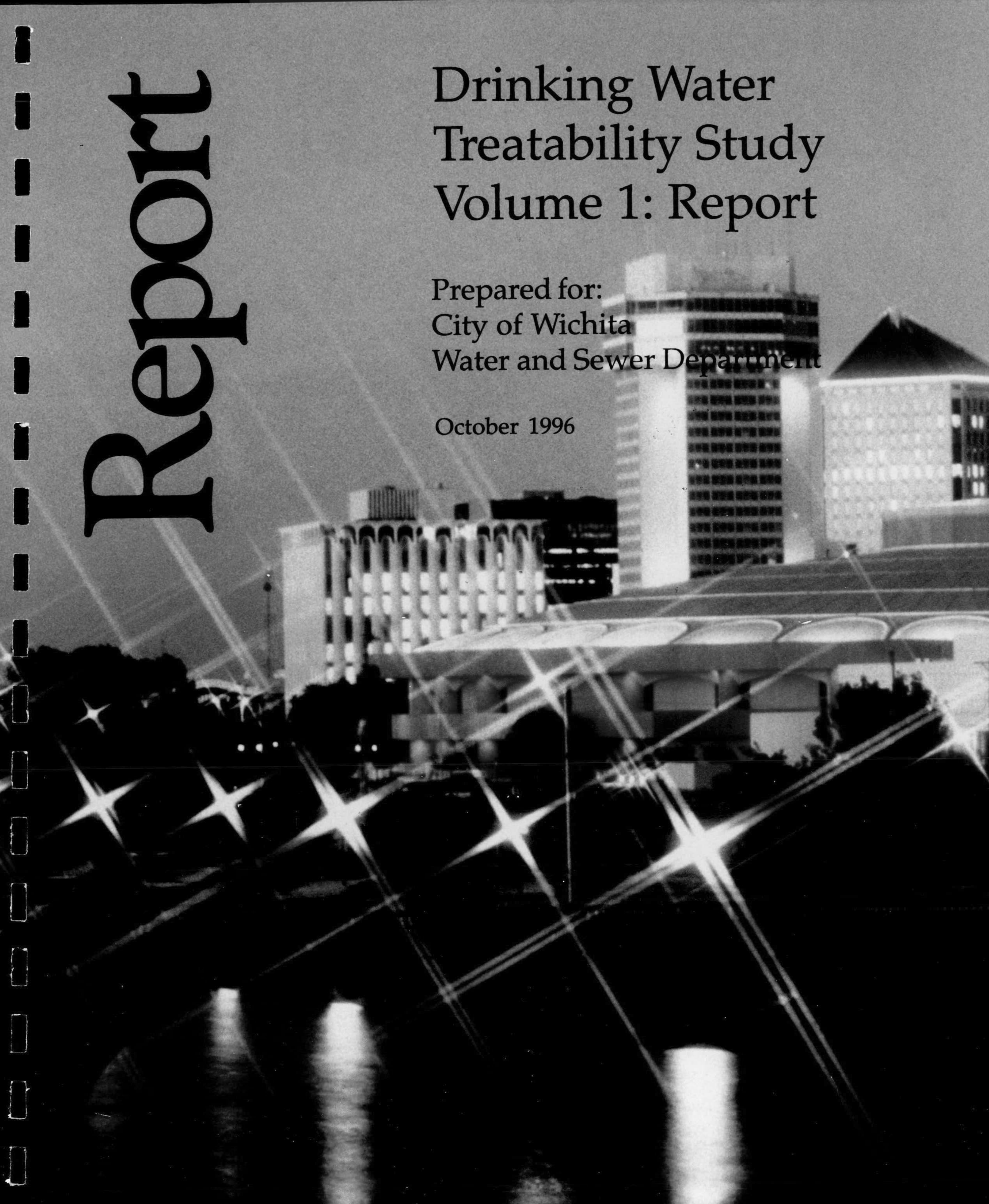
CDM Camp Dresser & McKee

Report

Drinking Water Treatability Study
Volume 1: Report



Prepared for:
City of Wichita
Water and Sewer Department

October 1996

CDM Camp Dresser & McKee Inc.

environmental services

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October 14, 1996

Mr. Gerald Blain, P.E.
Superintendents of
Treatment and Pumping
City Hall, 8th Floor
Wichita, Kansas 67202

Subject: Final Report - Wichita Treatability Study

Dear Mr. Blain:

Camp Dresser & McKee Inc. (CDM) is pleased to submit herewith 15 copies of the final report for the Drinking Water Treatability Study.

We would like to take this opportunity to thank the staff of City of Wichita, particularly those individuals at the water treatment plant and Cheney Reservoir, for the support and assistance provided to CDM throughout the course of the project. The teamwork demonstrated by these individuals was a genuine benefit is fostering the successful completion of this study. We would also like to thank the management staff at the City of Wichita for the confidence and trust placed in CDM by virtue of your selection of CDM to complete this important study.

It is our opinion that an extraordinary amount of valuable information regarding enhancements to your current mode of operation as well as future treatment options is presented in this report. If you have any further questions about the study or report recommendations, please do not hesitate to give us call.

