

University of New Mexico
UNM Digital Repository

Water Resources Professional Project Reports

Water Resources

4-29-2010

Cost of Compliance with a Lower Arsenic Drinking Water Standard in New Mexico

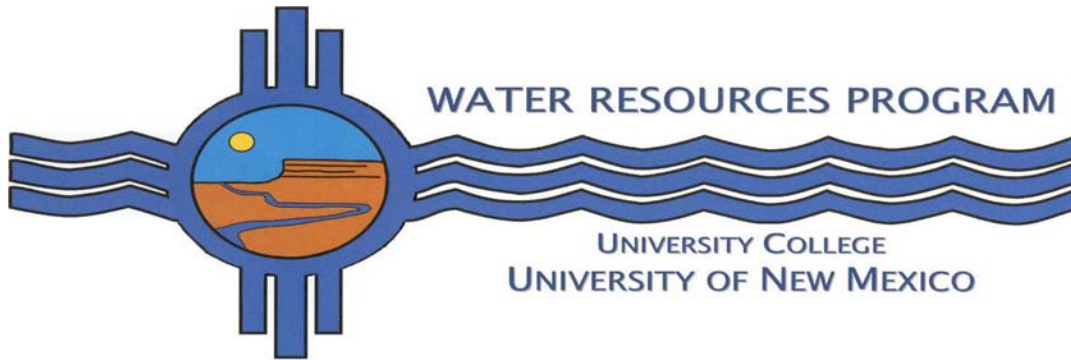
Kelly A. Bitner

Follow this and additional works at: https://digitalrepository.unm.edu/wr_sp

Recommended Citation

Bitner, Kelly A.. "Cost of Compliance with a Lower Arsenic Drinking Water Standard in New Mexico." (2010).
https://digitalrepository.unm.edu/wr_sp/148

This Other is brought to you for free and open access by the Water Resources at UNM Digital Repository. It has been accepted for inclusion in Water Resources Professional Project Reports by an authorized administrator of UNM Digital Repository. For more information, please contact disc@unm.edu.



**Cost of Compliance with a Lower Arsenic Drinking Water
Standard in New Mexico**

by

Kelly A. Bitner

**Water Resources Program
University of New Mexico
Albuquerque, New Mexico 87131-0001
www.unm.edu/~wrp/**

**Publication No. WRP-10
April 2004**

Note: This report is the Professional Project report of Kelly A. Bitner, submitted in partial fulfillment of the requirements for the Master of Water Resources degree at the University of New Mexico (January 2001). The project was supervised and approved by the following committee: Dr. Bruce M. Thomson, Department of Civil Engineering, UNM (Chair); Dr. Michael E. Campana, Water Resources Program and Department of Earth and Planetary Sciences, UNM; and Mr. Joseph Chwirka, CH₂M Hill, Inc.

Results presented herein are valid as of Spring 2001.

Cost of Compliance with a Lower Arsenic MCL in New Mexico

Executive Summary

On June 22, 2000 the Environmental Protection Agency (EPA) proposed a new drinking water standard for arsenic. The proposed enforceable standard, or maximum contaminant level (MCL) for arsenic is 5 micrograms/Liter ($\mu\text{g/L}$) which would replace the existing standard of 50 $\mu\text{g/L}$. This report describes an estimate of the costs of compliance with a lower arsenic MCL in New Mexico that is based on cost estimates for community water systems affected by the proposed standard.

Data on community water systems were provided by the New Mexico Environment Department (NMED) Drinking Water Bureau. Drinking water data for the pueblos is maintained by the NMED, so none of the pueblos were included in this analysis. The data provided by the NMED shows that 346 community water systems contain arsenic at or above the proposed MCL of 5 $\mu\text{g/L}$. For each of these communities, an estimate was prepared to determine the costs to construct, operate, and maintain four different treatment technologies.

The estimated cost of treating drinking water to meet the proposed arsenic standard was calculated by applying cost curves developed for the American Water Works Association Research Foundation (Frey et al., 2000). The costs are considered Budget Level Estimates, as defined by the American Association of

Cost Engineers. Budget estimates are prepared with the help of flow sheets, layouts, and equipment details. An estimate of this type is normally expected to be accurate within +30 percent or –15 percent.

The capital costs for compliance with the proposed MCL of 5 µg/L range from \$1.0 to \$1.2 billion, depending on the treatment technology used. Large systems (Q > 0.2 million gallons per day [mgd]) in 79 communities account for about 80% of the estimated capital costs and small systems (Q < 0.2 mgd) in 267 communities account for about 20% of the estimated capital costs. The estimated capital costs that may be expected at arsenic MCL of 10 µg/L are \$374 to \$436 million and at an MCL of 20 µg/L the estimated capital costs are \$139.66 to \$117.56 million.

The annual O & M costs for compliance with the proposed MCL of 5 µg/L range from \$48 to \$67 million, depending on the treatment technology. Large systems (Q > 0.2 mgd) in 79 communities account for about 92% of the estimated annual O & M costs and small systems (Q < 0.2 mgd) in 267 communities account for about 8% of the estimated annual O & M costs. The estimated annual O & M costs that may be expected at an arsenic MCL of 10 µg/L are \$16 to \$21 million and at an MCL of 20 µg/L the estimated annual O & M costs are \$5 to \$7 million.

The estimated annualized costs for compliance with the proposed MCL of 5 µg/L range from \$139 to \$172 million, depending on the treatment technology. This value represents the annual cost for the combined capital costs and annual O & M costs amortized over a 20 year period at an interest rate of 6%. Large

systems ($Q > 0.2$ mgd) in 79 communities account for about 88% of the estimated annualized costs and small systems ($Q < 0.2$ mgd) in 267 communities account for about 12% of the estimated annualized costs. The estimated annualized costs that may be expected at arsenic MCL of $10 \mu\text{g/L}$ are \$49 to \$60 million and at an MCL of $20 \mu\text{g/L}$ the estimated annualized costs are \$20 to \$24 million.

The estimated monthly increase in the cost of water for large systems ranges from \$47.27 to \$59.49 per customer, depending on the treatment technology. This represents an annual cost increase of \$570 to \$700. For small systems, the average monthly increase in the cost of water is estimated to be \$90.82 per customer, equivalent to a yearly increase of about \$1,100. The estimated average monthly increase in the cost of water may be expected at an arsenic MCL of $10 \mu\text{g/L}$ are \$41.03 to \$45.76 per customer in large systems and \$100.85 per customer in small systems. At an MCL of $20 \mu\text{g/L}$ the estimated average monthly increase is \$26.74 to \$35.23 per customer in large systems and \$62.55 per customer for small systems.

The Environmental Protection Agency (EPA) estimated the annualized costs at between \$377 - \$442 million (depending on the interest rate assumed, 3% or 7%) for the entire nation (EPA, 2000). The annualized costs for New Mexico based on this water system-by-water system analysis represent about 30% of the national costs developed by EPA. On behalf of the American Water Works

Association Research Foundation (AWWARF), Frey et al (2000) found the national annualized costs of an arsenic MCL of 5 $\mu\text{g/L}$ to be \$1.4 billion (assuming 6% interest rate). The annualized costs in New Mexico alone are higher than would be expected based on the national cost estimates. The source of the discrepancy is likely the national arsenic occurrence estimates, which are the basis for determining the number of systems affected.

ACKNOWLEDGEMENTS

I gratefully acknowledge the guidance and assistance of Bruce Thomson, Joe Chwirka, and Michael Campana. My thanks to Stephen Wust, Gil Salas, and Rich Asbury of the New Mexico Environment Department Drinking Water Bureau for providing the data used in developing this report.

Table of Contents

Table of Figures	TOC-2
Table of Tables.....	TOC-3
Table of Appendices.....	TOC-4
1.0 INTRODUCTION	1
2.0 ARSENIC DISTRIBUTION DATA	4
2.1 Arsenic in New Mexico	4
2.2 Data Sources.....	7
2.3 National Estimates of Arsenic Distribution.....	12
3.0 TREATMENT OPTIONS FOR ARSENIC IN WATER	16
3.1 Rationale for Treatment Technology Selection.....	17
3.2 Treatment Processes	19
3.2.1 Ion Exchange Treatment Technology	20
3.2.2 Activated Alumina Treatment Technology	28
3.2.3 Coagulation/Microfiltration Treatment Technology.....	35
4.0 COST ESTIMATION METHODOLOGY.....	41
4.1 Capital Costs.....	43
4.2 Operation and Maintenance Costs	46
4.3 Annualized Costs	47
4.4 Monthly Cost Calculations.....	48
4.5 Sources of Uncertainty	49
4.5.1 Capital Costs Based on Distribution Systems.....	49
4.5.2 Annual Water Demand	51
4.5.3 Interest Rate in the Present Worth Calculations	51
4.5.4 Costs Not Included	52
5.0 ESTIMATED COST OF COMPLIANCE	53
5.1 Estimates of Capital Costs	53
5.2 Estimated Operation and Maintenance (O & M) Costs.....	58
5.3 Estimated Annualized Costs	62
5.4 Estimated Monthly Costs.....	65
6.0 CONCLUSIONS	75
7.0 REFERENCES CITED.....	77

Table of Figures

Figure 1: Location of Community Water Systems with Arsenic Concentration > 5 ug/L	6
Figure 2: Distribution of Arsenic Concentration in Community Water Systems in New Mexico	6
Figure 3: Ion Exchange Treatment Process Diagram	23
Figure 4: Activated Alumina Treatment Process Diagram	29
Figure 5: Coagulation/Microfiltration Treatment Process Diagram	34
Figure 6: Capital Cost Curves for Ion Exchange, Activated Alumina, and Coagulation/Microfiltration	41
Figure 7: Estimated Capital Costs of Treatment with an Arsenic MCL of 5 ug/L in New Mexico	52
Figure 8: Estimated Capital Costs of Treatment with Potential Arsenic MCLs in New Mexico	54
Figure 9: Estimated Annual O & M Costs for Treatment with Arsenic MCL of 5 ug/L in New Mexico	56
Figure 10: Estimated Annual O & M Costs for Treatment with Potential Arsenic MCLs in New Mexico	57
Figure 11: Estimated Annualized Costs of Treatment with an Arsenic MCL of 5 ug/L in New Mexico	59
Figure 12: Estimated Annualized Costs for Treatment with Potential Arsenic MCLs in New Mexico	61
Figure 13: Estimated Monthly Cost of Water at Potential MCLs in New Mexico	70

Table of Tables

Table 1: Distribution of Less Than Method Detection Limit Arsenic Analytical Results in New Mexico	8
Table 2 Comparison of Cost of Compliance Estimates.....	15
Table 3: Best Available Technologies for Treatment of Arsenic in Water	16
Table 4: Summary of Ion Exchange Considerations.....	27
Table 5: Summary of Activated Alumina Considerations	34
Table 6: Summary of Coagulation/Microfiltration Considerations	39
Table 7 Components of Capital Costs for IX, AA, C/MF, and TAAA Treatment Technologies	43
Table 8 : Components Included in O & M Cost Curves.....	47
Table 9: Estimated Capital Costs to Comply with an Arsenic MCL of 5 ug/L	55
Table 10: Estimated Capital Costs of Treatment for Arsenic MCLs of 10 ug/L and 20 ug/L.....	57
Table 11 Estimated Annual O & M Costs for Treatment with Arsenic MCL of 5 ug/L in New Mexico	59
Table 12: Estimated Annual O & M Costs for Arsenic MCLs of 10 ug/L and 20 ug/L in New Mexico	61
Table 13 : Estimated Annualized Costs for Treatment with an Arsenic MCL of 5 ug/L in New Mexico	63
Table 14: Estimated Annualized Costs for Arsenic MCLs of 10 ug/L and 20 ug/L in New Mexico	64
Table 15: Estimated Monthly Cost of Water for an Arsenic MCL of 5 ug/L in New Mexico	66
Table 16: Comparison of Median Household Income to Estimated Annual Cost of Water Systems in Selected Communities.....	67
Table 17: Yearly Water Cost and Poverty Levels for Selected Large New Mexico Community Water Systems	69
Table 18: Estimated Monthly Cost of Water with an Arsenic MCL of 10 ug/L in New Mexico	72
Table 19: Estimated Monthly Cost of Water with an Arsenic MCL of 20 ug/L	72

Table of Appendices

Appendix A: New Mexico Community Water Systems with Arsenic Concentrations Equal to or Greater Than 5 $\mu\text{g/L}$

Appendix B: Estimated Costs of Arsenic Treatment for Large Community Water Systems in New Mexico (>0.2 mgd)

Appendix C: Estimated Costs of Arsenic Treatment for Small Community Water Systems in New Mexico (<0.2 mgd)

Appendix D: Estimated Monthly Increase in the Cost of Water Due to Treatment for Arsenic

1.0 INTRODUCTION

On June 22, 2000 the Environmental Protection Agency (EPA) proposed a revised drinking water standard for arsenic. The proposed enforceable standard, or maximum contaminant level (MCL), for arsenic is 5 micrograms/Liter ($\mu\text{g/L}$) which would replace the existing standard of 50 $\mu\text{g/L}$. The current standard for arsenic in drinking water of 50 $\mu\text{g/L}$ was set in 1975 and it was based on a standard set in 1943 by the U.S. Public Health Service for interstate water carriers (Abt Associates, 2000). The proposed MCL of 5 $\mu\text{g/L}$ is based on the results of a risk assessment to determine the cancer risk (EPA, 1988). The notice of proposed rulemaking (EPA, 2000) also requested comments on potential MCLs of 3 $\mu\text{g/L}$, 10 $\mu\text{g/L}$, and 20 $\mu\text{g/L}$.

In proposing a new standard, EPA is required to weigh the costs and the benefits. A regulatory impact analysis was done (Abt Associates, 2000) that found the total national annualized cost was \$445 million to treat water to meet the proposed standard of 5 $\mu\text{g/L}$. A similar study by Frey et al (2000) estimated the total national annualized cost \$1.46 billion, three times greater than EPA's regulatory impact analysis.

The benefits were calculated based on preventing diseases caused by consuming arsenic. Arsenic is a naturally occurring element that has been classified as a human carcinogen. A number of epidemiologic studies conducted in several countries, principally Taiwan, Japan, India, England, Mexico, Chile,

and Argentina, report an association between high concentration of arsenic in drinking water and skin cancers, internal cancers, and noncancerous effects in exposed populations (Abt Associates, 2000). Internal cancers which may be associated with exposure to arsenic are liver, bladder, kidney and lung.

In 1999, the National Research Council (NRC) of the National Academy of Sciences (NAS) completed an independent review of the arsenic toxicity data at the request of EPA (NRC, 1999). The NRC concluded that there is sufficient evidence from human epidemiological studies that chronic ingestion of inorganic arsenic at concentrations of several hundred micrograms per liter causes skin, bladder and lung cancer (NRC, 1999). However, a study conducted in Utah to evaluate the risk of bladder cancer in moderate exposure to arsenic in drinking water found no association between bladder cancer risk and arsenic exposure (NRC, 1999).

Non cancer effects due to arsenic exposure are due to interference with the actions of enzymes, essential cations, and transcriptional events in cells throughout the body. Thus multisystemic noncancer effects can include cutaneous manifestations (hyperpigmentation and hyperkeratoses), gastrointestinal disturbances, peripheral vascular disease (notably blackfoot disease), hematological effects, pulmonary effects, and immunological effects (NRC, 1999).

Both estimates of nationwide costs used statistical approaches (Abt Associates, 2000; Frey et al, 2000). The large discrepancy between these national estimates prompted this study to estimate of the costs of compliance with a lower arsenic

MCL in New Mexico. This estimate is based on the summation of estimated costs for every community water system that would be affected by the proposed standard. It provides a check on the assumptions used to develop the statistical approaches used in the nationwide estimates.

