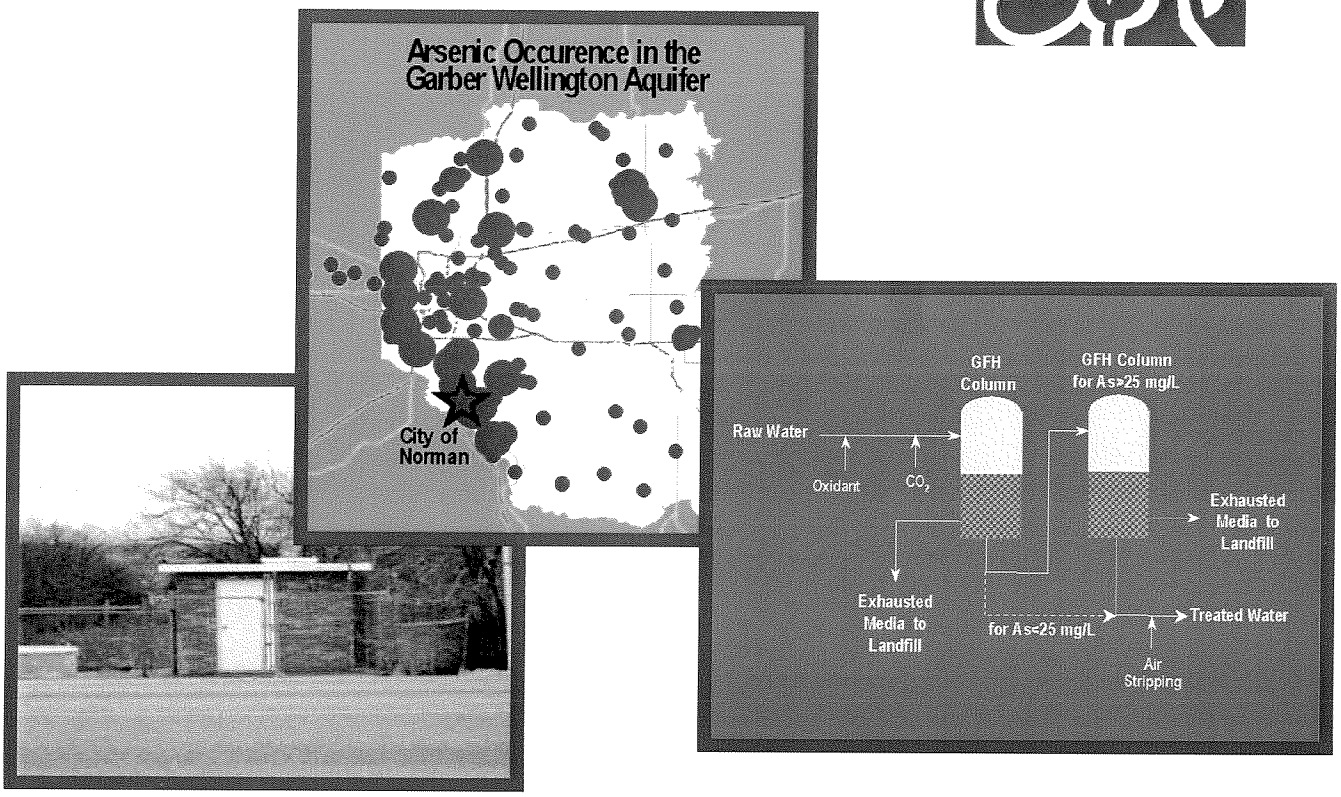
ARSENIC STUDY

For Groundwater Wells at Norman, Oklahoma
and the University of Oklahoma



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and
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Executive Summary

The City of Norman uses surface water and groundwater supply resources to meet the drinking water demands of residential, commercial, and industrial users, and the University of Oklahoma (OU) relies solely on its own groundwater wells to meet the needs of the university. The City's groundwater supply is especially important in meeting dry weather maximum demands. In order to meet increasing water demands over the next four decades, the City recently approved a 40-Year Strategic Water Supply Plan (SWSP) that includes construction of 30 new groundwater wells. Both the City and OU withdraw groundwater from the Garber-Wellington Aquifer (GWA), which provides a high-quality groundwater to a large portion of Central Oklahoma.

Recent changes to EPA drinking water regulations will greatly impact the City and OU groundwater supply systems. Specifically, the recently finalized Arsenic Rule (AR) will lower the arsenic standard from 50 micrograms per liter (µg/L) to 10 µg/L. As a result, the groundwater supply currently in use by the City and OU will be greatly reduced due to levels of arsenic unless solutions are not developed and implemented. This Arsenic Study (Study) is intended to assist the City and OU in developing the best-suited plan for dealing with the revised arsenic standard. In addition, the pending Groundwater Rule (GWR) pertains to disinfection of groundwater and is addressed herein. This Study includes the following sections:

- Background on Arsenic and Groundwater Rules
- Existing Water Quality Data
- Arsenic Source Control
- Treatment Technology Evaluation
- Treatment Technology Selection
- Development of System Alternatives

Background on Arsenic and Groundwater Rules

Arsenic Rule

Arsenic occurs naturally in rocks, soil, water, air, plants, and animals. Weathering rocks or erosion allow arsenic to enter surface or groundwater. In the GWA groundwater, the arsenic is originally bound to the rock layers, which form the aquifer. Certain subsurface chemical conditions allow the GWA rock layers to release the arsenic to the groundwater.

Since 1943, the federal government has regulated arsenic in drinking water at 50 µg/L, but did not base the regulated limit on health-based factors. As a result of the 1996 Amendments to the Safe Drinking Water Act (SDWA), the US Environmental Protection Agency (EPA) performed arsenic research studies and published the final AR in January 2001, establishing an arsenic standard of 10 µg/L. Following much debate and challenge of the AR, the EPA announced the decision to uphold the revised standard of 10 µg/L on

October 31, 2001. For existing water systems, the effective date of the revised arsenic standard is January 23, 2006.

Groundwater Rule

Previously, groundwater was thought to be free from microbial contamination. As a result, only surface water systems and systems under the direct influence of surface water were required to disinfect their water supplies while groundwater systems could discharge directly to the distribution system without providing disinfection. However, new research indicates some groundwater may be sources of waterborne diseases. Waterborne bacteria can cause diseases such as gastroenteritis, heart disease, meningitis, diabetes, hepatitis, paralysis, and kidney failure.

The proposed Groundwater Rule (GWR) specifies the appropriate use of groundwater disinfection for groundwater systems not previously regulated, and designates requirements for sanitary surveys, hydrogeologic sensitivity assessments, monitoring, and corrective action. The proposed GWR was published on May 10, 2000, although the final rule has not yet been published. Due to the GWA structure in the Study area, bacteria passage from the surface to the groundwater is not likely. Hence, the GWR is not likely to affect the City and OU water systems.

Existing Water Quality

Of the 43 wells considered in this Study, the City owns 32 and OU owns 11. Based on average production capacities of these wells, the average well can produce approximately 170 gallons per minute (gpm). The combined systems can produce about 10.3 million gallons per day (mgd.) The arsenic concentrations observed in the groundwater since 1984 were considered for this Study. The arsenic data varied widely, not only among individual wells, but also among sampling events of a given well. The reviewed data provided the average arsenic concentrations presented in Figure ES-1.

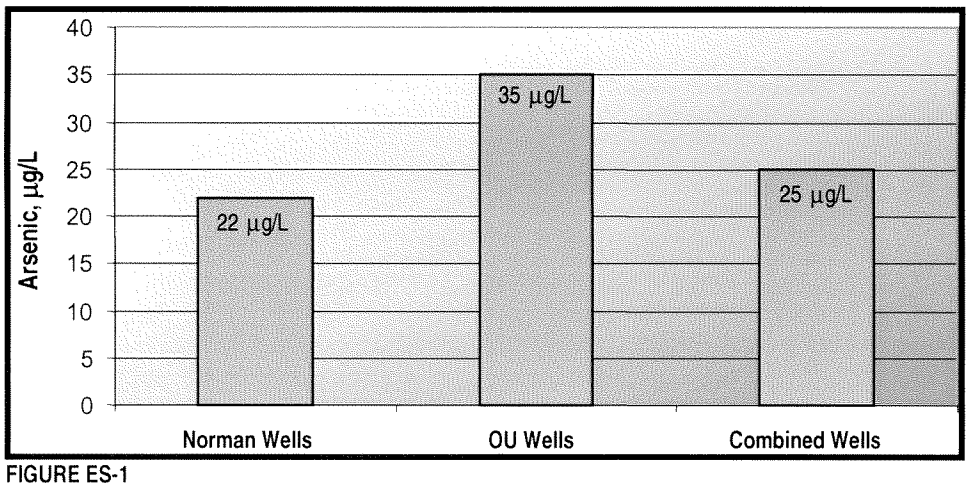

FIGURE ES-1
Average Arsenic Concentrations in Groundwater

Based on the arsenic levels observed in the groundwater wells, twenty of the City's wells and all of OU's wells, for a total of 31, are impacted by the AR. The City wells impacted by

the AR are currently not in operation. Based on historical average arsenic data since about 1984, Figure ES-2 shows which groundwater wells exceed the 10 µg/L arsenic standard.

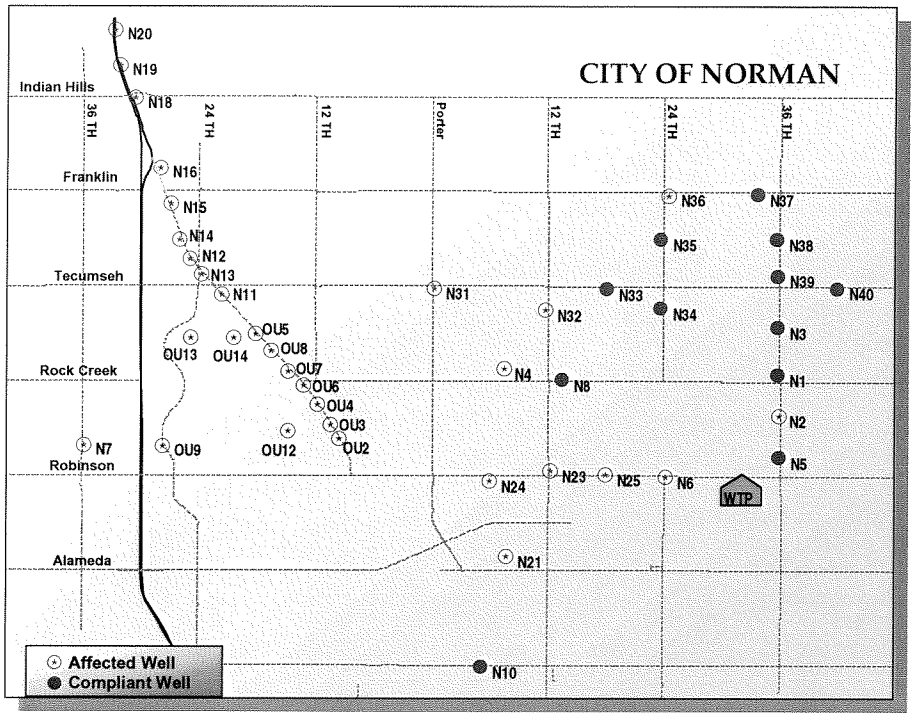

FIGURE ES-2
Groundwater Wells Affected by the Arsenic Rule

After review of City and OU arsenic data and identification of impacted groundwater wells, various options for reducing the arsenic levels in the drinking water system were developed. The options evaluated included both treatment and non-treatment options. The following paragraphs discuss those options.

Arsenic Source Control

Various solutions were considered for reducing the elevated arsenic levels in the City and OU water supplies. Arsenic source control options are defined as methods that prevent arsenic from entering the water distribution system. Options for arsenic source control include removing the impacted well from the drinking water system or isolating the water bearing formations of a well with higher levels of arsenic. Zonal isolation involves eliminating production from specific well intervals having the highest arsenic concentrations. This effort may drop the resulting arsenic concentration to an acceptable level. Also, blending the water, either in the distribution system or at the WTP, prior to the point-of-entry into the distribution system can also provide a means of arsenic reduction.

In addition, due to the widely variable arsenic data, Wells N2 and N19 (having average arsenic concentrations of 10 µg/L) are considered to be affected by the AR for the purpose of this Study although they are in compliance with an arsenic MCL. However, they are not

considered for abandonment because there is the possibility of maintaining AR compliance without well closure.

Treatment Technology Evaluation

Many options exist for the treatment of arsenic in drinking water. The following treatment technologies were evaluated and conceptually developed for treatment of the City and OU groundwater.

- Ion Exchange (IX)
- Granular Ferric Hydroxide Adsorption (GFH)
- Coagulation Microfiltration (C/MF)
- Coagulation Filtration (CF)
- Nanofiltration (NF)

Through the addition of certain chemicals, resulting reactions, and physical removal techniques, arsenic molecules can be removed from water. IX utilizes a resin that will exchange a chloride molecule for an arsenic molecule. Once the resin's exchange sites are fully utilized, a salt-water brine rinses the media and the arsenic molecules are released from the resin, which are collected as a waste. Then, another treatment cycle can occur. IX requires salt and produces waste solids that must be disposed at a landfill. This IX process is very similar to the water softening processes installed and used by individual homeowners.

In the same way arsenic bonds to surfaces in the aquifer, certain treatment media are prepared specifically for arsenic treatment and will attract and retain arsenic molecules. GFH uses this mechanism to reduce arsenic levels in water. The media, however, cannot be regenerated for reuse. Instead, the exhausted media is disposed at a landfill and new media is required. However, GFH produces the lowest waste stream of the treatment technologies considered.

Microfiltration, filtration, and nanofiltration utilize physical barriers for arsenic removal. Coagulation causes arsenic to adsorb on larger sized particles so that these particles can be physically removed through filtration. Otherwise, the arsenic molecule is too small and will pass through the filter. Nanofiltration, however, uses a filter size small enough to collect the arsenic molecule without coagulation. C/MF and CF produce solids, which require landfill disposal. NF produces a high volume liquid waste stream.

Treatment Technology Decision Analysis

To select which of the five arsenic treatment technologies is best suited for the City and OU water systems, a workshop was held on February 21, 2002. City, OU, and CH2M HILL staff attended and discussed the advantages and disadvantages of each technology. The five technologies were ranked according to numerous factors comprised of four main categories utilizing a "decision analysis" technique. The four categories and their resultant score for each technology are presented graphically on Figure ES-3.

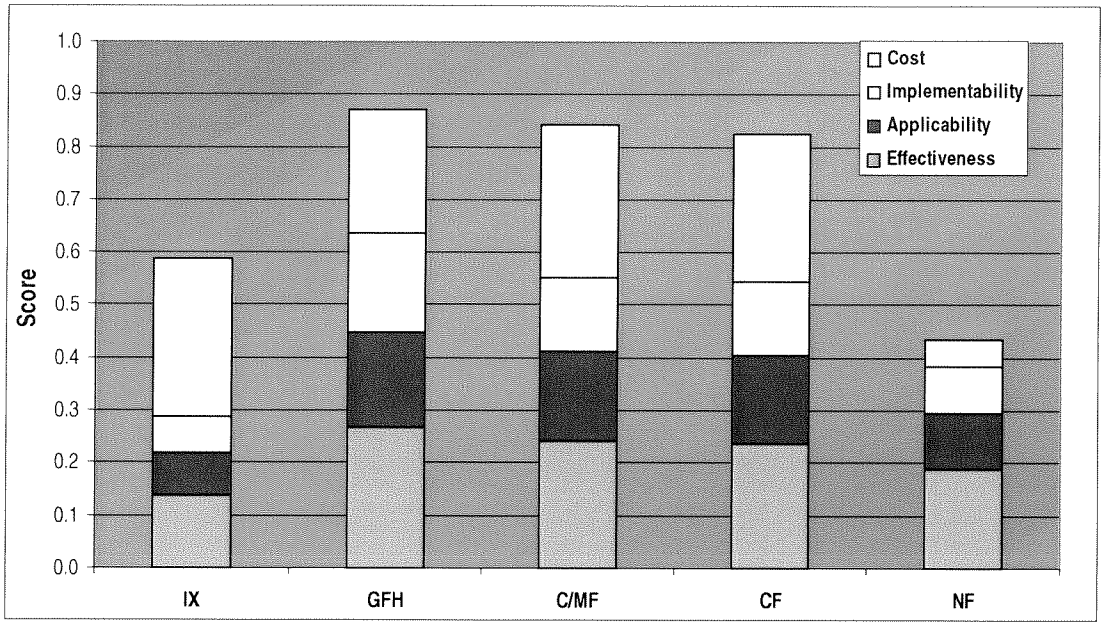

FIGURE ES-3
Results of Decision Analysis Workshop

As depicted, GFH scored the highest overall, closely followed by C/MF and CF. As a result of the decision analysis workshop, GFH was selected as the best suited arsenic treatment technology for City and OU groundwater.

Development of System Alternatives

Using various combinations of possible solutions, five alternatives were developed each being capable of achieving AR compliance and of meeting City and OU drinking water demands. The five alternatives are summarized in the following paragraphs with graphic representation on Figures ES-4 through ES-8.

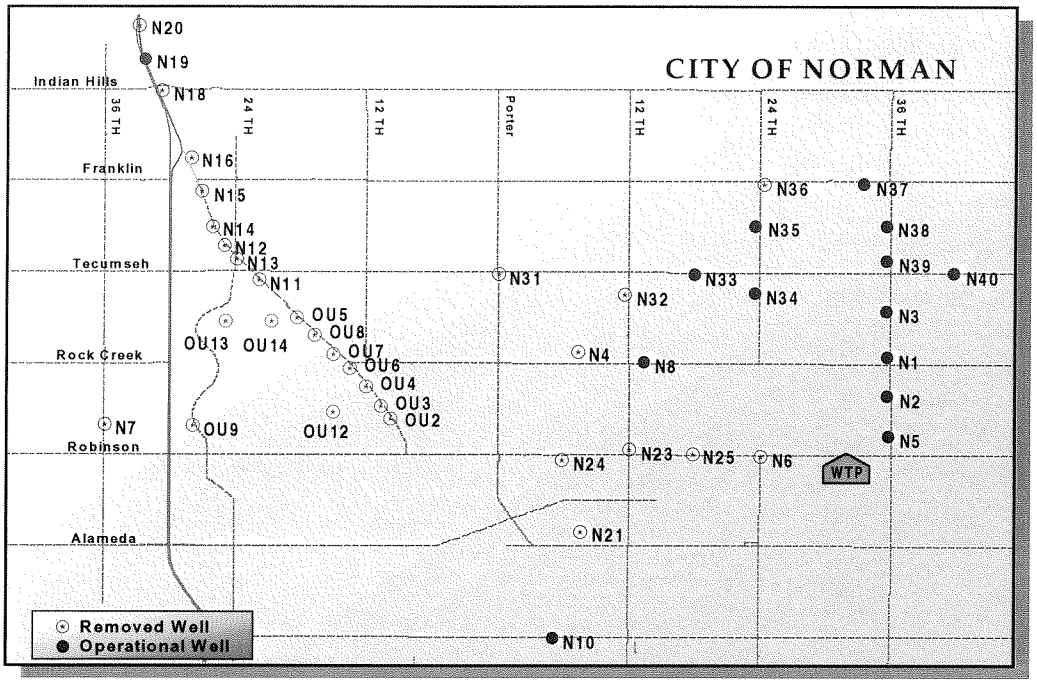

FIGURE ES-4
Plan A Map

Plan A includes the minimal effort required by the City and OU to achieve compliance with the AR. With this plan, any well exceeding the 10 µg/L arsenic standard will be closed and removed from the water supply system. For those wells removed, alternate uses may be developed such as irrigation or industrial process utilization. The water supply capacity lost will be replaced by purchasing City of Oklahoma City (OKC) treated water. Although the capital costs are low under this plan, the annual operation and maintenance costs are high. The details of Plan A are presented in Table ES-1.

TABLE ES-1
Plan A Summary

Summary Item	Result
Wells Removed from the System	29
Blended Wells	0
Wells with Zonal Isolation	0
Wells with Treatment	0
Additional Water Supply	OKC Treated Water
Estimated Capital Cost	$650,000
Estimated O&M Cost	$4.1 Million
Estimated Present Worth	$47 Million

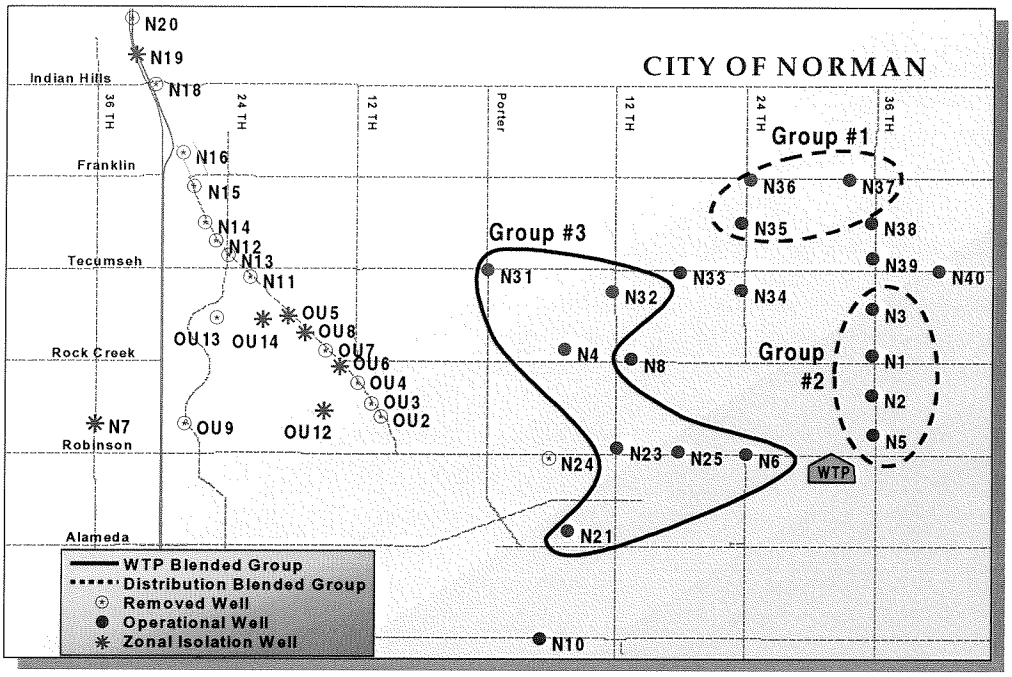

FIGURE ES-5
Plan B Map

Plan B achieves AR compliance without treating the groundwater, as in Plan A, and includes provisions to recover lost groundwater supply through blending and zonal isolation. However, because not all wells are eligible for blending and zonal isolation, well closure and removal is also included with this plan. Plan B provides conveyance for Group No. 3 wells to be blended at the WTP. Blending in the distribution system for Group Nos. 1 and 2 is also proposed under this plan. The summary of Plan B is provided in Table ES-2.

TABLE ES-2
Plan B Summary

Summary Item	Result
Wells Removed from the System	15
Blended Wells	14
Wells with Zonal Isolation	7
Wells with Treatment	0
Additional Water Supply	OKC Treated Water
Estimated Capital Cost	$4 Million
Estimated O&M Cost	$3 Million
Estimated Present Worth	$37 Million

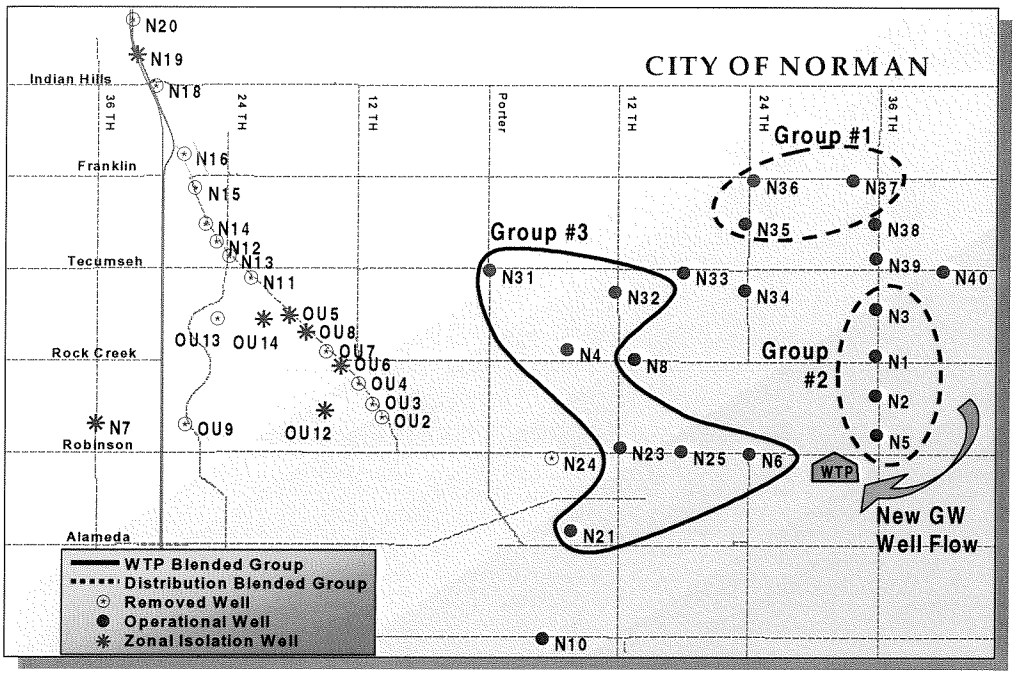

FIGURE ES-6
Plan C Map

The options provided under Plan C are similar to those presented for Plan B, with one exception. Where Plan B includes the purchase of OKC-treated water; Plan C provides construction of new groundwater wells to replace production capacity lost to well removal and zonal isolation. Although the capital cost estimate is higher for Plan C than for B, the overall present worth is lower because purchasing OKC-treated water is not required. The summary of Plan C is presented in Table ES-3.

TABLE ES-3
Plan C Summary

Summary Item	Result
Wells Removed from the System	15
Blended Wells	14
Wells with Zonal Isolation	7
Wells with Treatment	0
Additional Water Supply	11 New Groundwater Wells
Estimated Capital Cost	$9 Million
Estimated O&M Cost	$1.3 Million
Estimated Present Worth	$24 Million

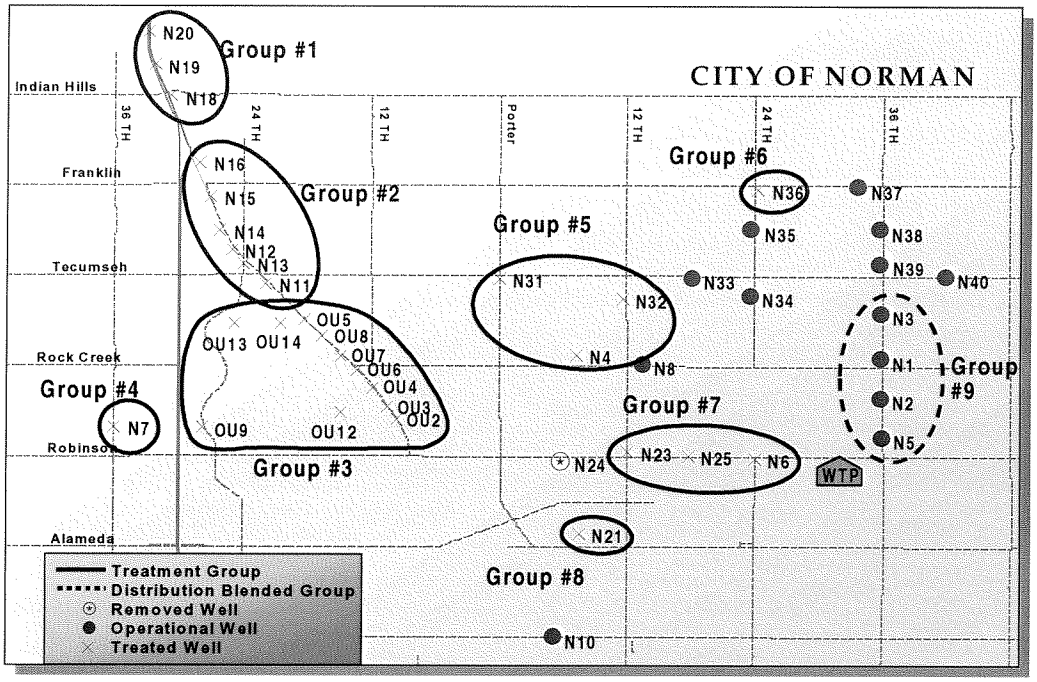

FIGURE ES-7
Plan D Map

As stated previously, Granular Ferric Hydroxide (GFH) adsorption is the preferred technology for treating arsenic. Plan D provides GFH treatment of the groundwater. The groundwater wells are grouped, as shown on Figure ES-7, and conveyed to common treatment facilities. The summary of Plan D is presented in Table ES-4. Notably, as all affected wells, except N24, are treated under Plan D, purchasing OKC-treated water or constructing new groundwater wells is not required. Well N24 is not included due to its higher than average arsenic concentration and lower than average production capacity.

TABLE ES-4
Plan D Summary

Summary Item	Result
Wells Removed from the System	1
Blended Wells	4
Wells with Zonal Isolation	0
Wells with Treatment	29
Additional Water Supply	N/A
Estimated Capital Cost	$17 Million
Estimated O&M Cost	$2.2 Million
Estimated Present Worth	$42 Million

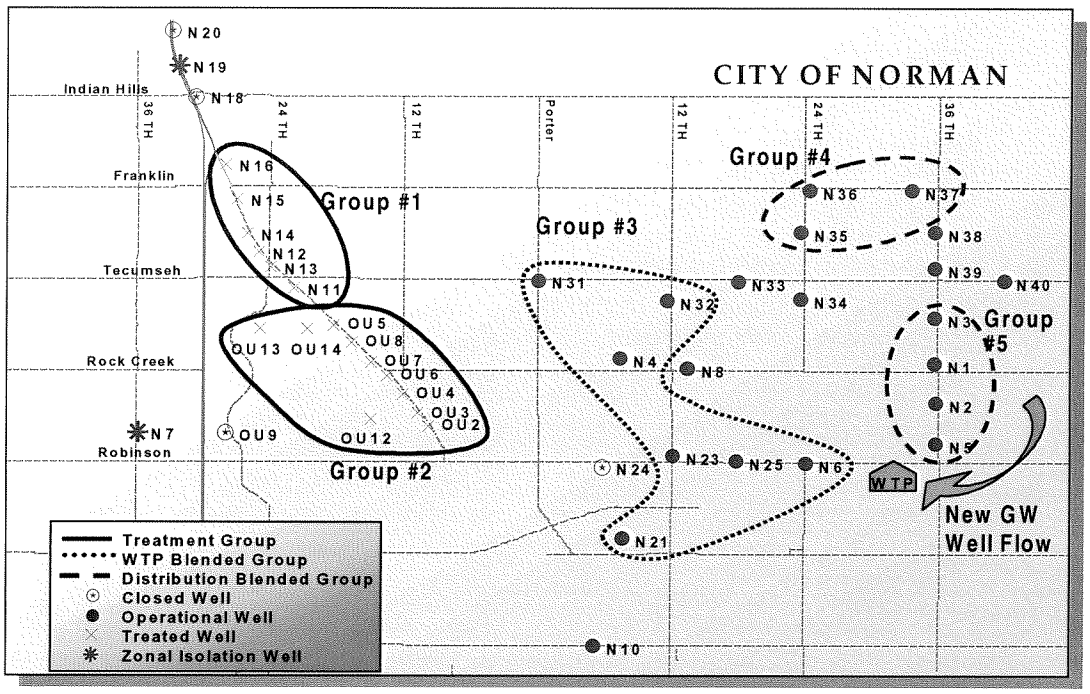

FIGURE ES-8
Plan E Map

Plan E, the final alternative, is a combination of options including treatment, zonal isolation, well removal, distribution blending, WTP blending, and construction of new wells to replace lost capacity. As indicated above, Group Nos. 1 and 2 will be treated through GFH adsorption. Group No. 3 wells are conveyed to the WTP for blending. Additional conveyance for new service line connections will be provided for Group Nos. 4 and 5 so that distribution blending can occur. The summary of Plan E is presented in Table ES-5.

TABLE ES-5
Plan E Summary

Summary Item	Result
Wells Removed from the System	4
Blended Wells	14
Wells with Zonal Isolation	2
Wells with Treatment	16
Additional Water Supply	3 New Groundwater Wells
Estimated Capital Cost	$12 Million
Estimated O&M Cost	$1.7 Million
Estimated Present Worth	$32 Million

Recommended Approach

Each of the five alternatives were presented and discussed with City and OU staff during a workshop on February 21, 2002. The advantages and disadvantages of each plan were discussed. Table ES-6, below, summarizes the information contained in Tables ES-1 through ES-5 for ease of comparison. Plan C was selected as the best plan alternative for the following reasons.

- Independence from relying on OKC treated water
- Non-treatment options for achieving AR compliance
- Development of non-potable uses for non-compliant groundwater wells thereby decreasing overall water demand for the City and OU water systems
- Lowest estimated present worth cost

Implementation of Plan C will involve integration of the Arsenic Study with the recently completed City of Norman 40-Year Strategic Water Supply Plan (SWSP). Specifically, the SWSP proposed a new wellfield for additional groundwater supply to meet future City demands. However, as a result of AR implementation, a portion of the groundwater production from the new wellfield will now be used to replace lost capacity. The success of identifying and implementing non-potable use of water from the closed wells will ultimately determine if additional water supply will need to be acquired for 2040 beyond that identified in the SWSP.

TABLE ES-6
Summary of Plan Alternatives

Plan	Wells Removed from Service	Blended Wells	Wells with Zonal Isolation	Wells with Treatment	Additional Water Supply	Estimated Capital Cost (million)	Estimated O&M Cost (million)	Estimated Present Worth (million)
A	29	0	0	0	OKC Treated	$0.65	$4.1	$47
B	15	14	7	0	OKC Treated	$4.0	$3.0	$37
C	15	14	7	0	New GW Wells	$9.0	$1.3	$24
D	1	0	0	29	N/A	$17	$2.2	$42
E	4	14	2	16	New GW Wells	$12	$1.7	$32

SECTION 1

Background on Arsenic and Groundwater Rules

The City of Norman (City) plans to conduct a Water Well and Water Distribution Improvement Project (Project) to expand their current wellfield to meet increasing water demands. However, the Project has been delayed until pending changes to the Arsenic Rule (AR) and Groundwater Rule (GWR) are finalized. In preparation for immediate Project initiation once the final rules are published, this Arsenic Treatment Study (Study) has been prepared to present and analyze the consequences associated with implementing the AR and GWR. Also included in the Study is the University of Oklahoma's (OU) groundwater wellfield.

Section 1 of the Study provides information on the background of the AR and GWR. Specifically, the following topics are discussed.

- Arsenic Rule. Discusses the AR, promulgation dates, national cost benefit analysis review, and health and risk analysis of arsenic in drinking water.
- Genesis of Arsenic in Groundwater.
- Groundwater Rule. Discusses the GWR including dates of promulgation, national cost benefit analysis review, and a review of associated health risks.

Arsenic Rule

Arsenic has been recognized as a poison for centuries and, more recently, identified as a potential carcinogen. Since 1943, the federal government has regulated arsenic in drinking water at 50 micrograms per liter (μg/L), but did not base the regulated limit on health-based factors (EPA, 1998).Taiwanese and Argentinean studies have provided new data and research findings that further identify arsenic's negative health effects, , both carcinogenic and non-carcinogenic; therefore, lowering the maximum contaminant level (MCL) is imminent. It should be noted that no arsenic-related illnesses have been found in the United States (US), even at arsenic concentrations up to 160 μg/L.

Current controversial debates surrounding arsenic in drinking water are focused on which MCL is appropriate to achieve a balance between health benefits and associated treatment costs. As charged by the 1996 Amendments to the Safe Drinking Water Act (SDWA), the US Environmental Protection Agency (EPA) performed arsenic studies and published the final AR in January 2001 that enforces a MCL of 10 μg/L and a maximum contaminant level goal (MCLG) of zero. However, subsequent events caused delays in the effective date, primarily due to the uncertainty of health risks associated with low levels of arsenic in drinking water. Specifically, several agencies, including states, public water systems (PWS), and other stakeholders, voiced concerns regarding the adequacy of science and the basis for cost estimates. Their concerns provoked a reassessment of the supporting studies on which the AR is based. The expected date of final publication of the reassessed AR is February 22,

2002. EPA staff has indicated that the MCL will not exceed 10 µg/L (Hoffbuhr, 2001). Table 1-1 lists the events leading to promulgation and reassessment of the pending AR.

TABLE 1-1
History of Arsenic in Drinking Water Regulations
Chronological Order of Events Since 1942

Date	Description of Event
1942	US Public Health Service (US PHS) set a 50 µg/L arsenic standard.
1974	EPA set a 50 µg/L interim arsenic standard, although commentors recommended an MCL of 100 µg/L based on no observed adverse health effects.
1980	EPA announced the availability of Water Quality Criteria Documents under the Clean Water Act (CWA). For protection of human health from ingestion of contaminated water and aquatic organisms at an increased cancer risk of 10^{-6}, the criteria was 2.2 ng/L or 0.0022 µg/L. [Note: On December 22, 1992, the CWA criteria were recalculated with updated cancer slope factor data to yield 0.018 µg/L for arsenic.
1983	EPA requested comments on whether the arsenic MCL should consider carcinogenicity, other health effects, and nutritional requirements; and whether MCLs are necessary for separate valence states.
1985	EPA proposed an MCLG of 50 µg/L based on the National Academy of Sciences (NAS) conclusion that 50 µg/L balanced toxicity and possible essentiality. EPA also requested comments on alternate MCLGs of 100 µg/L based on noncarcinogenic effects and zero µg/L based on carcinogenicity.
1986	Amendments to the SDWA converted the 1975 interim arsenic standard to a National Primary Drinking Water Regulation (NPDWR), subject to revision by 1989.
1988	An EPA Office of Drinking Water study presented evidence that the dose/response curve may be non-linear at low doses, and that hyperkeratosis is dose related with a threshold of 350-400 µg/day of arsenic.
1988	EPA's Cancer Risk Assessment Verification Endeavor (CRAVE) verified a quantification based on skin cancer risk resulting from arsenic ingestion. The 10^{-4} and 10^{-6} excess skin cancer risk for arsenic in water were 2 and 0.02 µg/L, respectively. In a report, EPA's Risk Assessment Forum evaluated the validity of the Taiwan 1968/1977 data for dose-response assessments in the US calculated at the 50 µg/L standard, and determined the US lifetime risk ranged from 1×10^{-3} to 3×10^{-3}.
1989	After reviewing the above report, the Science Advisory Board (SAB) declared that (1) the essentiality of arsenic is suggestive but not definitive; (2) hyperkeratosis may not be a precursor of skin cancer; (3) the Taiwan data are adequate to conclude that high doses of ingested arsenic can cause skin cancer; (4) the Taiwan study is inconclusive to determine cancer risk at levels ingested in the US; and (5) As (III) levels below 200-250 µg per day may be detoxified. SAB concluded that arsenic dose-response is nonlinear and reported that the 1988 Forum report did not apply nonlinearity in its risk assessment. EPA missed the 1989 deadline for proposing a revised NPDWR arsenic standard, and a citizen suit was filed against them. A new statutory deadline for the arsenic regulations was included in the 1996 amendments to the SDWA, and the litigation as to arsenic was dismissed in November 1996.
1992	The SAB reviewed EPA's 1991 arsenic recommendations and recommended projects that would impact the risk assessment. Due to the potential significance of two internal cancer studies published in 1992, EPA decided to evaluate and incorporate this new risk information into the revision of the arsenic regulation.

TABLE 1-1
History of Arsenic in Drinking Water Regulations
Chronological Order of Events Since 1942

Date	Description of Event
1993	The SAB reviewed an EPA's draft report on arsenic and concluded that data support an association between high levels of arsenic and internal cancer in humans. However, SAB recommended against the use of an uncertainty factor of three to derive the Reference Dose. SAB also recommended that EPA account for the differences between US and Taiwanese cancer risks.
1994	EPA thoroughly reviewed available information and determined that: (1) there is evidence of an association between internal cancer and arsenic; (2) the risk of internal cancer cannot be quantified using the available epidemiological data; and (3) the risk assessment will be based on the existing quantified skin cancer risk with a hazard identification for internal cancer. EPA's CRAVE workgroup concurred.
1995	SAB issued a report that reviewed occurrence, treatment technology, and analytical methods for arsenic. An Expert Workshop on Arsenic Research Needs sponsored by various agencies was held. The August 1995 final report prioritized research in mechanisms, epidemiology, toxicology, and treatment.
1996	SDWA Amendments were enacted, and required, in part: • development of a research plan to reduce the uncertainty in assessing health risks from low levels of arsenic; • research in consultation with the NAS, federal agencies, and interested public and private entities; • cooperative agreements for research; • proposal of an arsenic regulation by January 1, 2000; • publication of a final arsenic regulation by January 1, 2001; and • authorization of $2.5 million per year from 1997-2000 for the studies. Additionally, EPA was given discretionary authority to adjust the arsenic limit according to a cost to benefit analysis.
1999	National Research Council (NRC) EPA completed a study on arsenic in drinking water and concluded that chronic ingestion of inorganic arsenic causes bladder, lung, and skin cancer at levels of at least several hundred μg/L of arsenic, although the degree of cancer risk at lower levels was unknown. The study recommended more data be obtained, especially at lower levels of arsenic.
2000	EPA published the proposed AR setting the MCL at 5 μg/L, and took comments on other limits, including 3 (the technically feasible level), 10, and 20 μg/L.
Jan. 22, 2001	EPA finalized the AR setting the MCL at 10 μg/L using their discretionary authority to justify the costs versus benefits balance.
Jan. 24, 2001	A memorandum was submitted to EPA requesting that the new administration under President Bush have the opportunity to review any new or pending regulations, and a delay of the AR effective date was requested.
Mar. 23, 2001	EPA delayed the AR effective date for 60 days until May 22, 2001.
Apr. 23, 2001	EPA proposed a second effective date delay for adequate reassessment of the AR.

TABLE 1-1
History of Arsenic in Drinking Water Regulations
Chronological Order of Events Since 1942

Date	Description of Event
July 19, 2001	EPA issued a proposal requesting public comment on which MCL (3, 5, 10, or 20 μg/L) is justified according to the data and technical analyses associated with the Final AR of January 22, 2001. In addition, EPA requested new arsenic information for review and inclusion in the reassessment. Comments are accepted until October 31, 2001.
August 14, 2001	Arsenic Cost Working Group submitted to the National Drinking Water Advisory Council (NDWAC) a report on the *re-examination* of cost issues associated with Arsenic.
August 19, 2001	EPA's SAB's Arsenic Benefits Review Panel completed a report *re-evaluating* the AR Benefits Analysis.
September, 2001	A NRC subcommittee on arsenic finalized an *update* to the *1999 Arsenic in Drinking Water Report* to reflect several new studies and analyses published since the report was released.

As previously mentioned, the January 2001 AR set an enforceable MCL for arsenic in drinking water at 10 μg/L and a non-enforceable MCLG at zero. The AR also listed best available technologies (BAT), Consumer Confidence Reports (CCR) for community water systems (CWS), and a public notification requirement for PWS. The AR, as it was published in January 2001, is summarized below.

Maximum Contaminant Level

Originally and prior to EPA's AR proposal in 2000 establishing the arsenic MCL of 5 μg/L, a MCL of 3 μg/L was considered based on the benefit/cost provisions of the SDWA. EPA defined 3 μg/L as the feasible level based on their understanding of the proposed BATs. In addition, EPA set a practical quantitation limit (PQL), which is the concentration that most laboratories can detect accounting for the limits of the current measurement technologies. However, EPA determined that the benefits of regulating arsenic at 3 μg/L would not justify the costs and increased the proposed MCL to 5 μg/L, while requesting comments on MCL options of 3 μg/L, 10 μg/L, and 20 μg/L.

Following the proposal, EPA's Notice of Data Availability (NODA) was published October 20, 2000, which contained a revised risk analysis for bladder cancer and new risk information for lung cancer. A final MCL of 10 μg/L was established on January 22, 2001, based on dose-response models, extrapolation from a Taiwanese cancer study, and a review by EPA's SAB.

Currently, the EPA has published another NODA on October 5, 2001, relating to three new studies completed by EPA-appointed panels. The NRC evaluated the health risks associated with low levels of arsenic in a report entitled "Arsenic in Drinking Water: 2001 Update." In this report, the NRC concluded that the health risk related to arsenic in drinking water was higher than originally published in their 1999 report. The SAB reviewed the issue of benefits used in the cost benefit analysis and a report entitled "Arsenic Rule Benefits Analysis: An SAB Review." The SAB concluded that unquantified benefits such as a reduction of cardiovascular and cerebralvascular diseases, endocrine effects, reproductive health effects,

and non-malignant respiratory diseases should be included in EPA's analysis of benefits. It should be noted that there is currently no basis for causality associated with these unquantified benefits. The third panel consisted of a NDWAC work group who evaluated EPA's development of national costs of compliance. The NDWAC workgroup reported that EPA's costs were "credible," however, they provide seven pages of recommendations. EPA has requested comments on these reports, which were due October 31, 2001.

Best Available Technologies

As required by the SDWA, for every EPA regulation that establishes an MCL, technologies and treatment techniques must be provided for the purpose of meeting the new MCL. Of the provided technologies, BAT are selected based on the following criteria:

- the capability of a high removal efficiency;
- a history of full-scale operation;
- general geographic applicability;
- reasonable cost based on large and metropolitan water systems;
- reasonable service life;
- compatibility with other water treatment processes; and
- the ability to bring all of the water in a system into compliance.

In the AR, the EPA reviewed several technologies including ion exchange, activated alumina, reverse osmosis, nanofiltration, electrodialysis reversal, coagulation-assisted microfiltration, modified coagulation/filtration, modified lime softening, greensand filtration, conventional iron and manganese removal, among others. The selected BATs are listed in Table 1-2.

TABLE 1-2
Best Available Technologies and Removal Rates[a]

Technology	Maximum % Removal Rate[a]
Ion Exchange (sulfate =50 mg/L)	95
Activated Alumina	95
Reverse Osmosis	>95
Modified Coagulation/Filtration	95
Modified Lime Softening (pH > 10.5)	90
Electrodialysis Reversal	85
Oxidation/Filtration (20:1 iron : arsenic)	80

Notes:
[a] The removal rates are for arsenic (V) removal. Pre-oxidation may be required.

Section 5, Decision Analysis for Arsenic Treatment Technologies, evaluates these processes although most are not appropriate for groundwater systems.

Monitoring, Compliance, and Reporting

The AR defines acceptable testing methods, required monitoring events, methods to determine compliance, and reporting requirements for regulated drinking water systems containing certain levels of arsenic. The following paragraphs discuss these parameters.

Monitoring

Affected water systems must monitor for arsenic at each point-of-entry (POE) to the water distribution system. Typically, an entry point is defined as the first customer in distributed groundwater systems. Monitoring and compliance is further complicated in conjunctive use systems such as the City's. When surface water is used, the actual arsenic levels in the system will not be the same as when the high arsenic wells are in service. Thus, many people have commented that in conjunctive use systems, arsenic should be monitored the same as disinfection by-products, at specific points in the distribution system. Additionally, according to the AR, laboratory test methods approved for analyzing arsenic concentration include the following.

- Inductively Coupled Plasma Mass Spectroscopy
- Stabilized Temperature Platform Graphite Furnace Atomic Absorption (AA)
- Graphite Furnace AA
- Gaseous Hydride AA

The most cost-effective method of analysis will be the graphite furnace AA. Although the current AR is under assessment, the time allowed for compliance will likely remain the same, on a relative basis. A speculative monitoring compliance schedule is shown in Table 1-3 and is based on the January 2001 AR.

TABLE 1-3
Arsenic Rule Monitoring Requirements[a]

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

Notes:
[a] Dates for reassessed AR are speculative based on time period allowed for each monitoring requirement in the currently delayed AR.

The AR states that the initial monitoring event for arsenic should occur after the effective date of the MCL. Although, surface water systems must collect and analyze a sample every year, groundwater systems must take one sample in two years. If the initial event indicates an arsenic concentration less than the MCL, groundwater systems must collect a new sample every three years, while surface water systems must collect and sample annually.

Otherwise, if the initial event indicates the arsenic concentration exceeds the MCL, samples are required quarterly. If the arsenic concentration falls below the MCL on a consistent basis, the monitoring frequency can be reduced.

Compliance

With the finalization of the AR, compliance with inorganic contaminant (IOC), synthetic organic contaminant (SOC), and volatile organic contaminant (VOC) MCLs was revised. Arsenic is regulated as an IOC. The following items detail the changes regarding compliance/violation determination.

- Calculate compliance based on a running annual-average at each sampling point.
- Systems will not be in violation until one year of quarterly samples has been collected (unless fewer samples would cause the running annual-average to be exceeded.)

If a system does not collect all required samples, compliance will be based on the running annual-average of the samples collected.

For the City, wells enter the distribution system individually creating many points of compliance. Information provided by Oklahoma Department of Environmental Quality (ODEQ) staff indicates that if only a portion of the wells produce groundwater exceeding the MCL, then only those wells require an increased monitoring schedule. A compliance point triggered for increased monitoring is not in violation until monitoring has been performed quarterly for a year, unless any one quarterly sample is four times greater than the 10 μg/L MCL. Additionally, for the scenario of a well operating during only one quarter of a year, only that quarter's data can be used for the resultant annual arsenic level. Likewise, for a well operating during two quarters of a year, the two-quarterly samples are averaged for the resultant annual arsenic concentration.

Reporting

For CCR, Table 1-4 provides a speculative schedule based on provisions of the currently delayed AR.

TABLE 1-4
Arsenic Rule Reporting Requirements

Date	Reporting Requirement
July 1, 2001	For the report covering calendar year 2000, systems that detect higher ranges of arsenic must include an educational statement in the CCR.
July 1, 2002 & beyond	For reports covering calendar years 2001 and beyond, systems that detect lower ranges of arsenic must include an educational statement in the CCR.
July 1, 2002 to July 1, 2006	For reports covering calendar years 2001 to 2005, systems that detect arsenic between the MCL and 50 μg/L must include a health effects statement in their CCR.
July 1, 2007 & beyond	For reports covering calendar year 2006 and beyond, systems that are in violation of the arsenic MLC must include a health effects statement in their CCR.

Additionally, affected water systems violating the regulations set forth under the AR must provide public notification to consumers.

Affected Systems Costs and Benefits

Nationwide, EPA oversees approximately 54,000 CWS and approximately 20,000 non-transient non-community water systems (NTNCWS). A CWS is a system that serves 15 locations or 25 residents year-round. A NTNCWS is a PWS not defined as a CWS that regularly serves at least 25 of the same persons over six months per year. In the AR, EPA provides estimates of how many systems will be affected at a range of arsenic limits between 3 and 20 μg/L. Table 1-5 provides these estimates.

TABLE 1-5
Number of Systems Exceeding Various Arsenic Concentration Ranges
Arsenic Rule Estimates

System	Arsenic Concentration, μg/L			
	>3 to 5	>5 to 10	>10 to 20	>20
CWS				
Groundwater	3,384	2,949	1,432	870
Surface Water	270	239	51	34
Total	3,654	3,188	1,483	904
NTNCWS				
Groundwater	1,677	1,995	635	405
Surface Water	20	17	4	2
Total	1,697	2,012	639	407

EPA also provided estimates of national and per household costs to implement the AR. At a MCL of 3, 5, 10, and 20 μg/L, the estimated national cost of AR implementation is $697.8 million/yr, $414.8 million/yr, $180.4 million/yr, and $66.8 million/yr, respectively. These estimates were prepared based on a discounted rate of 3 percent and are in 1999 dollars. Utility treatment costs including capital, operation and maintenance, monitoring and reporting costs, and start-up costs were included in the cost estimates. EPA used decision-tree analysis to predict which treatment techniques systems would be used to treat arsenic.

The annual per household costs divided by system size categories for various ranges of arsenic concentrations, as estimated by EPA in the January 22, 2001 AR, are summarized in Table 1-6.

TABLE 1-6
Average Cost per Household[a]

System Size	3 μg/L	5 μg/L	10 μg/L	20 μg/L
<100	$317.00	$318.26	$326.82	$351.15
101-500	166.91	164.02	162.5	166.72
501-1,000	74.81	73.11	70.72	68.24
1,001-3,300	63.76	61.94	58.24	54.36
3,301-10,000	42.84	40.18	37.71	34.63
10,001-50,000	38.4	36.07	32.37	29.05
50,001-100,000	31.63	29.45	24.81	22.63
100,001-1,000,000	25.29	23.34	20.52	19.26
>1,000,000	7.41	2.79	0.86	0.15
All Categories	41.34	36.95	31.85	23.95

[a] Costs are in 1999 dollars.

The EPA also provided estimates on quantifiable health benefits associated with implementation of the AR for avoidance of lung and bladder cancer cases only. At various concentrations of arsenic in drinking water, the quantifiable health benefit cost estimates are listed below.

- At 3 μg/L: $213.8 million to $490.9 million
- At 5 μg/L: $191.1 million to $355.6 million
- At 10 μg/L: $139.6 million to $197.7 million
- At 20 μg/L: $66.2 million to $75. 3 million

To reach these cost estimates, EPA assumed mortality rates of 26 percent for bladder cancer and 88 percent for lung cancer. For the cancer cases resulting in mortality, the EPA assumed a value of statistical life (VSL) of $6.1 million. For those cancer cases not resulting in mortality, EPA assumes a willingness-to-pay estimate of $607,000 per each case. Other health benefits result from implementation of the AR, but due to data limitation, are not quantifiable. Those include skin, kidney, liver, and prostate cancer; cancer of the nasal passages; and effects to cardiovascular, pulmonary, immunological, neurological, and endocrine systems.

Reassessment

As mentioned previously, reassessment of the AR is ongoing and the revised AR is expected to be final in February 2002. The AR reassessment includes, in part, review of solicited public comments and consideration of the updates of following three reports.

- Report of the Arsenic Cost Working Group to the National Drinking Water Advisory Council
- Arsenic Rule Benefits Analysis – An SAB Review
- 1999 Arsenic in Drinking Water Report

The findings and conclusions of the updates to these reports will likely affect the outcome of the final AR. The updates of these reports are briefly discussed in the following sections. The update likely having the most affect on the AR is the 1999 Arsenic in Drinking Water report update. However, the other reports may provide changes to cost estimation and benefits analyses.

Report of the Arsenic Cost Working Group

The NDWAC was charged with re-examining EPA's methods for determining national costs associated with the AR. The NDWAC organized an Arsenic Cost Working Group to evaluate EPA's costing methodologies, assumptions, and information underlying the system-size cost estimates as well as the aggregated national estimate of system costs of the AR.

The working group concluded that EPA produced appropriate cost estimates given the inherent uncertainties of national cost estimates. However, the working group provided recommendations to improve the cost estimates. EPA will review the recommendations and decide whether or not to revise cost estimates for the final AR. The recommendations and suggestions of the working group were focused, in part, around changes to the following items:

- determining the number of affected systems, flow and entry points to the distribution system;
- unit technology and cost;
- determination of decision tree and compliance forecast;
- technologies not included in the current national cost estimate;
- residual handling and disposal;
- administrative costs;
- summary tables; and
- point-of-use (POU) technologies.

Additionally, the working group recommended using updated cost and technology data and information, where available, for inclusion in the pending AR. Additionally, the working group suggested consideration of only incremental cost estimates for treatment from the current standard (50 μg/L) to the new standard for entry points exceeding 50 μg/L; costs of additional technologies feasible for arsenic removal; land costs; costs for onsite pilot testing of all technologies; incorporating a multiplier for converting process costs to capital costs; process monitoring and maintenance labor requirements; and state

costs for small system operator certification, training, and administrative costs. The working group also made recommendations for the following POU applications.

- Update capital and operations and management unit costs for each treatment alternative to clearly define the size of community that would make it a preferable alternative.
- Increase the percentage of systems likely to use POU according to the above change.
- Specify the community action needed to achieve compliance.

Finally, the working group suggested that EPA establish a better approach for developing cost estimates. Specifically, the working group recommended an "approach based on aggregated county, regional, or state costs, coupled with extensive individual case analysis which would yield significantly better results than current procedures."

Arsenic Rule Benefits Analysis

The EPA asked that the SAB Panel re-evaluate the components, methodology, criteria, and estimates reflected in EPA's analysis of the benefits associated with reduction of arsenic in drinking water to conclude that they are reasonable and appropriate. As part of the review process, EPA also charged the Panel with answering five questions regarding the arsenic in drinking water issue. The SAB Panel's updated evaluation provided answers to the five questions posed by EPA, and provided general comments regarding the computation of benefits, computation of costs, and presentation of results.

SAB's recommendations to EPA for improved benefit quantification included utilizing different assumptions regarding the time required to achieve the expected reduction in cancer risk; estimating cancer-risk reduction by age; adding additional health risks associated with arsenic ingestion other than lung and bladder cancer; providing information on non-quantified health benefits; and calculating avoided nonfatal cancer cases the same as fatal cancers cases.

EPA will review SAB's update and consider inclusion of the recommendations into the final AR.

1999 Arsenic in Drinking Water Report

In accordance with requirements of the 1996 SDWA Amendments, EPA requested that the NRC review data related to the toxicity of arsenic and evaluate the scientific validity of EPA's 1988 risk assessment for arsenic in drinking water. As requested, the NRC appointed a subcommittee that reviewed information on the health effects of arsenic exposure and data on the disposition and the mechanism or mode of action of arsenic. The subcommittee concluded in their *Arsenic in Drinking Water* report the following on the health affects of arsenic ingestion.

- According to epidemiological studies in Taiwan, Chile, and Argentina, chronic ingestion of inorganic arsenic causes bladder and lung cancer, as well as skin cancer.
- With minor exceptions, epidemiological studies for cancer are based on populations exposed to arsenic concentrations in drinking water of at least several hundred μg/L.

- Little data addresses the cancer risk at lower concentrations of ingested arsenic. The cancer risk associated with low levels of drinking water arsenic may be as great as one in 100 persons.
- Non-carcinogenic effects occur at ingestion concentrations of 10 μg/kg and greater.
- Additional epidemiological evaluations are needed to characterize the dose-response relationship for arsenic health risks, especially at low dose rates.

The EPA's decision to propose the initial MCL of 5 μg/L and publish the final MCL of 10 μg/L relied heavily on the NRC's review of the relevant scientific information. In their report, *Arsenic in Drinking Water*, the NRC recommended that EPA's current MCL be revised: "... it is the subcommittee's consensus that the current MCL for arsenic in drinking water of 50 μg/L does not achieve EPA's goal for public-health protection and, therefore, requires downward revision as promptly as possible" (NRC, 1999). The following paragraphs provide a brief summary of NRC's report.

Regarding the disposition (absorption, distribution, metabolism, and excretion) of arsenic, the subcommittee concluded that humans and some animals transform inorganic arsenic into forms that are not as toxic and are more readily excreted. However, because disposition occurs differently for different interspecies, more human studies are needed, including research using human tissues. Additionally, the subcommittee recommended that methylation, tissue retention, and excretion of arsenic should be investigated.

The *Arsenic in Drinking Water* report also researched arsenic's mode of action and concluded that the mechanism by which arsenic causes cancer, or other toxic effects, is not well established. However, the subcommittee concluded the most accepted explanation of arsenic's carcinogenicity is induction of chromosonal abnormalities without interacting directly with deoxyribonucleic acid (DNA), which assumes arsenic is an indirect agent. Additionally, arsenic's mode of action for induction of noncarcinogenic effects is centered on its inhibitory effects on cellular respiration. Again, NCR suggested additional studies be performed to provide a greater understanding of the mode of action of arsenic's carcinogenicity and noncarcinogenicity.

The subcommittee's report considered human sensitivity factors and how they relate to arsenic's health affects, and concluded that some humans may retain more arsenic than others depending on factors such as genetics, metabolism, diet, health status, sex, and others. The NRC indicated that better characterizations of factors affecting human sensitivity of arsenic health affects are needed.

Regarding EPA's 1988 risk assessment for arsenic in drinking water , the NRC subcommittee concluded that "no human studies of sufficient statistical power or scope have examined whether consumption of arsenic in drinking water at the current MCL (50 μg/L) results in an increased incidence of cancer or noncancer effects." As such, NRC based their conclusions on what they considered to be the best available data for assessing arsenic's carcinogenicity. They concluded the ecological studies of Taiwan provided the best available data for their review; however, extrapolation of the data to lower arsenic dosages in order to determine a dose-response curve was insufficient and inconclusive. The subcommittee determined, according to statistical regression models, that the arsenic-induced cancer risk at the current MCL could be one in 100, although not all members of the

subcommittee agreed. They also concluded that an MCL of 50 μg/L does not achieve EPA's health protection goals. The subcommittee also indicated that additional analyses are needed.

1999 Arsenic in Drinking Water Report Update

Following the delay of the January 22, 2001, AR, EPA requested that NRC update the 1999 *Arsenic in Drinking Water* report to include toxicological, epidemiological, and risk assessments published since the report was prepared. The following paragraphs summarize the updated *Arsenic in Drinking Water* report.

The subcommittee concluded that evidence has surfaced since 1999 indicating chronic arsenic exposure may be associated with an increased risk of high blood pressure, diabetes, adverse reproductive outcomes, and respiratory effects. Additionally, three new studies in Taiwan and Chile since 1999 confirm arsenic to be carcinogenic. One of the studies indicated that life-style differences between populations in "southwestern Taiwan and the rest of Taiwan do not substantially affect estimates of the risk of cancers from ingesting arsenic in drinking water" (NRC, 2001). A fourth study prepared since 1999 was conducted in Utah and was the first attempt to consider the US population's cancer risk to arsenic exposure. However, the subcommittee concluded the Utah study was too limited for use in risk assessment analyses. Finally, the subcommittee indicated that recent studies show an increased strength of evidence for links between internal cancers and ingestion of arsenic through drinking water.

Regarding arsenic's mode of action, the NRC subcommittee concluded that data were still inadequate, as was the case in 1999, to define the shape of the dose-response curve. Hence, selection of a linear or nonlinear extrapolation for lower dosages of arsenic still can not be made.

Comments regarding the Taiwanese study included claims that poor nutrition might create higher susceptibility to arsenic effects indicating the data contained in the Taiwanese study would be conducive to extrapolation to areas with better nutrition, for example, the US. However, studies conducted in Chile and Argentina, where poor nutrition is not an issue, also confirmed increased cancer risks with arsenic exposure. Additionally, the subcommittee determined that although several studies indicate an interaction between increased cancer risk and smoking in combination with arsenic exposure, further characterization is needed.

When estimating cancer risk, the subcommittee performed statistical models to determine the ED_{01}, which is the exposure dose at which there is a one percent response for the studied population. They also presented maximum-likelihood risk estimated for excess risk of lung cancer and bladder cancer for US populations. Table 1-7 provides a summary of the subcommittee's findings.

TABLE 1-7
Theoretical Maximum-Likelihood Estimates of Excess Lifetime Cancer Risk per 10,000 *(NRC, 2001)*

Arsenic, μg/L	Bladder Cancer	Lung Cancer
3	11	9
5	17	16
10	35	32
20	69	63

The subcommittee described many uncertainties surrounding the estimates. However, they concluded that the data and studies since the 1999 *Arsenic in Drinking Water* report suggest that the risks for bladder and lung cancer occurrence related to arsenic exposure are greater than that presented in the risk assessment on which EPA based the January 2001 AR.

Health Risks

Although the NRC has estimated high health risks associated with very low levels of arsenic in drinking water, the actual health risks are very uncertain at this time. In EPA's own funded study in Millard County, Utah, there were no adverse health effect impacts observed even with arsenic levels up to 161 μg/L. The data being collected in the US does not fit the health risk models being proposed by the EPA. The NRC has concluded, "even at the highest risk estimates made by this subcommittee, the increases in cancer due to arsenic in drinking water would be difficult to detect statistically in the US population." If the risks were truly as high as the NRC estimates, it should be possible to detect increases in cancer rates at arsenic levels observed in the US. Many epidemiologists are questioning the dose response estimates provided by the latest NRC report. Thus, the health risks associated with low levels of arsenic in drinking water continue to be debated and studied. The AWWA Research Foundation is conducting a project, scheduled for completion in 2002, that evaluates arsenic health risks in the US. Preliminary data from Dr. Floyd Frost (Lovelace Research Institute) do not show increased health risks with populations exposed to higher levels of arsenic in the US.

Genesis of Arsenic in Drinking Water

Mineral Arsenic

The earth's crust is formed of layers of various rock formations composed of thousands of minerals. There are eight primary minerals making up the earth's crust: oxygen, silicon, aluminum, iron, magnesium, calcium, potassium, and sodium. However, there are over 3,000 known minerals falling into several groups. One known mineral, arsenic, falls in the element group and exists in combination with antimony, nickel, silver, iron, and sulfur.

Arsenic, a metalloid, ranks about 52nd in natural abundance among the elements in crustal rocks (Encarta article, MSN).

Table 1-8 lists the major arsenic minerals occurring in nature.

TABLE 1-8
Major Arsenic Minerals
(Smedley, et. al., 2001)

Mineral	Composition	Occurrence
Native arsenic	As	Hydrothermal veins
Niccolite	NiAs	Vein deposits and norites
Realgar	AsS	Vein deposits, often associated with orpiment, clays and limestones, also deposits from hot springs
Orpiment	As2S3	Hydrothermal veins, hot springs, volcanic sublimation product
Cobaltite	CoAsS	High-temperature deposits, metamorphic rocks
Arsenopyrite	FeAsS	The most abundant As mineral, dominantly mineral veins
Tennantite	(Cu,Fe)12As4S13	Hydrothermal veins
Enargite	Cu3AsS4	Hydrothermal veins
Arsenolite	As2O3	Secondary mineral formed by oxidation of arsenopyrite, native arsenic and other As minerals
Claudetite	As2O3	Secondary mineral formed by oxidation of realgar, arsenopyrite and other As minerals
Scorodite	FeAsO4.2H2O	Secondary mineral
Annabergite	(Ni,Co)3(AsO4)2.8H2O	Secondary mineral
Hoernesite	Mg3(AsO4)2.8H2O	Secondary mineral, smelter wastes
Haematolite	(Mn,Mg)4Al(AsO4)(OH)8	
Conichalcite	CaCu(AsO4)(OH)	Secondary mineral
Pharmacosiderite	Fe3(AsO4)2(OH)3.5H2O	Oxidation product of arsenopyrite and other As minerals

The chemistry of arsenic is similar to that of sulphur and the greatest concentrations of arsenic tend to occur in sulphide minerals. Concentrations of arsenic in pyrite, chalcopyrite and galena (sulphides) are variable, but in some cases can reach 10 weight percent (Smedley et. al., 2001). In addition, arsenic can be found in other rock-forming minerals such as oxides, silicates, carbonates, and sulphates.

There are many beneficial uses for arsenic, such as pesticides, wood preservatives, semiconductor manufacturing, petroleum refining, animal feed additives, herbicides, paints, dyes, metals, drugs, and soaps. It is present in trace amounts in all living matter, and a

typical individual living in the US receives between 5 and 10 μg/L of arsenic daily as part of a normal diet. (Christen, 1999)

Arsenic Occurrence in the Garber-Wellington Aquifer

Arsenic occurs naturally in rocks, soil, water, air, plants, and animals. It enters surface or groundwater mainly through the weathering of rocks or erosion, but can also enter water through seepage from hazardous waste sites. Additionally, if air contains arsenic particles from burning fossil fuels, metal production, agricultural uses, or waste incineration, precipitation will collect the particles and deposit on the earth's surfaces. As plants and animals uptake the deposited mineral, human consumption can occur. Other natural activities that induce arsenic's presence include volcanic activity and forest fires. Other than natural causes, anthropogenic events (caused by people) can also induce arsenic's presence. These events include agricultural, mining, and smelting activities.

The Garber-Wellington Aquifer (GWA), also termed the Central Oklahoma Aquifer, produces groundwater containing varying levels of arsenic and is the City's supply resource. The GWA is comprised of a complex stratigraphy of both the Wellington Formation and the Garber Sandstone geologic units. The Wellington Formation is red, massive, cross-bedded sandstone with irregularly interbedded shale (mudstone). The Garber Sandstone is red, massive, cross-bedded sandstone and siltstone both interbedded and interfingered with shale. Both are fine-grained and have wide variations in porosity and permeability. The sandstones are commonly poorly cemented and somewhat friable. The cements are red clays and some contain carbonates (calcite) as well as other rare minerals.

The dominant minerals of the GWA are quartz, plagioclase, dolomite, calcite, kaolinite, hematite (iron oxide), and illite (clays) (Parkhurst, 1992). Iron oxides and illite-clays both play important roles in arsenic dissolution into the groundwater. About 30 percent of the GWA rock sampled in a US Geological Survey (USGS) study contains illite-clays, while iron-oxides (hematite) comprised about 3.5 percent of the GWA rock sampled (Parkhurst, 1992).

