involves the oxidation of natural pyrite in the recharge area of the ground water containing arsenic. The reduction in the dissolved oxygen content associated with this process and an increasingly alkaline environment along the ground-water flow path will facilitate arsenic solubility and are consistent with the field observations above.

Of 606 active community water systems in New Jersey in 2002, there are 44 systems with arsenic concentrations at or above 3 µg/L, according to NJDEP, Bureau of Safe Drinking Water compliance data records from January 1993 - August 2002. The values reported in community water systems ranged from 3.7 µg/L to 50 µg/L. The majority of the community eater systems with arsenic concentrations greater than or equal to 3.0 µg/L produce more than 0.5 million gallons per day (mgd). Of the 970 active nontransient noncommunity water systems in New Jersey in 2002, there are 147 systems with arsenic concentrations that equal or exceed 3 µg/L. The values reported in nontransient noncommunity water systems ranged from 3.1 µg/L to 29 µg/L.

Health Effects of Arsenic and Recommendations of Health Effects Subcommittee

The Health Effects Subcommittee is responsible for evaluating health effects information and using risk assessment approaches to derive the health based level, known as Health-based MCL. A Health-based MCL is the goal for establishing the MCL if technological considerations allow. Arsenic is classified by USEPA as a Group A carcinogen, known to be a human carcinogen from human epidemiological studies. The Health-based MCL for carcinogens in drinking water in New Jersey is a one in one million excess cancer risk based on a lifetime exposure.

The Health Effects Subcommittee reviewed the March 1999 publication of the National Academy of Sciences Subcommittee on Arsenic of the Committee on Toxicology of the National Research Council (NRC) and the 2001 update. The NRC was charged with reviewing USEPA's arsenic risk assessment. Exposure to arsenic in drinking water has been linked to human cancers of several sites, including skin, bladder, lung, liver, and kidney. Systemic (non-cancer) effects of arsenic include dermatological toxicity, peripheral vascular disease, and increased risk of cardiovascular disease, diabetes, and gastroenterological disease.

The most recent quantitative estimates of the risk of cancer from arsenic in drinking water were developed by the NRC. Based on the analysis of the NRC, the Health Effects Subcommittee determined that the level of arsenic in drinking water resulting in a lifetime cancer risk of one in one million, or 10^{-6}, is estimated to be 0.003 µg/L. A more detailed description of the health information used to derive the Health-Based MCL recommendation is found in Appendix B.

Analytical Considerations and Recommendations of the Testing Subcommittee

The Testing Subcommittee is responsible for evaluating available analytical methods and deriving the Practical Quantitation Level (PQL), the level where quantitation can be achieved with acceptable uncertainty by most laboratories. This approach to standard setting, using PQLs instead of Method Detection Limits (MDLs) was first recommended by the Institute in 1987. At that time an inter-laboratory study was conducted to determine at which levels above the MDLs the PQLs could be established. Such New Jersey inter-laboratory study data were not available at this time for the determination of the arsenic PQL.

The Testing Subcommittee evaluated a number of resources in order to derive the PQL for arsenic. These resources include the New Jersey State and Federally approved analytical methods for arsenic in drinking water, arsenic regulatory sampling data submitted to the Bureau of Safe Drinking Water, and the USEPA document "Analytical Methods Support Document For Arsenic In Drinking Water" (December 1999).

The Testing Subcommittee concluded that accurate detection and quantitation of arsenic in drinking water can be achieved at the lower end of a range of the calculated PQL values using the published methods. The PQL value that the Testing Subcommittee is recommending is 3 μg/L. The USEPA "Analytical Methods Support Document" derived a PQL based upon a statistical analysis of laboratory proficiency test data that also supports this level of 3 μg/L. Appendix C contains a more detailed description of the analytical information used to derive the recommended PQL for arsenic.

Treatment Considerations and Recommendations of the Treatment Subcommittee

The Treatment Subcommittee is responsible for evaluating the capabilities of drinking water treatment methods to remove arsenic to the Health-based MCL. Because many of the technologies being used for the removal of arsenic from drinking water are very new, NJDEP contacted the New Jersey Center for Advanced Technology for assistance in locating a national expert in the field of arsenic treatment technology to assist NJDEP in evaluating treatment capability for New Jersey specific water quality conditions. Malcolm Pirnie, a national environmental engineering consulting firm, was hired to prepare a literature review that would address the treatment capability of current arsenic removal technologies in New Jersey. This document served as a basis for the recommendations of the Treatment Subcommittee. A summary of the findings is located in Appendix D.

Based on the findings of this study, the Treatment Subcommittee concluded that the most feasible and cost effective treatment technologies for New Jersey waters are likely to be 1) ion exchange (IX), 2) activated alumina adsorption (AA), 3) granular ferric hydroxide adsorption (GFH), and 4) coagulation/filtration (CF). Each of these four technologies has demonstrated reliable performance for reducing arsenic levels to below 3 μg/L when processing raw waters similar to those found in New Jersey. The capital and operating costs of each technology vary depending on the influent and targeted effluent arsenic levels.