Data on community water systems were provided by the New Mexico Environment Department (NMED) Drinking Water Bureau. Drinking water data for the pueblos is not maintained by the NMED, so none of the pueblos was included in this analysis. The data provided by the NMED were used to identify 346 community water systems with arsenic at or above the proposed MCL of 5 $\mu\text{g/L}$. For each of these communities, an estimate was prepared to determine the costs to construct, operate, and maintain four different treatment technologies. The costs for individual communities were summed and resulted in an annualized cost of \$139 - \$172 million for the state of New Mexico alone.

This report describes the distribution of arsenic and data sources used for this report in Section 2. Section 3 is a description of the treatment technologies that were used in this evaluation. Section 4 describes the cost estimating methodology and discusses the uncertainties in the analysis. Section 5 presents the results of the cost calculations and conclusions are presented in Section 6.

2.0 ARSENIC DISTRIBUTION DATA

The distribution of arsenic in drinking water, and thus the number of systems affected by the proposed standard, is a critical element in estimating the cost of compliance. The cost of treating drinking water to meet the proposed arsenic standard was calculated using data from New Mexico community water systems. This section describes the data sources used to determine which community water systems use water with arsenic above the proposed standard. It also includes a discussion of how the national estimates of arsenic distribution were derived.

2.1 Arsenic in New Mexico

In New Mexico only sixteen community water systems have arsenic concentrations in one or more sources that are above the current standard of 50 µg/L. An arsenic drinking water standard at 5 µg/L would affect 346 community water systems in New Mexico. Seventy-nine of these are "large" systems, serving more than 1,000 people. There are 267 "small" systems, serving between 25 and 1000 people, which would be affected by the standard. Figure 1 is a map showing the location of the 346 community water systems affected by the proposed MCL.

The number of community water systems that would be affected by the potential MCLs is shown in Figure 2. At an arsenic MCL of 10 $\mu\text{g/L}$, 114 of the 346 communities would be affected and at 20 $\mu\text{g/L}$, only 36 of the original 346 communities would be affected.

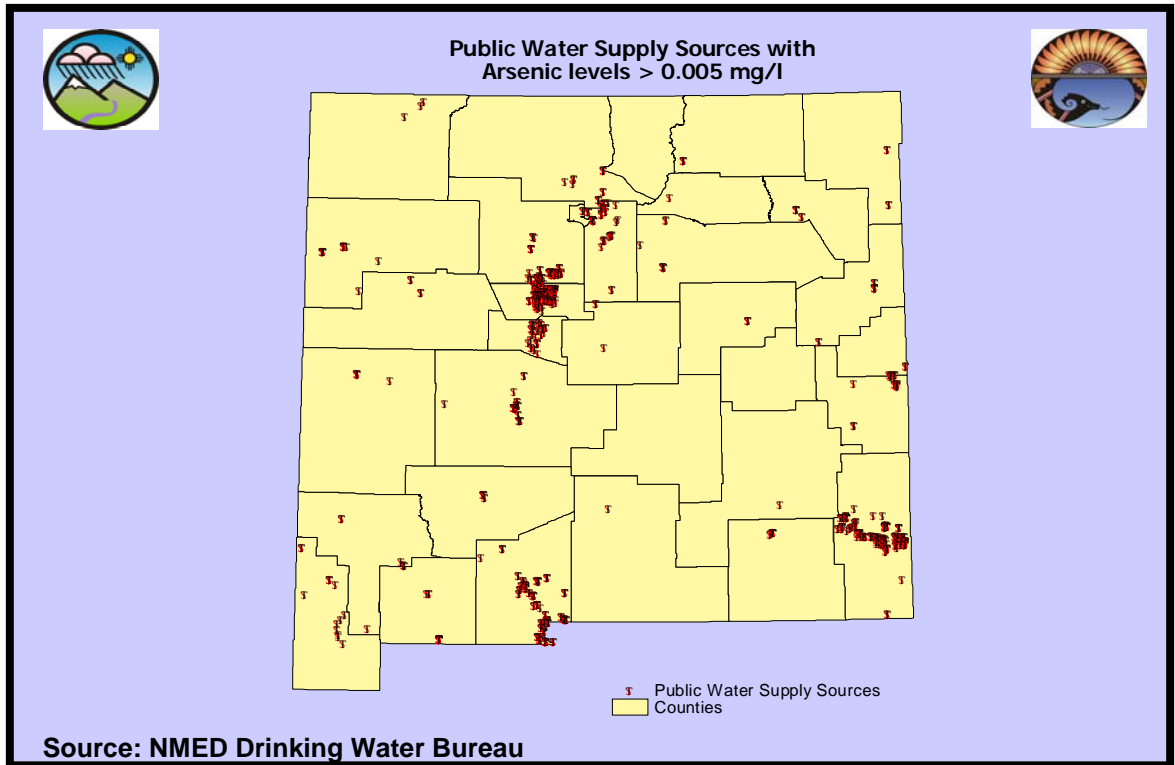


Figure 1: Location of Community Water Systems with Arsenic Concentration > 5 ug/L

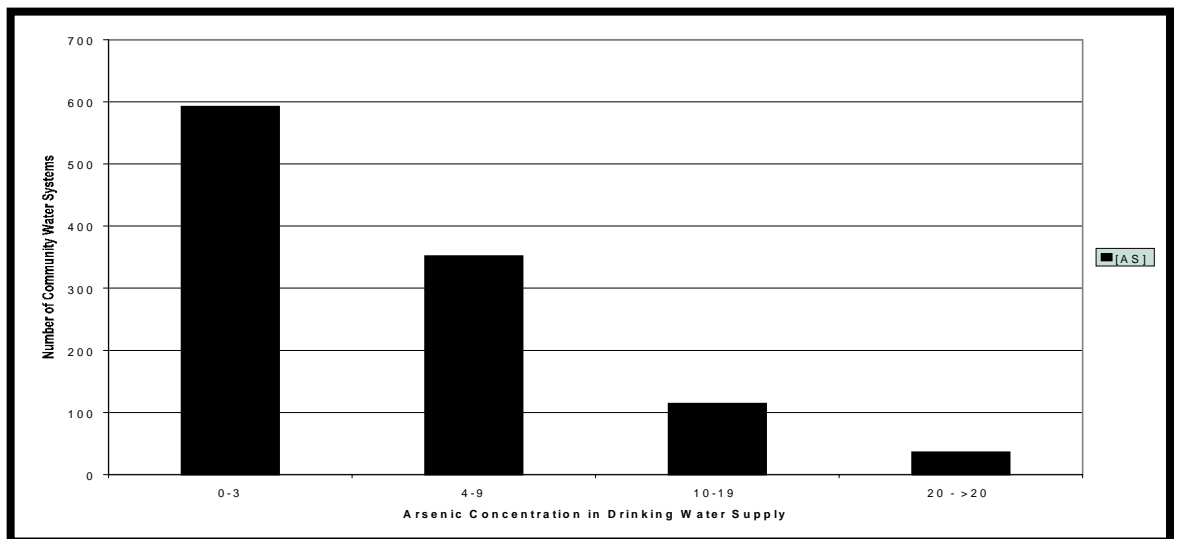


Figure 2: Distribution of Arsenic Concentration in Community Water Systems in New Mexico

2.2 Data Sources

The data used in this analysis were provided by the New Mexico Environment Department (NMED) Drinking Water Bureau. Note that drinking water quality data collected by the State does not include the pueblos or reservations in New Mexico, so these communities are not included in this analysis. The data provided by the NMED Drinking Water Bureau were:

- Arsenic concentration for every source or entry point for every community water system in New Mexico
- Sulfate concentration for every source or entry point in every community water system in New Mexico
- Number of people served by each community water system
- Capacity of the water supply wells in each community water system.

The data received from the NMED Drinking Water Bureau for arsenic concentration consisted of 5293 records representing 592 water systems. These records included multiple wells within the each system and analytical results from multiple sampling events. This data was screened to develop a data set that represented only those water systems that would be affected by the proposed MCL. The first screen selected only those sources within water systems that had measured arsenic concentrations at or above 5 µg/L.

To complete this screening step, the issue of method detection limit had to be addressed. Of the 592 water systems in New Mexico, 1632 had analytical results shown as "<", indicating that the arsenic present in the water was below the analytical method detection limit. The distribution of less than detection limit results is shown in Table 1. A common approach to using analytical data that is less than the method detection limit is to assume the concentration is one-half the method detection limit. Thus, if the analytical result for a well is shown as "< 10 µg/L", it is assumed to have a value of 5 µg/L. Using this approach, the 143 records where the arsenic concentration is indicated with analytical results "< 10 µg/L" were included in this analysis (Table 1). This screening for water above 5 µg/L resulted in 1042 records that represent drinking water wells in arsenic concentration of equal to or greater than 5 µg/L in one or more sampling events.

Table 1: Distribution of Less Than Method Detection Limit Arsenic Analytical Results in New Mexico

Arsenic Concentration	Number Analytical "<" Results
0 - 5 µg/L	1484
6 -9 µg/L	5
10 - > 20 µg/L	143

A second screen to remove Non-Transient, Non-Community water systems was then applied to the data. In the proposed rule (EPA, 2000), Non-Transient, Non-Community (NTNC) water systems are exempt the proposed arsenic standard, although they would be required to monitor for arsenic. NTNC water systems are defined as "public water systems that regularly serve at least 25 of the same persons more than 6 months per year" (EPA, 2000). Examples of NTNC water systems are nursing homes, food retailers, medical facilities, schools, military bases, parks, campgrounds, summer camps, offices, and prisons. Thirty-nine NTNC systems were identified in the data set and were removed for the cost estimate. The NTNC systems included Kirtland AFB, Holoman AFB, White Sands Missile Range, Philmont Boys Scout Ranch, Chaparral Girl Scout Camp, several schools, and conference centers.

A third screen to ensure only community water systems that are required to comply with drinking water standards were included in the data set. In the proposed rule, community water systems are defined as "systems that provide piped water to at least fifteen service connections used by year-round residents or regularly serves at least twenty-five year-round residents." (EPA, 2000). For this screen, it was assumed that there is an average of 2.5 people per household. The population served by each water system (provided by the NMED Drinking Water Bureau, Appendix A) was divided by 2.5 to estimate the number of service connections (customers). Twenty-four systems with less than 15 customers were removed from the data set.

The resulting screened data set includes 346 community water systems that would be required to comply with an arsenic standard of 5 µg/L. This is the data set that was used to estimate the costs of compliance in New Mexico and it is included as Appendix A to this report. Data for three cities in New Mexico (Albuquerque, Rio Rancho, and Las Cruces) were not included in the Appendix A data set used for cost calculations, because detailed cost estimates using the same cost curves had been completed for these cities by CH2M Hill (Chwirka, personal communication).

The screened data set was used to develop the parameters needed to input to the cost calculations. The input parameters are:

- Average arsenic concentration in each well in the community water system (in micrograms per liter [µg/L])
- Capacity of the well (in gallons per minute [gpm])
- Annual water demand (in million gallons per day [mgd])

The following describes how the data set shown in Appendix A was used to develop the input parameters:

Average Arsenic Concentration: Sources often had more than one value for arsenic concentration because the sources are sampled every three years. The arithmetic average of multiple analytical results were used as input to the cost curves. Results that are shown as "<" were assumed to be one-half the

detection limit and included in the average. There are instances where the arsenic concentration decreased between one sampling event and the next. It is possible that the latest sampling event is more representative than the earlier event. However, in the absence of additional information, the arithmetic mean of analytical results for all sampling events was used.

Capacity of the Well: NMED Drinking Water Bureau provided the well capacity where known. Where the well capacity was not known, one of three methods was applied:

- If there was more than one well in the water system where the capacity is known, the arithmetic average of the capacity of the other wells was assigned to the well with unknown capacity.
- If there is only one other well with known capacity, assign the same capacity to the well of unknown capacity
- If there are no other wells in the water system, assume that the well supplies at least 200 gallons per person per day using the population figure provided by NMED Drinking Water Bureau.

In many cases, the distribution system samples had arsenic concentrations at or above 5 µg/L. To assign a capacity to the distribution system, the sum of the capacity of the wells in the system was used. If no wells were identified or the capacity of the wells was unknown, it was assumed that the distribution system supplies 200 gallons per day per person for the population figures provided by NMED Drinking Water Bureau (Appendix A)

Annual Water Demand: The population for each community was provided by NMED Drinking Water Bureau (Appendix A). It was assumed that the demand on the system is 200 gallons per person per day. Use of 200 gallons per person per day is the average water use in southwestern cities, according to a recent survey (Spurlock, 2000). The population was multiplied by 200 gallons per day and divided by 1,000,000 to assign an annual demand in million of gallons of water per day.

2.3 National Estimates of Arsenic Distribution

Three separate estimates of arsenic occurrence have been conducted. The first was sponsored by the Water Industry Technical Action Fund and was conducted by Frey and Edwards (1997). The second estimate was done by the U.S. Geological Survey in 1999 (Focazio et al, 1999) and the third was completed by the EPA in 2000 (EPA, 2000b). Each of these estimates used water quality data from a subset of states to develop the regional distribution of mean arsenic concentration. The regional distributions were combined to determine national estimate of percent of systems expected to exceed different arsenic levels.

Frey and Edwards (1997) completed a representational (stratified) survey of public water systems. Drinking water sources were randomly selected from representational groups defined by source type (surface or groundwater); system size; and geographic location (regional assignments based on arsenic occurrence patterns). The study incorporated a stratifying variable that

qualitatively described the likelihood of arsenic occurrence in potable water supplies. A total of 800 sites were targeted to receive a questionnaire requesting participation in a sampling program. Frey and Edwards (1997) found that generally groundwater systems have higher arsenic than do surface water systems. Arsenic above 5 $\mu\text{g/L}$ was observed in 16-46% of groundwater systems but only in 0-11% of surface water systems. Regional trends in arsenic occurrence were also found. The east coast and southeastern regions generally have arsenic concentrations $<1 \mu\text{g/L}$, whereas arsenic concentrations between 5 and 20 $\mu\text{g/L}$ were found consistently in the midwest and west. Frey and Edwards (1997) estimated that 6-17% of public water systems would exceed 5 $\mu\text{g/L}$ and 1-3% would exceed 20 $\mu\text{g/L}$.

The USGS survey by Focazio et al (1999) associated arsenic concentrations measured in groundwater resources with the numbers and sizes of public water systems using groundwater in the same counties. A total of 18,850 sample locations were selected from the USGS National Water Information System (NWIS). The sample locations represented 1,528 counties that included 76% of all public water systems serving more than 10,000 people and 61% of systems serving 1,000 to 10,000 people. The set of measured arsenic values was used with the locations of public water supplies to produce estimates of percentages of public water supply systems in eight size classes. This study found regional patterns, generally with higher arsenic concentrations in the western states.

Nationwide, it estimated that 14% of public water supply systems exceed 5 $\mu\text{g/L}$, 8% exceed 10 $\mu\text{g/L}$, and 3% exceed 20 $\mu\text{g/L}$ (Focazio et al, 1999).

The EPA also completed an assessment of the distribution of arsenic levels in public community water systems as a basis for estimating the number of systems exceeding the MCL options (EPA, 2000b). The EPA selected a database that included arsenic data from 25 states as the data that would establish the most accurate and scientifically defensible national occurrence and exposure distributions of arsenic in public water systems. The national distribution of average arsenic concentrations was estimated in four steps:

- (1) Estimate system means in 25 states,
- (2) Aggregate the system means into two State lognormal distributions (surface and groundwater) to determine the percent of systems expected to exceed different arsenic levels,
- (3) Group states into seven regions and combine State occurrence estimates in that region, weighted by the total number of water systems in those specific states, and
- (4) Combined and weighted the national groundwater and surface water for a national estimate of percent of systems expected to exceed different arsenic levels.

The EPA study estimated that 10.3% of systems would exceed 5 µg/L, 4.5% of systems would exceed 10 µg/L, and 1.7% would exceed 20 µg/L (EPA, 2000b).