According to a 1998 USGS conference paper titled "Arsenic in Ground Water Supplies of the United States," the predominant method of arsenic dissolution in the GWA is through pH-influenced desorption. When iron oxide and organic carbon react in groundwater, hydrogen ions are consumed and the pH increases. As pH increases and the arsenic becomes oxidized (losing electrons, becoming more positively charged), the arsenic becomes inorganic in form and is more soluble than organic arsenic. The iron oxides on the GWA surface release arsenic into solution and the dissolved arsenic molecules bond with molecules in the groundwater.

The inorganic form of arsenic is more toxic than the organic form. Drinking water typically contains inorganic arsenic, while food typically contains organic arsenic. The inorganic form of arsenic, known as arsenate, has a valence state of plus five (As^{5+}).

The distribution of mudstone (shale) in the aquifer affects the level of dissolved arsenic. As mudstone is less permeable than sandstone, less flushing and higher residual concentrations of soluble arsenic exist in solid phases, and therefore, in groundwater contained in the mudstone. As the groundwater flow varies widely among the layers, the concentration of arsenic in groundwater samples also varies. As reported by the World Health Organization

(WHO), Table 1-9 lists average arsenic concentrations of materials that partly compose the GWA.

TABLE 1-9
Average Arsenic Concentrations

Material	Average Arsenic Concentration, μg/L
Sandstone	4.1
Non-Marine Shale (Mudstone)	3.0 – 12
Iron-Rich Sediment	1-2,900
Clay	6.5

As presented, arsenic concentrations tend to be higher in the less permeable layers (shale and clay) at averages ranging up to 6.5 μg/L, than in the more permeable layers (sandstone) at an average of 4.1 μg/L. Incidentally, iron-rich zones (in which arsenic normally exists) may exhibit average arsenic concentrations of up to 2,900 μg/L.

The USGS performed a study of arsenic occurrence in the US according to over 17,500 analyses. Figure 1-1 graphically depicts the levels of arsenic found in Oklahoma, as determined by the USGS study.

As the figure shows, the City lies in an area where levels of arsenic exceeding 10 μg/L exist in the groundwater supply. The GWA can be divided into two areas. The eastern area is unconfined and receives recharge from precipitation, lake, or stream infiltration. The western area is confined indicating recharge to the aquifer exists only from groundwater flow from the eastern portion of the aquifer. According to the figure, the confined area typically exhibits greater arsenic concentrations than that of the unconfined area.

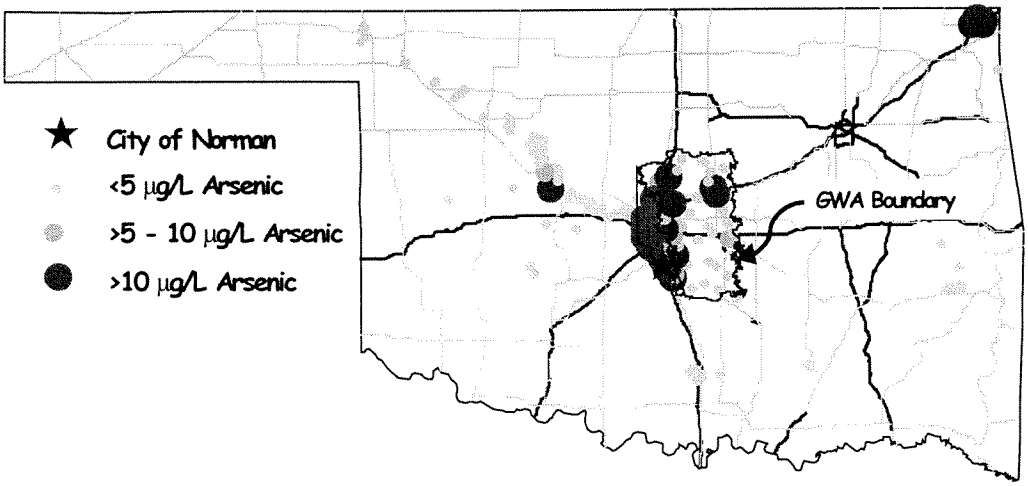

FIGURE 1-1
Arsenic Occurrence in Oklahoma
Data adopted from a USGS Study (USGS, 2000)

Groundwater Rule

Currently, only surface water systems and systems under the direct influence of surface water are required to disinfect their water supplies while groundwater systems can discharge directly to the distribution system without disinfection of any kind. Previously, groundwater was thought to be free from microbial contamination. However, new research indicates some groundwater may be sources of waterborne diseases. Waterborne bacteria can be responsible for causing diseases such as gastroenteritis, heart disease, meningitis, diabetes, hepatitis, paralysis, and kidney failure.

Prior to development of a rule specifically applied to groundwater, the Total Coliform Rule (TCR), Surface Water Treatment Rule (SWTR), the Interim Enhanced Surface Water Treatment Rule (IESWTR), and the Information Collection Rule (ICR) were the only rules applicable to groundwater systems. The TCR requires a certain frequency of monitoring based on the groundwater system size and type. The SWTR and the IESWTR applies to surface water systems and groundwater systems under the direct influence of surface water (GWUDI) and requires certain disinfectant requirements for removal of bacteria and pathogens from drinking water. The ICR applies a limited set of requirements to GWUDI systems serving between 50,000 and 100,000 people. However, none of these three rules are applied to groundwater systems **not** under the influence of surface water.

In January 1999, EPA released a Draft Preamble to the GWR and requested comments on the proposed requirements therein. The GWR specifies the appropriate use of groundwater disinfection for systems not under the influence of surface water and also designates requirements for sanitary surveys, hydrogeologic sensitivity assessments, monitoring, and corrective action. These requirements are summarized below. The proposed GWR was published on May 10, 2000, but has not yet been finalized. May 2002 is the deadline for the 1996 SDWA amendments, which includes the deadline for the final GWR.

Multiple Barrier Approach

EPA has proposed a "multiple-barrier approach" to reduce risks associated with drinking water containing waterborne pathogens from fecal contamination. The approach includes five components: periodic sanitary surveys, hydrogeologic assessments, source water monitoring, correction of deficiencies, and compliance monitoring. These components are discussed in the following paragraphs.

Sanitary Surveys

The EPA defines a sanitary survey as the following:

"an onsite review of the water source, facilities, equipment, operation and maintenance of a PWS for the purpose of evaluating the adequacy of such source, facilities, equipment, operation and maintenance for producing and distributing safe drinking water."

A sanitary survey is comprised of the following eight components.

- Source
- Treatment
- Pumps/Pump Facilities and Controls
- Monitoring, Reporting, and Data Verification

- Distribution System
- Finished Water Storage
- Water System Management and Operations
- Operator Compliance with State Requirements

EPA proposes that the ODEQ or state-authorized third parties conduct sanitary surveys of groundwater systems at least once every three years and five years for CWSs and non-community water systems (NCW), respectively. Additionally, ODEQ will develop a plan to identify high priority groundwater systems. Sanitary surveys for these systems would have to be completed within the first two years of the three-year monitoring cycle.

Systems determined to have deficiencies are required to perform one or a combination of the following options within 90 days:

- eliminate the source of contamination,
- correct the deficiency,
- provide an alternate source water; or
- provide treatment to achieve a 4-log (99.99 percent) virus removal and provide monitoring to verify correction and compliance.

If the groundwater system cannot correct the deficiency in 90 days, a correction plan and schedule must be prepared and approved by ODEQ.

Hydrogeologic Sensitivity Assessment

EPA proposes that ODEQ conduct a one-time sensitivity assessment of all systems that do not treat to 4-log virus inactivation within three years of promulgation of the GWR. This assessment will serve as additional support for the required sanitary surveys by investigating the source to determine if a hydrogeologic barrier is present to protect the source from contamination. A hydrogeologic barrier can be physical, biological, or chemical as long as it protects the source. The GWR identifies three aquifers as being sensitive. They are karsts, fractured bedrock aquifers, and gravel aquifers.

Any source determined to be sensitive (for instance, not have a hydrogeologic barrier) would be required to monitor for EPA-specified fecal indicators on a monthly basis for one year. Within six months of any system determined to require disinfection, the system would have to provide one or a combination of the following:

- eliminate the source of contamination,
- provide an alternate source water; or
- provide treatment to achieve a 4-log (99.99 percent) virus removal and provide monitoring to verify correction and compliance.

Monitoring

For systems practicing disinfection, compliance monitoring is required. Under the GWR, any system producing groundwater must continuously monitor the disinfectant concentration to ensure compliance with required disinfectant residuals or UV irradiance level, depending on the treatment technique. For systems using membrane filtration, a 4-log

removal of viruses is assumed as long as the system in operating in accordance with ODEQ guidelines for that process.

EPA has proposed certain source water monitoring criteria for those systems not currently disinfecting. According to the TCR, at least one source water sample is required following a total coliform-positive sample. If the source water sample tests positive for fecal contamination, it is considered to have a deficiency and must follow the deficient system requirements and monitoring described previously. However, if the source sample is not contaminated, ODEQ can waive the requirements on a case-by-case basis but must provide documentation of the occurrence and results.

For systems not providing disinfection but found to be within a hydrogeologically sensitive aquifer, monthly monitoring for a year is required. If no positive samples occur within a year of sampling, source monitoring can be reduced to quarterly, or completely waived if ODEQ determines contamination is highly unlikely. If a sample is identified as contaminated, the system is considered to be deficient and must follow the deficient system requirements and monitoring schedule described previously.

Correction of Deficiencies

EPA proposes that deficient systems (determined through sanitary surveys, hydrogeologic sensitivity assessment, or source water monitoring), that are not or cannot be corrected and where alternative sources of drinking water are not available, provide 4-log inactivation/ removal of viruses. The proposed compliance schedule is six months after receiving a positive fecal-indicator groundwater sample. EPA proposes two treatment techniques: (1) disinfection with chlorine, or (2) disinfection with an alternative disinfectant or treatment. Systems practicing chlorine disinfection would be required to provide at least 0.2 mg/L residual chlorine prior to the POE into the distribution system and maintain a chlorine residual throughout the distribution system. EPA would consider such systems as providing 4-log inactivation of viruses. For systems practicing alternative disinfection methods (use of chlorine dioxide, ozone, mixed oxidants, UV, or chloramines), 4-log inactivation would be determined by disinfection contact times (CT) values. Alternatively, EPA recognizes physical removal techniques, such as membrane processes.

Affected Systems, Costs and Benefits

The EPA estimates the number of affected systems by estimating the number of systems not currently practicing disinfection. As presented previously, the percent of CWSs, NTNCWSs, and transient non-community water systems (TNCWS) practicing disinfection is 68, 28, and 18, respectively. Based on these percentages, the number of systems affected by the GWR is as follows.

- CWSs affected ~ 14,080
- NTNCWSs affected ~ 13,680
- TNCWSs affected ~ 76,260

EPA also provides national cost of compliance and cost benefits for GWR implementation. The costs were divided into the categories of sanitary survey, sanitary survey and triggered monitoring; multi-barrier option; and across-the-board disinfection. The national cost of performing sanitary surveys will cost about $73 million. However, when monitoring

requirements are triggered by the sanitary survey, the cost increases to $158 million. Adding the need for a hydrogeological sensitivity assessment to the sanitary survey and triggered monitoring will increase the national costs to $183 million. And lastly, if disinfection is required for all systems, the cost is estimated at $777 million. Notably, the costs are calculated based on a 3 percent discount rate.

The quantifiable and monetary benefits of implementing the rule were also estimated for the same categories presented above. For sanitary surveys alone, the cost benefit is estimated at $33 million, which is less than the cost of implementation. When monitoring is triggered, the cost benefits increase to $178 million, which exceeds the cost of implementation by about $20 million. Similarly, the cost benefits of multi-barriers (sanitary survey, hydrogeologic assessment, and triggered monitoring) is $205 million, which exceeds the cost of implementation for the same. When disinfection is installed across-the-board, the cost benefit is $283 million, which is nearly $500 million less than the cost of implementation.

Health Risks

Fecal contamination can enter the groundwater via the following routes.

- Fecal contamination reaches groundwater from failed septic systems, leaking sewer lines, and surface water infiltration.
- Surface water with fecal contamination may enter a drinking water well along the casing or through cracks in the sanitary seal if the well is not properly constructed, protected, and/or maintained.
- In a distribution system when cross connections fail or when negative pressure occurs in a leaking pipe, infiltration into the distribution system may occur.

Once fecal contamination has entered a groundwater system, biofilm on the interior walls of pipes provides an environment for bacterial and viral pathogens to survive (EPA, 2000). Fecal contamination exists as either viral or bacterial pathogens and is responsible for causing a number of illnesses. Viral pathogens cannot reproduce or proliferate without a host cell. However, once a virus has infected a human, reproduction is possible. On the other hand, bacterial pathogens can reproduce in the biofilm of groundwater systems and can survive outside of a host cell. Illnesses caused by viral and bacterial pathogens are presented in Tables 1-10 and 1-11.

TABLE 1-10
Examples of Illnesses Caused by Viral Pathogens

Enteric Virus	Illnesses
Poliovirus	Paralysis
Coxsackievirus A	Meningitis, fever, respiratory disease
Coxsackievirus B	Myocarditis, congenital heart disease, rash, fever, meningitis, encephalitis, pleurodynia, diabetes melitis, eye infections
Echovirus	Meningitis, encephalitis, rash, fever, gastroenteritis
Norwalk virus and other caliciviruses	Gastroenteritis

TABLE 1-10
Examples of Illnesses Caused by Viral Pathogens

Enteric Virus	Illnesses
Hepatitis A virus	Hepatitis
Hepatitis E virus	Hepatitis
Small round structured viruses (probably caliciviruses)	Gastroenteritis
Rotavirus	Gastroenteritis
Enteric Adenovirus	Respiratory disease, eye infections, gastroenteritis
Astrovirus	Gastroenteritis

TABLE 1-11
Examples of Illnesses Caused by Bacterial Pathogens

Bacterial Pathogen	Illnesses
Campylobacter jejuni	Gastroenteritis, meningitis, associated with reactive arthritis and Guillain-Barre paralysis
Shigella species	Gastroenteritis, dysentery, hemolytic uremic syndrome, convulsions in young children, associated with Reiters Disease (reactive arthropathy)
Salmonella species	Gastroenteritis, septicemia, anorexia, arthritis, cholecystitis, meningitis, pericarditis, pneumonia, typhoid fever
Vibrio cholerae	Cholera (dehydration and kidney failure)
Escherichia coli (several species)	Gastroenteritis, hemolytic uremic syndrome (kidney failure)
Yersinia entercolitica	Gastroenteritis, acute mesenteric lymphadenitis, joint pain
Legionella species	Legionnaires Disease, Pontiac Fever

For the GWR, EPA provided estimates of the number of illnesses associated with viral pathogens in groundwater. The estimates were performed for Type A and Type B viruses. Type A represents viruses that are highly effective, but cause mild symptoms, while Type B represents viruses that are less effective, but cause more severe symptoms. As risks of bacterial pathogens are not directly quantifiable due to insufficient data, EPA adjusted risk estimates for viruses to include the approximate risk of bacterial illness. EPA estimates over 1.5 million people are exposed to Type A viral contamination and over 1.7 million people to Type B contamination annually in the US. These estimates are based on the number of water

systems not providing disinfection. Specifically, only 68 percent of CWSs disinfect and 28 percent of NTNCWS disinfect. Additionally, 18 percent of TNCWS practice disinfection.

Rates of mortality due to viral illnesses caused by contamination of public groundwater systems are shown in Table 1-12, as provided in the GWR. Also presented in this table are estimates of the number of illnesses caused by viral pathogen contamination.

TABLE 1-12
Number of Illnesses and Deaths Caused by Viral Contamination of Drinking Water

Cause of contamination	Type A		Type B		Total (Type A + B)	
	Illnesses	Deaths	Illnesses	Deaths	Illnesses	Deaths
Source Contamination of Undisinfected System	78,000	1	20,000	8	98,000	9
Source Contamination of Disinfected System	34,000	-	8,000	4	42,000	4
Distribution System Contamination	22,000	-	6,000	3	28,000	3
All Causes	134,000	1	34,000	14	168,000	16

Bacterial contamination may increase the above risks by approximately 20 percent (EPA, 2000). As such, the GWR estimates about 34,000 additional illnesses and three additional deaths may be caused by bacterial contamination.

SECTION 2

Existing Water Quality Data

This section presents the existing water quality and production data currently available for drinking water wells in the City's and OU's water systems. Current and future arsenic standards, which are enforced by the EPA, were discussed in Section 1, Background on Arsenic and GWR.

Compiling and evaluating existing City and OU well data will allow data gaps to be identified and subsequently filled through field sampling and well analysis. The data presented in this Study will assist the City and OU in determining how the new arsenic standard will impact their water supply systems. Currently, City Well Nos. 23, 24, and 25 have been removed from service because the water produced exceeds the current EPA arsenic standard. When the AR becomes final, more of the City's wells, along with all of OU's wells, will be out of compliance and will require treatment for continued utilization.

Section 2 is divided into the areas of: Well Production Capacities, which presents well capacity data for the City and OU wells; and Water Quality, which summarizes available water quality data and discusses arsenic concentration sampling results. Also discussed are suggested sampling methods to acquire additional data needed for the treatment facility design.

Well Production Capacities

This Study considers 43 groundwater wells that are currently or have been used for drinking water supply wells (see Figure 2-1). All 43 wells withdraw groundwater from the GWA, which was discussed in Section 1. The City has 32 drinking water wells. Twenty-nine of the City's wells are currently in operation and three are not in operation due to arsenic levels above the current standard. The City's 32 wells are mostly bound by Lindsey Street, 36th Avenue West, 36th Avenue East, and Indian Hills Road, although a few lie outside of this area. OU has 11 drinking water wells located primarily between Robinson Street and Tecumseh Road along and west of U.S. Highway 77. The geographic locations of the City's and OU's water wells are plotted on Figure 2-1.

Average production capacity data for most of the wells was provided by City and OU staff and was based on historical operational production rates over several years. Average capacities are considered by the City and OU to be average-annual production rates over several years of operation; however, a well may produce more or less than that shown depending on the groundwater level variations and conditions of the aquifer. Additionally, when evaluating treatment scenarios for these wells, the maximum capacity of each well should be considered as the treatment design capacity. This ensures well production is not limited by treatment capacity. According to City and OU records and staff comments, the average- and maximum-flow capacity for each well is listed in Table 2-1.

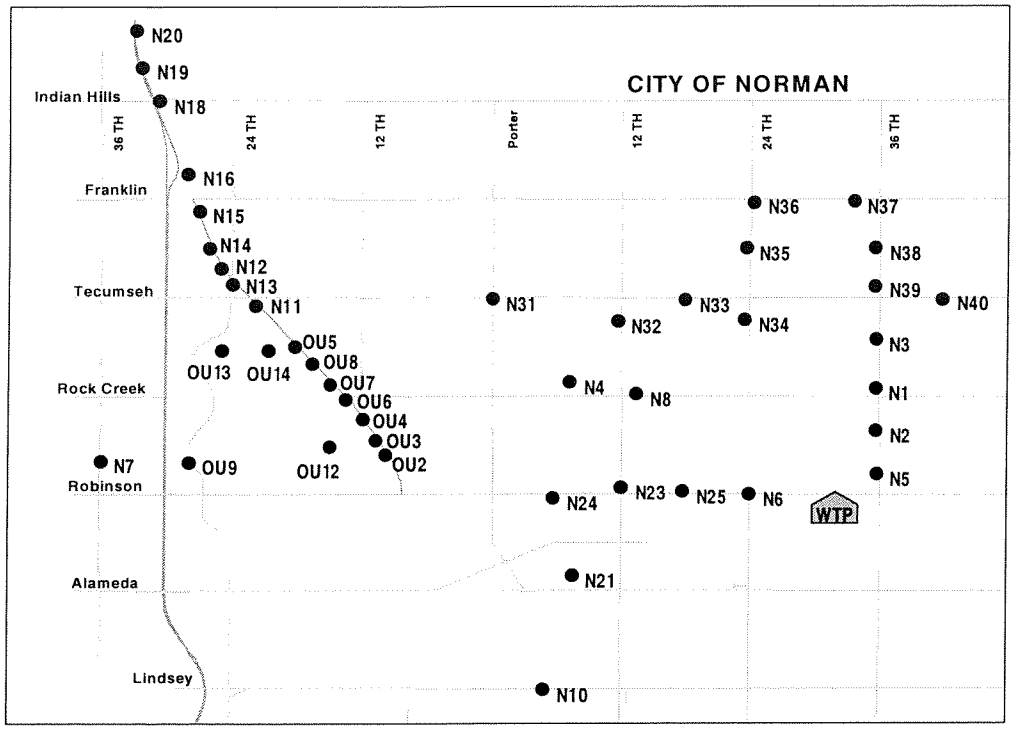

FIGURE 2-1
Drinking Water Well Map
City of Norman (N) and University of Oklahoma (OU) Wells

Based on the average capacities shown in Table 2-1, the City has a total production capacity of about 5,600 gallons per minute (gpm) or 8.1 million gallons per day (mgd), including the wells currently closed. OU has a total production capacity of 1,570 gpm or 2.2 mgd. Together, the City and OU can produce approximately 10.3 mgd, which is an average production rate per well of about 170 gpm. However, excluding the closed City Wells N23, N24, and N25, the total production capacity of both systems is 9.8 mgd.

TABLE 2-1
Average and Maximum Groundwater Well Capacities
City of Norman and University of Oklahoma Wells

Water Well[a]	Average Capacity (gpm)	Maximum Capacity[c] (gpm)	Water Well[a]	Average Capacity (gpm)	Maximum Capacity[c] (gpm)	Water Well[b]	Average Capacity (gpm)	Maximum Capacity[d] (gpm)
N1	245	307	N19	162	244	OU2	110	125
N2	110	335	N20	125	174	OU3	120	200
N3	180	278	N21	150	184	OU4	140	150
N4	160	215	N23	174	300	OU5	190	220
N5	186	248	N24	100	100	OU6	160	200
N6	210	286	N25	100	100	OU7	120	160
N7	160	212	N31	208	208	OU8	180	200

TABLE 2-1
Average and Maximum Groundwater Well Capacities
City of Norman and University of Oklahoma Wells

Water Well[a]	Average Capacity (gpm)	Maximum Capacity[c] (gpm)	Water Well[a]	Average Capacity (gpm)	Maximum Capacity[c] (gpm)	Water Well[b]	Average Capacity (gpm)	Maximum Capacity[d] (gpm)
N8	220	257	N32	190	274	OU9	120	165
N10	122	130	N33	300	300	OU12	160	200
N11	110	144	N34	306	306	OU13	120	160
N12	141	193	N35	190	190	OU14	150	160
N13	133	133	N36	230	230			
N14	108	182	N37	240	263			
N15	125	164	N38	225	250			
N16	140	140	N39	207	245			
N18	143	228	N40	216	255			

Notes:
[a] City of Norman Wells identified by "N."
[b] University of Oklahoma wells identified by "OU."
[c] Based on City of Norman operational well data logs between July 5, 2000 and July 4, 2001 and City staff comments.
[d] Based on OU operational well data logs between 1996 and 2001.

As mentioned previously, pumping rates are constantly changing with the dynamic characteristics of the aquifer, including well interference, lowering of the static water level, and decreasing pressure. In addition, prolonged pumping at maximum well capacity cannot be sustained by the aquifer as interference may become a problem due to the close proximity of the individual well sites, particularly applicable to OU's wells and Norman's northwest area wells.

The maximum capacities of the City wells based on City staff comments, and, in many cases, are equal to the average capacity of the well. This could be due to aquifer limitations, flow meter problems, or the age and condition of the wells. Also based on City staff comments regarding well condition and production, Wells N4, N10, and N25 have low flow and/or multiple pumping problems. Additionally, the close proximity and continued pumping of the City's northwest area wells have created a lowering of the water table level in the area, and closing some of these wells may be beneficial to the system. According to City staff comments, Well N21 is seldom used as residents of nearby neighborhoods complain of taste and odor. Pumps have recently been replaced in Wells N1, N2, and N3, and will most likely produce more than the average capacity shown in Table 2-1. However, for the purpose of this Study, the well flows presented are appropriate for an overall consideration of the City and OU's groundwater supply.

Water Quality

Table 2-2 provides a water quality summary of reviewed City and OU sampling data. Based on the water quality summary, the groundwater withdrawn from the GWA is a high-quality water. The groundwater can be classified as soft to hard water, according to the reported levels of hardness ranging from 47 to 220 milligrams per liter (mg/L) as calcium carbonate ($CaCO_3$). In addition, as the level of total dissolved solids (TDS) present in the water is less than 1,000 mg/L, the groundwater is classified as fresh. Historically, the groundwater has not required treatment or disinfection prior to distribution. However, the new AR will leave many of these wells out of compliance and treatment or blending will be required for continued operation. Additional support data for water quality is provided in Appendix B.

Arsenic Concentration in Groundwater

Arsenic sampling data results were obtained from City and OU records. While the City's arsenic sampling occurred between 1984 and 2001, OU arsenic sampling occurred in 2000 and 2001. Based on review of available data, the arsenic testing was performed using EPA test methods 200.7, 200.8, and 200.9. The PQL varied among samples depending on sample dilution and among sampling dates. The PQL is based on the maximum detection limit (MDL) for a given method. Typically, the PQL for the arsenic testing performed for the City and OU groundwater wells ranged between 0.33 to 7 µg/L.

The arsenic concentrations observed in the City and OU well systems show a significant variation ranging between 0.83 and 231 µg/L. As indicated in Section 1, this is most likely due to the wide variations in the geologic layers of the GWA. Additionally, as observed in City Wells N31 through N40, the lower than typical average arsenic level can be contributed to the City's zonal isolation construction method of closing intervals having elevated levels of arsenic. Presented on Figure 2-2 is a graphic summary of the average arsenic concentrations in the City and OU wells.

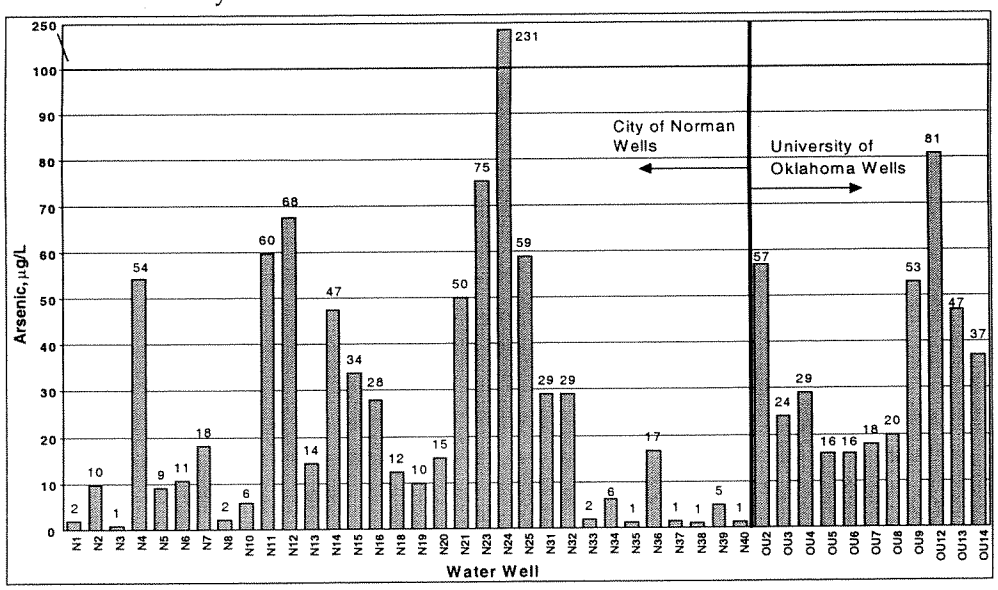

FIGURE 2-2
Average Arsenic Concentrations in Drinking Water Wells
City Well Data: Since 1984. OU Well Data: Since 2000

TABLE 2-2
City of Norman and University of Oklahoma Groundwater Quality Summary

Well	Arsenic, µg/L[d]	pH	Total Alkalinity	Total Hardness	Calcium Hardness	Total Dissolved Solids (TDS)	Phenols	Barium	Chromium	Iron	Manganese	Selenium	Sulfate	Chloride	Flouride	Nitrate-Nitrite
	[d]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
	µg/L		mg/L	mg/L	mg/L	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Current Standard	10[l]	6.5-8.5 [f]	[c]	[c]	[c]	500 [f]	[c]	2 [e]	0.1[e]	0.3[f]	0.05[f]	0.05 [e]	250[f]	250[f]	2[f]	10[e]
N1	2	8.1	239.9	134.5	51.5											
N2	10	8.1	239.3	89.7	43.8			0.17	0.08			0.02			0.67	0.21
N3	1	8.0	246.0	106.6	60.9			0.19	0.07						0.42	0.37
N4	54	8.5	191.4	95.1	32.2		<0.001	0.14	0.07	0.12	0.01	0.02	21.8	30.5	0.63	0.45
N5	9	7.9	291.2	78.6	28.2			0.25	0.07						0.70	0.27
N6	11	8.3	314	85	33	370	<0.001	0.43	0.03	0.06	0.20	0.01	18	49	0.32	0.20
N7	18	8.4	191	62	32		<0.001	0.06	0.01	0.05	<0.01	0.03	44	10	0.70	0.18
N8	2	8.2	242	104	49	240	<0.001	0.24	0.02	0.05	0.04		25	13	0.27	0.44
N10	6															
N11	60	8.5	186	92	33	240	<0.001	0.13	0.03	0.04	0.02	0.01	18	12	0.95	0.30
N12	68	8.3	327	72	27		<0.001			0.04	0.02		7			
N13	14	7.8	256	135	46											
N14	47	8.3	258	107	32			0.13	0.04			0.02			0.90	0.44
N15	34	8.2	241	116	66			0.23	0.03						0.26	0.50
N16	28	8.5	258	66	39	290	<0.001	0.10	0.02	0.07	0.02	0.02	14	12	0.27	0.53
N18	12	8.5	269	49	22	290	<0.001	0.07		0.06	<0.02	0.01	19	12	0.20	0.60
N19	10	8.2	206	62	40		<0.001	0.34	0.01	0.34	0.02		15	16	0.15	0.64
N20	15	8.1	79	78	51		<0.001	0.98		0.06	<0.01		11	8	0.73	0.62
N21	50	8.2	115	73	41		<0.001	0.35		0.08	0.01		12	18	0.84	0.50
N23	75	8.2	283	47	15		<0.001	0.06	0.03	0.08	0.03	0.02	60	29	0.78	0.30
N24	231	8.4	145	78	30		<0.001			0.04	0.01		121	40	0.58	
N25	59	8.3	223	71	36		<0.001		0.03	0.15	0.01	<0.01	15			
[h]																
N31[g]	29	8.5	264	76		364		0.32	0.08	15.80	0.20	<.05	15	21	0.43	0.65
N32[g]	29	8.4	307	61		440		0.19	0.09	8.50	0.10	<.05	18	13	0.54	0.72
N33[g]	2	8.7	297	78		368		0.23	0.1	4.8	0.1	<.08	23	20	0.51	0.63
N34[g]	6	8.8	309	60		365		0.14	0.1	0.85	<0.02	<.07	14	23	0.87	0.7
N35[g]	1	8.7	309	62		400		0.19	0.08	3.7	<.09	<.05	22	31	1.2	0.58
N36[g]	17	8	224	121		242		0.2	0.06	<0.05	<.02	<.05	14	80	0.73	0.3
N37[g]	1	8	223	117		277		0.25	0.05	<0.05	<.02	<.05	16	73	0.4	.<.14
N38[g]	1	8.2	235	180		290		0.26	0.03	<0.05	<.02	<.05	36	19	0.64	0.36
N39[g]	5	8.4	225	89		273		0.18	0.06	<0.05	<.02	<.05	26	14	0.61	0.32
N40[g]	1	8.2	242	220		363		0.21	0.04	<0.05	<.02	<.05	62	20	0.44	0.31
[k]	[j]								[j]			[j]				
OU2	57								0.027			0.019				
OU3	24								0.034			<.01				
OU4	29								0.039			0.013				
OU5	16															
OU6	16								0.037			<.01				
OU7	18															
OU8	20															
OU9	53								0.016			0.021				
OU12	81								0.022			0.011				
OU13	47															
OU14	37															

Notes:

[a] Average of samples from Jan 93 - Jun 98.
[c] No regulatory limit
[d] Arsenic averages were provided by City staff and are based on 1984 to 2001 dat
See Appendix B for support data.
[e] Primary standard.
[f] Secondary standard.
[g] Interval data available.
[i] Based on samples taken during February and March, 2001
[j] Based on samples tested during March 2001
[k] According to OU staff comments, OU is expanding their sampling efforts to include a wider range of test paramet
[l] Compliance with AR is required by January 2006 for water system requiring arsenic treatment; otherwise, compliance is required by January 2004.

The data averages presented above are based on all available data for both systems and, for the City, may extend back to 1984. However, determining compliance with the current arsenic MCL is based on a running quarterly annual average of the most recent year's data at the POE into the distribution system. Hence, while averages of operating wells N4, N11, and N12 exceed the current MCL of 50 µg/L, well compliance data is based on only the latest year's data. In addition, where blending is occurring prior to the POE and the arsenic concentration in the combined flow is less than the MCL, compliance is achieved, which is the case with OU wells. As mentioned previously, the only wells currently closed due to non-compliance are N23, N24, and N25.

Considering both City and OU wells, Well N24 has the greatest arsenic concentration. The greatest concentration of arsenic in OU wells is found in Well OU12. Notably, no wells have zero arsenic concentration, which indicates that arsenic is an inherent mineral of the GWA in the City and OU study area.

For the City's wells, some variation exists among sampling events for each well. To illustrate the variation of arsenic data for a given well, Figure 2-3 presents the standard deviations from the average arsenic concentration of each well. Notably, the wider the standard deviation, the greater the variance for a particular well. Arsenic data provided by OU is in limited quantity and is not included in the following figure.

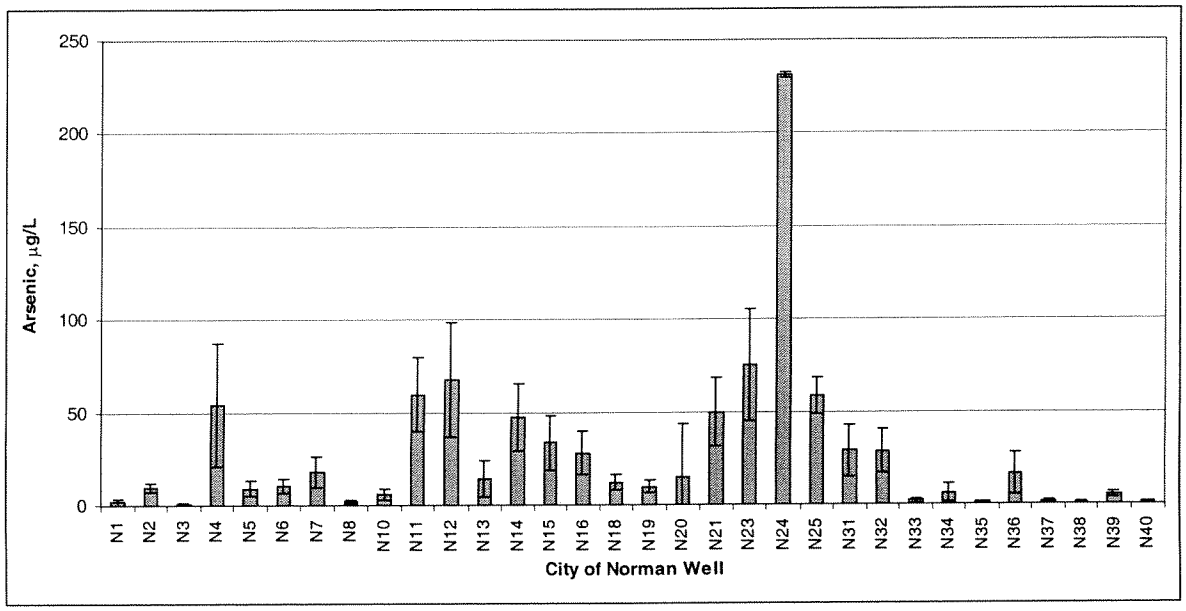

FIGURE 2-3
Arsenic Data Standard Deviations
City of Norman Drinking Water Wells

For further analysis of the City and OU water systems, the average arsenic concentration of each system and the combined systems has been determined. Although the City and OU water systems operate independently of each other, combining their system averages provides an indication of the average arsenic concentration in the groundwater of the local study area. Additionally, although the average of each system is not necessarily representative of actual arsenic concentrations found in the distribution system, the average

provides an indication of the overall level of arsenic contamination in each groundwater system, as a whole. Figure 2-4 illustrates the average arsenic concentration in the City and OU groundwater systems.

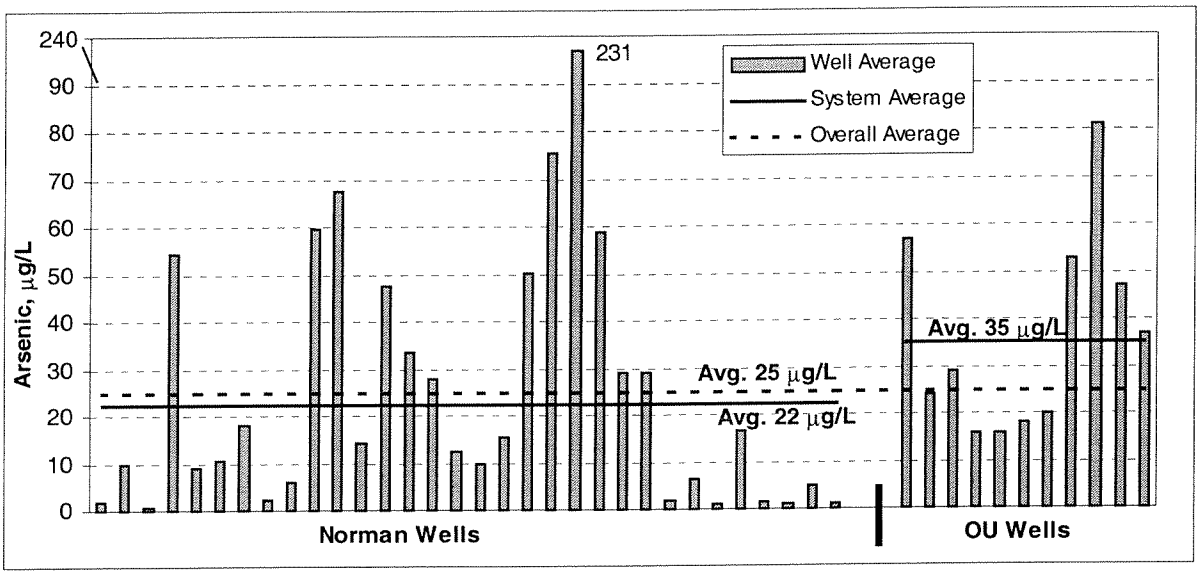

FIGURE 2-4
System Average Arsenic Concentrations
City and OU Groundwater Systems

As indicated, the City's average arsenic concentration is 22 µg/L, and OU's average arsenic concentration is 35 µg/L. The overall average of both the City and OU systems is 25 µg/L. As previously mentioned, depending on the geographic location within the water distribution system, the actual arsenic concentration can vary significantly from that shown on Figure 2-4. Another factor affecting the actual arsenic concentration in the City's water distribution system is the blended ratio of groundwater to surface water, as the City uses both to meet water demands. OU, however, relies solely on groundwater.

At the arsenic MCL of 10 µg/L, not all of the wells will be affected by the proposed AR. Although all of OU's wells are affected, only 20 of the City's wells are affected. Figure 2-5 illustrates which wells are affected. This figure is based on an average of all available data, rather than the running quarterly average data. According to the AR, quarterly sampling will be required only for those wells having an arsenic concentration above the MCL.

Overall, of the 31 affected wells in both systems (20 for the City; 11 for OU), the average arsenic concentration is 38 µg/L.

Based on the locations and arsenic concentrations of the affected wells, multiple treatment and blending scenarios can be developed to meet the proposed MCL of 10 µg/L. Not only does grouping the wells provide an example of possible treatment and blending scenarios, but grouping also provides a better indication of arsenic concentrations in different areas of the City's distribution system. To provide examples, the wells were grouped into geographic locations and their arsenic concentrations were averaged on a weighted basis. Based on distribution system maps, two affected wells, N2 and N36, have the potential to be blended in order to meet the 10 µg/L arsenic MCL, as shown on Figure 2-6.

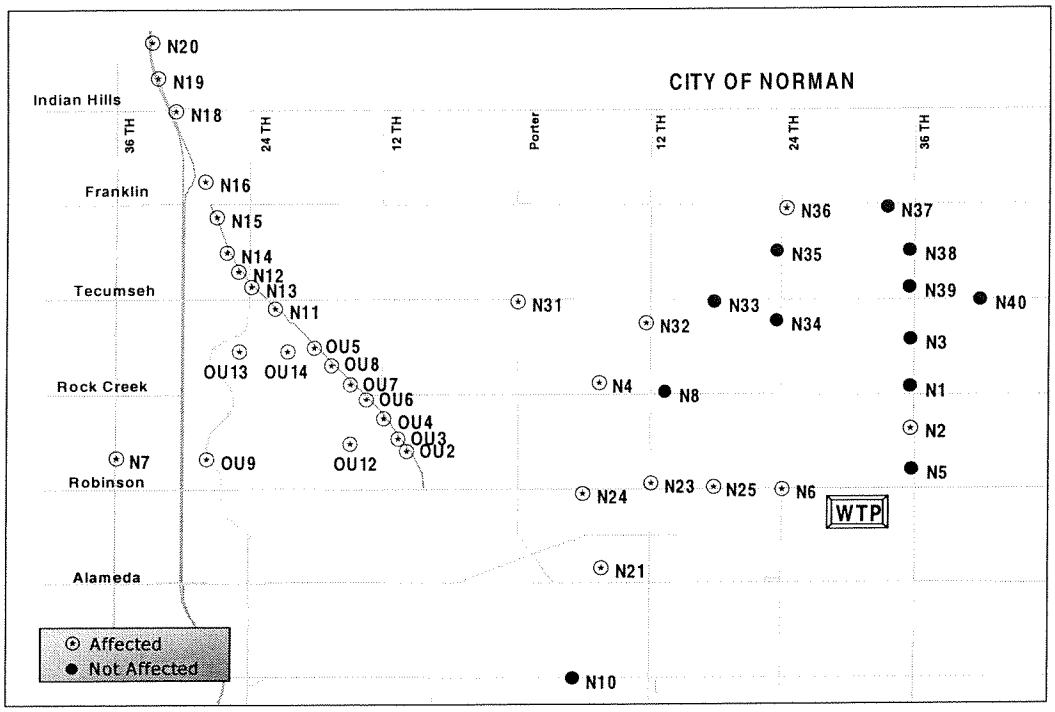

FIGURE 2-5
Wells Affected by 10 µg/L Arsenic Standard
City of Norman and OU Groundwater Systems

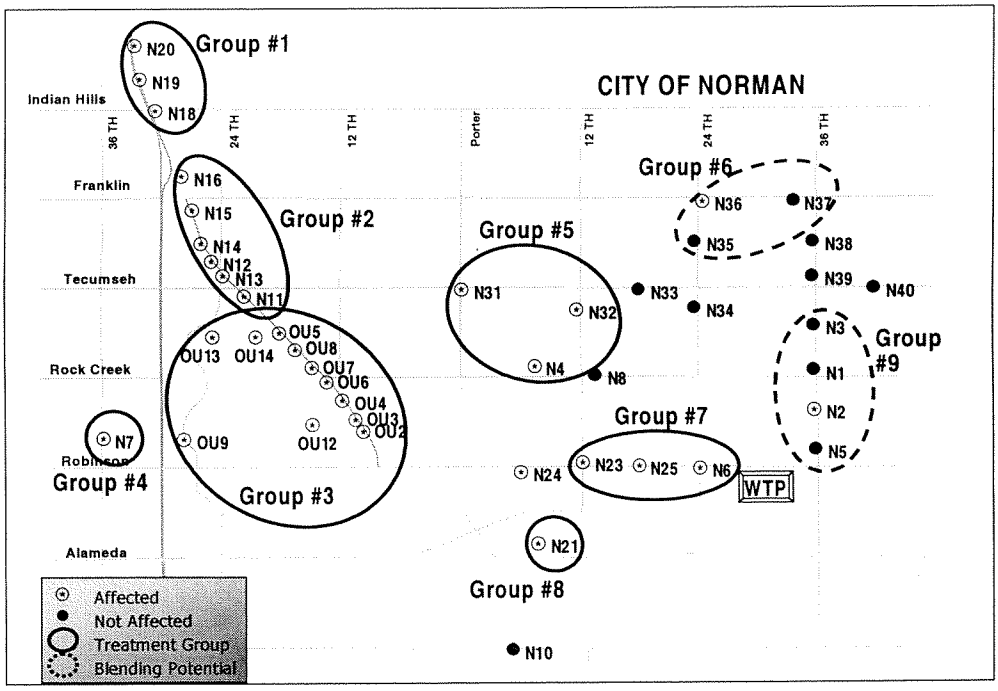

FIGURE 2-6
Groundwater Wells Groups
Multiple Well Treatment Scenarios

Figure 2-6 depicts one possible arrangement of groundwater wells for the purpose of multiple well treatment and blending. However, only one grouping scenario out of many is presented, and multiple grouping options are available to the City and OU. However, for the purpose of this Study, the grouping scenario presented above will be adopted. Well N24 has been removed from the groups as its lower-than-average flow and much higher-than-average arsenic concentration will most likely provide adequate reason to permanently close and decommission the well. However, N23 and N25, which are currently closed, are included in the groups.

As Figure 2-6 indicates, Groups 6 and 9 have the potential to be blended so that compliance may be achieved. Groups 1 through 5, 7, and 8 have the potential for individual wells to be conveyed to a common treatment facility for each group based on the close proximity of the wells. Although Wells N7 and OU9 could utilize a common treatment facility based on their close proximity, this example maintains separation of City and OU water systems. Another option might include conveying groundwater to the water treatment plant (WTP) for clearwell blending prior to distribution. The weighted arsenic concentration and combined average and maximum capacities for each group are indicated below in Table 2-3.

TABLE 2-3
Group Weighted Arsenic Concentrations
Maximum and Average Capacities

Well Group	Maximum Flow		Average Flow	
	Capacity (gpm)	Arsenic (µg/L)	Capacity (gpm)	Arsenic (µg/L)
1	646	12.25	430	12.32
2	956	43.55	757	41.30
3	1,940	35.19	1,570	35.08
4	212	18.16	160	18.16
5	697	36.84	558	36.30
6	683	6.52	660	6.69
7	686	45.95	484	43.85
8	184	50.06	150	50.06
9	1,168	5.45	721	4.71

As indicated above, Groups 6 and 9, if blended prior to distribution entry, can meet the proposed arsenic MCL of 10 µg/L with all wells pumping. However, to be sure of this, sampling at the POE into the distribution system should be performed when each well is operating. This is discussed further under the heading Additional Water Quality Data Needs. For the groups requiring treatment, the highest blended arsenic concentration based on average flows is 50.06 µg/L in Group 8 wells, while the lowest is 12.32 µg/L in Group 1. However, these grouped arsenic concentrations, though more accurate than the

overall system average, can vary significantly based on which wells of a group are operating and the ratio of groundwater to surface water in that geographic area of the distribution system. As mentioned previously, these groups are only one scenario of many possible scenarios. Section 4, Alternatives Development and Evaluation, provides further evaluation of grouping plans.

Often, environmental groundwater studies pertaining to contaminant concentrations include isopleth mapping for delineation of plume area. This allows for identification of higher and lower concentrated areas and plume dissipation, where applicable. For the City and OU study area, this same isopleth mapping concept can be used to identify the areas where the concentration of arsenic tends to be greatest and least according to available data. Based on the arsenic concentrations provided on previous figures, the following isopleth map, Figure 2-7, depicts the *rough* arsenic concentration contours in the City and OU study area. The contours are plotted for 5, 10, 20, 50, and 70 µg/L.

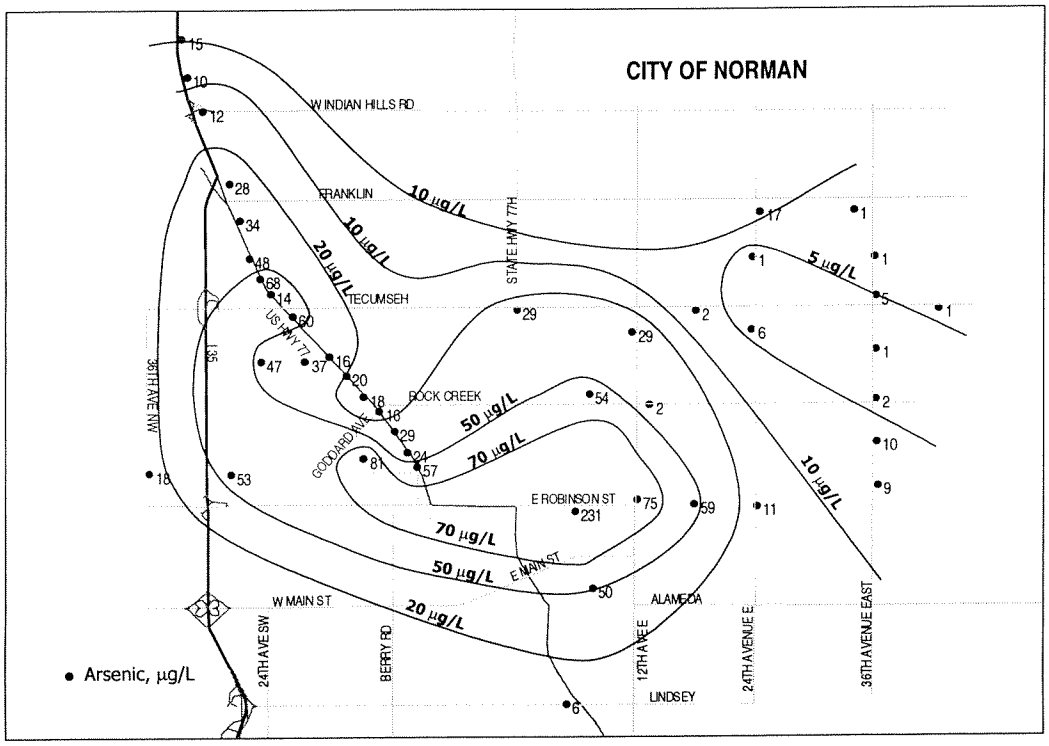

FIGURE 2-7
Arsenic Isopleth Map
City of Norman and University of Oklahoma Study Area

Even with limited well data in some geographic locations, the isopleth map provides an indication of high and low arsenic concentration areas. According to the map, the arsenic concentration tends to be least in the northeastern areas of the study area. In the south central area, the concentrations tend to be greater reaching a high of 231 µg/L in Well N24.

City staff has indicated that previous groundwater studies in the Norman area have introduced similar observations regarding the arsenic concentrations in the local study area. Specifically, wells constructed in the east area may have lower arsenic concentrations than do those in the west. During the past ten years, the City has acted on this notion and has

employed wellfield expansion, with zonal isolation construction methods, in the northeastern areas. Notably, some of the arsenic concentrations in the northeast area of Figure 2-7 are based on sample results from wells that have zonal isolation. Hence, the lower arsenic levels are partly contributable to the City's strategic method of construction. Additionally, the lower arsenic levels in the east and northeast areas may also be contributable to the unconfined nature of the GWA allowing a greater amount of recharge to infiltrate.

Additional Water Quality Data Needs

Although the data sampling suggested in this section will be needed during the treatment facility design phase, it is not needed to complete this conceptual study. Averages of existing data can be used to obtain adequate information for treatment technology review and evaluation.

Upon review of the water quality data available for the City and OU groundwater wells, additional sampling needs were identified. The success of certain arsenic removal technologies is based, in part, on various water quality parameters. As such, analysis of total arsenic, arsenic(III), phosphate, silica and pH is suggested for each groundwater well in the City's and OU's water systems. Additionally, OU's groundwater well sampling should include, at a minimum, analysis of alkalinity, iron, manganese, and sulfate. However, if possible, other OU groundwater well testing that will prove beneficial is total hardness, calcium hardness, TDS, barium, chloride, fluoride, and nitrate as nitrogen.

For phosphate, EPA Test Method 365.1 should be used as this method can detect lower concentrations than other methods. For arsenic speciation, the following paragraphs define the suggested method. For the remaining parameters, EPA-approved standard laboratory methods should be followed.

Arsenic Speciation

The oxidation state of the arsenic in groundwater has an impact on the ability of an arsenic treatment system to function effectively. The reduced form of arsenic(III) is more difficult to remove than arsenic(V). If high concentrations of arsenic(III) are found, then an oxidation step will be necessary in the treatment process to oxidize to arsenic(V). Arsenic(V) and arsenic(III) data are not available for City or OU wells.

Arsenic needs to be speciated at the site of sample collection. Arsenic(III) will easily oxidize to Arsenic(V) after the sample is taken. As such, sample speciation should occur at the well site immediately after sample collection. Speciation can be achieved with an Empore filter manufactured by 3M which is impregnated with ion exchange resin and will remove the Arsenic(V) while letting the Arsenic(III) pass through. The Empore filter and other sampling apparatus used for arsenic speciation can be purchased from Fisher Scientific.

Distribution System Sampling

There are certain wells that have been identified as possible candidates for blending in order to comply with the proposed arsenic standard of 10 μg/L. From a review of distribution maps, the proposed blended groups appear to be blended prior to any service connections.

Figure 2-8 indicates proposed locations for the needed distribution blending analysis. For each group, all wells should be in operation when blended samples are taken.

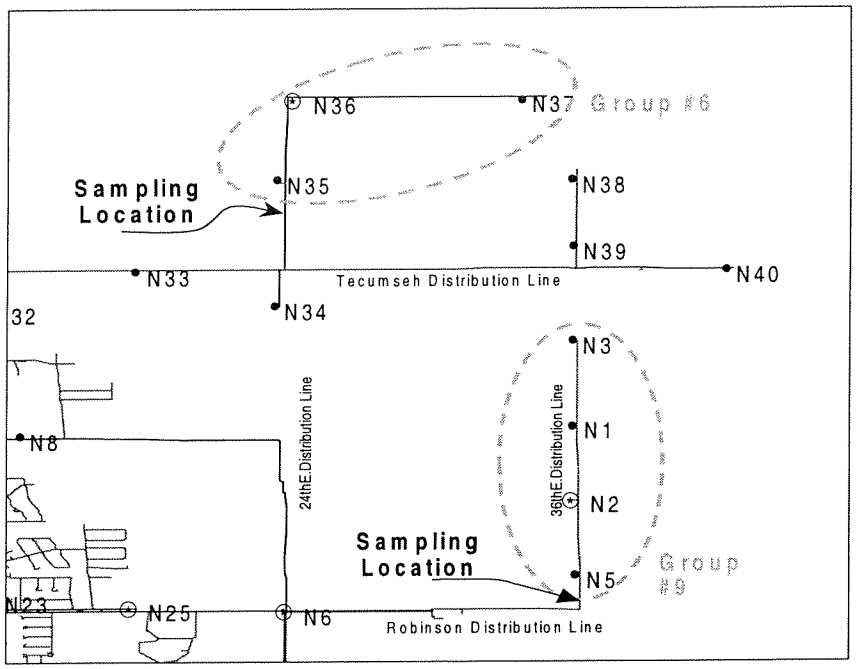

FIGURE 2-8
POE Sampling Needs

At the locations identified on Figure 2-8, analysis of total arsenic and arsenic speciation should occur in order to verify that the combined arsenic concentration of the grouped wells is below the proposed arsenic MCL.

SECTION 3

Arsenic Source Control

As documented in Section 2, Existing Water Quality Data, the City and OU have 43 drinking water wells. Currently, 3 of the 43 groundwater wells are not operating due to arsenic concentrations exceeding the current standard of 50 µg/L. Of the 40 wells currently in operation, several produce water with arsenic concentrations greater than 10 µg/L. The continued operation of these wells will need to be evaluated in light of the forthcoming AR. To comply with the new AR and avoid treatment, additional wells may need to be abandoned or altered to comply with the lower standard. The purpose of this section is to discuss the feasibility of source control, including well abandonment and zonal isolation, to reduce the levels of arsenic concentrations in water produced from existing wells.

Estimations of the costs and losses in production associated with source control are based on very limited data and are subject to a high degree of uncertainty. Prior to undertaking either option, additional data should be gathered and analyzed.

Existing Well Completion

Completion data was reviewed for 31 of the 43 drinking water wells. A summary of the information is found in Table 3-1. Of the 31 wells reviewed, 26 have been completed by cementing the casing and perforating at the desired depths, which eliminates the potential for fluid migration in the annulus outside the well casing. For this analysis, only City wells with completion records in the files were reviewed. Although not complete, the data is sufficient to make general conclusions related to abandonment and zonal isolation of the wells. Louvered and slotted screens with a gravel-packed annulus were used on five of the wells reviewed. These wells are also only completed over small, discrete intervals. However, the existence of a continuous gravel pack in the well annulus prevents total isolation of the zones. Best results would be obtained by limiting isolation treatments to the perforated completions.

TABLE 3-1
Existing Well Completion Data

City of Norman Well ID	Completion	Total Depth (ft)	Total Number of Intervals	Total Length of Intervals (ft)	Average Length of Interval (ft)	Average Interval Separation
N1	Screened	694	13	215	16.5	16.7
N2	Screened	638	15	201	13.4	13.6
N3	Screened			Incomplete Data		
N4	Perforated	707	15	284	18.9	13.1
N5	Perforated	697	8	158	19.7	24.7
N6	Perforated	652	5	124	24.8	44.5
N7	Perforated	756	13	105	8.1	20.4
N8	Perforated	592	5	118	23.6	17.5

TABLE 3-1
Existing Well Completion Data

City of Norman Well ID	Completion	Total Depth (ft)	Total Number of Intervals	Total Length of Intervals (ft)	Average Length of Interval (ft)	Average Interval Separation
N10	Screened			Incomplete Data		
N11	Perforated			Incomplete Data		
N12	Perforated	675	11	193	17.6	15.1
N13	Perforated	634	7	138	19.7	13.3
N14	Perforated	675		Incomplete Data		
N15	Perforated	674	18	217	12.1	11.9
N16	Perforated	682	9	185	20.6	21.5
N18	Perforated	697	14	193	13.8	18.3
N19	Perforated	692	21	192	9.1	9.4
N20	Perforated	704	12	158	13.2	22.2
N21	Perforated	640	13	185	14.2	16.9
N23	Cement and Perforated	638	11	130	11.8	13.4
N24	Incomplete Data	609		Incomplete Data		
N25	Cement and Perforated	624		Incomplete Data		
N31	Perforated	660	6	164	27.3	46.0
N32	Perforated	630	9	144	16.0	37.2
N33	Perforated	655	5	170	34.0	22.5
N34	Perforated	625	9	180	20.0	19.5
N35	Perforated	530	3	116	38.7	58.0
N36	Perforated	710	7	148	21.1	29.7
N37	Perforated	710	8	192	24.0	21.0
N38	Screened	698	11	154	14.0	22.8
N39	Perforated	705	8	128	16.0	24.4
N40	Perforated	707	6	162	27.0	33.8
Average Values		**665.86**	**10.08**	**167.46**	**19.05**	**23.37**

Well Abandonment

The first option considered for source control was well abandonment. Permanent abandonment of wells producing groundwater with concentrations of arsenic above the 10 μg/L MCL will result in significant losses to system capacity. The wells targeted for abandonment should be evaluated individually. In some situations, additional production may be obtained from existing nearby wells with superior water quality. However, this production may be limited by pump sizes, well efficiency, and aquifer characteristics. Figure 3-1 illustrates which wells would be abandoned if the 10 μg/L arsenic standard is adopted.

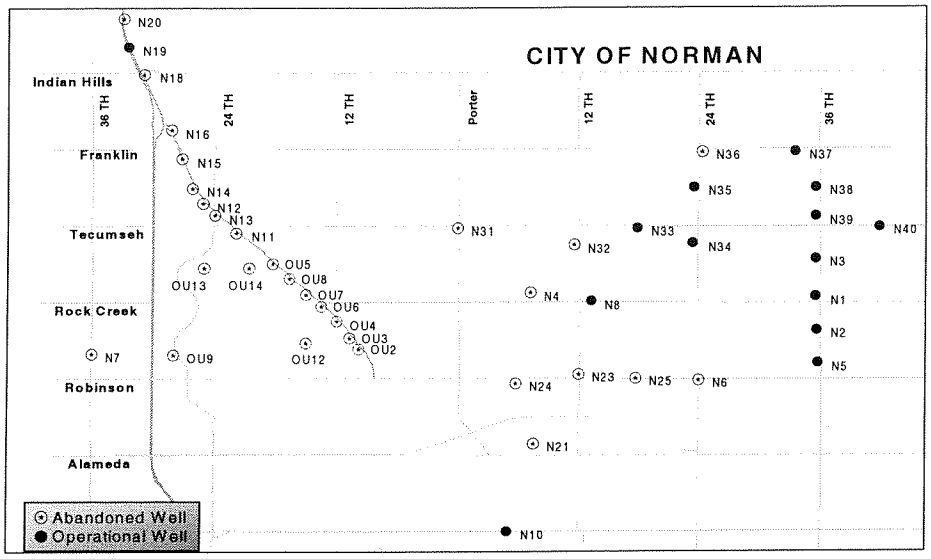

FIGURE 3-1
Location Map of Wells Considered for Abandonment
Based on 10 μg/L Arsenic MCL Exceedence

In general, the figure shows that most of the abandoned wells exist in the western portion of the wellfield. Note that all of OU's 11 wells are abandoned. In addition, due to the widely variable arsenic data, Wells N2 and N19 (having average arsenic concentrations of 10 μg/L) are considered to be affected by the AR for the purpose of this Study although they are in compliance with an arsenic MCL. However, they are not considered for abandonment because there is the possibility of maintaining AR compliance without well closure. Table 3-2 provides an estimate of the impact on total production assuming wells with average arsenic concentrations above 10 μg/L are abandoned.

TABLE 3-2
Groundwater Well Abandonment
Based on Arsenic > 10μg/L

Well	Arsenic (μg/L)	Average Capacity (gpm)	Abandon Well	Remaining Flow (gpm)
N1	2	245		245
N2	10	110		110
N3	1	180		180
N4	54	160	X	0
N5	9	186		186
N6	11	210	X	0
N7	18	160	X	0
N8	2	220		220
N10	6	122		122
N11	60	110	X	0

TABLE 3-2
Groundwater Well Abandonment
Based on Arsenic > 10μg/L

Well	Arsenic (μg/L)	Average Capacity (gpm)	Abandon Well	Remaining Flow (gpm)
N12	68	141	X	0
N13	14	133	X	0
N14	47	108	X	0
N15	34	125	X	0
N16	28	140	X	0
N18	12	143	X	0
N19	10	162		162
N20	15	125	X	0
N21	50	150	X	0
N23	75	174	X	0
N24	231	100	X	0
N25	59	100	X	0
N31	29	208	X	0
N32	29	190	X	0
N33	2	300		300
N34	6	306		306
N35	1	190		190
N36	17	230	X	0
N37	1	240		240
N38	1	225		225
N39	5	207		207
N40	1	216		216
OU2	57	110	X	0
OU3	24	120	X	0
OU4	29	140	X	0
OU5	16	190	X	0
OU6	16	160	X	0
OU7	18	120	X	0
OU8	20	180	X	0

TABLE 3-2
Groundwater Well Abandonment
Based on Arsenic > 10μg/L

Well	Arsenic (μg/L)	Average Capacity (gpm)	Abandon Well	Remaining Flow (gpm)
OU9	53	120	X	0
OU12	81	160	X	0
OU13	47	120	X	0
OU14	37	150	X	0
TOTAL	**43 wells**	**7,186 gpm 10.3 mgd**	**29 wells**	**2,909 gpm 4.2 mgd**

In this instance, 29 wells would be abandoned and about 2,909 gpm, or 4.2 mgd, of average flow capacity would remain. Overall, the flow lost to well abandonment is approximately 4,277 gpm, or about 6.1 mgd. This is a combined system loss of 59 percent—48 percent of the City's well capacity and 100 percent of OU's.

Procedure and Cost Estimate

Cost estimates were prepared for inclusion in the comparison analysis. In order to develop a preliminary cost estimate for well abandonment, the following general assumptions were made.

- The contractor is assumed to mobilize from the Oklahoma City area.
- Removal of an existing vertical turbine pump set at 500 feet would be required (a submersible pump would be less expensive.)
- Well depth would be 650 feet.
- Cement would be placed in stages through a tremmie pipe from bottom to near the surface.
- The top of the casing would be cut and removed.
- A small well house would be removed to allow for site restoration such as leveling and replanting grass.

Table 3-3 summarizes the costs associated with the abandonment option. These costs were developed assuming a single well would be abandoned. Abandoning several wells under a single contract could lower the cost per well. Note that these costs are general and should be revisited before budgets are developed.

TABLE 3-3
Well Abandonment Cost Estimate

Item	Cost
Mobilization	$2,000
Pull Turbine Pump	$2,000
Abandonment Cost – Cementing	$10,000
Remove Surface Facilities and Restore Site	$2,000
Construction Oversight & Inspection, 20%	$3,200
Contingency, 20%	$3,200
Total Cost per Well	**$22,400**

Considering the cost to abandon each well and the total number of well closures needed, the total capital cost of well abandonment would be $650,000.

Zonal Isolation

An alternative to abandonment of wells may be isolating zones that have excessively high arsenic concentrations. Data collected while constructing City Well Nos. 31 through 40 suggests that arsenic concentrations vary with depth. In general, it appears that the concentrations increase with increasing depth. However, the detection limits for much of the data collected were well above the proposed arsenic standard of 10 μg/L. The data does suggest the possibility of high concentrations entering the wellbore from discrete zones. Eliminating contributions from the intervals with the highest arsenic concentrations may drop the resulting concentrations to acceptable levels.

For the purpose of this Study, wells with zonal isolation potential have been selected based on several factors. First, the wells must have perforated completions. Second, it is assumed that the average flow capacity must be greater than 150 gpm. It is assumed that isolation treatment will decrease an effected well's capacity by half. A mass balance calculation was completed assuming the remaining half of the well's production is at 10 μg/L. The concentration of the removed flow was calculated and concentrations greater than 200 μg/L were considered unrealistic. For this scenario, these wells are assumed for abandonment. In addition to the completion method, production rates, water quality, age, and condition must be considered. Currently, no data exists to determine relative production from each of the zones within a well. Additionally, zonal water quality data is necessary for each well. In order for zonal isolation to be effective, the highly concentrated zones must be contributing a small percentage of the total flow. To identify wells that should be considered for zonal isolation, this Study assumes the OU wells are perforated. Based on this assumption, Figure 3-2 indicates which wells are candidates for zonal isolation.

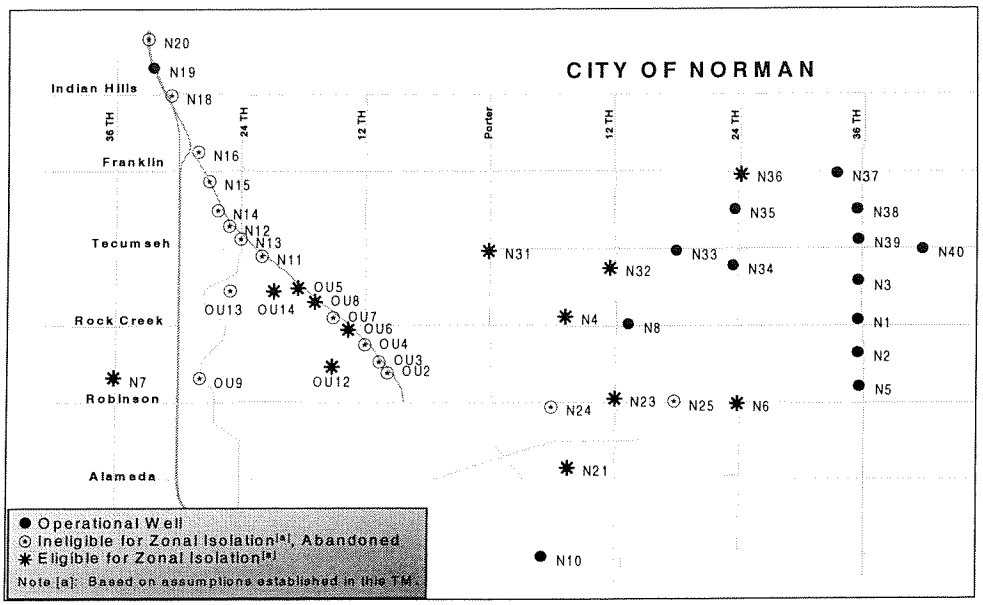

FIGURE 3-2
Location Map of Wells Considered for Zonal Isolation

The assumptions also provide a starting point for estimating the amount of flow gained by zonal isolation. In reality, the production loss and arsenic level decrease will vary widely among wells. Table 3-4 presents the zonal isolation scenario based on these assumptions.

