

DEALING WITH ARSENIC (III) IN BRACKISH WATER RO PERMEATE

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Abstract

The arsenic standard in drinking water has been part of the Federal Standards since the US Public Health Service (USPHS) established a “tolerance limit” of 50 parts per billion (ppb) in 1942. In 1996, Congress in its review of the Safe Drinking Water Act (SDWA) set January 1, 2001 as the deadline for a new arsenic Maximum Contaminant Level (MCL). EPA requested the National Research Council to initiate the study.

When the MCL was established at 50 ppb, very few utilities had difficulty achieving compliance. The principle area of the US for occurrence of high arsenic in water supplies is the Southwest, although there are scattered locations of high arsenic throughout the US. Faced with an 80% reduction in the arsenic MCL, many utilities that previously were in compliance will not be as of January of 2006 without implementing a reduction strategy. Arsenic is one of the most common elements in the earth’s crust, ranking in the top twenty.

Even though current literature extols the competency of brackish water RO membranes in reducing arsenic concentrations, at the Dare County North Carolina (USA) (NRO) plant, equipped with high rejection brackish water membranes, As (III) rejection is only about 50%. Since the feedwater contains about 60 ppb of total arsenic, almost equally distributed between As (V) and As (III), clearly the current treatment will not be sufficient to bring about compliance with the new standard when it becomes mandatory in 2006. The technologies currently available for arsenic removal from water can generally be grouped into the following categories: Precipitative processes, Adsorption processes, Anion exchange, Membrane processes, Emerging proprietary processes, Point-of-entry and point-of-use.

As identified in a technology review study commissioned by the County, the most attractive schemes from the point of view of integration into the existing infrastructure and operational logistics are:

- Oxidation of As (III) to As (V) in the feedwater with Manganese Greensand
- Oxidation of As (III) to As (V) in the RO permeate, and second pass nanofiltration
- Use of one of the proprietary iron oxide based technologies.

Successful implementation of the arsenic reduction strategy selected by Dare County will require careful integration of the new treatment hardware into the existing NRO facility. Review of the available technologies points out two significant impediments to seamless integration: space requirements and residuals management.

This paper will report on the results of five parallel pilot plant tests, which will be operated from early to mid 2003. The paper will describe the pilot plant program, present the results of the test program, including the test protocol and analytical results, detail the rationale for selection of the one process for implementation, and discuss anticipated costs and implementation issues.

Title 1 The Problem

Title 2 Known Remedial Technologies

Title 3 Thorough Overview of All Site Specific Options

Title 4 Recommendations for Pilot Plant Testing

Title 5 Pilot Test Program

Title 6 Rationale for Selection of the Best Process to Implement

Title 7 Anticipated Costs and Implementation issues

I. THE PROBLEM

The arsenic standard in drinking water has been part of the Federal Standards since the US Public Health Service (USPHS) established a “tolerance limit” of 50 ppb in 1942. This standard had very little impact on the drinking water industry, since it applied only to the supply of water across state lines. At that time very little data on the occurrence of arsenic or treatment techniques for its reduction were available.

In 1970, the US Environmental Protection Agency (EPA) was formed, taking over the drinking water regulatory function of USPHS. In 1974, EPA set a mandatory Maximum Contaminant Level (MCL) for arsenic at 50 ppb, and for the first time, this standard applied to all public drinking water supplies. In 1975, EPA initiated a review of the arsenic MCL, in preparation for establishing a revised standard by 1989, which it failed to do.

In 1996, Congress in its review of the Safe Drinking Water Act (SDWA) set January 1, 2001 as the deadline for a new arsenic MCL. EPA requested the National Research Council to initiate the study.

Since that time various values for a new arsenic MCL have been proposed:

- 1999 National Academy of Sciences and National Research Council (NRC) state that 50 ppb is too high. Estimated a 1 in 1000 change of bladder cancer among males.
- 2000 EPA considers 3 ppb to 20 ppb and proposes a new MCL of 5 ppb.
- 2001 Clinton administration approves 10 ppb as the new arsenic MCL.
- 2002 Bush administration withdraws the new MCL, and initiates a review by a blue ribbon NRC panel.
- 2002 NRC report released. Suggests previous estimates of risk from arsenic in drinking water were underestimated, estimates that 3 ppb would pose a 1 in 1000 risk of bladder or lung cancer.
- 2002 Bush administration accepts new NRC report, and resets the arsenic MCL 10 ppb. Compliance date of January 22nd, 2006 remains unchanged.