The national estimate of percent of systems exceeding the proposed 5 µg/L standard was about 15% in all three studies. In New Mexico, about 60% of community water systems will be affected by the proposed standard of 5 µg/L. Further, the number of affected communities in New Mexico is 5% of the EPA national estimate of number of systems affected and 8% of the AWWARF national estimate (Table 2). The higher percentage of affected systems in New Mexico than predicted in the three national arsenic occurrence studies is probably the source of the discrepancy in compliance cost estimates.

Table 2 Comparison of Cost of Compliance Estimates

Study	No. of Systems Affected	Capital Costs	Annual O & M Costs	Annualized Costs
New Mexico (This Study)	346	\$1 - 1.2 billion	\$48 - \$67 million	\$139- \$172 million
National (EPA)	6,956	Not Provided	Not Provided	\$ 442 million
National (AWWARF)	4,004	\$14.1 billion	Not Provided	\$1.46 billion

3.0 TREATMENT OPTIONS FOR ARSENIC IN WATER

The six treatment technologies selected by EPA as Best Available Technologies (BAT) for removing arsenic from water are listed in Table 3 (EPA, 2000). Two of the BAT, ion exchange (IX), and activated alumina (AA), were used to estimate the treatment costs for large New Mexico community water systems (> 0.2 mgd). Two additional treatment technologies were included in this analysis. For large systems, the costs for coagulation/microfiltration were estimated in addition IX and AA. For small New Mexico community water systems (<0.2 mgd), a packaged version of the activated alumina technology, referred to as "throw-away activated alumina" (TAAA) was used to estimate the treatment costs. This section presents the rationale for the treatment technologies selected for this analysis and describes the selected treatment technologies.

Table 3: Best Available Technologies for Treatment of Arsenic in Water

Treatment Technology	Removal Efficiency	Appropriate for Arid Groundwater Systems?
Ion Exchange	95	Yes, only 1.4% wasted water
Activated Alumina	90	Yes, only 0.4% wasted water
Reverse Osmosis	>95	No, 30-50% wasted water
Modified Coagulation/Filtration	95	No, surface water treatment technology that would require addition of solids in groundwater
Modified Lime Softening	80	No, surface water treatment technology

Treatment Technology	Removal Efficiency	Appropriate for Arid Groundwater Systems?
Electrodialysis Reversal	85	No, large water waste similar to Reverse Osmosis

Source: EPA (2000), Table VIII-1

3.1 Rationale for Treatment Technology Selection

The three treatment technologies evaluated in this study were selected because they are the most appropriate for New Mexico and other arid states that primarily use groundwater. Ion exchange as a technology for arsenic removal has been studied for many years. This technology is effective for drinking water supplies that has low to moderate sulfate levels (City of Albuquerque, 2000). Ion exchange wastes only 1.4% of the feedwater (CH2M Hill). As with IX, selective removal of arsenic by activated alumina (AA) has been investigated for many years (City of Albuquerque, 2000). AA also has a low rate of water wastage, about 0.4% of the feedwater (CH2M Hill, 1999). Coagulation/Microfiltration is a technology that has been pilot-tested in Albuquerque and found to be effective in removing arsenic, while it wastes only 0.1% of the feedwater (Clifford et al, 1998a, 1998b).

Four of the BAT selected by EPA were not considered, largely because of the high rates of water wastage. Reverse osmosis is a process which relies upon very high pressures (>400 psi) to force water through a semi-permeable membrane. Reported recovery rates are in the range of 50-85%; the other 50-15% of water is discharged as brine (City of Albuquerque, 2000). The principal

factor, which limits the recovery of the RO process, is the presence of minerals that will cause scaling of the membrane. These are usually divalent cations which are associated with hardness (Ca^{2+} , Mg^{2+} , Fe^{2+} , etc.) and silica. Many ground water supplies have very high silica contents which limits the recovery by the RO process to 50-70%. This means that 30-50% of the feed water must be wasted as brine (City of Albuquerque, 2000).

Coagulation/filtration is a technology used by water utilities that must rely on surface water sources for supply. Its primary function is to remove suspended solids. Modified coagulation/filtration is not appropriate for water utilities that rely upon groundwater for its potable water supply. Ground water rarely has suspended solids, therefore it is likely that a coagulation process would not work without addition of solids. This would greatly increase the volume and mass of sludge generated which in turn would further complicate residuals management and increase treatment costs.

Modified Lime Softening is used to soften hard water by adding lime ($\text{Ca}(\text{OH})_2$) to raise the solution pH to at least 10.5 at which metal carbonate and metal hydroxide precipitates form. This process can effectively remove arsenic from drinking water; however, as with coagulation/filtration, it requires a large complicated treatment plant that is not suitable for a water utility which relies on ground water produced by a widely distributed network of wells (City of Albuquerque, 2000).

Electrodialysis reversal is a membrane process that uses an alternating electrical potential to separate ionic constituents from solution. Similar to RO, this

treatment process wastes a high percentage of the feedwater (City of Albuquerque, 2000).

3.2 Treatment Processes

In water, the most common valence states of arsenic are As(V), or arsenate, which is more prevalent in aerobic surface waters and As(III), or arsenite, which is more likely to occur in anaerobic ground waters. In the pH range of 4 to 10, the predominant As (III) compound is neutral in charge, while the As (V) species are negatively charged. The As(V) species are negatively charged above pH 2.1, whereas negatively charged As(III) species do not predominate until the solution pH is greater than 9.2. This solution chemistry explains the poor removal of As(III) by ion exchange resins and activated alumina (CH2M Hill, 1999). In fact, removal efficiencies for As(III) are poor by any of the BAT evaluated due to the negative charge (EPA, 2000). However, As(III) is readily oxidized by common oxidizing agents including chlorine (Clifford and Lin, 1995). EPA (2000) states that any of the BAT, As (III) must be converted through pre-treatment to As(V). CH2M Hill (1999) recommend that all As removal involving adsorption or ion exchange processes utilize chlorinated water to assure that As(V) is present.

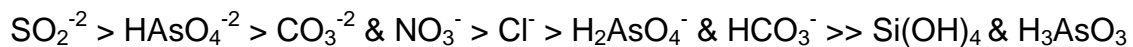
Most community water systems in New Mexico are groundwater-based. For groundwater systems, where water is distributed from the well to the customer, treatment must occur at the wellhead. For these systems, both the capital costs

and the O & M costs reflect treatment systems at each well with arsenic concentration above the proposed MCL(s).

For small community water systems (< 0.2 mgd), the only treatment technology evaluated was Throw-Away Activated Alumina. This treatment technology is available as a package plant that is pre-engineered, that is the process engineering has been done by the manufacturer. For TAAA the used media is disposed and not regenerated, so there are no costs for residuals management. However, this treatment technology still requires trained operators.

3.2.1 Ion Exchange Treatment Technology

The ion exchange (IX) process utilizes a strong-base anion, polystyrene-based exchange resin that adsorbs arsenic by exchanging arsenic for chloride (Frey et al., 2000; CH2M Hill, 1999). Well water containing arsenic is pumped through the IX resin bed(s) and the arsenic ions are exchanged for chloride ions. The selectivity of IX resin for feedwater ions is as follows:



Sulfate is removed preferentially to arsenic, and bicarbonate ions are removed less preferentially to arsenic. This creates a condition where bicarbonate, arsenic, and sulfate sequentially breakthrough and exit the bed. Therefore, the bicarbonate breakthrough provides an indication of when the IX process must be

taken offline and regenerated prior to the arsenic breakthrough (CH2M Hill, 1999).

The IX bed is regenerated utilizing a concentrated chloride solution. The regeneration process uses a concentrated brine to displace the adsorbed arsenic in the resin and replenish the resin with chloride (Frey et al, 2000). The arsenic-laden brine can be recycled numerous times before it must be disposed of. Brine recycling can minimize the mass of salt required for the IX process and reduce the volume of waste brine that must be disposed (CH2M Hill, 1999). In addition, the removal of bicarbonate by the IX resin will cause the pH of the treated water to drop significantly. When the brine is recycled, the pH depression is significantly reduced by the accumulation of bicarbonate in the brine. Therefore, brine recycling can provide several benefits for the use of the IX process (CH2M Hill, 1999).

In water where the sulfate concentration is much higher than the arsenic concentration, it is the most important factor in determining how many bed volumes of water can be treated before regeneration is required. This also determines how much water is lost to waste and how much salt is required for operation. All other factors being equal, it is the sulfate concentration in the well water that determines how cost effective the IX process will be for a given site (CH2M Hill, 1999). EPA (2000) states that ion exchange may be practical up to approximately 120 mg/L of sulfate. In New Mexico, about 60% of the 79 large community water systems (48 systems) have sulfate concentrations greater than

120 mg/L. Ion exchange may not be a practical treatment technology for these communities.

3.2.1.1 Ion Exchange Treatment Process

The operation of an IX process consists of several steps as illustrated in Figure 3 and in described below (CH2M Hill, 1999):

1. **Arsenic Removal:** Well water is pumped down through the ion exchange bed, producing water for distribution, until the bed capacity for arsenic is nearly exhausted.
2. **Backwash:** Treated water is passed upflow through the resin bed to remove any accumulated debris. The backwash step will not be required for every regeneration, but will be used periodically as required.
3. **Regeneration:** Concentrated brine is passed down through the resin bed to exchange the sulfate, arsenic, and bicarbonate with chloride. Three substeps are associated with regeneration. Displacement water is first pushed through the resin bed; as a result this water may contain a high concentration of arsenic. Then brine is passed through the IX bed, which will be recycled.
4. **Rinse:** Treated water is passed down through the bed to: (a) displace the brine in the bed and (b) slowly rinse the remaining brine from the bed. The

rinse water will have low concentrations of brine that must be disposed of to the sanitary sewer system.

5. **Fast rinse:** This step rinses out the traces of brine left in the bed prior to return to service.

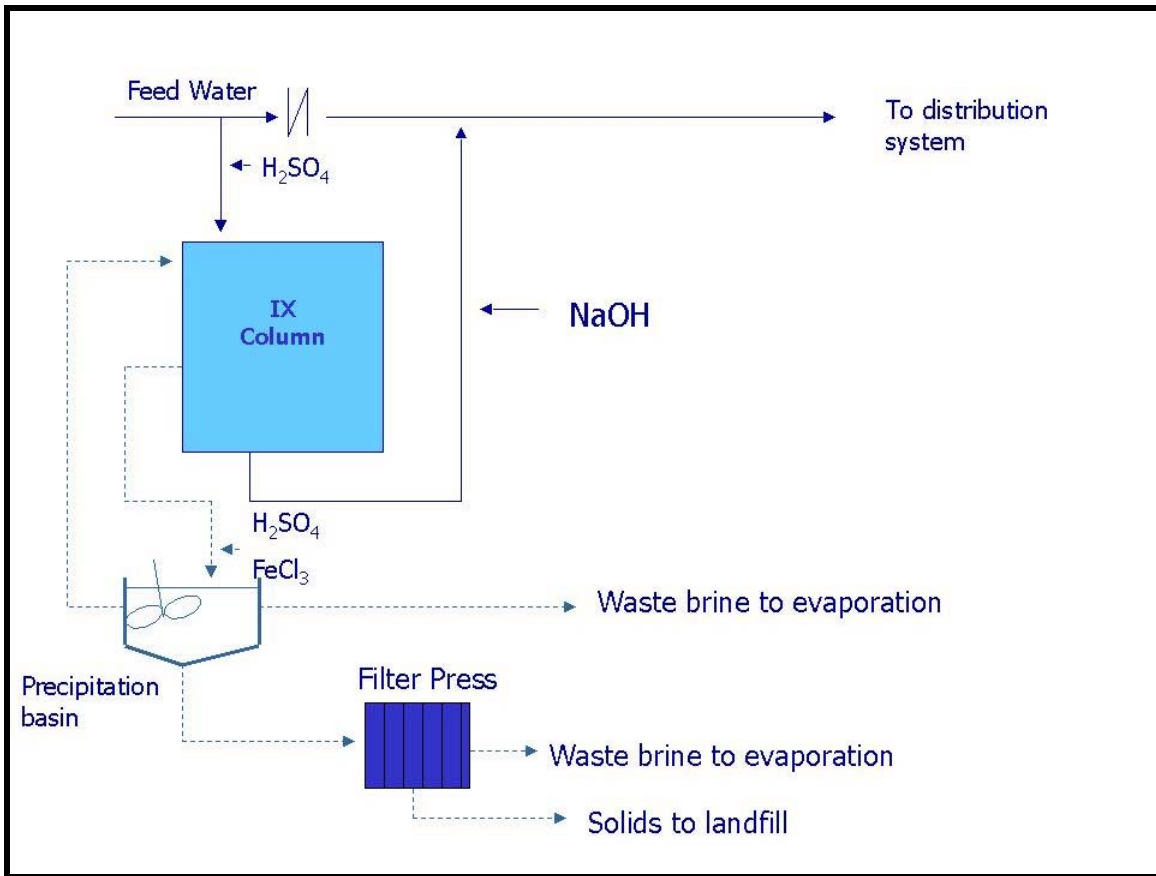


Figure 3: Ion Exchange Treatment Process Diagram

3.2.1.2 Ion Exchange Residuals

The use of brine to regenerate the IX resin can result in a significant mass of salt and volume of waste brine. The waste brine solution is treated in a process to separate the accumulated arsenic with iron precipitation. The arsenic/iron solids can be disposed of in a landfill and the remaining waste brine and rinse water is taken to an evaporation pond. Recycle of the brine minimizes the use of salt, the

volume of waste solids generated, and the volume of waste brine that must be handled. In addition, brine recycling will minimize pH depression of the water as it is treated by the IX process.

3.2.1.3 Summary of Ion Exchange Considerations

There are three major issues that communities that anticipate using IX for arsenic removal must consider. First, is the amount of salt required. For example, even with brine recycling, the amount of salt used in Albuquerque would be over 2,100 pounds per million gallons of water treated, resulting in a daily salt requirement of 145 tons (City of Albuquerque, 2000).

The second issue is the potential that the residuals would be hazardous waste. Depending on the amount of arsenic in the feedwater, the waste regenerant brine could contain a sufficiently high concentration of arsenic to make it hazardous waste. Recycling the brine will further concentrate the arsenic to levels (City of Albuquerque, 2000).

The third issue is that IX process is susceptible to extreme failure by a phenomenon known as chromatigraphic peaking. Because the IX resin prefers sulfate over arsenic and nitrate, if the run is not terminated prior to sulfate breakthrough, all the adsorbed arsenic and nitrate will be pushed off of the resin (CH2M Hill, 1999). This will result in a peak of arsenic or nitrates that is 3 to 5 times the influent concentration. In other words, if an IX system treating an

influent arsenic concentration of 30 ug/L is not regenerated properly, the process could release arsenic in the range of 90 ug/L to 150 ug/L (City of Albuquerque, 2000). Therefore, in order to be in compliance, the operations staff will need to monitor sulfate levels consistently and also monitor arsenic breakthrough. This could be a significant issue the time it takes to receive lab results confirming the arsenic concentration at the end of the run could exceed the run length.

Table 4 summarizes the considerations that communities should be aware of in evaluating ion exchange as a treatment technology for arsenic.