TABLE 3-4
Groundwater Well Zonal Isolation
Based on Arsenic > 10μg/L

Well	Arsenic (μg/L)	Flow (gpm)	Zonal Isolation Not Feasible, Abandon	Zonal Isolation Completed	No Treatment Necessary	Flow (gpm)
N1	2	245			x	245
N2	10	110			x	110
N3	1	180			x	180
N4	54	160		x		80
N5	9	186			x	186
N6	11	210		x		105
N7	18	160		x		80
N8	2	220			x	220
N10	6	122			x	122
N11	60	110	x			0
N12	68	141	x			0
N13	14	133	x			0

TABLE 3-4
Groundwater Well Zonal Isolation
Based on Arsenic > 10μg/L

Well	Arsenic (μg/L)	Flow (gpm)	Zonal Isolation Not Feasible, Abandon	Zonal Isolation Completed	No Treatment Necessary	Flow (gpm)
N14	47	108	x			0
N15	34	125	x			0
N16	28	140	x			0
N18	12	143	x			0
N19	10	162			x	162
N20	15	125	x			0
N21	50	150		x		75
N23	75	174		x		87
N24	231	100	x			0
N25	59	100	x			0
N31	29	208		x		104
N32	29	190		x		95
N33	2	300			x	300
N34	6	306			x	306
N35	1	190			x	190
N36	17	230		x		115
N37	1	240			x	240
N38	1	225			x	225
N39	5	207			x	207
N40	1	216			x	216
OU2	57	110	x			0
OU3	24	120	x			0
OU4	29	140	x			0
OU5	16	190		x		95
OU6	16	160		x		80
OU7	18	120	x			0
OU8	20	180		x		90
OU9	53	120	x			0
OU12	81	160		x		80

TABLE 3-4
Groundwater Well Zonal Isolation
Based on Arsenic > 10μg/L

Well	Arsenic (μg/L)	Flow (gpm)	Zonal Isolation Not Feasible, Abandon	Zonal Isolation Completed	No Treatment Necessary	Flow (gpm)
OU13	47	120	x			0
OU14	37	150		x		75
Totals		**7,186 gpm 10.3 mgd**	**16 wells**	**13 wells**	**14 wells**	**4,070 gpm 5.9 mgd**

Based on the assumptions, the resulting data implies that an additional 1,161 gpm or 1.7 mgd of groundwater flow over well abandonment may be provided through zonal isolation. This additional flow brings the overall remaining combined system production to between 5.9 mgd and 0.6 mgd by OU wells and 5.3 mgd by City wells. However, many variables exist when considering zonal isolation and actual flows will vary from these estimates.

Procedure and Cost Estimate

In order to develop a preliminary cost estimate, the following general assumptions were made relating to zonal isolation.

- The contractor would mobilize from the Oklahoma City area.
- Removal of an existing vertical turbine pump set at 500 feet would be required.
- The well depth is 650 feet.

To select appropriate zones, the flow rate and water quality from the zones must be determined, which require several steps.

1. Well construction data for the well should be reviewed to determine perforation intervals.

2. Next, a camera log should be run to determine the condition of the well casing and verify the locations of the perforation intervals. This is important since evidence suggests some wells were re-perforated after initial construction for the purpose of increasing production.

3. Upon completion of the video survey, it may be useful to clean the casing using a wire brush or jetting tool to remove scale buildup and open the perforations.

4. A small submersible pump would be set in the well and a spinner log would be run while pumping. The spinner log can be combined with a temperature log and fluid resistivity log to highlight zones where water is entering the well. The spinner log would measure fluid velocity and production from each of the zones estimated.

5. Next, water samples from selected intervals would be collected using inflatable packers to isolate the interval being sampled.

6. The results from the laboratory analysis can then be compared to the spinner logs to determine if any of the zones are contributing disproportionately to the arsenic mass loading.

The above procedure should provide representative water quality from the various zones sampled if the poentiometric head in each zone is similar. If there are significant head differentials between the discrete production zones, zones of higher head can flood zones with lower head when the well is at rest. Collection of representative samples from the lower head zones is difficult.

Cement can be used to plug the zone if removing a specific zone or several zones from production is expected to improve the overall quality of the water produced from the well without reducing the well production to unacceptable levels. If the zone is at the bottom of the well, a cement plug can be set. A more difficult situation may arise in cases where shallow water zones contribute the higher concentrations. In this case, the upper zones must be shut off. This would traditionally be accomplished with a cement squeeze across the affected perforations. Packers or a removable plug would be utilized to direct the cement to the intended intervals. Other solutions include setting a casing liner or installing a casing patch. However, the installation of a casing liner would be the more complicated and expensive solution. The casing patch technology appears to be limited by most manufacturers to smaller casing than is typically used in the wells, indicating custom made patches would be required.

After the intervals have been plugged and the equipment has been removed, the well's original pump could be reset and the well put back into production. If the well's production is drastically reduced, a replacement pump may be necessary.

Table 3-5 details general cost estimates for zonal isolation of a single well. The estimate is based on isolation of one zone or a set of adjacent zones. Note that these costs are general and should be revisited before developing budgets.

TABLE 3-5
Zonal Isolation Cost Estimate

Item	Cost
Mobilization	$4,000
Pull Turbine Pump	$2,000
Run Camera Log	$1,500
Clean Casing (jet or brush)	$2,000
Run Pumping (spinner) Log	$4,000
Inflatable Packer Rental Fee	$5,000
Set Packers/Plug - Obtain Water Quality Sample	$9,000
Set Packers/Plug - Squeeze Cement	$12,000
Replace Vertical Turbine Pump	$2,000
Full Water Quality Analysis	$3,000

TABLE 3-5
Zonal Isolation Cost Estimate

Item	Cost
Subtotal (one zone)	$44,500
Construction Oversight & Inspection, 20%	$9,000
Contingency, 30%	$13,000
Total Cost	**$66,500**

At an estimated cost of about $66,500 for each of 13 wells, the total estimated cost is about $865,000. However, additional zones in each well will increase the overall cost by approximately $5,000 for each zone. If only the lowest zones are to be removed from production, a cement plug may be set without the use of packers. This would eliminate the packer rental fee and reduce the actual cement job to approximately $15 per foot of plug assuming a 10-3/4-inch casing. A cost savings may be realized if a series of wells were treated concurrently.

Note that the cost estimate assumes the original pump will be reset in the well. Replacement of pumps not suited for the reduced production has not been included in the estimate.

Temporary Isolation

Sand plugs, retrievable plugs, and packers could also be used to temporarily isolate zones that produce excessive arsenic concentrations. These tools may be useful during preliminary testing of isolation techniques but do not represent a permanent solution to the problem.

Project Uncertainties

The limited water quality data from the wells indicate drastic changes in the produced water arsenic concentration, which may not be realistic. The data also does not show an obvious trend, adding to the uncertainty in selection of an optimal solution. Additional water quality data should be gathered to better define the water quality variability with depth and over time.

Significant differences in head conditions between zones may have resulted in movement of water between zones within a well, reducing the reliability of the collected water quality samples used to choose the isolated zones. Evidence of this condition may be found as water quality samples are collected.

With the limited data available to describe the complicated structure of the aquifer, water in isolated zones could potentially move vertically to adjacent production zones, which would negate the positive effects of retrofitted wells over time.

Other Considerations

The perforated completions in the wells are very effective in assuring zonal isolation. However, the perforations are generally inefficient at transferring water from the formation to the wellbore. If some wells are abandoned or production is reduced to remove concentrated arsenic zones, additional production may be gained from an analysis of well performance. If data suggests large head losses in the high quality water entering the wellbore, additional perforations may be added or the aquifer matrix near the well may be stimulated in some way to increase production.

Additional Data Needs

Reliable water quality measurements at different depths over different areas of the wellfield are necessary to more adequately assess the potential for zonal isolation. These can be obtained through installation of monitor wells completed over discrete intervals of interest. To better understand conditions in the wellfield, multi-zone monitoring wells may be installed to collect additional data over time.

SECTION 4

Alternatives Development and Evaluation

In this section, potential solutions for City and OU groundwater wells affected by the proposed AR and GWR are identified. More specifically, Section 4 discusses the following:

- identifies potential treatment technologies;
- provides an evaluation of the operational and economical impacts of those treatment technologies;
- provides results of the decision analysis workshop where the most appropriate technologies to meet the needs of the City and OU were evaluated; and
- discusses plan alternatives for AR compliance such as blending and well closure.

Treatment Technologies

Several arsenic treatment technologies, such as ion exchange and activated alumina, have been studied for many years. However, since the arsenic MCL has been lowered, new technologies are coming to the market place. It is difficult to evaluate some of the newer technologies, especially the adsorbent media technologies, because performance data is not yet available to determine how these technologies may function for the City and OU water systems. The water quality variations found in different waters will influence the operational characteristics of each technology. As such, the evaluation presented here will be based on the performance data available and engineering judgement. Only through pilot testing can operational characteristics of many of these technologies be confirmed with the water quality observed in the City and OU groundwater wells.

Based on literature review and communication with treatment system manufacturers, the treatment technologies listed below have been identified as having potential for arsenic treatment. All of the technologies presented may not be appropriate for the City or OU, however, the evaluations presented will assist staff in determining which technologies are appropriate for additional consideration.

The technologies discussed in subsequent paragraphs include:

- Ion Exchange
- Adsorption Media Technologies
- Coagulation/Microfiltration
- Coagulation/Filtration
- Nanofiltration

This report will evaluate the technologies as they would apply to the treatment of arsenic in groundwater wells in the City and OU water systems. Each evaluation will include a description of the general process, the conceptual facility, chemical use, residuals processing and handling, estimated capital and annual costs, and the pros and cons of each technology.

Basis of Cost Estimates

Capital as well as operation and maintenance (O&M) cost estimates are presented for each treatment technology evaluated in Appendices C through G. The opinions of cost shown, and any resulting conclusions on project financial or economic feasibility or funding requirements, have been prepared for guidance in project evaluation only. The final costs of the project and resulting feasibility will depend on actual labor and material costs, competitive market conditions, actual site conditions, final project scope, implementation schedule, continuity of personnel and engineering, and other variable factors. As a result, final project costs may vary from the opinions of cost presented herein. Because of these factors, decisions related to project feasibility, benefit/cost ratios, risks, and funding must be carefully reviewed prior to making specific financial decisions or establishing project budgets to help ensure proper project evaluation and adequate funding.

The cost opinions have been prepared by considering industry standard cost estimating practices, references, costs of similar projects, and material and equipment quotes from vendors. The costs are considered Budget Level Estimates, as defined by the American Association of Cost Engineers. An estimate of this type is normally expected to be accurate within +30 percent to –15 percent.

Unit costs include contractor labor burden, contractor's overhead and profit, mobilization, bonds and insurance, equipment, and material costs. A 20 percent contingency is included in the cost estimates to cover uncertainties at this level of design. The total capital costs do not include land costs for the treatment facilities, engineering design, and services during construction. All costs are presented January 2002 dollars.

Groundwater Rule Provisions

Based on comments by ODEQ staff, the GWR will not affect the existing City and OU groundwater systems within the confined portion of the GWA. Disinfection will be required for the wells located in the unconfined portion of the GWA if indicator test results, such as microbial sample analysis, are positive. Figure 4-1 shows which wells may be affected by the GWR.

As the figure indicates, seven of the City's wells are located within the unconfined portion of the GWA, therefore, ODEQ may require microbial sampling to determine if disinfection is needed. Based on the wells' close proximity to the confined GWA area, the characteristics of the GWA, and the depth of the wells, disinfection may not be required. Until indicator tests are performed and more data is acquired, the need for disinfection is unknown.

Onsite hypochlorite generation equipment can be utilized for disinfection, oxidation, and media cleaning, if required. The costs associated with onsite hypochlorite generation equipment are not provided in the capital and O&M cost estimates presented in the corresponding technology discussion. However, based on preliminary analysis, the capital and O&M present worth cost of adding the hypochlorite and ammonia feed equipment to the treatment facilities is estimated at $1.4 million. Of this amount, $400,000 is in capital costs and $1.0 million is in present worth O&M costs.

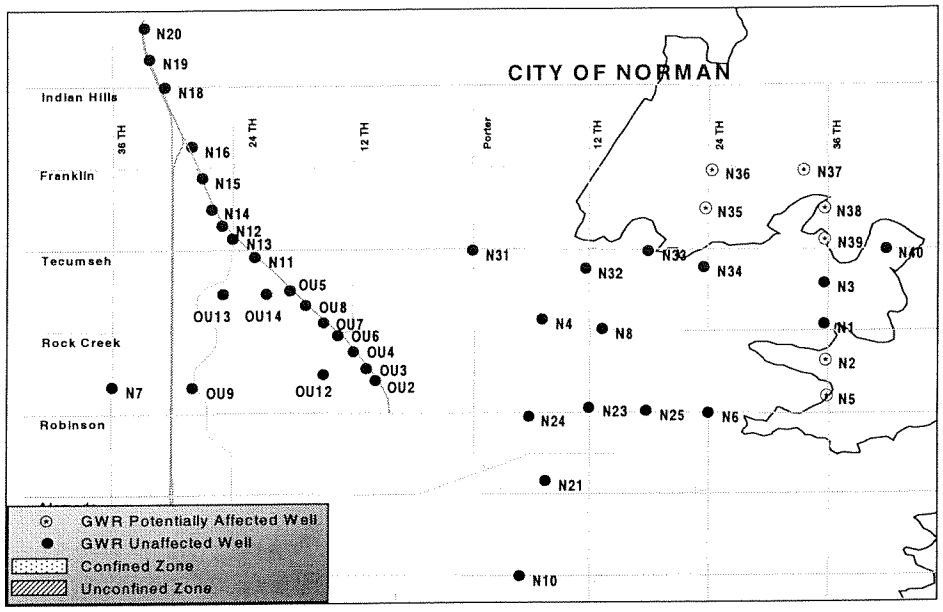

FIGURE 4-1
Map of Wells Located in Unconfined GWA

Well Groupings

Based on preliminary cost estimates for the treatment technologies considered in this Study, grouping City and OU wells into common treatment facilities would provide a more economical solution to arsenic treatment. A possible well grouping scenario was presented in Section 2. A diagram of well groupings, determined through discussion with City staff, is shown on Figure 4-2.

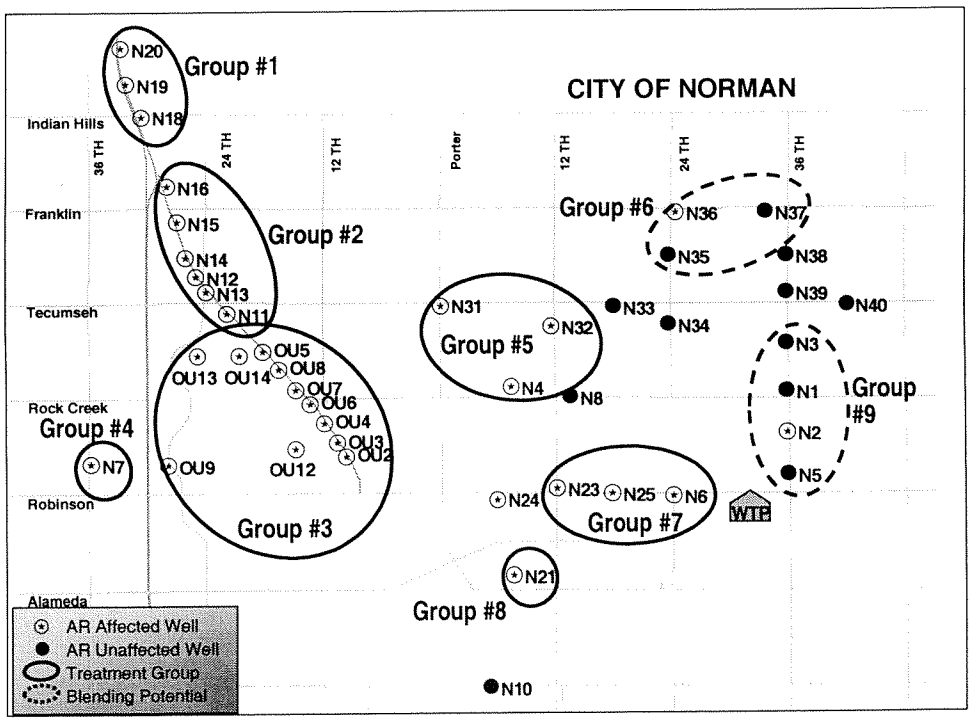

FIGURE 4-2
Groundwater Well Groups

For the purpose of developing conceptual treatment plans and cost estimates, the well groups presented on Figure 4-2 will be used. Data does not currently exist to show that Group Nos. 6 and 9 will be blended successfully. However, Group No. 9 has a high potential for blending success as the affected well in Group No. 9 (well number N2) has an average arsenic concentration of 10 μg/L. When the affected well is run in combination with any other well in Group No. 9, the blended concentration would be below 10 μg/L. On the other hand, the affected well in Group No. 6 (well number N36) has an average arsenic concentration of 17 μg/L. For the blended concentration of Group No. 6 to be below 10 μg/L, Well N37 must be run in combination with well N36. This would reduce the flexibility of that group to meet demands in the area. Because of that restriction, this Study assumes that blending may not be successful for Group No. 6; thus other alternative conceptual treatment provisions are provided. Hence, the groups considered for treatment include Group Nos. 1 through 8.

Grouping the wells will require not only treatment facilities but also raw water conveyance pipelines from individual wells to the common treatment site and a sewer connection from the treatment plant site to the wastewater collection system. Additionally, many other possible well groupings exist. For example, Group Nos. 7 and 8 could be conveyed to the WTP for clearwell blending. Also, OU's wells in Group No. 3 could be combined into different groups, such as Group Nos. 2 and 4. However, City and OU wells are currently maintained as separate water systems for consideration of treatment options. Should the City and OU elect to combine their systems, other well groupings are possible. These options, and others, will be further discussed in Section 6, Plan Alternatives.

This Study considers each well grouping as one common treatment facility with each well in the grouping creating average arsenic and flow results. However, within a well group, if some wells are not utilized, the arsenic concentration and process flow will not be the same. Should arsenic treatment systems for these groups or if other well arrangements are implemented, a Well Operational Plan will be required to ensure effective treatment.

Section Organization

Section 4 is divided into sub-sections as summarized below.

- Review of arsenic chemistry as it relates to treatment technologies discussed in this Study
- Discussion and conceptual development of the five treatment technologies being considered
- Summarizes the results of the technology workshop, including a decision analysis to determine which technologies best meet the needs of the City and OU.
- Develops four plan alternatives involving individual wellhead treatment, common facility treatment, blending, well closure, and zonal isolation. Each alternative considered will have the ability to meet the regulations of the new AR and GWR. Capital and O&M costs for each alternative are also presented.
- Develops a matrix analysis of the alternatives. The matrix analysis will be used for selecting the best plan to meet the needs of the City and OU.

- Summarizes the funding options for the City and OU that are available from public and private sources.

Arsenic Chemistry

The genesis of arsenic in groundwater was discussed Section 1, Background on Arsenic and Groundwater Rules, which identified the predominant method of arsenic dissolution in the GWA to be pH-influenced desorption. However, after the water is withdrawn from the GWA, there are specific chemical principals that govern treatment of the water for arsenic removal. This section discusses the general principals of arsenic removal that are applicable to the various arsenic treatment technologies.

Arsenic occurs in two oxidation states in natural waters; arsenite (AS(III)) and arsenate (As(V)). Under pH conditions less than around 8.0, As(III) has no charge, i.e. non-ionic. Surface complexation of the arsenic molecule with positively charged solids is the primary removal mechanism for arsenic removal. Thus, if the arsenite has no charge, it will not be effectively removed from water by adsorption technologies.

The oxidized form of arsenic is arsenate and has a negative charge at pH values less than around 11. Thus, arsenate will be removed by surface complexation, or adsorption on to positively charged solids. Therefore, for most technologies, if there is As(III) present in the water, it must be oxidized to As(V) for effective arsenic removal to occur.

The ionic state of arsenic (As(III) or As(V))is a function of the pH of the water. The charge on the arsenic species is a function of the solution pH. This is due to the dissociation of hydrogen ions from the arsenic species. The hydrogen ion dissociation of the two predominant arsenic species is shown on Figures 4-3 and 4-4.

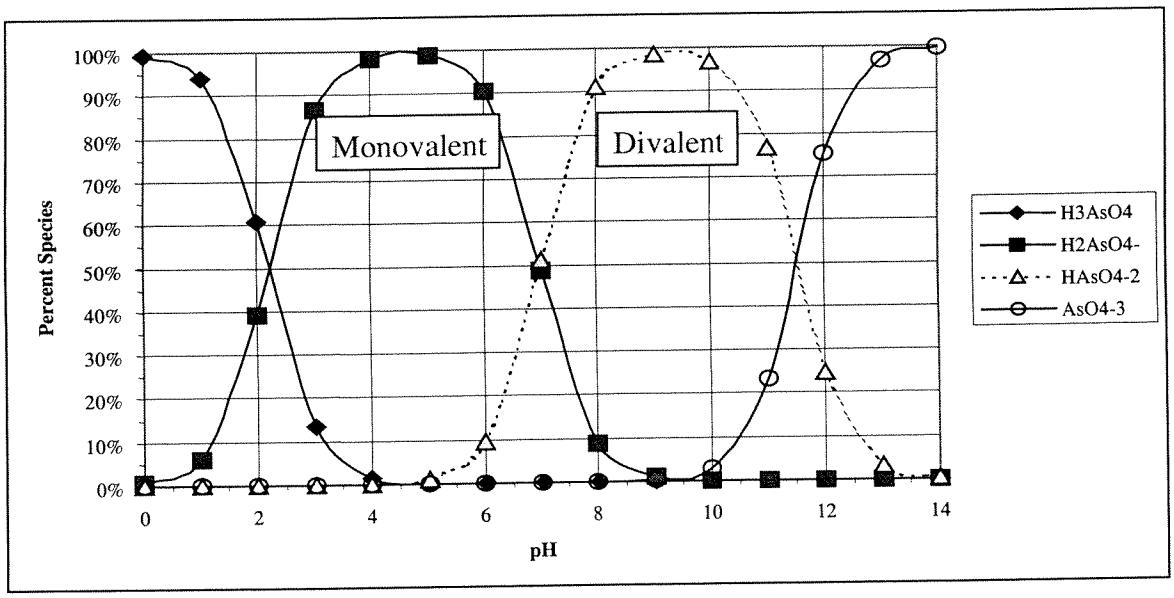

FIGURE 4-3
Distribution of As(V) Species as a Function of pH

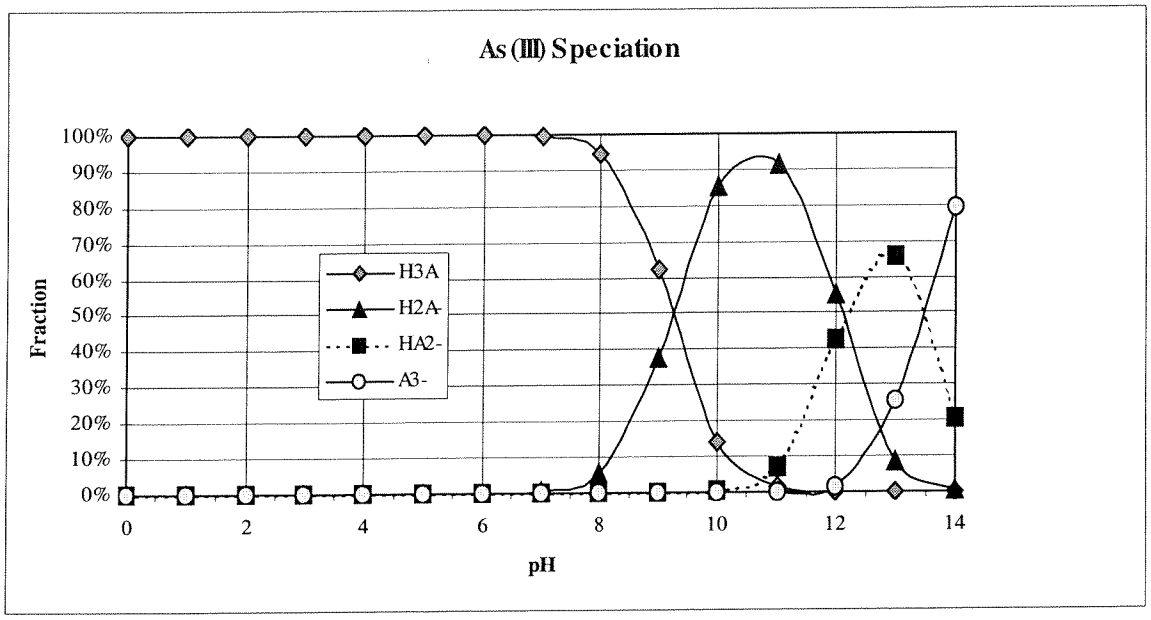

FIGURE 4-4
Distribution of As(III) Species as a Function of pH

Besides the effect on arsenic species charge, solution pH also affects the surface charge of the adsorption media. Some treatment technologies utilize adsorptive media to remove arsenic. The media's surface potential at various pH levels to attract negatively or positively charged ions is indicated by its pH of zero-point-of-charge (pH_{zpc}). At a pH below the pH_{zpc}, the media has an affinity for negatively charged ions (anions), while it has an affinity for positive ions (cations) at a pH above the pH_{zpc}. For example, for activated alumina resin, the pH_{zpc} is about 8.2, indicating activated alumina has an affinity for anions such as arsenate, in solution with a pH less than 8.2.

Common coagulants such as ferric chloride ($FeCl_3$) can be used as an adsorbent for arsenic. In conventional water treatment, a floc is created by the addition of $FeCl_3$ to the water. The addition of $FeCl_3$ creates a ferric hydroxide (FeOH) floc that will adsorb the arsenic. In addition, $FeCl_3$ is an acid and will lower the pH of the water to which it is applied. The surface charge of the FeOH floc is affected by the solution pH.

Adsorption of arsenic is impacted by competing ions, i.e., there is a selectivity sequence for most technologies. As an example, the selectivity sequence for ion exchange from the most preferred to the least preferred is as follows:

$$SO_4^{2-} > HAsO_4^{2-} > CO_3^{2-} \;\&\; NO_3^- > Cl^- > H_2AsO_4^- \;\&\; HCO_3^- >> Si(OH)_4 \;\&\; H_3AsO_3$$

This selectivity sequence indicates an ion exchange resin will preferentially remove sulfate (SO_4^{2-}) from solution and then will remove $HAsO_4^{2-}$ (As^{5+}), CO_3^{2-} and NO_3^{2-}. For iron hydroxide adsorption technologies, the selectivity sequence from the most preferred to the least preferred is as follows:

$$H_2AsO_4^- > H_2PO^{-4} > H_2AsO_3^- > Si(OH)_3O^- > HCO_3^-$$

For iron based technologies, although arsenate is preferred over phosphate, phosphate may occur in water at a concentration 1 to 2 orders of magnitude greater than arsenic. In these situations, phosphate will reduce the arsenic adsorption capacity of the media.

The water quality becomes an important issue in the selection of an appropriate resin. For example, if water treated with ion exchange has a high concentration of SO_4^{2-}, the technology would most likely not be a successful solution for arsenic removal.

Ion Exchange

Ion exchange (IX) has been studied for many years as a potential treatment technology for arsenic removal. The IX process for arsenic treatment would utilize a strong base anion exchange resin operated and regenerated in a downflow mode. The IX bed is regenerated utilizing a concentrated sodium chloride solution (brine). The arsenic-laden brine can be recycled numerous times before it must be disposed. When recycling occurs, the waste brine solution can be taken to a treatment process where the accumulated arsenic is separated with iron precipitation. The dewatered arsenic/iron solids can be disposed in a landfill and the remaining waste brine and rinse water taken to an evaporation pond. However, O&M costs for arsenic precipitation and solids handling can be very high and can also create a hazardous waste. In order to keep the waste brine from accumulating arsenic to a hazardous level, recycling of the brine will not be considered. Instead, the brine solution will be used only once and will then be sent to the City sanitary sewer system for treatment at the wastewater treatment plant (WWTP). The City limits arsenic discharge to the sewer system to 0.37 mg/L through its Industrial Pretreatment Program. In order to meet this discharge limit, the IX process must be operated in an inefficient manner to dilute the arsenic concentration in the waste brine.

IX is a removal process utilizing polystyrene-based resins. These resins are able to exchange ions on the resin of less preference for ions of greater preference in the water as they pass through the resin bed. The exchangeable ion is chloride and its source is sodium chloride, or common salt. Well water containing arsenic is pumped through the IX resin bed(s) and the arsenic ions are exchanged for chloride ions. As discussed previously, sulfate is removed preferentially to arsenic, and bicarbonate and nitrate ions are removed less preferentially to arsenic. This creates a condition where nitrate, bicarbonate, arsenic, and sulfate sequentially break through and exit the bed. Therefore, the IX process must be taken offline and regenerated prior to the arsenic breakthrough. Because the sulfate concentration is normally much higher than the arsenic concentration in the well water, it is the most important factor in determining how many bed volumes (BV) 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, the sulfate concentration in the well water determines how cost effective the IX process will be for a given site estimating arsenic breakthrough as a function of the sulfate concentration as presented on Figure 4-5.

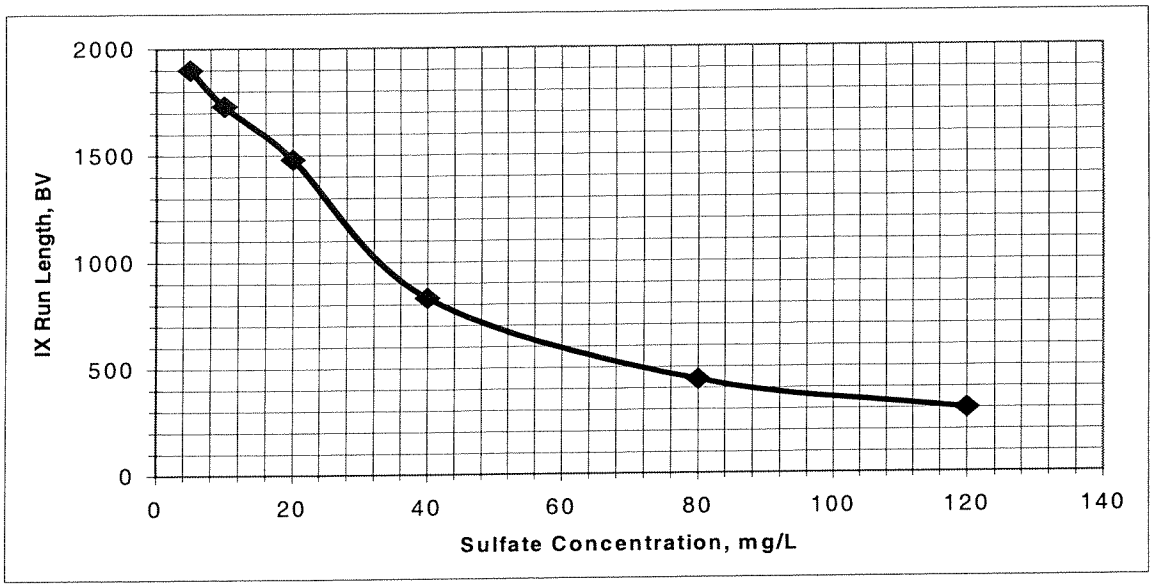

FIGURE 4-5
Impact of Sulfate on IX Run Length
(Clifford and Linn, 1995)

Figure 4-5 indicates that as the sulfate level increases, the number of (BV) of water that can be treated will decrease. A BV is a volume of water equivalent to the volume of media contained within the vessel. The sulfate levels in the groundwater of the City and OU study area are around 25 mg/L. Thus, an IX system for the groundwater wells would have an average run length of approximately 1,300 BV. However, maintaining the arsenic concentration in the waste brine below the 0.37 mg/L industrial pretreatment limit requires an even lower BV average.

The operation of an IX process consists of several steps:

1. **Service.** Well water is pumped through the 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. **Brining.** Concentrated brine is passed downflow through the resin bed to exchange the sulfate, arsenic, and bicarbonate with chloride. Three substeps are associated with brining. Approximately 0.5 BV of displacement water will be pushed through the resin bed, which may contain a high concentration of arsenic. Then approximately 2.8 BV of brine are passed through the IX bed, and then to the sanitary sewer system. Following the brine step, another 0.5 BV of rinse will be applied through the resin bed to remove the remaining brine.

4. **Rinse.** Treated water is passed downflow through the bed to: (a) displace the brine in the bed; and (b) slow rinse the remaining brine from the bed. This step requires approximately 2 to 4 BV of water. The rinse water will have low concentrations of brine that must be disposed 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.

A cycle is defined as one service run followed by a regeneration. At the end of each cycle, the spent brine and rinse water is conveyed to the arsenic precipitation and solids thickening process. Each new cycle uses fresh brine for regeneration. The IX resin will consume approximately 5.4 pounds of salt per cubic foot ($NaCl/ft^3$) resin, on an ionic basis for each regeneration. However, the concentration of the brine must be sufficiently high to force the exchange of arsenic for chloride on the resin. As such, a salt use of 10 pounds per cubic foot is required to achieve proper regeneration. Thus the brine strength is maintained at a minimum strength of 1 mole of NaCl per liter (M) or 58 grams per liter. The waste brine will contain a salt concentration of around 0.5 M. The brine time will be 70 minutes.

The brine rinsing steps will create a waste brine with high arsenic concentrations. The BV for each treatment site is varied until the arsenic concentration in the waste brine is less that 5 mg/L to avoid creating a hazardous waste. Following the brining steps, another rinse step of 4 BV over a 10-minute period will occur and will also be sent to the solids thickening process. Following regeneration, the vessel will remain offline until the next vessel is regenerated. The minimum size system will consist of four vessels in parallel, with three vessels operating and one vessel being regenerated.

Conceptual IX Facility

The conceptual IX facility cost computations for the City and OU water systems are included as Appendix C. Preliminary cost estimates indicates that individual wellhead treatment would be more costly than grouping the wells into several common treatment facilities. Therefore, common treatment facilities are assumed. The conceptual IX facilities for the City and OU would consist of eight treatment sites. Each site would have four vessels of various diameters.

The IX process should be capable of producing a treated water arsenic concentration of 2 µg/L as long as sufficient pH and $FeCl_3$ dose is applied. As such, it is possible to blend a portion of the untreated water with the treated water to minimize the design capacity of the facility.

The run length of the IX columns varies depending on the blended sulfate concentration and wasted brine arsenic concentration. Table 4-1 describes each treatment facility site.

TABLE 4-1
IX Conceptual Design Parameters

Item	Well Group No.							
	1	2	3	4	5	6	7	8
Treatment Design Capacity, gpm[a]	252	772	1,448	133	565	135	450	161
No. of Vessels	4	4	4	4	4	4	4	4
Vessel Diameter, ft	3	5	7	2	5	2	4	3
Media Depth, ft	3	3	3	3	3	3	3	3
Number of BV per Cycle[b]	1,700	420	550	900	500	1,700	400	350

TABLE 4-1
IX Conceptual Design Parameters

Item	Well Group No.							
	1	2	3	4	5	6	7	8
Volume Treated per Cycle, gals	269,652	185,055	474,975	63,448	220,304	119,845	112,796	55,517
Cycle Time, hrs	54	12	16	24	19	44	13	17
Total Salt Use, lb/MG treated	786	3,183	1,313	1,485	2,674	786	3,342	3,820
Annual Salt Use, tons	32	391	490	32	241	17	240	98

Notes:
[a] Treatment capacity based on IX achieving 2 µg/L finished water.
[b] Bed volumes based on raw water sulfate concentration and wasted bring arsenic concentration.

Based on estimates, the IX facilities will require an annual salt use of over 1,500 tons. The salt used for regeneration would be stored in brine generation basins located at each treatment facility. When recycling occurs in an IX process, multiple chemicals are needed at the treatment site, including $FeCl_3$ for arsenic precipitation, sulfuric acid for waste brine pH adjustment, and caustic soda for finished water pH adjustment.

Chemical Use

The chemicals required for the IX process consist of the following:

- NaCl, salt
- $FeCl_3$, ferric chloride
- H_2SO_4, sulfuric acid
- NaOH, caustic soda

The requirements of these chemicals are discussed below.

Salt

Salt is used to regenerate the IX resin. As discussed above, the IX resin will require approximately 10 pounds of salt per cubic foot of resin. The salt used for regeneration and the content in the wasted brine varies from 786 to 3,820 pounds of NaCl per million gallons of water treated. The total salt wasted ranges among treatment facilities from 17 to 490 tons annually. If hypochlorite generation is provided, additional salt will be required. The impact of the high volume of salt use on the wasted brine causes a significant increase in the TDS of the water conveyed to the WWTP. The WWTP currently does not have a TDS pretreatment limit. The waste brine may exceed 62,000 mg/L TDS, but pilot testing is required to determine the actual waste brine TDS concentration.

Ferric Chloride, $FeCl_3$

Ferric chloride will be used to remove the accumulated arsenic from the waste brine. The $FeCl_3$ will be added to a reaction basin, which contains the waste brine. The reaction basin will be mixed to cause the $FeCl_3$ to precipitate and adsorb the arsenic in the waste brine. The

precipitate, FeOH, will then be allowed to settle and the supernatant would be decanted from the top.

The amount of $FeCl_3$ to be added can be determined by the following equation as reported by Clifford and Lin (1995).

$$3Na_2HAsO_4 + 3\,H_2O + 2FeCl_3 = Fe(OH)_3 + Fe(H_2AsO_4)_3(s) + 6\,NaCl$$

Stoichiometrically, approximately 1.44 pounds of $FeCl_3$ are needed for each pound of arsenic (as As) in the waste brine solution. It has been reported that approximately 20 times the stoichiometric amount of $FeCl_3$ is required to generate a precipitate, which has a low Toxicity Characteristic Leaching Procedure (TCLP) leachate arsenic concentration of less than 1.5 mg/L. Applying a 20-times factor results in approximately 28.9 pounds of $FeCl_3$ for each pound of arsenic in the waste brine.

It should be noted that the waste brine will contain high concentrations of bicarbonate, which will cause a high pH. To allow the $FeCl_3$ to precipitate, it will be necessary to lower the pH of the waste brine. This can be accomplished with sulfuric acid as described below.

Sulfuric Acid

As discussed above, the waste brine will need pH adjustment prior to the addition of $FeCl_3$. The amount of acid will be dependent on the quantity of bicarbonate and other ions in the waste brine solution. The pH of the waste brine must be lowered to around 5.5 to 6.0 for effective FeOH formation. A dose of sulfuric acid ($HA_5O_4^2$) of approximately 0.014 gallons of concentrated $HA_5O_4^2$ per gallon of waste brine will be used. This dose will need to be confirmed through actual operation but will be used for the purposes of this evaluation. A 30-day storage volume will be provided.

Caustic Soda

The IX process will remove bicarbonate along with sulfate and arsenic. The pH of the finished water will be depressed by the removal of the bicarbonate and will require pH adjustment prior to being placed in the distribution system. Without recycling the brine, the product water could have an average pH of approximately 6 to 7. However, when the brine is recycled, the accumulation of bicarbonate in the brine solution will cause less bicarbonate removal from the water. Therefore, with brine recycling, the pH may only be reduced by 0.2 to 0.3 pH units. In addition, operating several IX vessels at the same time will reduce the potential of pH depression by blending the treated water. However, the IX process is expected to reduce the pH of the water by 0.2 to 0.3 pH units regardless of the method of operation.

To bring the pH of the water up to its pretreatment level and to prevent the production of corrosive water, a small amount of caustic soda (NaOH) will be utilized for pH adjustment. For the purposes of this evaluation, a caustic soda dose of 5 mg/L will be used. A 30-day storage volume will be provided.

Waste Brine and Bed Volume Rinses

The IX process will generate waste brine and FeOH residual, both of which require disposal. The quantities of residuals produced by IX are presented in Table 4-2.

TABLE 4-2
IX Residuals

Item	Well Group No.							
	1	2	3	4	5	6	7	8
Waste Brine Produced, gpd	797	9,888	9,398	797	6,086	429	6,062	2,477
Ferric Residuals, cy/yr	0.21	2.63	6.39	0.18	1.62	0.16	1.63	0.64
Dried Waste Salt, cy/hr	29	362	454	29	223	16	222	91

Estimated Capital Cost for IX Facilities

The estimated cost of conceptual IX facilities for the City and OU is summarized in Table 4-3. Based on the total unit cost for capital expenditures associated with the IX facilities, the unit capital cost is $1.96 per gallon per day of treatment capacity, which gives an overall capital cost estimate of about $11 million. Detailed IX cost estimates are provided in Appendix C.

Estimated Annual O&M Costs for IX Facilities

The annual O&M costs for City and OU IX facilities are based on annual-average flows according to the City and OU staff. The overall estimated O&M costs are presented in Table 4-4. Based on these estimates, the unit annual O&M cost per 1,000 gallons of treated water is about $0.40. Overall, the O&M total present worth at 6 percent for 20 years is $5.8 million.

Combined with capital, IX has an overall present worth of approximately $17 million and a unit cost of $0.67 per 1,000 gallons of treated water. Detailed IX cost estimates are provided in Attachment C.

Table 4-3: IX Capital Cost Estimates

Item	Well Group No. 1	2	3	4	5	6	7	8	Total
Booster Pumping/ Straining	$49,000	$94,000	$151,000	$40,000	$78,000	$40,000	$64,000	$42,000	$558,000
Ion Exchange Facilities	$213,000	$369,000	$536,000	$142,000	$369,000	$142,000	$288,000	$213,000	$2,272,000
Brine Handling Facilities	$39,000	$46,000	$54,000	$39,000	$46,000	$39,000	$39,000	$39,000	$341,000
Solids Handling	$41,000	$44,000	$49,000	$41,000	$44,000	$41,000	$41,000	$41,000	$342,000
Chemical Feed Systems	$33,000	$121,000	$104,000	$32,000	$88,000	$29,000	$79,000	$47,000	$533,000
Building	$150,000	$200,000	$260,000	$130,000	$200,000	$130,000	$170,000	$150,000	$1,390,000
Piping, I&C, Electrical, Yard Piping	$169,000	$304,000	$402,000	$132,000	$282,000	$131,000	$230,000	$172,000	$1,822,000
Total Facility Cost, $	$693,000	$1,178,000	$1,556,000	$556,000	$1,108,000	$551,000	$910,000	$704,000	$7,256,000
Ancillary Offsite Pipiing	$174,000	$286,000	$709,000	$10,000	$318,000	$238,000	$206,000	$10,000	$1,951,000
Contingency, 20%	$173,000	$293,000	$453,000	$113,000	$285,000	$158,000	$223,000	$143,000	$1,841,000
Total Estimated IX Facility Cost	$1,040,000	$1,757,000	$2,718,000	$679,000	$1,711,000	$947,000	$1,339,000	$857,000	$11,048,000

Table 4-4: IX O&M Cost Estimates

Item	Well Group No. 1	2	3	4	5	6	7	8	Total
Annual Power Cost, $/yr	$400	$2,100	$4,100	$400	$1,400	$300	$1,200	$600	$10,500
Annualized Resin Replacement Costs, $/yr	$1,900	$5,200	$10,200	$800	$5,200	$800	$3,300	$1,900	$29,300
Annual FeCl3 Cost, $/yr	$0	$300	$700	$20	$200	$0	$200	$100	$1,520
Annual NaOH Cost, $/yr	$400	$1,100	$3,300	$200	$800	$200	$600	$200	$6,800
Annual H2SO4 Cost, $/yr	$2,100	$26,000	$32,600	$2,100	$16,000	$1,100	$16,000	$6,500	$102,400
Annual Salt Cost, $/yr	$1,500	$19,000	$23,800	$1,500	$11,700	$800	$11,600	$4,800	$74,700
Total Residuals Disposal Costs, $/yr	$1,300	$16,400	$20,700	$1,300	$10,100	$700	$10,100	$4,100	$64,700
Total Estimated Labor Costs, $/yr	$16,500	$16,500	$16,500	$16,500	$16,500	$16,500	$16,500	$16,500	$132,000
Treatment Equipment Maintenance Cost	$8,300	$14,100	$18,700	$6,700	$13,300	$6,600	$10,900	$8,500	$87,100
Estimated O&M Costs for IX $/yr	$32,500	$100,700	$130,700	$29,600	$75,200	$27,100	$70,500	$43,100	$509,400
Unit Annual O&M Costs, $/1000 gal	$0.49	$0.50	$0.21	$0.85	$0.51	$0.76	$0.60	$1.02	$0.40
Present Worth	$372,000	$1,155,000	$1,499,000	$339,000	$862,000	$311,000	$808,000	$494,000	$5,840,000

Total Present Worth	$16,888,000
Total Unit Cost, $/1,000 gals	$0.67

Pros and Cons for IX

The IX process can be evaluated according to its pros and cons as presented in Table 4-5.

TABLE 4-5
IX Evaluation Criteria

Criteria	Consideration
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 and arsenic increasing the chloride content of finished water. 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 waste brine will contain elevated levels of arsenic but not be considered a hazardous waste. The solids handling will require two steps: precipitation reaction/thickening followed by 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 wasted feedwater varies among treatment facilities On average, the IX process will waste less than 2 percent of the feedwater for creating the brine solution and rinsing.
Reliability: Can process be scaled up?	IX can be scaled up; however, the salt storage and brine disposal becomes an issue with larger capacity facilities.
Reliability: How complex is the process to operate?	The IX run length is a function of sulfate levels and arsenic concentration in the wasted brine; therefore, each facility across the City 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. IX will not require pH adjustment of the feedwater.
Reliability: Will chemical handling be difficult?	The IX process requires the use of ferric chloride, sulfuric acid, and caustic soda, all of which are dangerous and need to be handled by trained personnel.
Reliability: How will process control and monitoring be accomplished?	There is no surrogate for arsenic; therefore, online monitoring for arsenic breakthrough is not appropriate. The process will be run by establishing a specific run length for each system. The IX column is stopped prior to arsenic breakthrough and regenerated. The run length will be determined experimentally. Changes in water quality (sulfate) will require adjustment of run length and a Well Operational Plan should be developed.
Reliability: What are the maintenance requirements?	IX will require resin replacement on a periodic basis. It will be necessary to monitor performance to determine when replacement is needed. The IX process requires many valves, which operate on a frequent basis. City Operations staff will need to maintain these valves regularly. In addition, the process will be controlled by a programmable logic controller (PLC) and require specialized maintenance. The solids handling facilities will require the most maintenance, including pumps, filter press, and basins.
System Applicability: Are there	IX requires significant quantities of salt. A waste brine will be produced that

TABLE 4-5
IX Evaluation Criteria

Criteria	Consideration
environmental impacts of treatment?	must be evaporated. Application of IX will result in the production of waste salt that must be disposed of. In addition, ferric hydroxide solids that contain high concentrations of arsenic will require disposal in a landfill. The use of large quantities of chemicals will increase the possibility of accidental release during transport.
System Applicability: Will treatment process be automated and will it integrate into supervisory, control, and data acquisition (SCADA)?	For the most part, the IX process will be automated; however, the solids handling will require a certain level of operator attention. All automated components will be tied into a SCADA system.
System Applicability: What are the space requirements for the treatment technology?	On average, the facilities can be accommodated in a building of about 1,000 ft^2 The entire facility can fit on less than one acre of land and will provide sufficient access for chemical delivery trucks.
System Applicability: How sensitive is the treatment process to water quality variations?	Changes in sulfate levels will significantly impact the operation of the treatment process. Temporal variations in sulfate will result in significant changes in IX column run length. Water that contains arsenite will require oxidation prior to IX. The IX manufacturers indicate that chlorine will damage the resin and reduce its operational life. Dechlorination may be required prior to the IX process.
Safety: How safe is the treatment process to operate and maintain?	The IX process will require the handling of four chemicals, three of which are hazardous. Operations staff will need to be specifically trained with handling, storage, and delivery of these chemicals. The remainder of the process will be similar to the facilities at a wastewater treatment plant (WWTP) and will require the same level of operator safety.
Upgradability: Can the process be upgraded in the future?	The IX facility will rely on the resin to function. Changes in resin technology or the use of other adsorbents may be implemented as long as the empty bed contact time (EBCT) requirement is less than 1.5 minutes.
Well Operation: Will the treatment technology impact the operation of the wells?	The wells will pump directly to the treatment facility. Following treatment, the water will be repumped into the distribution system.
System Optimization: Can the process be optimized so that it is not overdesigned?	The IX process can be effectively designed to meet specific requirements. However, the IX process will need to be designed to regenerate at some set time prior to the break through of arsenic. This safety factor will increase the size of the brine and solids handling facilities, not the IX columns themselves.
Public Acceptance: Will the treatment process be accepted by the public?	The environmental impacts of the high salt use and the potential of arsenic peaking may not be acceptable to the public. In addition, the use of large volumes of sulfuric acid, caustic soda, and ferric chloride may cause some public concern.
Public Education: Can the treatment process be used for public education?	The IX process can be designed so that public access is appropriate.
Permits: What permits are required?	The Oklahoma Department of Environment Quality will have specific monitoring requirements for the IX process. Construction permits will be similar to any industrial facility constructed in Cleveland County.
Sole Source: Does the equipment need to be sole sourced?	No. IX resin and equipment can be specified and purchased from several vendors.

Adsorptive Technologies

Adsorptive technologies are somewhat similar to the IX process except the media considered by this Study will not be regenerated. Utilizing non-regenerable media eliminates the possibility of generating a hazardous waste. The goal, therefore, is to provide a condition where the media has the highest adsorption capacity possible, resulting in a long media life. Similar to IX, adsorptive technologies remove arsenic from the feedwater as the feedwater is passed over the media contained in a column vessel. However, where IX replaces one ion with another, the adsorption process uses surface complexation to pull ions out of the water and store them on the media.

Multiple types of adsorptive media are available, both regenerable and non-regenerable. However, this Study considers only non-regenerable media, as indicated previously. This section discusses selected non-regenerable media types and how they would be applied as adsorptive technologies for treatment of arsenic in the City and OU water systems. Although several non-regenerable media exist, the two discussed are the most tested media: Granular Ferric Hydroxide (GFH) and Alcan FS50. A sensitivity analysis of various media costs and run lengths will be presented in this section to provide a present worth cost estimate for a range of media. Pilot testing will be required to determine which media is most suitable for the City's and OU's arsenic treatment goals.

Media Alternatives

When evaluating adsorption media technologies, the capital costs and system design remain basically the same. The main difference among adsorptive media technologies is the cost of media and how long the media will last before it must be replaced. The paragraphs below discuss GFH and FS50 media alternatives.

Granular Ferric Hydroxide Process Description

The normal method of operating a column treatment process is to run columns in series. Accordingly, the first column would run to near exhaustion to maximize the adsorptive capacity of the media, while the second column would function as a polishing column. Following first column breakthrough, the media in the first column would be regenerated or replaced and become the polishing column, while the polishing column becomes the first column. As such, the first column, which was formerly the polishing column, will be preloaded with arsenic at the beginning of each run at steady state.

An exhaustion curve provides an estimate of media run length. The exhaustion curve for a single column can be used to estimate the run length of columns operated in series. CH2M HILL research at a Nevada facility showed that series operation of the columns effectively doubles the life of the adsorptive media. The blended arsenic concentrations in the City and OU wells are not as high as those observed at the Nevada site. Specifically, the Nevada site has a raw water arsenic concentration of 130 μg/L, while the maximum blended arsenic concentrations of the City and OU grouped wells is approximately 50 μg/L. For the purpose of this Study, utilization of columns in series will be considered when the blended arsenic concentration exceeds 25 μg/L, but only one column will be used when the blended arsenic concentrations is less than 25 μg/L since utilizing columns in series is not a cost-effective practice for treating arsenic at low concentrations. This assumption will need

to be re-evaluated if pilot testing of City water is accomplished and an exhaustion curve for the media is established.

Water would be conveyed to the GFH filled vessels from the wells with the water being applied downflow in the vessel. The GFH media would be backwashed every 2 to 4 weeks with a chlorine solution to minimize the growth of bacteria on the media. The chlorine concentration in the backwash water should be around 25 mg/L. Backwash water would need to be disposed to the City sanitary sewer.

For preliminary evaluations of adsorptive processes, estimating the BV capacity of the media is a critical step for conceptual design and approximating capital and O&M costs. A BV, as defined previously, is the volume of media contained within the vessel. In 1998, Driehaus, et.al. performed studies of GFH in Germany and found that the adsorptive nature of GFH increases with decreasing pH. Figure 4-6 graphically summarizes this concept.

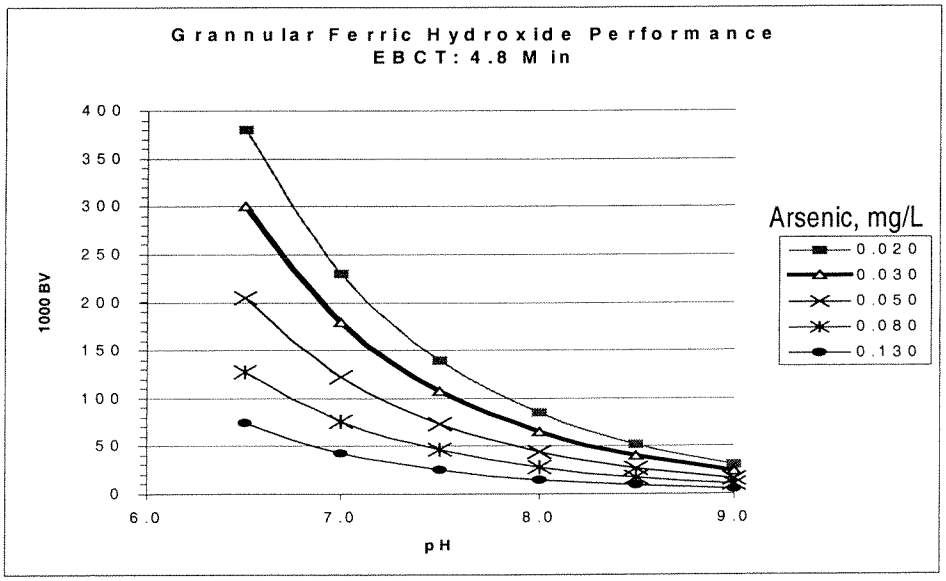

FIGURE 4-6
GFH Performance at EBCT of 4.8 Minutes
(After Driehaus)

As shown on Figure 4-6, with the arsenic concentration ranging from 20 to 130 µg/L and as pH decreases from 9.0 to 6.5, the BV treatment capacity of the GFH media increases. This indicates the pH of the feedwater has a significant impact on the adsorptive capacity of the GFH media and resulting media life. It should be noted that other water quality differences will likely impact the run length of the GFH media. As such, the run lengths presented on Figure 4-6 may not be observed when using City and OU water. As a conservative estimate, 50,000 BV for a single column GFH system and 80,000 for GFH columns operating in series was assumed for the City and OU GFH evaluation.

The kinetics of arsenic adsorption onto GFH media is somewhat slow and requires a longer EBCT than IX does. Adsorption media systems are typically designed for five-minute EBCT, which will be used for this GFH evaluation.

When the GFH media reaches exhaustion, it must be slurried from the vessels and disposed. The slurried media will be conveyed to a dumpster with a screened drain. The carrier water will be allowed to drain from the media over a period of several days to remove any free water in preparation for taking the spent media to the landfill. Because of the chemical nature of GFH, the exhausted media is expected to pass the TCLP test and will not be classified as a hazardous waste.

The pH of the City well water is typically above 8.0 and will cause adsorption media to have short run lengths. As such, the pH of the water should be adjusted to around 6.8 prior to being applied to the GFH. This can be accomplished by adding acid or carbon dioxide (CO_2). If acid is used, then a strong base such as sodium hydroxide will need to be added following the GFH to prevent a corrosive water. If CO_2 is used, then air stripping can be used to increase the pH by stripping out the CO_2.

Although previous studies have indicated the optimum pH range for GFH to be about 6.5, the cost of the GFH media and CO_2 needs to be considered as a function of operational pH in order to determine the most economical operating range. The cost of CO_2 will increase as the pH of the feedwater is lowered; however, the overall media replacement cost will go down as the pH is lowered. Presented on Figure 4-7 is the estimated cost of media and chemicals as a function of feedwater pH in the Study area. Figure 4-7 was prepared using the BV estimates established in the Dreihaus curve shown Figure 4-6.

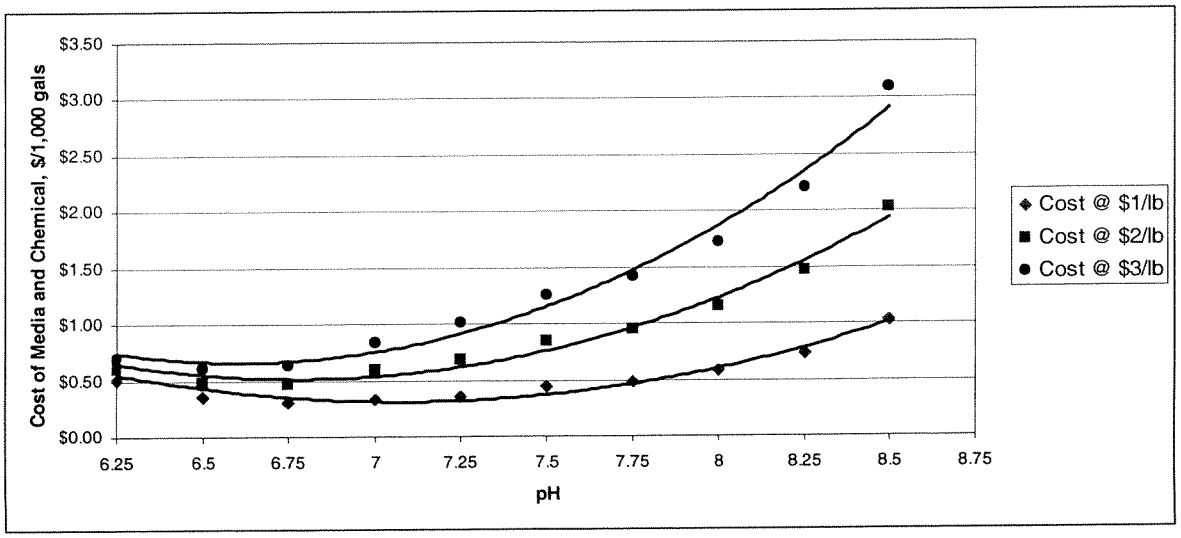

FIGURE 4-7
Estimated Cost of GFH and Chemicals as a Function of Operational pH

The costs on Figure 4-7 were developed using three costs for GFH media; these are $1.00, $2.00 and $3.00 per pound (lb). The actual cost of GFH delivered to the Study area is somewhat uncertain at this time. The current cost of GFH is around $2.50/lb. The GFH media is currently manufactured in Germany, however, US Filter has made an exclusive arrangement to market GFH in the US. If the demand for GFH is sufficient, it may become possible to produce it in the US and the cost may decrease. For the purposes of this Study, we have used a GFH cost of $2.50/lb to reflect a possible lowering of the cost in the near

future. As such, the cost curves on Figure 4-7 represent a possible range of costs for current and future conditions. The media replacement costs were developed with an estimated life using a series column operation. The CO_2 costs were estimated using $0.14/lb.

Figure 4-7 shows that with media costing $3.00/lb, the cost of media and chemicals reaches a minimum of about $0.60/1,000 gallons at a pH of approximately 6.6. At $2.00/lb, the unit cost of media and chemicals reaches a minimum of $0.47/1,000 gallons at a pH of around 6.8. If the GFH media cost were $1.00/lb, the minimum media and chemical cost occurs at a pH around 7.0 and at a cost of about $0.30/1,000 gallons. Therefore, as the price of the media goes down, the optimum pH for cost efficiency increases. Based on this data, a feedwater pH of 6.8 will be used to optimize the cost of media life.

Alternative Adsorption Media

There are other media that may be used in an adsorption media system in lieu of GFH. Such media may include Alcan FS50 or a new media developed by the Sandia National Labs (SNL). The Alcan FS50 media is an iron-coated activated alumina media and the SNL media is composed of a mixed metal oxide. Pilot testing of Alcan FS50 media in Fallon, Nevada, has demonstrated a run length of around 60 percent that of GFH. However, the cost of FS50 is around $1.00/lb, approximately 40 to 50 percent the cost of GFH.

In very preliminary small-scale column studies, the SNL media outlasted GFH by 3 to 5 times. At this point in time, GFH is the best media to consider for arsenic removal. However, if the City selects adsorption media technology, there may be other media to consider in the future.

Conceptual Adsorption Media Facilities

The facility design requirements and estimated costs are based on utilizing GFH as the adsorptive media, assuming a media cost of $2.50/lb, and a media run length of either 50,000 or 80,000 as described in the next paragraph. For the purposes of this Study, the costs developed will be based on the use of GFH.

The GFH facilities would have at least two treatment trains to allow switch-out of media while maintaining one vessel in service. For the wells with higher arsenic levels (above 25 μg/L) the design would consist of two vessels operated in series. This would allow the media to be more fully utilized; the first vessel would take out the majority of arsenic and the second vessel would act as a polishing filter. When the system reaches an arsenic leakage of 8 μg/L, the media in the first vessel would be replaced and the second column would then be used as the lead column. With low arsenic concentrations (below 25 μg/L) a single column train would be used. Table 4-6 provides information regarding columns and media volume and life for each facility.

TABLE 4-6
GFH Conceptual Design Parameters[a]

Item	Well Group No.							
	1	2	3	4	5	6	7	8
Design Capacity[b], gpm	646	956	1,940	212	697	230	686	184
Number of Trains	2	2	3	2	2	2	2	2
Vessels per Train	1	2	2	1	2	1	2	2
Vessel Diameter, ft	8	10	11	5	8	5	8	4
Total Facility Media, lbs	38,700	121,000	219,500	15,100	77,400	15,100	77,400	19,400
Life of Media per Train, days	202	341	305	241	300	222	304	284

Notes:
[a] Pilot testing is required to determine actual bed volume run time.
[b] Design Capacity based on 100% of groundwater being treated.

All rinse water and backwash water would be sent directly to the sanitary sewer system. Chemical storage and feed systems would be provided for CO_2. In addition each treatment site would include onsite sodium hypochlorite (NaOCl) generation equipment for arsenite oxidation and groundwater disinfection if needed.

Chemical Use for Adsorption Facilities

Carbon Dioxide, CO_2

Carbon dioxide would be used to lower the pH of the feedwater to around 6.8. Based on the chemistry of the Study area water supply, this would require a dose of around 100 mg/L, and would require post-treatment air stripping to readjust the pH level. The pH would need to be adjusted back up to avoid corrosive conditions.

Sodium Hypochlorite, NaOCl

Sodium hypochlorite is an effective disinfectant and oxidizer, which is generated by passing a concentration brine solution (NaCl and H_2O) through an electrolytic cell that separates the brine into hydrogen gas (H_2) and NaOCl. The process is safe and simple, and eliminates the handling of dangerous chemicals usually associated with disinfectants and oxidants.

At a concentration of 25 mg/L, chlorine would be added to the backwash water to minimize the growth of bacteria on the media. Backwashing would occur every two to three weeks. In addition, if further testing reveals that the groundwater requires disinfection according to the GWR, or if oxidation of arsenite to arsenate is needed, onsite NaOCl generation would be utilized.

GFH Media

Although several types of media are available for adsorption processes, this Study considers GFH. GFH media is assumed to have a life of around 80,000 BV for the City and OU systems when operated in series. For facilities operating a single-column system, a media life of 50,000 BV was assumed. Based on the average-annual flow, Table 4-6 provides estimates of the average life of GFH media at each treatment facility.

Impacts on Water Quality

The addition of CO_2 for pH adjustment would result in no adverse affects to the water quality. The pH would be lowered with the CO_2 addition and air stripping would be used to remove CO_2 prior to the distribution system.

Residuals Processing and Handling for Adsorption

All rinses and backwash volumes would be sent directly to the sanitary sewer system. The arsenic laden media would require disposal incrementally. As indicated previously, due to the chemical nature of the GFH, the exhausted media is expected to pass the TCLP test and not be classified as a hazardous waste; the same is true for other considered media. The GFH media must be drained of any free water before it is taken to a landfill. Table 4-7 indicates the volume of wasted media sent to the landfill and the volume of wasted water sent to the City WWTP.

TABLE 4-7
GFH Process Wasting

Item	Well Group No.								
	1	2	3	4	5	6	7	8	Total
Annual Wasted Media, pounds	37,200	41,000	84,900	13,900	30,200	19,900	26,200	8,100	261,400
Arsenic in Wasted Media, mg/kg	170	2,300	1,760	410	1,870	350	2,460	2,730	1,510
% Water Wasted	0.12%	0.12%	0.18%	0.12%	0.18%	0.08%	0.21%	0.17%	0.15%

The overall percent of water wasted is a very low 0.2 percent since the media is not regenerated and only backwashing to prevent biofilm production is required.

Estimated Capital Costs for Adsorption

The estimated capital costs for adsorptive facilities at the City and OU water systems are presented in Table 4-8. Considering a total capital cost estimate of $14.5 million, the unit cost is estimated at $1.81 per gallon per day of treatment capacity. Detailed GFH cost estimates are provided in Appendix D.

Estimated Annual O&M Costs for Adsorption Media

The estimated annual O&M costs associated with adsorption media facilities vary among media types, as indicated previously. Table 4-9 summarizes these estimated costs according

Table 4-8: GFH Capital Cost Estimates

Item	Well Group No. 1	2	3	4	5	6	7	8	Total
Booster Pumping/ Straining	$121,000	$143,000	$232,000	$73,000	$125,000	$73,000	$121,000	$69,000	$957,000
Media Facilities	$344,000	$939,000	$1,614,000	$186,000	$688,000	$186,000	$688,000	$281,000	$4,926,000
Chemical Feed Systems	$140,000	$206,000	$419,000	$46,000	$151,000	$50,000	$148,000	$40,000	$1,200,000
Building	$86,000	$150,000	$250,000	$60,000	$120,000	$60,000	$120,000	$68,000	$914,000
Piping, I&C, Electrical, Yard Piping Allowances	$181,000	$387,000	$680,000	$91,000	$289,000	$92,000	$287,000	$117,000	$2,124,000
Ancillary Offsite Pipiing	$174,000	$286,000	$709,000	$10,000	$318,000	$238,000	$206,000	$10,000	$1,951,000
Total Facility Cost, $	$1,046,000	$2,111,000	$3,904,000	$465,000	$1,691,000	$698,000	$1,570,000	$584,000	$12,069,000
Contingency	$209,000	$422,000	$781,000	$93,000	$338,000	$140,000	$314,000	$117,000	$2,414,000
Total Estimated Facility Cost	$1,255,000	$2,534,000	$4,684,000	$558,000	$2,029,000	$838,000	$1,884,000	$701,000	$14,480,000

Table 4-9: GFH O&M Cost Estimates

Item	Well Group No. 1	2	3	4	5	6	7	8	Total
Annual Power Cost, $/yr	$6,094	$8,890	$14,412	$4,717	$7,601	$6,369	$6,647	$4,942	$59,673
CO2 Cost, $/yr	$21,094	$37,135	$77,018	$7,849	$27,373	$11,283	$23,743	$7,358	$212,854
Residuals Disposal Costs, $/yr	$837	$921	$1,910	$311	$679	$448	$589	$182	$5,876
Annual Media Replacement Costs, $/yr	$92,988	$102,313	$212,195	$34,600	$75,417	$49,738	$65,415	$20,273	$652,938
Labor Costs, $/yr	$16,500	$16,500	$16,500	$16,500	$16,500	$16,500	$16,500	$16,500	$132,000
Equipment Maintenance Costs, $/yr	$10,456	$21,902	$38,335	$5,469	$16,472	$5,530	$16,365	$6,898	$121,427
Total O&M Costs for Treatment, $/yr	$147,968	$187,661	$360,370	$69,447	$144,042	$89,867	$129,260	$56,154	$1,184,768
Unit O&M Costs for Treatment, $/1000 gal	$0.82	$0.59	$0.55	$1.03	$0.61	$0.93	$0.64	$0.89	$0.65
Present Worth	$1,697,000	$2,152,000	$4,133,000	$797,000	$1,652,000	$1,031,000	$1,483,000	$644,000	$13,589,000

Total Present Worth	$28,069,000
Total Unit Cost, $/1,000 gals	$0.77

to the selected media cost of $2.50/lb and estimated GFH run length of either 50,000 or 80,000 BV, depending on column operation. Detailed GFH cost estimates are provided in Appendix D.