When the MCL was established at 50 ppb, very few utilities had difficulty achieving compliance. The principle area of the US for occurrence of high arsenic in water supplies is the Southwest, although there are scattered locations of high arsenic throughout the US.

Faced with an 80% reduction in the arsenic MCL, many utilities that previously were in compliance will not be as of January of 2006 without implementing a reduction strategy.

Testing at the other three Dare County RO plants and its Ion Exchange plant resulted in arsenic concentrations in the raw well and distributed waters below the 2006 MCL of 10 ppb. However, at the NRO, the distributed water contains arsenic concentrations of 15 to 21 ppb, well below the previous MCL of 50 ppb, but up to double the 2006 MCL of 10 ppb.

Arsenic is one of the most common elements in the earth's crust, ranking in the top twenty. It is a component in about 250 naturally occurring minerals. Although not a metal, it is known as a metalloid, and is found in group Va of the Periodic Table.

1.1 Arsenic Background

Arsenic occurs in natural waters predominantly in the oxidation states of +3 (As (III)) and +5 (As (V)). An organic state (methylated) has been detected, but is rarely found in concentrations greater than 1µg/l (1ppb), and is of little significance in drinking water treatment.

The two forms of concern at the North RO plant (NRO) appear in the ground water supply in approximately equal concentrations. As (V) is ionized at natural pH (between 6 and 8) and appears as either the monovalent species H_2AsO_4^- , or the divalent species HAsO_4^{2-} . The molecular weight of As (V) is approximately 140. As (III) is unionized at natural pH, appearing as arsenious acid H_3AsO_3 . The molecular weight is 126. This is important in the selection of a reduction strategy, because As (III) cannot be effectively removed by technologies based on charge, e.g. ion exchange or electrodialysis. Even though current literature extols the competency of brackish water RO membranes in reducing arsenic concentrations, at the NRO, equipped with high rejection brackish water membranes, As (III) rejection is only about 50%. Since the feedwater contains about 60 ppb of total arsenic, almost equally distributed between As (V) and As (III), clearly the current treatment will not be sufficient to bring about compliance with the new standard when it becomes mandatory in 2006.

II. KNOWN REMEDIAL TECHNOLOGIES

The technologies currently available for arsenic removal from water can generally be grouped into the following categories:

- Precipitative processes
- Adsorption processes
- Anion exchange
- Membrane processes
- Emerging proprietary processes
- Point-of-entry and point-of-use

As identified in a technology review study commissioned by the County, the most attractive schemes from the point of view of integration into the existing infrastructure and operational logistics are:

- Oxidation of As (III) to As (V) in the feedwater with Manganese Greensand
- Oxidation of As (III) to As (V) in the RO permeate, and second pass nanofiltration
- Use of one of the proprietary iron oxide based technologies.

Successful implementation of the arsenic reduction strategy selected by Dare County will require careful integration of the new treatment hardware into the existing NRO facility. Review of the available technologies points out two significant impediments to seamless integration: space requirements and residuals management.

III THOROUGH OVERVIEW OF ALL SITE SPECIFIC OPTIONS

Before exploring our options for lessening the Arsenic concentration to below the promulgated MCL of 10 parts per billion in the source and/or permeate waters at the NRO plant, other options for the reduction of the Arsenic in the final drinking water must be examined.



Dare County is located on the Atlantic Coast of the State of North Carolina in an area of the State known as the Outer Banks.

Figure 1 illustrates how, with 86 miles of coastline, the County of Dare is virtually centered in the midst of an abundant supply of salt water.

Figure 1

The County's NRO plant is located fairly close to the geographical center of the County (as indicated by the *). To the west of the plant is located the Albemarle Sound, a brackish surface water source and to the east the Atlantic Ocean. Both sources of water were found to have no detectable amounts of total Arsenic, creating an option to replace the existing Arsenic laden source water to the NRO plant to eliminate Arsenic in the feed to the RO system all together.

A closer look examined the economic feasibility of using the sound or the ocean for a new source. Both of these options were eventually eliminated based on the following facts:

1. The two waters both would create a need for extensive costs for pretreatment prior to demineralizing in the plant.
2. They both would require higher membrane feed pressures in that both have higher total dissolved solids content than the present brackish groundwater source and subsequently would require increased energy costs to process.
3. The subsurface intake structures alone would run million of dollars, which we eventually found out to cost more than our other options.