Overall Maximum Contaminant Level Recommendation

The health-based goal for establishing a drinking water standard for carcinogenic substances in New Jersey, as stated in the 1983 Amendments to the New Jersey Safe Drinking Water Act, is a one in one million excess cancer risk over a lifetime exposure period. The Institute determined that the drinking water concentration resulting in a one in one million excess cancer risk over a lifetime exposure for arsenic is 0.003 µg/L. The Institute has determined that 3 µg/L is the practical quantitation level that can be achieved by New Jersey certified drinking water laboratories using appropriate federally approved methods and that arsenic can be removed from drinking water to a level of 3 µg/L based on treatment technologies that are currently available.

The 1983 Amendments to the New Jersey Safe Drinking Water Act state that MCLs for carcinogens must be set, within the limits of medical, scientific and technological feasibility, at a level which would not permit cancer in more than one in one million persons ingesting the chemical for a lifetime. Since the health-based goal is not achievable within the limits of scientific and technological feasibility, the Institute recommends that NJDEP adopt a drinking water standard of 3 µg/L for New Jersey.

Appendix A: Members of the New Jersey Drinking Water Quality Institute
(March 10, 2003)

APPOINTED MEMBERS

1.   Bruce Chorba
2.   Raymond DiFrancesco
3.   Paul La Pierre, P.E., P.L.S., P.P.
4.   Jean M. Matteo
5.   David Pringle
6.   Kenneth Reuhl, Ph.D.

EX OFFICIO MEMBERS

- COMMISSIONER OF ENVIRONMENTAL PROTECTION
    Bradley M. Campbell
    ALTERNATE: Barker Hamill, Bureau Chief, Bureau of Safe Drinking Water, NJDEP

- CHAIRMAN, WATER SUPPLY ADVISORY COUNCIL
    Eugene Golub, Ph.D.

- DIRECTOR, DIVISION OF WATER RESOURCES
    DESIGNEE: Leslie McGeorge, M.S.P.H., Administrator, Water Monitoring and Standards, NJDEP

- DIRECTOR, OFFICE OF SCIENCE AND RESEARCH
    DESIGNEE: Eileen Murphy, Ph.D., Assistant Director, Division of Science, Research and Technology, NJDEP

- COMMISSIONER OF HEALTH
    Dr. Clifton R. Lacy
    DESIGNEE: Stephen W. Jenniss, Director, Environmental and Chemical Laboratory Services, NJDHSS

- DIRECTOR, DIVISION OF OCCUPATIONAL AND ENVIRONMENTAL HEALTH
    DESIGNEE: Perry Cohn, Ph.D., M.P.H., Research Scientist, Consumer and Occupational Health Services, NJDHSS

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Appendix B: Health Effects of Arsenic

Health Effects Subcommittee
New Jersey Drinking Water Quality Institute

Updated: December 6, 2002

Prepared by
Gloria Post, Ph.D.
Division of Science, Research, and Technology
New Jersey Department of Environmental Protection

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Health Effects of Arsenic

Summary

Exposure to arsenic in drinking water has been linked to human cancers of several sites, including skin, bladder, lung, liver, and kidney. Systemic (non-cancer) effects of arsenic include dermatological toxicity, peripheral vascular disease, and increased risk of cardiovascular disease, diabetes, and gastroenterological disease. The most recent quantitative estimates of the risk of cancer from arsenic in drinking water were developed by the National Research Council (2001). The lifetime cancer risks for lung and bladder cancer (the cancers considered most relevant to the population in the United States) were estimated to be 1 x 10^{-3} at 3 µg/L, 3-4 x 10^{-3} at 10 µg/L, and 6-7 x 10^{-3} at 20 µg/L. Based on this analysis, the level of arsenic in drinking water resulting in a lifetime cancer risk of one in one million, or 10^{-6}, is estimated to be 0.003 µg/L.

Overview of Arsenic Toxicity

Arsenic exists in drinking water primarily in the inorganic state, and arsenite (+3) and arsenate (+5) are the most prevalent toxic forms found in drinking water (NRC, 1999, USEPA, 2000a). Although arsenites are thought to be somewhat more toxic than arsenates, the forms are not considered separately when evaluating potential health effects in drinking water because the differences in toxicity are relatively small, the various forms of arsenic can be interconverted both in the environment and in the body, and the analytical methods used do not usually speciate arsenic (ATSDR, 2000).

The toxicity of arsenic has been thoroughly reviewed in four recent documents (NRC,1999, 2001; ATSDR,2000, USEPA, 2000a). The toxic endpoints of concern for arsenic in drinking water relate to chronic effects of arsenic; levels found in drinking water are below those resulting in acute effects. Acute effects resulting from accidental or intentional exposure to large doses of arsenic involve the skin, nervous system, gastrointestinal system, blood and kidneys. The LD_{50} for poisoning incidents has been reported to be 1-4 mg/kg (USEPA, 2000a).