Table 4: Summary of Ion Exchange Considerations

Criteria	IX Considerations
Effectiveness: Can the process effectively remove arsenic and meet the potential MCLs?	Good; IX can remove arsenic to below 0.5 µg/L. However, if mechanical failure occurs and the IX columns are not regenerated when required, there is a possibility that arsenic peaking can occur. This means that arsenic concentrations in the product water can be several times higher than in the feedwater.
Effectiveness: What is the impact of treatment on resulting water quality? Is there a deterioration of water quality?	IX will exchange chloride for sulfate increasing the chloride content. This is not expected to impact the ability to use this water for irrigation.
Effectiveness: Will residuals be difficult to handle and dispose of?	IX will generate two residuals—waste brine and a ferric hydroxide solid. The treatment of the waste brine will require trained operators, and will require the addition of ferric chloride and sulfuric acid. The solids handling will require two steps: precipitation reaction/thickening followed by dewatering. The residuals may not pass the TCLP for disposal at a landfill.
Effectiveness: What percent of water will be wasted by the process?	The IX process will waste approximately 1.4 percent of the feedwater for brine makeup and rinsing.
Reliability: How complex is the process to operate?	The IX run length is a function of sulfate levels; therefore, each facility will have different operational parameters. The IX process is simple; however, there will be many valves to maintain and understand. Failure of the system to regenerate may result in arsenic peaking in the product water. The handling of residuals will be more complex than the C/MF process. IX will not require pH adjustment of the feedwater.
Reliability: Will chemical handling be difficult?	The IX process requires four chemicals—salt, ferric chloride, caustic soda, and sulfuric acid. Salt is innocuous; however, the volume required will be significant and increases the operational labor to maintain the brine makers.

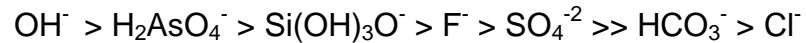
Criteria	IX Considerations
	Ferric chloride is an acidic material that will burn skin and stain materials. Caustic soda and sulfuric acid are both dangerous and should be handled carefully.
Source: CH2M Hill (1999)	

3.2.2 Activated Alumina Treatment Technology

The Activated Alumina and Throw-Away Activated Alumina treatment technologies both involve the pumping the water through columns of activated alumina media. The activated alumina media absorbs arsenic. Activated alumina (AA) is a mixture of amorphous and crystalline phase aluminum oxide of approximate composition Al_2O_3 . It is frequently prepared as a by-product of aluminum production in which an aluminum hydroxide slurry is heated to remove waters of hydration then activated with steam or acid to increase its surface area and adsorptive properties.

Activated alumina has a higher pH of zero-point-of-charge (pH_{zpc} ~ 8.2) than most oxide minerals; hence, it has an affinity for negatively charged constituents in water (anions). Furthermore, due to the molecular structure of the AA surface, it is selective for fluoride and some As, selenium, silica species. The removal mechanism involves exchange of hydroxide ions (OH⁻) for the contaminants. Contaminants that are removed by AA adsorption therefore must be anionic and the solution pH must be sufficiently low so that the surface of the AA is cationic.

AA has a different selectivity for ions in the feedwater than does IX. The selectivity for AA is as follows:



The optimum pH for As removal by AA was reported by Clifford et al. (1998b) to be in the range of 5.5 to 6. However, they also noted that reducing the feedwater pH to this value consumes nearly all of the alkalinity, increases the TDS through addition of acid, and requires subsequent neutralization of the treated water (CH2M Hill, 1999).

When the adsorption capacity of the activated alumina is reached, it can be regenerated or replaced, in the case of Throw-Away Activated Alumina.

Regeneration is accomplished by first rinsing the activated alumina with a caustic soda solution to dissolve some (2-3%) of the alumina (Frey et al, 2000). The rinse solution containing the dissolved alumina and arsenic is then acidified to precipitate aluminum hydroxide. The aluminum hydroxide will then adsorb the arsenic in the solution. The residual aluminum hydroxide-arsenic solids can be separated from the regeneration brine solution and disposed of.

3.2.2.1 Activated Alumina Treatment Process

The operation of an AA process consists of three steps as illustrated in Figure 4 and described below (CH2M Hill, 1999):

- 1. Arsenic Removal:** Well water is pumped into AA columns, and flows through the media to the bottom of the columns producing water for distribution, until the column capacity for arsenic is nearly exhausted. The use of AA columns can be implemented as either series or parallel systems. In the parallel method, each column would be operated independently and the total product water flow would be combined. In the series method of operation, two columns would be operated together with one column being the lead and the second column acting as a polishing step.
- 2. Regeneration:** The AA is regenerated with a caustic soda solution. The spent caustic soda regenerant solution will contain high concentrations of arsenic that must be removed prior to disposal. The arsenic can be removed by lowering the pH of the waste caustic solution to approximately 6. This will cause the dissolved aluminum to precipitate and adsorb the arsenic accumulated in the waste caustic solution. Sufficient sulfuric acid must be added to the waste caustic solution to achieve the required pH.
- 3. Dewatering of Residuals:** The solids generated from the AA process must be disposed of at a landfill. In order to dispose of the solids, they must be dewatered to approximately 20 percent solids to pass the paint filter test. The paint filter test is used by landfill operators to determine if there is free water in the solids. If there is free water, the solids will not be accepted by the landfill.

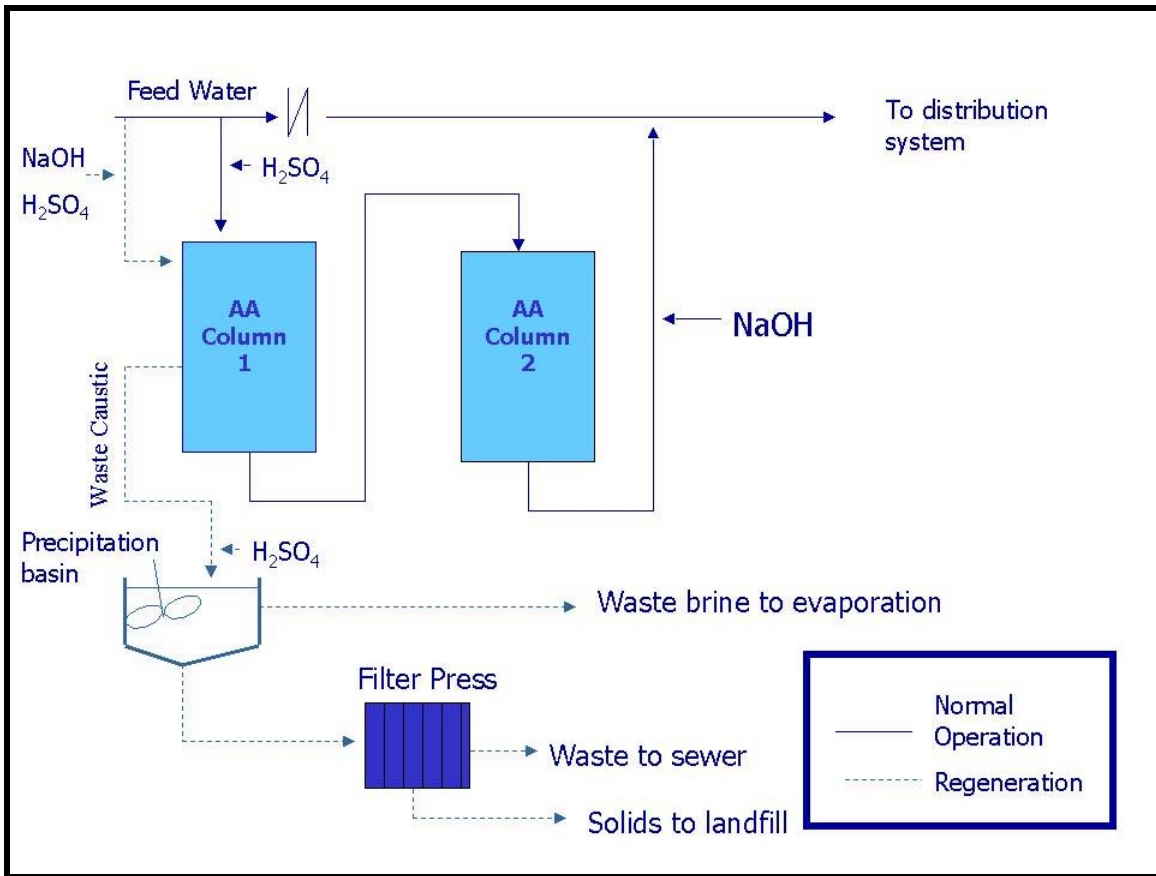


Figure 4: Activated Alumina Treatment Process Diagram

The Throw-Away Activated Alumina treatment technology does not require the regeneration or dewatering steps described above. For these package systems, the water is pumped through the activated alumina columns until the adsorption capacity is nearly reached, and then the columns are removed, disposed of, and replaced by fresh columns. The ease of operation makes these types of package plants much easier to use for small systems that serve less than 1000 people.

3.2.2.2 Activated Alumina Residuals

Residuals from the AA process include aluminum hydroxide solids and waste brine. The solids will have to be tested by the Toxicity Characteristic Leaching Procedure (TCLP) to determine if they can be disposed of in a landfill. CH2M Hill (1999) found that AA residuals from a pilot test in Albuquerque did pass the TCLP and could be accepted by the landfill.

Waste brine can either be discharged to the wastewater treatment plant, if the increased salinity in the effluent is acceptable. If not, the brine must be managed in some other fashion, most likely by evaporation. This would require the construction of evaporation ponds.

3.2.2.3 Summary of Activated Alumina Considerations

There are two major issues that communities that anticipate using AA for arsenic removal must consider. First is the amount of dangerous chemicals that are required. The process depends in large part on electrostatic attraction between the positively charged alumina surface and the negatively charge arsenate (As(V)) ions. The alumina surface charge, however, is pH dependent and decreases as the pH rises. Therefore, it will be necessary to lower the feed water pH, remove arsenic by the AA process, then raise the pH again to restabilize the water (CH2M Hill, 1999). This will require shipping, handling and

storing a very large amount of acid and base. For example, a 1 mgd treatment plant would require on the order of 1200 lbs/day of H₂SO₄ and 850 lbs/day of NaOH (City of Albuquerque, 2000). There would likely be concerns about shipping those volumes of acid and caustic through neighborhoods where wells are located.

The second issue with AA is the potential to generate a hazardous waste. Once the AA has been exhausted it must be regenerated. This is accomplished using concentrated caustic solutions ranging from 1% to 4% NaOH. This waste regenerant will have a high concentration of arsenic in it and, as with the IX process, it is likely that it will be classified a hazardous waste.

Table 5 summarizes the considerations that communities should be aware of in evaluating activated alumina as a treatment technology for arsenic.

Table 5: Summary of Activated Alumina Considerations

Criteria	AA Considerations
Effectiveness: Can the process effectively remove arsenic and meet the potential MCLs?	Good; AA can remove arsenic to around 2.0 µg/L. Arsenic peaking was observed by the Clifford et al (1998a, b) when using water at the natural pH. It is not known if this could occur when pH adjustment is practiced.
Effectiveness: What is the impact of treatment on resulting water quality? Is there a deterioration of water quality?	AA will remove natural fluoride requiring refluoridation following treatment. In addition, high volumes of sulfuric acid and caustic soda will be used for pH adjustment resulting in an increase of TDS.
Effectiveness: Will residuals be difficult to handle and dispose of?	AA will generate an aluminum hydroxide residual, which contains high concentration of arsenic. This residual may not pass the TCLP test and therefore could not be taken to a landfill. The generation of the solid residual will require a treatment step for the waste caustic soda followed by thickening and dewatering.
Effectiveness: What percent of water will be wasted by the process?	The AA process will waste approximately 0.4 percent of the feedwater for caustic soda solution makeup and rinsing.
Reliability: How complex is the	The AA run length is not as dependent on competing ions as the IX process;

Criteria	AA Considerations
process to operate?	however, the run length may vary across systems. The AA process is simple; however, there will be many valves to maintain and understand. Failure of the system to regenerate may result in arsenic peaking in the product water. The handling of residuals will be more complex than the C/MF process. AA requires adjustment of the feedwater pH.
Reliability: Will chemical handling be difficult?	The AA process requires two chemicals—sulfuric acid and caustic soda. Both are dangerous and should be handled carefully.
Source: CH2M Hill (1999)	

3.2.3 Coagulation/Microfiltration Treatment Technology

The coagulation/microfiltration (C/MF) process involves the formation of a ferric hydroxide precipitant that adsorbs arsenic. The ferric hydroxide-arsenic solids are filtered from the water (Frey et al, 2000). The precipitant is formed by the addition of ferric chloride under specific pH conditions in the water to hydrolyze and precipitate ferric hydroxide. Ferric chloride is an acid solution and will reduce the pH of the water as a function of the ferric chloride dose. The adsorption of arsenic to the ferric hydroxide is a function of pH: greater adsorption occurs at a lower pH (CH2M Hill, 1999). The ferric hydroxide-arsenic solids are filtered from the solution by a microfiltration (MF) unit.

3.2.3.1 Coagulation/Microfiltration Treatment Process

The operation of an AA process consists of four steps as illustrated on Figure 5 and described below (CH2M Hill, 1999):

- 1. Precipitation:** Ferric chloride must be added and hydrolyzed to a precipitate prior to filtration. This will require rapid mixing facilities to mix the ferric chloride with sufficient energy to form a floc.
- 2. Arsenic Removal by Filtration:** The microfiltration process consists of pumping the water through a microfilter. The filtered water is then collected at the end of the microfilter and solids will collect on the outside of the microfilter. The solids must be removed periodically. Removal of the solids is accomplished by backwashing.
- 3. Backwash:** The microfiltration units must be backwashed on a periodic basis to remove accumulated ferric hydroxide solids from the membranes
- 4. pH Adjustment:** The treated water will have low pH due to the ferric chloride addition and will require pH adjustment prior to conveying the water to the distribution system. Therefore, it will be desirable to minimize the pH reduction of the feedwater to minimize the chemical usage for both ferric chloride and caustic soda, yet still achieve the required arsenic removal.

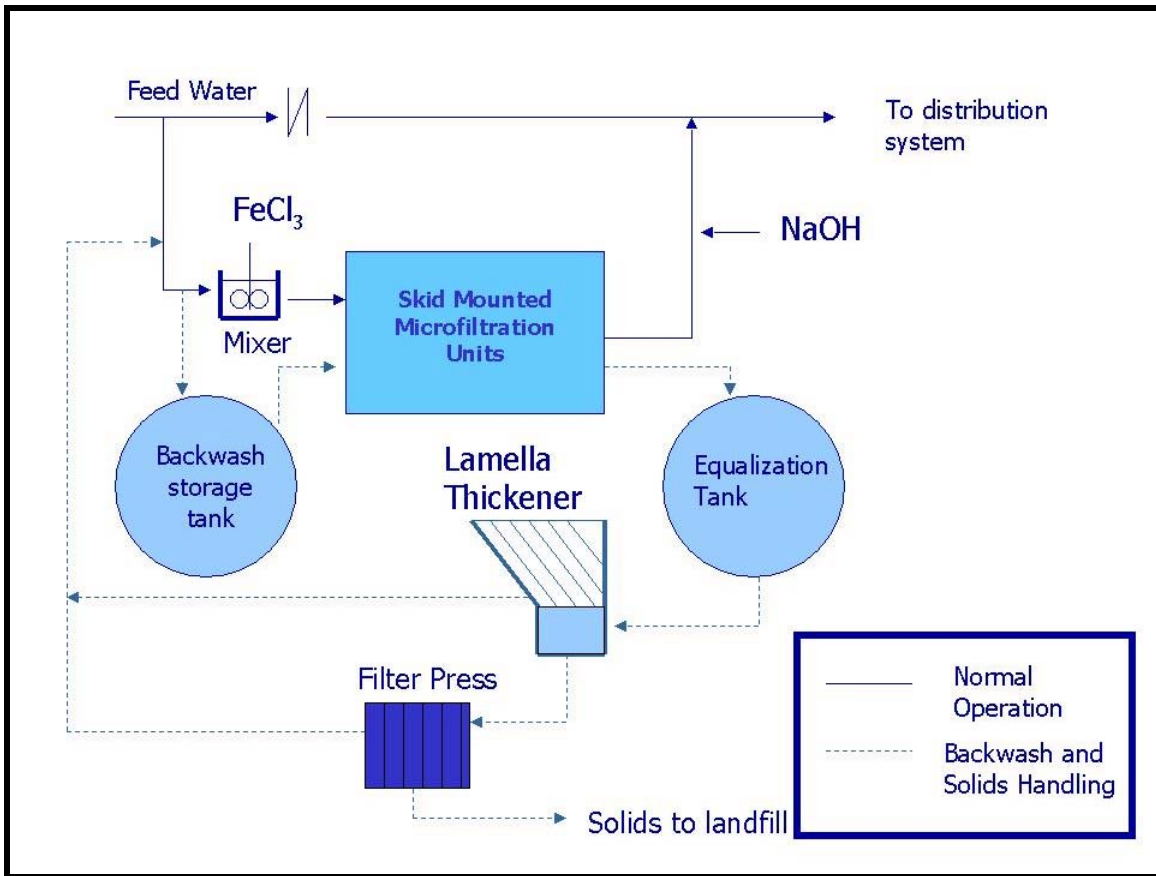


Figure 5: Coagulation/Microfiltration Treatment Process Diagram

3.2.3.2 Coagulation/Microfiltration Residuals

The solids from the microfiltration process should be thickened and dewatered to minimize their volume. CH2H Hill (1999) reported that in pilot tests conducted in Albuquerque showed that the arsenic containing residuals generated by the

C/MF process passed the TCLP and could be disposed of at a landfill. The disposal of solids containing arsenic may be a concern for communities with higher levels of arsenic in the groundwater.