Once again, we thank you for the opportunity to complete this study and hope that as your water supply and treatment needs at the City continue to develop over the coming years, you will continue to keep CDM in mind to assist you addressing these needs.

Very truly yours,

CAMP DRESSER & McKEE INC.

Larry E. Elliott

Larry E. Elliott, P.E.
Associate

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Executive Summary

Introduction

The Wichita Water Treatment Plant (WTP) is the sole source of treated drinking water for the City of Wichita. The WTP is a conventional lime-softening plant with aeration, rapid mixing, flocculation, sedimentation, filtration, and disinfection using a combination of chlorine and chloramines. Both ferric sulfate and cationic polymer are used as coagulants. At present, there are two water sources which supply the WTP:

- Cheney Reservoir — located approximately 25 miles west of Wichita, and
- Groundwater — from the Equus Bed Aquifer northwest of Wichita and from local wells near the plant.

Cheney Reservoir typically supplies from 40 to 60 percent of the plant's water with the remainder coming from the groundwater supplies.

Faced with the concern of a diminishing yield from the groundwater supply, in 1993 the City of Wichita approved an Integrated Local Water Supply Plan. The purpose of this plan was two-fold:

- ensure that Wichita has an adequate supply of water through 2050, and
- maximize the City's surface water sources, thereby minimizing over-pumping of groundwater.

To supplement the existing Cheney Reservoir supply, the Little Arkansas River was identified as a potential second surface water source. To better evaluate long-range treatment requirements for both Cheney Reservoir and the Little Arkansas River, in August 1994, the City retained Camp Dresser & McKee (CDM) to conduct a treatability study on each of these two surface water supplies. Tests evaluating blends of surface water and groundwater were also conducted to determine what blend of surface water/groundwater may be required to meet certain water quality goals.

Raw Water Quality

Raw water quality for both Cheney and the Little Ark was measured for the duration of the treatability study (November 1994 to December 1995). Turbidities for both Cheney and the Little Ark jumped significantly in the spring of 1995. This was mostly due to the large amount of rainfall received in the state. The turbidities seen at Cheney during the treatability study were abnormally high (average = 42 ntu) and this was some of the most turbid water Cheney has experienced in over 10 years. Turbidities for the Little Ark were significantly more variable than Cheney and averaged around 189 ntu. Total organic carbon (TOC) for the Cheney Reservoir was rather stable over the duration of the study, with an average of 4.7 mg/L, and did not vary as did turbidity. TOC for the Little Ark varied considerably more than Cheney, with a few samples exceeding 17 mg/L. The average TOC for the Little Ark was 7.3 mg/L. The hardness and alkalinity for Cheney remained fairly stable, however, both hardness and alkalinity dropped by about 40 mg/L (as $CaCO_3$) with the increased flows to the reservoir in the spring of 1995. Hardness and alkalinity for the Little Ark was erratic and generally inversely proportional to turbidity.

TOC Reduction

TOC is one of the surrogates commonly used to predict disinfection by-product (DBP) concentrations. The proposed Disinfectant/Disinfection By-Product Rule (D/DBPR) has established a required percent reduction of TOC based on the WTP's source water alkalinity and TOC. TOC removal is generally more difficult for high alkalinity, low TOC waters such as Wichita's. Because of the TOC reduction requirements of the proposed D/DBPR, evaluations of various coagulants and alternative TOC reduction methods were required to determine what, if any, process alternatives would have to made to the Wichita WTP in order to treat the Cheney Reservoir and Little Arkansas River. For the average raw water TOC and alkalinity for each of the surface waters, a minimum 25% TOC reduction goal was established for the treatability study to comply with the proposed D/DBPR. Jar and pilot tests evaluated the following process alternatives:

- Coagulants/Enhanced Coagulation
- Softening/Enhanced Softening
- Adsorption
- Oxidation
- Source Water Control

Of the various TOC reduction alternatives evaluated, adsorption with PAC proved to be the most effective and cost efficient. Conventional softening and ferric sulfate coagulation, the process currently practiced at the Wichita WTP, did not meet the 25% TOC reduction goal for either the Cheney or Little Ark waters. Ironically, if the raw water TOC for these surface waters were higher, the TOC reduction goal would likely have been easier to meet since higher TOC reduction is generally achieved with waters that have a higher TOC content.

Disinfection By-Product Control

Because of the Stage 1 and Stage 2 MCLs for both THMs and HAA5 proposed in the D/DBPR, alternative disinfection schemes were evaluated for both the Cheney Reservoir and Little Ark River to determine each disinfection scheme's effectiveness for complying with Stage 1 and Stage 2 of the D/DBPR. The three disinfection schemes evaluated were:

- Chlorine/Chloramines
- Ozone/Chloramines
- Chlorine Dioxide/Chloramines

In addition to oxidation, adsorption with GAC was also assessed.