On a unit cost basis, O&M for the City and OU adsorption media facilities is estimated at about $0.65 per 1,000 gallons per day, which is approximately $1.2 million annually. The total present worth of the estimated annual O&M costs for the eight facilities, determined at a net interest rate of 6 percent over a 20-year period, is $14 million. Combined with the capital cost estimate of $14.5 million, adsorption media facilities would have a total present worth cost estimate of about $28 million.

Because the cost of GFH is tentative at this time and the run length has not been confirmed, there is a level of uncertainty associated with the GFH costs presented. The same is true for the other adsorptive media considered. In an effort to normalize the potential adsorptive system costs as a function of media cost and run length, Figure 4-8 has been prepared. This figure presents the present worth cost for varying media life and four unit media costs.

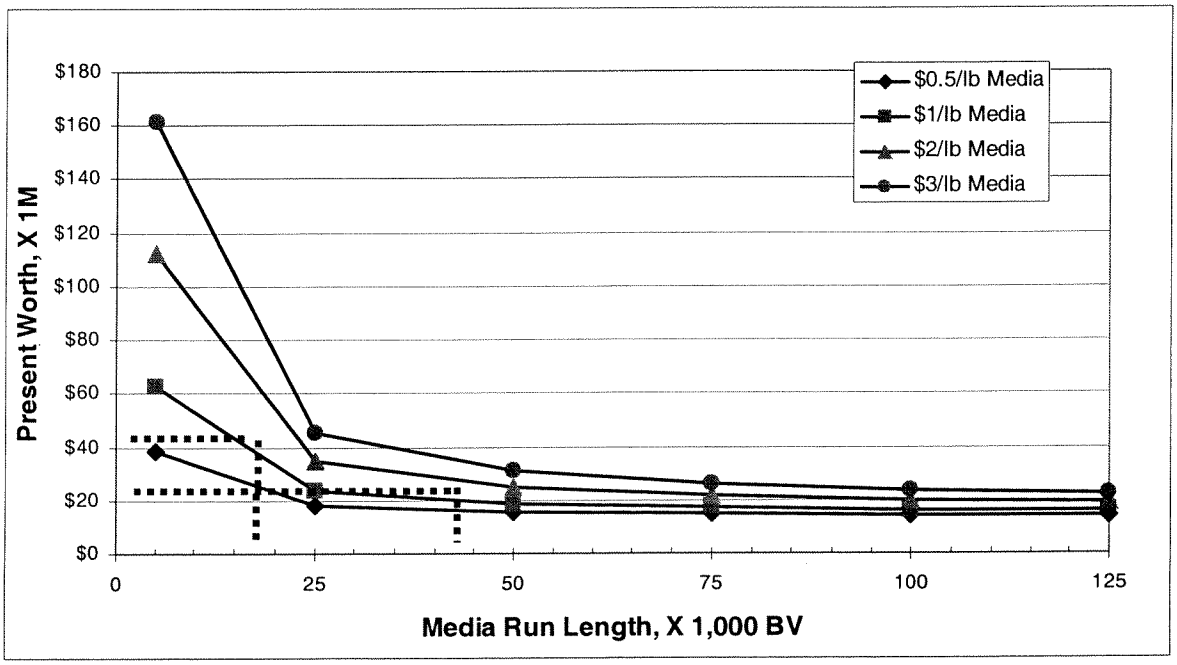

FIGURE 4-8
Comparison of GFH Present Worth Costs Vs Media Life
Estimated for Media Costs Ranging from $0.50 to $3.00 per Pound

Figure 4-8 considers the cumulative present worth cost of all eight grouped treatment facilities for a GFH treatment technology. The figure illustrates how the present worth of the GFH technology is impacted by media run length and media unit cost. For example, a present worth cost of $20 million is estimated at a run length of 42,000 BV when media cost is $1.00/lb. However, at the same media cost but at a decreased media run length of 22,000 BV, the present worth is increased to $40 million. The following conclusions can be made from the data shown on Figure 4-8.

- For all evaluated media costs, there is a significant increase in present worth when the run lengths are less than 50,000 BV.
- When media cost is constant and as the media run length or adsorptive capacity of the media decreases, the present worth costs increases.
- When present worth is constant and the media unit cost increases, the required media run length also increases.

This figure can also be used to compare present worth costs of other technologies, such as membranes or IX, to the adsorptive process costs. Specifically, at a Coagulation/ Microfiltration present worth cost of about $21 million, the media run length required is about 100,000 BV if the media cost is $2.00/lb. In other words, Figure 4-8 shows the run lengths that must be achieved at various media costs to be equivalent to the present worth costs of other treatment technologies.

Pros and Cons for Adsorption Media

The adsorption media process can be evaluated according to its pros and cons as presented in Table 4-10.

TABLE 4-10
Adsorption Process Evaluation Criteria

Criteria	Considerations
Effectiveness: Can the process effectively remove arsenic and meet the potential MCLs?	Appears to be good. Mechanical failure would only result in product water arsenic levels equal to the feedwater, except for media where pH adjustment may be necessary to avoid the occurrence of arsenic peaking.
Effectiveness: What is the impact of treatment on resulting water quality? Is there a deterioration of water quality?	The effective use of adsorption media will require pH adjustment of the raw and product water to maximize run length and avoid corrosion. Atomic Absorption (AA) and FS50 will remove naturally occurring fluoride from the water. Re-fluoridation is dependent on each water systems goals, but is not required by regulations.
Effectiveness: Will residuals be difficult to handle and dispose?	Spent adsorption media will be replaced on a regular interval determined by run length. Media life could range from 3 months to 3 years, depending on the media adsorptive capacity and the raw water arsenic concentration. However, for the media considered in this Study, run length is estimated around 1 to 2 years. The residuals will likely pass the TCLP for disposal at a landfill.
Effectiveness: What percent of water will be wasted by the process?	On an average basis, the adsorption media will waste less than 0.5 percent of the feed water. The majority of wastewater will be generated by backwashing.
Reliability: Can the process be scaled up?	Adsorption media can be scaled up; however, the chemical storage may become an issue with larger capacity facilities.
Reliability: How complex is the process to operate?	In an adsorption process, there are many valves to maintain and understand. Adsorption is a simple process requiring only the pH of the feedwater to be monitored for control of carbon dioxide feed. Water quality changes will have minimal impact since pH is the main controlling factor of the process. For iron based media, such as AA or FS50, failure to regenerate may result in arsenic peaking in the product water.
Reliability: Will chemical	The adsorptive process considered in this Study requires carbon dioxide,

TABLE 4-10
Adsorption Process Evaluation Criteria

Criteria	Considerations
handling be difficult?	which is dangerous and should be handled carefully.
Reliability: How will process control and monitoring be accomplished?	The GFH process will be controlled by maintaining the appropriate pH of the feedwater and checking the treated water arsenic on a regular basis. Because of the long run length of the media, the likelihood of inadvertently exceeding the MCL is small. However, since media has no surrogate for arsenic, online monitoring for arsenic breakthrough is not appropriate.
Reliability: What are the maintenance requirements?	The adsorption media facilities considered in this Study will require backwashing on a periodic basis and media replacement every 1 to 2 years. The chemical storage and feed equipment will require the most maintenance. In addition, the process will be controlled by a PLC and require specialized maintenance.
System Applicability: Are there environmental impacts of treatment?	The exhausted media solids that contain small concentrations of arsenic will require disposal in a landfill. The residuals are expected to pass the TCLP. Onsite storage of carbon dioxide increases the potential for accidents and releases.
System Applicability: Will the treatment process be automated and will it integrate into SCADA?	For the most part, the adsorption media processes will be automated; however, a certain level of operator attention will be required to monitor the chemical feed facilities. All automated components will be tied into a SCADA system.
System Applicability: What are the space requirements for the treatment technology?	Since solids processing and handling will not occur, the space requirement is small. An adsorptive media system of about 2,000-gpm will require a building footprint of approximately 600 ft^2.
System Applicability: How sensitive is the treatment process to water quality variations?	The adsorption media process will not be impacted by silica levels in the water because the operational pH is too low. Water with arsenite may require oxidation prior to the media absorbers. Pilot testing will provide more information. Spatial and temporal variations in water quality may result in changes in product water.
Safety: How safe is the treatment process to operate and maintain?	The adsorption media process will require the handling of carbon dioxide. Operations staff will need to be specifically trained with handling, storage, and delivery of the chemicals. The remainder of the process is typical to water treatment facilities and will require the same level of operator safety.
Upgradability: Can the process be upgraded in the future?	Changes can be implemented with the adsorption media facilities by simply switching the media if another media proves to be better suited to the application.
Well Operation: Will the treatment technology impact the operation of the wells?	The pressure loss through an adsorption process will be less than 10 psi. The wells will pump directly to the treatment facility. Following treatment, the water will be re-pumped into the distribution system.
System Optimization: Can the process be optimized so that it is not over-designed?	The adsorption media process can be effectively designed to meet specific requirements.
Public Acceptance: Will the treatment process be accepted by the public?	The onsite storage of carbon dioxide may not be acceptable to the public.
Public Education: Can the treatment process be used for public education?	The adsorption media process can be designed so that public access is appropriate.

TABLE 4-10
Adsorption Process Evaluation Criteria

Criteria	Considerations
Permits: What permits are required?	ODEQ will have specific monitoring requirements for the adsorption media process. Construction permits will be similar to any industrial facility constructed in Cleveland County.
Fluoride Addition: Will fluoride addition be required following treatment?	Although not GFH, some of the adsorptive media may remove natural fluoride in the water. Re-fluoridation is not a regulatory requirement but may be performed based on City and OU water system goals.
Sole Source: Does the equipment need to be sole sourced?	At this time, GFH and FS50 media can only be supplied by their manufacturer. The vessel and other hardware can be purchased from several manufacturers.

Coagulation/Microfiltration

The coagulation/microfiltration (C/MF) process requires adding $FeCl_3$ and attaining specific pH levels in the feedwater to function effectively. $FeCl_3$ is added to the feedwater and subsequently hydrolyzes to the precipitate FeOH. $FeCl_3$ is an acid solution and will reduce the pH of the feedwater as a function of the $FeCl_3$ dose. The arsenic will adsorb onto the FeOH floc. Then the floc will be filtered from the solution by the microfiltration (MF) unit. The adsorption of arsenic to the FeOH floc is a function of pH. Specifically, greater adsorption occurs at a lower pH. Thus, the addition of $FeCl_3$ performs two functions: it creates a FeOH floc to adsorb the arsenic, and it acts as an acid to lower the pH of the feedwater. Higher doses of $FeCl_3$ will further reduce the pH and improve arsenic adsorption and removal. $FeCl_3$ must be added and hydrolyzed to a precipitate prior to filtration. This will require rapid mixing facilities to mix the $FeCl_3$ with sufficient energy to form a floc.

The MF units would be backwashed periodically to remove accumulated FeOH solids from the membranes. The MF systems being considered utilize air to assist with the backwashing. Backwashing occurs approximately every 20 to 30 minutes. The MF unit would also have provisions for chemical cleaning when needed. Chemical cleaning would be performed using citric acid.

The treated water would have low pH from the addition of CO_2 and $FeCl_3$, requiring pH adjustment prior to conveying the finished water to the distribution system. Air stripping can be used to increase pH. It is desirable to minimize the pH reduction of the feedwater to minimize the energy required for air stripping, yet still achieve the required arsenic removal.

The generated residuals would then be thickened and dewatered to minimize their volume. Previous testing has indicated that the arsenic-containing residuals generated by the C/MF process will pass the TCLP and can be disposed at a landfill.

Rapid Mixing

Effective rapid mixing of the $FeCl_3$ is required to create a FeOH floc that can be removed by MF. The mixing intensity of a rapid mixer can be defined by the velocity gradient, G. The value of G is inverse seconds, sec^{-1} and is a function of the power applied by a mixer, the water viscosity, and volume of the mixing vessel. The equation for velocity gradient is presented below:

$$G = \sqrt{\frac{P}{uV}}$$

where:

G	=	Velocity gradient, sec^{-1}
P	=	Power imparted to the water per unit volume of basin, hp/ft^3
u	=	Absolute viscosity of the water, $lb\text{-}sec/ft^2$
V	=	Basin volume, ft^3

Recent pilot testing performed by CH2M HILL in Albuquerque, New Mexico, and confirmed in Fallon, Nevada, used transmembrane pressure (TMP) as an indicator of mixing effectiveness and minimum detention time. The TMP is a pressure difference upstream and downstream of the membrane and is a measure of membrane fouling. The results are presented on Figure 4-9.

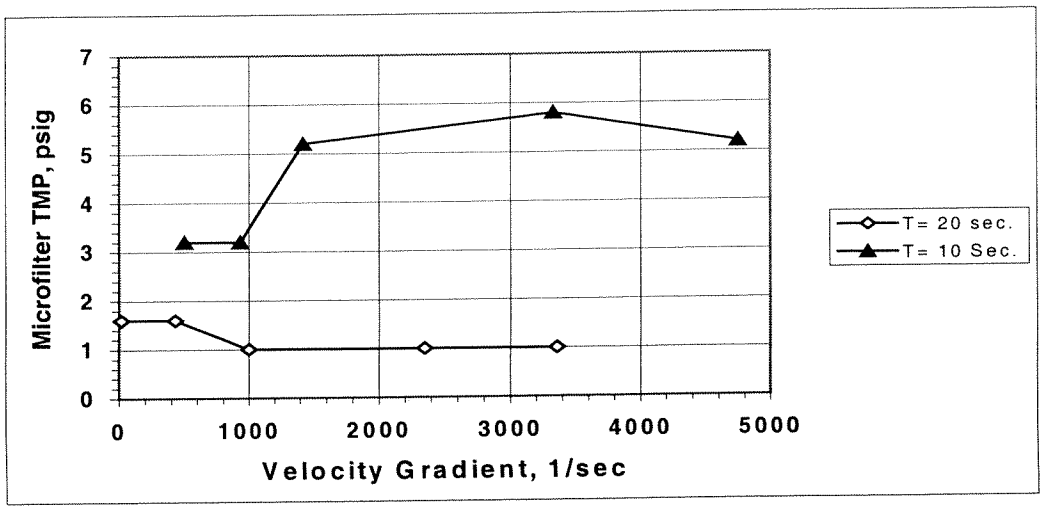

FIGURE 4-9
Impact of Rapid Mixing on C/MF

At a 10-second detention time, the TMP increased to approximately 6 pounds per square inch (psi) regardless of the mixing energy. This indicates that 10 seconds detention time is insufficient to create a FeOH floc. At 20 seconds detention time, the TMP drops when the G value approaches 1,000 sec^{-1}. This figure indicates that at a G value of approximately 1,000 sec^{-1} and a mixing time of 20 seconds, the TMP is the lowest, indicating that there was no membrane fouling and a strong FeOH floc was formed.

Therefore, it is recommended that the design criteria for a rapid mixing unit be as follows:

- Velocity Gradient: 1,000 sec^{-1} minimum
- Minimum Detention Time: 20 seconds

Microfiltration Unit Process

The flux rate of the MF unit appears to be a key parameter for effective operation when a coagulant is used. In the past, microfilters have been applied to drinking water supplies for turbidity removal. Natural turbidity typically consists of sediments that can be easily removed from a microfilter by backwashing. MF treatment processes are typically designed to meet a 30-day chemical cleaning frequency. Chemical cleaning of the membranes is accomplished using a citric-acid solution to dissolve the iron materials that may have accumulated within the membrane cartridge. Pilot testing in Albuquerque, New Mexico, and Fallon, Nevada, have shown that low total organic carbon (TOC) groundwater does not seem to cause significant fouling as is sometimes seen with surface waters.

Flux is defined as the instantaneous flow per unit area of membrane and is typically expressed in terms of gallons-per-square-foot-per-day (gfd). The membranes are tubular in shape and the surface area is calculated based on the outside surface area of the membrane.

The flux rate is also determined by the type of microfilter configuration. The Pall microfilter includes a recirculation line that allows the feed solids to keep moving through the membrane cartridge. The Memcor unit is a dead-end system that functions without recirculation. Preliminary pilot testing in Fallon, Nevada, and El Paso, Texas, indicates that a flux rate of around 50 gfd for the Pall system and around 23 gfd for the Memcor system may provide a conservative design. The maximum flux rate necessary to provide a chemical cleaning frequency of 30 days will need to be confirmed during pilot testing.

Conceptual C/MF Facility

The conceptual C/MF facilities for the City and OU sites would each consist of a single rapid mix unit followed by the microfilter equipment. The rapid mixer would provide a detention time of around 20 seconds. The microfilter equipment would consist of either a two-skid Pall system or a four-skid Memcor system. Backwash would be conveyed to the solids thickening processes for dewatering. The supernatent would be recycled. Each treatment site may also require onsite NaOCl generation equipment for arsenite oxidation and groundwater disinfection, although testing is required for verification.

Treated water would be delivered directly to the water distribution system. Chemical requirements would include $FeCl_3$ and CO_2. Air stripping would occur to stabilize the pH of the water following treatment. Chemical storage at each site would be accomplished by placing a storage tank within a secondary containment vault located outside of the treatment building.

The C/MF process should be capable of producing a treated water arsenic concentration of 2 μg/L as long as sufficient pH and $FeCl_3$ dose is applied. As such, it is possible to blend a portion of the untreated water with the treated water to minimize the design capacity of the facility.

Chemical Use for C/MF

Ferric Chloride, $FeCl_3$

The dose of $FeCl_3$ required to achieve arsenic removal will vary depending on the arsenic removal required. Figure 4-10 presents the impact of varying $FeCl_3$ dosage as observed in the Albuquerque, New Mexico, pilot study.

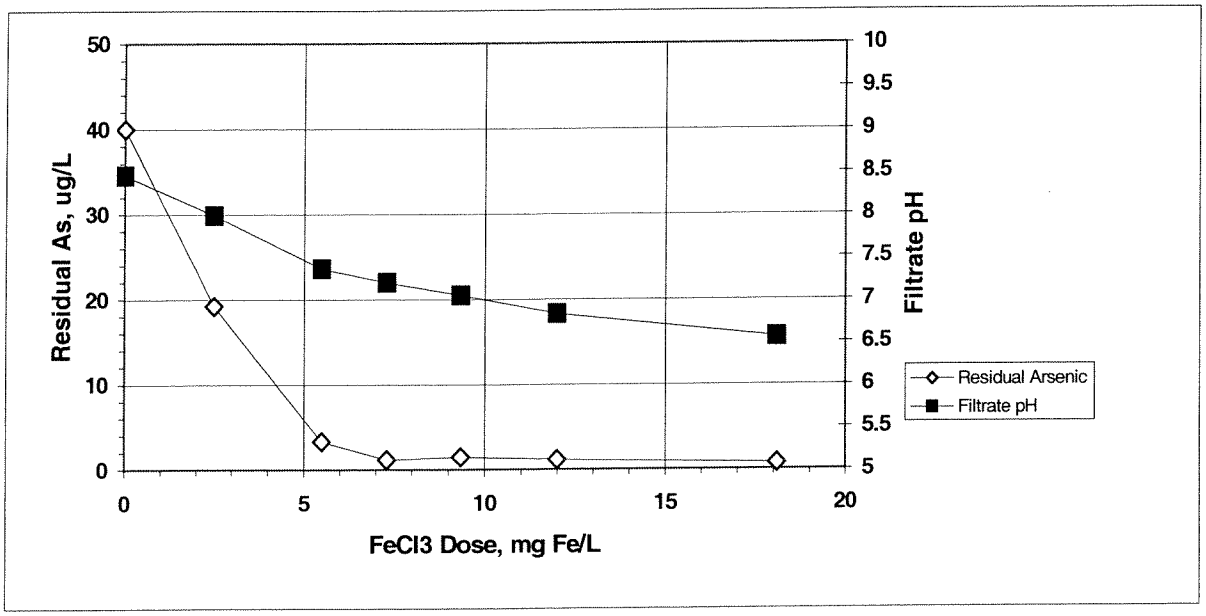

FIGURE 4-10
C/MF Arsenic Removal Vs Ferric Chloride Dose

Figure 4-10 indicates that a finished water arsenic level of 2 μg/L can be achieved with a $FeCl_3$ dose of approximately 8 mg/L as Fe(III) (23 mg/L as $FeCl_3$) based on a New Mexico site's raw water that has an average pH similar to City's and OU's. For the purpose of this study, a dose of 15 mg/L of $FeCl_3$ is assumed, although pilot testing is required to determine the actual dose required. This dose should reduce the pH of the water to 7.3, which is optimum for the MF process. However, if pilot testing proves otherwise, CO_2, which can be air stripped prior to distribution, would be used for further pH adjustment.

C/MF relies on the addition of $FeCl_3$ to adsorb the arsenic from the water. There is some evidence to suggest that pH is more important than the $FeCl_3$ dose. This is shown on Figure 4-11.

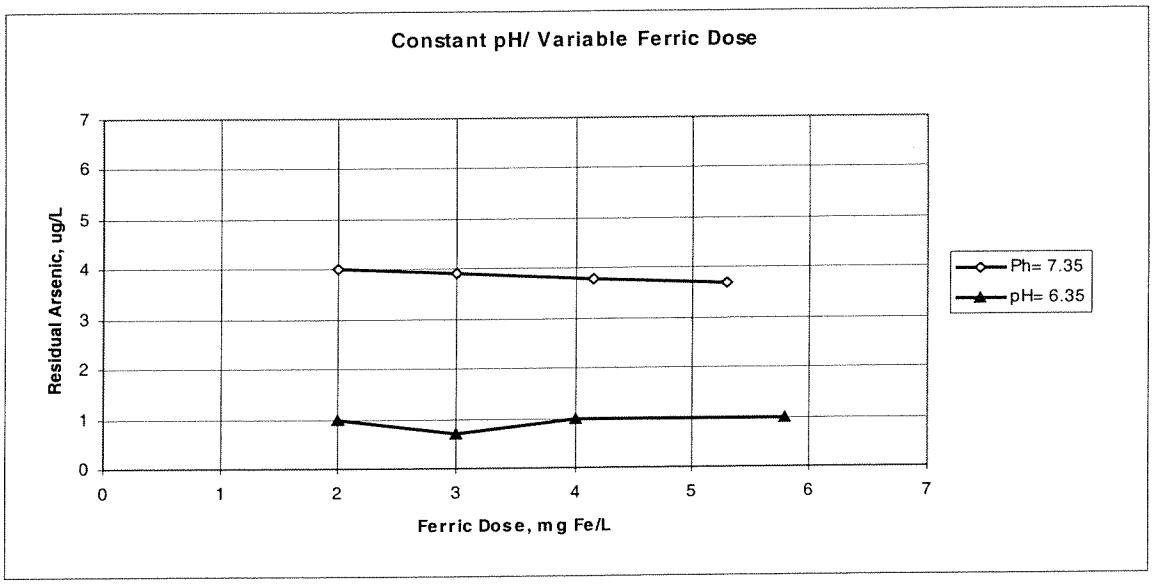

FIGURE 4-11
Impact of pH on Ferric Chloride Dose

Figure 4-11 indicates that an increased $FeCl_3$ dose does not result in an increased arsenic removal if the pH is held constant. Therefore, it appears that pH may control the removal of arsenic more than dosing with $FeCl_3$. Taking this information into consideration, the removal of arsenic is expected to be achieved by adding only enough $FeCl_3$ to lower the pH to the appropriate level.

Silicates may impact arsenic removal by surface complexation with the FeOH. Silicate interference is more of a problem at higher pH due to the specific form of the silicate. The dissociation of silicic acid is as follows:

$$H_4SiO_4 = H_3SiO_4^- + H^+$$

The pKa, the negative log equilibrium constant, at 25°C is 9.5. This means that at a pH of 9.5, the species distribution will be 50 percent H_4SiO_4 and 50 percent $H_3SiO_4^-$. At a lower pH, the more neutral and noncompeting H_4SiO_4 species will predominate. Based on USGS data, the silica levels in the City and OU Study areas range from 6.3 to 54 mg/L and have an average concentration of 14 mg/L, a relatively low level. This concentration of silica is not expected to significantly impact $FeCl_3$ dosage at an operational pH of 7.3. The actual dose of $FeCl_3$ needed for effective arsenic removal will be confirmed during pilot testing.

Sodium Hypochlorite, NaOCl

Sodium hypochlorite is an effective disinfectant and oxidizer, and is generated by passing a concentration brine solution (NaCl and H_2O) through an electrolytic cell that separates the brine into H_2 and NaOCl. The process is safe and simple, and eliminates the handling of dangerous chemicals usually associated with disinfectants and oxidants. Further sampling is needed to verify whether or not arsenite oxidation is needed for treatment and whether or not the wells located in the unconfined portion of the GWA require disinfection. However, provisions for the equipment are considered for this conceptual analysis.

Impacts on Water Quality

The addition of $FeCl_3$ will not result in any adverse affects to the water quality. The TDS of the finished water may be increased slightly, but will not cause the finished water to exceed the EPA secondary standard for TDS of 500 mg/L. The current TDS of the groundwater is around 320 mg/L.

The addition of CO_2 to the water, if needed, will not adversely affect the water quality. Following treatment, air stripping will be used to remove the CO_2 and increase the pH to acceptable pH distribution levels, which range from 6.5 to 8.5.

Residuals Processing and Handling for C/MF

Residuals production and handling would occur at the C/MF treatment facilities. Table 4-11 summarizes the estimated wasted solids and water in the C/MF process.

TABLE 4-11
C/MF Process Wasting

Item	Well Group No.							
	1	2	3	4	5	6	7	8
Design Capacity[a], gpm	252	772	1,448	133	565	135	450	161
Ferric Solids Produced, lbs/yr	5,900	18,100	33,900	3,100	13,200	3,200	10,500	3,800
Dewatered Solids to Disposal, cy/yr	7	21	65	4	16	4	12	4
Arsenic Concentration in Dry Solids, mg/kg	1,900	7,700	6,100	3,000	6,500	2,700	8,100	8,900
Arsenic in Backwash, µg/L	76	314	236	63	290	58	291	228
Water Wasted, %	0.04	0.09	0.08	0.07	0.09	0.06	0.07	0.09

Notes:
[a] Treatment capacity based on C/MF achieving 2 µg/L finished water.

The total estimated residuals production would be about 57,000 lbs/yr. Additionally, the estimated annual dewatered solids to be disposed would be about 130 cubic yards per year.

Estimated Capital Costs for C/MF

The estimated capital costs for C/MF facilities for the City and OU are presented in Table 4-12. Based on a combined facility capital cost estimate of $15 million, the unit cost is about $2.62 per gallon per day of treatment capacity. Detailed C/MF cost estimates are provided in Appendix E.

Table 4-12: C/MF Capital Cost Estimates

Item	Well Group No. 1	2	3	4	5	6	7	8	Total
Booster Pumping/ Straining	$74,000	$139,000	$196,000	$65,000	$113,000	$65,000	$89,000	$67,000	$808,000
Rapid Mixing	$18,000	$18,000	$18,000	$18,000	$18,000	$18,000	$18,000	$18,000	$144,000
Microfiltration	$320,000	$812,000	$1,349,000	$187,000	$628,000	$190,000	$521,000	$220,000	$4,227,000
Solids Handling	$144,000	$213,000	$288,000	$117,000	$172,000	$117,000	$164,000	$118,000	$1,333,000
Chemical Feed Systems	$56,000	$150,000	$270,000	$35,000	$114,000	$35,000	$92,000	$40,000	$792,000
Building	$129,000	$189,000	$267,000	$115,000	$165,000	$116,000	$152,000	$119,000	$1,252,000
Piping, I&C, Electrical, Yard Piping Allowances	$153,000	$333,000	$531,000	$106,000	$261,000	$106,000	$221,000	$116,000	$1,827,000
Facility Cost, $	$894,000	$1,853,000	$2,920,000	$643,000	$1,472,000	$647,000	$1,256,000	$698,000	$10,383,000
Contingency, 20%	$179,000	$371,000	$584,000	$129,000	$294,000	$129,000	$251,000	$140,000	$2,077,000
Total Facility Cost, $	$1,073,000	$2,224,000	$3,504,000	$772,000	$1,766,000	$776,000	$1,507,000	$838,000	$12,460,000
Ancillary Facilities Capital Cost	$209,000	$343,000	$851,000	$11,400	$382,000	$285,000	$247,000	$11,400	$2,339,800
Total Estimated C/MF Facility Cost	$1,282,000	$2,567,000	$4,354,000	$783,000	$2,148,000	$1,062,000	$1,755,000	$848,000	$14,799,000

Table 4-13: C/MF O&M Cost Estimates

Item	Well Group No. 1	2	3	4	5	6	7	8	Total
Annual Power Cost, $/yr	$3,200	$6,100	$15,000	$2,700	$4,900	$2,700	$4,400	$2,800	$41,800
Annual Membrane Replacement Cost, $/yr	$4,500	$13,500	$27,000	$4,500	$9,000	$4,500	$9,000	$4,500	$76,500
FeCl3 Cost, $/yr	$800	$2,500	$7,700	$400	$1,900	$400	$1,500	$500	$15,700
CO2 Cost, $/yr	$6,200	$18,900	$57,500	$3,300	$13,900	$3,300	$11,000	$3,900	$118,000
Residuals Disposal Costs, $/yr	$300	$1,000	$2,900	$200	$700	$200	$600	$200	$6,100
Total Estimated Labor Costs, $/yr	$16,500	$16,500	$16,500	$16,500	$16,500	$16,500	$16,500	$16,500	$132,000
Equipment Maintenance Costs, $/yr	$10,700	$22,200	$35,000	$7,700	$17,700	$7,800	$15,100	$8,400	$124,600
Total Estimateded O&M for Treatment, $/yr	$42,300	$80,800	$161,700	$35,300	$64,500	$35,400	$58,000	$36,900	$514,900
Unit O&M Costs for C/MF	$0.64	$0.40	$0.26	$1.01	$0.43	$1.00	$0.49	$0.87	$0.41
Present Worth	$485,000	$926,000	$1,855,000	$404,000	$740,000	$406,000	$666,000	$423,000	$5,905,000

Total Present Worth	$20,700,000
Total Unit Cost, $/1,000 gals	$0.82

Estimated Annual O&M Costs for C/MF

The estimated annual O&M costs associated with C/MF facilities operated on City and OU common well sites are presented in Table 4-13. Based on the combined annual costs of approximately $515,000 annually, the total present worth is $6 million, which was determined at a net interest rate of 6 percent over a 20-year period. This results in an O&M unit cost of $0.41 per 1,000 gallons of treated water. Combined with the capital cost estimate of $15 million, C/MF treatment has a total present worth cost estimate of about $21 million. Detailed C/MF cost estimates are provided in Appendix E.

Pros and Cons for C/MF

The C/MF process can be evaluated according to its pros and cons as presented in Table 4-14.

TABLE 4-14
C/MF Evaluation Criteria

Criteria	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 may require pH adjustment of the product water to minimize corrosiveness, which may be achieved by air stripping. The ferric chloride will slightly increase the TDS of the drinking water. Addition of carbon dioxide, if needed, will not adversely affect the final water quality since air stripping will occur.
Effectiveness: Will residuals be difficult to handle and dispose of?	The solids handling will require two steps—thickening followed by dewatering. The residuals will likely pass the TCLP for disposal at a landfill. It may be possible to discharge the backwash to a sanitary sewer.
Effectiveness: What percent of water will be wasted by the process?	The C/MF process will waste about 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 the 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 will require ferric chloride, which is an acidic material that will burn skin and stain materials. Ferric chloride is dangerous and should be handled carefully. Carbon dioxide may also be required for further pH adjustment, which is not hazardous.
Reliability: How will process control and monitoring be accomplished?	The C/MF process will be controlled by maintaining the appropriate pH of the feedwater. The pH of the product water downstream of the membrane will be monitored to prevent fouling of the pH probe. The pH controller will increase or decrease the ferric chloride addition to the rapid mixer. Wells taken out of service can be brought back online with minimal preparation.
Reliability: What are the maintenance requirements?	The MF facilities will require membrane replacement periodically. The process will be controlled by a PLC and require specialized maintenance.

TABLE 4-14
C/MF Evaluation Criteria

Criteria	Considerations
	The solids handling facilities will require the most maintenance, including pumps and filter press.
System Applicability: Are there any environmental impacts of treatment?	The ferric hydroxide solids that contain concentrations of arsenic will require disposal in a landfill.
System Applicability: Will the treatment process be automated and will it integrate into SCADA?	For the most part, the C/MF process will be automated. However, a certain level of operator attention will be required periodically. All automated components will be tied into the SCADA system.
System Applicability: What are the space requirements for the treatment technology?	Although the space requirements vary among treatment sites, a nearly 2,000 gpm C/MF system will require a building footprint of approximately 2,700 ft^2.
System Applicability: How sensitive is the treatment process to water quality variations?	The C/MF process may be impacted by silica levels in the water. Silica may increase the ferric chloride dose. However, silica levels in the City and OU area are relatively low. Water with arsenite will require oxidation prior to microfiltration. The MF membranes specified should be PvDf to allow the use of sodium hypochlorite, if needed.
Safety: How safe is the treatment process to operate and maintain?	The C/MF process will require handling chemicals, which are hazardous. The operations staff will need to be specifically trained in the handling, storage, and delivery of these chemicals.
Upgradability: Can the process be upgraded in the future?	As membrane technology improves, the C/MF process could be upgraded, but only by redesign of the membrane system since each system is proprietary.
Well Operation: Will the treatment technology impact the operation of the wells?	The pressure loss through the C/MF process will be around 15 to 20 psi. The wells will pump directly to the treatment facility. Following treatment, the water will be repumped into the distribution system.
System Optimization: Can the process be optimized so that it is not overdesigned?	The C/MF process can be effectively designed to meet specific requirements.
Public Acceptance: Will the treatment process be accepted by the public?	The large volumes of ferric chloride may not be acceptable to the public.
Public Education: Can the treatment process be used for public education?	The C/MF process can be designed so that public access is appropriate.
Permits: What permits are required?	ODEQ will have specific monitoring requirements for the C/MF process. Construction permits will be similar to any industrial facility constructed in Cleveland County.
Fluoride Addition: Will fluoride addition be required following treatment?	C/MF will likely remove natural fluoride in the water and will require fluoride addition following treatment, if desired by the City and OU.
Sole Source: Does the equipment need to be sole sourced?	No. Microfiltration membranes and equipment can be specified and purchased from several vendors.

Coagulation/Filtration

The coagulation/filtration (CF) process is presented by EPA as a BAT and is mainly intended for use by existing surface WTPs that only need to enhance their coagulation. Conventional water treatment facilities can be used effectively to remove arsenic from groundwater, however, the construction of a conventional WTP for arsenic removal from groundwater would not be cost effective. In order to be cost effective for groundwater sources, the use of pressure filters would be required. Pressure filters used in a direct filtration mode have been used for removing iron and manganese from groundwater. The CF process is very similar to C/MF except that a pressure filter would be used in lieu of a microfilter to remove the FeOH precipitate.

Under specific pH and ferric dose, arsenic would be adsorbed onto the FeOH. The FeOH floc particles would be filtered from the water by single- or dual-media filters. It should be noted that pressure filters are typically designed for operation with very low solids loading, so higher filtration rates can be achieved. However, when significant doses of $FeCl_3$ are added for arsenic removal, the filtration rate must be reduced. For arsenic removal from groundwater, the ferric dose should be limited to no more than 10 mg/L and the filtration rate should be limited to 3 gpm/ft^2. These design limitations will allow the pressure filters to operate for around 10 to 12 hours between backwash events.

The treated water would have low pH due to the $FeCl_3$ addition and would require pH adjustment prior to conveying the water to the distribution system. Air stripping can be used to increase pH. It is desirable to minimize the pH reduction of the feedwater to minimize the chemical usage, yet still achieve the required arsenic removal. Backwash residuals would be thickened and wasted, and supernatant from the process would be recycled.

Rapid Mixing

Effective rapid mixing of the $FeCl_3$ is required to create a FeOH floc for arsenic adsorption. This floc will be removed by filtration. The rapid mixing design used for C/MF will also apply for CF. Refer to the discussion on C/MF for additional information on rapid mixing. As with C/MF, it is recommended that the design criteria for a rapid mixing unit be as follows:

- Velocity Gradient: 1,000 sec^{-1} minimum
- Minimum Detention Time: 20 seconds

Filtration

The pressure filters using sand and anthracite media require a filtration rate of 3 gpm/ft^2 of filter area, which provides an estimated 12-hour run time between backwashes. The water would be conveyed from the rapid mixer to the filter vessels in a downflow direction, and the media would be backwashed regularly based on headloss through the filter. When the headloss through the filters reaches a certain point, backwashing to remove accumulated iron solids from the filter media would be required. The backwash water, carrying the FeOH floc, would be sent through a solids thickening and wasting process.

Chemicals utilized in the CF process would consist of $FeCl_3$ for coagulation, CO_2 for pH pretreatment, and chlorine for occasional filter media cleaning. CO_2 would be used to lower the pH level so that operating conditions may be achieved; and post-treatment air stripping would be used to increase the pH level to avoid corrosive conditions. The treated effluent water would be delivered directly to the distribution system.

Conceptual CF Facility

The CF process should be capable of producing a treated water arsenic concentration of 2 μg/L so long as a sufficient pH level is maintained and $FeCl_3$ is applied. As such, it is possible to blend a portion of the untreated water with the treated water to minimize the design capacity of the facility.

The conceptual CF facilities for the City and OU sites would each consist of a single, rapid-mix unit followed by a minimum of two pressure filters. The rapid mixer would provide a detention time of around 20 seconds. The pressure filters would be designed for a filtration rate of 3 gpm/ft^2. The pressure filters would be designed to have at least two filters in operation with a third filter out-of-service for backwashing. As such, each facility would have a minimum of three pressure filters. The filters would be backwashed at a rate of 16 to 18 gpm/ft^2, which is greater than the production of the other filters. As such, either a backwash storage tank would be required or a connection to the distribution system made to handle the additional flows. For the purposes of this study, a backwash storage tank would be provided. Onsite NaOCl generation equipment would also be included to aid in oxidation of arsenite and disinfection, if required.

The number of vessels required varies among treatment facilities based on maximum flow. Table 4-15 presents the estimated number of filters required and diameter of the filters for each conceptual CF process.

TABLE 4-15
CF Conceptual Design Parameters

Item	Well Group No.							
	1	2	3	4	5	6	7	8
Design Capacity, gpm	252	772	1,448	133	565	135	450	161
Flow Rate, gpm/ft^2	3	3	3	3	3	3	3	3
Number of Vessels per Facility	3	4	6	3	3	3	3	3
Vessel Diameter, ft	8	11	12	6	11	6	10	6

Notes:
[a] Treatment capacity based on CF achieving 2 μg/L finished water.

Treated water would be delivered directly to the water distribution system. Chemical storage and feed systems would be provided for $FeCl_3$ also for CO_2, should pilot testing confirm the need. Additionally, salt storage and hypochlorite generation equipment may be required for an oxidation phase if arsenic speciation results reveal a high level of As(III), or

if microbial sampling results are positive for the wells located in the unconfined portion of the GWA, as shown on Figure 4-1.

Chemical Use for CF

Ferric Chloride, $FeCl_3$

Similar to C/MF, CF relies on the addition of $FeCl_3$ to adsorb the arsenic from the water. $FeCl_3$ will hydrolyze to FeOH when mixed with water. The arsenic will adsorb to the FeOH precipitate. The pH needs to be sufficiently low for the effective adsorption of arsenic to the FeOH. Refer to the discussion on C/MF regarding the effects of pH on arsenic removal.

The dose of $FeCl_3$ required to achieve arsenic removal would vary depending on the arsenic removal required for the various facilities. A dose of 10 mg/L of $FeCl_3$ was assumed for the CF process. The addition of CO_2 would be required to further reduce the pH.

Carbon Dioxide

Based on initial water quality analysis, a $FeCl_3$ dose of 10 mg/L would not adequately reduce the pH optimum treatment conditions. Conceptual development of City and OU CF facilities includes a provision for CO_2 addition. Following treatment, the water would need to have the pH adjusted to a level that is not corrosive to the distribution system piping. This would occur through air stripping.

Sodium Hypochlorite, NaOCl

Sodium hypochlorite is an effective disinfectant and oxidizer and is generated by passing a concentration brine solution (NaCl and H_2O) through an electrolytic cell that separates the brine into H_2 and NaOCl . The process is safe and simple, and eliminates operations staff from handling dangerous chemicals usually associated with disinfectants and oxidants. Further sampling is needed to verify whether or not arsenite oxidation would be needed for treatment and whether or not the wells located in the unconfined portion of the GWA would require disinfection. However, provisions for the equipment are considered for this conceptual analysis.

Impacts on Water Quality

The addition of $FeCl_3$ would not result in any adverse affects to the water quality. The TDS of the finished water may be increased slightly, but would not cause the finished water to exceed the EPA secondary standard for TDS of 500 mg/L. The current TDS of the groundwater is around 320 mg/L.

Adding CO_2 to the water, if needed, would not adversely affect water quality. Following treatment, air stripping would be used to remove the CO_2 and increase the pH to acceptable pH distribution levels, which range from 6.5 to 8.5.

Residuals Production and Handling for CF

Residuals production and handling would occur at the CF treatment facilities. Table 4-16 summarizes estimates of wasted solids and water in the CF process.

TABLE 4-16
CF Process Wasting

Item	Well Group No.								
	1	2	3	4	5	6	7	8	Total
Solids Produced Annually, lbs	5,900	18,100	33,900	3,100	13,200	3,200	10,500	3,800	91,700
Dewatered Solids to Disposal, cy/yr	7	21	65	4	16	4	12	4	133
Arsenic Concentration in Dry Solids, mg/kg	1,900	7,700	6,100	3,000	6,500	2,700	8,100	8,900	-
Arsenic in Backwash, µg/L	74	324	245	110	298	101	363	394	-
Water Wasted, %	0.03	0.06	0.06	0.05	0.06	0.04	0.05	0.07	0.05

According to estimates, by recycling the supernatant, the CF process wastes less than 0.1 percent of process water. Additionally, about 92,000 pounds of solids is estimated annually.

Estimated Capital Costs for CF

The estimated capital costs for CF facilities for City and OU are presented in Table 4-17. Based on estimates, the total capital cost for the eight facilities is approximately $15 million, which is a unit cost estimate of $2.71 per gallon per day of treatment capacity. Detailed CF cost estimates are provided in Appendix F.

Estimated Annual O&M Costs for CF

The estimated annual O&M costs associated with a CF facilities operated on the City and OU well sites are presented in Table 4-18. The average O&M cost per 1,000 gallons of treated water is $0.35. According to cost estimates, the total present worth for O&M of the CF facilities is $5 million, determined at a net interest rate of 6 percent over a 20-year period. Combined with capital cost estimates, the total present worth cost of CF facilities is about $20 million. Detailed CF cost estimates are provided in Appendix F.

Table 4-17: CF Capital Cost Estimates

Item	Well Group No. 1	2	3	4	5	6	7	8	Total
Design Capacity, gpm	252	772	1,448	133	565	135	450	161	3,917
Booster Pumping	$56,000	$121,000	$175,000	$47,000	$95,000	$47,000	$71,000	$49,000	$661,000
Rapid Mixing	$18,000	$18,000	$18,000	$18,000	$18,000	$18,000	$18,000	$18,000	$144,000
Filtration	$415,000	$742,000	$1,147,000	$306,000	$592,000	$306,000	$531,000	$306,000	$4,345,000
Thickener	$95,000	$146,000	$220,000	$87,000	$138,000	$87,000	$132,000	$88,000	$993,000
Dewatering	$60,000	$96,000	$101,000	$37,000	$64,000	$37,000	$60,000	$37,000	$492,000
Chemical Feed Systems	$56,000	$150,000	$270,000	$35,000	$114,000	$35,000	$92,000	$40,000	$792,000
Building	$145,000	$248,000	$396,000	$118,000	$191,000	$118,000	$175,000	$118,000	$1,509,000
Piping, I&C, Electrical, Yard Piping Allowances	$175,000	$318,000	$483,000	$133,000	$255,000	$133,000	$226,000	$135,000	$1,858,000
Facility Cost, $	$1,020,000	$1,840,000	$2,809,000	$781,000	$1,467,000	$781,000	$1,304,000	$791,000	$10,793,000
Contingency, 20%	$204,000	$368,000	$562,000	$156,000	$293,000	$156,000	$261,000	$158,000	$2,158,000
Total Facility Cost, $	$1,220,000	$2,210,000	$3,370,000	$940,000	$1,760,000	$940,000	$1,570,000	$950,000	$12,960,000
Ancillary Facilities Capital Cost	$209,088	$343,411	$850,925	$11,405	$382,061	$285,120	$247,104	$11,405	$2,341,000
Total Estimated C/F Facility Cost	$1,430,000	$2,550,000	$4,220,000	$950,000	$2,140,000	$1,220,000	$1,810,000	$960,000	$15,280,000
Unit Cost, $/gpd	$3.95	$2.30	$2.02	$4.95	$2.63	$6.26	$2.79	$4.14	$2.71

Table 4-18: CF O&M Cost Estimates

Item	Well Group No. 1	2	3	4	5	6	7	8	Total
Annual Power Cost, $/yr	$2,900	$5,500	$14,100	$2,300	$4,500	$2,300	$3,900	$2,400	$37,900
FeCl3 Cost, $/yr	$800	$2,500	$7,700	$400	$1,900	$400	$1,500	$500	$15,700
CO2 Cost, $/yr	$6,000	$19,000	$58,000	$3,000	$14,000	$3,000	$11,000	$4,000	$118,000
Total Estimated Labor Costs, $/yr	$17,000	$17,000	$17,000	$17,000	$17,000	$17,000	$17,000	$17,000	$136,000
Equipment Maintenance Costs, $/yr	$12,000	$22,000	$34,000	$9,000	$18,000	$9,000	$16,000	$9,000	$129,000
Residuals Disposal Costs, $/yr	$300	$1,000	$2,900	$200	$700	$200	$600	$200	$6,100
Total Estimated Annual O&M Costs, $/yr	$39,000	$67,000	$132,000	$32,000	$55,000	$32,000	$49,000	$33,000	$439,000
Unit O&M Costs for C/F, $/1000 gals	$0.59	$0.33	$0.22	$0.92	$0.37	$0.90	$0.42	$0.78	$0.35
Present Worth	$447,000	$763,000	$1,519,000	$368,000	$631,000	$369,000	$564,000	$380,000	$5,035,000

Total Present Worth	$20,315,000
Total Unit Cost, $/1,000 gals	$0.80

Pros and Cons for CF

The process can be evaluated according to its pros and cons as presented in Table 4-19.

TABLE 4-19
CF Evaluation Criteria

Criteria	Considerations
Effectiveness: Can the process effectively remove arsenic and meet the potential MCLs?	Good. CF can remove arsenic to below 2 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?	The addition of $FeCl_3$ will increase the TDS of the process water. Additionally, CO_2 will be added for pH reduction. Neither of these chemicals will adversely affect the finished water quality. If a treated water pH increase is required to avoid corrosive conditions, air stripping will be used.
Effectiveness: Will residuals be difficult to handle and dispose of?	The solids handling will require two steps—thickening followed by 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 CF process, on average, will waste less than 0.1% of the feedwater.
Reliability: Can process be scaled up?	CF can be scaled up by adding additional vessels, however, chemical storage may become an issue with larger capacity facilities.
Reliability: How complex is the process to operate?	The CF process is a simple process requiring only the pH of the feedwater to be monitored to ensure optimum conditions. The control of pH is a simple process. Water quality changes will have minimal impact since pH is the main controlling factor of the CF process.
Reliability: Will chemical handling be difficult?	The CF process requires ferric chloride as a coagulant and carbon dioxide for additional pH adjustment. Ferric chloride is an acidic material that will burn skin and stain materials. Carbon dioxide is also considered a hazardous material. Ferric chloride is dangerous and should be handled carefully. Carbon dioxide is not hazardous. Sodium hypochlorite may be used as an oxidant and disinfectant.
Reliability: How will process control and monitoring be accomplished?	The CF process will be controlled by maintaining the appropriate pH of the feedwater. The pH of the product water downstream of the membrane will be monitored to prevent fouling of the pH probe. The pH controller will increase or decrease the carbon dioxide addition to the process water. Wells taken out of service can be brought back online with minimal preparation.
Reliability: What are the maintenance requirements?	The process will be controlled by a PLC and require specialized maintenance.
System Applicability: Are there environmental impacts of treatment?	The ferric hydroxide solids that contain concentrations of arsenic will require disposal in a landfill.
System Applicability: Will the treatment process be automated and will it integrate into SCADA?	For the most part, the CF process will be automated. However, a certain level of operator attention will be required periodically. All automated components will be tied into the SCADA system.
System Applicability: What are the space requirements for the treatment technology?	The largest CF facility (1,940 gpm) will require an approximately 5,000 ft^2 building due to the large filter sizes. Additional exterior space will be needed for backwash and chemical storage and chemical delivery access.

TABLE 4-19
CF Evaluation Criteria

System Applicability: How sensitive is the treatment process to water quality variations?	The CF process may be impacted by silica levels in the water. Silica may increase the ferric chloride dose required. However, silica levels in the City and OU area are relatively low. Water with high amounts of arsenite will require oxidation prior to filtration. Oxidation with sodium hypochlorite can be used with the CF process.
Safety: How safe is the treatment process to operate and maintain?	The CF process will require handling chemicals, some of which are hazardous. The facility operations staff will need to be specifically trained with handling, storage, and delivery of these chemicals.
Upgradability: Can the process be upgraded in the future?	The process can be upgraded to accommodate additional flow; however, media options for filtration are limited.
Well Operation: Will the treatment technology impact the operation of the wells?	The pressure loss through the CF process will be around 15 to 20 psi. The wells will pump directly to the treatment facility. Following treatment, the water will be repumped into the distribution system.
System Optimization: Can the process be optimized so that it is not overdesigned?	The CF process can be effectively designed to meet specific requirements.
Public Acceptance: Will the treatment process be accepted by the public?	The ferric chloride, as well as onsite storage of carbon dioxide, and possibly hypochlorite generation equipment may not be acceptable to the public.
Public Education: Can the treatment process be used for public education?	The CF process can be designed so that public access is appropriate.
Permits: What permits are required?	ODEQ will have specific monitoring requirements for the CF process. Construction permits will be similar to any industrial facility constructed in Cleveland County.
Fluoride Addition: Will fluoride addition be required following treatment?	CF will not likely remove natural fluoride in the water.
Sole Source: Does the equipment need to be sole sourced?	No. Rapid mixing and filtration equipment can be specified and purchased from several vendors.

Nanofiltration

The use of pressure-driven membranes to remove arsenic from drinking water has been suggested as a BAT by the EPA in the AR. Pressure-driven membrane separation processes can be generally divided into four categories of increasing selectivity: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). As the driving pressure is increased, generally the selectivity is increased. MF and UF membranes use mechanical sieving to cause separation (rejection) of particles from water. However, in NF and RO processes, solution diffusion causes separation of the solutes from the water. The NF process is a pressure-driven membrane that relies on solution diffusion for separation of arsenic from water.

This section will provide information on the use of NF as it relates arsenic removal. Its effectiveness for arsenate and arsenite removal, as well as practical issues related to implementation of the NF process for arsenic removal are also discussed.

Nanofiltration Unit Process Description

Pressure-driven membranes act as a semi-permeable barrier that prevents the passage of many solutes while allowing water to pass. NF uses pressure to force water through the membrane and reject the movement of specific solutes through the membranes. The rejection of solutes such as arsenic is a function of the type of membrane and the applied pressure to the membrane.

In drinking water applications, NF membranes typically have a pore size ranging from 0.001 to 0.002 μm and a molecular weight cut off (MWCO) of approximately 200 to 300 daltons. NF membranes are capable of removing colloidal organics as well as calcium and magnesium ions. In addition, NF membranes are capable of removing arsenic from drinking water. However, if significant concentrations of arsenite are present in the water, it must be oxidized to arsenate prior to NF (Amy, 2000).

Recovery of process water is a function of several factors including feed water quality, pretreatment, and permeate water quality. Feed water quality impacts recovery from the standpoint of potential scaling due to the concentration of solutes. As recovery is increased, the concentration factor and the potential for scaling also increase. The salts that cause scaling concerns in most waters include calcium sulfate, barium sulfate, strontium sulfate, calcium carbonate, and silica.

The membrane elements can be designed to optimize recovery by staging. Assume that a single membrane can be effectively operated at a recovery of approximately 50 percent. A total system recovery of 75 percent can be achieved by a concentrate-staged design. In this design, the concentrate flow serves as the feed to a second stage membrane. This is shown on Figure 4-12.

The rejection of arsenic by NF membranes is typically very good, resulting in permeate arsenic concentrations of 5 to 10 percent of the feed water concentration. In the case of low arsenic feed water concentrations, say 20 μg/L, the permeate will be less than one μg/L. For the purposes of this study, the rejection rate has been assumed to be 92.5 percent and the recovery is estimated to be 85 percent. These low levels of arsenic in the finished water allow for blending with non-treated water to meet arsenic MCL requirements.

The advantages of blending include:

- reduction in required membrane capacity for a given finished water flow rate;
- reduced concentrate flow requiring disposal;
- corresponding reduction in the capital cost of the treatment facility including O&M costs; and
- reduction in the amount of permeate post-treatment required for corrosion control.

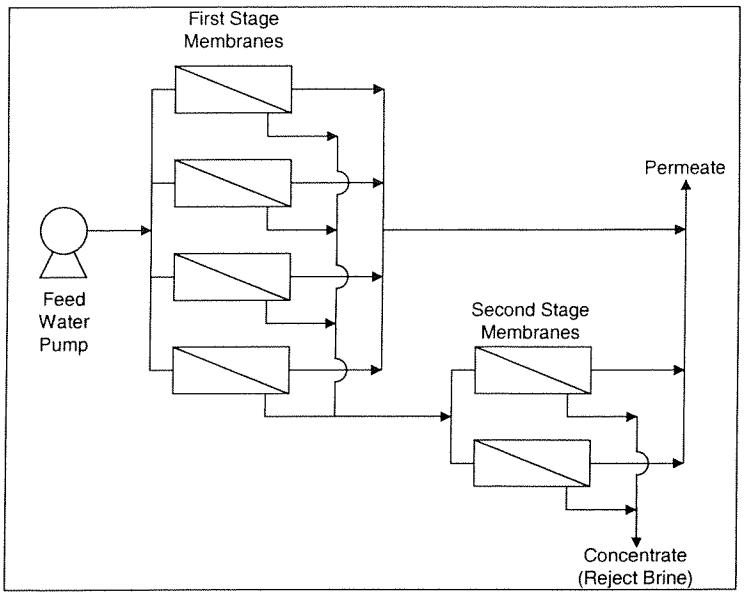

FIGURE 4-12
Concentrate Staging Design

The NF systems would utilize a pretreatment cartridge filter for backup protection of the primary membranes. In addition, to prevent membrane fouling, pretreatment of process water would occur to inhibit scaling, hydrogen sulfide gas production, iron and manganese precipitation, and microbial growth. Additional controlled parameters would include organic matter and pH.

Conceptual NF Facility

The conceptual NF facility will be based treated water with the nontreated water to achieve the target arsenic level. The treated water would be delivered directly to the water distribution system. Pretreatment of water prior to NF is discussed in the following paragraph. Pretreatment is necessary for scaling and biofilm prevention; pilot testing will provide additional information.

Chemicals and Feed Water Pretreatment

Most feed waters require some form of pretreatment for NF and RO systems. Pretreatment would increase the complexity of the treatment system and should be a consideration in the selection of an arsenic treatment process. The type of pretreatment depends on the feed water quality and membrane type. For example, pretreatment may be used to maximize the time between chemical cleanings and to prolong membrane life by preventing plugging, fouling, and scaling. Typically, pretreatment consists of providing for the control of one or more of the following: suspended solids, scale, microbial fouling, hydrogen sulfide, iron and manganese, organics, and pH.

Suspended Solids Control

Nearly all NF membrane systems use pretreatment cartridge filters nominally rated at one to 25 µm, depending on the type of system. Where solids loading may result in frequent

filter cartridge replacement or where cartridge filters are used for backup protection only, additional pretreatment such as granular media filtration or MF would be used. In groundwater with high arsenic levels, a silt density index (SDI as per ASTM D4189) test is completed to ensure that suspended solids are not being generated from the well system.

Antiscalant

Scaling control for NF membrane systems must consider carbonate, sulfate, and silica control. Depending on the hydraulic recovery, the concentration of salt ions and silica in the feed water can be concentrated during treatment by as much as 10 times. If the concentration of ions exceeds the solubility limits of the compound, scale can form in the membranes causing a deterioration of productivity and permeate quality. More important, it can cause membrane failure. The sparingly soluble salts of concern include calcium carbonate; and the sulfate salts of calcium, barium, and strontium, and silica. A scale inhibitor would be added to the raw water assist with scale prevention.

Sodium Hypochlorite, NaOCl

Microbial growth on membranes can result in membrane fouling, thus causing deterioration to productivity. In addition, several types of cellulose acetate membranes can be degraded by specific bacteria. NaOCl would be used for chlorine disinfection. The chlorine dose must be carefully controlled. Most types of cellulose acetate NF membranes can tolerate up to 1.0 mg/L of free chlorine. Oxidation will also inhibit iron or manganese precipitation, which can foul the NF membrane.

Impacts on Water Quality

NF technology would result in arsenic removal as well as calcium and magnesium removal. As such, the product water will generally be softer than is experienced now.

Residuals Processing and Handling for NF

Residuals handling is not included for the NF conceptual analysis. Instead, all backwash water would be sent directly to the City's sanitary sewer system. Table 4-20 predicts the final concentration of arsenic in the concentrate, along with an estimate of annual yield.

NF wastes approximately 15 percent of the process water. Through pilot testing, the effluent arsenic concentrations would be verified. Based on the effluent concentrations estimated (see Table 4-20), the City's industrial pretreatment limit of 0.37 mg/L for arsenic is not exceeded, nor is the arsenic total load daily limit of 1.37 pounds.

TABLE 4-20
NF Process Wasting

Item	Well Group No.							
	1	2	3	4	5	6	7	8
Design Capacity, gpm	230	772	1448	133	565	250	450	161
Effluent Arsenic, µg/L[a]	0.94	3.14	3.26	1.36	2.81	1.24	3.62	3.75
Concentrate Arsenic, µg/L	78	261	272	113	234	103	301	312

Notes:
[a] Based on 92.5% arsenic removal which assumes arsenite has been oxidized.

Estimated Capital Costs for NF

Capital costs for the NF system were based on case study curves. The results are provided in Table 4-21 along with the estimated capital costs. Based on this estimate, the unit capital cost per gallon of treated water is approximately $3.39 and the total capital cost estimate is nearly $22 million. Detailed NF cost estimates are provided in Appendix G.

Estimated O&M Costs for NF

The estimated annual O&M costs associated with the NF facilities are also based on case study cost curves. The estimated annual O&M costs are presented in Table 4-22. Based on a total annual O&M estimate of $5 million, the unit cost per 1,000 gallons is $4.03. The total present worth of the capital and annual costs for NF facilities, determined at a net interest rate of 6 percent over a 20-year period, is over $80 million. Combined with the capital cost estimate of $22 million, the NF facilities are estimated to have a total present worth of nearly $102 million. Detailed NF cost estimates are provided in Appendix G.

Table 4-21: NF Capital Cost Estimates

Item	Well Group No. 1	2	3	4	5	6	7	8	Total
Facility Cost, $	$1,644,000	$3,409,000	$4,983,000	$1,184,000	$2,827,000	$1,730,000	$2,465,000	$1,327,000	$19,569,000
Facility Unit Cost, $/gpd	$4.97	$3.07	$2.39	$6.17	$3.48	$4.81	$3.80	$5.73	$3.39
Ancillary Facilities, $	$209,000	$343,000	$851,000	$11,000	$382,000	$285,000	$247,000	$11,000	$2,339,000
Total Facility Cost, $	$1,853,000	$3,753,000	$5,834,000	$1,195,000	$3,209,000	$2,015,000	$2,712,000	$1,338,000	$21,909,000

Table 4-22: NF O&M Cost Estimates

Item	Well Group No. 1	2	3	4	5	6	7	8	Total
Annual O&M Costs, $/yr	$592,000	$655,000	$838,000	$581,000	$631,000	$581,000	$617,000	$584,000	$5,079,000
Unit O&M Cost for Treated, $/1,000	$9.80	$3.23	$1.36	$16.59	$4.25	$16.34	$5.22	$13.80	$4.03
Present Worth, 6%, 20 yrs	$8,640,000	$11,262,000	$15,440,000	$7,854,000	$10,443,000	$8,676,000	$9,794,000	$8,033,000	$80,142,000

Total Present Worth	$102,051,000
Total Unit Cost, $/1,000 gals	$4.05

Pros and Cons for NF

The process can be evaluated according to its pros and cons as presented in Table 4-23.

TABLE 4-23
NF Evaluation Criteria

Criteria	Considerations
Effectiveness: Can the process effectively remove arsenic and meet the potential MCLs?	Good. NF 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?	As adding chemicals to the raw water is not required, NF will not deteriorate water quality. However, NF removes particles associated with taste, the City and OU may require post-treatment in order to maintain a quality of water meeting the existing quality.
Effectiveness: Will residuals be difficult to handle and dispose of?	Onsite residuals processing and disposal will not occur. Rather, the backwash and concentrate would be sent directly to the City WWTP, which has processes to treat arsenic.
Effectiveness: What percent of water will be wasted by the process?	The NF process would waste up to 25 percent of the feedwater.
Reliability: Can process be scaled up?	NF can be scaled up to a larger capacity, if needed.
Reliability: How complex is the process to operate?	The NF process is a simple process requiring little monitoring. Additionally, influent water quality changes would have minimal impact on the system.
Reliability: Will chemical handling be difficult?	The NF process may not require chemical addition to the influent water although pilot testing would provide more information. However, citric acid for membrane cleaning would be onsite. Precautions should me made to avoid skin and eye contact with citric acid.
Reliability: How will process control and monitoring be accomplished?	The NF process would be fully automated and require little monitoring. As wells are taken out of and service and brought back online, finished water quality would remain constant. The effluent concentrate would most likely remain well below industrial pretreatment limits, but would require occasional sampling for verification.
Reliability: What are the maintenance requirements?	The NF facilities would require membrane replacement periodically. The process would be controlled by a PLC, which requires specialized maintenance.
System Applicability: Are there environmental impacts of treatment?	NF concentrates constituents present in the influent feed stream and sends the concentrated effluent to the WWTP. Hence, as the total load to the WWTP would increase, solids disposal to landfills would also increase.
System Applicability: Will treatment process be automated and will it integrate into SCADA?	The NF process would be automated and all automated components tied into the SCADA system.
System Applicability: What are the space requirements for the treatment technology?	Although space requirements vary among facilities, the largest facility would require approximately 2,500 ft^2. Additional exterior space would be required for chemical delivery trucks.
System Applicability: How sensitive is the treatment process to water quality	NF is sensitive to changes in influent water quality. However, the GWA produces a consistent quality of water. Depending on the arsenate content in the feed water, oxidation may be required. If so, an appropriate membrane

TABLE 4-23
NF Evaluation Criteria

Criteria	Considerations
variations?	must be selected.
Safety: How safe is the treatment process to operate and maintain?	The NF process would require the occasional handling of chemical used for spent membrane cleaning. The operations staff would need to be specifically trained with handling, storage, and delivery of this chemical, or any other chemical selected for pretreatment.
Upgradability: Can the process be upgraded in the future?	Should better suited membranes be introduced, changes can be implemented at the NF facilities.
Well Operation: Will the treatment technology impact the operation of the wells?	The pressure loss through the NF process can reach up to 100 psi. The wells would pump directly to the treatment facility. Following treatment, the water would be repumped into the distribution system.
System Optimization: Can the process be optimized so that it is not overdesigned?	The NF process can be effectively designed to meet specific requirements.
Public Acceptance: Will the treatment process be accepted by the public?	The practice of not adding chemicals to the raw water would be accepted, however, NF may produce water that does not taste as good as the original water. This may not be accepted without a post-treatment process.
Public Education: Can the treatment process be used for public education?	The NF process can be designed so that public access is appropriate.
Permits: What permits are required?	ODEQ will have specific monitoring requirements for the NF process. Construction permits will be similar to any industrial facility constructed in Cleveland County.
Fluoride Addition: Will fluoride addition be required following treatment?	NF would likely remove natural fluoride from the process water. Based on the goals of the City and OU water system, re-fluoridation may be needed but regulations do not require.
Sole Source: Does the equipment need to be sole sourced?	No. Nanofiltration membranes and equipment can be specified and purchased from several vendors.

Treatment Technologies Comparison

In order to summarize the various treatment technologies considered, Table 4-24 lists capital, O&M, and present worth cost estimates, as well as volume of wasted water and final production volume for each technology.

TABLE 4-24
Treatment Alternative Summary

Well Group No.	IX	GFH	C/MF	CF	NF
Capital, Million $	$11	$14	$15	$15	$22
Annual O&M, Thousand $	$509	$1,185	$515	$439	$5,079
Total Present Worth[a], Million $	$17	$28	$21	$20	$102
Total Unit Cost[b], $/1,000 gals	$0.67	$0.77	$0.82	$0.80	$4.05
Wasted Water	1.3%	0.15%	0.07%	0.07%	15%

Notes:
[a] Based on a 6% interest rate for 20 years.
[b] Based on average volume of treated water over 20 years.

SECTION 5

Decision Analysis for Arsenic Treatment Technologies

The purpose of this section is to summarize the results of the decision analysis that evaluated the relevant aspects of the various arsenic treatment technologies. City and OU staff evaluated the alternatives to determine which technologies best meet the needs and objectives. A decision analysis workshop was held with the staff on February 21, 2002, at the City's library meeting room. Listed below are the workshop participants.

Vernon Campbell/City of Norman
Mark Daniels/City of Norman
Brad Gambill/City of Norman
Bryan Hapke/City of Norman
Bryan Mitchell/City of Norman
Geri Wellborn/City of Norman
Don Carter/University of Oklahoma
Harvey McLaughlin/University of Oklahoma
Candy Akins/CH2M HILL
Joe Chwirka/CH2M HILL
Murry Fleming/CH2M HILL
Shane Oyler/CH2M HILL

Evaluation Criteria

To effectively evaluate the arsenic treatment technologies presented in this study, a list of screening criteria was developed and discussed at the beginning of the Study and at the workshop.

The evaluation of the technologies was based on a set of criteria intended to identify all the major issues related to the selection of a preferred technology. These criteria became the basis for measuring how well individual treatment technologies achieved the overall objective of the criteria. Listed below are the criteria used in the decision analysis for the City and OU.

Treatment Effectiveness

- Does the technology meet MCL
- Residuals handling and disposal
- Upgradability of the technology
- Ease of operation
- Maintenance requirements
- Water quality degradation
- Water recovery
- Chemical handling issues
- Process control
- Onsite and offsite safety issues

System Applicability

- Environmental impacts
- Ease of automation
- Space requirements
- Impacts of water quality variations
- Impacts on well operation

Implementability

- Public acceptance
- Public education
- Permits

Costs

- Capital costs/Annual O&M costs/Present Worth
- Optimally designed process
- Sole source issues

The workshop participants discussed the relative importance of each of the four major evaluation criteria. Each workshop participant was then asked to relatively rank the importance of each criterion. This was accomplished using a swing ranking technique and by asking the participants the following question: "If you could change (or swing) only one criterion to implement an arsenic treatment technology, which criterion would you change; or in other words, which criterion is the single most important." The participants then ranked the most important criteria by giving that criterion a score of 100 percent. The other criteria were then ranked similarly and scored appropriately. The results of the major criteria scoring are shown below.

Criteria	Score
Treatment Effectiveness	30.0%
System Applicability	21.0%
Implementability	19.0%
Costs	30.0%

The ranking of the major criteria reflects the relative importance of each criterion to the City and OU staff. Treatment effectiveness and costs criteria ranked highest followed by system applicability. Implementability ranked the lowest. The cost of the treatment facility ranked high due to the need to select a cost-effective treatment technology. The criterion weighting was then used to score the treatment technologies being considered in the Study.

This section describes the performance measures identified by the workshop participants and presents the results of the evaluation. The results presented reflect the values and opinions of the participants of the workshop.

The project team developed measurement scales for quantifying and comparing the degree to which each of the treatment technologies meets the criteria. A scale was developed for each performance measure described above. Because the treatment technologies being considered in this evaluation are being compared to each other (a relative measure) rather than to absolute objective measures, most of the performance measures are relative, as described in the following paragraphs.

The workshop participants estimated the relative performance of the technologies based on the performance measures identified in the workshop. During the workshop participants

reviewed the preliminary results of the evaluation to confirm the reasonableness of the scoring. The scoring was then revised as necessary.

The scoring for the performance measures was based on a scale of 0.0 to 1.0. A score of 0.0 indicated a less favorable or poorer than average performance. A score of 1.0 indicates a favorable or better than average performance. A summary of the final criteria scoring is presented below.