Effects of chronic exposure of humans to lower levels of arsenic include both systemic (non-cancer) toxicity and cancer. Much of the data on these effects comes from studies of populations with elevated levels of arsenic in their drinking water in a number of locations throughout the world including Taiwan, Bangladesh, South America, and the western United States.

The most prominent systemic effects of long-term arsenic exposure involve the skin, and include hyperpigmentation and development of keratoses. The peripheral vascular system may also be affected, and hardening of the arteries can occur. Black foot disease, a severe peripheral vascular insufficiency which can cause gangrene of the extremities, has been reported in Taiwanese individuals exposed to arsenic. In Utah, exposure to arsenic in drinking water has been linked to hypertensive heart disease, demonstrating impacts on the cardiovascular system. Arsenic exposure has also been linked to an increased risk of diabetes, and adverse effects on the gastroenterological system.

Arsenic is one of a relatively small number of chemicals which has been classified by USEPA as a Known Human Carcinogen, based on human epidemiological data. Unlike most other carcinogens of environmental concern, arsenic does not induce cancer in the animal models in which it has been tested, perhaps due to differences in metabolism between the test animals and humans.

Exposure to arsenic through drinking water has long been linked to an increased risk of skin cancer in humans. More recently, an elevated risk of internal cancers has been demonstrated in populations from Taiwan, Argentina, and Chile. The organs in which cancer rates were reported to be elevated include bladder, lung, liver, and kidney (reviewed in NRC, 1999 and 2001). A recent study of the relationship between arsenic in drinking water and cancer in Utah (Lewis et al., 1999) was negative; however, NRC (2001) concluded that limitations in the study design make it unsuitable for qualitative risk assessment.

The mechanism of action by which arsenic causes cancer has not been definitively elucidated. Arsenic appears to impact a number of cellular processes involved with DNA repair and chromosome replication, leading to he hypothesis that it causes cancer by indirect mechanisms, rather than by directly interacting with DNA. However, a recent study (Mass et al., 2001) demonstrates that methylated trivalent forms of arsenic, which can be formed through metabolic processes from inorganic arsenic, can act directly to damage DNA <u>in vitro</u>.

<u>Overview of Risk Assessment</u>
Quantitative estimates of risks of arsenic in drinking water come from human epidemiological studies, rather than studies in laboratory animals. The fact that cancer and systemic diseases have been observed in humans, rather than only in non-human species, strengthens the conclusion that humans are at risk from exposure to arsenic. However, the exposures to arsenic in these individuals are not controlled, as in laboratory studies, but must be estimated from information on drinking water arsenic levels and water consumption data in the populations of interest.

As discussed above, the mode of action for arsenic carcinogenicity has not been established. The National Research Council (NRC, 1999) concluded that: "…the several modes of action that are considered plausible (namely, indirect mechanisms of mutagenicity) would lead to a sublinear dose-response curve at some point below the point at which a significant increase in tumors is observed. …. However, because a specific mode (or modes) of action has not yet been identified, it is prudent not to rule out the possibility of a linear response." USEPA's public health policy is to assume linearity of dose-response for chemicals whose mode of action has not been sufficiently characterized. This science policy approach is intended to provide a "public health conservative assessment of risk" (USEPA, 2000a). Furthermore, the National Research Council (NRC, 2001) concluded that arsenic exposures at relatively low levels are of concern since "…in laboratory studies, cellular effects of arsenic occur at concentrations below those found in the urine of people who had ingested drinking water with arsenic at concentrations as low as 10 µg/L."

The National Research Council (NRC, 1999, 2001) concluded that the data from Taiwanese epidemiology studies are the best source of data for developing quantitative estimates of arsenic

risk. The types of cancers found to be elevated in individuals exposed to arsenic in Taiwan include bladder, lung, and liver. The risk estimates considered relevant for estimation of risk from drinking water in the United States are those based on bladder and lung cancer data. The Taiwanese liver cancer data was not utilized because most of the Taiwanese liver cancers were hepatocellular tumors which are linked to hepatitis, and this type of cancer is extremely rare in the United States.

Morales et al. (2000) presented risk estimates based on a number of variations of the generalized linear model and the multistage-Weibull model. Estimates were developed both using mortality data from an external comparison population (other parts of Taiwan) whose exposure was assumed to be zero, or without a comparison population, using dose-response data developed only from the study population.