Of the various DBP control alternatives evaluated, the chlorine/chloramine disinfection scheme proved the most effective and economical for satisfying the D/DBPR Stage 1 requirements of 80 μg/l for TTHMs and 60 μg/L for HAA5. Chlorine/chloramines can also be used to satisfy the Stage 2 MCLs of 40 μg/L and 30 μg/L for TTHMs and HAA5, respectively; however, carbon adsorption with PAC or blending with at least 50% groundwater will be required to meet the Stage 2 MCLs. One important note is if the City can produce average TTHM and HAA5 concentrations of 40 μg/L and 30 μg/L, respectively, the TOC reduction requirements do not have to be met for either Stage 1 or 2 of the D/DBPR.

Taste and Odor Control

The City of Wichita currently experiences intermittent taste and odor (T&O) episodes from the Cheney Reservoir supply — primarily in late spring, summer, and/or early fall. No historical data is available on the actual T&O causing compounds present in the Cheney supply; however, the City has relayed that when the T&O events occur, an "earthy/musty" odor in the water is detectable. A policy standard of "no objectionable tastes and odors" has been established by the City.

Jar and pilot tests were conducted on both the Cheney and Little Ark supplies and synthetic samples of geosmin and MIB were spiked into the raw water. The various treatment alternatives evaluated for taste and odor control included adsorption with PAC and/or GAC and oxidation with ozone. Of the processes examined, adsorption with PAC was found to be the most economical and effective for reducing tastes and odors. An additional benefit of PAC is that it also proved to be effective for TOC reduction.

Recommendation

To comply with the requirements of the proposed D/DBPR and to control tastes and odors at the Wichita WTP, CDM recommends the City incorporate the following process modifications.

- At the Cheney Pump Station, add piping, valves, and appurtenances to the second PAC feed pump. There are a total of two 550 gph PAC feed pumps (only one pump currently has piping). It is our understanding the PAC system is in satisfactory condition and will not require further improvements.

- Expand the capacity of the existing ferric sulfate feed system so that the system can treat 100% surface water, if necessary.

- Feed chlorine at the Cheney Pump Station and wellfields only as necessary to keep these lines clean. No disinfection credit (CT) with chlorine will be allowed until after the TOC reduction requirements have been met.

- Begin obtaining disinfection (CT) credit with free chlorine through the modified chlorine contact basin and ammonia addition at the basin outlet to tie up the remaining free chlorine and form chloramines. If the running average for TTHMs and HAA5 can be kept below 40 μg/L and 30 μg/L, respectively, the City will not be required to meet the TOC reduction requirements of the D/DBPR.

- Process modifications to accommodate treatment of the Little Ark are dependent not only on the amount of Little Ark the City wishes to treat, but also whether the Little Ark water is obtained directly from the river or from recharge injection wells. The treatability study evaluated taking Little Ark water directly from the river. One of the conclusions from this study was treatment of the Little Ark directly from the river would be very difficult due to the wide and rapid variability in raw water quality (e.g., turbidity, hardness, alkalinity, TOC). As a minimum, treatment of Little Ark water directly from the river would require pretreatment facilities to better even out the incoming water quality. A new soda ash system may be required to treat the non-carbonate hardness in the Little Ark raw water. However, the need for this system is dependent on the amount and quality of the Little Ark water to be treated.

The PAC improvements at the Cheney Pump Station and the ferric sulfate system improvements at the water treatment plant should be implemented as soon as possible to provide additional treatment capabilities. Chlorine disinfection in the new chlorine contact basin must be in operation before promulgation of Stage 1 of the D/DBPR in November 1998. Any process modifications for treatment of Little Ark water should be added, as necessary, at the same time as the Little Ark raw water supply system.

Section 1
Introduction

1.0 General

The Wichita Water Treatment Plant (WTP) is the sole source of treated drinking water for the City of Wichita. The WTP is a conventional lime-softening plant with aeration, rapid mixing, flocculation, sedimentation, filtration, and disinfection using a combination of chlorine and chloramines. Both ferric sulfate and cationic polymer are used as coagulants. At present, there are two water sources which supply the WTP:

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Cheney Reservoir typically supplies from 40 to 60 percent of the plant's water with the remainder coming from the groundwater supplies.

Faced with the concern of a diminishing yield from the groundwater supply, in 1993 the City of Wichita approved an Integrated Local Water Supply Plan. The purpose of this plan is two-fold:

- ensure that Wichita has an adequate supply of water through 2050, and
- maximize the City's surface water sources, thereby minimizing over-pumping of groundwater.

To supplement the existing Cheney Reservoir supply, the Little Arkansas River was identified as a potential second surface water source. To better evaluate long-range treatment requirements for both Cheney Reservoir and the Little Arkansas River, in August 1994, the City retained Camp Dresser & McKee (CDM) to conduct a treatability study on each of these two surface water supplies.

1.2 Study Objectives

To better evaluate both the Cheney Reservoir (Cheney) and Little Arkansas River (Little Ark), jar and pilot tests were conducted on each of these waters. The primary objectives of these tests were to determine what treatment schemes would be required for each of the waters in order to satisfy the treatment goals established by the City. The results and conclusions of this treatability study will serve as a basis for determining what modifications, if any, need to be made to the Wichita WTP in order for the City to efficiently treat and maximize use of its surface water sources.