Treatment Effectiveness

The performance criteria associated with this main criterion relate to how the arsenic treatment technology would function in the City and OU. The workshop participants ranked this criterion, tied with cost, as the most important aspect of an arsenic treatment facility.

Does the Technology Meet MCL

It is anticipated that all the technologies presented will be capable of meeting the proposed EPA MCL of 10 $\mu g/L$. Each technology will have slightly different levels of treatment that are achievable. Table 5-1 presents the rankings based on the estimated levels of treatment that each technology is expected to achieve.

TABLE 5-1
Criteria: Water Quality, Does Technology Meet MCL?

Description	IX	GFH	C/MF	CF	NF
Less favorable than average					
About average		x	x	x	
More favorable than average	x				x

The GFH, C/MF, and CF technologies were ranked similarly by the workshop participants. The IX and NF processes were ranked more favorably because they can achieve very low levels of arsenic in the treated water.

Water Quality Degradation

The addition of chemicals to the water for pH adjustment will have a negative impact on the overall water quality. The secondary standard for TDS is 500 mg/L. None of the technologies investigated for this Study will increase the TDS or sulfate levels in the finished water. It was assumed that CO_2 would be used for pH adjustment and stripped out of the water following treatment, causing no increase in TDS or sulfates as mineral acid addition would.

Presented in Table 5-2 is the group ranking of water quality deterioration related to chemical addition for the various arsenic treatment technologies.

TABLE 5-2
Criteria: Water Quality, Does Treatment Technology Deteriorate Finished Water Quality?

Description	IX	GFH	C/MF	CF	NF
Less favorable than average	x				
About average		x	x	x	
More favorable than average					x

The IX technology was ranked least favorably because of the addition of chloride ions to the finished water. The GFH, C/MF, and CF were all judged to have minimal impact on finished water quality. The NF was judged to have the least impact on water quality and was judged to be more favorable because it would improve the water quality by providing softening of the water.

Residuals Handling and Disposal

The production of residuals is a significant component associated with the selection of an arsenic treatment technology. It is important that the quantity of the residuals be minimized. Presented in Table 5-3 are the estimated quantities of residuals produced by the various arsenic treatment technologies.

TABLE 5-3
Estimated Residual Production for Arsenic Treatment Technologies

Technology	Waste Brine (gal/yr)	Waste Salt (lb/yr)	Dewatered Ferric Hydroxide (lb/yr)	Exhausted Media (lb/yr)
IX	7,625,000	3,081,000	25,200	NA
GFH	NA	NA	NA	261,000
C/MF	NA	NA	91,800	NA
CF	NA	NA	91,800	NA
NF	9,060,000	NA	NA	NA

Ion exchange generates the largest quantity of residuals of all the technologies evaluated, consisting mostly of waste salt. The C/MF and CF processes generate the least volume of waste because of the estimated long run length of the media.

As decided by workshop participants, the scores for the five technologies as they impact liquid and solid residuals are presented in Table 5-4. The ranking of the liquid residuals was based on a relative scale. The ranking for the solid residuals was based on a numerical ranking of the total solid residuals produced from each technology from 0.0 to 1.0 and was approved by the workshop participants.

TABLE 5-4
Ranking of Arsenic Treatment Technologies for Liquid and Solids Residuals

Technology	Ranking of Technologies for Liquid Residuals	Ranking of Technologies for Solid Residuals
IX	Less Favorable	0.0
GFH	More Favorable	0.92
C/MF	More Favorable	0.97
CF	More Favorable	0.97
NF	Less Favorable	1.00

Water Recovery

The amount of water wasted by each technology varies. Presented in Table 5-5 are the estimated amounts of water wasted by each technology. The ranking for each technology is based on a numerical ranking of the total water wasted and was approved by the workshop participants.

TABLE 5-5
Estimated Water Waste for Arsenic Treatment Technologies

Technology	Water Waste (%)	Ranking of Technologies
IX	1.31%	0.917
GFH	0.15%	0.995
C/MF	0.07%	1.0
CF	0.10%	0.998
NF	15%	0.0

Upgradability of the Technology

This criteria relates to the ability to upgrade in the future with new or improved technology. The IX technology will be designed with an EBCT of 1.5 minutes. Therefore, the IX vessels could not be used for media requiring longer contact times. The GFH adsorption media facilities will be designed with an EBCT of 5 minutes. This contact time can be used by many media and can therefore accommodate changes of media in the future. The C/MF technology may be influenced by changes in membrane technology in the future. It is envisioned that the cost of membranes will continue to decrease and the ability to utilize coagulants with microfilters will increase in the future.

The rankings for the five technologies as they impact process upgradability agreed to by the workshop participants are presented in Table 5-6.

TABLE 5-6
Upgradability of Technology

Description	IX	GFH	C/MF	CF	NF
Less favorable than average	x				
About average				x	
More favorable than average		x	x		x

Chemical Handling Issues

The chemicals used for the various arsenic treatment technologies consist of salt, sulfuric acid, caustic soda, ferric chloride, and the media used for adsorption media technologies. Presented in Table 5-7 is a relative ranking of chemical use for the various technologies evaluated in this study.

TABLE 5-7
Relative Ranking of Chemical Use

Description	IX	GFH	C/MF	CF	NF
Less favorable than average	x				x
About average			x	x	
More favorable than average		x			

In terms of total pounds of chemicals, the IX treatment process uses the largest quantity of chemicals including salt, sulfuric acid, and caustic soda. The least amount of chemicals is used by the GFH process, which uses only CO_2 and media. The C/MF and CF technologies both use ferric chloride and CO_2.

The chemicals used for arsenic treatment can present safety issues for the workers who run the facilities. Sulfuric acid and caustic soda are dangerous chemicals and must be handled by trained operations staff using proper personal protection clothing. The storage facilities must have secondary containment and safety showers are required in areas where these chemicals can come in contact with workers.

Ease of Operation

The ease of operation is somewhat subjective. However, the IX and NF technologies were judged to be the most complex to operate. The C/MF technology is a mechanical system that operates automatically and should not require significant operational attention. However, dewatering the ferric hydroxide residuals will require operator attention. The

adsorption media technologies will require operator attention for the chemical feed facilities. The adsorption media will require minor attention except during media changeout.

The ranking for the five technologies as they impact ease of operation agreed to by the workshop participants is presented in Table 5-8.

TABLE 5-8
Relative Ranking of Ease of Operation

Description	IX	GFH	C/MF	CF	NF
Less favorable than average	x				x
About average			x	x	
More favorable than average		x			

Process Control

The control of the treatment process will play an important role in assuring that the drinking water consistently meets the arsenic MCL. There are currently no online arsenic measurement instruments available to monitor and control the arsenic treatment processes. As such, the confirmation of operational performance related to arsenic removal would be accomplished by sending water samples to a laboratory for analysis.

The day-to-day control of the treatment processes varies. All adsorption media technologies including GFH would be controlled as a function of water volume placed through the vessels. As such, changes in water quality or the condition of the media could impact the run length of the media to breakthrough. The adsorption media technologies will likely have long run lengths, so the risk of running the media past exhaustion should be low. The pH of the treated water would need to be monitored to control the dose of CO_2 required for pretreatment and post-treatment.

The C/MF process would be controlled through monitoring the filtrate water pH. As long as the filtrate pH is maintained at the level required for arsenic removal, the process will function properly.

The IX process would have a relatively short run length, averaging about 800 BV. If the media is not regenerated on time, there is a chance that the arsenic levels in the effluent will exceed the influent concentration by 2 to 5 times. This is caused by the chromatigraphic peaking effect. As such, it would be necessary to monitor the effectiveness of the IX treatment technology regularly to ensure IX resin is regenerated at the proper times.

The relative ranking for the five technologies as they impact process control agreed to by the workshop participants is presented in Table 5-9.

TABLE 5-9
Relative Ranking of Process Control

Description	IX	GFH	C/MF	CF	NF
Less favorable than average	x				x
About average					
More favorable than average		x	x	x	

Maintenance Requirements

Maintenance requirements of the arsenic treatment technologies would impact the desirability of the facility. The technologies needing regeneration would require greater maintenance because of the greater number of pumps, piping, basins, and controls. The adsorption media technologies would likely require the least amount of maintenance. The C/MF would require slightly more maintenance than the adsorption media because of the solids dewatering facilities.

The relative ranking for the five technologies as they impact maintenance agreed to by the workshop participants is presented in Table 5-10.

TABLE 5-10
Relative Ranking of Maintenance Requirements

Description	IX	GFH	CMF	CF	NF
Less favorable than average	x				x
About average			x	x	
More favorable than average		x			

Onsite Safety Issues

Onsite safety refers to the issues associated with safety at the treatment facility site. Such issues as chemical handling, truck delivery, residuals removal, etc. were considered. The IX and NF processes use the largest volume of chemicals and therefore were judged to have the highest risk of onsite accidents. The C/MF and CF processes should have less risk because of the lower volume of chemicals used. The adsorption media technologies such as GFH were judged to have the lowest risk.

The relative ranking for the five technologies as they impact onsite safety agreed to by the workshop participants is presented in Table 5-11.

TABLE 5-11
Relative Ranking

Description	IX	GFH	C/MF	CF	NF
Less favorable than average	x				x
About average			x	x	
More favorable than average		x			

Offsite Safety Issues

Offsite safety refers to safety issues that may be caused by a technology off the treatment facility site. These safety issues may include truck traffic through town and the potential of chemical spills offsite. The IX process would require a high volume of truck traffic for salt delivery and waste brine removal. This high level of truck traffic would create a higher level of safety concern than would be observed with C/MF, CF, or GFH. The NF technology was judged to have highest offsite risk because of the need for pre- and post-treatment chemical delivery.

The relative ranking for the five technologies as they impact offsite safety agreed to by the workshop participants is presented in Table 5-12.

TABLE 5-12
Relative Ranking of Off-site Safety

Description	IX	GFH	C/MF	CF	NF
Less favorable than average	x				x
About average		x	x	x	
More favorable than average					

Summary of Treatment Effectiveness Scoring

The scoring of the criteria associated with arsenic treatment effectiveness is shown on Figure 5-1. The figure shows that GFH scored highest followed closely by C/MF and CF.

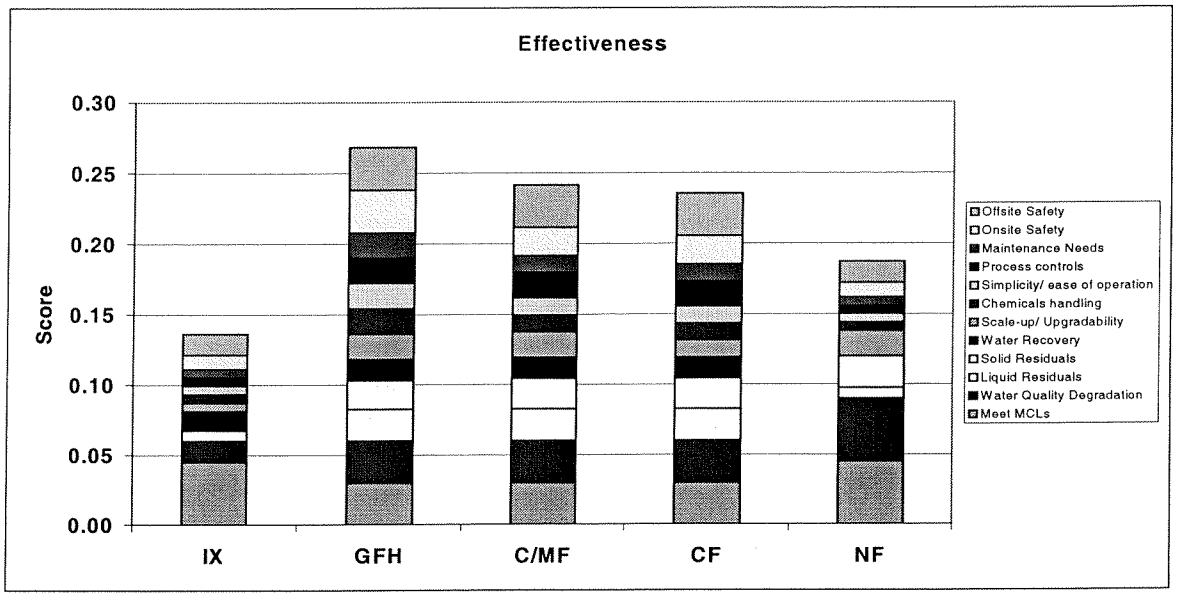

FIGURE 5-1
Summary of Scoring for Treatment Effectiveness Scoring

System Applicability

System applicability relates to the treatment technology's ability to function effectively with the City and OU water supply system. The performance criteria include environmental impacts, ease of automation, space requirements, sensitivity to water quality variations, and impacts on well operation.

Environmental Impacts

The environmental impacts for arsenic treatment include issues related to chemical use and residuals disposal. The delivery of hazardous chemicals to the treatment facility site may result in an increased potential for an accident and a spill. The residuals that will be produced are not anticipated to be hazardous for any of the technologies; however, the residuals will need to be disposed of in a landfill and the quantities should be minimized. It should be noted that the IX technology generates waste brine that may be classified as a hazardous waste under RCRA if the arsenic concentrations are greater than 5 mg/L.

Ion exchange will require sulfuric acid, ferric chloride, and caustic soda for operation. In addition, large quantities of salt will be required for regeneration, and large quantities of waste salt will be produced requiring transport and disposal. The C/MF process will require ferric chloride and CO_2 to operate. The residuals will consist of only ferric hydroxide solids with a relatively low arsenic concentration. The adsorption media technologies will require CO_2 for pre-treatment of the water to lower the pH. The only residual from the adsorption media technologies will be the exhausted media, which is anticipated to pass the TCLP test.

The relative ranking for the five technologies as they impact environmental issues agreed to by the workshop participants is presented in Table 5-13.

TABLE 5-13
Relative Ranking of Environmental Impacts

Description	IX	GFH	C/MF	CF	NF
Less favorable than average	x				
About average		x			x
More favorable than average			x	x	

Ease of Automation

The relative ease of automation is an important aspect of implementing a treatment system for the City and OU. Minimizing labor requirements will result in greater efficiency and lower costs in the long run.

The IX process can be automated to regenerate based on pre-set volumes of water treated. However, water quality variations both spatially and temporally will require water testing to assure the proper regeneration frequency. In addition the large volume of brine produced and the associated ferric precipitation requirements will require manual labor to oversee the operations.

The C/MF process can be controlled by monitoring the pH of the filtrate and would therefore be capable of being automated. The dewatering processes would still require manual labor to operate.

The adsorption media technologies would require pH monitoring for feed and treated water, which can be effectively automated. The run length would be monitored by flowmeters and stopped when the allowable number of bed volumes has been treated.

The relative ranking for the five technologies as they impact ease of automation agreed to by the workshop participants is presented in Table 5-14.

TABLE 5-14
Relative Ranking of Ease of Automation

Description	IX	GFH	C/MF	CF	NF
Less favorable than average	x				x
About average			x	x	
More favorable than average		x			

Space Requirements

The arsenic treatment facilities could potentially be located at eight sites around the City. A small footprint for the treatment technology is an advantage from several standpoints including a lower overall cost, lower construction impacts, and minimizing the visual impact of the building.

The average footprint and the ranking for the various technologies is presented in Table 5-15.

TABLE 5-15
Estimated Building Footprint for Arsenic Treatment

Technology	Average Footprint (ft^2)	Ranking of Technologies
IX	1,750	0.56
GFH	1,150	1.00
C/MF	1,550	0.69
CF	1,900	0.45
NF	2,500	0.00

Impacts of Water Quality Variations

The ability of the treatment technology to operate within the range of water quality variations that may be observed is important. The water quality in the City and OU wells has been relatively stable and not subject to significant variations. All of the technologies evaluated here should not have problems adjusting to the minor water quality variations that may be observed.

The relative ranking for the five technologies as they are impacted by raw water quality variations agreed to by the workshop participants is presented in Table 5-16.

TABLE 5-16
Relative Ranking of Impacts of Raw Water Quality Variations

Description	IX	GFH	C/MF	CF	NF
Less favorable than average	x				
About average		x			x
More favorable than average			x	x	

Mixing of Treated and Non-Treated Water

The treatment technologies would have minimal impacts on treated water quality and there should be no problems with mixing treated and non-treated water. It was judged by the

workshop participants that GFH would have a slightly less impact on mixing than the other technologies. Presented in Table 5-17 is the relative ranking of the five technologies as agreed to by the workshop participants.

TABLE 5-17
Relative Ranking of Issues Related to Mixing Treated and Non-Treated Water

Description	IX	GFH	C/MF	CF	NF
Less favorable than average					
About average	x		x	x	x
More favorable than average		x			

Impacts of Well Operation

The City and OU groundwater wells currently pump directly into the transmission line leading to the base distribution system. The treatment technologies would require around 10 to 20 psi of head to operate. City staff was concerned that variations in the pumping capacity of the wells may cause problems with the treatment facilities. The GFH adsorption media technology is designed to treat the total flow of water, i.e. no blending. As such, variations in flow would have no impact on this technology in terms of control of the blending volumes.

The relative ranking for the five technologies as they impact well operation agreed to by the workshop participants is presented in Table 5-18.

TABLE 5-18
Relative Ranking of Impact of Well Operations

Description	IX	GFH	C/MF	CF	NF
Less favorable than average					
About average	x		x	x	x
More favorable than average		x			

Summary of System Applicability Scoring

The scoring of the criteria associated with system applicability for the seven technologies evaluated is shown on Figure 5-2. This figure shows that the GFH process is ranked higher than the other technologies.

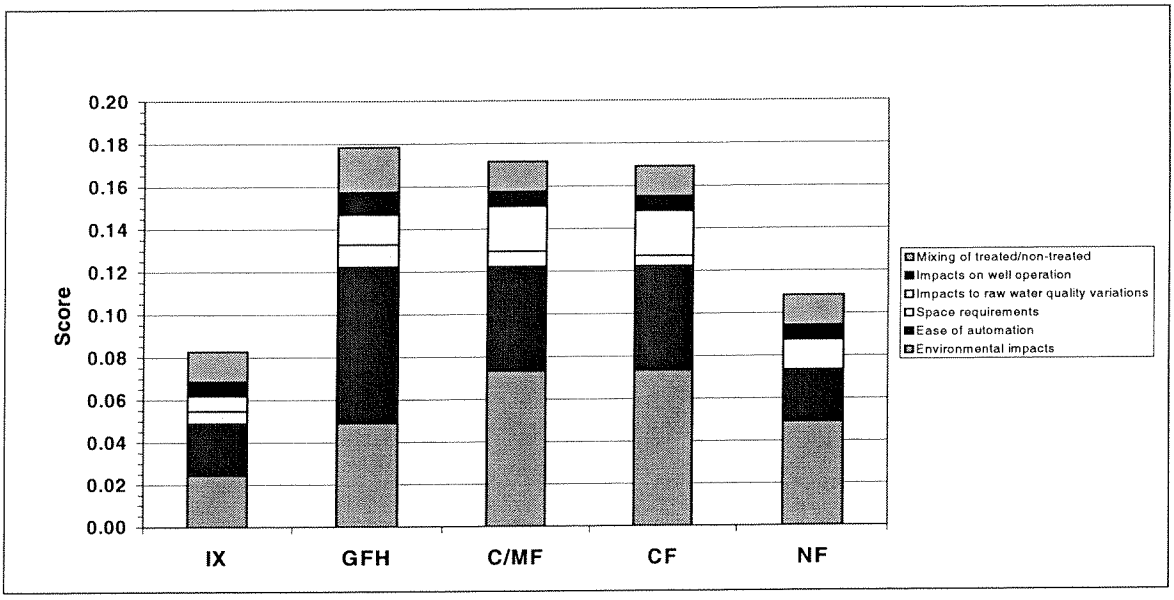

FIGURE 5-2
Summary of Scoring for System Applicability

Implementability

The ability to construct the arsenic treatment facility is an important consideration. These criteria include performance measures such as public acceptance, the ability to use the treatment facility for public education, and identifying permits that may be required.

Public Acceptance

The public acceptance of an arsenic treatment facility may determine if a technology is implementable or not. Considerations related to public acceptability may include the following.

- Will loud and continuous noise be associated with the process?
- Will high traffic volume be associated with the process?
- What will be the visual impact of the facility?
- Will hazardous materials be stored onsite?
- Will any odors be associated with the process?
- Will any taste or odor be associated with the product water?
- Will the process increase the hardness of the water?
- Will the process increase the corrosivity of the water?
- Will the product water have any negative health impacts?
- Will the process have offsite environmental impacts such as brine disposal?
- Will the process operate reliably?
- Will any process impact the water rates more than the others?
- Does the process have a scariness factor, such as loud noises, big truck traffic, potential release of spills, etc.?

The main factors impacting public acceptance are the shear volume of salt or chemical delivered to the site. The IX process requires that large volumes of salt be delivered and large volumes of waste brine removed. The C/MF, CF, GFH, and NF processes were judged to be similar in terms of public acceptance.

The relative ranking for the five technologies as they are impacted by public acceptance agreed to by the workshop participants is presented in Table 5-19.

TABLE 5-19
Relative Ranking of Public Acceptance

	IX	GFH	C/MF	CF	NF
Less favorable than average	x				
About average		x	x	x	x
More favorable than average					

Public Education

The workshop participants agreed that public education would be a very minor activity. The IX process was judged to be less attractive to public education because of the large volume of salt and chemicals required for the process. The relative ranking for the five technologies for public education potential agreed to by the workshop participants is presented in Table 5-20.

TABLE 5-20
Relative Ranking of Public Education Potential

Description	IX	GFH	C/MF	CF	NF
Less favorable than average	x				
About average		x	x	x	x
More favorable than average					

Permits

All of the treatment facilities will require the same level of permitting for construction of the facilities. However, because the IX has the potential to generate hazardous waste, it is possible that a significant level of additional permitting related to RCRA may be required. The NF technology was judged to be less favorable due to the chemicals needed for operation of the process. The GFH technology ranked the most favorable because it minimizes chemical use. The C/MF and CF technologies were ranked around average. The relative ranking for the five technologies as impacted by permitting agreed to by the workshop participants is presented in Table 5-21.

TABLE 5-21
Relative Ranking of Issues Related to Permitting

Description	IX	GFH	C/MF	CF	NF
Less favorable than average	x				x
About average			x	x	
More favorable than average		x			

Summary of Implementability Scoring

The scoring of the criteria associated with implementability for the five technologies evaluated is shown on Figure 5-3. This figure shows that the GFH technology scored the highest. The IX and NF processes scored very low due to permitting issues.

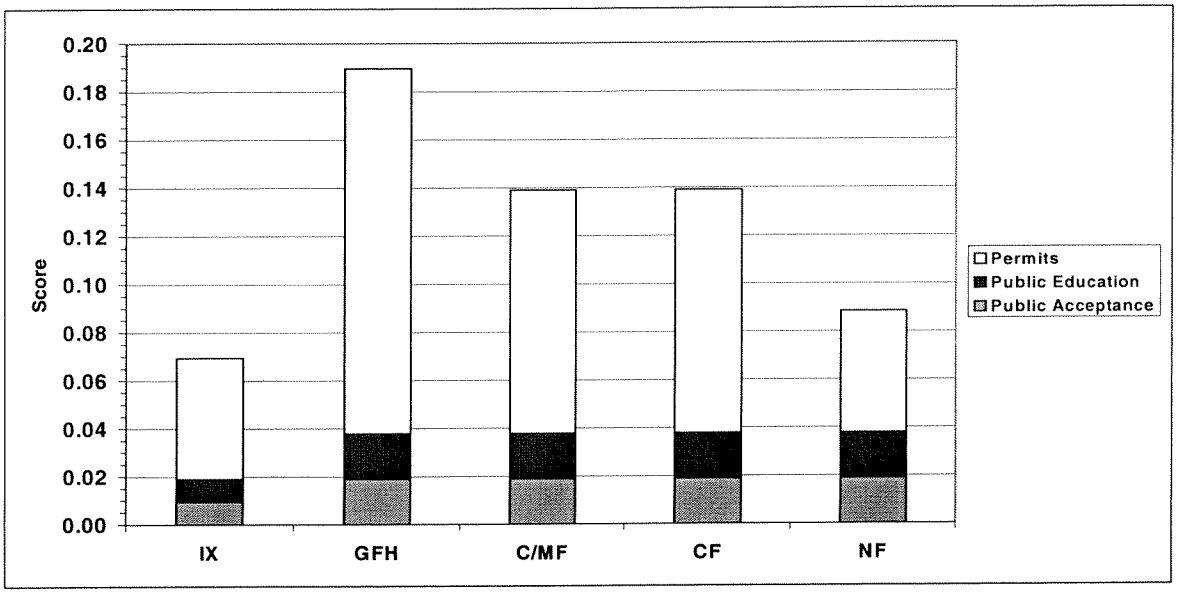

FIGURE 5-3
Summary of Implementability Scoring

Cost Impacts

The criteria included in cost impacts relate to capital costs, annual O&M costs, present worth, the ability to optimize the process to minimize over design, and the ability to purchase equipment without sole sourcing.

Capital, Annual, and Present Worth Costs

The arsenic treatment technologies presented in this evaluation have a wide range of estimated capital and O&M costs. It should be noted that the cost estimates are considered

to be budget level and should be refined during preliminary design and again during final design. The capital, annual O&M, and estimated present worth costs for the technologies presented in this evaluation are shown in Table 5-22. The present worth costs are based on a period of 20 years and a net interest rate of 6 percent.

TABLE 5-22
Ranking of Estimated Costs

Technology	Capital Cost	Annual O&M Costs	Present Worth	Ranking
IX	$11,000,000	$510,000	$16,900,000	1.00
GFH	$14,500,000	$1,200,000	$28,100,000	0.87
C/MF	$14,800,000	$515,000	$20,700,000	0.96
CF	$15,300,000	$440,000	$20,300,000	0.96
NF	$21,900,000	$5,100,000	$102,100,000	0.00

The NF has the highest present worth cost due to high operation cost of this complicated technology. The least expensive present worth cost was the IX technology.

Can the Process be Optimally Designed

This performance criteria relates to the ability to optimally design the treatment process such that it is not over-designed and more costly. The workgroup judged that because of the uncertainty related to the performance of the GFH media, that process would be ranked less favorably. The relative ranking for the five technologies related to optimal design agreed to by the workshop participants is presented in Table 5-23.

TABLE 5-23
Relative Ranking of Optimal Design Potential

Description	IX	GFH	C/MF	CF	NF
Less favorable than average		x			
About average				x	x
More favorable than average	x		x		

Sole Source Issues

The equipment for the arsenic removal treatment facilities would be purchased on a low-bid basis. It is important that the equipment is available from several suppliers so that a competitive bid can be received. All of the three technologies can be purchased from several manufacturers with the exception of the GFH technology. The workshop participants agreed that at this time, an equal product to GFH has not been demonstrated.

The relative ranking for the five technologies related to sole source issues agreed to by the workshop participants is presented in Table 5-24.

TABLE 5-24
Relative Ranking of Sole Source Requirement

Description	IX	GFH	C/MF	CF	NF
Less favorable than average		x			
About average	x		x	x	x
More favorable than average					

Summary of Cost Criteria Scoring

The scoring of the criteria associated with cost for the three technologies evaluated is shown on Figure 5-4. This figure shows that the GFH adsorption technology is ranked slightly higher than the other technologies. It should be noted that the run length associated with GFH is very uncertain at this time and may not be as long as estimated. If the run length of the GFH media is much shorter than estimated, the present worth will be higher and the ranking would be lower.

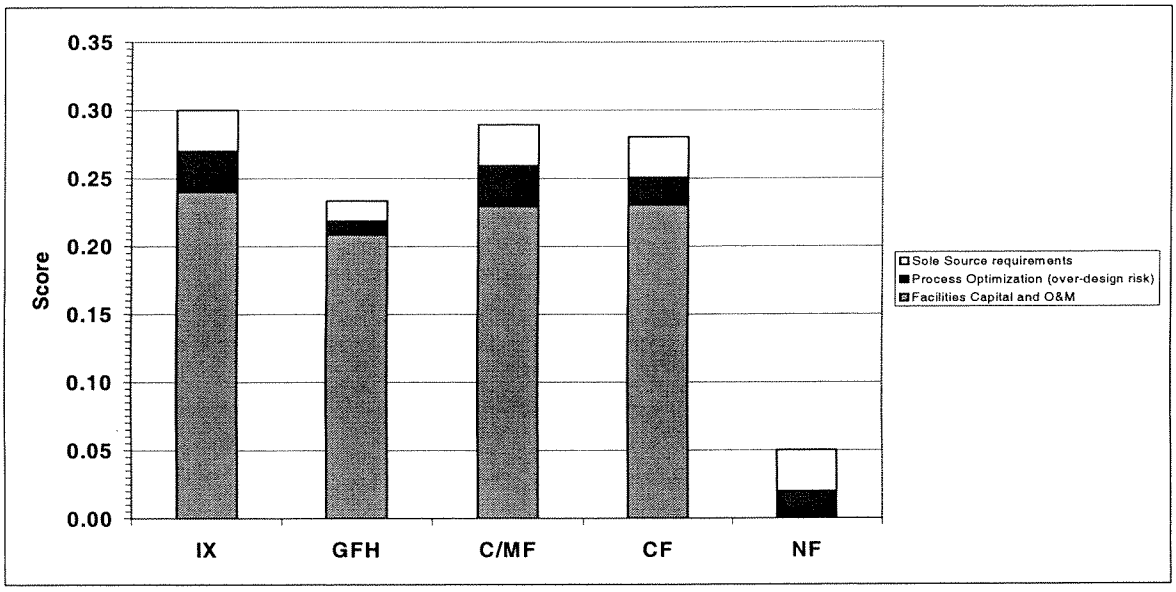

FIGURE 5-4
Summary of Cost Impact Scoring

Summary of Decision Analysis Scoring

The overall ranking of the three arsenic treatment technologies was computed and consolidated based on the four main evaluation criteria categories. The workgroup

participants reviewed the results for accuracy and agreed with the final ranking. Presented on Figure 5-5 is a graphical summary of the overall ranking of the five technologies.

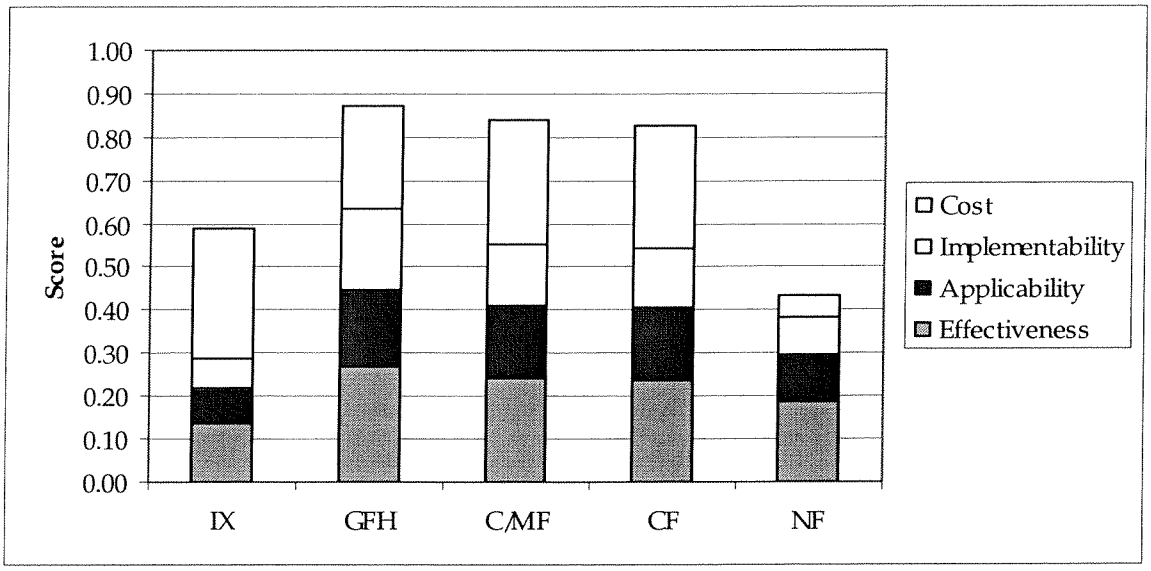

FIGURE 5-5
Summary of Total Scoring for Arsenic Treatment Technologies

The results of the decision analysis is presented in Appendix H of this report. The decision analysis scoring resulted in the GFH technology being the preferred technology for implementation in the City and OU water systems. The IX and NF technologies scored lowest of all the technologies. Close behind the GFH was the C/MF and CF technologies.

As indicated previously, the run length for the GFH media used in this study was an estimate and has a high level of uncertainty associated with it. Pilot testing with City and OU water will confirm the performance of the GFH media.

In conclusion, based on the evaluation of arsenic treatment technologies presented in this study and the decision analysis workshop, the City and OU staff decided that the GFH adsorption media technology was the preferred technology.

SECTION 6

Alternative Development and Evaluation

As with any water treatment study, several alternatives exist, each being capable of meeting the AR compliance goals of the Study. Each alternative consists of various options available for arsenic removal or reduction. Not only are there several treatment options, but other possibilities exist including blending in the distribution system, blending at the WTP, isolation of underground water bearing zones, and removing high arsenic wells from the drinking water system. To replace lost capacity, the options considered include installing new groundwater wells and purchasing treated water from OKC. This section reviews these options and compiles five plan alternatives for evaluation. Under the heading, Available Options, the various options available to the City and OU are summarized including a discussion of integrating the Arsenic Study with the City of Norman 2040-Year Strategic Water Supply Plan (SWSP). Five alternatives comprised of these options along with their evaluation are summarized under the heading, Identification of Alternatives.

Available Options

Previous sections of this Study have defined several options available to the City and OU that can be used to achieve AR compliance. This section briefly summarizes those options, which are listed below.

- Well Removal and Development of Non-Potable Uses
- Isolation of Water Bearing Zones
- Distribution and WTP Blending
- Treatment

Additionally, as implementation of many of these options will reduce groundwater supply capacity available to the City and OU, additional supply capacity can be gained through construction of new groundwater wells and/or purchasing OKC treated water.

Well Removal and Development of Non-Potable Uses

Well closure was discussed in Section 3, Arsenic Source Control, as a source control option for arsenic compliance. Well closure is considered for wells producing groundwater exceeding the arsenic MCL of 10 μg/L. As presented in Section 3, well closure has an estimated cost of approximately $22,000 per well.

Although well closure has been discussed, consideration should be given to continued use of these wells to meet other non-potable water demands. Several water demands; such as, public irrigation, industrial and commercial, power, and recreation, require fresh water. However, it is reasonable that water meeting public water supply standards is not required for such demands. As discussed at the February 21, 2002, Study Workshop with City and OU staff, several of these demands within Norman and OU are currently being met with supply from the potable water system. As such, conservation of the potable water system resources would be gained if water supply from groundwater wells removed from the

drinking water system could be used to meet non-potable demands. Such conservation would likely have the greatest benefit in reducing the maximum-day demands of the public system, when outside water uses are at their peak. Although, this conservation could also aid in reducing average-annual water demands of the public system. City and OU staff identified the following potential non-potable water demand options.

- Irrigation of OU campus lawns and gardens
- Irrigation of Westheimer Airport Industrial Park
- Utilization in the OU power plant
- Utilization in nearby industrial facilities
- Utilization for City and OU swimming pools

Isolation of Water Bearing Zones

The concept of isolating water bearing zones was presented in Section 3. Isolation of intervals producing groundwater having elevated levels of arsenic is a current construction method for new City groundwater wells. For this Study, the eligibility of wells for this technique is based on water quality, arsenic concentration, age, and condition. As Section 3 indicates, the City and OU groundwater systems have 13 wells where zonal isolation may be advantageous. Although this method of source control may provide reduced arsenic levels in produced groundwater, it will also reduce available capacity in the City and OU groundwater supplies. However, compared to well closure, zonal isolation may recover otherwise lost production. The estimated cost per well for zonal isolation is estimated at approximately $67,000, as presented in Section 3.

Blending

According to EPA and ODEQ, compliance with the AR must be achieved at the POE into the distribution system. With this in mind, plausible blending of multiple wells has been identified. Potential distribution blending locations were presented in Section 2, Existing Water Quality Data. Another option for blending groundwater is through conveyance to the WTP. The anticipated blended arsenic levels, based on average flows, are presented in Table 6-1, and the groundwater wells identified for blending are presented in Figure 6-1.

TABLE 6-1
Flow Weighted Arsenic Concentrations
Group Maximum and Average Capacities

Group	Number of Wells	Maximum Flow		Average Flow	
		Capacity (gpm)	Arsenic (μg/L)	Capacity (gpm)	Arsenic (μg/L)
1	3	683	6.5	660	6.7
2	4	1,168	5.5	721	4.7
3	7	1,567	42	1,192	41

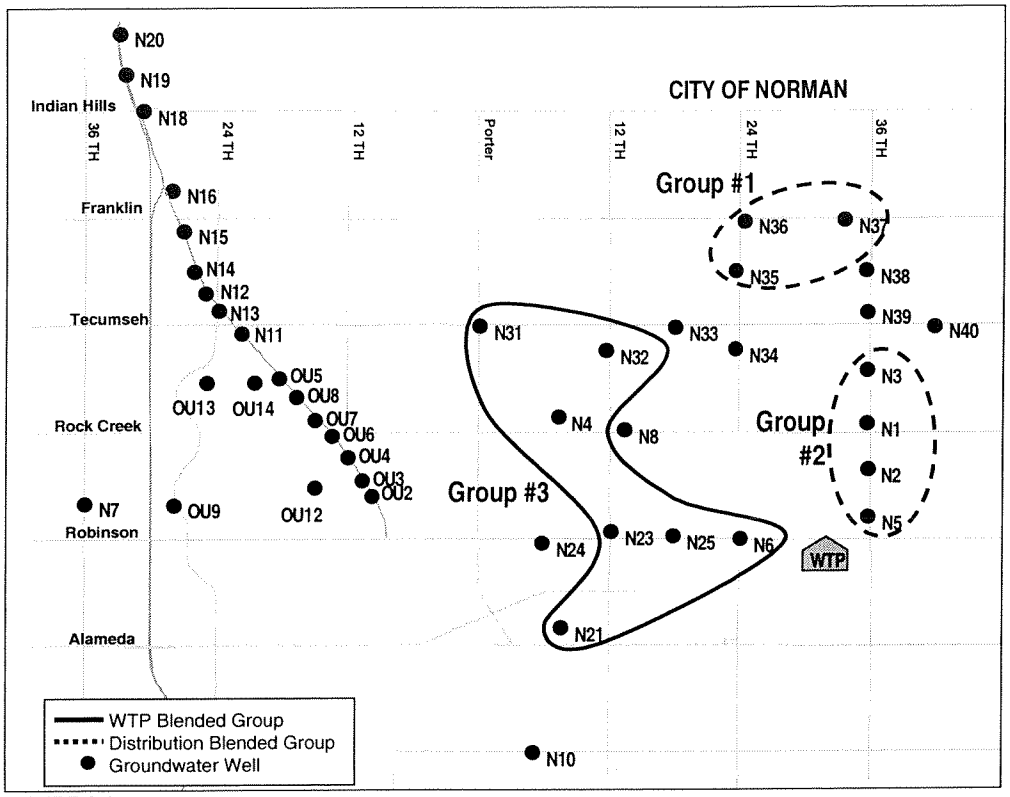

FIGURE 6-1
Blending Map

Blending by Well Groups

Existing data indicates that water supply from wells in each of Group 1 and Group 2 wells could be blended to effectively reduce the Arsenic concentration below the MCL. Based on City staff comments, Groups 1 and 2 have a low number of residential water service line connections. As such, it is likely water produced from the wells in these groups could be blended within water transmission mains prior to the POE into the system if new residential service connections are provided for these few end-users. Additionally, if blending is adopted for these well groups, provisions would be required to ensure that future distribution system connections do not interfere with blending. Also, additional testing is suggested to verify that blending can effectively maintain a less than 10 μg/L arsenic concentration in these groups.

For Group No. 1 wells, focus would be required for Well N36 due to its relatively high arsenic concentration. It is likely that the operation of Well N36 would require simultaneous operation of Well N37 for blending to meet the arsenic MCL. If costs associated with blending are found to be prohibitive, Well N36 may be eligible for zonal isolation as a means to reduce the arsenic concentration in the production water.

For Group No. 2 wells, Well N2 produces water with an average arsenic concentration of 9.79 μg/L. As such, the potential exists to maintain operation with no modification. However, this provides little-to-no safety factor for compliance. With such a marginal arsenic compliance concentration, consideration of blending is warranted. It is likely that any other well in Group No. 2 could be operated with Well N2 to achieve effective blending.

Conceptually, distribution conveyance includes an additional service main to provide blended water to local residents. Based on conceptual cost development, the distribution system conveyance for Group No. 1 is approximately $400,000 and for Group No. 2 is approximately $450,000.

Blending at the Water Treatment Plant

Group No. 3 has the potential for blending to meet the arsenic MCL. However, it is unlikely that blending within distribution mains could be achieved prior to the POE into the system due to the location of these wells. Additionally, due to the arsenic concentration in the water produced from these wells, blending will require a relatively large amount of water with low concentration of arsenic. Such supply is available with finished water from the Norman WTP. As such, development of this blending scenario considers conveying water from the Group No. 3 wells to the WTP for blending.

To aid in blending groundwater and finished water from the WTP, a likely operation scenario would be to queue wells into service based on the arsenic level. If operation allowed, wells with low arsenic would be queued on first, followed by wells producing water with higher arsenic levels. In any event, with seven wells in Group No. 3, flexibility is provided to produce water from these wells to meet demand. From the standpoint of blending with finished water from the WTP, the greatest blending demand would be required when all seven wells are in operation. Such operational requirements would likely be limited to maximum-day demands during peak summer time water use. In such a case, approximately 10 mgd of finished water from the WTP water is required to effectively blend the water supply to below the arsenic MCL.

Historically, Norman WTP has produced approximately 8.5 mgd of finished water on an annual-average basis. To meet peak demands, WTP production increases upwards of 15 mgd during the summer months. To achieve these production rates and comply with disinfection requirements, the WTP must maintain chloramine residual contact time through the process treatment train, including the clearwells. Clearwell operation is limited to achieve full compliance with disinfection requirements at the WTP. To prevent limiting the production potential of the WTP, existing clearwell capacity is not considered available for groundwater blending. Also, because groundwater is, for the most part, high quality water, there is little, if any, need to provide the same level of treatment as for the surface water supply from Lake Thunderbird. This considered, groundwater blending should be achieved with finished water supply from the WTP.

Noteworthy, Well N24 is in close proximity to the Group No. 3 wells; and therefore, consideration was given to adding Well N24 to Group No. 3. However, due the relatively high arsenic concentration in water produced from Well N24, such an addition was not considered effective. A WTP finished flow of some 14 mgd would be required for blending groundwater from Group No. 3 to below the arsenic MCL if Well N24 was included in this group. Such a requirement would limit production flexibility. Similarly, consideration was given to adding the OU grouped wells to the WTP blending scenario. However, the amount of finished water that would be required for blending would be nearly 20 mgd, which exceeds the Norman WTP current production capacity. To achieve blending of water produced from the Group No. 3 wells with water supply from the WTP, new blending facilities would be required at the WTP. Additionally, a total combined production capacity

of 12.3 mgd, approximately 10 mgd from the WTP and 2.3 from the wells, would be available following blending. Assuming the WTP high-service pumps are fully utilized for WTP production, additional high-service pumping capacity would likely be required to handle the additional groundwater flow of 2.3 mgd.

In order to achieve AR compliance by blending groundwater at the WTP, blending facilities under this Study could be incorporated with the disinfection clearwell facility provisions of the SWSP. The City's SWSP includes conceptual development of a new wellfield. To address potential regulatory hurdles of the forthcoming GWR requirements, the well development plan incorporates potential provisions for new disinfection clearwells for groundwater treatment and high-service pumping facilities at the existing WTP site. As developed under the SWSP, the new storage and pumping facilities were sized to accommodate a 10-mgd annual-average supply and a peak production of 14 mgd, from 30 new groundwater wells to be located east of the existing wellfield. To accommodate blending for AR compliance, the proposed facilities would require approximately 2.3 mgd of additional capacity for a total of 16.3 mgd. With such facilities in place, groundwater from Group No. 3 wells could be blended with finished water from the WTP while the eastern wellfield is being developed. The potential exists to transition, at least in part, to blending with groundwater from the proposed eastern wellfield in the mid- and long-term.

As new wells are constructed, groundwater from these wells could be conveyed to the groundwater clearwell. The groundwater produced from the eastern wellfield is likely to have a low arsenic concentration based on strategic methods of well construction and on aquifer hydrologic characteristics in the area. The arsenic levels in the existing eastern wells along 36th Avenue average 3.2 μg/L. If the trend continues, and the weighted arsenic concentration of the new eastern wellfield groundwater supply is 3.2 μg/L or less, then 11.8 mgd of eastern wellfield groundwater would be required to blend Group No. 3 at the WTP. If the arsenic level increases in the eastern wellfield, the required volume of water for blending with Group No. 3 wells would also increase. For example, if the arsenic level of the eastern wellfield groundwater is 4 or 5 μg/L, the required flow would be 13.5 and 16.5 mgd, respectively. In any event, the development of a 10 mgd wellfield in eastern Norman, as proposed in the SWSP, should be based on hydrogeological testing and analysis of the aquifer to quantify aquifer response to large scale pumping. Short of actual development and analysis of the aquifer and water quality, some WTP finished water will likely be required for blending of the Group No. 3 wells. However, the new eastern wellfield has the potential of providing an additional water supply source for the City as well as decreasing the amount of finished water from the WTP required for blending the Group No. 3 wells. If the facilities were to be developed, the combination of groundwater from the eastern wellfield and finished water from the WTP would provide flexibility and some degree of redundancy for bringing the Group No. 3 wells into compliance with the arsenic standard. An estimate for conceptual development of Group No. 3 conveyance is approximately $2 million. Assigning proportionate costs of incorporating the SWSP groundwater facilities into this Study is discussed under the heading, Arsenic Study Integration with Strategic Water Supply Plan.

Arsenic Treatment and Removal

Treatment technologies considered in this Study are presented in Section 4, Alternatives Development and Evaluation, and include ion exchange, granular ferric hydroxide adsorption, coagulation/microfiltration, coagulation/ filtration, and nanofiltration. A Decision Analysis Workshop was held on February 21, 2002, during which participants utilized a Decision Analysis tool for evaluating treatment options. The workshop allowed City and OU staff to identify which technology is best suited for arsenic treatment based on several criteria. Considered criteria and results of the Decision Analysis Workshop are presented in Section 5, Decision Analysis for Arsenic Treatment Technologies. The technology identified as most appropriate for arsenic treatment of the City and OU groundwater is granular ferric hydroxide (GFH) adsorption.

In addition to the Decision Analysis process , a second workshop was held on February 22, 2002, to discuss the City and OU arsenic issues with researchers from OU and EPA. Some discussion during this workshop gave consideration to in-situ treatment of groundwater in the City and OU study area. Specifically, by injecting chlorinated water into the subsurface and lowering the in-situ groundwater pH to about 6.8, arsenic may adsorb back onto the ferric surfaces inherent to the GWA. Pilot studies are required to verify success of in-situ chlorination in the Study area. Additionally, other factors include the affect of mixing treated surface water with groundwater in the subsurface and regulatory effects.

Until further research and studies are completed, the success of in-situ chlorination treatment is unknown. Therefore, for the purpose of this Study, treatment of groundwater will consist of GFH treatment facilities as described in Section 4. The estimated costs of GFH treatment of groundwater, including costs for conveyance and sanitary sewer collection, for each of the eight treatment groups is presented in Table 6-2.

TABLE 6-2
Treatment Cost Estimates

Group	20-Yr Present Worth of Treatment Costs	Conveyance and Collection Costs	Total
Group 1	$3,000,000	$210,000	$3,200,000
Group 2	$4,700,000	$290,000	$5,000,000
Group 3	$8,800,000	$860,000	$9,700,000
Group 4	$1,400,000	$11,000	$1,400,000
Group 5	$3,700,000	$380,000	$4,100,000
Group 6	$1,900,000	$290,000	$2,200,000
Group 7	$3,400,000	$250,000	$3,700,000
Group 8	$1,300,000	$11,000	$1,310,000
Total	**$28,000,000**	**$2,300,000**	**$30,300,000**

Replacement of Lost Capacity

Although very little water is wasted through GFH treatment, the other options considered for AR compliance will decrease the City and OU groundwater capacity. Of greatest degree, is the lost of water production capacity from well closure and the potential loss from zonal isolation. Each plan alternative considers replacing the supply capacity lost from well closure or zonal isolation. To this end, an average- and maximum-day production baseline was established, as discussed in the following paragraphs.

Annual-Average and Maximum-Day Production Baseline

In order to continue meeting average-annual and maximum-day water demands, new water supply sources will be required to replace lost supplies from well closures or zonal isolation. For this Study, such replacement supply is considered to be either purchasing OKC-treated water or constructing new groundwater wells. As indicated in the City's SWSP, annual-average production from the City's existing wellfield is estimated at approximately 4.2 mgd, with maximum-day production capacity at 8.1 mgd. The production capacity of OU's wells is estimated at 2.2 mgd. Combining the two production capacities, the average-annual capacity of City and OU wells is estimated at 6.4 mgd. Similarly, the maximum-day production capacity for City and OU wells is estimated at 10.3 mgd.

City of Oklahoma City Treated Water

Norman's distribution system presently has connections to Oklahoma City's distribution system and recently has purchased OKC-treated water on an as-needed basis to meet peak water demands. As such, the purchase of OKC-treated water is considered an option for replacing capacity lost from well closure or zonal isolation. For the purpose of developing costs associated with purchasing OKC-treated water to meet average- and maximum-day demands, a take-or-pay plan is proposed. With this plan, the City defines an average-daily demand that will be purchased on a monthly basis from OKC at $1.60 per thousand gallons. The average-daily demand can be adjusted on an annual basis at OKC's discretion. Any treated water usage above the defined average-daily demand but below 2.5 times the average-daily demand, on a monthly basis, would cost an additional $1.60 per thousand gallons. Any usage above 2.5 times the average-daily demand, on a monthly basis, would cost $2.85 per thousand gallons. These costs increase between 3 and 5 percent annually.

New Groundwater Well Construction

Another option for replacing well production capacity associated with well closure and zonal isolation is through construction of new groundwater wells. Such replacement should consider wells for replacing annual-average supply as well as peak production capacity to meet maximum-day demands. As discussed previously, the Norman SWSP proposed provisions for 30 new groundwater wells. In order to continue meeting water demands, production from a portion of these wells should be applied toward the supply deficit created through implementation of the AR. The number of wells required would vary among plan alternatives depending on the amount of production capacity lost.

Based on the SWSP schedule, four years remain in the short-term planning schedule—from 2002 to 2005. To replace capacity lost through AR implementation, consideration should be given to accelerating the implementation schedule of the SWSP. Acceleration would include:

1) construction of the wells planned during the 2002 to 2005 construction window to meet increases in water demand; and 2) construction of additional wells to replace production capacity created as wells are taken offline for AR compliance. If accelerated, production capacity could be in place to replace lost production for both the City and OU water systems, and the City could be on track to meet projected 2005 water demands.

Arsenic Study Integration with Strategic Water Supply Plan

Previous sections regarding the options of blending at the WTP and construction of new groundwater wells have suggested incorporation as a component of the recommended SWSP facilities as a solution for achieving AR compliance. The SWSP includes provisions for 30 new groundwater wells and associated conveyance, disinfection clearwells, chemical storage and feed equipment, and high-service pumping located at the WTP. The future facilities were proposed based on the potential for obtaining an additional annual-average capacity of 10 mgd, with a maximum-day production of 14 mgd, from development of the eastern wellfield.

This Study proposes integration of the SWSP well development scheme into two of the five plan alternatives evaluated in the following paragraphs. To this end, adopting an accelerated SWSP well development schedule is suggested. Specifically, the proposed disinfection clearwell and high-service pumping facility to be located at the WTP is integrated into the Study plan alternatives and utilized as blending facilities for AR compliance. Additionally, a portion of the 30 new groundwater wells proposed by the SWSP is incorporated into the plan alternatives to replace lost groundwater supply.

Conceptual costs of incorporating the SWSP disinfection clearwell and pumping facilities into the Study is based on prorating the costs of the original facility to a slightly greater capacity (14 mgd to 16.3 mgd) and assigning the appropriate portion of the estimated cost to each plan alternative. The costs also include assigning a proportionate share of the groundwater facility capacity related to the groundwater wells being transferred from the SWSP to this Study.

Identification of Alternatives

This section includes the identification and evaluation of the five alternatives considered for this Study. Budgetary cost estimates based on conceptual development of each alternative are presented to provide a relative comparison of plan alternatives. The details of any future agreements between the City and OU water systems were unknown at Study completion. Therefore, for the purpose of plan evaluation and conceptual development, City and OU groundwater well systems are considered as one.

The five plan alternatives evaluated in this Section are the following:

- Plan A – Well Closure and OKC Treated Water
- Plan B – Well Closure, Blending, Zonal Isolation, and OKC Treated Water
- Plan C – well Closure, Blending ,Zonal Isolation, and New Wells
- Plan D – Treatment
- Plan E – Blending, Zonal Isolation, Treatment and New Wells

Based on the anticipated provisions of the Groundwater Rule and input by ODEQ staff, the potential exists that the unconfined portion of the GWA may not meet certain barrier requirements of the rule; and as such, may be classified as a sensitive water supply source. If such deficiencies are identified and cannot be mitigated, disinfection of water produced from wells in the unconfined aquifer would be required. Some of the existing wells remaining in operation in each plan alternative may tap areas just outside of the GWA confining layer. However, these wells have historically produced high quality water. As such, it is doubtful that disinfection of the existing wells will be required, and provisions for such are not provided in the plan alternatives.

Plan A – Well Closure and OKC Water Purchase

Due to the AR regulations and compliance schedule, OU and Norman will be required to take some action. Plan A considers the minimal effort required to comply with the AR. Removing groundwater wells that exceed the 10 µg/L arsenic MCL from the City and OU drinking water systems will achieve AR compliance. As stated previously, developing alternative non-potable uses for the lost drinking water capacity is a potential substitute for well closure.

Figure 6-2 below details which groundwater wells will be removed from the drinking water systems under Plan A.

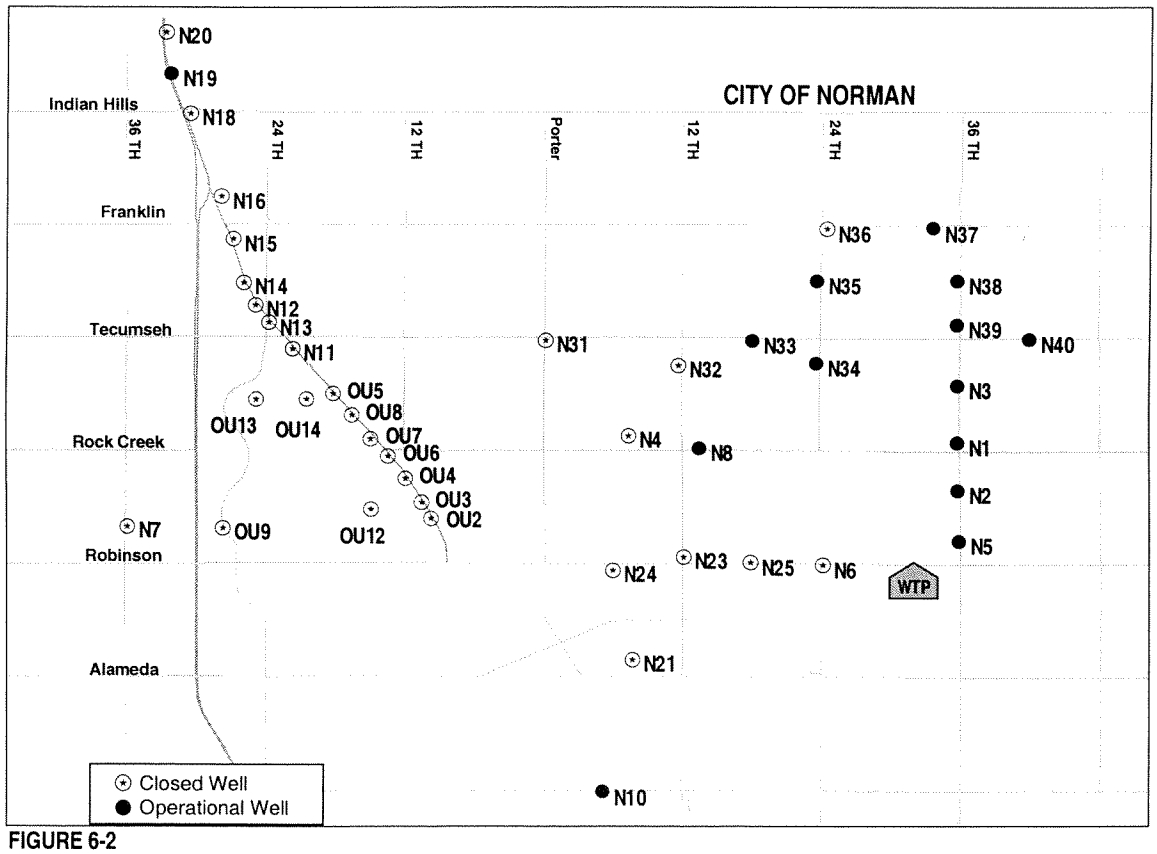

FIGURE 6-2
Plan A Map
Well Removal & OKC Treated Water

For this Study, Wells N2 and N19 are considered to be affected by the AR as they exhibit arsenic concentrations of 9.79 and 9.94 μg/L, respectively. These concentrations are just under the MCL of 10 μg/L, but due to the wide variability in arsenic data, the likelihood exists for the wells to exceed 10 μg/L. However, the wells remain open under this plan to avoid lost supply. An annual-average of quarterly data will provide more information on whether production should be discontinued. The total number of groundwater wells removed from both systems under Plan A is 29, leaving the number of operating wells at 14. Notably, all OU wells would be closed if Plan A is implemented.

With Plan A, about 6.1 mgd of water supply capacity is lost leaving 4.2 mgd of groundwater supply, all of which is produced by City wells. Of this supply, 60 percent, or 2.5 mgd is assumed to be available as annual-average supply. With an average-annual demand of 6.4 mgd, as discussed previously, an additional annual-average OKC-treated water purchase of 3.9 mgd is required.

There are certain advantages and disadvantages to Plan A. On the upside, capital costs are relatively low, AR compliance is achieved, and implementation is relatively simple. However, the amount of groundwater supply available to the City and OU is greatly reduced. In fact, OU's groundwater supply becomes nonexistent. In addition, purchasing water from OKC greatly increases annual O&M costs.

Estimated capital costs incurred through Plan A are about $650,000. At an estimated annual O&M cost of $4.1 million, the annual O&M present worth costs taken at 6 percent for 20 years is nearly $46.7 million. Combining the capital and O&M present worth costs produces a total present worth of approximately $47 million. Detailed cost estimates of Plan A are presented in Appendix I.

Plan B – Well Closure, Blending, Zonal Isolation, and OKC Water Purchase

Plan B considers achieving AR compliance without treating the groundwater, as in Plan A, but also includes provisions to recover lost groundwater through blending and zonal isolation. However, because not all wells are eligible for blending and zonal isolation, well closure is also included with this plan. Plan B provides conveyance for multiple wells to be blended at the WTP in order to achieve AR compliance. Blending groups of wells within the distribution system is also proposed under this plan. Figure 6-3 identifies wells that may be conducive to blending, wells that may be suitable for zonal isolation, and wells that will be closed as they are not suitable for either.

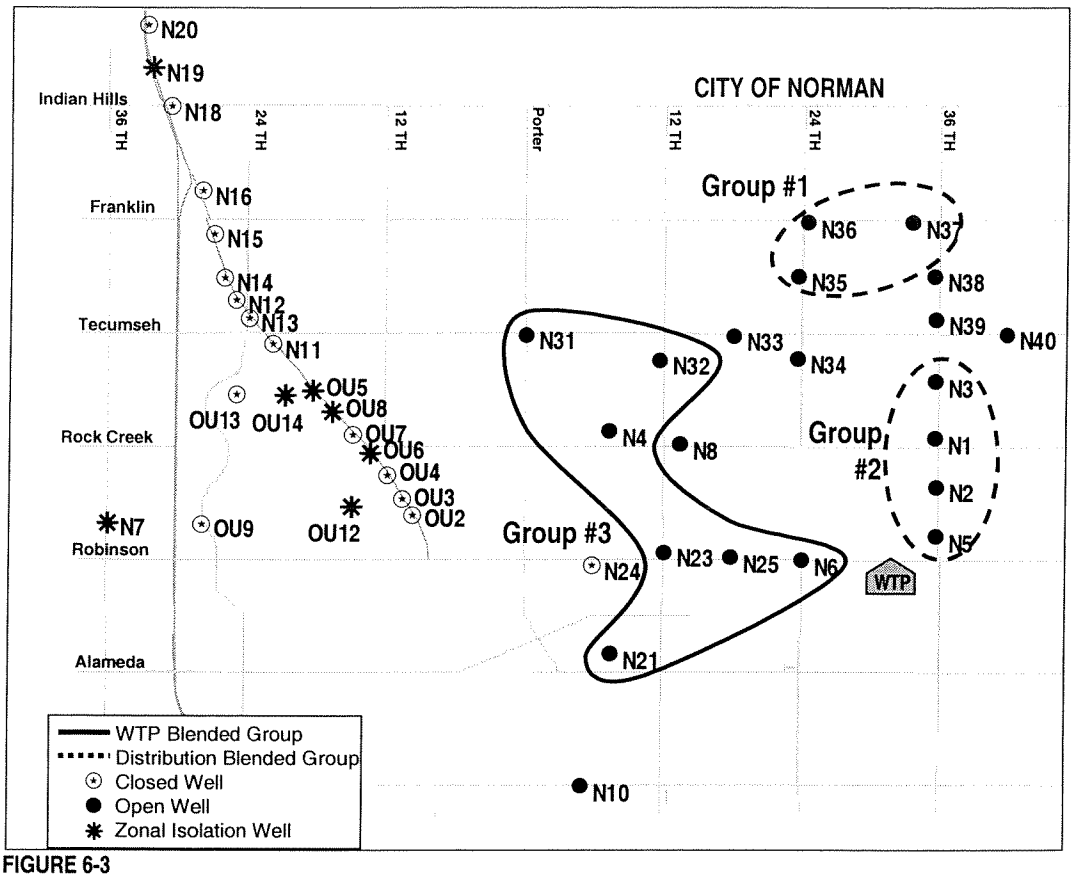

FIGURE 6-3
Plan B Map
Well Removal, Blending, Zonal Isolation, and OKC Water Purchase

Overall, Plan B allows about 6.8 mgd of original groundwater supply to remain in the water systems—6.2 mgd by City wells and 0.6 mgd by OU wells. Of the 3.5 mgd of lost capacity, 0.8 mgd is lost through zonal isolation and 2.7 mgd is lost to well closure, although alternate non-potable uses may be developed. On an average-day basis, this plan provides a remaining groundwater supply of 4.2 mgd, leaving a deficit of 2.7 mgd. In summary, 15 wells are closed, 7 are considered for zonal isolation, 14 are blended, and the remaining 7 are open and continue operation without any changes.

As indicated previously, this plan provides a total available groundwater flow of about 6.8 mgd, which is concentrated in the eastern area of the existing wellfield. For the purpose of conceptual development of Plan B, the average-annual day supply remaining with this plan is estimated at 4.2 mgd, leaving an average-annual day deficit of nearly 2.3 mgd. Plan B assumes this deficit will be met by purchasing OKC-treated water under a take-or-pay contract.

Although this plan has a higher capital cost than Plan A, it provides a greater amount of groundwater supply and therefore a lower dependence on OKC-treated water. This plan incorporates both zonal isolation and blending to conserve production of otherwise closed groundwater wells under Plan A. Plan B provides does not involve any treatment options, to achieve AR compliance. Original groundwater remaining under this plan is 4.2 mgd of annual-average supply, which is about 60 percent higher than Plan A.

Estimated capital costs incurred through Plan B are about $3.9 million. At an estimated annual O&M of $2.8 million, the present worth O&M costs taken at 6 percent for 20 years are estimated at nearly $33 million. This brings the total estimated present worth cost of this plan to approximately $37 million.

Plan C - Well Closure, Blending, and Construction of New Wells

The options provided under Plan C are similar to those presented for Plan B, with one exception. Where Plan B requires the purchase of OKC-treated water, Plan C provides construction of new groundwater wells to replace production capacity lost to well closure and zonal isolation. The well development plan of the City of Norman SWSP is placed on an accelerated schedule, as described in the earlier sections, and construction of new wells is implemented earlier than planned. Plan C is presented on Figure 6-4.

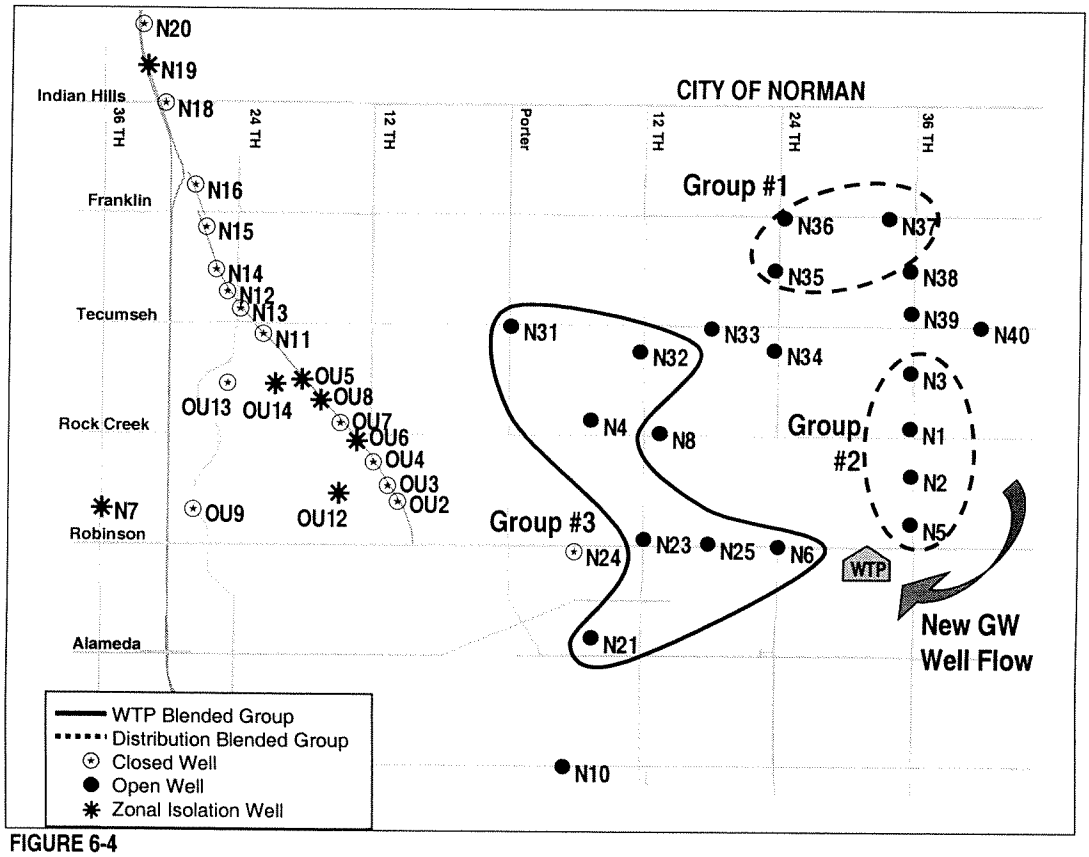

FIGURE 6-4
Plan C Map
Zonal Isolation, Blending and Construct New Wells

There are several advantages to Plan C. Plan C provides independence from purchasing and relying on OKC-treated water supply. Additionally, Plan C does not require treatment of groundwater to achieve AR compliance. Similar to previous plans, Plan C allows the opportunity of utilizing AR non-compliant wells for non-potable uses, thereby decreasing average- and maximum-day water demands. However, this plan incorporates new groundwater wells, which were otherwise reserved for future City demand as part of the SWSP.

As Plan C places no dependence on OKC-treated water, the annual O&M costs are decreased. However, estimated capital costs are increased. Capital costs incurred with Plan C are estimated at about $9.2 million. At an estimated annual O&M of $1.3 million, the present worth O&M costs taken at 6 percent for 20 years are estimated at about $15 million. This brings the total estimated present worth of this plan to approximately $24 million.

Plan D – Treatment

During the workshop held on February 21, 2002, City and OU staff selected GFH adsorption as the arsenic treatment option best suited for City and OU needs. The treatment technology selection criteria and process is further discussed in Section 5. Plan D provides GFH treatment of the groundwater as described in Section 4. The groundwater wells are grouped and conveyed to common treatment facilities. Plan D is presented on Figure 6-5.