The most recent analysis of arsenic risks developed by the National Research Council (NRC, 2001 recommends using an external comparison population, based on recent evidence that lifestyle factors such as nutritional status and smoking have little influence on the arsenic risk. The 2001 NRC analysis used a linear extrapolation from the ED_{01} (dose causing 1% increase over background) to derive its risk-based levels. The risk levels given are maximum likelihood (central-point) estimates, not 95% upper bound (worst case) estimates, which would be more conservative. The risk estimates presented are based on increase over background cancer rates in the United States, rather than in Taiwan. Since the background cancer rates are higher in the U.S. than in Taiwan, the risks based on the U.S. background are 2-3 fold higher than if Taiwan background rates were used.

The National Research Council (NRC, 2001) concluded that it would be difficult to detect increases in cancer risk from arsenic statistically in the U.S. population, even at the highest of the possible risk levels. The lifetime cancer risks for lung and bladder cancer for various arsenic concentrations given are approximately: 3 µg/L - 1 x 10^{-3}; 10 µg/L - 3-4 x 10^{-3}; 20 µg/L - 6 -7 x 10^{-3}. These are maximum likelihood estimates based on southwestern Taiwan data with an external comparison population, and US background cancer rates. Arsenic exposure was estimated using body weight and water ingestion assumptions appropriate for Taiwan. These values are very close to those that would be obtained from the Chile study.

The risk estimates presented in NRC (2001) are somewhat higher than the lifetime cancer risk estimates previously presented by USEPA of 5-8 x 10^{-4} for the maximum likelihood estimate at 10 µg/L (USEPA, 2000b). Differences from the earlier analysis are based on factors such as different comparison population, use of background cancer incidence from US instead of Taiwan, method for adjustment for arsenic in food, and assumptions for water consumption.

Conclusion and Recommendation

Based on the analysis of NRC (2001), the level of arsenic in drinking water resulting in a lifetime cancer risk of one in one million, or 10^{-6}, is estimated to be 0.003 µg/L. It is recommended that the risk estimates presented in NRC (2001) be utilized by the New Jersey Drinking Water Quality Institute in its development of an MCL for arsenic.

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USEPA (2000b). United States Environmental Protection Agency. Arsenic in Drinking Water Rule Economic Analysis. EPA 815-R-00-026. December 2000.

Appendix C: Basis and Background for Arsenic Practical Quantitation Level (PQL)

Testing Subcommittee
New Jersey Drinking Water Quality Institute

February 19, 2003

Prepared by
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Bureau of Safe Drinking Water
New Jersey Department of Environmental Protection

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Basis and Background
For
Arsenic Practical Quantitation Level (PQL)

The Practical Quantitation Level (PQL) is defined as the level above the Method Detection Limit (MDL) at which quantitation can be achieved by most laboratories within acceptable levels of uncertainty. This approach to standard setting, using PQLs instead of MDLs, was first recommended by the Drinking Water Quality Institute in 1987. At that time an inter-laboratory study was conducted to determine at which levels above the MDLs the PQLs could be established. Such New Jersey inter-laboratory study data were not available at this time for the determination of the arsenic PQL. The Testing Subcommittee evaluated a number of resources in order to derive the PQL for arsenic. They are as follows:

1. NJ State and Federally approved analytical methods for arsenic in drinking water.

2. Arsenic regulatory sampling data submitted to the Bureau of Safe Drinking Water for the period January 1, 2001 to September 11, 2002 and phone inquiries to certified labs that perform significant amounts of drinking water work for New Jersey.

3. The United States Environmental Protection Agency (USEPA) document "Analytical Methods Support Document For Arsenic In Drinking Water"

Approved Analytical Methods for Arsenic in Drinking Water

There are currently eight methods approved by the USEPA for the analysis of arsenic in drinking water. Two of these methods have allowable modifications. The eight methods have been adopted by reference by NJDEP's Office of Quality Assurance (OQA) and appear in their Part III of the Application for Certification of Environmental Measurements/Analytical Parameters. These methods (including the modifications) and their MDLs are listed below along with estimated cost, in Table 1.

As part of the PQL determination, the Testing Subcommittee reviewed the arsenic data which were submitted for compliance monitoring by public water systems to the Bureau of Safe Drinking Water for the period from January 1, 2001 to September 11, 2002. The Testing Subcommittee used these data to determine which of the approved methods were being used by NJ certified labs to analyze arsenic in drinking water. For this period of time there were 1731 valid data submissions. Table 2 details the number of times each method was used for compliance purposes as well as the number of labs using each method.

The compliance date for requirements related to the revised federal arsenic in drinking water standard is January 23, 2006. After that date, the two ICP-AES methods, USEPA 200.7 and SM 3120B, will no longer be approved for arsenic in drinking water compliance determinations because of their high MDLs. As a result of this action, the Testing Subcommittee also did not consider them when determining a PQL for arsenic.