1.3 Treatment Goals

The treatment goals established for this study include producing treated water in compliance with the following standards and/or guidelines:

- All proposed and promulgated primary drinking water standards (i.e., maximum contaminant levels, or MCLs).

1.5 Acknowledgment

This study would not have been possible without the assistance, cooperation, and support received from the Wichita Water & Sewer Department. Special thanks are extended to Mr. David Warren, Mr. Gerald Blain, Ms. Terryl Pajor, Mr. Vernon Strasser, Mr. Paul Mills, and Mr. Harold Cantrell.

Section 2
Water Quality

2.1 Introduction

Section 2 provides an overview of the water quality issues which impact this study. These issues are presented in two major categories:

- Water Quality Regulations
- Historical Water Quality Data

2.2 Water Quality Regulations

The most significant new water quality standards on the regulatory horizon are a three-rule package which were proposed in 1994. The three rules are:

- Disinfectant/Disinfection By-Product Rule (D/DBPR)
- Enhanced Surface Water Treatment Rule (ESWTR)
- Information Collection Rule (ICR)

These rules, which will be promulgated in stages between 1996 and 2002, are closely related and attempt to balance the following disinfection and disinfection by-product concerns in an integrated manner:

- Disinfection of drinking water is necessary to destroy pathogenic micro-organisms and avoid outbreaks of water-borne diseases. Increasing the disinfectant concentration and contact time improves the microbial quality of drinking water.

- However, disinfectants react with naturally-occurring precursors in the water to form by-products (for example, trihalomethanes), many of which have been determined by EPA to pose health risks to consumers.

- Furthermore, the disinfectants themselves (for example, chlorine, chloramines, and chlorine dioxide) also have possible deleterious health effects.

- Current knowledge about the health risks of disinfection by-products, disinfectants, and even pathogenic micro-organisms is very limited. Moreover, little is known about disinfection by-products (less than half of all chlorinated DBPs have even been identified) or about how to remove them.

The purpose of the proposed D/DBPR is to limit the levels of both disinfectants and disinfection by products in drinking water. The purpose of the ESWTR is to ensure that disinfection is sufficient to provide adequate microbial quality. Finally, the aim of the ICR is to collect industry-wide information about pathogenic micro-organisms, DBP precursors, and the formation and removal of disinfection by-products. This information will be used in developing the final versions of the D/DBPR and ESWTR.

The ICR, D/DBPR and ESWTR will have a major impact on the U.S. water industry and, in many cases, will require both capital improvements and operational changes. It is important to recognize that any treatment modifications implemented to comply with the new rules must not compromise compliance with other SDWA regulations. When treatment changes are made to comply with one rule, the effect of those changes may negatively impact the ability to comply with other rules. For example, the Lead and Copper Rule requires that some plants will have to increase the pH of the finished water. However, increasing the pH reduces the effectiveness of disinfectants such as chlorine and increases the formation of THMs, thereby making compliance with the D/DBPR more difficult.

2.2.1 Disinfectant/Disinfection By-Product Rule

Maximum Contaminant Levels for DBPs

Presently, trihalomethanes (THMs) are the only disinfection by-products (DBPs) regulated under the SDWA. The current standard for total trihalomethanes (TTHMs) is 100 μg/L. The proposed D/DBPR will revise the current TTHM standard and will regulate another class of disinfection by-products formed by chlorination — haloacetic acids. The MCLs for TTHMs and the sum of five of the nine known species of haloacetic acids (HAA5) will be promulgated in two stages:

- Stage 1 - TTHMs less than 80 μg/L
  HAA5 less than 60 μg/L

- Stage 2 - TTHMs less than 40 μg/L
  HAA5 less than 30 μg/L

Compliance with these MCLs will be based on running averages of monitoring data, similar to the current standard for TTHMs. Monitoring requirements will depend on a specific water system's size and source water.

The D/DBPR will also establish the following limits on bromate, a by product formed by ozonation of water containing bromide, and chlorite, a degradation product of chlorine dioxide:

- Bromate less than 10 μg/L
- Chlorite less than 1.0 mg/L

Treatment Technique for DBP Precursors

Analytical methods and toxicological data is not available or is scarce for many DBPs. Therefore, the formation of DBPs with potentially harmful effects will be controlled by limiting the level of DBP precursors in the water. Rather than require monitoring of the various organic precursors, the D/DBPR will limit the level of total organic carbon (TOC), which is an indicator of precursors. Specified percent removals of TOC will be required prior to primary disinfection to assure that precursors to DBPs are reduced before contact with the disinfectant. The required TOC removal will be based on source water TOC and alkalinity as shown in Table 2-1. Removal of TOC will be accomplished using "enhanced coagulation" or "enhanced precipitative softening." In simple terms, enhanced coagulation means using a higher coagulant dose in order to obtain a greater removal of TOC from the water. Enhanced precipitative softening generally means softening at a high pH (i.e., 10.5 or greater) in order to remove at least 10 mg/L (as $CaCO_3$) of magnesium hardness. If removal of 10 mg/L of magnesium hardness is achieved, the TOC removal requirements listed in the far right column of Table 2-1 do not have to be met.