3.2.3.3 Summary of Coagulation/Microfiltration Considerations

The C/MF process has been pilot-tested in Albuquerque (Clifford et al, 1998a, 1998b), but is not in full-scale operation in the United States. Based on the pilot test, there is one major issue that should be considered by communities considering C/MF as technology for removing arsenic. The C/MF uses large amounts of two chemicals that are dangerous: ferric chloride and caustic soda. Ferric chloride is a caustic soda that will burn skin and stain materials (CH2M Hill, 1999). There may be concerns if these chemicals have to be transported through neighborhoods to the wells. Table 6 summarizes the considerations that communities should be aware of in evaluating coagulation/microfiltration as a treatment technology for arsenic.

Table 6: Summary of Coagulation/Microfiltration Considerations

Criteria	C/MF Considerations
Effectiveness: Can the process effectively remove arsenic and meet the potential MCLs?	Good; C/MF can remove arsenic to below 1.0 µg/L. Mechanical failure would only result in product water arsenic levels equal to the feedwater.
Effectiveness: What is the impact of treatment on resulting water quality? Is there a deterioration of water quality?	C/MF will require pH adjustment of the product water to minimize corrosiveness. The ferric chloride will add a small amount of chloride to the water; however, it should have no impact on water quality.
Effectiveness: Will residuals be difficult to handle and dispose	The solids handling will require two steps—thickening followed by

Criteria	C/MF Considerations
of?	dewatering. The residuals will likely pass the TCLP for disposal at a landfill.
Effectiveness: What percent of water will be wasted by the process?	The C/MF process will waste less than 0.1 percent of the feedwater. The backwash water will be recycled within the treatment facility and the only loss will be through the solids disposal and the strainer.
Reliability: Can process be scaled up?	C/MF can be scaled up; however, the chemical storage may become an issue with larger capacity facilities.
Reliability: How complex is the process to operate?	The C/MF process is a simple process requiring only the pH of the feedwater to be monitored to control the ferric chloride feed. The control of pH is a simple process. Water quality changes will have minimal impact since pH is the main controlling factor of the C/MF process.
Reliability: Will chemical handling be difficult?	The C/MF process requires two chemicals—ferric chloride and caustic soda. Ferric chloride is an acidic material that will burn skin and stain materials. Both ferric chloride and caustic soda are dangerous and should be handled carefully.
Source: CH2M Hill (1999)	

4.0 COST ESTIMATION METHODOLOGY

As discussed in Section 3, of the six treatment technologies are identified by EPA at Best Available Technology (BAT) for arsenic removal, only two technologies (ion exchange and activated alumina) are considered appropriate for water supply systems that rely on groundwater. A third technology, coagulation/microfiltration, has been shown to be effective during pilot testing in Albuquerque (Clifford, 1998a, b). The capital, O&M, and annualized costs for each community water system applying each of the three technologies has been estimated and is presented in Appendices B and C of this report. The costs for ion exchange, activated alumina and coagulation/microfiltration were estimated using cost curves developed by CH2M Hill for the City of Albuquerque (CH2M Hill, 1999) and used for five other southwestern cities (Frey et al, 2000). Costs for these technologies were estimated for "large" systems in New Mexico. A large system is defined as one with an annual demand of greater than 0.2 million gallons per day, which equates to a community with greater than 1000 people. These communities are more likely to have the ability to construct and operate treatment facilities. There are 79 "large" New Mexico community water systems that will be affected by the proposed arsenic MCL of 5 $\mu\text{g/L}$ (Appendix B).

Consistent with EPA (EPA, 2000), throw-away activated alumina was assumed to be the only treatment technology appropriate for "small" systems. Small systems for this study are those with an annual demand of less than 0.2 million

gallons per day. There are 267 small community water systems in New Mexico that will be affected by the proposed arsenic MCL of 5 µg/L (Appendix C). The cost curve for throw away activated alumina is provided in American Water Works Association Arsenic Treatment Cost Estimating Tool (Chwirka and Narasimhan, 2000).

The cost estimates were prepared to assessing the economic impact of the proposed arsenic MCL from the information available at the time this report was prepared. The actual costs would depend on actual labor and material costs, competitive market conditions, site conditions, final project scope, implementation schedule, continuity of personnel and engineering, and other variable factors. The cost curves prepared by CH2M Hill (1999), Frey et al (2000), and Chwirka and Narasimhan (2000) used industry standard cost estimating practices, references, costs of similar projects, and material quotes from vendors. The costs are considered Budget Level Estimates, as defined by the American Association of Cost Engineers. The capital cost curves for ion exchange, activated alumina, and coagulation/microfiltration are provided in Figure 6.

The cost curves were developed based on flow sheets, layouts, and equipment details. In other words, enough preliminary engineering has been done to further define the project scope. An estimate of this type is normally expected to be accurate within +30 percent or –15 percent. The unit costs include contractor labor burden, equipment, and material costs. Mark-ups include contractor's overhead and profit, mobilization, bonds, and insurance. A contingency is

included at this level of design for scope. The total capital costs do not include engineering and service during construction. All costs are presented in January 1999 dollars.

The cost curves shown in Figure 6 were developed by estimating the costs of building treatment systems capable of treating water at various flow rates. The costs at each flow rate included the components shown on Table 7. The curve was established by a linear regression through the points. The slope of the curve was used to estimate the costs for community water systems of specific capacity.

4.1 Capital Costs

The capital costs shown in Appendix B for ion exchange, activated alumina, and coagulation/microfiltration include the capital costs of treatment facilities and residuals handling facilities. The components of capital costs for each of these treatment technologies are shown in Table 7. The capital costs shown in Appendix C, for the throw-away activated alumina, do not include residuals management components (Table 7). Capital costs do not include land acquisition costs, engineering design, or engineering service during construction.

Table 7 Components of Capital Costs for IX, AA, C/MF, and TAAA

Treatment Technologies

IX Capital Cost Components	AA Capital Cost Components	C/MF Capital Cost Components	TAAA Capital Cost Components
Booster	Booster	Booster Pumping	Booster

IX Capital Cost Components	AA Capital Cost Components	C/MF Capital Cost Components	TAAA Capital Cost Components
Pumping/Straining	Pumping/Straining	Straining	Pumping/Straining
Ion Exchange Facilities	Activated Alumina Facilities	Rapid Mixing	Activated Alumina Facilities
Brine Handling Facilities	Waste Caustic/AA Precipitation Facilities	Microfiltration	Chemical Feed Systems
Brine Evaporation Facilities	Solids Handling	Solids Handling	Building
Solids Handling	Chemical Feed Systems	Chemical Feed Systems	Piping, I&C, Electrical, Yard Piping Allowances
Chemical Feed Systems	Building	Building	Contingency - 20%
Building	Brine Evaporation Ponds	Piping, I&C, Electrical, Yard Piping Allowances	
Piping, I&C, Electrical, Yard Piping Allowances	Piping, I&C, Electrical, Yard Piping Allowances	Contingency - 20%	
Contingency - 20%	Contingency - 20%		

Source: CH2M Hill (1999)

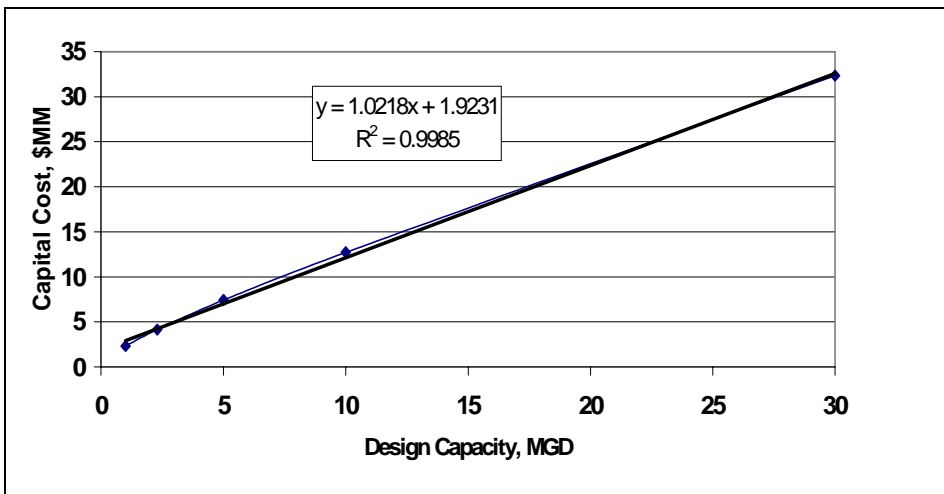
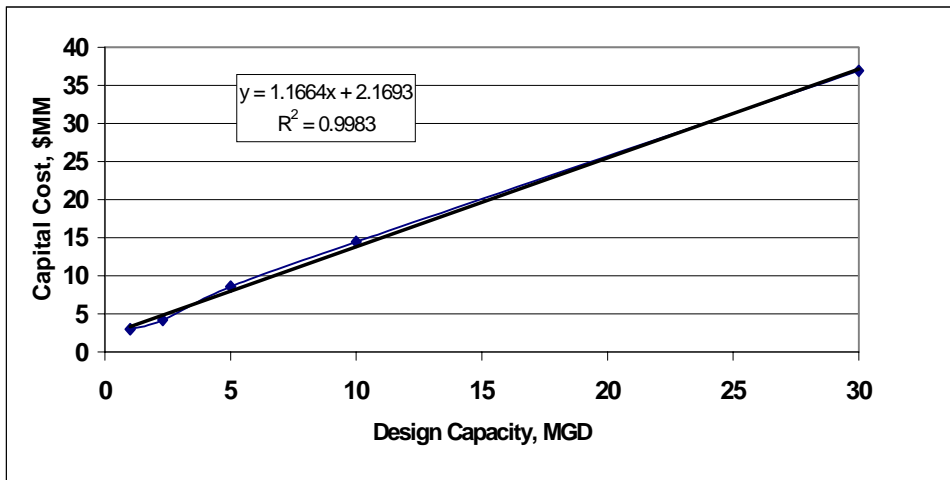
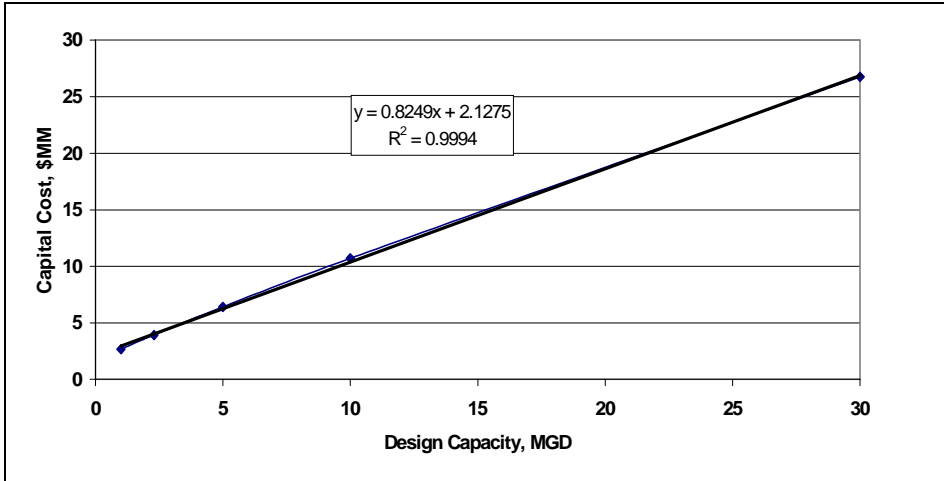


Figure 6: Capital Cost Curves for Ion Exchange (top); Activated Alumina (middle); and Coagulation/Microfiltration (bottom) Treatment Technologies

Assumptions made in developing capital costs are (Frey et al, 2000):

- The arsenic treatment systems are applied on a well basis. This means that capital costs calculated for each source well.
- The treatment system would have a design capacity defined by average arsenic concentrations of the individual wells.
- The design is based on removing arsenic to a concentration that is 80% of the potential MCL to provide a margin of safety in the design. In other words, if the MCL were set at 10 $\mu\text{g/L}$, treatment systems would be designed to obtain a finished water arsenic level of 8 $\mu\text{g/L}$.
- A mass balance was completed for each well to determine the flow rate of water that would need to be treated to meet the MCL.

4.2 Operation and Maintenance Costs

The estimated annual operation and maintenance costs (O & M) for treatment facilities and residuals facilities were estimated for the IX, AA and C/MF treatment technologies. O & M costs for throw-away activated alumina do not include residuals management, because the spent alumina will be directly disposed. The components of O & M costs included in these estimates are shown in Table 8.

Table 8 : Components Included in O & M Cost Curves

IX O & M Cost Components	AA O & M Cost Components	TAAA O & M Cost Components	C/MF O & M Cost Components
Power	Power	Power	Power
Resin replacement	Chemicals: H ₂ SO ₄ , NaOH, Fluosilicic Acid	Chemicals: H ₂ SO ₄ , NaOH, Fluosilicic Acid	Membrane replacement
Chemicals: NaOH, FeCl ₃ , H ₂ SO ₄	AA replacement	Equipment maintenance	Chemicals: FeCl ₃ , NaOH, Fluosilicic Acid
Salt	Brine hauling	Labor	Residuals disposal
Residuals disposal	Residuals disposal		Labor
Brine hauling	Labor		Equipment maintenance
Labor	Equipment maintenance		
Equipment maintenance			

Source: CH2M Hill (1999)

4.3 Annualized Costs

Calculation of the annualized cost is a way to allow comparison of fiscal expenditures where a non-uniform series of money disbursements occurs over the life of a project (Grant and Ireson, 1960). This calculation includes the time value of money and converts the total cost into a series of comparable disbursements. The annualized costs combine the capital and O and M costs and spread them out over a period of 20 years at an interest rate of 6%.

Annualized costs were calculated in order to produce cost estimates comparable to nationwide estimates of costs to comply with lower arsenic MCLs by Frey et al (2000) and EPA (Abt Associates, 2000). Annualized costs calculations produce an equivalent uniform annual cost and are calculated using the following equation (Grant and Ireson, 1960):

$$\text{Annual Costs} = \frac{(\text{Capital Costs}) \cdot (\text{interest rate}) \cdot (1 + \text{interest rate})^{\text{period}}}{(1 + \text{interest rate})^{\text{period}} - 1} + (\text{O \& M Costs})$$

The annualized of arsenic treatment for all 346 community water systems affected by the proposed arsenic MCL is shown in Appendix B ("large" systems) and Appendix C ("small systems").