Table 1. Approved Analytical Methods (and Method Updates) for Arsenic (40 CFR 141.23) Allowed Prior to Effective Date of Federal Revision to Arsenic Drinking Water Standard *

Methodology	Reference Method	Published MDL (µg/L)	Estimated Analytical Cost Range ($)
Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES)	EPA 200.7	8	15 to 25
Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES)	SM 3120B	50	15 to 25
Inductively Coupled Plasma-Mass Spectroscopy (ICP/MS)	EPA 200.8	1.4	10 to 15
Inductively Coupled Plasma-Mass Spectroscopy (ICP/MS) (modification)	EPA 200.8 SIM	0.1	Not specified
Stabilized Temperature Platform Graphite Furnace Atomic Absorption (STP/GFAA)	EPA 200.9	0.5	15 to 50
Stabilized Temperature Platform Graphite Furnace Atomic Absorption (STP/GFAA) (modification)	EPA 200.9 multiple deposition	0.1	Not specified
Graphite Furnace Atomic Absorption (GFAA)	SM 3113B**	1	15 to 50
Graphite Furnace Atomic Absorption (GFAA)	ASTM D2972-93C	5	15 to 50
Gaseous Hydride Atomic Absorption (GHAA)	SM 3114B**	0.5	15 to 50
Gaseous Hydride Atomic Absorption (GHAA)	ASTM D2972-93B	1	15 to 50

* Source: National Primary Drinking Water Regulations: Arsenic and Clarifications to Compliance and New Source Contaminant Monitoring: **Federal Register**, Vol. 65, No. 121, June 22, 2000 and **Federal Register**, Vol. 66, No. 14, January 22, 2001.
** 19th Edition of Standard Methods for the Examination of Water and Wastewater.

Table 2. Arsenic Data Submitted to the Bureau of Safe Drinking Water for Regulatory Compliance with the State and Federal Safe Drinking Water Acts

Methodology	Reference Method	Number of Samples Submitted	% of Samples Submitted	Number of Labs Using Method
ICP-AES	EPA 200.7	539	31	9
ICP-AES	SM 3120B	0	0	0
ICP/MS	EPA 200.8	85	5	5
STP/GFAA	EPA 200.9	456	26	16
GFAA	SM 3113B	651	38	16
GFAA	ASTM D2972-93C	0	0	0
GHAA	SM 3114B	0	0	0
GHAA	ASTM D 2972-93B	0	0	0

As noted above in Table 1, both USEPA Method 200.8 and 200.9 have allowable modifications that result in a lower method detection limit. Specifically, in 1994 (59 FR 62456), USEPA approved the use of the updated "Methods for the Determination of Metals in Environmental Samples - Supplement I." This allows for the use of selective ion monitoring (SIM) with ICP-

MS (EPA Method 200.8). The MDL listed in the method (Supplement I) for the SIM analysis of arsenic in aqueous samples is 0.1 μg/L. In addition, Supplement I also allows the use of multiple depositions monitoring with STP-GFAA (EPA Method 200.9). The published MDL for arsenic using multiple deposition with STP-GFAA is 0.1 μg/L.

The Testing Subcommittee contacted the certified labs that perform the majority of data submissions for New Jersey public water systems using EPA Methods 200.8 and 200.9. All of the contacted labs reported that they do not run EPA Method 200.8 or 200.9 with the modifications. As a result of this, the Testing Subcommittee did not consider these two method modifications when determining the current PQL for arsenic.

The Testing Subcommittee also did not consider ASTM Method D2972-93C when determining the PQL. While this is currently an acceptable method for arsenic, and will continue to be allowed under the new federal regulations for arsenic, this method has a relatively high method detection level and there are currently no public water systems submitting data for compliance with the Federal and State Drinking Water Acts using this method.

Table 3 shows the methods finally considered by the Testing Subcommittee to determine the PQL for arsenic:

Table 3. Method Detection Limits for Arsenic Methods Considered by the Testing Subcommittee in Determination of a Practical Quantitation Level (PQL)

Methodology	Reference Method	Published MDL (μg/L)	MDL Range Reported by NJ Labs (μg/L) *
Inductively Coupled Plasma-Mass Spectroscopy (ICP/MS)	EPA 200.8	1.4	0.15-0.5
Stabilized Temperature Platform Graphite Furnace Atomic Absorption (STP/GFAA)	EPA 200.9	0.5	0.48-10
Graphite Furnace Atomic Absorption (GFAA)	SM 3113B	1	0.2-8
Gaseous Hydride Atomic Absorption (GHAA)	SM 3114B	0.5	--
Gaseous Hydride Atomic Absorption (GHAA)	ASTM D2972-93B	1	--

* New Jersey MDLs collected by phone inquiries in the summer of 2001.

The Testing Subcommittee discussed the application of various multiplication factors applied to MDLs to derive a PQL. Historically, New Jersey has used a factor of 5 applied to an analytical method detection limit to calculate a PQL. This approach has been used by the Testing Subcommittee to develop PQLs for new contaminants for regulation in drinking water (Maximum Contaminant Recommendations for Hazardous Contaminants in Drinking Water, September 26, 1994) and is codified in the Ground Water Standards (N.J.A.C. 7:9-6). This procedure for establishing PQLs was based on an evaluation of approaches used by the other agencies, such as the USEPA drinking water program and the American Chemical Society. These other programs use factors ranging from 3.3 to 5 for PQL calculation.