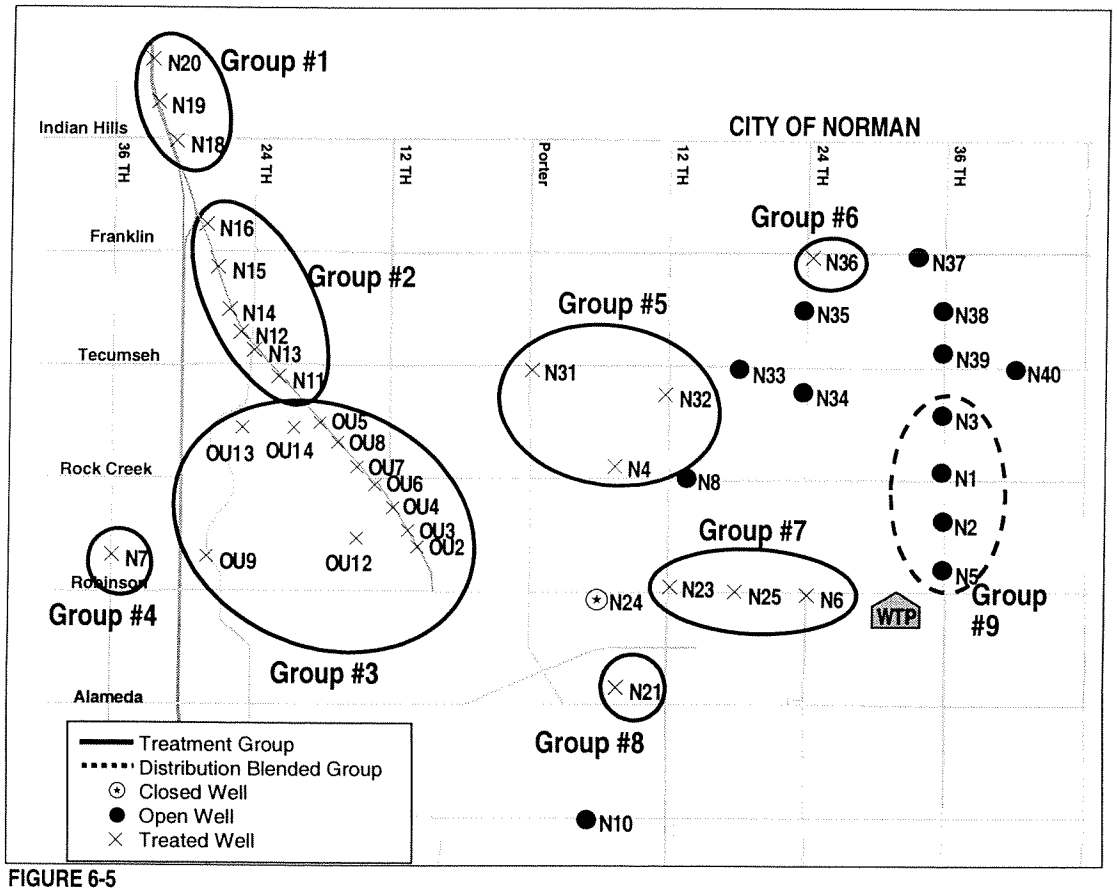

FIGURE 6-5
Plan D Map
GFH Treatment

Plan D utilizes eight treatment facilities for treatment of all affected groundwater wells except Well N24, which is closed due to its lower-than-average production and much higher-than-average arsenic concentration. Plan D assumes distribution blending would be successful for Group No. 9. Conceptual cost development includes treatment of the groundwater, as well as construction of groundwater collection and sanitary sewer collection lines. Plan D conserves the greatest amount of existing groundwater supply of any of the evaluated plan alternatives. With Plan D, since neither new groundwater wells

nor WTP blending are provided, the SWSP well development plan schedule and planned groundwater disinfection facilities are not affected, which is another advantage.

However, Plan D is the most difficult to implement of the evaluated plans. This plan would create eight treatment sites throughout Norman, requiring increased labor and administration requirements, chemical storage facilities, and media handling for replacement and disposal. In addition, another downside of this plan is providing millions of dollars in capital costs for western area wells that are nearing the end of their useful life.

For the eight common well treatment facilities, including the cost of groundwater conveyance and sanitary sewer collection, the capital costs are estimated at $17 million. The annual O&M costs are estimated at $2.2 million and the present worth of the annual O&M costs taken at 6 percent for 20 years is just over $25 million. Combining the capital costs and present worth O&M costs produces a total present worth of $42 million.

Plan E – Combined Options

The final plan alternative considered is a combination of options including treatment, zonal isolation, well removal, distribution blending, WTP blending, and construction of new wells to replace lost capacity. Figure 6-6 presents Plan E.

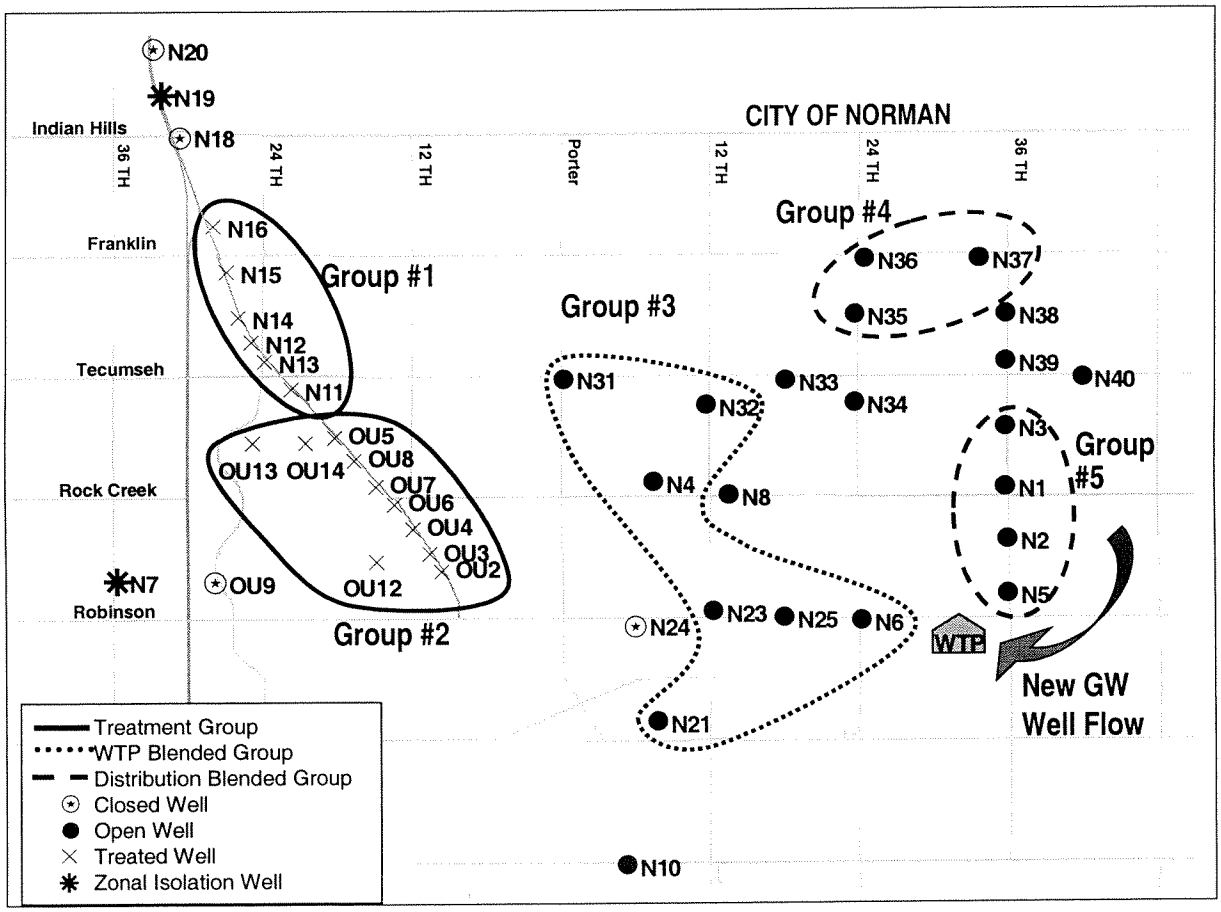

FIGURE 6-6
Plan E Map
Blending, Zonal Isolation, Treatment and New Wells

As indicated above, Group Nos. 1 and 2 would be treated through GFH adsorption, which is the option selected by City and OU staff as the most suitable treatment option. With Plan E, the seven wells of Group No. 3 are conveyed to the WTP for blending. Additional conveyance for new service line connections would be provided for Group Nos. 4 and 5 so that distribution blending can occur.

Overall, this plan closes 4 wells, blends 14 wells, performs zonal isolation on 2 wells, treats 16 wells, and continues operating 7 wells without change. About 9.4 mgd of groundwater production is retained with Plan E. To replace the nearly one mgd of lost groundwater supply, new groundwater wells are proposed. The construction of these wells calls for an accelerated SWSP well development schedule. In addition, the groundwater storage tank and high-service pump station specified in the SWSP would be constructed and utilized as a blending facility for Group No. 3 wells. Details of this accelerated SWSP well development schedule were discussed under the heading, Available Options.

There are several advantages to Plan E. Plan E was developed to optimize remaining original groundwater production capacity while lowering present worth. Compared to Plan D, which retains the greatest amount of original capacity, Plan E groundwater capacity is reduced by only 7 percent. However, the present worth cost are decreased by over three times that percentage. Another advantage of Plan E incorporates the maximum benefit of non-treatment options such as blending and zonal isolation to achieve compliance with the AR.

On the downside, Group Nos. 2 and 3, for which blending is not feasible, require treatment to optimize original groundwater production capacity. Treating Group Nos. 2 and 3 means treating the oldest and lowest producing wells, on average, of the combined water systems. In addition, considering the useful life of a groundwater well to be about 50 years, the treatment facilities for Group Nos. 2 and 3 may outlast the groundwater wells.

For Plan E, including the cost of raw water conveyance and sanitary sewer collection, the capital costs are estimated at $12 million. The annual O&M costs are estimated at $1.7 million and the present worth of the annual O&M costs taken at 6 percent for 20 years is just over $19 million. Combining the capital costs and present worth O&M costs produces a total present worth of approximately $32 million.

Recommended Approach

The plan alternatives were presented to City and OU staff during a workshop to provide City and OU staff the opportunity to identify which plan is most suitable for meeting the AR compliance needs. Table 6-3 summarizes the capital and O&M cost estimates of each of the five plan alternatives.

TABLE 6-3
Plan Alternative Cost Summary[1]

Plan Alternative	Capital Cost	Annual O&M	Present Worth
Plan A - Well Closure	$0.7	$4.1	$47
Plan B - Zonal Isolation, Blending and OKC Water Purchase	$3.9	$2.8	$37
Plan C - Zonal Isolation, Blending and Construct New Wells	$9.2	$1.3	$24
Plan D – Treatment	$17.2	$2.2	$42
Plan E - Zonal Isolation, Blending, Treatment and Construct New Wells	$12.4	$1.7	$32

Notes:
[1] Costs are presented in millions of dollars.

Considering the advantages and disadvantages of each plan alternative, along with the estimated present worth costs, the workshop participants selected Plan C as the most suitable for the City and OU needs. Specifically, Plan C provides the following.

- Independence from relying on OKC treated water
- Non-treatment options for achieving AR compliance
- Development of non-potable uses for AR non-compliant groundwater wells thereby decreasing overall water demand for the City and OU water systems
- Lowest estimated present worth cost

For these reasons, Plan C is recommended as the best approach for the City and OU to achieve AR compliance. Although capital costs are higher with Plan C than with Plan A or B, some of the capital costs associated with Plan C will result in a savings in SWSP costs. Specifically, approximately $5.5 million in estimated capital costs is transferred to this Study from the SWSP.

As discussed previously, to implement Plan C an accelerated SWSP well development schedule must be employed. The original SWSP well development schedule provided for one new groundwater well per year for the first five years—the short-term schedule of 2001 to 2005. However, due to well closure and zonal isolation provided with Plan C, the City and OU will be required to purchase OKC-treated water to meet water demands until construction of the new groundwater wells and associated conveyance are complete. Hence, completion of new groundwater wells becomes a more important issue.

Implementation Schedule

Based on the SWSP schedule, four years remain in the short-term planning schedule—2002 to 2005. The SWSP plans for construction of one well per year during these four years. To

replace capacity lost through AR implementation, the accelerated SWSP should also include construction of 11 additional wells during these four years. To this end, four new groundwater wells per year would be constructed during 2002 to 2004 followed by three new wells in 2005. With this schedule, by the end of 2005, the City will have replaced the capacity lost to well removal and zonal isolation for both the City and OU water systems. The original SWSP well development schedule could continue in 2006; and by 2010 the 30 wells planned for the eastern wellfield will be completed. Therefore, the construction of one well per year during 2011 to 2020 becomes void without further aquifer testing to ascertain whether or not the aquifer will sustain addition yield.

The SWSP also includes provisions for groundwater disinfection and high-service pumping facilities to be included in the Phase I Expansion of the City WTP. For the purpose of providing blending of Group No. 3 wells, the disinfection clearwell and high-service pump station should be constructed in the short-term schedule, rather than in the mid-term as originally planned. Additional capacity should be added to the facility design to accommodate the additional 2.3 mgd capacity of Group No. 3 wells at maximum capacity. As a result of early construction, blending facilities and subsequent high-service pumping for will be provided for Group No. 3 blending. As an added benefit, early construction of the disinfection clearwell will provide additional in-system storage for meeting maximum demands.

Impact on Strategic Water Supply Plan

The trade-off for developing wells in the eastern wellfield for arsenic mitigation, as discussed previously, is that a portion of the groundwater supply from the eastern wellfield will effectively replace only lost production from the existing wellfield. In short, well production from the west will be transferred to the east to tap fresh water with lower arsenic concentrations. This transfer would not provide additional water supply to meet future increases in demand. At face value, this trade-off has the potential of accelerating the need to bring new water supply sources of the recommended SWSP online ahead of schedule to prevent a shortfall in the mid- to long-term of the planning horizon. Obviously, such acceleration will be driven by actual increases in water demands experienced by the system. To some degree, developing non-potable uses for the wells to be decommissioned from the potable water supply system could potentially off-set the required replacement capacity as well as curtail a portion of the increase in demand. Additionally, the trade-off may be less than anticipated, as development and monitoring of the eastern wellfield may prove to allow greater than the 10-mgd annual-average supply to be developed. In any event, it appears development of the eastern wellfield could provide beneficial use to the City—both in arsenic mitigation and additional water supply. If the eastern wellfield is developed as planned, the City is encouraged to progress in a systematic and planned method. Such an approach will allow reaction of the aquifer to such development to be quantified and water quality to be monitored. Subsequently, such an approach will allow the City to adjust water supply development strategies, as needed, to meet demands and address regulatory hurdles.

Additional Sampling

Before a groundwater well is permanently altered, whether by zonal isolation or through well closure, further arsenic analysis should occur particularly for those wells exhibiting

arsenic levels close to the MCL of 10 μg/L. Due to the wide variability in arsenic data observed from the groundwater wells over the past years, closure of a groundwater well should be based on the most recent annual average of quarterly data to avoid undue loss of production. For example, the arsenic level for Well N20 is 15.29 μg/L, which is based on an arsenic database of about 1989. However, considering only data since January 2001, the average arsenic concentration of Well N20 is 3.67 μg/L. However, Well N5, which is presented as having an arsenic concentration of 9.18 μg/L based on data since 1989, has an arsenic concentration of 11.35 μg/L when considering arsenic data since January 2001 only. Hence, a quarterly arsenic sampling schedule should be implemented for those wells exhibiting arsenic levels close to the MCL.

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Appendix A

Acronyms and Abbreviations

µg/L	micrograms per liter
AA	Atomic Absorption
AR	Arsenic Rule
AS(III)	arsenite
AS(V)	arsenate
BAT	best available technologies
BV	bed volumes
CF	coagulation/filtration
C/MF	coagulation/microfiltration
$CaCO_3$	calcium carbonate
CCR	Consumer Confidence Report
City	City of Norman
CO_2	carbon dioxide
CO_3^2	carbonate
CRAVE	Cancer Risk Assessment Verification Endeavor
CT	contact times
CWA	Clean Water Act
CWS	community water system
DNA	deoxyribonucleic acid
EBCT	empty bed contact time
EPA	US Environmental Protection Agency
$FeCl_3$	ferric chloride
FeOH	ferric hydroxide
ft^2	square foot/feet
ft^3	cubic foot/feet
G	velocity gradient
gfd	gallons per square foot per day

GFH	granular ferric hydroxide
gpm	gallons per minute
GWA	Garber-Wellington Aquifer
GWR	Groundwater Rule
GWUDI	groundwater systems under direct influence of surface water
H_2	hydrogen gas
H_2O	water
H_2SO_4	sulfuric acid
$HAsO_4^2$	arsenic acid
ICR	Information Collection Rule
IESWTR	Interim Enhanced Surface Water Treatment Rule
IOC	inorganic contaminant
IX	ion exchange
lb	pound
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MDL	maximum detection limit
MF	microfiltration
mgd	million gallons per minute
mg/L	milligrams per liter
MWCO	molecular weight cut off
NaCl	salt
NaOCl	sodium hypochlorite
NaOH	caustic soda
NAS	National Academy of Sciences
NCW	non-community water system
NDWAC	National Drinking Water Advisory Committee
NF	nonofiltration
NO_3^2	nitrate
NODA	Notice of Data Availability

NPDWR	National Primary Drinking Water Regulation
NRC	National Research Council
NTNCWS	non-transient non-community water system
O&M	operation and maintenance
ODEQ	Oklahoma Department of Environmental Quality
OU	University of Oklahoma
pH_{zpc}	zero point of charge
pKa	negative log equilibrium constant
POE	point-of-entry
POU	point-of-use
PQL	practical quantifiable limit
Project	Water Well and Water Distribution Improvement Project
psi	pounds per square inch
PWS	public water system
RO	reverse osmosis
SAB	Science Advisory Board
SDI	silt density index
SDWA	Safe Drinking Water Act
SNL	Sandia National Labs
SO_4^2	sulfate
SOC	synthetic organic contaminant
Study	Arsenic Treatment Study
SWTR	Surface Water Treatment Rule
TCLP	Toxicity Characteristic Leaching Procedure
TCR	Total Coliform Rule
TDS	total dissolved solids
TMP	transmembrane pressure
TNCWS	transient non-community water system
TOC	total organic carbon
UF	ultrafiltration

US	United States
US PHS	US Public Health Service
USGS	US Geological Survey
VOC	volatile organic contaminant
VSL	value of statistical life
WHO	World Health Organization
WTP	water treatment plant
WWTP	wastewater treatment plant

Appendix B

Table B-1
Arsenic Concentration Data
Data provided by City of Norman

Well Number	Year Constructed	Arsenic Testing Date	Arsenic Test Results, μg/L	Testing Laboratory
1	Jul-63	Jun-01	0.614	Southwell
1	Jul-63	Jun-01	0.64	Accurate Labs
1	Jul-63	Jan-00	1.3	Accurate Labs
1	Jul-63	Jan-95	5	ODEQ
1	Jul-63	Jul-89	Below PQL	ODEQ
		Average	**1.89**	
2	Jul-63	Jun-01	10.1	Southwell
2	Jul-63	Jun-01	12	Accurate Labs
2	Jul-63	Jun-01	13	Accurate Labs
2	Jul-63	Jun-01	10.4	Southwell
2	Jul-63	Feb-01	8.7	Accurate Labs
2	Jul-63	Feb-01	9.36	Southwell
2	Jul-63	Jan-00	Below PQL	Accurate Labs
2	Jul-63	Jan-95	5	ODEQ
2	Jul-63	Jun-89	Below PQL	ODEQ
		Average	**9.79**	
3	Jul-63	Jun-01	0.945	Southwell
3	Jul-63	Jun-01	1.1	Accurate
3	Jul-63	Feb-01	0.44	Accurate
3	Jul-63	Jan-95	Below PQL	ODEQ
3	Jul-63	Jul-89	Below PQL	ODEQ
		Average	**0.83**	
4	Jul-63	Jun-01	68.9	Southwell
4	Jul-63	Jun-01	48	Accurate
4	Jul-63	Jun-01	41	Accurate
4	Jul-63	Jan-01	46	Accurate
4	Jul-63	Feb-97	21	ODEQ
4	Jul-63	Sep-96	20	ODEQ
4	Jul-63	Feb-96	23	ODEQ
4	Jul-63	Nov-95	28	ODEQ
4	Jul-63	Jan-95	112	ODEQ
4	Jul-63	Oct-91	96	ODEQ
4	Jul-63	Oct-91	94	ODEQ
4	Jul-63	Jun-89	Below PQL	ODEQ
		Average	**54.35**	

Note: Samples below PQL are not included in average.

Table B-1
Arsenic Concentration Data
Data provided by City of Norman

Well Number	Year Constructed	Arsenic Testing Date	Arsenic Test Results, µg/L	Testing Laboratory
5	Mar-82	Jun-01	12	Southwell
5	Mar-82	Jun-01	13	Accurate
5	Mar-82	Feb-01	9.7	Accurate
5	Mar-82	Jan-95	2	ODEQ
5	Mar-82	Sep-91	12	ODEQ
5	Mar-82	Sep-91	13	ODEQ
5	Mar-82	Jun-89	Below PQL	ODEQ
		Average	**9.18**	
6	Mar-82	Jun-01	7.14	Southwell
6	Mar-82	Jun-01	9.4	Accurate
6	Mar-82	Feb-01	7.2	Accurate
6	Mar-82	Feb-01	8.21	Southwell
6	Mar-82	Jan-00	Below PQL	Accurate
6	Mar-82	Jan-95	10	ODEQ
6	Mar-82	Jul-89	16	ODEQ
6	Mar-82	Jan-87	16	ODEQ
		Average	**10.56**	
7	Mar-82	Jun-01	13.3	Southwell
7	Mar-82	Jun-01	15	Accurate
7	Mar-82	Jun-01	13	Accurate
7	Mar-82	Feb-01	3.2	Accurate
7	Mar-82	Feb-01	27.9	Southwell
7	Mar-82	Jan-00	14	Accurate
7	Mar-82	Jan-95	28	ODEQ
7	Mar-82	Sep-91	24	ODEQ
7	Mar-82	Sep-91	25	ODEQ
7	Mar-82	Jun-89	Below PQL	ODEQ
		Average	**18.16**	
8	Nov-82	Jun-01	1.79	Southwell
8	Nov-82	Jun-01	2.2	Accurate
8	Nov-82	Feb-01	1.9	Accurate
8	Nov-82	01-Feb	1.77	Southwell
8	Nov-82	Jan-00	Below PQL	Accurate
8	Nov-82	Jan-95	3	ODEQ
8	Nov-82	Jun-89	Below PQL	ODEQ
8	Nov-82	Jan-87	Below PQL	ODEQ
		Average	**2.13**	
9	ABANDONED			

Note: Samples below PQL are not included in average.

Table B-1
Arsenic Concentration Data
Data provided by City of Norman

Well Number	Year Constructed	Arsenic Testing Date	Arsenic Test Results, µg/L	Testing Laboratory
10	1942	Jun-01	4.39	Southwell
10	1942	Jun-01	3.7	Accurate
10	1942	Feb-01	5.4	Accurate
10	1942	Jan-00	Below PQL	Accurate
10	1942	Jan-96	10	ODEQ
		Average	**5.87**	
11	Nov-44	Jun-01	47.8	Southwell
11	Nov-44	Jun-01	35	Accurate
11	Nov-44	Jun-01	38	Accurate
11	Nov-44	Feb-01	74	Accurate
11	Nov-44	Jan-00	Below PQL	Accurate
11	Nov-44	Oct-91	82	ODEQ
11	Nov-44	Oct-91	81	ODEQ
11	Nov-44	Jun-89	60	ODEQ
		Average	**59.69**	
12	Dec-44	Jun-01	90.5	Southwell
12	Dec-44	Jun-01	48	Accurate
12	Dec-44	Jun-01	48	Accurate
12	Dec-44	Feb-01	26	Accurate
12	Dec-44	Jan-00	Below PQL	Accurate
12	Dec-44	Mar-91	91	ODEQ
12	Dec-44	Dec-84	102	ODEQ
		Average	**67.58**	
13	Aug-52	Jun-01	11.6	Southwell
13	Aug-52	Jun-01	11	Accurate
13	Aug-52	Feb-01	7.9	Accurate
13	Aug-52	Feb-01	9.4	Southwell
13	Aug-52	Jan-00	Below PQL	Accurate
13	Aug-52	Oct-91	32	ODEQ
13	Aug-52	Jun-89	Below PQL	ODEQ
		Average	**14.38**	
14	Aug-52	Jun-01	79.7	Southwell
14	Aug-52	Jun-01	39	Accurate
14	Aug-52	Jun-01	40	Accurate
14	Aug-52	Feb-01	48	Accurate
14	Aug-52	Jan-00	32	Accurate
14	Aug-52	Nov-95	47	ODEQ
14	Aug-52	Jan-95	27	ODEQ
14	Aug-52	Jun-89	67	ODEQ
		Average	**47.46**	

Note: Samples below PQL are not included in average.

Table B-1
Arsenic Concentration Data
Data provided by City of Norman

Well Number	Year Constructed	Arsenic Testing Date	Arsenic Test Results, µg/L	Testing Laboratory
15	Apr-53	Jun-01	26.1	Southwell
15	Apr-53	Jun-01	31	Accurate
15	Apr-53	Feb-01	15	Accurate
15	Apr-53	Jan-00	Below PQL	Accurate
15	Apr-53	Jan-95	20	ODEQ
15	Apr-53	Apr-91	53	ODEQ
15	Apr-53	Jun-89	42	ODEQ
15	Apr-53	Dec-84	49	ODEQ
		Average	**33.73**	
16	Jun-53	Jun-01	34	Soutwell
16	Jun-53	Jun-01	36	Accurate
16	Jun-53	Feb-01	16	Accurate
16	Jun-53	Feb-01	14.8	Soutwell
16	Jun-53	Jan-95	39	ODEQ
		Average	**27.96**	
17	Jun-53	NO RECORDS		
18	May-53	Jun-01	10.8	Southwell
18	May-53	Jun-01	12	Accurate
18	May-53	Feb-01	10	Accurate
18	May-53	Feb-01	9.25	Southwell
18	May-53	Jan-00	Below PQL	Accurate
18	May-53	Jan-95	20	ODEQ
18	May-53	Jun-90	Below PQL	ODEQ
		Average	**12.41**	
19	May-53	Jun-01	5.66	Southwell
19	May-53	Jun-01	7.5	Accurate
19	May-53	Feb-01	8.5	Accurate
19	May-53	Jan-00	Below PQL	Accurate
19	May-53	Jan-95	15	ODEQ
19	May-53	Oct-91	11	ODEQ
19	May-53	Oct-91	12	ODEQ
19	May-53	Jun-89	Below PQL	ODEQ
		Average	**9.94**	

Note: Samples below PQL are not included in average.

Table B-1
Arsenic Concentration Data
Data provided by City of Norman

Well Number	Year Constructed	Arsenic Testing Date	Arsenic Test Results, µg/L	Testing Laboratory
20	May-53	Jun-01	3.74	Southwell
20	May-53	Jun-01	4.9	Accurate
20	May-53	Feb-01	3.2	Accurate
20	May-53	Feb-01	2.9	Southwell
20	May-53	Jan-00	Below PQL	Accurate
20	May-53	Jan-00	73	Accurate
20	May-53	Jan-95	4	ODEQ
20	May-53	Jul-89	Below PQL	ODEQ
		Average	**15.29**	
21	Jun-55	Jun-01	66.7	Southwell
21	Jun-55	Jun-01	34	Accurate
21	Jun-55	Jun-01	26	Accurate
21	Jun-55	Feb-01	51	Accurate
21	Jun-55	Jan-00	24	Accurate
21	Jun-55	Nov-95	60	ODEQ
21	Jun-55	Jan-95	21	ODEQ
21	Jun-55	Oct-91	69	ODEQ
21	Jun-55	Oct-91	66	ODEQ
21	Jun-55	Apr-91	61	ODEQ
21	Jun-55	Jul-89	56	ODEQ
21	Jun-55	Dec-84	66	ODEQ
		Average	**50.06**	
22	NO RECORDS			

Note: Samples below PQL are not included in average.

Table B-1
Arsenic Concentration Data
Data provided by City of Norman

Well Number	Year Constructed	Arsenic Testing Date	Arsenic Test Results, µg/L	Testing Laboratory
23	Apr-57	Jun-01	106	Southwell
23	Apr-57	Jun-01	71	Accurate
23	Apr-57	Jun-01	62	Accurate
23	Apr-57	Feb-01	98	Accurate
23	Apr-57	Feb-01	89	Accurate
23	Apr-57	Feb-01	14	Accurate
23	Apr-57	Feb-01	89	Accurate
23	Apr-57	Feb-01	110	Accurate
23	Apr-57	Feb-01	84	Accurate
23	Apr-57	Feb-01	74	Accurate
23	Apr-57	Feb-01	86	Accurate
23	Apr-57	Feb-01	73	Accurate
23	Apr-57	Feb-01	85	Accurate
23	Apr-57	Feb-01	79	Accurate
23	Apr-57	Feb-01	91	Accurate
23	Apr-57	Feb-01	92	Accurate
23	Apr-57	Feb-99	39	ODEQ
23	Apr-57	Mar-99	43	ODEQ
23	Apr-57	Apr-99	43	ODEQ
23	Apr-57	Dec-99	108	ODEQ
23	Apr-57	Aug-98	43	ODEQ
23	Apr-57	Sep-98	46	ODEQ
23	Apr-57	Dec-98	46	ODEQ
23	Apr-57	Nov-98	42	ODEQ
23	Apr-57	Oct-98	45	ODEQ
23	Apr-57	Sep-98	46	ODEQ
23	Apr-57	Aug-98	43	ODEQ
23	Apr-57	Mar-98	49	ODEQ
23	Apr-57	Feb-98	120	ODEQ
23	Apr-57	Dec-97	118	ODEQ
23	Apr-57	Sep-96	110	ODEQ
23	Apr-57	Feb-97	108	ODEQ
23	Apr-57	Sep-84	135	ODEQ
		Average	**75.36**	
24	Sep-57	Abandoned		
24	Sep-57	Aug-94	230	Accurate
24	Sep-57	Apr-91	232	ODEQ
		Average	**231.00**	
25	May-59	Jun-01	70.4	Southwell
25	May-59	Jun-01	41	Accurate
25	May-59	Feb-01	57	Accurate
25	May-59	Jan-00	69	Accurate
25	May-59	Oct-91	58	ODEQ
25	May-59	Oct-91	57	ODEQ
25	May-59	Jul-90	47	ODEQ
25	May-59	Jan-87	65	ODEQ
25	May-59	Dec-84	66	ODEQ
		Average	**58.93**	

Note: Samples below PQL are not included in average.

Table B-1
Arsenic Concentration Data
Data provided by City of Norman

Well Number	Year Constructed	Arsenic Testing Date	Arsenic Test Results, μg/L	Testing Laboratory
26	NO RECORDS			
27	NO RECORDS			
28	NO RECORDS			
29	NO RECORDS			
30	NO RECORDS			
31	May-96	Jun-01	44.5	Southwell
31	May-96	Jun-01	43	Accurate
31	May-96	Feb-01	17	Accurate
31	May-96	Feb-01	16	Southwell
31	May-96	Jan-00	25	Accurate
		Average	**29.10**	
32	Jun-97	Jun-01	33.9	Southwell
32	Jun-97	Jun-01	37	Accurate
32	Jun-97	Feb-01	16	Accurate
32	Jun-97	Jan-00	Below PQL	Accurate
		Average	**28.97**	
33	Jul-98	Feb-01	1.3	Accurate
33	Jul-98	Feb-01	2.64	Southwell
33	Jul-98	Jan-00	Below PQL	Accurate
		Average	**1.97**	
34	Jun-98	Jun-01	8.27	Southwell
34	Jun-98	Jun-01	9.6	Accurate
34	Jun-98	Feb-01	0.86	Accurate
34	Jun-98	Jan-00	Below PQL	Accurate
		Average	**6.24**	
35	Jul-98	Jun-01	0.753	Southwell
35	Jul-98	Jun-01	Below PQL	Accurate
35	Jul-98	Jun-01	Below PQL	Accurate
35	Jul-98	Jun-01	1.29	Southwell
35	Jul-98	Feb-01	Below PQL	Accurate
		Average	**1.29**	

Note: Samples below PQL are not included in average.

Table B-1
Arsenic Concentration Data
Data provided by City of Norman

Well Number	Year Constructed	Arsenic Testing Date	Arsenic Test Results, µg/L	Testing Laboratory
36	Jun-99	Jun-01	22.5	Southwell
36	Jun-99	Jun-01	26	Accurate
36	Jun-99	Feb-01	0.73	Accurate
36	Jun-99	Feb-01	17.1	Southwell
36	Jun-99	Jun-99	Below PQL	Techrad
		Average	**16.58**	
37	May-99	Jun-01	2.24	Southwell
37	May-99	Jun-01	1.8	Accurate
37	May-99	Feb-01	0.75	Accurate
37	May-99	Feb-01	1.15	Southwell
		Average	**1.49**	
38	Jul-00	Jun-01	Below PQL	Southwell
38	Jul-00	Jun-01	0.81	Accurate
38	Jul-00	Feb-01	Below PQL	Accurate
38	Jul-00	Feb-01	Below PQL	Southwell
38	Jul-00	Jul-00	1.2	Southwell
		Average	**1.01**	
39	May-00	Jun-01	6.91	Southwell
39	May-00	Jun-01	5.2	Accurate
39	May-00	Feb-01	4	Accurate
39	May-00	Feb-01	4.1	Southwell
39	May-00	Jul-00	Below PQL	Southwell
39	May-00	Jul-00	Below PQL	Southwell
		Average	**5.05**	
40	May-00	Jun-01	1.49	Southwell
40	May-00	Jun-01	0.44	Accurate
40	May-00	Feb-01	1.3	Accurate
40	May-00	Feb-01	Below PQL	Southwell
		Average	**1.30**	

Note: Samples below PQL are not included in average.

Appendix C

City of Norman Arsenic Study
Ion Exchange Arsenic Treatment Costs
CH2M HILL
06/03/2002

Arsenic MCL, ug/L	10
Design Criteria	
Design Treatment Capacity. MGD	0.36
Total Production Capacity, MGD	0.93
Average Day Treatment Capacity, MGD	0.18
Average Production Flow, MGD	0.46

Booster Pumping Capital Costs

Booster Pump, gpm	252
Number of Pumps	3
Pump Capacity	126
Pumping Head, ft	35
Pump Driver Size, Hp	1.4
Estimated Pump Cost, $ Each	$4,200
Pumping Facility Installation Cost, %	50
Sump	$12,000
Total Pumping Facility Estimated Costs, $	$30,900
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	4,554

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Ion Exchange Facilities Capital Costs

Number of IX Vessels	4
IX Vessel Resin Volume, Each, cf	21
IX Vessel Diameter, ft	3
Total Facility Resin Volume, cf	85
Cost per Vessel Including Valves, $	$30,000
Total Vessel Cost including Valves, $	$120,000
Automatic Controller System	$18,000
Air Compressor/ Receiver	$5,000
Unit Resin Cost, $/cf	$110
Total Resin Cost, $	$9,330
Subtotal IX & Resin Costs, $	$152,330
IX Installation Cost, %	40
Subtotal IX System Costs, $	$213,263
Ion Exchange Facilities Annual Costs	
Resin Life, yrs	5
Annualized Resin Replacement Costs, $/yr	$1,866

Brine Regeneration Facilities Capital Costs

Number of Brine Recycle/Reaction Tanks	1
Minimum Batch Brine Rendering Time, days	1.0
Days Between Brine Waste Cycles	0.74
Brine & Rinse Storage, gal	593
Recycle/Reaction Basin Cost, Each, $	$10,000
Total Reaction Basin Cost, $	$10,000
Mixer Driver, Hp	0.13
Mixer/Support , Each, $	$8,000
Total Mixer Cost, $	$8,000
Brine Recirculation Pumps Cost per Tank, $	$2,000
Reaction Basin Supematant Pumps Cost per Tank, $	$4,000
Total Brine Regeneration/Reaction Facility Cost	$24,000
Brine Regeneration Facilities Annual Costs	
Mixer Power Requirement, kWh/yr	139
Brine Recirc Pumps Power Requirement, kWh/yr	1,014
Reaction Basin Supematant Pump Power, kWh/yr	3
Total Annual Estimated Brine Power, kWh/yr	1,156
Brine Trucking, gpd Based on Average Flow	399
Brine Trucking Round Trip, miles	0
Trucking Costs, $/gal/mile	0.0004
Trucking Down Time per 4600 gal load, hrs	2
Cost of Trucking Down Time, $/hr	0
Annual Brine Hauling Cost, $/yr	$0

City of Norman Arsenic Study
Ion Exchange Arsenic Treatment Costs
CH2M HILL
06/03/2002

Brine Maker Costs

Salt Storage, Tons	4.3
Number of Brine Maker Tanks	1
Cost per Brine Maker Tank, $	$15,000
Total Brine Maker Costs, $	$15,000

Brine Evaporation

Brine Evap. Pond, acres	0.00
Land Area Including 100 foot Buffer, acres	0.0
Land Cost, $/acre	$0
Total Land Cost, $	$0
Fencing Cost, $	$0
Excavation for Pond, cy	0
Unit Excavation Cost, $/cy	$0.00
Excavation Cost, $	$0
Unit Liner & Concrete Cost, $/sf	$0.00
Liner & Concrete Cost, $	$0
Evaporation Facility Cost, $	$0

Dewatering Facilities Capital Costs

Number of Filter Presses	1.00
Filter Press, cf	0.023
Filter Press Cost, Each, $	$26,000
Dumpster	$3,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$40,800
Dewatering Facilities Annual Costs	
Filter Feed Pump Power Use, kWh/yr	595

Chemical Storage Capital Costs

FeCl3 Storage, gals	6
FeCl3 Storage Cost, $	$56
FeCl3 Metering Pump Cost, $	$10,000
NaOH Storage, gals	71
NaOH Storage Cost, $	$355
NaOH Feed Pumps, $	$4,000
H2SO4 Storage, gals	245
H2SO4 Storage Cost, $	$4,904
H2SO4 Feed Pumps, $	$4,000
Chemical Feed Facility Installation Cost, %	40
Total Chemical Feed Facility Estimated Costs	$32,642

Total IX System Equipment Cost Summary

Equipment Subtotal	$374,604
Internal Piping Allowance,%	15
I&C Allowance, %	10
Electrical Allowance, %	5
Yard Piping Allowance,%	15
Total Process Estimated Cost,$	$543,176

Building Facilities

Building, sf	1,500
Building Unit Cost, $/sf	$100
Building Cost, $	$150,000

Total Estimated Capital Costs

Subtotal Estimated Facility Cost, $	$693,176
Contingency, %	20
Total IX Arsenic Removal Facility Cost, $	$831,812
Unit Cost, $/gpd	$2.30

City of Norman Arsenic Study
Ion Exchange Arsenic Treatment Costs
CH2M HILL
06/03/2002

Annual O&M Costs

Annual Power Use, kWh/yr	6,387
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$447
Annualized Resin Replacement Costs, $/yr	$1,866
FeCl3 Use, PPD Based on Average Flow	0.45
Unit FeCl3 Cost, $/lb	0.15
Annual FeCl3 Cost, $/yr	$24
NaOH Use, PPD Based on Average Flow	8
Unit NaOH Cost, $/lb	0.13
Annual NaOH Cost, $/yr	$358
H2SO4 Use, PPD Based on Average Flow	58
Unit H2SO4 Cost, $/lb	0.10
Annual H2SO4 Cost, $/yr	$2,099
Salt Use, Tons/Day Based on Average Flow	0.07
Unit Salt Cost Delivered to Albuquerque, $/ton	$59
Annual Salt Cost, $/yr	$1,529
Dewatered Iron Residuals Production, cy/day Based on Average Flow	0.0006
Dewatered Waste Salt Production, cy/yr	29
Residuals Disposal Costs, $/cy	$45
Total Residuals Disposal Costs, $/yr	$1,324
Brine Hauling Costs	$0
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Unit Labor Cost, Management, $/yr	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$8,318
Total Estimated Annual O&M Costs, $/yr	$32,465
Unit Annual O&M Costs, $/1000 gal	$0.49

Capital Cost Summary

Booster Pumping/ Straining	$48,900
Ion Exchange Facilities	$213,263
Brine Handling Facilities	$39,000
Brine Evaporation Facilities	$0
Solids Handling	$40,800
Chemical Feed Systems	$32,642
Building	$150,000
Piping, I&C, Electrical, Yard Piping Allowances	$168,572
Total Facility Cost, $	$693,176
Ancillary Offsite Piping	$174,240
Contingency, 20%	$173,483
Total Estimated IX Facility Cost	$1,040,900

Summary of IX Annual O&M Costs

Item	Cost
Annual Power Cost, $/yr	$447
Annualized Resin Replacement Costs, $/yr	$1,866
Annual FeCl3 Cost, $/yr	$24
Annual NaOH Cost, $/yr	$358
Annual H2SO4 Cost, $/yr	$2,099
Annual Salt Cost, $/yr	$1,529
Total Residuals Disposal Costs, $/yr	$1,324
Brine Hauling Costs	$0
Total Estimated Labor Costs, $/yr	$16,500
Treatment Equipment Maintenance Cost	$8,318
Estimated O&M Costs for IX $/yr	$32,465
Unit Annual O&M Costs, $/1000 gal	$0.49

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$372,375
Total Capital Cost	$1,040,900
Total Present Value of IX Facitlities	$1,413,275

City of Norman Arsenic Study
Ion Exchange Arsenic Treatment Costs
CH2M HILL
06/03/2002

Arsenic MCL, ug/L	10
Design Criteria	
Design Treatment Capacity. MGD	1.11
Total Production Capacity, MGD	1.38
Average Day Treatment Capacity, MGD	0.56
Average Production Flow, MGD	0.69

Booster Pumping Capital Costs

Booster Pump, gpm	772
Number of Pumps	3
Pump Capacity	386
Pumping Head, ft	35
Pump Driver Size, Hp	4.3
Estimated Pump Cost, $ Each	$12,800
Pumping Facility Installation Cost, %	50
Sump	$18,000
Total Pumping Facility Estimated Costs, $	$75,600
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	13,963

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Ion Exchange Facilities Capital Costs

Number of IX Vessels	4
IX Vessel Resin Volume, Each, cf	59
IX Vessel Diameter, ft	5
Total Facility Resin Volume, cf	236
Cost per Vessel Including Valves, $	$50,000
Total Vessel Cost including Valves, $	$200,000
Automatic Controller System	$30,000
Air Compressor/ Receiver	$8,000
Unit Resin Cost, $/cf	$110
Total Resin Cost, $	$25,918
Subtotal IX & Resin Costs, $	$263,918
IX Installation Cost, %	40
Subtotal IX System Costs, $	$369,485
Ion Exchange Facilities Annual Costs	
Resin Life, yrs	5
Annualized Resin Replacement Costs, $/yr	$5,184

Brine Regeneration Facilities Capital Costs

Number of Brine Recycle/Reaction Tanks	1
Minimum Batch Brine Rendering Time, days	1.0
Days Between Brine Waste Cycles	0.17
Brine & Rinse Storage, gal	1,648
Recycle/Reaction Basin Cost, Each, $	$12,000
Total Reaction Basin Cost, $	$12,000
Mixer Driver, Hp	1.63
Mixer/Support , Each, $	$9,000
Total Mixer Cost, $	$9,000
Brine Recirculation Pumps Cost per Tank, $	$3,000
Reaction Basin Supernatant Pumps Cost per Tank, $	$4,000
Total Brine Regeneration/Reaction Facility Cost	$28,000
Brine Regeneration Facilities Annual Costs	
Mixer Power Requirement, kWh/yr	8,006
Brine Recirc Pumps Power Requirement, kWh/yr	4,531
Reaction Basin Supernatant Pump Power, kWh/yr	142
Total Annual Estimated Brine Power, kWh/yr	12,679
Brine Trucking, gpd Based on Average Flow	4,948
Brine Trucking Round Trip, miles	0
Trucking Costs, $/gal/mile	0.0004
Trucking Down Time per 4600 gal load, hrs	2
Cost of Trucking Down Time, $/hr	0
Annual Brine Hauling Cost, $/yr	$0

City of Norman Arsenic Study
Ion Exchange Arsenic Treatment Costs
CH2M HILL
06/03/2002

Brine Maker Costs

Salt Storage, Tons	53.0
Number of Brine Maker Tanks	1
Cost per Brine Maker Tank, $	$18,000
Total Brine Maker Costs, $	$18,000

Brine Evaporation

Brine Evap. Pond, acres	0.00
Land Area Including 100 foot Buffer, acres	0.0
Land Cost, $/acre	$0
Total Land Cost, $	$0
Fencing Cost, $	$0
Excavation for Pond, cy	0
Unit Excavation Cost, $/cy	$0.00
Excavation Cost, $	$0
Unit Liner & Concrete Cost, $/sf	$0.00
Liner & Concrete Cost, $	$0
Evaporation Facility Cost, $	$0

Dewatering Facilities Capital Costs

Number of Filter Presses	1.00
Filter Press, cf	0.065
Filter Press Cost, Each, $	$26,000
Dumpster	$3,000
Sludge Feed Pumps Cost, $	$8,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$44,400
Dewatering Facilities Annual Costs	
Filter Feed Pump Power Use, kWh/yr	2,659

Chemical Storage Capital Costs

FeCl3 Storage, gals	70
FeCl3 Storage Cost, $	$699
FeCl3 Metering Pump Cost, $	$12,000
NaOH Storage, gals	218
NaOH Storage Cost, $	$1,088
NaOH Feed Pumps, $	$6,000
H2SO4 Storage, gals	3,043
H2SO4 Storage Cost, $	$60,858
H2SO4 Feed Pumps, $	$6,000
Chemical Feed Facility Installation Cost, %	40
Total Chemical Feed Facility Estimated Costs	$121,304

Total IX System Equipment Cost Summary

Equipment Subtotal	$674,789
Internal Piping Allowance,%	15
I&C Allowance, %	10
Electrical Allowance, %	5
Yard Piping Allowance,%	15
Total Process Estimated Cost,$	$978,445

Building Facilities

Building, sf	2,000
Building Unit Cost, $/sf	$100
Building Cost, $	$200,000

Total Estimated Capital Costs

Subtotal Estimated Facility Cost, $	$1,178,445
Contingency, %	20
Total IX Arsenic Removal Facility Cost, $	$1,414,134
Unit Cost, $/gpd	$1.27

City of Norman Arsenic Study
Ion Exchange Arsenic Treatment Costs
CH2M HILL
06/03/2002

Annual O&M Costs

Annual Power Use, kWh/yr	29,382
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$2,057
Annualized Resin Replacement Costs, $/yr	$5,184
FeCl3 Use, PPD Based on Average Flow	6
Unit FeCl3 Cost, $/lb	0.15
Annual FeCl3 Cost, $/yr	$304
NaOH Use, PPD Based on Average Flow	23
Unit NaOH Cost, $/lb	0.13
Annual NaOH Cost, $/yr	$1,098
H2SO4 Use, PPD Based on Average Flow	714
Unit H2SO4 Cost, $/lb	0.10
Annual H2SO4 Cost, $/yr	$26,045
Salt Use, Tons/Day Based on Average Flow	0.88
Unit Salt Cost Delivered to Albuquerque, $/ton	$59
Annual Salt Cost, $/yr	$18,974
Dewatered Iron Residuals Production, cy/day Based on Average Flow	0.01
Dewatered Waste Salt Production, cy/yr	362
Residuals Disposal Costs, $/cy	$45
Total Residuals Disposal Costs, $/yr	$16,424
Brine Hauling Costs	$0
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Unit Labor Cost, Management, $/yr	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$14,141
Total Estimated Annual O&M Costs, $/yr	$100,727
Unit Annual O&M Costs, $/1000 gal	$0.50

Capital Cost Summary

Booster Pumping/ Straining	$93,600
Ion Exchange Facilities	$369,485
Brine Handling Facilities	$46,000
Brine Evaporation Facilities	$0
Solids Handling	$44,400
Chemical Feed Systems	$121,304
Building	$200,000
Piping, I&C, Electrical, Yard Piping Allowances	$303,655
Total Facility Cost, $	$1,178,445
Ancillary Offsite Pipling	$286,176
Contingency, 20%	$292,924
Total Estimated IX Facility Cost	$1,757,545

Summary of IX Annual O&M Costs

Item	Cost
Annual Power Cost, $/yr	$2,057
Annualized Resin Replacement Costs, $/yr	$5,184
Annual FeCl3 Cost, $/yr	$304
Annual NaOH Cost, $/yr	$1,098
Annual H2SO4 Cost, $/yr	$26,045
Annual Salt Cost, $/yr	$18,974
Total Residuals Disposal Costs, $/yr	$16,424
Brine Hauling Costs	$0
Total Estimated Labor Costs, $/yr	$16,500
Treatment Equipment Maintenance Cost	$14,141
Estimated O&M Costs for IX $/yr	$100,727
Unit Annual O&M Costs, $/1000 gal	$0.50

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$1,155,333
Total Capital Cost	$1,757,545
Total Present Value of IX Facitlities	$2,912,878

City of Norman Arsenic Study
Ion Exchange Arsenic Treatment Costs
CH2M HILL
06/03/2002

Arsenic MCL, ug/L	10

Design Criteria

Design Treatment Capacity. MGD	2.08
Total Production Capacity, MGD	2.79
Average Day Treatment Capacity, MGD	1.69
Average Production Flow, MGD	2.26

Booster Pumping Capital Costs

Booster Pump, gpm	1448
Number of Pumps	3
Pump Capacity	724
Pumping Head, ft	35
Pump Driver Size, Hp	8.0
Estimated Pump Cost, $ Each	$24,000
Pumping Facility Installation Cost, %	50
Sump	$22,000
Total Pumping Facility Estimated Costs, $	$130,000
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	42,429

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$17,500
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$21,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Ion Exchange Facilities Capital Costs

Number of IX Vessels	4
IX Vessel Resin Volume, Each, cf	115
IX Vessel Diameter, ft	7
Total Facility Resin Volume, cf	462
Cost per Vessel Including Valves, $	$70,000
Total Vessel Cost including Valves, $	$280,000
Automatic Controller System	$42,000
Air Compressor/ Receiver	$10,000
Unit Resin Cost, $/cf	$110
Total Resin Cost, $	$50,799
Subtotal IX & Resin Costs, $	$382,799
IX Installation Cost, %	40
Subtotal IX System Costs, $	$535,919
Ion Exchange Facilities Annual Costs	
Resin Life, yrs	5
Annualized Resin Replacement Costs, $/yr	$10,160

Brine Regeneration Facilities Capital Costs

Number of Brine Recycle/Reaction Tanks	1
Minimum Batch Brine Rendering Time, days	1.0
Days Between Brine Waste Cycles	0.23
Brine & Rinse Storage, gal	2,142
Recycle/Reaction Basin Cost, Each, $	$15,000
Total Reaction Basin Cost, $	$15,000
Mixer Driver, Hp	3.14
Mixer/Support , Each, $	$10,000
Total Mixer Cost, $	$10,000
Brine Recirculation Pumps Cost per Tank, $	$5,000
Reaction Basin Supernatant Pumps Cost per Tank, $	$4,000
Total Brine Regeneration/Reaction Facility Cost	$34,000
Brine Regeneration Facilities Annual Costs	
Mixer Power Requirement, kWh/yr	11,271
Brine Recirc Pumps Power Requirement, kWh/yr	3,314
Reaction Basin Supernatant Pump Power, kWh/yr	159
Total Annual Estimated Brine Power, kWh/yr	14,744
Brine Trucking, gpd Based on Average Flow	7,612
Brine Trucking Round Trip, miles	0
Trucking Costs, $/gal/mile	0.0004
Trucking Down Time per 4600 gal load, hrs	2
Cost of Trucking Down Time, $/hr	0
Annual Brine Hauling Cost, $/yr	$0

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Brine Maker Costs

Salt Storage, Tons	41.0
Number of Brine Maker Tanks	1
Cost per Brine Maker Tank, $	$20,000
Total Brine Maker Costs, $	$20,000

Brine Evaporation

Brine Evap. Pond, acres	0.00
Land Area Including 100 foot Buffer, acres	0.0
Land Cost, $/acre	$0
Total Land Cost, $	$0
Fencing Cost, $	$0
Excavation for Pond, cy	0
Unit Excavation Cost, $/cy	$0.00
Excavation Cost, $	$0
Unit Liner & Concrete Cost, $/sf	$0.00
Liner & Concrete Cost, $	$0
Evaporation Facility Cost, $	$0

Dewatering Facilities Capital Costs

Number of Filter Presses	1.00
Filter Press, cf	0.133
Filter Press Cost, Each, $	$26,000
Dumpster	$3,000
Sludge Feed Pumps Cost, $	$12,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$49,200
Dewatering Facilities Annual Costs	
Filter Feed Pump Power Use, kWh/yr	1,945

Chemical Storage Capital Costs

FeCl3 Storage, gals	105
FeCl3 Storage Cost, $	$1,048
FeCl3 Metering Pump Cost, $	$12,000
NaOH Storage, gals	409
NaOH Storage Cost, $	$2,043
NaOH Feed Pumps, $	$6,000
H2SO4 Storage, gals	2,356
H2SO4 Storage Cost, $	$47,115
H2SO4 Feed Pumps, $	$6,000
Chemical Feed Facility Installation Cost, %	40
Total Chemical Feed Facility Estimated Costs	$103,890

Total IX System Equipment Cost Summary

Equipment Subtotal	$894,008
Internal Piping Allowance,%	15
I&C Allowance, %	10
Electrical Allowance, %	5
Yard Piping Allowance,%	15
Total Process Estimated Cost,$	$1,296,312

Building Facilities

Building, sf	2,600
Building Unit Cost, $/sf	$100
Building Cost, $	$260,000

Total Estimated Capital Costs

Subtotal Estimated Facility Cost, $	$1,556,312
Contingency, %	20
Total IX Arsenic Removal Facility Cost, $	$1,867,575
Unit Cost, $/gpd	$0.90

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Annual O&M Costs

Annual Power Use, kWh/yr	59,200
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$4,144
Annualized Resin Replacement Costs, $/yr	$10,160
FeCl3 Use, PPD Based on Average Flow	13
Unit FeCl3 Cost, $/lb	0.15
Annual FeCl3 Cost, $/yr	$739
NaOH Use, PPD Based on Average Flow	70
Unit NaOH Cost, $/lb	0.13
Annual NaOH Cost, $/yr	$3,337
H2SO4 Use, PPD Based on Average Flow	894
Unit H2SO4 Cost, $/lb	0.10
Annual H2SO4 Cost, $/yr	$32,636
Salt Use, Tons/Day Based on Average Flow	1.11
Unit Salt Cost Delivered to Albuquerque, $/ton	$59
Annual Salt Cost, $/yr	$23,775
Dewatered Iron Residuals Production, cy/day Based on Average Flow	0.02
Dewatered Waste Salt Production, cy/yr	454
Residuals Disposal Costs, $/cy	$45
Total Residuals Disposal Costs, $/yr	$20,719
Brine Hauling Costs	$0
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Unit Labor Cost, Management, $/yr	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$18,676
Total Estimated Annual O&M Costs, $/yr	$130,686
Unit Annual O&M Costs, $/1000 gal	$0.21

Capital Cost Summary

Booster Pumping/ Straining	$151,000
Ion Exchange Facilities	$535,919
Brine Handling Facilities	$54,000
Brine Evaporation Facilities	$0
Solids Handling	$49,200
Chemical Feed Systems	$103,890
Building	$260,000
Piping, I&C, Electrical, Yard Piping Allowances	$402,304
Total Facility Cost, $	$1,556,312
Ancillary Offsite Pipiing	$709,104
Contingency, 20%	$453,083
Total Estimated IX Facility Cost	$2,718,499

Summary of IX Annual O&M Costs

Item	Cost
Annual Power Cost, $/yr	$4,144
Annualized Resin Replacement Costs, $/yr	$10,160
Annual FeCl3 Cost, $/yr	$739
Annual NaOH Cost, $/yr	$3,337
Annual H2SO4 Cost, $/yr	$32,636
Annual Salt Cost, $/yr	$23,775
Total Residuals Disposal Costs, $/yr	$20,719
Brine Hauling Costs	$0
Total Estimated Labor Costs, $/yr	$16,500
Treatment Equipment Maintenance Cost	$18,676
Estimated O&M Costs for IX $/yr	$130,686
Unit Annual O&M Costs, $/1000 gal	$0.21

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$1,498,954
Total Capital Cost	$2,718,499
Total Present Value of IX Facitlities	$4,217,454

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Arsenic MCL, ug/L	10
Design Criteria	
Design Treatment Capacity. MGD	0.19
Total Production Capacity, MGD	0.31
Average Day Treatment Capacity, MGD	0.10
Average Production Flow, MGD	0.15

Booster Pumping Capital Costs

Booster Pump, gpm	133
Number of Pumps	3
Pump Capacity	67
Pumping Head, ft	35
Pump Driver Size, Hp	0.7
Estimated Pump Cost, $ Each	$2,200
Pumping Facility Installation Cost, %	50
Sump	$12,000
Total Pumping Facility Estimated Costs, $	$21,900
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	2,412

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Ion Exchange Facilities Capital Costs

Number of IX Vessels	4
IX Vessel Resin Volume, Each, cf	9
IX Vessel Diameter, ft	2
Total Facility Resin Volume, cf	38
Cost per Vessel Including Valves, $	$20,000
Total Vessel Cost including Valves, $	$80,000
Automatic Controller System	$12,000
Air Compressor/ Receiver	$5,000
Unit Resin Cost, $/cf	$110
Total Resin Cost, $	$4,147
Subtotal IX & Resin Costs, $	$101,147
IX Installation Cost, %	40
Subtotal IX System Costs, $	$141,606
Ion Exchange Facilities Annual Costs	
Resin Life, yrs	5
Annualized Resin Replacement Costs, $/yr	$829

Brine Regeneration Facilities Capital Costs

Number of Brine Recycle/Reaction Tanks	1
Minimum Batch Brine Rendering Time, days	1.0
Days Between Brine Waste Cycles	0.33
Brine & Rinse Storage, gal	264
Recycle/Reaction Basin Cost, Each, $	$10,000
Total Reaction Basin Cost, $	$10,000
Mixer Driver, Hp	0.02
Mixer/Support , Each, $	$8,000
Total Mixer Cost, $	$8,000
Brine Recirculation Pumps Cost per Tank, $	$2,000
Reaction Basin Supernatant Pumps Cost per Tank, $	$4,000
Total Brine Regeneration/Reaction Facility Cost	$24,000
Brine Regeneration Facilities Annual Costs	
Mixer Power Requirement, kWh/yr	41
Brine Recirc Pumps Power Requirement, kWh/yr	2,283
Reaction Basin Supernatant Pump Power, kWh/yr	6
Total Annual Estimated Brine Power, kWh/yr	2,330
Brine Trucking, gpd Based on Average Flow	399
Brine Trucking Round Trip, miles	0
Trucking Costs, $/gal/mile	0.0004
Trucking Down Time per 4600 gal load, hrs	2
Cost of Trucking Down Time, $/hr	0
Annual Brine Hauling Cost, $/yr	$0

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Brine Maker Costs

Salt Storage, Tons	4.3
Number of Brine Maker Tanks	1
Cost per Brine Maker Tank, $	$15,000
Total Brine Maker Costs, $	$15,000

Brine Evaporation

Brine Evap. Pond, acres	0.00
Land Area Including 100 foot Buffer, acres	0.0
Land Cost, $/acre	$0
Total Land Cost, $	$0
Fencing Cost, $	$0
Excavation for Pond, cy	0
Unit Excavation Cost, $/cy	$0.00
Excavation Cost, $	$0
Unit Liner & Concrete Cost, $/sf	$0.00
Liner & Concrete Cost, $	$0
Evaporation Facility Cost, $	$0

Dewatering Facilities Capital Costs

Number of Filter Presses	1.00
Filter Press, cf	0.009
Filter Press Cost, Each, $	$26,000
Dumpster	$3,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$40,800
Dewatering Facilities Annual Costs	
Filter Feed Pump Power Use, kWh/yr	1,340

Chemical Storage Capital Costs

FeCl3 Storage, gals	5
FeCl3 Storage Cost, $	$47
FeCl3 Metering Pump Cost, $	$10,000
NaOH Storage, gals	38
NaOH Storage Cost, $	$188
NaOH Feed Pumps, $	$4,000
H2SO4 Storage, gals	245
H2SO4 Storage Cost, $	$4,906
H2SO4 Feed Pumps, $	$4,000
Chemical Feed Facility Installation Cost, %	40
Total Chemical Feed Facility Estimated Costs	$32,398

Total IX System Equipment Cost Summary

Equipment Subtotal	$293,704
Internal Piping Allowance,%	15
I&C Allowance, %	10
Electrical Allowance, %	5
Yard Piping Allowance,%	15
Total Process Estimated Cost,$	$425,870

Building Facilities

Building, sf	1,300
Building Unit Cost, $/sf	$100
Building Cost, $	$130,000

Total Estimated Capital Costs

Subtotal Estimated Facility Cost, $	$555,870
Contingency, %	20
Total IX Arsenic Removal Facility Cost, $	$667,044
Unit Cost, $/gpd	$3.48

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Annual O&M Costs

Annual Power Use, kWh/yr	6,164
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$431
Annualized Resin Replacement Costs, $/yr	$829
FeCl3 Use, PPD Based on Average Flow	0
Unit FeCl3 Cost, $/lb	0.15
Annual FeCl3 Cost, $/yr	$20
NaOH Use, PPD Based on Average Flow	4
Unit NaOH Cost, $/lb	0.13
Annual NaOH Cost, $/yr	$190
H2SO4 Use, PPD Based on Average Flow	58
Unit H2SO4 Cost, $/lb	0.10
Annual H2SO4 Cost, $/yr	$2,100
Salt Use, Tons/Day Based on Average Flow	0.07
Unit Salt Cost Delivered to Albuquerque, $/ton	$59
Annual Salt Cost, $/yr	$1,530
Dewatered Iron Residuals Production, cy/day Based on Average Flow	0.00
Dewatered Waste Salt Production, cy/yr	29
Residuals Disposal Costs, $/cy	$45
Total Residuals Disposal Costs, $/yr	$1,323
Brine Hauling Costs	$0
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Unit Labor Cost, Management, $/yr	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$6,670
Total Estimated Annual O&M Costs, $/yr	$29,593
Unit Annual O&M Costs, $/1000 gal	$0.85

Capital Cost Summary

Booster Pumping/ Straining	$39,900
Ion Exchange Facilities	$141,606
Brine Handling Facilities	$39,000
Brine Evaporation Facilities	$0
Solids Handling	$40,800
Chemical Feed Systems	$32,398
Building	$130,000
Piping, I&C, Electrical, Yard Piping Allowances	$132,167
Total Facility Cost, $	$555,870
Ancillary Offsite Pipiing	$9,504
Contingency, 20%	$113,075
Total Estimated IX Facility Cost	$678,449

Summary of IX Annual O&M Costs

Item	Cost
Annual Power Cost, $/yr	$431
Annualized Resin Replacement Costs, $/yr	$829
Annual FeCl3 Cost, $/yr	$20
Annual NaOH Cost, $/yr	$190
Annual H2SO4 Cost, $/yr	$2,100
Annual Salt Cost, $/yr	$1,530
Total Residuals Disposal Costs, $/yr	$1,323
Brine Hauling Costs	$0
Total Estimated Labor Costs, $/yr	$16,500
Treatment Equipment Maintenance Cost	$6,670
Estimated O&M Costs for IX $/yr	$29,593
Unit Annual O&M Costs, $/1000 gal	$0.85

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$339,435
Total Capital Cost	$678,449
Total Present Value of IX Facitlities	$1,017,884

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Arsenic MCL, ug/L	10

Design Criteria

Design Treatment Capacity, MGD	0.81
Total Production Capacity, MGD	1.00
Average Day Treatment Capacity, MGD	0.41
Average Production Flow, MGD	0.50

Booster Pumping Capital Costs

Booster Pump, gpm	565
Number of Pumps	3
Pump Capacity	283
Pumping Head, ft	35
Pump Driver Size, Hp	3.1
Estimated Pump Cost, $ Each	$9,400
Pumping Facility Installation Cost, %	50
Sump	$18,000
Total Pumping Facility Estimated Costs, $	$60,300
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	10,232

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Ion Exchange Facilities Capital Costs

Number of IX Vessels	4
IX Vessel Resin Volume, Each, cf	59
IX Vessel Diameter, ft	5
Total Facility Resin Volume, cf	236
Cost per Vessel Including Valves, $	$50,000
Total Vessel Cost including Valves, $	$200,000
Automatic Controller System	$30,000
Air Compressor/ Receiver	$8,000
Unit Resin Cost, $/cf	$110
Total Resin Cost, $	$25,918
Subtotal IX & Resin Costs, $	$263,918
IX Installation Cost, %	40
Subtotal IX System Costs, $	$369,485
Ion Exchange Facilities Annual Costs	
Resin Life, yrs	5
Annualized Resin Replacement Costs, $/yr	$5,184

Brine Regeneration Facilities Capital Costs

Number of Brine Recycle/Reaction Tanks	1
Minimum Batch Brine Rendering Time, days	1.0
Days Between Brine Waste Cycles	0.27
Brine & Rinse Storage, gal	1,648
Recycle/Reaction Basin Cost, Each, $	$12,000
Total Reaction Basin Cost, $	$12,000
Mixer Driver, Hp	1.63
Mixer/Support , Each, $	$9,000
Total Mixer Cost, $	$9,000
Brine Recirculation Pumps Cost per Tank, $	$3,000
Reaction Basin Supernatant Pumps Cost per Tank, $	$4,000
Total Brine Regeneration/Reaction Facility Cost	$28,000
Brine Regeneration Facilities Annual Costs	
Mixer Power Requirement, kWh/yr	4,928
Brine Recirc Pumps Power Requirement, kWh/yr	2,789
Reaction Basin Supernatant Pump Power, kWh/yr	54
Total Annual Estimated Brine Power, kWh/yr	7,771
Brine Trucking, gpd Based on Average Flow	3,046
Brine Trucking Round Trip, miles	0
Trucking Costs, $/gal/mile	0.0004
Trucking Down Time per 4600 gal load, hrs	2
Cost of Trucking Down Time, $/hr	0
Annual Brine Hauling Cost, $/yr	$0

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Brine Maker Costs

Salt Storage, Tons	32.6
Number of Brine Maker Tanks	1
Cost per Brine Maker Tank, $	$18,000
Total Brine Maker Costs, $	$18,000

Brine Evaporation

Brine Evap. Pond, acres	0.00
Land Area Including 100 foot Buffer, acres	0.0
Land Cost, $/acre	$0
Total Land Cost, $	$0
Fencing Cost, $	$0
Excavation for Pond, cy	0
Unit Excavation Cost, $/cy	$0.00
Excavation Cost, $	$0
Unit Liner & Concrete Cost, $/sf	$0.00
Liner & Concrete Cost, $	$0
Evaporation Facility Cost, $	$0

Dewatering Facilities Capital Costs

Number of Filter Presses	1.00
Filter Press, cf	0.065
Filter Press Cost, Each, $	$26,000
Dumpster	$3,000
Sludge Feed Pumps Cost, $	$8,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$44,400
Dewatering Facilities Annual Costs	
Filter Feed Pump Power Use, kWh/yr	1,637

Chemical Storage Capital Costs

FeCl3 Storage, gals	43
FeCl3 Storage Cost, $	$430
FeCl3 Metering Pump Cost, $	$12,000
NaOH Storage, gals	160
NaOH Storage Cost, $	$798
NaOH Feed Pumps, $	$6,000
H2SO4 Storage, gals	1,873
H2SO4 Storage Cost, $	$37,460
H2SO4 Feed Pumps, $	$6,000
Chemical Feed Facility Installation Cost, %	40
Total Chemical Feed Facility Estimated Costs	$87,762

Total IX System Equipment Cost Summary

Equipment Subtotal	$625,948
Internal Piping Allowance,%	15
I&C Allowance, %	10
Electrical Allowance, %	5
Yard Piping Allowance,%	15
Total Process Estimated Cost,$	$907,624

Building Facilities

Building, sf	2,000
Building Unit Cost, $/sf	$100
Building Cost, $	$200,000

Total Estimated Capital Costs

Subtotal Estimated Facility Cost, $	$1,107,624
Contingency, %	20
Total IX Arsenic Removal Facility Cost, $	$1,329,149
Unit Cost, $/gpd	$1.63