IV RECOMMENDATIONS FOR PILOT PLANT TESTING

In review of the remedial technologies available at this time, three basic approaches to reducing the arsenic in the finished NRO water are:

- Remove the arsenic from the Feedwater
- Removed the arsenic from the permeate
- Remove the arsenic from the product water

As mentioned earlier, six Arsenic remedial available technologies exist.

4.1 Precipitative Processes

Considerable research has been reported on the removal of arsenic by coagulation and flocculation by the EPA and AWWARF. They entail:

- Coagulation/Filtration
 - Agglomeration of finer particles into a larger particle for settling and filtration
- Iron/Manganese Oxidation
 - Creating hydroxides that absorb or precipitate the soluble arsenic
- Coagulation Assisted Microfiltration
 - Similar to Coagulation/Filtration above, but assisted by a superior Microfiltration step

All three of these processes will generate sludge. This sludge will contain a fair amount of concentrated arsenic, could possibly be classified as a hazardous waste under the Resource Conservation and Recovery Act and will eventually need to be disposed of in a landfill.

4.2 Adsorptive Processes

- Activate Alumina
 - Adsorption of arsenic ions on an oxide surface.
- Ion Exchange
 - Requires increased pH and oxidation of As (III) to As (V) before ability to remove.
- Iron Oxide Coated Sand
 - Ferric hydroxide coated sand demonstrates limited As (III) and As (V) removal.

4.3 Anion Exchange Processes

- Since arsenic appears as an anion in water, anion exchange resins in the chloride form are employed. AS (V) follows sulphate and nitrate in order of preference, while As (II) is not exchanged and passes through the column. Once again, oxidation of As (III) to As (V) must take place for complete arsenic reduction.

4.4 Membrane Processes

- Sieving Processes
 - The molecular weight of the As (V) would allow for the use of RO membranes for separation, therefore the As (III) in the permeate would need to be oxidized to As (V) for effective removal.
- Diffusion-controlled Processes
 - With both Nanofiltration and Reverse Osmosis being diffusion-controlled processes, inconsistent data from previous studies have shown possibilities that some rejection of both the As (III) and As (V) are achievable.

4.5 Emerging Proprietary Processes

With the advent of the reduced arsenic MCL, a number of proprietary processes are being advertised as being a solution to the arsenic issue. For the most part, these processes are based on some form of adsorption onto an iron-impregnated media. This media is typically granular ferric hydroxide (GFH), which was developed in Germany, and is licensed in the US by USFilter. A variation of this technology, based on granular ferric oxide (GFO) has been developed by Bayer, also in Germany, and is license to Severn Trent Services in the US. A third process is being marketed by Water Remediation Technology, LLC, located in Colorado, and is based on the use of natural zeolite in the iron form. All three of these processes claim to be effective in the removal of As (III), and all three processes involve a throw away media.

Typical of these processes are:

1. Granular Ferric Hydroxide
2. Sorb33™ Process
3. Z-33™ Process

4.6 Point-of-entry and point-of-use

Although a very feasible option for removal of arsenic, the Dare County Water System chose not to explore this option siting the cost to be prohibitive to install individual treatment systems in its 14,000 plus home, commercial establishment, service and medical facilities.

V THE PILOT TEST PROGRAM

Based on the results of the technology study that was performed and considering the two most important criteria of cost and integration into the existing treatment plant infrastructure, five separate pilot test units were proposed and implemented. The processes selected for testing are:

- a. Manganese Greensand treatment of the RO plant feedwater
- b. Sorb™ 33 treatment of the RO permeate
- c. Z-33™ treatment of the RO permeate
- d. GFH™ treatment of the RO permeate
- e. Second pass treatment of the RO permeate using high recovery Nanofiltration to remove oxidized As (III).

One integral part of the testing, which we felt needed to be explored in detail, was our ability to receive repeatable analyses. It has been the authors' previous experience that split samples for AsIII and AsV for speciated Arsenic (arsenite and arsenate) at levels of parts per billion were not similar, and off by as much as 25% from each other. This created a need to send split samples for speciated Arsenic analyses to two different laboratories. An in depth search on the Internet resulted in only *two laboratories in the United States* that had the ability to perform AsIII and AsV analyses. They were Huffman Laboratories in Golden Colorado and Frontier Geosciences, Inc. in Seattle Washington.