The MDLs for arsenic reported by New Jersey labs are generally higher than the MDLs listed in the published methods, with the exception of those laboratories that use EPA method 200.8. This is because an MCL of 50 μg/L was in effect prior to February 22, 2002 and compliance

with the MCL of 10 µg/L adopted by USEPA is not required until January 23, 2006. The ranges of MDLs from New Jersey laboratories, collected in 2001, are reported in Table 3. The Testing Subcommittee contacted the five New Jersey certified labs that submit data using EPA Method 200.8, which has the highest published detection limit of 1.4 µg/L. Some of these five laboratories reported that their laboratory method detection limit for this method is an order of magnitude lower that the published MDL.

The Testing Subcommittee chose to review the published MDLs in their analysis because accurate MDL data were difficult to obtain from the historic DEP database. It was the opinion of the Testing Subcommittee that the test results submitted by water systems (for compliance purposes) were not reported to the lowest MDL possible. The published method detection limits in Table 3 range from 0.5 µg/L to 1.4 µg/L. In a PQL determination using a factor of 5, a practical quantitation range of 2.5 to 7.0 µg/L would result. This is generally consistent with the MDLs being reported by NJ labs.

As a result of the preceding information, the Testing Subcommittee concluded that accurate detection and quantitation of arsenic in drinking water can be achieved at the lower end of a range of the calculated PQL values using the published methods. The PQL value that the Testing Subcommittee is recommending is 3 µg/L. A study[1] by USEPA that derived a PQL based upon a statistical analysis of laboratory proficiency test data also supports this level of 3 µg/L.

Additional Considerations

1. Occurrence Data:

The Testing Subcommittee looked at the number of times arsenic was detected within the time period of data submitted between January 1, 2001 and September 11, 2002. Overall, arsenic was detected in 150 of the 1731 data submissions. However, because the MDL for EPA Method 200.7 was much higher than the other methods (typically 8 µg/L versus 1-3 µg/L), the Testing Subcommittee expects the total number of systems with detections to increase if the PQL is set at 3 µg/L. This is illustrated in Table 4, below.

Table 4. Percentage of Detections by Method in Data Submitted for Regulatory Compliance Between January 1, 2001 and September 11, 2002

Method	Total Number of Submissions	Number of Detections	Percentage of Detections
EPA 200.7	539	14	2.6%
EPA 200.8	85	7	8.2%
EPA 200.9	456	84	18.4%
SM 3113B	651	45	6.9%

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[1] "Analytical Methods Support Document for Arsenic in Drinking Water," December 1999, EPA-814-R-00-010.

2. Laboratory Capacity:

Of the nine labs that had submitted arsenic data by method 200.7, only five have accreditation exclusively in EPA Method 200.7. Of those five, two have "Applied Status" in EPA Method 200.9 and another has recently purchased an ICP/MS. The two labs that submit the bulk of the data to the state using EPA Method 200.7 also have accreditation for EPA Method 200.9 which has a lower MDL. The investigation of these data has revealed that there exists a sufficient number of certified methods and certified laboratories that should be capable of reliably and accurately measuring arsenic to the low μg/L level.

3. Calibration Range:

The Testing Subcommittee recommends that the NJDEP's Office of Quality Assurance require laboratories to use a standard calibration range that is between 0.5 μg/L and 50 μg/L with the lowest calibration point not to exceed 2 μg/L. This will improve the reported laboratory MDLs and add confidence in the lower level values.

4. Use of EPA Method 200.7:

The Testing Subcommittee is recommending a PQL for arsenic in drinking water of 3 μg/L. Currently, EPA Method 200.7 has a published method detection limit of 8 μg/L. In addition, 512 of 539 results submitted to NJDEP using this method during the period reviewed had a reported MDL greater than 3.4 μg/L. The question of how to deal with this method if there is an interim period between the New Jersey establishment of a lower Maximum Contaminant Level and the USEPA sunset of the method for arsenic analysis must be addressed by NJDEP's Office of Quality Assurance. The NJDEP Bureau of Safe Drinking Water may be able to accept data from laboratories using EPA Method 200.7 if certain quality assurance criteria are met. The Testing Subcommittee recommends that the NJDEP Office of Quality Assurance assess this issue and determine if 1) EPA Method 200.7 should be suspended as a NJ certified method or 2) permit laboratories to use EPA Method 200.7 provided that certain quality control and assurance criteria are met by the laboratories and that they demonstrate their ability to achieve an MDL significantly below 3 μg/L. The Testing Subcommittee also recommends that if the Office of Quality Assurance decides to permit the usage of EPA Method 200.7 during this interim period, that the laboratories be required to use a lower calibration range as discussed above and that the proficiency test sample used by the NJDEP to evaluate a laboratory's testing capability during that period be of a concentration below 8 and as close to the new PQL as reasonably possible.