Table 2-1
Required Removal of TOC by
Enhanced Coagulation

Source Water TOC (mg/L)	Source Water Alkalinity (mg/L as $CaCO_3$)		
	0 to 60	>60 to 120	>120[1]
0-2	No Action	No Action	No Action
> 2-4	40%	30%	20%
> 4-8	45%	35%	25%
> 8	50%	40%	30%

[1] Systems practicing softening must meet the TOC removal requirements in this column.

The D/DBPR also provides alternate performance criteria for compliance with the enhanced coagulation requirements. The purpose of the alternative performance criteria is to avoid the addition of excessive amounts of coagulant with little additional removal of TOC. The two alternate performance criteria are based on:

- a point of diminishing returns, and
- a maximum pH.

The "point of diminishing returns" is defined as the alum dose beyond which less than 0.3 mg/L TOC is removed per 10 mg/L alum addition (as active chemical prior to dilution). Equivalent values are given for other coagulants. For ferric sulfate the equivalent coagulant dose is 9.5 mg/L (as active chemical prior to dilution). The "maximum pH" is defined as the coagulant dose required to achieve a target pH value which is set based on cost considerations. The maximum pH is a function of source water alkalinity and is shown in Table 2-2.

Table 2-2
Enhanced Coagulation Maximum pH

Source Water Alkalinity (mg/L as $CaCO_3$)	Maximum pH
0 - 60	5.5
> 60 - 120	6.3
> 120 - 240	7.0
> 240	7.5

Alternate performance criteria have not yet been established for systems practicing softening. As part of the proposed D/DBPR, EPA has requested comments on what alternate performance criteria would be appropriate for softening systems.

The D/DBPR will require enhanced coagulation or enhanced precipitative softening unless:

- TOC concentration in the treated water is less than 2.0 mg/L, or
- TOC concentration in the raw water is less than 4.0 mg/L, alkalinity is greater than 60 mg/L, and TTHMs and HAA5 in the treated water are less than 40 μg/L and 30 μg/L, respectively with any disinfectant, or
- TTHMs and HAA5 in the treated water are less than 40 μg/L and 30 μg/L, respectively with chlorine, or
- Magnesium hardness removal is greater than or equal to 10 mg/L $CaCO_3$ (this applies to softening systems only).

The D/DBPR will not allow CT credit for preoxidation using chlorine or chloramines, unless the water temperature is below 5°C and TTHM and HAA5 levels are less than 40 μg/L and 30 μg/L, respectively. This requirement is intended to discourage the application of disinfectants until after enhanced coagulation has reduced the TOC levels. However, preoxidation will be permitted (without CT credit) for control of water quality problems such as algal growth, Zebra mussels and Asiatic clams, taste and odor, iron and manganese, and so on.

The D/DBPR will allow CT credit for preoxidation with ozone and chlorine dioxide before enhanced coagulation, provided specific conditions are met. For ozone, the treatment plant must include biologically active filtration. For chlorine dioxide, the generators must be at least 95 percent efficient.

Maximum Residual Disinfectant Levels

The D/DBPR will limit disinfectant levels in drinking water by the use of maximum residual disinfectant levels (MRDLs). The MRDLs will be:

- Chlorine 4.0 mg/L
- Chloramines 4.0 mg/L
- Chlorine dioxide 0.8 mg/L

Short-term increases for chlorine and chloramines will be permitted to control specific microbiological problems.

Summary

In summary, the D/DBPR will consist of three main elements:

- MCLs for DBPs (TTHMs, HAA5, bromate and chlorite).

- Treatment technique for DBP precursors (enhanced coagulation to reduce TOC with no CT credit for preoxidation by chlorine or chloramines).
- MRDLs for disinfectants (chlorine, chloramines and chlorine dioxide).

The rule will be promulgated in two stages. Stage 1 will be based on current knowledge. Stage 2 will be developed after analysis of data collected under the ICR and consideration of further toxicity studies.

Stage 1 of the D/DBPR was proposed in July 1994. According to EPA's latest schedule, promulgation of Stage 1 will take place in November 1998, and become effective for large water systems in 2000. Plants needing to install GAC or membrane technology will be given an extended compliance date. Stage 2 of the D/DBPR was also proposed in July 1994, but will be reproposed in 2000 following consideration of the latest data and studies. Stage 2 is expected to be promulgated in the year 2002 and to become effective in 2003, with an extended compliance date for GAC and membrane technologies.

2.2.2 Enhanced Surface Water Treatment Rule

The interim Enhanced Surface Water Treatment Rule (ESWTR) was proposed on July 29, 1994. The primary focus of the ESWTR will be to revise the removal and/or inactivation requirements for *Giardia* cysts and viruses, previously defined in the SWTR, as well as adding new removal and/or inactivation requirements for *Cryptosporidium*, based on source water quality.

Proposed revisions to the SWTR include:

- Inclusion of *Cryptosporidium* in the definition of "Groundwater Under the Direct Influence of Surface Water".
- Inclusion of *Cryptosporidium* in watershed control requirements.
- Sanitary surveys for all surface water systems.