4.4 Monthly Cost Calculations

The monthly cost of water after treatment for compliance with the proposed arsenic MCL of 5 µg/L was estimated for each community water system (Appendix D). The equation used to estimate the monthly cost is:

$$\text{Monthly Costs} = \frac{\text{Annualized Costs}}{(\text{Number of Customers})(12 \text{ months/yr})}$$

The monthly cost estimates should be considered a rough indication of the magnitude of potential increases. It is based on assumptions about interest rate (6%) and amortization period (20 years). It does not reflect community-specific information on the current water rates and methods of financing that may be available for constructing and maintaining treatment systems.

4.5 Sources of Uncertainty

As with any set of data and calculations, there is inherent uncertainty in the results. The degree of uncertainty is dependent on the data available to represent the population of interest and the assumptions that are made in using the data. The major uncertainties in the estimates contained in this report are:

- Capital costs based on distribution systems
- Annual Water Demand
- Interest Rate in annualized cost calculations
- Costs not included

The following sections discuss the affect of these uncertainties on the cost estimates presented in Appendices B and C. The overall impact of these uncertainties appears to be that the estimates of the compliance costs for a lower arsenic MCL in New Mexico are probably lower than the true costs.

4.5.1 Capital Costs Based on Distribution Systems

Groundwater systems supply water from single or multiple wells to the distribution system with little or no prior treatment. The ability to provide centralized treatment to these widely distributed sources is limited. Therefore,

treatment facilities must be at the well head. The capital costs of constructing treatment facilities for a community water system is, to some degree, proportional to the number of wells requiring treatment. Likewise, the O & M costs would also reflect the requirements of multiple treatment systems.

Almost 30% of the records in data set used in the compliance cost calculations (Appendix A) reflect information on the distribution system for the community rather than water quality in individual wells. Small systems (< 0.2 mgd) are likely to have only one or two wells, so there is expected to be little impact on the cost estimates for these small systems. Frey et al (2000) found that for water systems with 1-2 sources (or entry points) the cost estimates could accurately be based on the system mean conditions (distribution systems). However, a number of larger municipalities in New Mexico were in the final data set because the distribution systems had arsenic concentrations at or above 5 µg/L, including Alamogordo, Bloomfield, Farmington, Red River, Ruidoso, Silver City, and Taos. The cost estimates for these cities are likely to be low because they do not reflect the number of sources that may need treatment. Frey et al (2000) found that for an MCL of 5 µg/L, the use of a mean system condition (distribution system) rather than the number of entry points in larger systems underestimated the costs by about 15%. Thus, the cost estimate for about 10% of the "large" systems is probably too low, possibly by about 15%.

4.5.2 Annual Water Demand

The community annual water demand is used in calculating the annual O & M costs. The more water that is used, the higher the O & M costs. Annual water demand in this study was derived by multiplying the population by water use of 200 gallons per person per day. While this water use is representative of that for southwestern cities (Spurlock, 2000), it may be an over-estimate of water use in rural areas, where irrigation for landscaping and recreational facilities is not as extensive as in urban communities. A better estimate could be developed based on the actual amount of water provided to customers, which is data that could be requested of the water utilities. The result of the 200 gallons per person per day assumption for water demand may be that the O & M cost estimates are high in those communities for which flow data are not available in the NMED database.

4.5.3 Interest Rate in the Present Worth Calculations

The interest rate used in the annualized cost calculations was 6%. This is based on an assumption that community water systems would be able to use municipal bonds to finance the construction of treatment facilities. In August 2000, the interest rate for corporate AAA bonds was 5.75%. However, the AAA bond rating is not available to most New Mexico municipalities. Additionally, many of the small systems shown in Appendix C are not municipalities and would not have public financing available to them. The many mobile home parks, homeowner

associations, and subdivisions would be forced to secure financing through banks or other commercial financial institutions. As of August, 2000 the prime lending rate was 9.5%. Thus the annualized cost estimates may be too low, particularly for privately-owned community water systems.

4.5.4 Costs Not Included

There are a number of costs that were not included in these cost estimates, largely because they are too site-specific to include in the cost curves. Not included in the capital costs are: land acquisition, legal fees, permitting costs, and engineering fees for design and construction. One item not included in the O & M costs is the training of operators. Many community water systems have no operators with no training or qualifications in operating and monitoring water treatment systems. Operators will be required to receive training in the operation and maintenance of the treatment systems. This is expected to have significantly larger impact on smaller systems. The overall effect of omitting these site-specific cost items is that the O & M cost estimates are too low.

5.0 ESTIMATED COST OF COMPLIANCE

This section summarizes the cost of compliance with a lower arsenic MCL in New Mexico. The costs are discussed in terms of estimated capital, operation and maintenance, annualized, and increased monthly costs. Spreadsheets with the cost estimates for the 346 community water systems that would be affected by the potential MCLs of 5 µg/L, 10 µg/L, and 20 µg/L are presented in Appendices B, C, and D.

5.1 Estimates of Capital Costs

The capital costs for compliance with the proposed MCL of 5 µg/L range from \$1.0 to \$1.2 billion, depending on the treatment technology. Large systems ($Q > 0.2$ mgd) in 79 communities account for about 80% of the estimated capital costs and small systems ($Q < 0.2$ mgd) in 267 communities account for about 20% of the estimated capital costs. Table 9 shows the estimated capital costs associated with three treatment technologies for large community water systems and with one treatment technology for small systems. Figure 7 shows the same information graphically.

To place these estimated capital costs in context, they represent about 3% of the 1997 Gross State Product for New Mexico (\$45 billion) and about 50% of the Construction Gross State Product (\$2.01 billion)(BBER, 1999). Based on these

comparisons, it is uncertain whether the construction capacity would be available to complete this work within the time frames in the proposed rule. Under the proposed rule, community water systems serving greater than 10,000 people must comply within 3 years; smaller systems have 5 years to come into compliance. To construct all of the treatment facilities, would require about 12% of the construction resources in the state each year for 5 years.

Availability of funding for the construction of treatment facilities would further limit the ability of water supply systems to comply with a lower arsenic MCL. The New Mexico Clean Water State Revolving Fund has about \$6 million per year available to local authorities to construct wastewater facilities. Another funding program, the New Mexico Rural Communities Assistance Program, has about \$410,000 available to loan for construction of wastewater facilities. It is not clear that construction of water treatment facilities would be eligible for either of these loan programs. One other funding program, the Rural Infrastructure Revolving Loan Program has available \$500,000 per year to loan specifically for construction or modification of water supply facilities. Thus, if the funds from all three programs were available for water treatment, approximately \$7 million per year could be loaned to communities to construct arsenic treatment facilities.

With these potentially available loan funds, it would take approximately 157 years to construct all the facilities necessary to comply with an arsenic MCL of 5 µg/L. It is important to note that these low-interest loan programs are not available to private water supply systems, such as mobile home parks.

National capital costs for treatment of arsenic with an MCL of 5 µg/L were estimated at about \$14 billion by Frey et al (2000), based on a statistical approach. EPA (Abt Associates, 2000) also used a statistical approach, but has not provided their estimates of capital costs. The analysis presented in this report, based on a Budget Level Estimate (accuracy of + 30% and -15%) for each community water system in New Mexico, produces an estimate that is 8% of the Frey et al (2000) nationwide capital costs.

Table 9: Estimated Capital Costs to Comply with an Arsenic MCL of 5 ug/L

Large Systems (\$ Millions)		Small Systems (\$ Millions)	Capital Cost Total (\$ Millions)
Treatment Technology:		Treatment: Throw-Away AA	
Ion Exchange	\$939.40	\$186.60	\$1,126.00
Activated Alumina	\$1,022.00	\$186.60	\$1,208.60

Coagulation/ Microfiltration	\$865.30	\$186.60	\$1,051.90
---------------------------------	----------	----------	-------------------

Figure 7: Estimated Capital Costs of Treatment with an Arsenic MCL of 5 ug/L in New Mexico

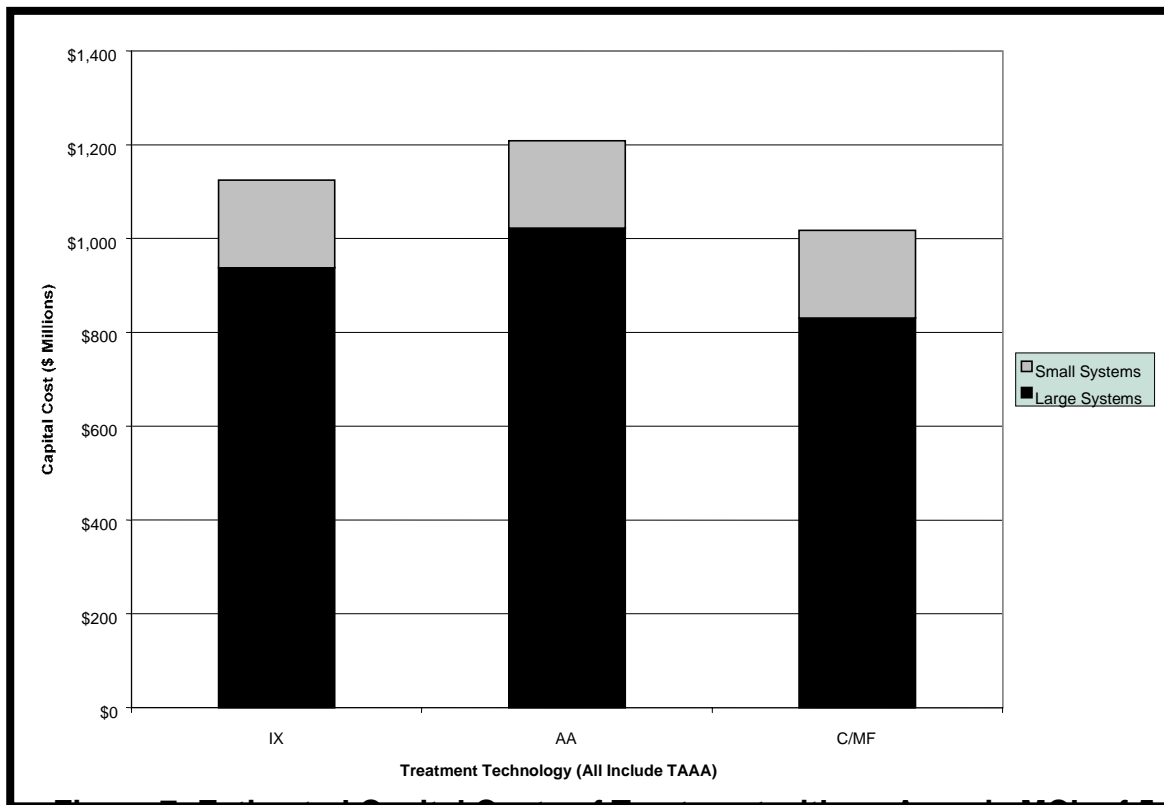


Figure 7. Estimated Capital Costs of Treatment with an Arsenic MCL of 5 ug/L

EPA has requested comment on three other potential arsenic MCLs: 3 µg/L, 10 µg/L, and 20 µg/L. This analysis did not address the economic impacts of setting the arsenic MCL at 3 µg/L. The estimated capital costs that may be expected at arsenic MCL of 10 µg/L are \$374 to \$436 million and at an MCL of 20 µg/L the estimated capital costs are \$139.66 to 117.56 million (Table 10, Figure 8).

Table 10: Estimated Capital Costs of Treatment for Arsenic MCLs of 10 ug/L and 20 ug/L

10 µg/L	Capital Cost (\$ Millions)			20 µg/L	Capital Cost (\$ Millions)			
	Treat- ment	Large	Small		Total	Treatment	Large	Small
IX		\$368.60	\$55.62	\$424.22	IX	\$137.67	\$10.35	\$148.02
AA		\$380.86	\$55.62	\$436.48	AA	\$139.66	\$10.35	\$150.01
C/M F		\$318.5	\$55.62	\$374.12	C/MF	\$117.56	\$10.35	\$127.91

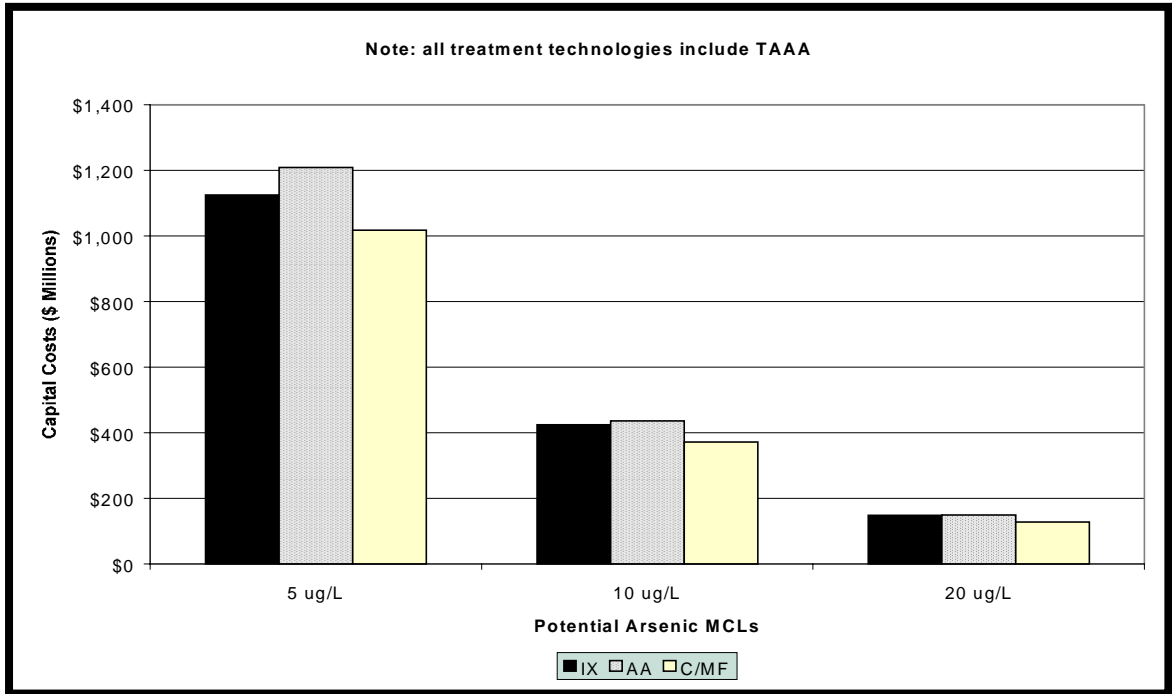


Figure 8: Estimated Capital Costs of Treatment with Potential Arsenic MCLs in New Mexico

5.2 Estimated Operation and Maintenance (O & M) Costs

The annual O & M costs for compliance with the proposed MCL of 5 $\mu\text{g/L}$ range from \$48 to \$67 million, depending on the treatment technology. Large systems (> 0.2 mgd) in 79 communities account for about 92% of the estimated annual O & M costs and small systems (< 0.2 mgd) in 267 communities account for about 8% of the estimated annual O & M costs. Table 11 and Figure 9 show the estimated annual O & M costs associated with three treatment technologies for large community water systems and with one treatment technology for small systems.