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Annual O&M Costs

Annual Power Use, kWh/yr	19,720
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$1,380
Annualized Resin Replacement Costs, $/yr	$5,184
FeCl3 Use, PPD Based on Average Flow	3
Unit FeCl3 Cost, $/lb	0.15
Annual FeCl3 Cost, $/yr	$187
NaOH Use, PPD Based on Average Flow	17
Unit NaOH Cost, $/lb	0.13
Annual NaOH Cost, $/yr	$805
H2SO4 Use, PPD Based on Average Flow	439
Unit H2SO4 Cost, $/lb	0.10
Annual H2SO4 Cost, $/yr	$16,032
Salt Use, Tons/Day Based on Average Flow	0.54
Unit Salt Cost Delivered to Albuquerque, $/ton	$59
Annual Salt Cost, $/yr	$11,679
Dewatered Iron Residuals Production, cy/day Based on Average Flow	0.00
Dewatered Waste Salt Production, cy/yr	223
Residuals Disposal Costs, $/cy	$45
Total Residuals Disposal Costs, $/yr	$10,109
Brine Hauling Costs	$0
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Unit Labor Cost, Management, $/yr	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$13,291
Total Estimated Annual O&M Costs, $/yr	$75,167
Unit Annual O&M Costs, $/1000 gal	$0.51

Capital Cost Summary

Booster Pumping/ Straining	$78,300
Ion Exchange Facilities	$369,485
Brine Handling Facilities	$46,000
Brine Evaporation Facilities	$0
Solids Handling	$44,400
Chemical Feed Systems	$87,762
Building	$200,000
Piping, I&C, Electrical, Yard Piping Allowances	$281,676
Total Facility Cost, $	$1,107,624
Ancillary Offsite Piping	$318,384
Contingency, 20%	$285,202
Total Estimated IX Facility Cost	$1,711,209

Summary of IX Annual O&M Costs

Item	Cost
Annual Power Cost, $/yr	$1,380
Annualized Resin Replacement Costs, $/yr	$5,184
Annual FeCl3 Cost, $/yr	$187
Annual NaOH Cost, $/yr	$805
Annual H2SO4 Cost, $/yr	$16,032
Annual Salt Cost, $/yr	$11,679
Total Residuals Disposal Costs, $/yr	$10,109
Brine Hauling Costs	$0
Total Estimated Labor Costs, $/yr	$16,500
Treatment Equipment Maintenance Cost	$13,291
Estimated O&M Costs for IX $/yr	$75,167
Unit Annual O&M Costs, $/1000 gal	$0.51

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$862,163
Total Capital Cost	$1,711,209
Total Present Value of IX Facitlities	$2,573,373

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Arsenic MCL, ug/L	10

Design Criteria

Design Treatment Capacity. MGD	0.19
Total Production Capacity, MGD	0.33
Average Day Treatment Capacity, MGD	0.10
Average Production Flow, MGD	0.17

Booster Pumping Capital Costs

Booster Pump, gpm	135
Number of Pumps	3
Pump Capacity	68
Pumping Head, ft	35
Pump Driver Size, Hp	0.7
Estimated Pump Cost, $ Each	$2,200
Pumping Facility Installation Cost, %	50
Sump	$12,000
Total Pumping Facility Estimated Costs, $	$21,900
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	2,450

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Ion Exchange Facilities Capital Costs

Number of IX Vessels	4
IX Vessel Resin Volume, Each, cf	9
IX Vessel Diameter, ft	2
Total Facility Resin Volume, cf	38
Cost per Vessel Including Valves, $	$20,000
Total Vessel Cost including Valves, $	$80,000
Automatic Controller System	$12,000
Air Compressor/ Receiver	$5,000
Unit Resin Cost, $/cf	$110
Total Resin Cost, $	$4,147
Subtotal IX & Resin Costs, $	$101,147
IX Installation Cost, %	40
Subtotal IX System Costs, $	$141,606
Ion Exchange Facilities Annual Costs	
Resin Life, yrs	5
Annualized Resin Replacement Costs, $/yr	$829

Brine Regeneration Facilities Capital Costs

Number of Brine Recycle/Reaction Tanks	1
Minimum Batch Brine Rendering Time, days	1.0
Days Between Brine Waste Cycles	0.62
Brine & Rinse Storage, gal	264
Recycle/Reaction Basin Cost, Each, $	$10,000
Total Reaction Basin Cost, $	$10,000
Mixer Driver, Hp	0.02
Mixer/Support , Each, $	$8,000
Total Mixer Cost, $	$8,000
Brine Recirculation Pumps Cost per Tank, $	$2,000
Reaction Basin Supernatant Pumps Cost per Tank, $	$4,000
Total Brine Regeneration/Reaction Facility Cost	$24,000
Brine Regeneration Facilities Annual Costs	
Mixer Power Requirement, kWh/yr	22
Brine Recirc Pumps Power Requirement, kWh/yr	1,227
Reaction Basin Supernatant Pump Power, kWh/yr	2
Total Annual Estimated Brine Power, kWh/yr	1,251
Brine Trucking, gpd Based on Average Flow	214
Brine Trucking Round Trip, miles	0
Trucking Costs, $/gal/mile	0.0004
Trucking Down Time per 4600 gal load, hrs	2
Cost of Trucking Down Time, $/hr	0
Annual Brine Hauling Cost, $/yr	$0

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Brine Maker Costs

Salt Storage, Tons	2.3
Number of Brine Maker Tanks	1
Cost per Brine Maker Tank, $	$15,000
Total Brine Maker Costs, $	$15,000

Brine Evaporation

Brine Evap. Pond, acres	0.00
Land Area Including 100 foot Buffer, acres	0.0
Land Cost, $/acre	$0
Total Land Cost, $	$0
Fencing Cost, $	$0
Excavation for Pond, cy	0
Unit Excavation Cost, $/cy	$0.00
Excavation Cost, $	$0
Unit Liner & Concrete Cost, $/sf	$0.00
Liner & Concrete Cost, $	$0
Evaporation Facility Cost, $	$0

Dewatering Facilities Capital Costs

Number of Filter Presses	1.00
Filter Press, cf	0.015
Filter Press Cost, Each, $	$26,000
Dumpster	$3,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$40,800
Dewatering Facilities Annual Costs	
Filter Feed Pump Power Use, kWh/yr	720

Chemical Storage Capital Costs

FeCl3 Storage, gals	4
FeCl3 Storage Cost, $	$43
FeCl3 Metering Pump Cost, $	$10,000
NaOH Storage, gals	38
NaOH Storage Cost, $	$191
NaOH Feed Pumps, $	$4,000
H2SO4 Storage, gals	132
H2SO4 Storage Cost, $	$2,638
H2SO4 Feed Pumps, $	$4,000
Chemical Feed Facility Installation Cost, %	40
Total Chemical Feed Facility Estimated Costs	$29,220

Total IX System Equipment Cost Summary

Equipment Subtotal	$290,526
Internal Piping Allowance,%	15
I&C Allowance, %	10
Electrical Allowance, %	5
Yard Piping Allowance,%	15
Total Process Estimated Cost,$	$421,263

Building Facilities

Building, sf	1,300
Building Unit Cost, $/sf	$100
Building Cost, $	$130,000

Total Estimated Capital Costs

Subtotal Estimated Facility Cost, $	$551,263
Contingency, %	20
Total IX Arsenic Removal Facility Cost, $	$661,515
Unit Cost, $/gpd	$3.40

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Ion Exchange Arsenic Treatment Costs
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Annual O&M Costs

Annual Power Use, kWh/yr	4,503
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$315
Annualized Resin Replacement Costs, $/yr	$829
FeCl3 Use, PPD Based on Average Flow	0
Unit FeCl3 Cost, $/lb	0.15
Annual FeCl3 Cost, $/yr	$19
NaOH Use, PPD Based on Average Flow	4
Unit NaOH Cost, $/lb	0.13
Annual NaOH Cost, $/yr	$193
H2SO4 Use, PPD Based on Average Flow	31
Unit H2SO4 Cost, $/lb	0.10
Annual H2SO4 Cost, $/yr	$1,129
Salt Use, Tons/Day Based on Average Flow	0.04
Unit Salt Cost Delivered to Albuquerque, $/ton	$59
Annual Salt Cost, $/yr	$822
Dewatered Iron Residuals Production, cy/day Based on Average Flow	0.00
Dewatered Waste Salt Production, cy/yr	16
Residuals Disposal Costs, $/cy	$45
Total Residuals Disposal Costs, $/yr	$714
Brine Hauling Costs	$0
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Unit Labor Cost, Management, $/yr	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$6,615
Total Estimated Annual O&M Costs, $/yr	$27,136
Unit Annual O&M Costs, $/1000 gal	$0.76

Capital Cost Summary

Booster Pumping/ Straining	$39,900
Ion Exchange Facilities	$141,606
Brine Handling Facilities	$39,000
Brine Evaporation Facilities	$0
Solids Handling	$40,800
Chemical Feed Systems	$29,220
Building	$130,000
Piping, I&C, Electrical, Yard Piping Allowances	$130,737
Total Facility Cost, $	$551,263
Ancillary Offsite Pipiing	$237,600
Contingency, 20%	$157,773
Total Estimated IX Facility Cost	$946,635

Summary of IX Annual O&M Costs

Item	Cost
Annual Power Cost, $/yr	$315
Annualized Resin Replacement Costs, $/yr	$829
Annual FeCl3 Cost, $/yr	$19
Annual NaOH Cost, $/yr	$193
Annual H2SO4 Cost, $/yr	$1,129
Annual Salt Cost, $/yr	$822
Total Residuals Disposal Costs, $/yr	$714
Brine Hauling Costs	$0
Total Estimated Labor Costs, $/yr	$16,500
Treatment Equipment Maintenance Cost	$6,615
Estimated O&M Costs for IX $/yr	$27,136
Unit Annual O&M Costs, $/1000 gal	$0.76

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$311,252
Total Capital Cost	$946,635
Total Present Value of IX Facitlities	$1,257,887

City of Norman Arsenic Study
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Arsenic MCL, ug/L	10
Design Criteria	
Design Treatment Capacity. MGD	0.65
Total Production Capacity, MGD	0.99
Average Day Treatment Capacity, MGD	0.32
Average Production Flow, MGD	0.49

Booster Pumping Capital Costs

Booster Pump, gpm	450
Number of Pumps	3
Pump Capacity	225
Pumping Head, ft	35
Pump Driver Size, Hp	2.5
Estimated Pump Cost, $ Each	$7,500
Pumping Facility Installation Cost, %	50
Sump	$12,000
Total Pumping Facility Estimated Costs, $	$45,750
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	8,152

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Ion Exchange Facilities Capital Costs

Number of IX Vessels	4
IX Vessel Resin Volume, Each, cf	38
IX Vessel Diameter, ft	4
Total Facility Resin Volume, cf	151
Cost per Vessel Including Valves, $	$40,000
Total Vessel Cost including Valves, $	$160,000
Automatic Controller System	$24,000
Air Compressor/ Receiver	$5,000
Unit Resin Cost, $/cf	$110
Total Resin Cost, $	$16,587
Subtotal IX & Resin Costs, $	$205,587
IX Installation Cost, %	40
Subtotal IX System Costs, $	$287,822
Ion Exchange Facilities Annual Costs	
Resin Life, yrs	5
Annualized Resin Replacement Costs, $/yr	$3,317

Brine Regeneration Facilities Capital Costs

Number of Brine Recycle/Reaction Tanks	1
Minimum Batch Brine Rendering Time, days	1.0
Days Between Brine Waste Cycles	0.17
Brine & Rinse Storage, gal	1,055
Recycle/Reaction Basin Cost, Each, $	$10,000
Total Reaction Basin Cost, $	$10,000
Mixer Driver, Hp	0.53
Mixer/Support , Each, $	$8,000
Total Mixer Cost, $	$8,000
Brine Recirculation Pumps Cost per Tank, $	$2,000
Reaction Basin Supernatant Pumps Cost per Tank, $	$4,000
Total Brine Regeneration/Reaction Facility Cost	$24,000
Brine Regeneration Facilities Annual Costs	
Mixer Power Requirement, kWh/yr	2,513
Brine Recirc Pumps Power Requirement, kWh/yr	4,340
Reaction Basin Supernatant Pump Power, kWh/yr	83
Total Annual Estimated Brine Power, kWh/yr	6,936
Brine Trucking, gpd Based on Average Flow	3,033
Brine Trucking Round Trip, miles	0
Trucking Costs, $/gal/mile	0.0004
Trucking Down Time per 4600 gal load, hrs	2
Cost of Trucking Down Time, $/hr	0
Annual Brine Hauling Cost, $/yr	$0

City of Norman Arsenic Study
Ion Exchange Arsenic Treatment Costs
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Brine Maker Costs

Salt Storage, Tons	32.5
Number of Brine Maker Tanks	1
Cost per Brine Maker Tank, $	$15,000
Total Brine Maker Costs, $	$15,000

Brine Evaporation

Brine Evap. Pond, acres	0.00
Land Area Including 100 foot Buffer, acres	0.0
Land Cost, $/acre	$0
Total Land Cost, $	$0
Fencing Cost, $	$0
Excavation for Pond, cy	0
Unit Excavation Cost, $/cy	$0.00
Excavation Cost, $	$0
Unit Liner & Concrete Cost, $/sf	$0.00
Liner & Concrete Cost, $	$0
Evaporation Facility Cost, $	$0

Dewatering Facilities Capital Costs

Number of Filter Presses	1.00
Filter Press, cf	0.042
Filter Press Cost, Each, $	$26,000
Dumpster	$3,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$40,800
Dewatering Facilities Annual Costs	
Filter Feed Pump Power Use, kWh/yr	2,547

Chemical Storage Capital Costs

FeCl3 Storage, gals	43
FeCl3 Storage Cost, $	$432
FeCl3 Metering Pump Cost, $	$10,000
NaOH Storage, gals	127
NaOH Storage Cost, $	$635
NaOH Feed Pumps, $	$4,000
H2SO4 Storage, gals	1,865
H2SO4 Storage Cost, $	$37,309
H2SO4 Feed Pumps, $	$4,000
Chemical Feed Facility Installation Cost, %	40
Total Chemical Feed Facility Estimated Costs	$78,927

Total IX System Equipment Cost Summary

Equipment Subtotal	$510,300
Internal Piping Allowance,%	15
I&C Allowance, %	10
Electrical Allowance, %	5
Yard Piping Allowance,%	15
Total Process Estimated Cost,$	$739,935

Building Facilities

Building, sf	1,700
Building Unit Cost, $/sf	$100
Building Cost, $	$170,000

Total Estimated Capital Costs

Subtotal Estimated Facility Cost, $	$909,935
Contingency, %	20
Total IX Arsenic Removal Facility Cost, $	$1,091,921
Unit Cost, $/gpd	$1.68

City of Norman Arsenic Study
Ion Exchange Arsenic Treatment Costs
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Annual O&M Costs

Annual Power Use, kWh/yr	17,717
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$1,240
Annualized Resin Replacement Costs, $/yr	$3,317
FeCl3 Use, PPD Based on Average Flow	3
Unit FeCl3 Cost, $/lb	0.15
Annual FeCl3 Cost, $/yr	$188
NaOH Use, PPD Based on Average Flow	14
Unit NaOH Cost, $/lb	0.13
Annual NaOH Cost, $/yr	$641
H2SO4 Use, PPD Based on Average Flow	437
Unit H2SO4 Cost, $/lb	0.10
Annual H2SO4 Cost, $/yr	$15,967
Salt Use, Tons/Day Based on Average Flow	0.54
Unit Salt Cost Delivered to Albuquerque, $/ton	$59
Annual Salt Cost, $/yr	$11,632
Dewatered Iron Residuals Production, cy/day Based on Average Flow	0.00
Dewatered Waste Salt Production, cy/yr	222
Residuals Disposal Costs, $/cy	$45
Total Residuals Disposal Costs, $/yr	$10,069
Brine Hauling Costs	$0
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Unit Labor Cost, Management, $/yr	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$10,919
Total Estimated Annual O&M Costs, $/yr	$70,474
Unit Annual O&M Costs, $/1000 gal	$0.60

Capital Cost Summary

Booster Pumping/ Straining	$63,750
Ion Exchange Facilities	$287,822
Brine Handling Facilities	$39,000
Brine Evaporation Facilities	$0
Solids Handling	$40,800
Chemical Feed Systems	$78,927
Building	$170,000
Piping, I&C, Electrical, Yard Piping Allowances	$229,635
Total Facility Cost, $	$909,935
Ancillary Offsite Pipiing	$205,920
Contingency, 20%	$223,171
Total Estimated IX Facility Cost	$1,339,025

Summary of IX Annual O&M Costs

Item	Cost
Annual Power Cost, $/yr	$1,240
Annualized Resin Replacement Costs, $/yr	$3,317
Annual FeCl3 Cost, $/yr	$188
Annual NaOH Cost, $/yr	$641
Annual H2SO4 Cost, $/yr	$15,967
Annual Salt Cost, $/yr	$11,632
Total Residuals Disposal Costs, $/yr	$10,069
Brine Hauling Costs	$0
Total Estimated Labor Costs, $/yr	$16,500
Treatment Equipment Maintenance Cost	$10,919
Estimated O&M Costs for IX $/yr	$70,474
Unit Annual O&M Costs, $/1000 gal	$0.60

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$808,335
Total Capital Cost	$1,339,025
Total Present Value of IX Facitlities	$2,147,361

City of Norman Arsenic Study
Ion Exchange Arsenic Treatment Costs
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06/03/2002

Arsenic MCL, ug/L	10

Design Criteria

Design Treatment Capacity. MGD	0.23
Total Production Capacity, MGD	0.26
Average Day Treatment Capacity, MGD	0.12
Average Production Flow, MGD	0.13

Booster Pumping Capital Costs

Booster Pump, gpm	161
Number of Pumps	3
Pump Capacity	81
Pumping Head, ft	35
Pump Driver Size, Hp	0.9
Estimated Pump Cost, $ Each	$2,700
Pumping Facility Installation Cost, %	50
Sump	$12,000
Total Pumping Facility Estimated Costs, $	$24,150
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	2,914

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Ion Exchange Facilities Capital Costs

Number of IX Vessels	4
IX Vessel Resin Volume, Each, cf	21
IX Vessel Diameter, ft	3
Total Facility Resin Volume, cf	85
Cost per Vessel Including Valves, $	$30,000
Total Vessel Cost including Valves, $	$120,000
Automatic Controller System	$18,000
Air Compressor/ Receiver	$5,000
Unit Resin Cost, $/cf	$110
Total Resin Cost, $	$9,330
Subtotal IX & Resin Costs, $	$152,330
IX Installation Cost, %	40
Subtotal IX System Costs, $	$213,263
Ion Exchange Facilities Annual Costs	
Resin Life, yrs	5
Annualized Resin Replacement Costs, $/yr	$1,866

Brine Regeneration Facilities Capital Costs

Number of Brine Recycle/Reaction Tanks	1
Minimum Batch Brine Rendering Time, days	1.0
Days Between Brine Waste Cycles	0.24
Brine & Rinse Storage, gal	593
Recycle/Reaction Basin Cost, Each, $	$10,000
Total Reaction Basin Cost, $	$10,000
Mixer Driver, Hp	0.13
Mixer/Support , Each, $	$8,000
Total Mixer Cost, $	$8,000
Brine Recirculation Pumps Cost per Tank, $	$2,000
Reaction Basin Supernatant Pumps Cost per Tank, $	$4,000
Total Brine Regeneration/Reaction Facility Cost	$24,000
Brine Regeneration Facilities Annual Costs	
Mixer Power Requirement, kWh/yr	433
Brine Recirc Pumps Power Requirement, kWh/yr	3,152
Reaction Basin Supernatant Pump Power, kWh/yr	25
Total Annual Estimated Brine Power, kWh/yr	3,610
Brine Trucking, gpd Based on Average Flow	1,239
Brine Trucking Round Trip, miles	0
Trucking Costs, $/gal/mile	0.0004
Trucking Down Time per 4600 gal load, hrs	2
Cost of Trucking Down Time, $/hr	0
Annual Brine Hauling Cost, $/yr	$0

City of Norman Arsenic Study
Ion Exchange Arsenic Treatment Costs
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Brine Maker Costs

Salt Storage, Tons	13.3
Number of Brine Maker Tanks	1
Cost per Brine Maker Tank, $	$15,000
Total Brine Maker Costs, $	$15,000

Brine Evaporation

Brine Evap. Pond, acres	0.00
Land Area Including 100 foot Buffer, acres	0.0
Land Cost, $/acre	$0
Total Land Cost, $	$0
Fencing Cost, $	$0
Excavation for Pond, cy	0
Unit Excavation Cost, $/cy	$0.00
Excavation Cost, $	$0
Unit Liner & Concrete Cost, $/sf	$0.00
Liner & Concrete Cost, $	$0
Evaporation Facility Cost, $	$0

Dewatering Facilities Capital Costs

Number of Filter Presses	1.00
Filter Press, cf	0.023
Filter Press Cost, Each, $	$26,000
Dumpster	$3,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$40,800
Dewatering Facilities Annual Costs	
Filter Feed Pump Power Use, kWh/yr	1,850

Chemical Storage Capital Costs

FeCl3 Storage, gals	17
FeCl3 Storage Cost, $	$169
FeCl3 Metering Pump Cost, $	$10,000
NaOH Storage, gals	45
NaOH Storage Cost, $	$227
NaOH Feed Pumps, $	$4,000
H2SO4 Storage, gals	762
H2SO4 Storage Cost, $	$15,243
H2SO4 Feed Pumps, $	$4,000
Chemical Feed Facility Installation Cost, %	40
Total Chemical Feed Facility Estimated Costs	$47,094

Total IX System Equipment Cost Summary

Equipment Subtotal	$382,307
Internal Piping Allowance,%	15
I&C Allowance, %	10
Electrical Allowance, %	5
Yard Piping Allowance,%	15
Total Process Estimated Cost,$	$554,345

Building Facilities

Building, sf	1,500
Building Unit Cost, $/sf	$100
Building Cost, $	$150,000

Total Estimated Capital Costs

Subtotal Estimated Facility Cost, $	$704,345
Contingency, %	20
Total IX Arsenic Removal Facility Cost, $	$845,214
Unit Cost, $/gpd	$3.65

City of Norman Arsenic Study
Ion Exchange Arsenic Treatment Costs
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Annual O&M Costs

Annual Power Use, kWh/yr	8,456
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$592
Annualized Resin Replacement Costs, $/yr	$1,866
FeCl3 Use, PPD Based on Average Flow	1
Unit FeCl3 Cost, $/lb	0.15
Annual FeCl3 Cost, $/yr	$73
NaOH Use, PPD Based on Average Flow	5
Unit NaOH Cost, $/lb	0.13
Annual NaOH Cost, $/yr	$229
H2SO4 Use, PPD Based on Average Flow	179
Unit H2SO4 Cost, $/lb	0.10
Annual H2SO4 Cost, $/yr	$6,523
Salt Use, Tons/Day Based on Average Flow	0.22
Unit Salt Cost Delivered to Albuquerque, $/ton	$59
Annual Salt Cost, $/yr	$4,752
Dewatered Iron Residuals Production, cy/day Based on Average Flow	0.00
Dewatered Waste Salt Production, cy/yr	91
Residuals Disposal Costs, $/cy	$45
Total Residuals Disposal Costs, $/yr	$4,112
Brine Hauling Costs	$0
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Unit Labor Cost, Management, $/yr	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$8,452
Total Estimated Annual O&M Costs, $/yr	$43,101
Unit Annual O&M Costs, $/1000 gal	$1.02

Capital Cost Summary

Booster Pumping/ Straining	$42,150
Ion Exchange Facilities	$213,263
Brine Handling Facilities	$39,000
Brine Evaporation Facilities	$0
Solids Handling	$40,800
Chemical Feed Systems	$47,094
Building	$150,000
Piping, I&C, Electrical, Yard Piping Allowances	$172,038
Total Facility Cost, $	$704,345
Ancillary Offsite Pipiing	$9,504
Contingency, 20%	$142,770
Total Estimated IX Facility Cost	$856,618

Summary of IX Annual O&M Costs

Item	Cost
Annual Power Cost, $/yr	$592
Annualized Resin Replacement Costs, $/yr	$1,866
Annual FeCl3 Cost, $/yr	$73
Annual NaOH Cost, $/yr	$229
Annual H2SO4 Cost, $/yr	$6,523
Annual Salt Cost, $/yr	$4,752
Total Residuals Disposal Costs, $/yr	$4,112
Brine Hauling Costs	$0
Total Estimated Labor Costs, $/yr	$16,500
Treatment Equipment Maintenance Cost	$8,452
Estimated O&M Costs for IX $/yr	$43,101
Unit Annual O&M Costs, $/1000 gal	$1.02

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$494,363
Total Capital Cost	$856,618
Total Present Value of IX Facitlities	$1,350,981

Appendix D

City of Norman Arsenic Study
GFH Arsenic Treatment Costs
CH2M HILL
06/03/2002

Design Criteria

Design Treatment Capacity, MGD	0.93
Average Day Flow, MGD	0.49

Booster Pumping Capital Costs

Booster Pump, gpm	646
Number of Pumps	3
Pump Capacity	323
Pumping Head, ft	35
Pump Driver Size, Hp	3.6
Estimated Pump Cost, $ Each	$11,000
Sump for Pumps	$18,000
Cost of CO2 Stripping Tank, Aeration System	$35,000
CO2 Stripper Blower HP, Total	20
Pumping Facility Installation Cost, %	50
Total Pumping Faciity Estimated Costs, $	$102,500
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	79,057

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

GFH Facilities Capital Costs

Number of Trains	2
Number of Vessels per Train	1
Media Volume, Each Vessel, cf	251
Vessel Diameter, ft	8
Total Facility Media Volume, cf	503
Media Bulk Density, PCF	77
Total Facility Media Mass, lbs	38,704
Cost per Vessel Including Valves, $	$80,000
Total Vessel Cost including Valves, $	$160,000
Automatic Controller System	$8,000
Unit Media Cost, $/lb	$2.50
Total Media Cost, $	$96,760
Subtotal Vessel and & Media Costs, $	$264,760
Equipment Installation Cost, %	30
Subtotal System Costs, $	$344,188
GFH Facilities Annual Costs	
Media Use Per Year, lbs/Yr Based on Average Flow	37,195
Total Annual Media Costs, $/yr Based on Average Flow	$92,988

Chemical Feed Facility Costs

CO2 Storage, tons	12
CO2 Storage Cost, $	$116,280
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$139,536

Total GFH System Equipment Cost Summary

Total Equipment Subtotal	$604,224
Interior Piping Allowance,%	10
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$785,492

City of Norman Arsenic Study
GFH Arsenic Treatment Costs
CH2M HILL
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Building Facilities

Building, sf	858
Building Unit Cost, $/sf	$100
Building Cost, $	$85,800

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$871,292
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$1,045,550
Unit Cost, $/gpd	$1.12

Annual O&M Costs

Annual Estimated Power Use, kWh/yr	87,053
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$6,094
CO2 Use, Lbs/Yr	150,672
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$21,094
Annual Media Replacement Costs, $/yr	$92,988
Spent Media Production, Tons/yr	18.6
Residuals Disposal Costs, $/Ton	$45
Residuals Disposal Costs, $/yr	$837
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$10,456
Total Estimated Annual O&M Costs, $/yr	$147,968
Unit Annual O&M Costs, $/1000 gal Based on Average Flo	$0.82

Capital Cost Summary

Booster Pumping/ Straining	$120,500
Media Facilities	$344,188
Chemical Feed Systems	$139,536
Building	$85,800
Piping, I&C, Electrical, Yard Piping Allowances	$181,267
Ancillary Offsite Pipiing	$174,240
Total Facility Cost, $	$1,045,532
Contingency	$209,106
Total Estimated Facility Cost	$1,254,638

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$6,094
CO2 Cost, $/yr	$21,094
Residuals Disposal Costs, $/yr	$837
Annual Media Replacement Costs, $/yr	$92,988
Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$10,456
Total O&M Costs for Treatment, $/yr	$147,968
Unit O&M Costs for Treatment, $/1000 gal	$0.82

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$1,697,177
Treatment Facility Capital Cost	$1,254,638
Total Capital Cost	$1,254,638
Total Present Value of Facitlities	$2,951,815

City of Norman Arsenic Study
GFH Arsenic Treatment Costs
CH2M HILL
06/03/2002

Design Criteria

Design Treatment Capacity. MGD	1.38
Average Day Flow, MGD	0.87

Booster Pumping Capital Costs

Booster Pump, gpm	956
Number of Pumps	3
Pump Capacity	478
Pumping Head, ft	35
Pump Driver Size, Hp	5.3
Estimated Pump Cost, $ Each	$16,000
Sump for Pumps	$18,000
Cost of CO2 Stripping Tank, Aeration System	$35,000
CO2 Stripper Blower HP, Total	20
Pumping Facility Installation Cost, %	50
Total Pumping Faciity Estimated Costs, $	$125,000
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	115,371

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

GFH Facilities Capital Costs

Number of Trains	2
Number of Vessels per Train	2
Media Volume, Each Vessel, cf	393
Vessel Diameter, ft	10
Total Facility Media Volume, cf	1571
Media Bulk Density, PCF	77
Total Facility Media Mass, lbs	120,950
Cost per Vessel Including Valves, $	$100,000
Total Vessel Cost including Valves, $	$400,000
Automatic Controller System	$20,000
Unit Media Cost, $/lb	$2.50
Total Media Cost, $	$302,376
Subtotal Vessel and & Media Costs, $	$722,376
Equipment Installation Cost, %	30
Subtotal System Costs, $	$939,089
GFH Facilities Annual Costs	
Media Use Per Year, lbs/Yr Based on Average Flow	40,925
Total Annual Media Costs, $/yr Based on Average Flow	$102,313

Chemical Feed Facility Costs

CO2 Storage, tons	17
CO2 Storage Cost, $	$172,080
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$206,496

Total GFH System Equipment Cost Summary

Total Equipment Subtotal	$1,288,585
Interior Piping Allowance,%	10
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$1,675,160

City of Norman Arsenic Study
GFH Arsenic Treatment Costs
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Building Facilities

Building, sf	1,500
Building Unit Cost, $/sf	$100
Building Cost, $	$150,000

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$1,825,160
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$2,190,193
Unit Cost, $/gpd	$1.59

Annual O&M Costs

Annual Estimated Power Use, kWh/yr	126,997
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$8,890
CO2 Use, Lbs/Yr	265,253
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$37,135
Annual Media Replacement Costs, $/yr	$102,313
Spent Media Production, Tons/yr	20.5
Residuals Disposal Costs, $/Ton	$45
Residuals Disposal Costs, $/yr	$921
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$21,902
Total Estimated Annual O&M Costs, $/yr	$187,661
Unit Annual O&M Costs, $/1000 gal Based on Average Flow	$0.59

Capital Cost Summary

Booster Pumping/ Straining	$143,000
Media Facilities	$939,089
Chemical Feed Systems	$206,496
Building	$150,000
Piping, I&C, Electrical, Yard Piping Allowances	$386,575
Ancillary Offsite Pipiing	$286,176
Total Facility Cost, $	$2,111,336
Contingency	$422,267
Total Estimated Facility Cost	$2,533,604

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$8,890
CO2 Cost, $/yr	$37,135
Residuals Disposal Costs, $/yr	$921
Annual Media Replacement Costs, $/yr	$102,313
Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$21,902
Total O&M Costs for Treatment, $/yr	$187,661
Unit O&M Costs for Treatment, $/1000 gal	$0.59

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$2,152,455
Total Capital Cost	$2,533,604
Total Present Value of Facitlities	$4,686,058

City of Norman Arsenic Study
GFH Arsenic Treatment Costs
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Design Criteria

Design Treatment Capacity. MGD	2.79
Average Day Flow, MGD	1.81

Booster Pumping Capital Costs

Booster Pump, gpm	1940
Number of Pumps	3
Pump Capacity	970
Pumping Head, ft	35
Pump Driver Size, Hp	10.7
Estimated Pump Cost, $ Each	$32,000
Sump for Pumps	$22,000
Cost of CO2 Stripping Tank, Aeration System	$45,000
CO2 Stripper Blower HP, Total	20
Pumping Facility Installation Cost, %	50
Total Pumping Faciity Estimated Costs, $	$211,000
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	187,088

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$17,500
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$21,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

GFH Facilities Capital Costs

Number of Trains	3
Number of Vessels per Train	2
Media Volume, Each Vessel, cf	475
Vessel Diameter, ft	11
Total Facility Media Volume, cf	2851
Media Bulk Density, PCF	77
Total Facility Media Mass, lbs	219,525
Cost per Vessel Including Valves, $	$110,000
Total Vessel Cost including Valves, $	$660,000
Automatic Controller System	$33,000
Unit Media Cost, $/lb	$2.50
Total Media Cost, $	$548,813
Subtotal Vessel and & Media Costs, $	$1,241,813
Equipment Installation Cost, %	30
Subtotal System Costs, $	$1,614,356
GFH Facilities Annual Costs	
Media Use Per Year, lbs/Yr Based on Average Flow	84,878
Total Annual Media Costs, $/yr Based on Average Flow	$212,195

Chemical Feed Facility Costs

CO2 Storage, tons	35
CO2 Storage Cost, $	$349,200
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$419,040

Total GFH System Equipment Cost Summary

Total Equipment Subtotal	$2,265,396
Interior Piping Allowance,%	10
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$2,945,015

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Building Facilities

Building, sf	2,496
Building Unit Cost, $/sf	$100
Building Cost, $	$249,600

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$3,194,615
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$3,833,538
Unit Cost, $/gpd	$1.37

Annual O&M Costs

Annual Estimated Power Use, kWh/yr	205,887
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$14,412
CO2 Use, Lbs/Yr	550,128
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$77,018
Annual Media Replacement Costs, $/yr	$212,195
Spent Media Production, Tons/yr	42.4
Residuals Disposal Costs, $/Ton	$45
Residuals Disposal Costs, $/yr	$1,910
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$38,335
Total Estimated Annual O&M Costs, $/yr	$360,370
Unit Annual O&M Costs, $/1000 gal Based on Average Flow	$0.55

Capital Cost Summary

Booster Pumping/ Straining	$232,000
Media Facilities	$1,614,356
Chemical Feed Systems	$419,040
Building	$249,600
Piping, I&C, Electrical, Yard Piping Allowances	$679,619
Ancillary Offsite Pipiing	$709,104
Total Facility Cost, $	$3,903,719
Contingency	$780,744
Total Estimated Facility Cost	$4,684,463

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$14,412
CO2 Cost, $/yr	$77,018
Residuals Disposal Costs, $/yr	$1,910
Annual Media Replacement Costs, $/yr	$212,195
Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$38,335
Total O&M Costs for Treatment, $/yr	$360,370
Unit O&M Costs for Treatment, $/1000 gal	$0.55

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$4,133,411
Total Capital Cost	$4,684,463
Total Present Value of Facitlities	$8,817,875

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GFH Arsenic Treatment Costs
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Design Criteria

Design Treatment Capacity. MGD	0.31
Average Day Flow, MGD	0.18

Booster Pumping Capital Costs

Booster Pump, gpm	212
Number of Pumps	3
Pump Capacity	106
Pumping Head, ft	35
Pump Driver Size, Hp	1.2
Estimated Pump Cost, $ Each	$4,000
Sump for Pumps	$12,000
Cost of CO2 Stripping Tank, Aeration System	$25,000
CO2 Stripper Blower HP, Total	20
Pumping Facility Installation Cost, %	50
Total Pumping Faciity Estimated Costs, $	$55,000
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	61,183

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

GFH Facilities Capital Costs

Number of Trains	2
Number of Vessels per Train	1
Media Volume, Each Vessel, cf	98
Vessel Diameter, ft	5
Total Facility Media Volume, cf	196
Media Bulk Density, PCF	77
Total Facility Media Mass, lbs	15,119
Cost per Vessel Including Valves, $	$50,000
Total Vessel Cost including Valves, $	$100,000
Automatic Controller System	$5,000
Unit Media Cost, $/lb	$2.50
Total Media Cost, $	$37,797
Subtotal Vessel and & Media Costs, $	$142,797
Equipment Installation Cost, %	30
Subtotal System Costs, $	$185,636
GFH Facilities Annual Costs	
Media Use Per Year, lbs/Yr Based on Average Flow	13,840
Total Annual Media Costs, $/yr Based on Average Flow	$34,600

Chemical Feed Facility Costs

CO2 Storage, tons	4
CO2 Storage Cost, $	$38,160
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$45,792

Total GFH System Equipment Cost Summary

Total Equipment Subtotal	$304,428
Interior Piping Allowance,%	10
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$395,757

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GFH Arsenic Treatment Costs
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Building Facilities

Building, sf	600
Building Unit Cost, $/sf	$100
Building Cost, $	$60,000

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$455,757
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$546,908
Unit Cost, $/gpd	$1.79

Annual O&M Costs

Annual Estimated Power Use, kWh/yr	67,391
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$4,717
CO2 Use, Lbs/Yr	56,064
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$7,849
Annual Media Replacement Costs, $/yr	$34,600
Spent Media Production, Tons/yr	6.9
Residuals Disposal Costs, $/Ton	$45
Residuals Disposal Costs, $/yr	$311
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$5,469
Total Estimated Annual O&M Costs, $/yr	$69,447
Unit Annual O&M Costs, $/1000 gal Based on Average Flow	$1.03

Capital Cost Summary

Booster Pumping/ Straining	$73,000
Media Facilities	$185,636
Chemical Feed Systems	$45,792
Building	$60,000
Piping, I&C, Electrical, Yard Piping Allowances	$91,328
Ancillary Offsite Pipiing	$9,504
Total Facility Cost, $	$465,261
Contingency	$93,052
Total Estimated Facility Cost	$558,313

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$4,717
CO2 Cost, $/yr	$7,849
Residuals Disposal Costs, $/yr	$311
Annual Media Replacement Costs, $/yr	$34,600
Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$5,469
Total O&M Costs for Treatment, $/yr	$69,447
Unit O&M Costs for Treatment, $/1000 gal	$1.03

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$796,552
Total Capital Cost	$558,313
Total Present Value of Facitlities	$1,354,865

City of Norman Arsenic Study
GFH Arsenic Treatment Costs
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Design Criteria

Design Treatment Capacity. MGD	1.00
Average Day Flow, MGD	0.64

Booster Pumping Capital Costs

Booster Pump, gpm	697
Number of Pumps	3
Pump Capacity	349
Pumping Head, ft	35
Pump Driver Size, Hp	3.9
Estimated Pump Cost, $ Each	$12,000
Sump for Pumps	$18,000
Cost of CO2 Stripping Tank, Aeration System	$35,000
CO2 Stripper Blower HP, Total	20
Pumping Facility Installation Cost, %	50
Total Pumping Faciity Estimated Costs, $	$107,000
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	98,631

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

GFH Facilities Capital Costs

Number of Trains	2
Number of Vessels per Train	2
Media Volume, Each Vessel, cf	251
Vessel Diameter, ft	8
Total Facility Media Volume, cf	1005
Media Bulk Density, PCF	77
Total Facility Media Mass, lbs	77,408
Cost per Vessel Including Valves, $	$80,000
Total Vessel Cost including Valves, $	$320,000
Automatic Controller System	$16,000
Unit Media Cost, $/lb	$2.50
Total Media Cost, $	$193,521
Subtotal Vessel and & Media Costs, $	$529,521
Equipment Installation Cost, %	30
Subtotal System Costs, $	$688,377
GFH Facilities Annual Costs	
Media Use Per Year, lbs/Yr Based on Average Flow	30,167
Total Annual Media Costs, $/yr Based on Average Flow	$75,417

Chemical Feed Facility Costs

CO2 Storage, tons	13
CO2 Storage Cost, $	$125,460
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$150,552

Total GFH System Equipment Cost Summary

Total Equipment Subtotal	$963,929
Interior Piping Allowance,%	10
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$1,253,108

City of Norman Arsenic Study
GFH Arsenic Treatment Costs
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Building Facilities

Building, sf	1,196
Building Unit Cost, $/sf	$100
Building Cost, $	$119,600

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$1,372,708
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$1,647,249
Unit Cost, $/gpd	$1.64

Annual O&M Costs

Annual Estimated Power Use, kWh/yr	108,583
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$7,601
CO2 Use, Lbs/Yr	195,523
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$27,373
Annual Media Replacement Costs, $/yr	$75,417
Spent Media Production, Tons/yr	15.1
Residuals Disposal Costs, $/Ton	$45
Residuals Disposal Costs, $/yr	$679
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$16,472
Total Estimated Annual O&M Costs, $/yr	$144,042
Unit Annual O&M Costs, $/1000 gal Based on Average Flow	$0.61

Capital Cost Summary

Booster Pumping/ Straining	$125,000
Media Facilities	$688,377
Chemical Feed Systems	$150,552
Building	$119,600
Piping, I&C, Electrical, Yard Piping Allowances	$289,179
Ancillary Offsite Pipiing	$318,384
Total Facility Cost, $	$1,691,092
Contingency	$338,218
Total Estimated Facility Cost	$2,029,310

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$7,601
CO2 Cost, $/yr	$27,373
Residuals Disposal Costs, $/yr	$679
Annual Media Replacement Costs, $/yr	$75,417
Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$16,472
Total O&M Costs for Treatment, $/yr	$144,042
Unit O&M Costs for Treatment, $/1000 gal	$0.61

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$1,652,154
Total Capital Cost	$2,029,310
Total Present Value of Facitlities	$3,681,464

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Design Criteria

Design Treatment Capacity. MGD	0.33
Average Day Flow, MGD	0.26

Booster Pumping Capital Costs

Booster Pump, gpm	230
Number of Pumps	3
Pump Capacity	115
Pumping Head, ft	35
Pump Driver Size, Hp	1.3
Estimated Pump Cost, $ Each	$4,000
Sump for Pumps	$12,000
Cost of CO2 Stripping Tank, Aeration System	$25,000
CO2 Stripper Blower HP, Total	20
Pumping Facility Installation Cost, %	50
Total Pumping Faciity Estimated Costs, $	$55,000
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	82,632

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

GFH Facilities Capital Costs

Number of Trains	2
Number of Vessels per Train	1
Media Volume, Each Vessel, cf	98
Vessel Diameter, ft	5
Total Facility Media Volume, cf	196
Media Bulk Density, PCF	77
Total Facility Media Mass, lbs	15,119
Cost per Vessel Including Valves, $	$50,000
Total Vessel Cost including Valves, $	$100,000
Automatic Controller System	$5,000
Unit Media Cost, $/lb	$2.50
Total Media Cost, $	$37,797
Subtotal Vessel and & Media Costs, $	$142,797
Equipment Installation Cost, %	30
Subtotal System Costs, $	$185,636
GFH Facilities Annual Costs	
Media Use Per Year, lbs/Yr Based on Average Flow	19,895
Total Annual Media Costs, $/yr Based on Average Flow	$49,738

Chemical Feed Facility Costs

CO2 Storage, tons	4
CO2 Storage Cost, $	$41,400
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$49,680

Total GFH System Equipment Cost Summary

Total Equipment Subtotal	$308,316
Interior Piping Allowance,%	10
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$400,811

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Building Facilities

Building, sf	600
Building Unit Cost, $/sf	$100
Building Cost, $	$60,000

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$460,811
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$552,973
Unit Cost, $/gpd	$1.67

Annual O&M Costs

Annual Estimated Power Use, kWh/yr	90,985
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$6,369
CO2 Use, Lbs/Yr	80,592
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$11,283
Annual Media Replacement Costs, $/yr	$49,738
Spent Media Production, Tons/yr	9.9
Residuals Disposal Costs, $/Ton	$45
Residuals Disposal Costs, $/yr	$448
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$5,530
Total Estimated Annual O&M Costs, $/yr	$89,867
Unit Annual O&M Costs, $/1000 gal Based on Average Flow	$0.93

Capital Cost Summary

Booster Pumping/ Straining	$73,000
Media Facilities	$185,636
Chemical Feed Systems	$49,680
Building	$60,000
Piping, I&C, Electrical, Yard Piping Allowances	$92,495
Ancillary Offsite Pipiing	$237,600
Total Facility Cost, $	$698,411
Contingency	$139,682
Total Estimated Facility Cost	$838,093

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$6,369
CO2 Cost, $/yr	$11,283
Residuals Disposal Costs, $/yr	$448
Annual Media Replacement Costs, $/yr	$49,738
Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$5,530
Total O&M Costs for Treatment, $/yr	$89,867
Unit O&M Costs for Treatment, $/1000 gal	$0.93

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$1,030,767
Total Capital Cost	$838,093
Total Present Value of Facitlities	$1,868,860

City of Norman Arsenic Study
GFH Arsenic Treatment Costs
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Design Criteria

Design Treatment Capacity. MGD	0.99
Average Day Flow, MGD	0.56

Booster Pumping Capital Costs

Booster Pump, gpm	686
Number of Pumps	3
Pump Capacity	343
Pumping Head, ft	35
Pump Driver Size, Hp	3.8
Estimated Pump Cost, $ Each	$11,000
Sump for Pumps	$18,000
Cost of CO2 Stripping Tank, Aeration System	$35,000
CO2 Stripper Blower HP, Total	20
Pumping Facility Installation Cost, %	50
Total Pumping Facility Estimated Costs, $	$102,500
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	86,248

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

GFH Facilities Capital Costs

Number of Trains	2
Number of Vessels per Train	2
Media Volume, Each Vessel, cf	251
Vessel Diameter, ft	8
Total Facility Media Volume, cf	1005
Media Bulk Density, PCF	77
Total Facility Media Mass, lbs	77,408
Cost per Vessel Including Valves, $	$80,000
Total Vessel Cost including Valves, $	$320,000
Automatic Controller System	$16,000
Unit Media Cost, $/lb	$2.50
Total Media Cost, $	$193,521
Subtotal Vessel and & Media Costs, $	$529,521
Equipment Installation Cost, %	30
Subtotal System Costs, $	$688,377
GFH Facilities Annual Costs	
Media Use Per Year, lbs/Yr Based on Average Flow	26,166
Total Annual Media Costs, $/yr Based on Average Flow	$65,415

Chemical Feed Facility Costs

CO2 Storage, tons	12
CO2 Storage Cost, $	$123,480
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$148,176

Total GFH System Equipment Cost Summary

Total Equipment Subtotal	$957,053
Interior Piping Allowance,%	10
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$1,244,169

City of Norman Arsenic Study
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Building Facilities

Building, sf	1,196
Building Unit Cost, $/sf	$100
Building Cost, $	$119,600

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$1,363,769
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$1,636,523
Unit Cost, $/gpd	$1.66

Annual O&M Costs

Annual Estimated Power Use, kWh/yr	94,963
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$6,647
CO2 Use, Lbs/Yr	169,594
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$23,743
Annual Media Replacement Costs, $/yr	$65,415
Spent Media Production, Tons/yr	13.1
Residuals Disposal Costs, $/Ton	$45
Residuals Disposal Costs, $/yr	$589
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$16,365
Total Estimated Annual O&M Costs, $/yr	$129,260
Unit Annual O&M Costs, $/1000 gal Based on Average Flo	$0.64

Capital Cost Summary

Booster Pumping/ Straining	$120,500
Media Facilities	$688,377
Chemical Feed Systems	$148,176
Building	$119,600
Piping, I&C, Electrical, Yard Piping Allowances	$287,116
Ancillary Offsite Pipiing	$205,920
Total Facility Cost, $	$1,569,689
Contingency	$313,938
Total Estimated Facility Cost	$1,883,627

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$6,647
CO2 Cost, $/yr	$23,743
Residuals Disposal Costs, $/yr	$589
Annual Media Replacement Costs, $/yr	$65,415
Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$16,365
Total O&M Costs for Treatment, $/yr	$129,260
Unit O&M Costs for Treatment, $/1000 gal	$0.64

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$1,482,601
Total Capital Cost	$1,883,627
Total Present Value of Facitlities	$3,366,228

City of Norman Arsenic Study
GFH Arsenic Treatment Costs
CH2M HILL
06/03/2002

Design Criteria

Design Treatment Capacity. MGD	0.26
Average Day Flow, MGD	0.17

Booster Pumping Capital Costs

Booster Pump, gpm	184
Number of Pumps	3
Pump Capacity	92
Pumping Head, ft	35
Pump Driver Size, Hp	1.0
Estimated Pump Cost, $ Each	$3,000
Sump for Pumps	$12,000
Cost of CO2 Stripping Tank, Aeration System	$25,000
CO2 Stripper Blower HP, Total	20
Pumping Facility Installation Cost, %	50
Total Pumping Faciity Estimated Costs, $	$50,500
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	64,105

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

GFH Facilities Capital Costs

Number of Trains	2
Number of Vessels per Train	2
Media Volume, Each Vessel, cf	63
Vessel Diameter, ft	4
Total Facility Media Volume, cf	251
Media Bulk Density, PCF	77
Total Facility Media Mass, lbs	19,352
Cost per Vessel Including Valves, $	$40,000
Total Vessel Cost including Valves, $	$160,000
Automatic Controller System	$8,000
Unit Media Cost, $/lb	$2.50
Total Media Cost, $	$48,380
Subtotal Vessel and & Media Costs, $	$216,380
Equipment Installation Cost, %	30
Subtotal System Costs, $	$281,294
GFH Facilities Annual Costs	
Media Use Per Year, lbs/Yr Based on Average Flow	8,109
Total Annual Media Costs, $/yr Based on Average Flow	$20,273

Chemical Feed Facility Costs

CO2 Storage, tons	3
CO2 Storage Cost, $	$33,120
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$39,744

City of Norman Arsenic Study
GFH Arsenic Treatment Costs
CH2M HILL
06/03/2002

Total GFH System Equipment Cost Summary

Total Equipment Subtotal	$389,538
Interior Piping Allowance,%	10
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$506,400

Building Facilities

Building, sf	684
Building Unit Cost, $/sf	$100
Building Cost, $	$68,400

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$574,800
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$689,760
Unit Cost, $/gpd	$2.61

Annual O&M Costs

Annual Estimated Power Use, kWh/yr	70,605
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$4,942
CO2 Use, Lbs/Yr	52,560
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$7,358
Annual Media Replacement Costs, $/yr	$20,273
Spent Media Production, Tons/yr	4.1
Residuals Disposal Costs, $/Ton	$45
Residuals Disposal Costs, $/yr	$182
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1.0
Equipment Maintenance Costs, $/yr	$6,898
Total Estimated Annual O&M Costs, $/yr	$56,154
Unit Annual O&M Costs, $/1000 gal Based on Average Flov	$0.89

Capital Cost Summary

Booster Pumping/ Straining	$68,500
Media Facilities	$281,294
Chemical Feed Systems	$39,744
Building	$68,400
Piping, I&C, Electrical, Yard Piping Allowances	$116,861
Ancillary Offsite Pipiing	$9,504
Total Facility Cost, $	$584,304
Contingency	$116,861
Total Estimated Facility Cost	$701,164

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$4,942
CO2 Cost, $/yr	$7,358
Residuals Disposal Costs, $/yr	$182
Annual Media Replacement Costs, $/yr	$20,273
Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$6,898
Total O&M Costs for Treatment, $/yr	$56,154
Unit O&M Costs for Treatment, $/1000 gal	$0.89

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$644,081
Total Capital Cost	$701,164
Total Present Value of Facitlities	$1,345,246

Appendix E

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
CH2M HILL
06/03/2002

Chemical Storage Capital Costs

FeCl3 Storage, gals	122
FeCl3 Storage Cost, $	$486
FeCl3 Metering Pump Cost, $	$10,000
CO2 Storage, tons	2.3
CO2 Storage, Cost	$23,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$40,183
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/MF System Equipment Cost Summary

Total Equipment Subtotal	$463,110
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$578,887

Building Facilities

Building, sf	1,185
Building Unit Cost, $/sf	$100
Building Cost, $	$119,000

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$697,887
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$837,465
Unit Treatment Facility Capital Cost, $/gpd	$3.61

Annual O&M Costs

Annual Power Use, kWh/yr	39,999
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$2,800
Annual Membrane Replacement Cost, $/yr	$4,500
FeCl3 Use, PPD Based on Average Flow	10
FeCl3 Unit Cost, $/lb	0.15
FeCl3 Cost, $/yr	$529
CO2 Use, PPD Based on Average Flow	77
CO2 Unit Cost, $/lb	0.14
CO2 Cost, $/yr	$3,950
Dewatered Residuals Production, CY/yr Based on Average Flow	4.45
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$200
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$8,375
Total Estimated Annual O&M Costs, $/yr	$36,854
Unit Annual O&M Costs, $/1000 gal	$0.87

Capital Cost Summary

Booster Pumping/ Straining	$67,150
Rapid Mixing	$18,000
Microfiltration	$219,817
Solids Handling	$117,960
Chemical Feed Systems	$40,183
Building	$119,000
Piping, I&C, Electrical, Yard Piping Allowances	$115,777
Total Facility Cost, $	$697,887
Contingency, 20%	$139,577
Total Estimated C/MF Facility Cost	$837,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$2,800
Annual Membrane Replacement Cost, $/yr	$4,500
FeCl3 Cost, $/yr	$529
CO2 Cost, $/yr	$3,950
Residuals Disposal Costs, $/yr	$200
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$8,375
Total Estimateded O&M for Treatment, $/yr	$36,854
Unit O&M Costs for C/MF	$0.87

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$422,708
Treatment Facility Capital Cost	$837,000
Ancillary Facilities Capital Cost	$11,405
Total Capital Cost	$848,405
Total Present Value of Facitlities	$1,271,000

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity, MGD	0.23
Total Production Capacity, MGD	0.26
Average Day Treatment Capacity, MGD	0.12
Total Average Day Production, MGD	0.13

Booster Pumping Capital Costs

Booster Pump, gpm	161
Number of Pumps	3
Pump Capacity per Pump, gpm	81
Pumping Head, ft	35
Pump Driver Size, Hp	0.9
Estimated Pump Cost, $ Each	$2,700
Pumping Facility Installation Cost, %	50
Sump for Pumps	$12,000
CO2 Stripper/Blowers	$25,000
CO2 Stripper Blower HP, Total	10
Total Pumping Facility Estimated Costs, $	$49,150
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	28,321

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	7
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.17
Rapid Mixer, Hp	0.2
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	807

Microfiltration Facilites Capital Costs

Microfiltration, 90M10C Units	1
Microfiltration Costs, $	$179,780
Microfiltation Installation Costs, %	20
Number of Backwash Tanks and Feed Pumps	1
Backwash Supply Tank/Pump Cost, $	$3,400
Total Backwash Supply Tank/Pump Cost, $	$3,400
Total MF Estimated Capital Costs, $	$219,817
Microfiltration Facilities Annual Costs	
MF Membrane Repalcement, yrs	5
Cost to Replace Membranes per Unit, $	$22,500
Annualized Cost for Membrane Replacement, $/yr	$4,500
Air Compressor, Hp	5
Annual Air Compressor Power Use, kWh/yr	2,184
Backwash Pump, HP	15
Annual Backwash Power Use, kWh/yr	3,296
Total Annual Power Use, kWh/yr	5,480

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	1,753
Thickened Sludge Storage Cost, $	$5,300
Thickened Sludge Pumps, $	$10,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	1,700
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$7,000
Total Recycling Tank/Pump Cost, $	$7,000
Total Thickener Facility Estimated Cost, $	$80,760

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	5
Filter Press Cost, $	$26,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$37,200
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
CH2M HILL
06/03/2002

Chemical Storage Capital Costs

FeCl3 Storage, gals	340
FeCl3 Storage Cost, $	$1,360
FeCl3 Metering Pump Cost, $	$10,000
CO2 Storage, tons	6.5
CO2 Storage, Cost	$65,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$91,632
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/MF System Equipment Cost Summary

Total Equipment Subtotal	$883,509
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$1,104,386

Building Facilities

Building, sf	1,519
Building Unit Cost, $/sf	$100
Building Cost, $	$152,000

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$1,256,386
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$1,507,663
Unit Treatment Facility Capital Cost, $/gpd	$2.33

Annual O&M Costs

Annual Power Use, kWh/yr	62,506
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$4,375
Annual Membrane Replacement Cost, $/yr	$9,000
FeCl3 Use, PPD Based on Average Flow	27
FeCl3 Unit Cost, $/lb	0.15
FeCl3 Cost, $/yr	$1,480
CO2 Use, PPD Based on Average Flow	216
CO2 Unit Cost, $/lb	0.14
CO2 Cost, $/yr	$11,049
Dewatered Residuals Production, CY/yr Based on Average Flow	12.46
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$561
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$15,077
Total Estimated Annual O&M Costs, $/yr	$58,041
Unit Annual O&M Costs, $/1000 gal	$0.49

Capital Cost Summary

Booster Pumping/ Straining	$88,750
Rapid Mixing	$18,000
Microfiltration	$521,087
Solids Handling	$164,040
Chemical Feed Systems	$91,632
Building	$152,000
Piping, I&C, Electrical, Yard Piping Allowances	$220,877
Total Facility Cost, $	$1,256,386
Contingency, 20%	$251,277
Total Estimated C/MF Facility Cost	$1,508,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$4,375
Annual Membrane Replacement Cost, $/yr	$9,000
FeCl3 Cost, $/yr	$1,480
CO2 Cost, $/yr	$11,049
Residuals Disposal Costs, $/yr	$561
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$15,077
Total Estimateded O&M for Treatment, $/yr	$58,041
Unit O&M Costs for C/MF	$0.49

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$665,727
Treatment Facility Capital Cost	$1,508,000
Ancillary Facilities Capital Cost	$247,104
Total Capital Cost	$1,755,104
Total Present Value of Facitlities	$2,421,000

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity, MGD	0.65
Total Production Capacity, MGD	0.99
Average Day Treatment Capacity, MGD	0.32
Total Average Day Production, MGD	0.49

Booster Pumping Capital Costs

Booster Pump, gpm	450
Number of Pumps	3
Pump Capacity per Pump, gpm	225
Pumping Head, ft	35
Pump Driver Size, Hp	2.5
Estimated Pump Cost, $ Each	$7,500
Pumping Facility Installation Cost, %	50
Sump for Pumps	$12,000
CO2 Stripper/Blowers	$25,000
CO2 Stripper Blower HP, Total	10
Total Pumping Facility Estimated Costs, $	$70,750
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	44,036

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	20
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.43
Rapid Mixer, Hp	0.7
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	2,258

Microfiltration Facilites Capital Costs

Microfiltration, 90M10C Units	2
Microfiltration Costs, $	$430,039
Microfiltation Installation Costs, %	20
Number of Backwash Tanks and Feed Pumps	1
Backwash Supply Tank/Pump Cost, $	$4,200
Total Backwash Supply Tank/Pump Cost, $	$4,200
Total MF Estimated Capital Costs, $	$521,087
Microfiltration Facilities Annual Costs	
MF Membrane Repalcement, yrs	5
Cost to Replace Membranes per Unit, $	$22,500
Annualized Cost for Membrane Replacement, $/yr	$9,000
Air Compressor, Hp	5
Annual Air Compressor Power Use, kWh/yr	2,184
Backwash Pump, HP	15
Annual Backwash Power Use, kWh/yr	6,592
Total Annual Power Use, kWh/yr	8,776

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	4,904
Thickened Sludge Storage Cost, $	$14,700
Thickened Sludge Pumps, $	$20,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	1,700
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$7,000
Total Recycling Tank/Pump Cost, $	$7,000
Total Thickener Facility Estimated Cost, $	$104,040

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	13
Filter Press Cost, $	$45,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$60,000
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
CH2M HILL
06/03/2002

Chemical Storage Capital Costs

FeCl3 Storage, gals	102
FeCl3 Storage Cost, $	$409
FeCl3 Metering Pump Cost, $	$10,000
CO2 Storage, tons	1.9
CO2 Storage, Cost	$19,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$35,290
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/MF System Equipment Cost Summary

Total Equipment Subtotal	$424,921
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$531,151

Building Facilities

Building, sf	1,156
Building Unit Cost, $/sf	$100
Building Cost, $	$116,000

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$647,151
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$776,582
Unit Treatment Facility Capital Cost, $/gpd	$3.99

Annual O&M Costs

Annual Power Use, kWh/yr	38,324
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$2,683
Annual Membrane Replacement Cost, $/yr	$4,500
FeCl3 Use, PPD Based on Average Flow	8
FeCl3 Unit Cost, $/lb	0.15
FeCl3 Cost, $/yr	$445
CO2 Use, PPD Based on Average Flow	65
CO2 Unit Cost, $/lb	0.14
CO2 Cost, $/yr	$3,320
Dewatered Residuals Production, CY/yr Based on Average Flow	3.74
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$168
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$7,766
Total Estimated Annual O&M Costs, $/yr	$35,381
Unit Annual O&M Costs, $/1000 gal	$1.00

Capital Cost Summary

Booster Pumping/ Straining	$64,900
Rapid Mixing	$18,000
Microfiltration	$189,851
Solids Handling	$116,880
Chemical Feed Systems	$35,290
Building	$116,000
Piping, I&C, Electrical, Yard Piping Allowances	$106,230
Total Facility Cost, $	$647,151
Contingency, 20%	$129,430
Total Estimated C/MF Facility Cost	$777,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$2,683
Annual Membrane Replacement Cost, $/yr	$4,500
FeCl3 Cost, $/yr	$445
CO2 Cost, $/yr	$3,320
Residuals Disposal Costs, $/yr	$168
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$7,766
Total Estimateded O&M for Treatment, $/yr	$35,381
Unit O&M Costs for C/MF	$1.00

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$405,822
Treatment Facility Capital Cost	$777,000
Ancillary Facilities Capital Cost	$285,120
Total Capital Cost	$1,062,120
Total Present Value of Facitlities	$1,468,000

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity. MGD	0.19
Total Production Capacity, MGD	0.33
Average Day Treatment Capacity, MGD	0.10
Total Average Day Production, MGD	0.17

Booster Pumping Capital Costs

Booster Pump, gpm	135
Number of Pumps	3
Pump Capacity per Pump, gpm	68
Pumping Head, ft	35
Pump Driver Size, Hp	0.7
Estimated Pump Cost, $ Each	$2,200
Pumping Facility Installation Cost, %	50
Sump for Pumps	$12,000
CO2 Stripper/Blowers	$25,000
CO2 Stripper Blower HP, Total	10
Total Pumping Faciity Estimated Costs, $	$46,900
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	26,927

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	6
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.13
Rapid Mixer, Hp	0.2
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	678

Microfiltration Facilites Capital Costs

Microfiltration, 90M10C Units	1
Microfiltration Costs, $	$154,809
Microfiltation Installation Costs, %	20
Number of Backwash Tanks and Feed Pumps	1
Backwash Supply Tank/Pump Cost, $	$3,400
Total Backwash Supply Tank/Pump Cost, $	$3,400
Total MF Estimated Capital Costs, $	$189,851
Microfiltration Facilities Annual Costs	
MF Membrane Repalcement, yrs	5
Cost to Replace Membranes per Unit, $	$22,500
Annualized Cost for Membrane Replacement, $/yr	$4,500
Air Compressor, Hp	5
Annual Air Compressor Power Use, kWh/yr	2,184
Backwash Pump, HP	15
Annual Backwash Power Use, kWh/yr	3,296
Total Annual Power Use, kWh/yr	5,480

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	1,473
Thickened Sludge Storage Cost, $	$4,400
Thickened Sludge Pumps, $	$10,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	1,700
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$7,000
Total Recycling Tank/Pump Cost, $	$7,000
Total Thickener Facility Estimated Cost, $	$79,680

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	4
Filter Press Cost, $	$26,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$37,200
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
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Chemical Storage Capital Costs

FeCl3 Storage, gals	427
FeCl3 Storage Cost, $	$1,707
FeCl3 Metering Pump Cost, $	$12,000
CO2 Storage, tons	8.1
CO2 Storage, Cost	$81,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$113,648
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/MF System Equipment Cost Summary

Total Equipment Subtotal	$1,045,619
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$1,307,023

Building Facilities

Building, sf	1,651
Building Unit Cost, $/sf	$100
Building Cost, $	$165,000

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$1,472,023
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$1,766,428
Unit Treatment Facility Capital Cost, $/gpd	$2.17

Annual O&M Costs

Annual Power Use, kWh/yr	70,001
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$4,900
Annual Membrane Replacement Cost, $/yr	$9,000
FeCl3 Use, PPD Based on Average Flow	34
FeCl3 Unit Cost, $/lb	0.15
FeCl3 Cost, $/yr	$1,857
CO2 Use, PPD Based on Average Flow	271
CO2 Unit Cost, $/lb	0.14
CO2 Cost, $/yr	$13,867
Dewatered Residuals Production, CY/yr Based on Average Flow	15.63
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$703
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$17,664
Total Estimated Annual O&M Costs, $/yr	$64,492
Unit Annual O&M Costs, $/1000 gal	$0.43

Capital Cost Summary

Booster Pumping/ Straining	$113,300
Rapid Mixing	$18,000
Microfiltration	$628,471
Solids Handling	$172,200
Chemical Feed Systems	$113,648
Building	$165,000
Piping, I&C, Electrical, Yard Piping Allowances	$261,405
Total Facility Cost, $	$1,472,023
Contingency, 20%	$294,405
Total Estimated C/MF Facility Cost	$1,766,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$4,900
Annual Membrane Replacement Cost, $/yr	$9,000
FeCl3 Cost, $/yr	$1,857
CO2 Cost, $/yr	$13,867
Residuals Disposal Costs, $/yr	$703
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$17,664
Total Estimateded O&M for Treatment, $/yr	$64,492
Unit O&M Costs for C/MF	$0.43

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$739,717
Treatment Facility Capital Cost	$1,766,000
Ancillary Facilities Capital Cost	$382,061
Total Capital Cost	$2,148,061
Total Present Value of Facitlities	$2,888,000

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
CH2M HILL
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MCL	10

Design Criteria

Design Treatment Capacity, MGD	0.81
Total Production Capacity, MGD	1.00
Average Day Treatment Capacity, MGD	0.41
Total Average Day Production, MGD	0.50

Booster Pumping Capital Costs

Booster Pump, gpm	565
Number of Pumps	3
Pump Capacity per Pump, gpm	283
Pumping Head, ft	35
Pump Driver Size, Hp	3.1
Estimated Pump Cost, $ Each	$9,400
Pumping Facility Installation Cost, %	50
Sump for Pumps	$18,000
CO2 Stripper/Blowers	$35,000
CO2 Stripper Blower HP, Total	10
Total Pumping Facility Estimated Costs, $	$95,300
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	50,274

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	25
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.50
Rapid Mixer, Hp	0.9
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	2,834

Microfiltration Facilites Capital Costs

Microfiltration, 90M10C Units	2
Microfiltration Costs, $	$519,526
Microfiltation Installation Costs, %	20
Number of Backwash Tanks and Feed Pumps	1
Backwash Supply Tank/Pump Cost, $	$4,200
Total Backwash Supply Tank/Pump Cost, $	$4,200
Total MF Estimated Capital Costs, $	$628,471
Microfiltration Facilities Annual Costs	
MF Membrane Repalcement, yrs	5
Cost to Replace Membranes per Unit, $	$22,500
Annualized Cost for Membrane Replacement, $/yr	$9,000
Air Compressor, Hp	5
Annual Air Compressor Power Use, kWh/yr	2,184
Backwash Pump, HP	15
Annual Backwash Power Use, kWh/yr	6,592
Total Annual Power Use, kWh/yr	8,776

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	6,155
Thickened Sludge Storage Cost, $	$18,500
Thickened Sludge Pumps, $	$20,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	1,700
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$7,000
Total Recycling Tank/Pump Cost, $	$7,000
Total Thickener Facility Estimated Cost, $	$108,600

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	16
Filter Press Cost, $	$45,000
Sludge Feed Pumps Cost, $	$8,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$63,600
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
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Chemical Storage Capital Costs

FeCl3 Storage, gals	101
FeCl3 Storage Cost, $	$402
FeCl3 Metering Pump Cost, $	$10,000
CO2 Storage, tons	1.9
CO2 Storage, Cost	$19,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$35,283
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/MF System Equipment Cost Summary

Total Equipment Subtotal	$422,469
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$528,086

Building Facilities

Building, sf	1,153
Building Unit Cost, $/sf	$100
Building Cost, $	$115,000

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$643,086
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$771,703
Unit Treatment Facility Capital Cost, $/gpd	$4.02

Annual O&M Costs

Annual Power Use, kWh/yr	38,189
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$2,673
Annual Membrane Replacement Cost, $/yr	$4,500
FeCl3 Use, PPD Based on Average Flow	8
FeCl3 Unit Cost, $/lb	0.15
FeCl3 Cost, $/yr	$438
CO2 Use, PPD Based on Average Flow	64
CO2 Unit Cost, $/lb	0.14
CO2 Cost, $/yr	$3,269
Dewatered Residuals Production, CY/yr Based on Average Flow	3.69
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$166
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$7,717
Total Estimated Annual O&M Costs, $/yr	$35,263
Unit Annual O&M Costs, $/1000 gal	$1.01