In addition to the above, EPA is also considering possible supplemental requirements which might include:

- Regulations that require systems to have a cross-connection control program.
- More strict requirements for notifying the State during high finished water turbidity events.

The interim ESWTR is for systems serving more than 10,000 people and is expected to be promulgated in November 1998. The final ESWTR will be promulgated in November 2000 and become effective in 2002.

2.2.3 Information Collection Rule

The Information Collection Rule (ICR) arose from the recognition that insufficient knowledge currently exists about the perceived health risks which the D/DBPR and ESWTR are intended to address. These rules involve risk/cost trade-offs and without adequate knowledge about the magnitude of the risks involved, a proper balance between microbial risks, risks from DBPs, and costs cannot be achieved. The ICR is a means of accelerating the collection of information so that EPA can develop new rules to appropriately address health risks as mandated by the SDWA.

The ICR will require all surface water systems serving more than 10,000 people to collect information relating to microbial water quality, formation of DBPs, and removal of DBP precursors. In addition to extensive monitoring, the ICR will require surface water systems which serve more than 100,000 people to conduct a DBP precursor removal study unless:

- Chlorine is the primary/residual disinfectant and the annual average of four quarterly averages are less than 40 μg/L TTHM and less than 30 μg/L HAA5, or

- The raw water TOC level is less than 4.0 mg/L for the average of the initial 12 monthly samples.

The ICR was proposed in February 1994 and promulgated in May 1996. Monitoring is anticipated to begin February 1997.

2.3 Historical Water Quality Data

2.3.1 Wichita WTP Water Quality Data

Tables 2-3 and 2-4 compare the quality of the raw and treated waters at the Wichita WTP to the primary and secondary drinking water regulations, respectively. Unless noted otherwise, all data on organics is the average from 1993 and 1994 and all other data is the average for 1993, and radionuclides and microbials are for 1995. The data presented in Tables 2-3 and 2-4 is for the combined Cheney Reservoir and wellfield supplies to the plant.

In addition to this data, in 1995 the City began collecting monthly TOC data on the raw and treated water. Percent TOC reductions for 1995 are shown in Figure 2-1. For raw water TOCs of 2.5 - 3.4 mg/L, TOC reduction through the plant varied anywhere from 3% - 30%, with an average removal of 13% for the year. Note, the low raw water TOCs are due to blends of groundwater ranging from 38% to 57%.

2.3.2 Cheney Reservoir and Little Ark River Raw Water Quality Data

Figures 2-2 through 2-9 show some of the raw water quality for both Cheney and the Little Ark for the duration of the treatability study (November 1994 to December 1995). An average of all the data is provided on each graph. Turbidities for both Cheney and the Little Ark jumped significantly in the spring of 1995. This was mostly due to the large amount of rainfall received in the state. The turbidities seen at Cheney during the treatability study were abnormally high and this was some of the most turbid water Cheney has experienced in over 10 years. For the Little Ark, there was an extreme variation in turbidity, as might be expected with a river source. TOC for the Cheney Reservoir was rather stable over the duration of the study and did not vary as did turbidity. TOC for the Little Ark varied considerably more than Cheney, with a few samples exceeding 17 mg/L. The hardness and alkalinity for Cheney remained fairly stable, however, both hardness and alkalinity dropped by about 40 mg/L (as $CaCO_3$) with the increased flows to the reservoir in the spring of 1995. Hardness and alkalinity for the Little Ark was erratic and generally inversely proportional to turbidity.

Table 2-3
Wichita WTP Water Quality vs. Primary Drinking Water Regulations[1]

Contaminant	MCL[2][3]	Raw Water	Treated Water
Organics			
Acrylamide	TT	NM[13]	ND[3][14]
Alachlor	0.002	NM	ND
Aldicarb	0.003[11]	NM	ND
Aldicarb sulfone	0.002[11]	NM	ND
Aldicarb sulfoxide	0.004[11]	NM	ND
Atrazine	0.003	NM	ND
Benzene	0.005	NM	ND
Benzo(a)pyrene	0.0002	NM	ND
Carbofuran	0.04	NM	ND
Carbon tetrachloride	0.005	NM	ND
Chlordane	0.002	NM	ND
2,4-D	0.07	NM	ND
Dalapon	0.2	NM	ND
Di(2-ethylhexyl)adipate	0.4	NM	ND[14]
Di(2-ethylhexyl)phthalate	0.006	NM	ND[14]
Dibromochloropropane(DBCP)	0.0002	NM	ND
p-Dichlorobenzene	0.075	NM	ND
o-Dichlorobenzene	0.6	NM	ND
1,2-Dichloroethane	0.005	NM	ND
1,1-Dichloroethylene	0.007	NM	ND
cis-1,2-Dichloroethylene	0.07	NM	ND
trans-1,2-Dichloroethylene	0.1	NM	ND
Dichloromethane (methylene chloride)	0.005	NM	ND
1,2-Dichloropropane	0.005	NM	ND
Dinoseb	0.007	NM	ND
Diquat	0.02	NM	NM[15]
Endothall	0.1	NM	NM[15]
Endrin	0.002	NM	ND
Epichlorohydrin	TT	NM	ND[14]
Ethylbenzene	0.7	NM	ND
Ethylene dibromide (EDB)	0.00005	NM	ND
Glyphosate	0.7	NM	NM[15]
Haloacetic acids (5)	30 to 60 μg/L[6]	NM	ND[14]
Heptachlor	0.0004	NM	ND
Heptachlor epoxide	0.0002	NM	ND
Hexachlorobenzene	0.001	NM	ND