Table 11 Estimated Annual O & M Costs for Treatment with Arsenic MCL of 5 ug/L in New Mexico

Large Systems (\$ Millions)		Small Systems (\$ Millions)	Annual O & M Cost Total (\$ Millions)
Treatment Technology:		Treatment: Throw-Away AA	
Ion Exchange	\$50.93	\$4.24	\$55.17
Activated Alumina	\$62.47	\$4.24	\$66.71
Coagulation/ Microfiltration	\$43.52	\$4.24	\$47.76

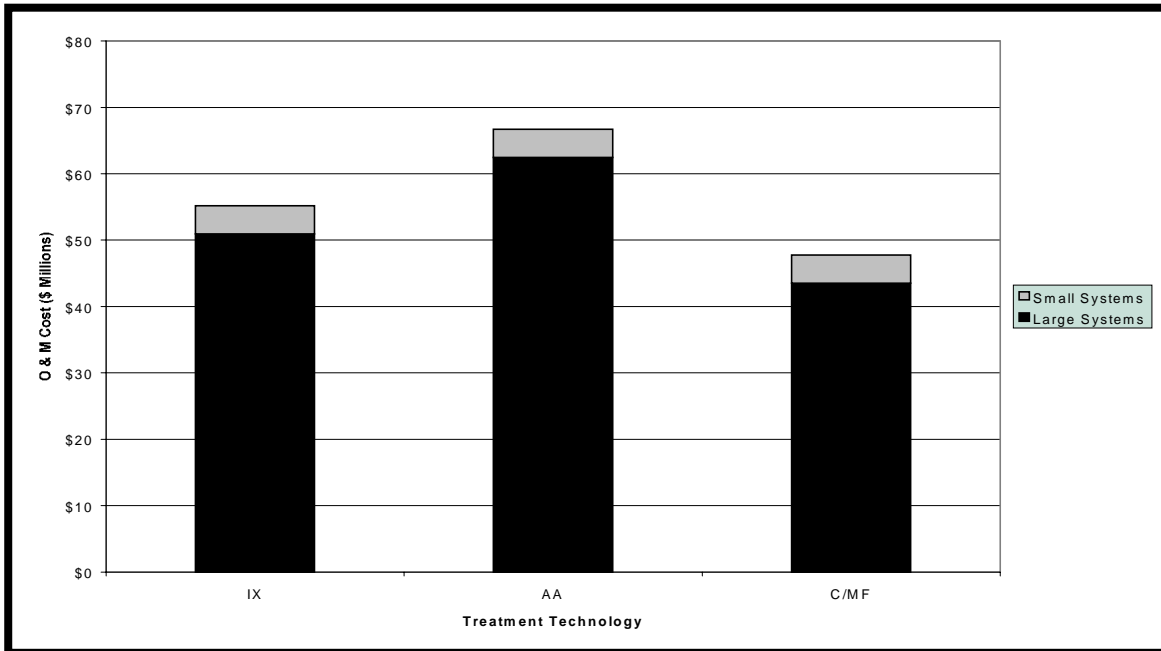


Figure 9: Estimated Annual O & M Costs for Treatment with an Arsenic MCL of 5 ug/L in New Mexico

The estimated annual O & M costs that may be expected at an arsenic MCL of 10 $\mu\text{g/L}$ are \$16 to \$21 million and at an MCL of 20 $\mu\text{g/L}$ the estimated annual O & M costs are \$5 to \$7 million (Table 12, Figure 10). Note that O & M costs for small systems are based on the selection of the activated alumina adsorption process with direct disposal of the spent alumina (Throw-Away activated alumina - TAAA).

Table 12: Estimated Annual O & M Costs for Arsenic MCLs of 10 ug/L and 20 ug/L in New Mexico

10 µg/L	Annual O & M Cost (\$ Millions)			20 µg/L	Annual O & M Cost (\$ Millions)			
	Treat- ment	Large	Small		Total	Treatment	Large	Small
IX		\$18.17	\$1.01	\$19.18	IX	\$4.98	\$0.29	\$5.27
AA		\$20.49	\$1.01	\$21.50	AA	\$6.93	\$0.29	\$7.22
C/M F		\$15.30	\$1.01	\$16.31	C/MF	\$4.50	\$0.29	\$4.79

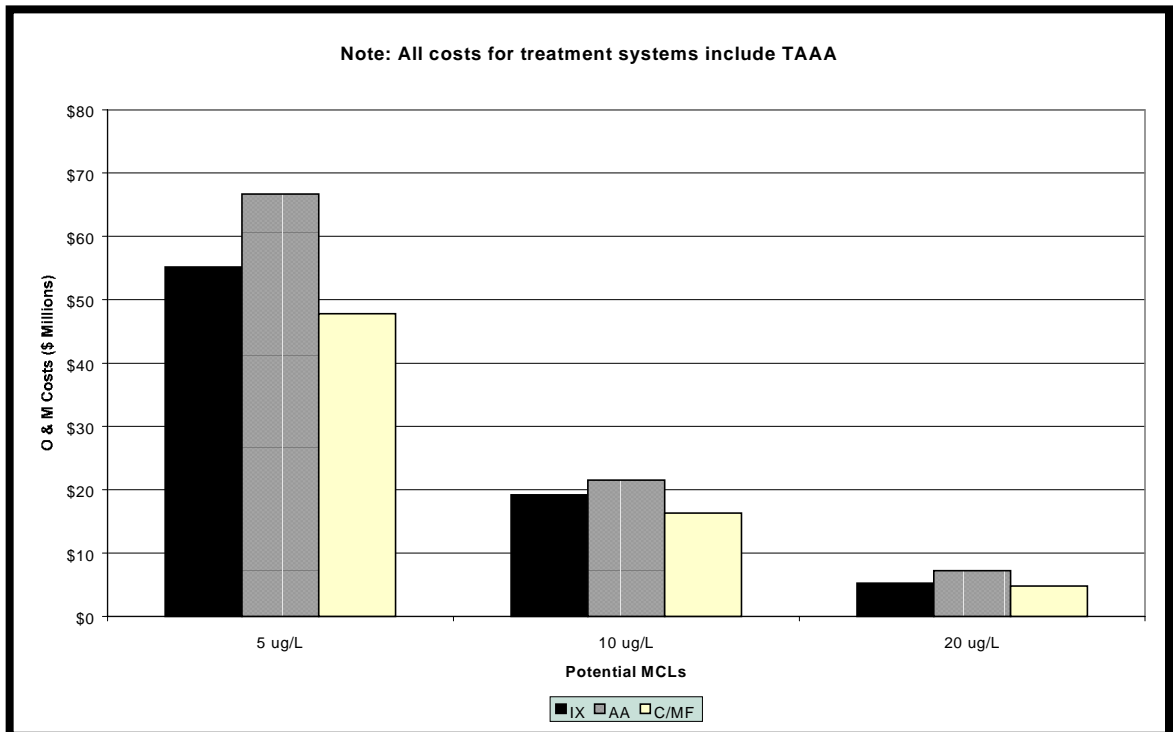


Figure 10: Estimated Annual O & M Costs for Treatment with Potential Arsenic MCLs in New Mexico (All Systems)

5.3 Estimated Annualized Costs

The estimated annualized costs for compliance with the proposed MCL of 5 µg/L range from \$139 to \$172 million, depending on the treatment technology. This value represents the annual cost for the combined capital costs and annual O & M costs over a 20-year period at an interest rate of 6%. Large systems (> 0.2 mgd) in 79 communities account for about 88% of the estimated annualized costs and small systems (< 0.2 mgd) in 267 communities account for about 12% of the estimated annualized. Table 13 and Figure 11 show the estimated annualized costs associated with three treatment technologies for large community water systems combined with "throw away" activated alumina treatment technology for small systems.

National annualized costs for treatment of arsenic at an MCL of 5 µg/L have been estimated by EPA (Abt, 2000) and by Frey et al (2000). The EPA estimate of national costs ranges from \$377 million based on an interest rate of 3% to \$442 million based on an interest rate of 7%. The assumed period over which the costs were annualized is not disclosed. Frey et al (2000) estimated national annualized costs of \$1.4 billion assuming 6% interest over a 20-year period. The annualized costs estimated in this analysis are about 30% and 10% of the EPA and Frey national estimates, respectively.

Table 13 : Estimated Annualized Costs for Treatment with an Arsenic MCL of 5 ug/L in New Mexico

Large Systems (\$ Millions)		Small Systems (\$ Millions)	Annualized Costs Total (\$ Millions)
Treatment Technology:	Cost (\$ Millions)	Treatment: Throw-Away AA	
Ion Exchange	\$132.74	\$20.51	\$153.25
Activated Alumina	\$151.61	\$20.51	\$172.12
Coagulation/ Microfiltration	\$118.96	\$20.51	\$139.47

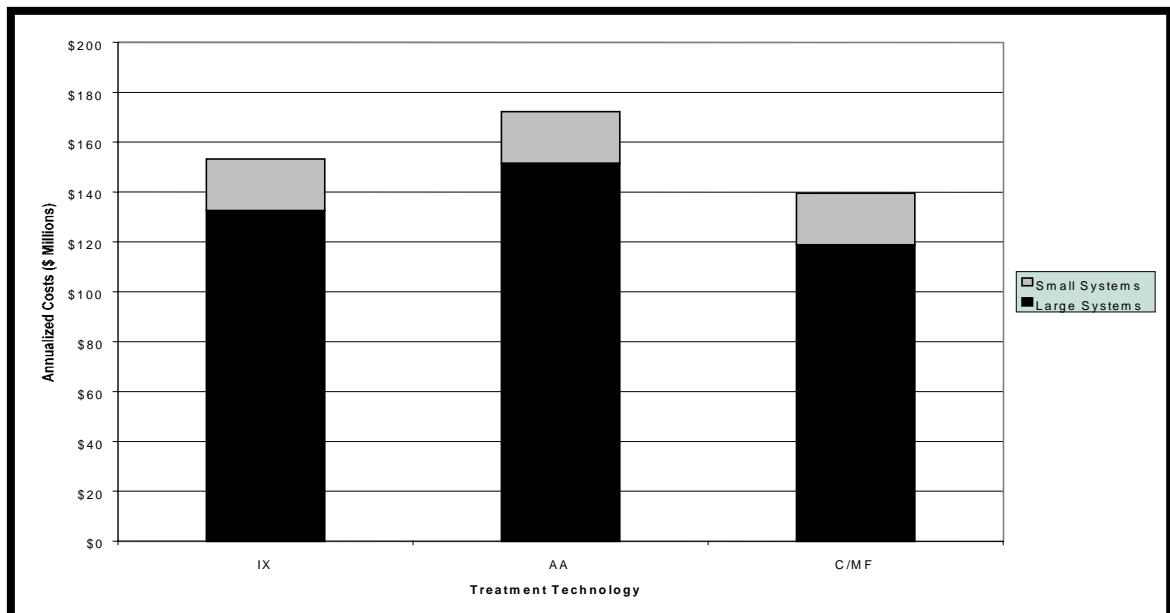


Figure 11: Estimated Annualized Costs of Treatment with an Arsenic MCL of 5 ug/L in New Mexico

The estimated annualized costs that may be expected at an arsenic MCL of 10 $\mu\text{g/L}$ are \$49 to \$60 million and at an MCL of 20 $\mu\text{g/L}$ the estimated annualized costs are \$20 to \$24 million (Table 14, Figure 12).

Table 14: Estimated Annualized Costs for Arsenic MCLs of 10 $\mu\text{g/L}$ and 20 $\mu\text{g/L}$ in New Mexico

10 $\mu\text{g/L}$	Annualized Cost (\$ Millions)			20 $\mu\text{g/L}$	Annualized Cost (\$ Millions)			
	Treatment	Large	Small		Total	Treatment	Large	Small
IX		\$50.31	\$5.86	\$56.17	IX	\$16.98	\$5.14	\$22.12
AA		\$53.70	\$5.86	\$59.56	AA	\$19.11	\$5.14	\$24.25
C/M F		\$43.07	\$5.86	\$48.93	C/MF	\$14.75	\$5.14	\$19.89

5.4 Estimated Monthly Costs

The estimated monthly increase in the cost of water is shown in Table 15. The average cost for large systems ranges from \$47.27 to \$59.49 per customer, depending on the treatment technology. This represents an annual cost of \$570 to \$700. For small systems, the average monthly cost of water is estimated to be \$90.82 per customer, equivalent to a yearly cost of about \$1,100. For small systems the maximum monthly cost is estimated to be \$663.58 per customer in one community and the minimum cost is estimated to be \$5.86 per customer in another community.

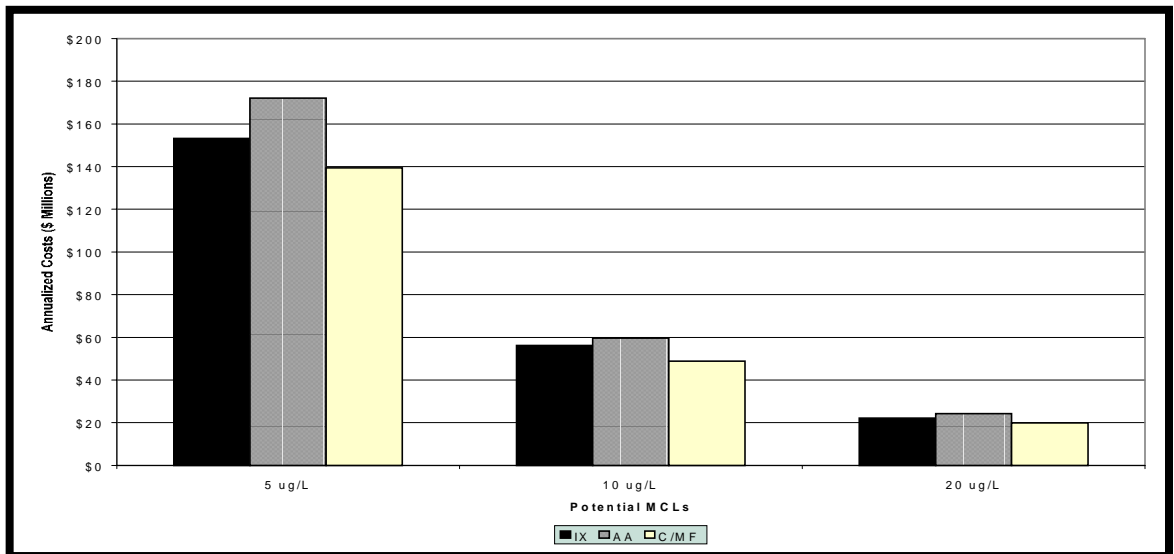


Figure 12: Estimated Annualized Costs for Treatment with Potential Arsenic MCLs in New Mexico

Table 15: Estimated Monthly Cost of Water for an Arsenic MCL of 5 µg/L in New Mexico

Monthly Cost of Water for MCL = 5 µg/L	Monthly Cost for Large Systems (\$/customer)			Monthly Cost for Small Systems (\$/customer)
	IX	AA	C/MF	
Treatment Type:	IX	AA	C/MF	TAAA
Average	\$47.27	\$59.49	\$47.33	\$90.82
Standard Deviation	\$33.05	\$50.43	\$41.52	\$80.54
Maximum	\$158.82	\$245.28	\$187.29	\$663.58
Minimum	\$2.76	\$3.61	\$2.57	\$5.86

The affordability of water under these MCL scenarios was evaluated using two approaches. The first is to use the EPA affordability methodology as described in Abt Associates (2000). The second is to follow an approach used by Rubin (2000) who found a level of affordability for low-income families.

EPA considered that the median household expends about 0.7% of its income on water and other public services (Abt Associates, 2000). The annual cost of water with the proposed arsenic standard of 5 µg/L would mean the median New Mexico household would expend 2% of the annual income (\$31,500 in 1998) on water alone. Rubin (2000) reported that if water service is within 1.5% of the

median household income in the community, the water service is considered affordable (Rubin, 2000). The most recent median household income data are from 1989. These income amounts were inflated by the change in Consumer Price Index from the annual level for 1989 to the annual level for 1999, an increase of 34.35% (Rubin, 2000). Neither income distributions nor poverty distributions have changed significantly between 1989 and 1997, the most recent year for which a complete analysis is available for (Rubin, 2000). In the absence of information indicating a change in trend from 1989 to 1997, it is reasonable to assume that income distributions have remained fairly constant (Rubin, 2000). The estimated annual cost in water service in 7 of the 34 large communities (20%) will be above 1.5% of median household income (Table 16). This approach also suggests that there will be a concern about the affordability of water under an MCL of 5 µg/L in New Mexico.