5. Future Use of Analytical Methods:

The Testing Subcommittee recognizes that the modifications to EPA Methods 200.8 and 200.9, as discussed above, may result in a lower method detection limit. The Testing Subcommittee did not consider these method modifications in determining the current PQL; however, in the future, that may be an appropriate issue to address.

6. Summary of USEPA Development of the PQL:

A USEPA Document published in 1999, <u>Analytical Methods Support Document For Arsenic In Drinking Water</u> described the PQL determination process for arsenic.

 In the derivation of a PQL, the USEPA considers the following:
- Quantitation
- Precision and bias
- Normal operations of a laboratory
- The availability of a sufficient number of labs able to conduct compliance monitoring analyses.

In the derivation of a PQL the USEPA employs one of two processes:

a)   The use of data from Water Supply (WS) studies

        Regulations for certifying laboratories for drinking water compliance testing require that the laboratories analyze proficiency samples at least once a year. Until 1998 this program was run by the USEPA and utilized what was termed Water Supply (WS) studies, for each performance evaluation cycle. The data generated from these studies were used to assess individual laboratory testing performance, as well as the overall drinking water laboratory performance nationally.

b)   In the absence of sufficient WS study data, the USEPA uses the multiplier method:

        The multiplier method uses a factor between 5 and 10 with the exact multiplier dependent on the degree of concern of the contamination. This factor is applied to the USEPA derived MDL to arrive at the PQL.

In the case of arsenic, the USEPA PQL was derived from actual WS data.

In 1994, the USEPA derived a PQL of 2 µg/L for arsenic with an acceptance limit of + or – 40%, based on Water Supply study data. The American Water Works Association (AWWA) ran their own study which resulted in a PQL of 4 µg/L. These numbers were subsequently reviewed by the USEPA's Science Advisory Board (SAB). In 1995, The SAB noted that the USEPA's WS derived PQL acceptance limits for arsenic were wider than those for other regulated metal contaminants. They recommended that the USEPA not compromise protection at a certain risk level by accepting less precision and accuracy. This recommendation resulted in a further evaluation of the PQL by the USEPA in 1999. In this process, the USEPA employed the following:

-   data from six low level arsenic WS studies
-   acceptance limits similar to other low level inorganics
-   linear regression analysis to determine the point at which 75% of USEPA and State laboratories fell within the acceptance range.

The USEPA used results of six low level (< 6 µg/L) arsenic WS studies to arrive at a PQL of 3 µg/L with acceptance limits of - or + 30%. The acceptance range was chosen based on the recommendation from the SAB that an acceptance range similar to the other regulated metals be used. These range from 15%, for beryllium, barium and chromium to 30%, for mercury and thallium. The USEPA chose the wider range of 30% to ensure that a sufficient number of labs could be certified for arsenic determinations.

Conclusion

The Testing Subcommittee has concluded that the accurate detection and quantitation of arsenic in drinking water can be achieved down to a level of 3 µg/L. Future improvements in analytical methods are likely to improve the ability to accurately detect and quantify low levels of arsenic and should be followed by NJDEP's Office of Quality Assurance.

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Appendix D: Capability of Current Arsenic Removal Technologies to Remove Arsenic to Levels Below 3 Micrograms per Liter

Treatment Subcommittee
New Jersey Drinking Water Quality Institute

March 10, 2003

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CAPABILITY OF CURRENT ARSENIC REMOVAL TECHNOLOGIES TO REMOVE ARSENIC TO LEVELS BELOW 3 MICROGRAMS PER LITER

BASIS AND BACKGROUND

GENERAL

To protect human health, the United States Environmental Protection Agency (USEPA) recently lowered the federal drinking water standard for arsenic to 10 µg/L; it had previously been 50 µg/L. This new MCL (Maximum Contaminant Level) took effect on February 22, 2002, and public water systems have until January 2006 to comply.

Of 606 active Community Water Systems (CWS) in New Jersey in 2002, there are 44 CWS with arsenic concentrations at or above 3 µg/L, according to Bureau of Safe Drinking Water compliance data records from January 1993 - August 2002. The majority of these produce more than 0.5 million gallons per day (mgd). Of the 970 active Non-transient, Non-Community Water Systems (NCWSs) in New Jersey in 2002, there are 147 NCWS with arsenic concentrations that equal or exceed 3 µg/L.

Notably, the average water quality characteristics of these systems do not preclude any established arsenic treatment technologies. In particular, background ion concentrations (e.g., phosphate, silica, sulfate) are generally below the levels that might cause interference. However, there are a few cases where the levels are such that certain technologies may be less suitable than others. For example, several of the impacted waters exhibit sulfate concentrations above 100 mg/L, the threshold level at which ion exchange treatment becomes cost prohibitive.