Table 2-3
Wichita WTP Water Quality vs. Primary Drinking Water Regulations[1]
(Cont'd)

Contaminant	MCL[2][3]	Raw Water	Treated Water
Organics (continued)			
Lindane	0.2 μg/L	NM	ND
Methoxychlor	0.04	NM	ND
Monochlorobenzene	0.1	NM	ND
Oxamyl(vydate)	0.2	NM	ND
Pentachlorophenol	0.001	NM	ND
Picloram	0.5	NM	ND
Polychlorinated byphenyls (PCBs)	0.0005	NM	ND
Simazine	0.004	NM	ND
Styrene	0.1	NM	ND
2,3,7,8-TCDD (dioxin)	3×10^{-8}	NM	NM[15]
Tetrachloroethylene	0.005	NM	ND
Toluene	1	NM	ND
Toxaphene	0.003	NM	ND
2,4,5-TP (silvex)	0.05	NM	ND
1,2,4-Trichlorobenzene	0.07	NM	ND[14]
1,1,1-Trichloroethane	0.2	NM	ND
1,1,2-Trichloroethane	0.005	NM	ND[14]
Trichloroethylene	0.005	NM	ND[14]
Total organic carbon	TT[6]	3.26[13]	2.25[12]
Total trihalomethanes	100 μg/L[10] 40 to 80 μg/L[6][10]	NM	29[12]
Vinyl chloride	0.002	NM	ND
Xylenes (total)	10	NM	ND
Inorganics			
Antimony	0.006	ND[14]	ND[14]
Arsenic	0.05[6]	0.0083	0.004
Asbestos	7 million fibers/L >10 μm	NM	ND[14]
Barium	2	ND	ND
Beryllium	0.004	ND[14]	ND[14]
Cadmium	0.005	0.00027	0.00019
Chromium	0.1	0.0024	ND
Copper	TT	ND	ND
Cyanide (as free cyanide)	0.2	NM	ND[14]
Fluoride	4	0.40	0.34
Lead	TT	0.0025	0.0029

Table 2-3
Wichita WTP Water Quality vs. Primary Drinking Water Regulations[1]
(Cont'd)

Contaminant	MCL[2][3]	Raw Water	Treated Water
Inoganics (Cont'd)			
Mercury	0.002	ND	0.00026
Nickel	0.1	ND	ND
Nitrate (as N)	10	0.59[14]	0.67[14]
Nitrite (as N)	1	ND[14]	ND[14]
Nitrate + Nitrite (both as N)	10	0.59[14]	0.67[14]
Selenium	0.05	0.0032	0.0041
Sulfate	500[4]	69	72
Thallium	0.002	ND[14]	ND[14]
Radionuclides			
Beta particle and photon emitters	4 mrem/yr[4]	NM	NM
Alpha emitters	15 pCi/L[4]	NM	2 pCi/L
Radium-226 + 228	5 pCi/L[5]	NM	NM
Radium-226	20 pCi/L[4]	NM	NM
Radium-228	20 pCi/L[4]	NM	NM
Radon	300 pCi/L[4]	NM	NM
Uranium	20 μg/L[4]	NM	NM
Microbials			
Giardia lamblia	TT	ND	NM
Legionella	TT	ND	2 pCi/L
Heterotrophic bacteria	TT	< 1 col/mL	< 1 col/mL
Total coliforms	PS[7]	< 1 col/100 mL	< 1 col/100 mL
Viruses	TT	ND	ND
Physical Properties			
Turbidity	PS[8]	9.9 NTU	0.33 NTU

(1) Concentrations are average values in mg/L, unless otherwise noted. Organics data is for 1993-4 unless otherwise noted. Inorganics and physical properties are for 1993 unless otherwise noted. Radionuclides and microbials are for 1995.
(2) MCLs are promulgated, unless otherwise noted.
(3) TT - Treatment Technique
PS - Performance Standard
(4) Proposed
(5) Interim
(6) Anticipated
(7) No more than 5 percent of samples per month may be positive for systems which collect at least 40 bacteriological samples per month; no more than 1 sample per month may be positive for systems which collect fewer than 40 bacteriological samples per month.
(8) Must be less than 5 NTU at all times and equal to or less than 0.5 NTU on at least 95 percent of measurements taken each month.
(9) ND - None Detected

Table 2-3
Wichita WTP Water Quality vs. Primary Drinking Water Regulations[1]
(Cont'd)

(10) Running annual average of at least 4 points in system at no less than quarterly intervals.
(11) Draft
(12) 1993 Average
(13) NM - Not Measured
(14) 1995 Average
(15) Analysis exempted by KDHE