The results of the analyses prove that USEPA may not only be giving Public Water Supplies until January 26, 2006 to remediate Arsenic levels, but also might be giving laboratories around the country ample time to improve their testing techniques to repeatable analytical levels.

The tables on the next page list results of the certified analyses from the pilot units in parts per billion.

#	Cert. Lab.	Date	Raw Water		Permeate Feed to Pilot Units		Pilot (a)		Pilot (b)	
			AsIII (ppb)	AsV (ppb)	AsIII (ppb)	AsV (ppb)	AsIII (ppb)	AsV (ppb)	AsIII (ppb)	AsV (ppb)
1	1	4/1/03	23.0	33.0	9.0	5.00	<0.5	6	0	0
2	2		32.4	25.1	11.1	5.14	<0.01	0.86	<0.01	0.03
3	1	4/15/03	<0.5	8	8.0	6.0	<0.5	8	0	0
4	2		<0.001	1.8	8.38	11.2	<0.001	1.8	0.015	<0.206
5	1	4/30/03	0.5	88	5	11	4	0.5	0	0
6	2		0.015	11	4.89	13.5	0.003	0.408	<0.003	0.408
7	1	5/13/03	<0.5	87	2	11	1	16	<0.5	<0.5
8	2		<0.45	<85.6	0.792	23.7	<0.030	7.88	<0.006	<0.135
9	1	5/27/03	13	43	1	15	1	31	<0.5	<0.5
10	2		14.1	10.2	1.03	15.7	0.634	1.17	<0.006	<0.135

#	Cert. Lab.	Date	Pilot (c)		Pilot (d)		Pilot (e)	
			AsIII (ppb)	AsV (ppb)	AsIII (ppb)	AsV (ppb)	AsIII (ppb)	AsV (ppb)
11	1	4/1/03	1	1	0	0	0	0
12	2		2.12	0.11	<0.01	<0.02	<0.01	<0.02
13	1	4/15/03	2	1	0	0	4	<0.5
14	2		1.77	0.493	<0.001	<0.206	5.8	0.349
15	1	4/30/03	1	1	0	0	0	0
16	2		1.86	1.05	<0.003	<0.408	0.096	0.422
17	1	5/13/03	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
18	2		0.075	<0.571	<0.003	<0.571	<0.06	83.3
19	1	5/27/03	<0.5	<0.5	<0.5	<0.5	1	<0.05
20	2		0.076	0.211	<0.006	<0.135	1.2	<0.68



FIVE PILOT UNITS

The first pilot unit (a) oxidized the feedwater Arsenite to Arsenate which then could easily be removed by the existing RO process. Flow through the vessel was set at 1.5 gallons per minute (gpm). The initial data proved that the media itself was removing the majority of the overall Arsenic, whether it is AsIII or AsV, as shown by the data on the Table 1. Figure 2 shows the pilot Ferric Hydroxide pilot unit in operation.

Figure 2

The second pilot (Figure 3) unit (b) utilized a proprietary media with a Sorb 33™ treatment of the RO permeate. The adsorbent is a granular ferric oxide (GFO) media, with a flow of 0.4 gpm through the unit.



Figure 3

The third pilot (c) unit (Figure 4) ran with Z-33™ treatment of the RO permeate at a flow of 0.4 gpm.



Figure 4



Figure 5

GFH™ treatment of the RO permeate (Figure 5) - Pilot unit (d) employed the treatment option to adsorb the AsIII & AsV onto a Granular Ferric Hydroxide for removal.

Second pass treatment of the RO permeate (Figure 6) was the only one – Pilot unit (e) of the five pilot units tested that used high recovery Nanofiltration membranes to remove oxidized AsIII in its AsV form. This pilot unit was the only one of the five that did not utilize a media that needed replaced or created a sludge requiring disposal.



Figure 6

VI RATIONALE FOR SELECTION OF THE BEST PROCESS TO IMPLEMENT

Successful implementation of the arsenic reduction strategy selected by Dare County will require careful integration of the new treatment hardware into the existing NRO facility. Review of the available technologies points out two significant impediments to seamless integration: space requirements and residuals management.