TREATMENT TECHNOLOGIES

Based on the findings of the "Evaluation and Assessment of Arsenic Removal Technologies for New Jersey Drinking Water" (Malcolm Pirnie, February 21, 2003), the most feasible and cost effective treatment technologies for New Jersey waters are likely to be:

- Ion Exchange (IX)
- Activated Alumina Adsorption (AA)
- Granular Ferric Hydroxide Adsorption (GFH)
- Coagulation/Filtration (CF)

Each of these four technologies has demonstrated reliable performance for reducing arsenic levels to below 3 µg/L when processing raw waters similar to those found in New Jersey. The capital and operating costs of each technology vary depending on the influent and targeted effluent arsenic levels. In this study, preliminary cost estimates were developed using a computerized tool previously created by Malcolm Pirnie as part of a USEPA-sponsored project.

With respect to ion exchange (IX), there are several impacted systems in New Jersey with sulfate concentrations above 100 mg/L, the threshold levels at which IX treatment is no longer cost

effective. Furthermore, IX processes generate large quantities of liquid waste and require intensive monitoring. Therefore, although IX is a reliable means for lowering arsenic levels, it may not be an attractive alternative for many New Jersey systems.

Activated alumina (AA) treatment is not likely to be affected by the background pH and silica concentrations of New Jersey waters. Overall, AA appears to be the least expensive alternative for NCWS applications (GFH is similarly cost effective). AA can be operated such that it does not generate a liquid waste stream and thus avoids potential disposal issues.

As in the case of AA, granular ferric hydroxide (GFH) treatment would not be adversely affected by the typical background quality of New Jersey waters. GFH can also be operated such that it does not generate a liquid waste stream. For this reason, GFH and AA may ultimately be the most practical alternatives for arsenic removal in New Jersey. Regarding cost, GFH appears to be the lease expensive option for CWSs, although AA costs are similar.

Coagulation/Filtration (C/F) and the Coagulation/Microfiltration (CMF) are likely to perform well, given the typical background chemistry of New Jersey waters. However, these systems produce residuals that require some processing prior to disposal, and this will elevate their associated costs.

RESIDUALS

The general characteristics of New Jersey waters are not unique and thus the technical aspects of residuals handling will be no different than in other parts of the country. However, New Jersey's surface water criteria for arsenic, which is based on USEPA's Recommended Criteria, is far below the current drinking water standard of 10 μg/L. Consequently, a wastewater treatment plant that accepts liquid residuals from an arsenic treatment system will almost certainly produce an effluent that exceeds the surface water requirement. This is true whether the drinking water standard is 10, 7, 5, or 3 μg/L. To date, this has not been a critical issue because relatively few drinking water systems have targeted arsenic removal. It is important to realize that some wastewater plants are currently receiving municipal sewage with a background arsenic level that exceeds the surface water standard.

Further, the location of selected well supplies may preclude the use of the sewage treatment collection system as the means of disposal for the arsenic-laden residuals. This could be due either to hydraulic restrictions in the system if it is at full capacity or the lack of a system in the vicinity of the well supply.

Although these are not technical treatment issues, per se, they must still be addressed, even for the current MCL of 10 μg/l to be cost effective. If there is no change in the existing surface water standard, many wastewater plants will not be able to accept liquid residuals from arsenic treatment systems, thereby eliminating certain technologies as practical alternatives.

COST CONSIDERATIONS

Information on treatment alternatives for arsenic removal indicates that activated alumina is the least expensive alternative for noncommunity water supplies, and granular ferric hydroxide is the least expensive option for community water supplies. This difference is linked to operations and maintenance costs rather than capital expenses. Capital costs for these two treatments are relatively similar, but the operating and maintenance costs vary considerably.

Cost will be a factor for water systems in determining what type of technology to use. The cost can be significant both for the initial expenditure of the equipment and media as well as operating and maintenance. Water systems will need to thoroughly investigate options when considering which types of treatment systems to install.

CONCLUSIONS

In conclusion, the general water chemistry of the impacted systems in New Jersey is such that any of the four above-listed treatment technologies could reliably reduce arsenic concentrations to 3 µg/L. The overall treatment cost will increase as the target level decreases. This information is based on a significant number of studies, although there are only a few full-scale systems operating in this country and even fewer pilot studies specific to New Jersey.

Overall, GFH and AA appear to be the most practical and economical alternatives for arsenic removal in New Jersey.

There is a significant regulatory issue associated with the disposal of arsenic-laden waste streams, and this is directly tied to the stringent surface water quality parameters that wastewater plants must currently meet. The regulatory issue exists, whether the drinking water standard is 10 µg/L or some lower concentration and whether the issue is addressed at the water supply or wastewater treatment plants, that could ultimately affect the relative cost, but not the feasibility, of reliably reducing arsenic levels to below 3 µg/L when processing raw waters in New Jersey.