Table 16: Comparison of Median Household Income to Estimated Annual Cost of Water Systems in Selected Communities

Community	1989 Median Household Income	Estimated 1999 Median Household Income	% of Households under the Poverty Level	1.5% of 1989 Median Household Income	Estimated Annual Water Service Cost
Bernalillo	\$19,663	26417	23	\$396.26	\$621.37
Eunice	\$24,142	32435	15	\$486.52	\$1,746.83
Hobbs	\$22,807	30641	21	\$459.62	\$787.96
Portales	\$16,162	21714	28	\$325.70	\$854.12
Socorro	\$20,728	27848	23	\$417.72	\$623.82
Sunland Park	\$12,338	16593	51	\$248.90	\$969.82

Community	1989 Median Household Income	Estimated 1999 Median Household Income	% of Households under the Poverty Level	1.5% of 1989 Median Household Income	Estimated Annual Water Service Cost
Tularosa	\$15,054	20225	27	\$202.25	\$480.66

In a study of affordability of water service (Rubin, 2000), an increase of less than \$50 per year was found to be affordable for a low-income household, while an increase of \$100 per year could raise serious affordability concerns for low-income households. Data from U.S. Bureau of Census 1994 County and City Data Books (GEOSTAT), on the 1989 median household income for census designated places with population of 2,500 persons, includes 34 of the large community water systems identified in this study. Table 17 shows the percentage of low-income households served by the 34 large community water systems. Although the percentage of low-income households is from 1989, the statewide percentage of low-income households has not changed significantly between 1990 (20.9%) and 1999 (20.4%) (U.S. Census Bureau, 1999).

Therefore it is reasonable to assume that the distribution of income has not changed significantly in that period. Households in 27 of the 34 large community water systems (79%) would have annual water cost greater than \$100 affordability concern level. This means 25,820 New Mexican low-income households in large community water systems would have annual water costs above the level of concern for affordability. Considering the large systems the average cost of complying with a 5 µg/L MCL of \$567.96, is 5 times the level that would cause affordability concerns for low-income households.

The concern for small New Mexico communities is greater because the average cost of water is 11 times the level of concern for affordability. In 266 of the 267 small community water system, the annual cost of water is greater than \$100. If the percentage of household below the poverty level in the state is applied to the small community water systems, about 20.4% of the households or 5,898 households in small community water systems are low-income. The total number of low-income New Mexico households that could see increases in the cost of water above the level of concern for affordability if the MCL for arsenic is lower to 5 µg/L could be as much as 31,700. It is important to note that the fraction of households with incomes below the federal poverty level is far greater in rural communities than in urban communities. This means that many of these communities simply could not afford to comply with a new arsenic standard because the customers could not pay for the service.

Table 17: Yearly Water Cost and Poverty Levels for Selected Large New Mexico Community Water Systems

Large Community Water System in Census Designated Place	Estimated Yearly Cost of Water	% of Households with Income Below Poverty Level	# of Households with Income Below Poverty Level
Alamogordo	\$60.48	11	880
Albuquerque	\$117.36	10	10291
Anthony	\$750.96	42	491
Artesia	\$237.36	16	464
Aztec	\$110.04	21	295

Large Community Water System in Census Designated Place	Estimated Yearly Cost of Water	% of Households with Income Below Poverty Level	# of Households with Income Below Poverty Level
Belen	\$68.88	24	413
Bernalillo	\$621.37	23	363
Bloomfield	\$133.08	15	210
Bosque Farms	\$388.92	2	27
Carlsbad	\$345.00	17	1134
Clovis (New Mexican American Water)	\$302.88	17	1456
Deming	\$129.48	26	778
Espanola	\$221.52	22	505
Eunice	\$1,746.84	15	116
Farmington	\$61.80	12	1108
Gallup	\$30.48	19	923
Hobbs	\$787.96	21	1610
Las Cruces	\$214.56	17	2616
Los Alamos	\$103.56	1	51
Los Lunas	\$346.63	24	387
Lovington	\$1336.68	22	554
Paradise Hills (New Mexico Utilities)	\$506.52	3	52
Portales	\$854.12	28	701
Raton	\$75.24	18	361
Rio Communities (Rio Grande Utilities)	\$329.28	10	103
Rio Rancho	\$277.20	3	319
Ruidoso	\$251.64	15	206
Santa Fe	\$195.12	9	1290
Silver City	\$84.36	21	590

Large Community Water System in Census Designated Place	Estimated Yearly Cost of Water	% of Households with Income Below Poverty Level	# of Households with Income Below Poverty Level
Socorro	\$623.82	23	473
Sunland Park	\$969.82	51	885
Taos	\$156.60	24	260
Truth or Consequences	\$96.12	14	249
Tularosa	\$480.66	27	183

The estimated average monthly cost of water may be expected at arsenic MCL of 10 µg/L are \$41.03 to \$45.76 per customer in large systems and \$100.85 per customer in small systems (Table 18). At an MCL of 20 µg/L the estimated average monthly cost is \$26.74 to \$35.23 per customer in large systems and \$62.55 per customer for small systems (Table 19). Figure 13 compares the average monthly cost at the 5 µg/L, 10 µg/L, and 20 µg/L potential MCLs. It is apparent from Figure 13 that the small systems (shown as "TAAA" for the treatment technology assumed) shoulder the heaviest burden in terms of monthly cost of water.

**Table 18: Estimated Monthly Cost of Water with an Arsenic MCL of 10 ug/L
in New Mexico**

Monthly Cost of Water for MCL = 10 µg/L	Monthly Cost for Large Systems (\$/customer)			Monthly Cost for Small Systems (\$/customer)	
	Treatment Type:	IX	AA		C/MF
Average		\$38.58	\$42.34	\$37.77	\$96.83
Standard Deviation		\$28.18	\$40.10	\$33.20	\$87.23
Maximum		\$110.06	\$203.41	\$162.69	\$580.68
Minimum		\$4.04	\$2.53	\$2.34	\$19.91

Table 19: Estimated Monthly Cost of Water with an Arsenic MCL of 20 ug/L

Monthly Cost of Water for MCL = 20 µg/L	Monthly Cost for Large Systems (\$/customer)			Monthly Cost for Small Systems (\$/customer)	
	Treatment Type:	IX	AA		C/MF
Average		\$25.34	\$32.58	\$26.70	\$57.46

Monthly Cost of Water for MCL = 20 µg/L	Monthly Cost for Large Systems (\$/customer)			Monthly Cost for Small Systems (\$/customer)
	Treatment Type:	IX	AA	
Standard Deviation	\$49.18	\$41.88	\$34.56	\$31.54
Maximum	\$94.71	\$129.92	\$114.18	\$139.82
Minimum	\$4.04	\$2.53	\$2.34	\$10.23

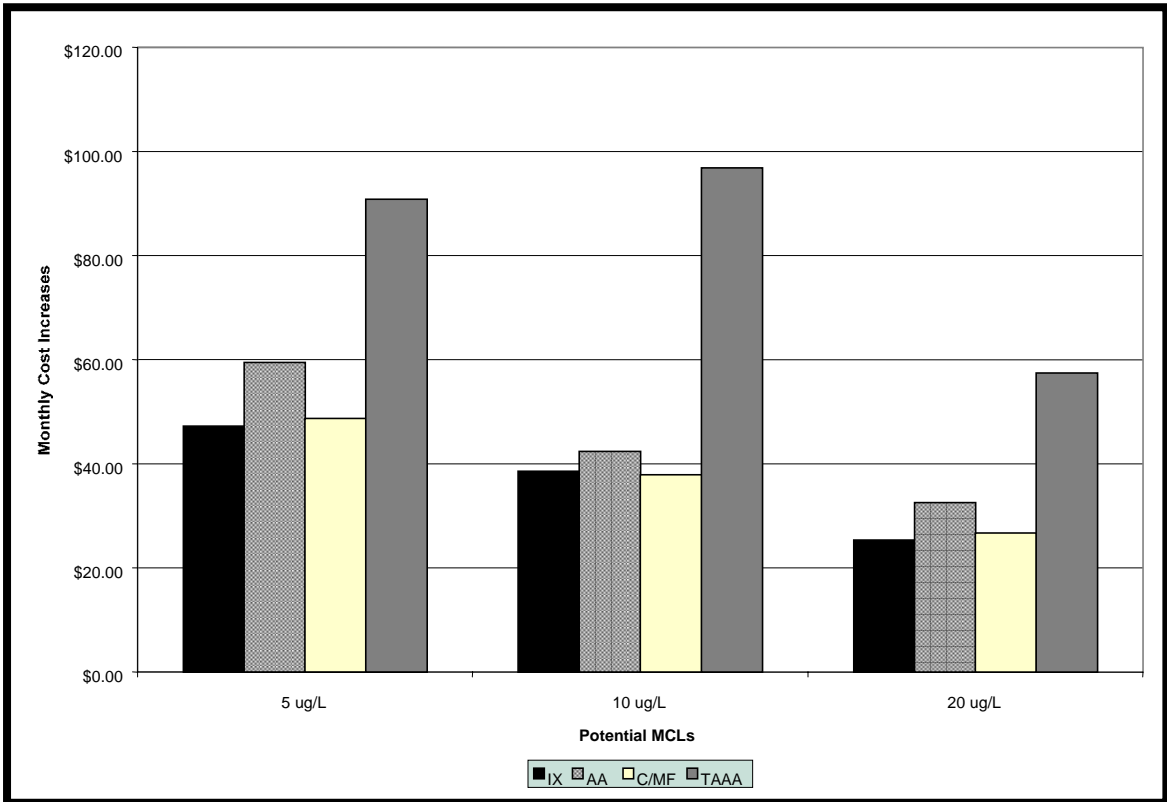


Figure 13: Estimated Monthly Cost of Water at Potential MCLs in New Mexico

6.0 CONCLUSIONS

This analysis has determined that community water systems in State of New Mexico will incur capital costs of \$1 - \$1.2 billion and annualized costs of \$139 - \$172 million (assuming a 6% interest rate) to meet an arsenic MCL of 5 $\mu\text{g/L}$. These costs will result in average annual increases in the cost of water of \$567 - \$1,090 for customers in 346 community water systems. It is likely that many utilities will not be able to afford these cost as New Mexico ranks number 1 in the US for the percent of the population below the poverty level and 46th in the median household income in 1998 (U.S. Bureau of the Census, 1999).

The Environmental Protection Agency (EPA) estimated the annualized costs of compliance with a 5 $\mu\text{g/L}$ arsenic MCL at between \$377 - \$442 million (depending on the interest rate assumed, 3% or 7%) (EPA, 2000). The annualized costs based on this analysis for all water systems in New Mexico therefore represent about 30% of the national costs developed by EPA. On behalf of the American Water Works Association Research Foundation (AWWARF), Frey et al (2000) found the national annualized costs of an arsenic MCL of 5 $\mu\text{g/L}$ to be \$1.4 billion (assuming 6% interest rate). The annualized costs in New Mexico represent about 10% of the national costs developed by Frey et al (2000). Although the cost of compliance estimates for New Mexico presented in this report is more in line with the estimate by Frey et al (2000),

there remains a discrepancy that is likely attributable to the national estimates of arsenic occurrence.

National estimates of arsenic occurrence and percent of systems exceeding the proposed 5 µg/L standard was about 15% in all three studies (Frey and Edwards, 1997; Focazio et al, 1999; and EPA, 2000b). In New Mexico, about 60% of community water systems will be affected by the proposed standard of 5 µg/L. Further, the number of affected communities in New Mexico is 5% of the EPA national estimate of number of systems affected and 8% of the AWWARF national estimate. The higher percentage of affected systems in New Mexico than predicted in the three national arsenic occurrence studies is probably the source of the discrepancy in compliance cost estimates.

If the arsenic MCL were set at 10 µg/L or 20 µg/L, the annualized cost impacts to the States water utilities would be about \$49 - \$60 million and \$20 - \$24 million, respectively.

7.0 REFERENCES CITED

Abt Associates Inc., 2000. Proposed Arsenic in Drinking Water Rule Regulatory Impact Analysis. EPA 815-R-00-013. Developed for Environmental Protection Agency, Office of Groundwater and Drinking Water, Washington, DC.

Bureau of Business and Economic Research (BBER), 1999. Gross State Product. Prepared by the Bureau of Business and Economic Research, University of New Mexico. Available at www.edd.state.nm.us/SERVICES/RESEARCH/research.htm.

City of Albuquerque, 2000. Comments on the Proposed Arsenic in Drinking Water Rule.

Chwirka, J. D. and R. Narasinhham, 2000. AWWA Arsenic Treatment Cost Estimating Tool. Available through the American Water Works Association web page at www.awwa.org/govtaff/AWWAArsenicCostsRev.xls.

Clifford, D., A. Ghurye, A. Tripp, and T. Jian, 1998a. Field Studies of Arsenic Removal in Albuquerque, New Mexico, using the University of Houston/EPA Mobile Drinking Water Treatment Research Facility, Final Report: Phases 1 and 2, City of Albuquerque Arsenic Study, Albuquerque, NM. pp. 126.

Clifford, D., A. Ghurye, A. Tripp, and T. Jian, 1998b. Field Studies of Arsenic Removal in Albuquerque, New Mexico, using the University of Houston/EPA Mobile Drinking Water Treatment Research Facility, Final Report: Phase 3, City of Albuquerque Arsenic Study, Albuquerque, NM. pp. 50.

Clifford, D. and C.C. Lin, 1995. Ion Exchange, Activated Alumina and Membrane Processes for Arsenic Removal from Groundwater. Proceedings of the 45th Annual Environmental Engineering Conference, University of Kansas, Department of Civil Engineering, Lawrence, Kansas, February 1, 1995.

CH2M Hill, 1999. Arsenic Treatment Evaluation Report, prepared for the City of Albuquerque, Prepared by J. D. Chwirka, J. Lozier, J. Lowry, B. Thomson, K. Carlson, and G. Guter, April 1999.

Environmental Protection Agency (EPA), 2000. National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring, Proposed Rule, Federal Register, June 22, 2000, Volume 56, Number 11, pp. 38887 -38983.

Environmental Protection Agency (EPA), 1988. Special Report on Ingested Inorganic Arsenic: Skin Cancer; Nutritional Essentiality. EPA 625/3-87/013. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, D.C.

Focazio, M.J., A.H. Welch, S.A. Watkins, D.R. Helsel, and M.A. Horn, 1999. A Retrospective Analysis on the Occurrence of Arsenic in Ground-Water Resources of the United States and Limitations in Drinking-Water-Supply Characterizations. Water-Resources Investigations Report 99-4279.

Frey, M. M., J. D. Chwirka, S. Kommineni, Z. Chowdhury, and R. Narasimhan, 2000. Cost Implications of a Lower Arsenic MCL Final Report. American Water Works Research Foundation and American Water Works Association. May 5, 2000.

Frey, M.M. and M.A. Edwards, 1997. Surveying Arsenic Occurrence. Journal of American Water Works Association, 89(3):105-117.

GEOSTAT. Geospatial & Statistical Data Center.

<http://fisher.lib.virginia.edu/ccdb/>.

Grant, E. L. and W. G. Ireson, 1960. Principles of Engineering Economy. The Ronald Press Company, New York. 574 pp.

National Research Council (NRC), 1999. Arsenic in Drinking Water. National Academy Press, Washington, DC.

Rubin, S. J., 2000. Estimating the Effect of Different Arsenic Maximum Contaminant Levels on the Affordability of Water Service. Prepared under contract to the American Water Works Association.

Spurlock, M., 2000. Issues for New Mexico on the Lower Rio Grande. Presentation at New Mexico Water Law Conference, CLE International, Santa Fe New Mexico, August 24-25, 2000.

United States Bureau of the Census, 1999. State Profile from Statistical Abstract of the United States. <http://www.census.gov/statab/www/states/nm.txt>