As discussed earlier, the arsenic in the NRO well water is split almost evenly between As(III) and As(V). Virtually all of the As(V) is removed in the RO process, but is still present in the blend water that bypasses the RO. As a result, there is varying concentration of As(III) as As(V) in the product water:

The selected treatment for the reduction of arsenic will thus vary depending on the point of application. From the consultant's technology review, it was clear that As(III) is not well removed by any of the competing methods. Therefore, a common element for As reduction treatment applied at any point will be oxidation of the As(III) to As(V).

Total Feed Treatment Option

Treating the entire raw water inlet to the plant is constrained primarily by space and residuals handling. The best approach is to use a manganese greensand system to oxidize As(III) to As(V), for rejection by the RO membranes. The iron and manganese in the feedwater will also be oxidized and removed.

In terms of space requirement, and assuming a 5 MGD RO operation, it will be difficult to fit the necessary equipment and facilities in the available space between the existing plant building and the

5 MG ground storage tank. At 75% recovery, raw feed water flow from the wells will be 6.45 mgd (4480 gpm), of which 0.65 mgd will be the blend bypass volume. A pressure filter system, be it filled with dual media or greensand, will probably be of horizontal design. At a filtration rate of 3.5 gpm/ft² of surface area, the total area required will be 1280 ft². Additional space will be required to accommodate expansion of the NRO plant to its design capacity of 8.0 MGD.

The table below shows the number of vessels and approximate land area required. This area does not include the area needed for backwash pumps, backwash basin or sludge handling equipment.

Vessel Length	Diameter	No. Required	Area Required ft ²
30	10	6	3,740
30	12	5	3,520
40	10	5	3,780
40	12	4	3,400

Vertical 12 ft. diameter vessels would require over 4,000 ft²

This space is not available behind the plant, and would require using the space reserved for the third storage tank. Obviously, future expansion beyond 5 MGD would require additional land area than that shown above.

Permeate Treatment Option

Essentially only As(III) exists in the permeate. This has been determined by extensive analysis. As mentioned previously, none of the technologies except the emerging adsorption technologies are effective for the removal of As(III). In all other cases, As(III) must be oxidized to As(V) prior to treatment for effective removal.

As has been discussed, As(V) is very well rejected by RO and NF membranes. This permeate treatment option considers the use of low salt rejection NF membranes as a second pass treatment. Piloting and the conceptual design phase has determined that the process is feasible, and that both the existing Membrane supports and the expansion units can accommodate the necessary NF vessels, piping and controls within the existing process footprint

At this time it is not believed that it will be necessary to treat the blend water. It has been estimated that the blend water contributes about 2 µg/l of total arsenic to the blended product water totals, at the current blend ratio. However, if in the future this becomes necessary, a small Mn greensand system to treat just the blend flow can be installed outside the building in the available open space.

The major advantage of this approach is that there is no sludge production at all (assuming that the blend is not treated). Given the costs, haul distance (about 90 miles each way), and regulatory concerns associated with sludge handling and disposal, this is considered to be a major advantage.

In addition to the membrane option discussed above, the use of the proprietary adsorption processes to treat permeate appears to hold promise. Since the influent water to the adsorption process is permeate, it has a low pH and is devoid of ions that would compete with arsenic for adsorption sites. Long run times can therefore be expected for each charge of media, possibly as long as two years.

Pilot test results have been very positive, and all of the competing vendors have indicated a willingness to consider providing a long term maintenance agreement that removes the burden of spent media disposal from Dare County. Clearly this will be an additional cost consideration, which the County must weigh against the costs of self-disposal.

Selection Criteria

From the discussion above, it is clear that not only will cost be of importance in process selection, but also the space requirements of the process chosen. The NF second pass option will fit into the existing process space. The only real concerns are the ability to design and operate a chlorination/dechlorination system that adequately protects the NF membranes selected for implementation, and the loss of production inherent in adding a second pass to an existing plant. To offset, the improved permeate quality may permit some additional raw water blending, making up some of the loss of production capacity.

A feedwater treatment, or a permeate treatment option using absorption media will have to be constructed outside the building. Limited space is available on site immediately adjacent to the building. There is additional space approximately 500 feet away that is presently reserved for a third 5.0 MG ground storage tank. If the adjacent space proves to be too little, this tank area will have to be used which will add cost to the project for additional piping runs, relocation of the raw water blending station, etc.