Capital Cost Summary

Booster Pumping/ Straining	$64,900
Rapid Mixing	$18,000
Microfiltration	$187,406
Solids Handling	$116,880
Chemical Feed Systems	$35,283
Building	$115,000
Piping, I&C, Electrical, Yard Piping Allowances	$105,617
Total Facility Cost, $	$643,086
Contingency, 20%	$128,617
Total Estimated C/MF Facility Cost	$772,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$2,673
Annual Membrane Replacement Cost, $/yr	$4,500
FeCl3 Cost, $/yr	$438
CO2 Cost, $/yr	$3,269
Residuals Disposal Costs, $/yr	$166
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$7,717
Total Estimateded O&M for Treatment, $/yr	$35,263
Unit O&M Costs for C/MF	$1.01

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$404,467
Treatment Facility Capital Cost	$772,000
Ancillary Facilities Capital Cost	$11,405
Total Capital Cost	$783,405
Total Present Value of Facitlities	$1,188,000

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity. MGD	0.19
Total Production Capacity, MGD	0.31
Average Day Treatment Capacity, MGD	0.10
Total Average Day Production, MGD	0.15

Booster Pumping Capital Costs

Booster Pump, gpm	133
Number of Pumps	3
Pump Capacity per Pump, gpm	67
Pumping Head, ft	35
Pump Driver Size, Hp	0.7
Estimated Pump Cost, $ Each	$2,200
Pumping Facility Installation Cost, %	50
Sump for Pumps	$12,000
CO2 Stripper/Blowers	$25,000
CO2 Stripper Blower HP, Total	10
Total Pumping Faciity Estimated Costs, $	$46,900
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	26,815

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	6
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.12
Rapid Mixer, Hp	0.2
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	668

Microfiltration Facilites Capital Costs

Microfiltration, 90M10C Units	1
Microfiltration Costs, $	$152,772
Microfiltation Installation Costs, %	20
Number of Backwash Tanks and Feed Pumps	1
Backwash Supply Tank/Pump Cost, $	$3,400
Total Backwash Supply Tank/Pump Cost, $	$3,400
Total MF Estimated Capital Costs, $	$187,406
Microfiltration Facilities Annual Costs	
MF Membrane Repalcement, yrs	5
Cost to Replace Membranes per Unit, $	$22,500
Annualized Cost for Membrane Replacement, $/yr	$4,500
Air Compressor, Hp	5
Annual Air Compressor Power Use, kWh/yr	2,184
Backwash Pump, HP	15
Annual Backwash Power Use, kWh/yr	3,296
Total Annual Power Use, kWh/yr	5,480

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	1,451
Thickened Sludge Storage Cost, $	$4,400
Thickened Sludge Pumps, $	$10,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	1,700
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$7,000
Total Recycling Tank/Pump Cost, $	$7,000
Total Thickener Facility Estimated Cost, $	$79,680

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	4
Filter Press Cost, $	$26,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$37,200
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
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Chemical Storage Capital Costs

FeCl3 Storage, gals	1,093
FeCl3 Storage Cost, $	$4,373
FeCl3 Metering Pump Cost, $	$12,000
CO2 Storage, tons	20.9
CO2 Storage, Cost	$209,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$270,447
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	2,570

Total C/MF System Equipment Cost Summary

Total Equipment Subtotal	$2,122,016
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$2,652,520

Building Facilities

Building, sf	2,667
Building Unit Cost, $/sf	$100
Building Cost, $	$267,000

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$2,919,520
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$3,503,425
Unit Treatment Facility Capital Cost, $/gpd	$1.68

Annual O&M Costs

Annual Power Use, kWh/yr	214,967
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$15,048
Annual Membrane Replacement Cost, $/yr	$27,000
FeCl3 Use, PPD Based on Average Flow	141
FeCl3 Unit Cost, $/lb	0.15
FeCl3 Cost, $/yr	$7,701
CO2 Use, PPD Based on Average Flow	1125
CO2 Unit Cost, $/lb	0.14
CO2 Cost, $/yr	$57,504
Dewatered Residuals Production, CY/yr Based on Average Flow	64.83
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$2,917
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$35,034
Total Estimated Annual O&M Costs, $/yr	$161,704
Unit Annual O&M Costs, $/1000 gal	$0.26

Capital Cost Summary

Booster Pumping/ Straining	$196,000
Rapid Mixing	$18,000
Microfiltration	$1,349,209
Solids Handling	$288,360
Chemical Feed Systems	$270,447
Building	$267,000
Piping, I&C, Electrical, Yard Piping Allowances	$530,504
Total Facility Cost, $	$2,919,520
Contingency, 20%	$583,904
Total Estimated C/MF Facility Cost	$3,503,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$15,048
Annual Membrane Replacement Cost, $/yr	$27,000
FeCl3 Cost, $/yr	$7,701
CO2 Cost, $/yr	$57,504
Residuals Disposal Costs, $/yr	$2,917
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$35,034
Total Estimateded O&M for Treatment, $/yr	$161,704
Unit O&M Costs for C/MF	$0.26

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$1,854,733
Treatment Facility Capital Cost	$3,503,000
Ancillary Facilities Capital Cost	$850,925
Total Capital Cost	$4,353,925
Total Present Value of Facitlities	$6,209,000

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity, MGD	2.08
Total Production Capacity, MGD	2.79
Average Day Treatment Capacity, MGD	1.69
Total Average Day Production, MGD	2.26

Booster Pumping Capital Costs

Booster Pump, gpm	1448
Number of Pumps	3
Pump Capacity per Pump, gpm	724
Pumping Head, ft	35
Pump Driver Size, Hp	8.0
Estimated Pump Cost, $ Each	$24,000
Pumping Facility Installation Cost, %	50
Sump for Pumps	$22,000
CO2 Stripper/Blowers	$45,000
CO2 Stripper Blower HP, Total	10
Total Pumping Facility Estimated Costs, $	$175,000
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	158,976

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$17,500
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$21,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	65
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.81
Rapid Mixer, Hp	2.2
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	11,752

Microfiltration Facilites Capital Costs

Microfiltration, 90M10C Units	6
Microfiltration Costs, $	$1,116,741
Microfiltation Installation Costs, %	20
Number of Backwash Tanks and Feed Pumps	1
Backwash Supply Tank/Pump Cost, $	$7,600
Total Backwash Supply Tank/Pump Cost, $	$7,600
Total MF Estimated Capital Costs, $	$1,349,209
Microfiltration Facilities Annual Costs	
MF Membrane Repalcement, yrs	5
Cost to Replace Membranes per Unit, $	$22,500
Annualized Cost for Membrane Replacement, $/yr	$27,000
Air Compressor, Hp	5
Annual Air Compressor Power Use, kWh/yr	2,184
Backwash Pump, HP	15
Annual Backwash Power Use, kWh/yr	19,776
Total Annual Power Use, kWh/yr	21,961

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$82,000
Thickened Sludge Storage, gal	15,768
Thickened Sludge Storage Cost, $	$47,300
Thickened Sludge Pumps, $	$20,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	1,700
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$7,000
Total Recycling Tank/Pump Cost, $	$7,000
Total Thickener Facility Estimated Cost, $	$187,560

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	41
Filter Press Cost, $	$72,000
Sludge Feed Pumps Cost, $	$12,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$100,800
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
CH2M HILL
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Chemical Storage Capital Costs

FeCl3 Storage, gals	582
FeCl3 Storage Cost, $	$2,329
FeCl3 Metering Pump Cost, $	$12,000
CO2 Storage, tons	11.1
CO2 Storage, Cost	$111,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$150,395
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/MF System Equipment Cost Summary

Total Equipment Subtotal	$1,331,264
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$1,664,079

Building Facilities

Building, sf	1,888
Building Unit Cost, $/sf	$100
Building Cost, $	$189,000

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$1,853,079
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$2,223,695
Unit Treatment Facility Capital Cost, $/gpd	$2.00

Annual O&M Costs

Annual Power Use, kWh/yr	87,077
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$6,095
Annual Membrane Replacement Cost, $/yr	$13,500
FeCl3 Use, PPD Based on Average Flow	46
FeCl3 Unit Cost, $/lb	0.15
FeCl3 Cost, $/yr	$2,534
CO2 Use, PPD Based on Average Flow	370
CO2 Unit Cost, $/lb	0.14
CO2 Cost, $/yr	$18,924
Dewatered Residuals Production, CY/yr Based on Average Flow	21.33
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$960
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$22,237
Total Estimated Annual O&M Costs, $/yr	$80,751
Unit Annual O&M Costs, $/1000 gal	$0.40

Capital Cost Summary

Booster Pumping/ Straining	$138,600
Rapid Mixing	$18,000
Microfiltration	$811,629
Solids Handling	$212,640
Chemical Feed Systems	$150,395
Building	$189,000
Piping, I&C, Electrical, Yard Piping Allowances	$332,816
Total Facility Cost, $	$1,853,079
Contingency, 20%	$370,616
Total Estimated C/MF Facility Cost	$2,224,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$6,095
Annual Membrane Replacement Cost, $/yr	$13,500
FeCl3 Cost, $/yr	$2,534
CO2 Cost, $/yr	$18,924
Residuals Disposal Costs, $/yr	$960
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$22,237
Total Estimateded O&M for Treatment, $/yr	$80,751
Unit O&M Costs for C/MF	$0.40

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$926,202
Treatment Facility Capital Cost	$2,224,000
Ancillary Facilities Capital Cost	$343,411
Total Capital Cost	$2,567,411
Total Present Value of Facitlities	$3,494,000

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity. MGD	1.11
Total Production Capacity, MGD	1.38
Average Day Treatment Capacity, MGD	0.56
Total Average Day Production, MGD	0.69

Booster Pumping Capital Costs

Booster Pump, gpm	772
Number of Pumps	3
Pump Capacity per Pump, gpm	386
Pumping Head, ft	35
Pump Driver Size, Hp	4.3
Estimated Pump Cost, $ Each	$12,800
Pumping Facility Installation Cost, %	50
Sump for Pumps	$18,000
CO2 Stripper/Blowers	$45,000
CO2 Stripper Blower HP, Total	10
Total Pumping Facility Estimated Costs, $	$120,600
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	61,467

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	34
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.59
Rapid Mixer, Hp	1.2
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	3,867

Microfiltration Facilites Capital Costs

Microfiltration, 90M10C Units	3
Microfiltration Costs, $	$671,257
Microfiltation Installation Costs, %	20
Number of Backwash Tanks and Feed Pumps	1
Backwash Supply Tank/Pump Cost, $	$5,100
Total Backwash Supply Tank/Pump Cost, $	$5,100
Total MF Estimated Capital Costs, $	$811,629
Microfiltration Facilities Annual Costs	
MF Membrane Repalcement, yrs	5
Cost to Replace Membranes per Unit, $	$22,500
Annualized Cost for Membrane Replacement, $/yr	$13,500
Air Compressor, Hp	5
Annual Air Compressor Power Use, kWh/yr	2,184
Backwash Pump, HP	15
Annual Backwash Power Use, kWh/yr	9,888
Total Annual Power Use, kWh/yr	12,072

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	8,399
Thickened Sludge Storage Cost, $	$25,200
Thickened Sludge Pumps, $	$20,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	1,700
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$7,000
Total Recycling Tank/Pump Cost, $	$7,000
Total Thickener Facility Estimated Cost, $	$116,640

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	22
Filter Press Cost, $	$72,000
Sludge Feed Pumps Cost, $	$8,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$96,000
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
CH2M HILL
06/03/2002

Chemical Storage Capital Costs

FeCl3 Storage, gals	190
FeCl3 Storage Cost, $	$760
FeCl3 Metering Pump Cost, $	$10,000
CO2 Storage, tons	3.6
CO2 Storage, Cost	$36,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$56,112
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/MF System Equipment Cost Summary

Total Equipment Subtotal	$612,274
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$765,343

Building Facilities

Building, sf	1,290
Building Unit Cost, $/sf	$100
Building Cost, $	$129,000

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$894,343
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$1,073,211
Unit Treatment Facility Capital Cost, $/gpd	$2.96

Annual O&M Costs

Annual Power Use, kWh/yr	45,911
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$3,214
Annual Membrane Replacement Cost, $/yr	$4,500
FeCl3 Use, PPD Based on Average Flow	15
FeCl3 Unit Cost, $/lb	0.15
FeCl3 Cost, $/yr	$827
CO2 Use, PPD Based on Average Flow	121
CO2 Unit Cost, $/lb	0.14
CO2 Cost, $/yr	$6,172
Dewatered Residuals Production, CY/yr Based on Average Flow	6.96
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$313
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$10,732
Total Estimated Annual O&M Costs, $/yr	$42,258
Unit Annual O&M Costs, $/1000 gal	$0.64

Capital Cost Summary

Booster Pumping/ Straining	$73,900
Rapid Mixing	$18,000
Microfiltration	$320,022
Solids Handling	$144,240
Chemical Feed Systems	$56,112
Building	$129,000
Piping, I&C, Electrical, Yard Piping Allowances	$153,069
Total Facility Cost, $	$894,343
Contingency, 20%	$178,869
Total Estimated C/MF Facility Cost	$1,073,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$3,214
Annual Membrane Replacement Cost, $/yr	$4,500
FeCl3 Cost, $/yr	$827
CO2 Cost, $/yr	$6,172
Residuals Disposal Costs, $/yr	$313
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$10,732
Total Estimateded O&M for Treatment, $/yr	$42,258
Unit O&M Costs for C/MF	$0.64

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$484,697
Treatment Facility Capital Cost	$1,073,000
Ancillary Facilities Capital Cost	$209,088
Total Capital Cost	$1,282,088
Total Present Value of Facitlities	$1,767,000

City of Norman Arsenic Study
Coagulation/Microfiltration Arsenic Treatment Costs
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity. MGD	0.36
Total Production Capacity, MGD	0.93
Average Day Treatment Capacity, MGD	0.18
Total Average Day Production, MGD	0.46

Booster Pumping Capital Costs

Booster Pump, gpm	252
Number of Pumps	3
Pump Capacity per Pump, gpm	126
Pumping Head, ft	35
Pump Driver Size, Hp	1.4
Estimated Pump Cost, $ Each	$4,200
Pumping Facility Installation Cost, %	50
Sump for Pumps	$12,000
CO2 Stripper/Blowers	$25,000
CO2 Stripper Blower HP, Total	10
Total Pumping Faciity Estimated Costs, $	$55,900
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	33,242

Influent Straining Capital Costs

Number of Strainers	1
500 micron Self Cleaning Strainer, in	4
Cost of Strainer, $	$15,000
Strainer Installation Cost, %	20
Total Strainer Facilities Estimated Costs, $	$18,000
Influent Straining Annual Costs	
Driver Size, Hp	0.25
Estimated Operation Time, %	0.05
Annual Power Use, kWh.yr	82

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	11
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.27
Rapid Mixer, Hp	0.4
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	1,261

Microfiltration Facilites Capital Costs

Microfiltration, 90M10C Units	1
Microfiltration Costs, $	$263,285
Microfiltation Installation Costs, %	20
Number of Backwash Tanks and Feed Pumps	1
Backwash Supply Tank/Pump Cost, $	$3,400
Total Backwash Supply Tank/Pump Cost, $	$3,400
Total MF Estimated Capital Costs, $	$320,022
Microfiltration Facilities Annual Costs	
MF Membrane Repalcement, yrs	5
Cost to Replace Membranes per Unit, $	$22,500
Annualized Cost for Membrane Replacement, $/yr	$4,500
Air Compressor, Hp	5
Annual Air Compressor Power Use, kWh/yr	2,184
Backwash Pump, HP	15
Annual Backwash Power Use, kWh/yr	3,296
Total Annual Power Use, kWh/yr	5,480

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	2,740
Thickened Sludge Storage Cost, $	$8,200
Thickened Sludge Pumps, $	$10,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	1,700
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$7,000
Total Recycling Tank/Pump Cost, $	$7,000
Total Thickener Facility Estimated Cost, $	$84,240

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	7
Filter Press Cost, $	$45,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$60,000
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

Appendix F

City of Norman & OU Arsenic Study
Coagulation/Filtration
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity. MGD	0.36
Total Production Capacity, MGD	0.93
Average Day Treatment Capacity, MGD	0.18
Total Average Day Production, MGD	0.46

Booster Pumping Capital Costs

Booster Pump, gpm	252
Number of Pumps	3
Pump Capacity per Pump, gpm	126
Pumping Head, ft	35
Pump Driver Size, Hp	1.4
Estimated Pump Cost, $ Each	$4,200
Pumping Facility Installation Cost, %	50
Sump for Pumps	$12,000
CO2 Stripper/Blowers	$25,000
CO2 Stripper Blower HP, Total	10
Total Pumping Faciity Estimated Costs, $	$55,900
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	33,242

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	11
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.27
Rapid Mixer, Hp	0.4
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	1,261

Filtration Facilites Capital Costs

Number of Pressure Filters	3
Vessel Diameter, ft	8
Cost per Pressure Filter, $	$80,000
Total Vessel Cost including Valves, $	$240,000
Automatic Controller System	$12,000
Air Compressor System Cost, $	$12,000
Backwash Supply Tank, gal	18,850
Backwash Supply Tank Cost, $	$23,562
Backwash Recycle Tank, gal	18,850
Backwash Recycle Tank Cost, $	$23,562
Backwash Supply Pump Cost, $	$5,000
Backwash Recycle Pump Cost, $	$3,000
Subtotal Pressure Filter Costs, $	$319,124
Equipment Installation Cost, %	30
Pressure Filter System Cost, $	$414,861
Filtration Facilities Annual Costs	
Annual Power , KwH	1,733

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	2,740
Thickened Sludge Storage Cost, $	$8,000
Thickened Sludge Pumps, $	$10,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	12,566
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$16,283
Total Recycling Tank/Pump Cost, $	$16,283
Total Thickener Facility Estimated Cost, $	$95,140

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	7
Filter Press Cost, $	$45,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$60,000
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

City of Norman & OU Arsenic Study
Coagulation/Filtration
CH2M HILL
06/03/2002

Chemical Storage Capital Costs

FeCl3 Storage, gals	190
FeCl3 Storage Cost, $	$760
FeCl3 Metering Pump Cost, $	$10,000
CO2 Storage, tons	3.6
CO2 Storage, Cost	$36,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$56,112
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/F System Equipment Cost Summary

Total Equipment Subtotal	$700,013
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$875,016

Building Facilities

Building, sf	1,452
Building Unit Cost, $/sf	$100
Building Cost, $	$145,200

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$1,020,216
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$1,224,259
Unit Treatment Facility Capital Cost, $/gpd	$3.38

Annual O&M Costs

Annual Power Use, kWh/yr	41,699
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$2,919
FeCl3 Use, PPD Based on Average Flow	15
FeCl3 Unit Cost, $/lb	$0.15
FeCl3 Cost, $/yr	$827
CO2 Use, PPD Based on Average Flow	121
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$6,172
Dewatered Residuals Production, CY/yr Based on Average Flow	6.96
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$313
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$12,243
Total Estimated Annual O&M Costs, $/yr	$38,974
Unit Annual O&M Costs, $/1000 gal	$0.59

Capital Cost Summary

Booster Pumping	$55,900
Rapid Mixing	$18,000
Filtration	$414,861
Thickener	$95,140
Dewatering	$60,000
Chemical Feed Systems	$56,112
Building	$145,200
Piping, I&C, Electrical, Yard Piping Allowances	$175,003
Total Facility Cost, $	$1,020,216
Contingency, 20%	$204,043
Total Estimated C/F Facility Cost	$1,224,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$2,919
FeCl3 Cost, $/yr	$827
CO2 Cost, $/yr	$6,172
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$12,243
Residuals Disposal Costs, $/yr	$313
Total Estimated Annual O&M Costs, $/yr	$38,974
Unit O&M Costs for C/F, $/1000 gals	$0.59

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$447,026
Treatment Facility Capital Cost	$1,224,000
Ancillary Facilities Capital Cost	$209,088
Total Capital Cost	$1,433,088
Total Present Value of Facitlities	$1,880,000

City of Norman & OU Arsenic Study
Coagulation/Filtration
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity, MGD	1.11
Total Production Capacity, MGD	1.38
Average Day Treatment Capacity, MGD	0.56
Total Average Day Production, MGD	0.69

Booster Pumping Capital Costs

Booster Pump, gpm	772
Number of Pumps	3
Pump Capacity per Pump, gpm	386
Pumping Head, ft	35
Pump Driver Size, Hp	4.3
Estimated Pump Cost, $ Each	$12,800
Pumping Facility Installation Cost, %	50
Sump for Pumps	$18,000
CO2 Stripper/Blowers	$45,000
CO2 Stripper Blower HP, Total	10
Total Pumping Faciity Estimated Costs, $	$120,600
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	61,467

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	34
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.59
Rapid Mixer, Hp	1.2
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	3,867

Filtration Faciliites Capital Costs

Number of Pressure Filters	4
Vessel Diameter, ft	11
Cost per Pressure Filter, $	$110,000
Total Vessel Cost including Valves, $	$440,000
Automatic Controller System	$22,000
Air Compressor System Cost, $	$12,000
Backwash Supply Tank, gal	35,637
Backwash Supply Tank Cost, $	$44,547
Backwash Recycle Tank, gal	35,637
Backwash Recycle Tank Cost, $	$44,547
Backwash Supply Pump Cost, $	$5,000
Backwash Recycle Pump Cost, $	$3,000
Subtotal Pressure Filter Costs, $	$571,094
Equipment Installation Cost, %	30
Pressure Filter System Cost, $	$742,422
Filtration Facilities Annual Costs	
Annual Power , KwH	4,914

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	8,399
Thickened Sludge Storage Cost, $	$25,000
Thickened Sludge Pumps, $	$20,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	23,758
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$31,879
Total Recycling Tank/Pump Cost, $	$31,879
Total Thickener Facility Estimated Cost, $	$146,255

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	22
Filter Press Cost, $	$72,000
Sludge Feed Pumps Cost, $	$8,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$96,000
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

City of Norman & OU Arsenic Study
Coagulation/Filtration
CH2M HILL
06/03/2002

Chemical Storage Capital Costs

FeCl3 Storage, gals	582
FeCl3 Storage Cost, $	$2,329
FeCl3 Metering Pump Cost, $	$12,000
CO2 Storage, tons	11.1
CO2 Storage, Cost	$111,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$150,395
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/F System Equipment Cost Summary

Total Equipment Subtotal	$1,273,672
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$1,592,089

Building Facilities

Building, sf	2,484
Building Unit Cost, $/sf	$100
Building Cost, $	$248,400

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$1,840,489
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$2,208,587
Unit Treatment Facility Capital Cost, $/gpd	$1.99

Annual O&M Costs

Annual Power Use, kWh/yr	79,113
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$5,538
FeCl3 Use, PPD Based on Average Flow	46
FeCl3 Unit Cost, $/lb	$0.15
FeCl3 Cost, $/yr	$2,534
CO2 Use, PPD Based on Average Flow	370
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$18,924
Dewatered Residuals Production, CY/yr Based on Average Flow	21.33
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$960
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$22,086
Total Estimated Annual O&M Costs, $/yr	$66,542
Unit Annual O&M Costs, $/1000 gal	$0.33

Capital Cost Summary

Booster Pumping	$120,600
Rapid Mixing	$18,000
Filtration	$742,422
Thickener	$146,255
Dewatering	$96,000
Chemical Feed Systems	$150,395
Building	$248,400
Piping, I&C, Electrical, Yard Piping Allowances	$318,418
Total Facility Cost, $	$1,840,489
Contingency, 20%	$368,098
Total Estimated C/F Facility Cost	$2,209,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$5,538
FeCl3 Cost, $/yr	$2,534
CO2 Cost, $/yr	$18,924
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$22,086
Residuals Disposal Costs, $/yr	$960
Total Estimated Annual O&M Costs, $/yr	$66,542
Unit O&M Costs for C/F, $/1000 gals	$0.33

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$763,231
Treatment Facility Capital Cost	$2,209,000
Ancillary Facilities Capital Cost	$343,411
Total Capital Cost	$2,552,411
Total Present Value of Facitlities	$3,316,000

City of Norman & OU Arsenic Study
Coagulation/Filtration
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity. MGD	2.08
Total Production Capacity, MGD	2.79
Average Day Treatment Capacity, MGD	1.69
Total Average Day Production, MGD	2.26

Booster Pumping Capital Costs

Booster Pump, gpm	1448
Number of Pumps	3
Pump Capacity per Pump, gpm	724
Pumping Head, ft	35
Pump Driver Size, Hp	8.0
Estimated Pump Cost, $ Each	$24,000
Pumping Facility Installation Cost, %	50
Sump for Pumps	$22,000
CO2 Stripper/Blowers	$45,000
CO2 Stripper Blower HP, Total	10
Total Pumping Faciity Estimated Costs, $	$175,000
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	158,976

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	65
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.81
Rapid Mixer, Hp	2.2
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	11,752

Filtration Facililites Capital Costs

Number of Pressure Filters	6
Vessel Diameter, ft	12
Cost per Pressure Filter, $	$120,000
Total Vessel Cost including Valves, $	$720,000
Automatic Controller System	$36,000
Air Compressor System Cost, $	$12,000
Backwash Supply Tank, gal	42,412
Backwash Supply Tank Cost, $	$53,014
Backwash Recycle Tank, gal	42,412
Backwash Recycle Tank Cost, $	$53,014
Backwash Supply Pump Cost, $	$5,000
Backwash Recycle Pump Cost, $	$3,000
Subtotal Pressure Filter Costs, $	$882,029
Equipment Installation Cost, %	30
Pressure Filter System Cost, $	$1,146,637
Filtration Facilities Annual Costs	
Annual Power , KwH	9,747

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$82,000
Thickened Sludge Storage, gal	15,768
Thickened Sludge Storage Cost, $	$47,000
Thickened Sludge Pumps, $	$20,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	28,274
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$34,137
Total Recycling Tank/Pump Cost, $	$34,137
Total Thickener Facility Estimated Cost, $	$219,765

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	41
Filter Press Cost, $	$72,000
Sludge Feed Pumps Cost, $	$12,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$100,800
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

City of Norman & OU Arsenic Study
Coagulation/Filtration
CH2M HILL
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Chemical Storage Capital Costs

FeCl3 Storage, gals	1,093
FeCl3 Storage Cost, $	$4,373
FeCl3 Metering Pump Cost, $	$12,000
CO2 Storage, tons	20.9
CO2 Storage, Cost	$209,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$270,447
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	2,570

Total C/F System Equipment Cost Summary

Total Equipment Subtotal	$1,930,649
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$2,413,312

Building Facilities

Building, sf	3,959
Building Unit Cost, $/sf	$100
Building Cost, $	$395,900

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$2,809,212
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$3,371,054
Unit Treatment Facility Capital Cost, $/gpd	$1.62

Annual O&M Costs

Annual Power Use, kWh/yr	201,442
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$14,101
FeCl3 Use, PPD Based on Average Flow	141
FeCl3 Unit Cost, $/lb	$0.15
FeCl3 Cost, $/yr	$7,701
CO2 Use, PPD Based on Average Flow	1125
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$57,504
Dewatered Residuals Production, CY/yr Based on Average Flow	64.83
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$2,917
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$33,711
Total Estimated Annual O&M Costs, $/yr	$132,434
Unit Annual O&M Costs, $/1000 gal	$0.22

Capital Cost Summary

Booster Pumping	$175,000
Rapid Mixing	$18,000
Filtration	$1,146,637
Thickener	$219,765
Dewatering	$100,800
Chemical Feed Systems	$270,447
Building	$395,900
Piping, I&C, Electrical, Yard Piping Allowances	$482,662
Total Facility Cost, $	$2,809,212
Contingency, 20%	$561,842
Total Estimated C/F Facility Cost	$3,371,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$14,101
FeCl3 Cost, $/yr	$7,701
CO2 Cost, $/yr	$57,504
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$33,711
Residuals Disposal Costs, $/yr	$2,917
Total Estimated Annual O&M Costs, $/yr	$132,434
Unit O&M Costs for C/F, $/1000 gals	$0.22

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$1,519,003
Treatment Facility Capital Cost	$3,371,000
Ancillary Facilities Capital Cost	$850,925
Total Capital Cost	$4,221,925
Total Present Value of Facitlities	$5,741,000

City of Norman & OU Arsenic Study
Coagulation/Filtration
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity, MGD	0.19
Total Production Capacity, MGD	0.31
Average Day Treatment Capacity, MGD	0.10
Total Average Day Production, MGD	0.15

Booster Pumping Capital Costs

Booster Pump, gpm	133
Number of Pumps	3
Pump Capacity per Pump, gpm	67
Pumping Head, ft	35
Pump Driver Size, Hp	0.7
Estimated Pump Cost, $ Each	$2,200
Pumping Facility Installation Cost, %	50
Sump for Pumps	$12,000
CO2 Stripper/Blowers	$25,000
CO2 Stripper Blower HP, Total	10
Total Pumping Faciity Estimated Costs, $	$46,900
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	26,815

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	6
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.12
Rapid Mixer, Hp	0.2
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	668

Filtration Faciliites Capital Costs

Number of Pressure Filters	3
Vessel Diameter, ft	6
Cost per Pressure Filter, $	$60,000
Total Vessel Cost including Valves, $	$180,000
Automatic Controller System	$9,000
Air Compressor System Cost, $	$12,000
Backwash Supply Tank, gal	10,603
Backwash Supply Tank Cost, $	$13,254
Backwash Recycle Tank, gal	10,603
Backwash Recycle Tank Cost, $	$13,254
Backwash Supply Pump Cost, $	$5,000
Backwash Recycle Pump Cost, $	$3,000
Subtotal Pressure Filter Costs, $	$235,507
Equipment Installation Cost, %	30
Pressure Filter System Cost, $	$306,159
Filtration Facilities Annual Costs	
Annual Power , KwH	975

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	1,451
Thickened Sludge Storage Cost, $	$4,000
Thickened Sludge Pumps, $	$10,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	7,069
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$13,534
Total Recycling Tank/Pump Cost, $	$13,534
Total Thickener Facility Estimated Cost, $	$87,041

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	4
Filter Press Cost, $	$26,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$37,200
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

City of Norman & OU Arsenic Study
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Chemical Storage Capital Costs

FeCl3 Storage, gals	101
FeCl3 Storage Cost, $	$402
FeCl3 Metering Pump Cost, $	$10,000
CO2 Storage, tons	1.9
CO2 Storage, Cost	$19,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$35,283
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/F System Equipment Cost Summary

Total Equipment Subtotal	$530,583
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$663,229

Building Facilities

Building, sf	1,178
Building Unit Cost, $/sf	$100
Building Cost, $	$117,800

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$781,029
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$937,235
Unit Treatment Facility Capital Cost, $/gpd	$4.89

Annual O&M Costs

Annual Power Use, kWh/yr	33,143
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$2,320
FeCl3 Use, PPD Based on Average Flow	8
FeCl3 Unit Cost, $/lb	$0.15
FeCl3 Cost, $/yr	$438
CO2 Use, PPD Based on Average Flow	64
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$3,269
Dewatered Residuals Production, CY/yr Based on Average Flow	3.69
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$166
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$9,372
Total Estimated Annual O&M Costs, $/yr	$32,065
Unit Annual O&M Costs, $/1000 gal	$0.92

Capital Cost Summary

Booster Pumping	$46,900
Rapid Mixing	$18,000
Filtration	$306,159
Thickener	$87,041
Dewatering	$37,200
Chemical Feed Systems	$35,283
Building	$117,800
Piping, I&C, Electrical, Yard Piping Allowances	$132,646
Total Facility Cost, $	$781,029
Contingency, 20%	$156,206
Total Estimated C/F Facility Cost	$937,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$2,320
FeCl3 Cost, $/yr	$438
CO2 Cost, $/yr	$3,269
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$9,372
Residuals Disposal Costs, $/yr	$166
Total Estimated Annual O&M Costs, $/yr	$32,065
Unit O&M Costs for C/F, $/1000 gals	$0.92

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$367,787
Treatment Facility Capital Cost	$937,000
Ancillary Facilities Capital Cost	$11,405
Total Capital Cost	$948,405
Total Present Value of Facitlities	$1,316,000

City of Norman & OU Arsenic Study
Coagulation/Filtration
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity, MGD	0.81
Total Production Capacity, MGD	1.00
Average Day Treatment Capacity, MGD	0.41
Total Average Day Production, MGD	0.50

Booster Pumping Capital Costs

Booster Pump, gpm	565
Number of Pumps	3
Pump Capacity per Pump, gpm	283
Pumping Head, ft	35
Pump Driver Size, Hp	3.1
Estimated Pump Cost, $ Each	$9,400
Pumping Facility Installation Cost, %	50
Sump for Pumps	$18,000
CO2 Stripper/Blowers	$35,000
CO2 Stripper Blower HP, Total	10
Total Pumping Faciity Estimated Costs, $	$95,300
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	50,274

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	25
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.50
Rapid Mixer, Hp	0.9
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	2,834

Filtration Faciliites Capital Costs

Number of Pressure Filters	3
Vessel Diameter, ft	11
Cost per Pressure Filter, $	$110,000
Total Vessel Cost including Valves, $	$330,000
Automatic Controller System	$16,500
Air Compressor System Cost, $	$12,000
Backwash Supply Tank, gal	35,637
Backwash Supply Tank Cost, $	$44,547
Backwash Recycle Tank, gal	35,637
Backwash Recycle Tank Cost, $	$44,547
Backwash Supply Pump Cost, $	$5,000
Backwash Recycle Pump Cost, $	$3,000
Subtotal Pressure Filter Costs, $	$455,594
Equipment Installation Cost, %	30
Pressure Filter System Cost, $	$592,272
Filtration Facilities Annual Costs	
Annual Power , KwH	3,276

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	6,155
Thickened Sludge Storage Cost, $	$18,000
Thickened Sludge Pumps, $	$20,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	23,758
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$31,879
Total Recycling Tank/Pump Cost, $	$31,879
Total Thickener Facility Estimated Cost, $	$137,855

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	16
Filter Press Cost, $	$45,000
Sludge Feed Pumps Cost, $	$8,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$63,600
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

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Chemical Storage Capital Costs

FeCl3 Storage, gals	427
FeCl3 Storage Cost, $	$1,707
FeCl3 Metering Pump Cost, $	$12,000
CO2 Storage, tons	8.1
CO2 Storage, Cost	$81,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$113,648
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/F System Equipment Cost Summary

Total Equipment Subtotal	$1,020,675
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$1,275,843

Building Facilities

Building, sf	1,908
Building Unit Cost, $/sf	$100
Building Cost, $	$190,800

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$1,466,643
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$1,759,972
Unit Treatment Facility Capital Cost, $/gpd	$2.16

Annual O&M Costs

Annual Power Use, kWh/yr	63,861
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$4,470
FeCl3 Use, PPD Based on Average Flow	34
FeCl3 Unit Cost, $/lb	$0.15
FeCl3 Cost, $/yr	$1,857
CO2 Use, PPD Based on Average Flow	271
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$13,867
Dewatered Residuals Production, CY/yr Based on Average Flow	15.63
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$703
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$17,600
Total Estimated Annual O&M Costs, $/yr	$54,998
Unit Annual O&M Costs, $/1000 gal	$0.37

Capital Cost Summary

Booster Pumping	$95,300
Rapid Mixing	$18,000
Filtration	$592,272
Thickener	$137,855
Dewatering	$63,600
Chemical Feed Systems	$113,648
Building	$190,800
Piping, I&C, Electrical, Yard Piping Allowances	$255,169
Total Facility Cost, $	$1,466,643
Contingency, 20%	$293,329
Total Estimated C/F Facility Cost	$1,760,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$4,470
FeCl3 Cost, $/yr	$1,857
CO2 Cost, $/yr	$13,867
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$17,600
Residuals Disposal Costs, $/yr	$703
Total Estimated Annual O&M Costs, $/yr	$54,998
Unit O&M Costs for C/F, $/1000 gals	$0.37

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$630,818
Treatment Facility Capital Cost	$1,760,000
Ancillary Facilities Capital Cost	$382,061
Total Capital Cost	$2,142,061
Total Present Value of Facitlities	$2,773,000

City of Norman & OU Arsenic Study
Coagulation/Filtration
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity, MGD	0.19
Total Production Capacity, MGD	0.33
Average Day Treatment Capacity, MGD	0.10
Total Average Day Production, MGD	0.17

Booster Pumping Capital Costs

Booster Pump, gpm	135
Number of Pumps	3
Pump Capacity per Pump, gpm	68
Pumping Head, ft	35
Pump Driver Size, Hp	0.7
Estimated Pump Cost, $ Each	$2,200
Pumping Facility Installation Cost, %	50
Sump for Pumps	$12,000
CO2 Stripper/Blowers	$25,000
CO2 Stripper Blower HP, Total	10
Total Pumping Faciity Estimated Costs, $	$46,900
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	26,927

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	6
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.13
Rapid Mixer, Hp	0.2
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	678

Filtration Faciliites Capital Costs

Number of Pressure Filters	3
Vessel Diameter, ft	6
Cost per Pressure Filter, $	$60,000
Total Vessel Cost including Valves, $	$180,000
Automatic Controller System	$9,000
Air Compressor System Cost, $	$12,000
Backwash Supply Tank, gal	10,603
Backwash Supply Tank Cost, $	$13,254
Backwash Recycle Tank, gal	10,603
Backwash Recycle Tank Cost, $	$13,254
Backwash Supply Pump Cost, $	$5,000
Backwash Recycle Pump Cost, $	$3,000
Subtotal Pressure Filter Costs, $	$235,507
Equipment Installation Cost, %	30
Pressure Filter System Cost, $	$306,159
Filtration Facilities Annual Costs	
Annual Power , KwH	975

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	1,473
Thickened Sludge Storage Cost, $	$4,000
Thickened Sludge Pumps, $	$10,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	7,069
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$13,534
Total Recycling Tank/Pump Cost, $	$13,534
Total Thickener Facility Estimated Cost, $	$87,041

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	4
Filter Press Cost, $	$26,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$37,200
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

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Chemical Storage Capital Costs

FeCl3 Storage, gals	102
FeCl3 Storage Cost, $	$409
FeCl3 Metering Pump Cost, $	$10,000
CO2 Storage, tons	1.9
CO2 Storage, Cost	$19,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$35,290
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/F System Equipment Cost Summary

Total Equipment Subtotal	$530,591
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$663,239

Building Facilities

Building, sf	1,178
Building Unit Cost, $/sf	$100
Building Cost, $	$117,800

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$781,039
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$937,246
Unit Treatment Facility Capital Cost, $/gpd	$4.81

Annual O&M Costs

Annual Power Use, kWh/yr	33,278
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$2,329
FeCl3 Use, PPD Based on Average Flow	8
FeCl3 Unit Cost, $/lb	$0.15
FeCl3 Cost, $/yr	$445
CO2 Use, PPD Based on Average Flow	65
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$3,320
Dewatered Residuals Production, CY/yr Based on Average Flow	3.74
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$168
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$9,372
Total Estimated Annual O&M Costs, $/yr	$32,135
Unit Annual O&M Costs, $/1000 gal	$0.90

Capital Cost Summary

Booster Pumping	$46,900
Rapid Mixing	$18,000
Filtration	$306,159
Thickener	$87,041
Dewatering	$37,200
Chemical Feed Systems	$35,290
Building	$117,800
Piping, I&C, Electrical, Yard Piping Allowances	$132,648
Total Facility Cost, $	$781,039
Contingency, 20%	$156,208
Total Estimated C/F Facility Cost	$937,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$2,329
FeCl3 Cost, $/yr	$445
CO2 Cost, $/yr	$3,320
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$9,372
Residuals Disposal Costs, $/yr	$168
Total Estimated Annual O&M Costs, $/yr	$32,135
Unit O&M Costs for C/F, $/1000 gals	$0.90

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$368,584
Treatment Facility Capital Cost	$937,000
Ancillary Facilities Capital Cost	$285,120
Total Capital Cost	$1,222,120
Total Present Value of Facitlities	$1,591,000

City of Norman & OU Arsenic Study
Coagulation/Filtration
CH2M HILL
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MCL	10

Design Criteria

Design Treatment Capacity. MGD	0.65
Total Production Capacity, MGD	0.99
Average Day Treatment Capacity, MGD	0.32
Total Average Day Production, MGD	0.49

Booster Pumping Capital Costs

Booster Pump, gpm	450
Number of Pumps	3
Pump Capacity per Pump, gpm	225
Pumping Head, ft	35
Pump Driver Size, Hp	2.5
Estimated Pump Cost, $ Each	$7,500
Pumping Facility Installation Cost, %	50
Sump for Pumps	$12,000
CO2 Stripper/Blowers	$25,000
CO2 Stripper Blower HP, Total	10
Total Pumping Faciity Estimated Costs, $	$70,750
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	44,036

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	20
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.43
Rapid Mixer, Hp	0.7
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	2,258

Filtration Facillites Capital Costs

Number of Pressure Filters	3
Vessel Diameter, ft	10
Cost per Pressure Filter, $	$100,000
Total Vessel Cost including Valves, $	$300,000
Automatic Controller System	$15,000
Air Compressor System Cost, $	$12,000
Backwash Supply Tank, gal	29,452
Backwash Supply Tank Cost, $	$36,816
Backwash Recycle Tank, gal	29,452
Backwash Recycle Tank Cost, $	$36,816
Backwash Supply Pump Cost, $	$5,000
Backwash Recycle Pump Cost, $	$3,000
Subtotal Pressure Filter Costs, $	$408,631
Equipment Installation Cost, %	30
Pressure Filter System Cost, $	$531,220
Filtration Facilities Annual Costs	
Annual Power , KwH	2,707

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	4,904
Thickened Sludge Storage Cost, $	$15,000
Thickened Sludge Pumps, $	$20,000
Thickener Installation, %	20
Supernatant Recycling Tank, gal	19,635
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$29,817
Total Recycling Tank/Pump Cost, $	$29,817
Total Thickener Facility Estimated Cost, $	$131,781

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	13
Filter Press Cost, $	$45,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$60,000
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

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Chemical Storage Capital Costs

FeCl3 Storage, gals	340
FeCl3 Storage Cost, $	$1,360
FeCl3 Metering Pump Cost, $	$10,000
CO2 Storage, tons	6.5
CO2 Storage, Cost	$65,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$91,632
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/F System Equipment Cost Summary

Total Equipment Subtotal	$903,383
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$1,129,229

Building Facilities

Building, sf	1,750
Building Unit Cost, $/sf	$100
Building Cost, $	$175,000

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$1,304,229
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$1,565,075
Unit Treatment Facility Capital Cost, $/gpd	$2.41

Annual O&M Costs

Annual Power Use, kWh/yr	55,741
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$3,902
FeCl3 Use, PPD Based on Average Flow	27
FeCl3 Unit Cost, $/lb	$0.15
FeCl3 Cost, $/yr	$1,480
CO2 Use, PPD Based on Average Flow	216
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$11,049
Dewatered Residuals Production, CY/yr Based on Average Flow	12.46
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$561
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$15,651
Total Estimated Annual O&M Costs, $/yr	$49,142
Unit Annual O&M Costs, $/1000 gal	$0.42

Capital Cost Summary

Booster Pumping	$70,750
Rapid Mixing	$18,000
Filtration	$531,220
Thickener	$131,781
Dewatering	$60,000
Chemical Feed Systems	$91,632
Building	$175,000
Piping, I&C, Electrical, Yard Piping Allowances	$225,846
Total Facility Cost, $	$1,304,229
Contingency, 20%	$260,846
Total Estimated C/F Facility Cost	$1,565,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$3,902
FeCl3 Cost, $/yr	$1,480
CO2 Cost, $/yr	$11,049
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$15,651
Residuals Disposal Costs, $/yr	$561
Total Estimated Annual O&M Costs, $/yr	$49,142
Unit O&M Costs for C/F, $/1000 gals	$0.42

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$563,651
Treatment Facility Capital Cost	$1,565,000
Ancillary Facilities Capital Cost	$247,104
Total Capital Cost	$1,812,104
Total Present Value of Facitlities	$2,376,000

City of Norman & OU Arsenic Study
Coagulation/Filtration
CH2M HILL
06/03/2002

MCL	10

Design Criteria

Design Treatment Capacity, MGD	0.23
Total Production Capacity, MGD	0.26
Average Day Treatment Capacity, MGD	0.12
Total Average Day Production, MGD	0.13

Booster Pumping Capital Costs

Booster Pump, gpm	161
Number of Pumps	3
Pump Capacity per Pump, gpm	81
Pumping Head, ft	35
Pump Driver Size, Hp	0.9
Estimated Pump Cost, $ Each	$2,700
Pumping Facility Installation Cost, %	50
Sump for Pumps	$12,000
CO2 Stripper/Blowers	$25,000
CO2 Stripper Blower HP, Total	10
Total Pumping Faciity Estimated Costs, $	$49,150
Booster Pumping Annual Costs	
Annual Power Use, kWh/yr	28,321

Rapid Mixing

Number of Rapid Mix Units	1
Rapid Mix Vessel, cf	7
Impellor Speed, rpm	125
Impellor Diameter, ft.	1.17
Rapid Mixer, Hp	0.2
Rapid Mixer Cost, $	$15,000
Rapid Mixer Installation Cost, %	20
Total Rapid Mixer Facilities Cost, $	$18,000
Rapid Mixer Annual Costs	
Annual Power Use, kWh/yr	807

Filtration Faciliites Capital Costs

Number of Pressure Filters	3
Vessel Diameter, ft	6
Cost per Pressure Filter, $	$60,000
Total Vessel Cost including Valves, $	$180,000
Automatic Controller System	$9,000
Air Compressor System Cost, $	$12,000
Backwash Supply Tank, gal	10,603
Backwash Supply Tank Cost, $	$13,254
Backwash Recycle Tank, gal	10,603
Backwash Recycle Tank Cost, $	$13,254
Backwash Supply Pump Cost, $	$5,000
Backwash Recycle Pump Cost, $	$3,000
Subtotal Pressure Filter Costs, $	$235,507
Equipment Installation Cost, %	30
Pressure Filter System Cost, $	$306,159
Filtration Facilities Annual Costs	
Annual Power , KwH	975

Thickener Facilities Capital Costs

Number of Thickener Units	1
Thickener Cost, Each, $	$45,000
Thickened Sludge Storage, gal	1,753
Thickened Sludge Storage Cost, $	$5,000
Thickened Sludge Pumps, $	$10,000
Thickener Installation, %	20
Supematant Recycling Tank, gal	7,069
Number of Recycling Tanks & Pumps	1
Recycling Tank/Pump Cost, $	$13,534
Total Recycling Tank/Pump Cost, $	$13,534
Total Thickener Facility Estimated Cost, $	$88,241

Dewatering Facilities Capital Costs

Filter Press Days per Cycle	7
Filter Press, cf	5
Filter Press Cost, $	$26,000
Sludge Feed Pumps Cost, $	$5,000
Filter Press Installation, %	20
Total Filter Press Estimated Costs, $	$37,200
Dewatering Facilities Capital Costs	
Filter Feed Pump Power Use, kWh/yr	84

City of Norman & OU Arsenic Study
Coagulation/Filtration
CH2M HILL
06/03/2002

Chemical Storage Capital Costs

FeCl3 Storage, gals	122
FeCl3 Storage Cost, $	$486
FeCl3 Metering Pump Cost, $	$10,000
CO2 Storage, tons	2.3
CO2 Storage, Cost	$23,000
Chemical Feed Facility Installation Cost, %	20
Total Chemical Feed Facility Estimated Costs	$40,183
Chemical Storage Annual Costs	
Total Estimated Feed Pump Power Use, kWh/yr	1,588

Total C/F System Equipment Cost Summary

Total Equipment Subtotal	$538,934
Interior Piping Allowance,%	5
I&C Allowance, %	5
Electrical Allowance, %	5
Yard Piping Allowance,%	10
Total Process Estimated Cost,$	$673,667

Building Facilities

Building, sf	1,178
Building Unit Cost, $/sf	$100
Building Cost, $	$117,800

Total Estimated Capital Costs

Subtotal Estimatd Facility Cost, $	$791,467
Contingency, %	20
Total Arsenic Removal Facility Cost, $	$949,761
Unit Treatment Facility Capital Cost, $/gpd	$4.10

Annual O&M Costs

Annual Power Use, kWh/yr	34,953
Power Cost, $/kWh	0.07
Annual Power Cost, $/yr	$2,447
FeCl3 Use, PPD Based on Average Flow	10
FeCl3 Unit Cost, $/lb	$0.15
FeCl3 Cost, $/yr	$529
CO2 Use, PPD Based on Average Flow	77
CO2 Unit Cost, $/lb	$0.14
CO2 Cost, $/yr	$3,950
Dewatered Residuals Production, CY/yr Based on Average Flow	4.45
Residuals Disposal Costs, $/cy	$45
Residuals Disposal Costs, $/yr	$200
Labor, Operations, FTE	0.4
Unit Labor Cost, Operations, $/yr	$30,000
Labor, Management, FTE	0.1
Labor, Management, FTE	$45,000
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, % of Capital Costs	1
Equipment Maintenance Costs, $/yr	$9,498
Total Estimated Annual O&M Costs, $/yr	$33,123
Unit Annual O&M Costs, $/1000 gal	$0.78

Capital Cost Summary

Booster Pumping	$49,150
Rapid Mixing	$18,000
Filtration	$306,159
Thickener	$88,241
Dewatering	$37,200
Chemical Feed Systems	$40,183
Building	$117,800
Piping, I&C, Electrical, Yard Piping Allowances	$134,733
Total Facility Cost, $	$791,467
Contingency, 20%	$158,293
Total Estimated C/F Facility Cost	$950,000

Summary of Annual O&M Costs

Annual Power Cost, $/yr	$2,447
FeCl3 Cost, $/yr	$529
CO2 Cost, $/yr	$3,950
Total Estimated Labor Costs, $/yr	$16,500
Equipment Maintenance Costs, $/yr	$9,498
Residuals Disposal Costs, $/yr	$200
Total Estimated Annual O&M Costs, $/yr	$33,123
Unit O&M Costs for C/F, $/1000 gals	$0.78

Present Worth Analysis

Net Interest Rate	6.0%
Period, Years	20
Present Worth of Annual O&M Costs	$379,923
Treatment Facility Capital Cost	$950,000
Ancillary Facilities Capital Cost	$11,405
Total Capital Cost	$961,405
Total Present Value of Facitlities	$1,341,000

Appendix G

City of Norman and OU Arsenic Study
Nanofiltration Facilty Cost

Design Criteria	MCL 10 ug/L
Design Flow, MGD	0.33
Average Day Flow, MGD	0.17

Capital Cost Summary

Facility Cost, $	$1,643,679
Facility Unit Cost, $/gpd	$4.97
Ancillary Facilities, $	$209,088
Total Facility Cost, $	$1,852,767
Total Unit Cost, $/gpd	$5.60

O&M Cost Summary

Annual O&M Costs, $/yr	$591,734
Unit O&M Cost for Treated, $/1,000	$9.80
Present Worth, 6%, 20 yrs	$8,639,911

City of Norman and OU Arsenic Study
Nanofiltration Facilty Cost

Design Criteria	MCL 10 ug/L
Design Flow, MGD	1.11
Average Day Flow, MGD	0.56

Capital Cost Summary

Facility Cost, $	$3,409,390
Facility Unit Cost, $/gpd	$3.07
Ancillary Facilities, $	$343,411
Total Facility Cost, $	$3,752,801
Total Unit Cost, $/gpd	$3.38

O&M Cost Summary

Annual O&M Costs, $/yr	$654,694
Unit O&M Cost for Treated, $/1,000	$3.23
Present Worth, 6%, 20 yrs	$11,262,091

City of Norman and OU Arsenic Study
Nanofiltration Facilty Cost

Design Criteria	MCL 10 ug/L
Design Flow, MGD	2.08
Average Day Flow, MGD	1.69

Capital Cost Summary

Facility Cost, $	$4,983,000
Facility Unit Cost, $/gpd	$2.39
Ancillary Facilities, $	$850,925
Total Facility Cost, $	$5,833,925
Total Unit Cost, $/gpd	$2.80

O&M Cost Summary

Annual O&M Costs, $/yr	$837,512
Unit O&M Cost for Treated, $/1,000	$1.36
Present Worth, 6%, 20 yrs	$15,440,128

City of Norman and OU Arsenic Study
Nanofiltration Facilty Cost

Design Criteria	MCL 10 ug/L
Design Flow, MGD	0.19
Average Day Flow, MGD	0.10

Capital Cost Summary

Facility Cost, $	$1,183,726
Facility Unit Cost, $/gpd	$6.17
Ancillary Facilities, $	$11,405
Total Facility Cost, $	$1,195,131
Total Unit Cost, $/gpd	$6.23

O&M Cost Summary

Annual O&M Costs, $/yr	$580,512
Unit O&M Cost for Treated, $/1,000	$16.59
Present Worth, 6%, 20 yrs	$7,853,559

City of Norman and OU Arsenic Study
Nanofiltration Facilty Cost

Design Criteria	MCL 10 ug/L
Design Flow, MGD	0.81
Average Day Flow, MGD	0.41

Capital Cost Summary

Facility Cost, $	$2,826,995
Facility Unit Cost, $/gpd	$3.48
Ancillary Facilities, $	$382,061
Total Facility Cost, $	$3,209,056
Total Unit Cost, $/gpd	$3.94

O&M Cost Summary

Annual O&M Costs, $/yr	$630,731
Unit O&M Cost for Treated, $/1,000	$4.25
Present Worth, 6%, 20 yrs	$10,443,493

City of Norman and OU Arsenic Study
Nanofiltration Facilty Cost

Design Criteria	MCL 10 ug/L
Design Flow, MGD	0.36
Average Day Flow, MGD	0.10

Capital Cost Summary

Facility Cost, $	$1,729,932
Facility Unit Cost, $/gpd	$4.81
Ancillary Facilities, $	$285,120
Total Facility Cost, $	$2,015,052
Total Unit Cost, $/gpd	$5.60

O&M Cost Summary

Annual O&M Costs, $/yr	$580,752
Unit O&M Cost for Treated, $/1,000	$16.34
Present Worth, 6%, 20 yrs	$8,676,230

City of Norman and OU Arsenic Study
Nanofiltration Facilty Cost

Design Criteria	MCL 10 ug/L
Design Flow, MGD	0.65
Average Day Flow, MGD	0.32

Capital Cost Summary

Facility Cost, $	$2,465,369
Facility Unit Cost, $/gpd	$3.80
Ancillary Facilities, $	$247,104
Total Facility Cost, $	$2,712,473
Total Unit Cost, $/gpd	$4.19

O&M Cost Summary

Annual O&M Costs, $/yr	$617,377
Unit O&M Cost for Treated, $/1,000	$5.22
Present Worth, 6%, 20 yrs	$9,793,739

City of Norman and OU Arsenic Study
Nanofiltration Facilty Cost

Design Criteria	MCL 10 ug/L
Design Flow, MGD	0.23
Average Day Flow, MGD	0.12

Capital Cost Summary

Facility Cost, $	$1,326,551
Facility Unit Cost, $/gpd	$5.73
Ancillary Facilities, $	$11,405
Total Facility Cost, $	$1,337,956
Total Unit Cost, $/gpd	$5.77

O&M Cost Summary

Annual O&M Costs, $/yr	$583,737
Unit O&M Cost for Treated, $/1,000	$13.80
Present Worth, 6%, 20 yrs	$8,033,368

Appendix H

Goal: Effectiveness

Criterion/Subcriterion	Treated Water Quality: Meet MCL							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average							
2	About average		x	x	x		GFH CMF CF	All can meet MCL
3	More favorable than average	x				x	IX NF	

Criterion/Subcriterion:	Treated Water Quality: Deterioration							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average	x					IX	Many chemical added for pre- and post-treatment
2	About average		x	x	x		GFH CMF CF	Adds chloride
3	More favorable than average					x	NF	Water quality improved

Criterion/Subcriterion:	Residuals: Liquid							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average	x				x	IX NF	Waste brine or waste concentrate
2	About average							
3	More favorable than average		x	x	x		GFH CMF CF	Very little liquid residuals

Criterion/Subcriterion:	Residuals: Solid							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average							Nearly 4,000 tons of residual salt annually
2	About average							From about 60,000 to 250,000 pounds of solids annually
3	More favorable than average							No solids residuals

Criterion/Subcriterion:	Water Recovery							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average							Wastes 15%
2	About average							Wastes betweem 0.15% and 1.4%
3	More favorable than average							Wastes < 0.1%

Criterion/Subcriterion:	Reliability: Scale-up/Upgradability							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average	x					IX	Requires large area
2	About average				x		CF	
3	More favorable than average		x	x		x	GFH CMF NF	Significant technolgy improvements more likely

Goal: *Effectiveness*

Criterion/Subcriterion:	Reliability: Chemicals handling							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average	x				x	IX NF	Sulfuric plus tons of salt for IX, extensive chemical use for NF
2	About average			x	x		CMF CF	Few chemicals to handle.
3	More favorable than average		x				GFH	Little chemical handling

Criterion/Subcriterion:	Reliability: Simplicity/ease of operation							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average	x				x	IX NF	Multi-process system; dynamic conditions
2	About average			x	x		CMF CF	
3	More favorable than average		x				GFH	Long run times

Criterion/Subcriterion:	Reliability: Process controls							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average	x				x	IX NF	High monitoring frequency
2	About average							pH important, mechanical rapid mixing
3	More favorable than average		x	x	x		GFH CMF CF	pH important

Criterion/Subcriterion:	Reliability: Maintenance Needs							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average	x				x	IX NF	More valves, pumps, tank cleaning, chemical feed, waste ...
2	About average			x	x		CMF CF	Maintenace for mechanical mixing, periodic backwashes, filters can clog, occasional media replacment
3	More favorable than average		x				GFH	Media replaced every 9 months on average

Criterion/Subcriterion:	Safety: Onsite							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average	x				x	IX NF	Chemical handling concerns greatest
2	About average			x	x		CMF CF	Some chemical handling and mechanical mixing process
3	More favorable than average		x				GFH	Only CO_2

Criterion/Subcriterion:	Safety: Offsite							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average	x				x	IX NF	Truck traffic and disposal issues
2	About average		x	x	x		GFH CMF CF	
3	More favorable than average							

Goal: *Systemwide Applicability*

Criterion: Subcriterion **Environmental impacts**

Level	Description	IX	GFH	CMF	CF	NF	Alternative	Comments
1	Less favorable than average	x					IX	Brine and disposal issues magnified
2	About average		x			x	GFH NF	TDS inceases, solids residuals, onsite chemicals
3	More favorable than average			x	x		CMF CF	Only wasted media or wasted concentrate

Criterion/Subcriterion: **Ease of automation**

Level	Description	IX	GFH	CMF	CF	NF	Alternative	Comments
1	Less favorable than average	x				x	IX NF	High monitoring frequency
2	About average			x	x		CMF CF	Moderate monitoring
3	More favorable than average		x				GFH	Little monitoring

Criterion/Subcriterion: **Space requirements**

Level	Description	IX	GFH	CMF	CF	NF	Alternative	Comments
1	Less favorable than average							More space required for multi process, or bulky filters
2	About average							Avg. space requirements
3	More favorable than average							Less space required.

Criterion/Subcriterion: **Sensitivity to raw water quality**

Level	Description	IX	GFH	CMF	CF	NF	Alternative	Comments
1	Less favorable than average	x					IX	Large run variation due to sulfate (5x)
2	About average		x			x	GFH NF	Silica impacts, but proper pH solves
3	More favorable than average			x	x		CMF CF	Appears to be insensitive to local range of water quality

Criterion/Subcriterion: **Mixing of treated/non-treated**

Level	Description	IX	GFH	CMF	CF	NF	Alternative	Comments
1	Less favorable than average							
2	About average	x		x	x	x	IX CMF CF NF	Requires mixing
3	More favorable than average		x				GFH	All water is treated

Criterion/Subcriterion: **Impacts on well operation**

Level	Description	IX	GFH	CMF	CF	NF	Alternative	Comments
1	Less favorable than average							
2	About average	x		x	x	x	IX CMF CF NF	
3	More favorable than average		x				GFH	

Goal: *Cost*

Criterion: Subcriterion	Facilities Capital and O&M							
Level		**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average							About $104 Million
2	About average							About $30 Million, driven by media cost
3	More favorable than average							About $20 Million

Criterion/Subcriterion:	Process Optimization (over-design risk)							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average		x				GFH	
2	About average				x	x	CF NF	
3	More favorable than average	x		x			IX CMF	

Criterion/Subcriterion:	Fluoride addition							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average							
2	About average							
3	More favorable than average							

Criterion/Subcriterion:	Sole Source requirements							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average		x				GFH	
2	About average	x		x	x	x	IX CMF CF NF	
3	More favorable than average							

Goal: *Implementability*

Criterion: Subcriterion	Public Acceptance							
Level		**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average	x					IX	
2	About average		x	x	x	x	GFH CMF CF NF	
3	More favorable than average							

Criterion/Subcriterion:	Public Education							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average	x					IX	
2	About average		x	x	x	x	GFH CMF CF NF	
3	More favorable than average							

Criterion/Subcriterion:	Permits							
Level	**Description**	**IX**	**GFH**	**CMF**	**CF**	**NF**	**Alternative**	**Comments**
1	Less favorable than average	x				x	IX NF	Multi-jurisdictional controversy
2	About average			x	x		CMF CF	Onsite Residuals Production, chemicals
3	More favorable than average		x				GFH	No onsite solids facilities, less chemicals

Appendix I

Figure I-1
City of Norman and OU Arsenic Study
Plan A - Well Closure

Capital

Item	Description	Cost	Total
Well Closure	29 Wells	$650,000	
			$650,000

Annual O&M

Item	Description	Average Annual	Total
Wellfield Pumping	2.5 MGD	$390,000	
OKC Water Purchase	3.9 MGD	$3,670,000	
Annual O&M Summary		Average Annual Total	$4,100,000

20-Year Present Worth Summary [1,2]

Item	Cost		Total
Capital			
Well Closure	$650,000		
		Subtotal	$650,000
O&M			
Wellfield Pumping	$4,500,000		
OKC Water Purchase[1]	$42,200,000		
		Total	$47,000,000

Notes:

1. Where OKC raw or treated water costs are used, the rate of inflation is assumed at 4%.
2. Present Worth assumes a duration of 20 years, annual inflation rate of 3%, and an annual interest rate of 6%.

Figure I-2
City of Norman and OU Arsenic Study
Plan B - Non-Treatment

Capital

Item	Description	Cost	Total
Well Closure	15 Wells	$340,000	
Zonal Isolation	7 Wells	$466,000	
Distribution Blending Conveyance[3]	2.6 Miles	$850,000	
Conveyance for WTP Blending[3]	7 Miles	$2,100,000	
GW Storage and HSPS[4]	2.3 MGD Capacity	$190,000	
			$3,900,000

Item	Description	Annual Average	Total
Wellfield Pumping	4.2 MGD	$640,000	
High Service Pumping	1 MGD	$60,000	
OKC Water Purchase	2.3 MGD	$2,100,000	
Annual O&M Summary		Annual Average Total	$2,800,000

20-Year Present Worth Summary[1,2]

Item	Cost		Total
Capital			
Closure, Zonal Isolation, and Conveyance	$3,800,000		
GW Storage and HSPS	$190,000		
		Subtotal	$3,900,000
O&M			
Wellfield Pumping and High Service Pumping	$8,200,000		
OKC Water Purchase	$24,500,000		
		Total	$37,000,000

Notes:

1. Where OKC raw or treated water costs are used, the rate of inflation is assumed at 4%.
2. Present Worth assumes a duration of 20 years, annual inflation rate of 3%, and an annual interest rate of 6%.
3. Conveyance pipe costs are based on $6.50 per inch diameter per linear foot; right-of-way/easement costs are not included.
4. Assumed to be an additional cost incurred over and above the costs of GW Disinfection Facilities of SWSP.

Figure I-3
City of Norman and OU Arsenic Study
Plan C - Non-Treatment

Capital

Item	Description	Cost	Total
Well Closure	15 Wells	$340,000	
Zonal Isolation	7 Wells	$466,000	
Distribution Blending Conveyance[3]	2.6 Miles	$850,000	
Conveyance for WTP Blending	7 Miles	$2,100,000	
GW Storage and HSPS[4]	7.4 MGD Capacity	$630,000	
New Groundwater Wells[5]	11 Wells	$2,200,000	
Conveyance for New Wells[5]	6 Miles	$2,700,000	
			$9,300,000

Annual O&M

Item	Description	Annual Average	Total
Wellfield Pumping	6.4 MGD	$990,000	
High Service Pumping	3.1 MGD	$180,000	
GW Rights Long-Term Lease	11 Wells	$120,000	
Annual O&M Summary			
		Annual Average Total	$1,300,000

20-Year Present Worth Summary[1,2]

Item	Cost	Item	Total
Capital			
Closure, Zonal Isolation, and WTP Conveyance	$3,800,000		
New Wells, Storage, & Conveyance	$5,530,000		
		Subtotal	$9,300,000
O&M			
Wellfield Pumping and High Service Pumping	$13,600,000		
GW Rights Long-Term Lease	$1,500,000		
		Total	$24,000,000

Notes:

1. Where OKC raw or treated water costs are used, the rate of inflation is assumed at 4%.
2. Present Worth assumes a duration of 20 years, annual inflation rate of 3%, and an annual interest rate of 6%.
3. Conveyance pipe costs are based on $6.50 per inch diameter per linear foot; right-of-way/easement costs are not included.
4. Assumed to be a portion of plus an additional cost over and above the costs of GW Disinfection Facilities of SWSP.
5. Assumed to be a portion of the costs of SWSP well development and associated conveyance.

Figure I-4
City of Norman and OU Arsenic Study
Plan D - Treatment

Capital

Item	Description	Cost	Total
Well Closure	1 Wells	$22,000	
Distribution Blending Conveyance[3]	1.3 Miles	$440,000	
Treatment Facilities	8 MGD Capacity	$14,500,000	
Treatment Group Conveyance	8.7 Miles	$1,800,000	
Treatment Group Sewer Collection	4 Miles	$470,000	
			$17,000,000

Item	Description	Average Annual	Total
Wellfield Pumping	6.4 MGD	$990,000	
Treatment O&M	5 MGD	$1,200,000	
Annual O&M Summary			$2,200,000

Well Closure

20-Year Present Worth Summary [1,2]

Item	Cost		Total
Capital			
Treatment Facilities	$16,770,000		
Well Closure and Distibution Blending	$460,000		
		Subtotal	$17,000,000
O&M			
Wellfield Pumping	$11,600,000		
Treatment O&M	$13,600,000		
		Total	$42,000,000

Notes:

1. Where OKC raw or treated water costs are used, the rate of inflation is assumed at 4%.
2. Present Worth assumes a duration of 20 years, annual inflation rate of 3%, and an annual interest rate of 6%.
3. Conveyance pipe costs are based on $6.50 per inch diameter per linear foot; right-of-way/easement costs are not included.

Figure I-5
City of Norman and OU Arsenic Study
Plan E - Combination

Capital

Item	Description	Cost	Total
Well Closure	4 Wells	$90,000	
Zonal Isolation	2 Wells	$133,000	
Distribution Blending Conveyance[3]	2.6 Miles	$850,000	
Treatment Facilities	4.2 MGD Capacity	$7,200,000	
Treatment Group Conveyance	5 Miles	$1,120,000	
Treatment Group Sewer Collection	0.2 Miles	$34,000	
Conveyance for WTP Blending[3]	7 Miles	$2,100,000	
New Groundwater Wells[5]	3 Wells	$590,000	
Conveyance for New Wells[5]	1.6 Miles	$735,000	
GW Storage and HSPS[4]	3.7 MGD Capacity	$310,000	
			$13,000,000

Item	Description	Average Annual	Total
Wellfield Pumping	6.4 MGD	$990,000	
Treatment O&M	2.7 MGD	$550,000	
High Service Pumping	1.6 MGD	$90,000	
GW Rights Long-Term Lease	3 Wells	$30,000	
		Annual O&M Summary	$1,700,000

20-Year Present Worth Summary [1,2]

Item	Cost		Total
Capital			
Closure, Zonal Isolation, & Blending Conveyance	$3,200,000		
Treatment Facilities and Associated Piping	$8,400,000		
New GW Wells, Storage, and HSPS	$1,600,000		
		Subtotal	$13,000,000
O&M			
Wellfield Pumping and High Service Pumping	$12,600,000		
Treatment O&M	$6,300,000		
GW Rights Long-Term Lease	$400,000		
		Total	$32,000,000

Notes:

1. Where OKC raw or treated water costs are used, the rate of inflation is assumed at 4%.
2. Present Worth assumes a duration of 20 years, annual inflation rate of 3%, and an annual interest rate of 6%.
3. Conveyance pipe costs are based on $6.50 per inch diameter per linear foot; right-of-way/easement costs are not included.
4. Assumed to be a portion of plus an additional cost over and above the costs of GW Disinfection Facilities of SWSP.
5. Assumed to be a portion of the costs of SWSP well development and associated conveyance.