A feedwater treatment also will involve sludge disposal, which the County is not anxious to undertake. This will be carefully investigated, particularly in terms of the ability of the dewatered sludge to pass the leaching test, and the desirability of purchasing and maintaining sludge trucks.

From the perspective of residuals handling, the NF option, which will operate at 90% recovery at least, is clearly the preferred option, since there will be no residual. The NF concentrate will be recycled to the RO feedwater if the added concentration of As(V) in the feedwater is not too high. Some may need to be wasted to the concentrate outfall if the recycle volume is limited.

VII ANTICIPATED COSTS AND IMPLEMENTATION ISSUES

Prior to selecting the processes for pilot testing a matrix was constructed to rank the processes in terms of suitability for integration with the existing operations. This matrix is reproduced below.

Based on this matrix five processes would appear most suitable for integration with the existing plant. These are:

- A. Treatment of the feed water with manganese greensand filtration. Rank = B
- B. Treatment of the blended product water with coagulation and membrane filtration. Rank = B
- C. Ion exchange treatment of the blended product water to remove the As(V) formed by chlorination in the blended product water. Rank = B
- D. Oxidation of the As(III) in the permeate of the NRO plant, and removal in a second pass nanofiltration (NF) system. Rank = A
- E. Utilization of one of the proprietary iron absorbent processes. Rank = A

Based on the preferences of the County, A, D, and E were selected for pilot testing

Process	Position in Treatment	Solid Waste	Liquid Waste	Effectiveness for As(III_)	Ranking
Oxidation Coagulation Filtration	Pretreatment	Y++	Y++	As(III) must be oxidized as As(V)	C
Oxidation Coagulation Filtration	Post Treatment	Y++	Y++	As(III) must be oxidized as As(V)	C
Manganese Greensand	Pretreatment	Y	Y+	Oxidizes As(III) in the process	B
Oxidation Coagulation Membrane Filtration	Pretreatment	Y+	Y++	Oxidant required for As(III)	C
Oxidation Coagulation Membrane Filtration	Post Treatment	Y+	Y++	Oxidant required for As(III)	B
Activated Alumina	Post Treatment	Y-	Y++	Ineffective. Oxidation required.	C
Ion Exchange	Post Treatment	No	Y++	Ineffective for As(III). Oxidation required.	B
Nanofiltration	Post Treatment	No	No	Oxidation of As(III) required.	A
Iron Media Adsorption	Post Treatment	Throwaway media	No	No oxidation required.	A

The construction cost data used to prepare the opinions of cost presented here were drawn from the consultant's files, published data, and vendor quotes. Process and civil works costs are modified by the addition of the following:

- Engineering, Administrative and Legal 15%
- Interest during construction 5% for 6 months
- Contingency 15%
- Building Cost \$100/ft²

Construction costs were assumed for the year 2002, whereas actual construction will take place in 2004/2005.

The present worth factor for operating and maintenance cost is based on a discount rate of 6% per year, for 20 years. The present worth factor is 11.47.

Proper comparison of the total cost of each of the arsenic removal strategies requires that capital and operating costs be combined on a common footing. In this case the capital; cost is assumed to be a one time cost, and the present worth of the operating costs is added in each case. Comparison of the totals provides a simulated life cycle cost comparison.

The cost estimate for each of the selected processes (for 5.0 MGD) is shown in the following table:

Alternative Strategy	Technology	Capital Cost \$x10⁶	Operating Cost \$/year	Present Worth Of Operating Cost \$x10⁶	Total 20 year cost \$x10⁶
A	Manganese greensand oxidation-feedwater	3.177	90,000	1.032	4.202(1)
D	Second pass nanofiltration- permeate	4.438	135,000	1.548	5.986
E	Iron media adsorption- product water	5.539	135,000	1.548	7.087(2)

(1) Does not include sludge disposal cost

(2) Does include media removal and replacement

It is clear from this comparison that the preferred process from an operational view is not the least expensive, nor the most expensive. It may be that the cost of sludge handling and disposal for Strategy A may offset its present worth advantage. Regardless of which strategy is selected for implementation, it is clear that an 80% reduction in the Arsenic MCL, from 50 µg/l to 10 µg/l, will result in a significant cost to the Dare County Water System for compliance by January of 2006.

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