Table 2-4
Wichita WTP Water Quality vs. Secondary Drinking Water Regulations[1]

Contaminant	SMCL[2]	Raw Water	Treated Water
Aluminum	0.05 - 0.20[3]	1.80[6]	0.085[6]
Chloride	250	79	82
Color	15 color units	NM	7 units
Copper	1.0	ND	ND
Corrosivity	Non-corrosive	L1 0.18[4][6]	LI 0.19[4]
Fluoride	2.0	0.40	0.34
Foaming agents	0.5	NM	0.02
Iron	0.3	0.89	ND
Manganese	0.05	0.19	ND
Odor	3 threshold odor number	1 TON[6]	1 TON[6]
pH	6.5 - 8.5	7.1	8.3
Sulfate	250	69	72
Total dissolved solids	500	442	333
Zinc	5.0	ND	ND

(1) Concentrations are 1993, average values in mg/L, unless otherwise noted.
(2) SMCLs are promulgated, unless otherwise noted.
(3) Range
(4) LI - Langelier Index
(5) NM - Not Measured
(6) 1995 Average

Figure 2-1
1995 Wichita WTP TOC Reduction

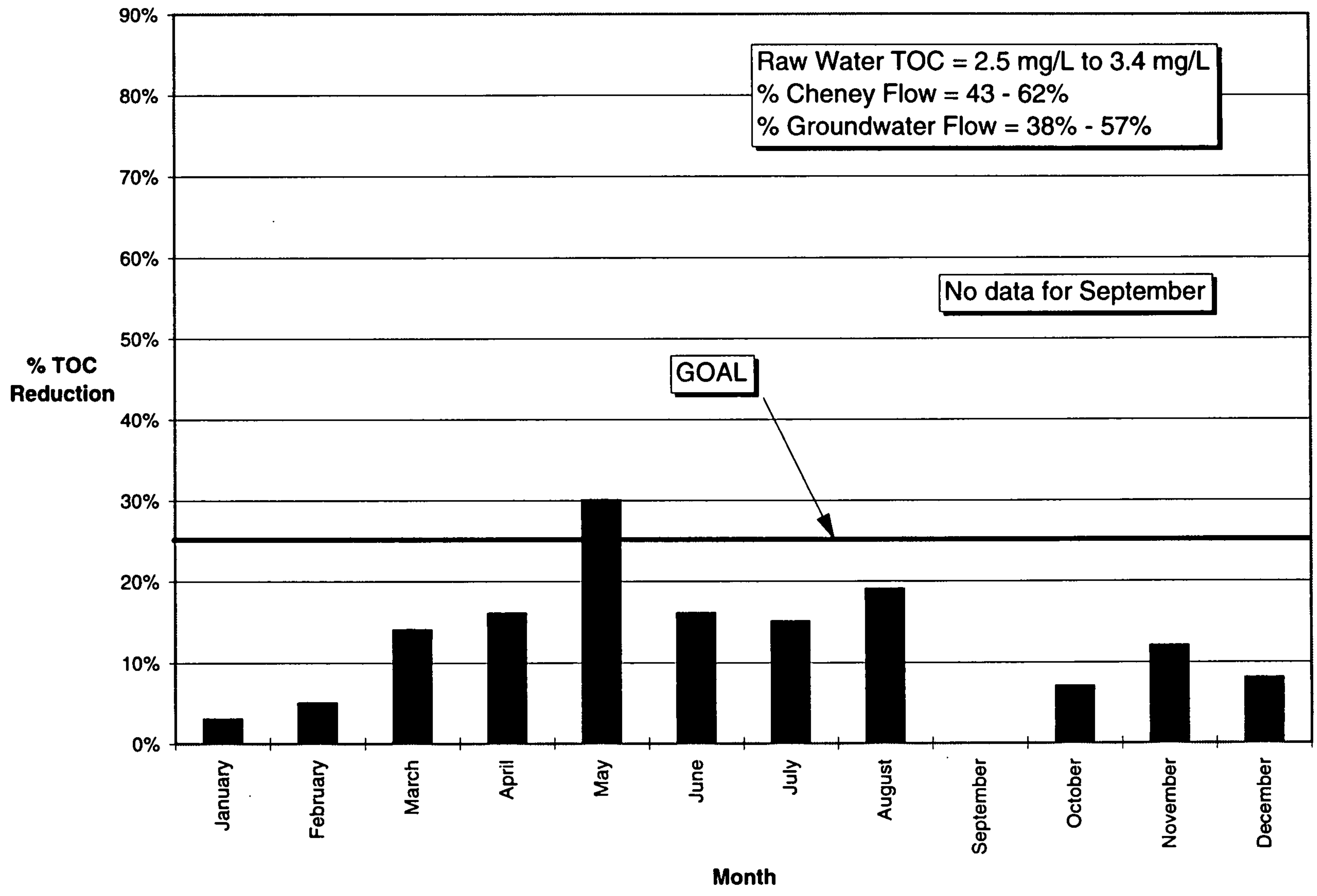


Figure 2-2
Cheney Reservoir
Raw Water Turbidity

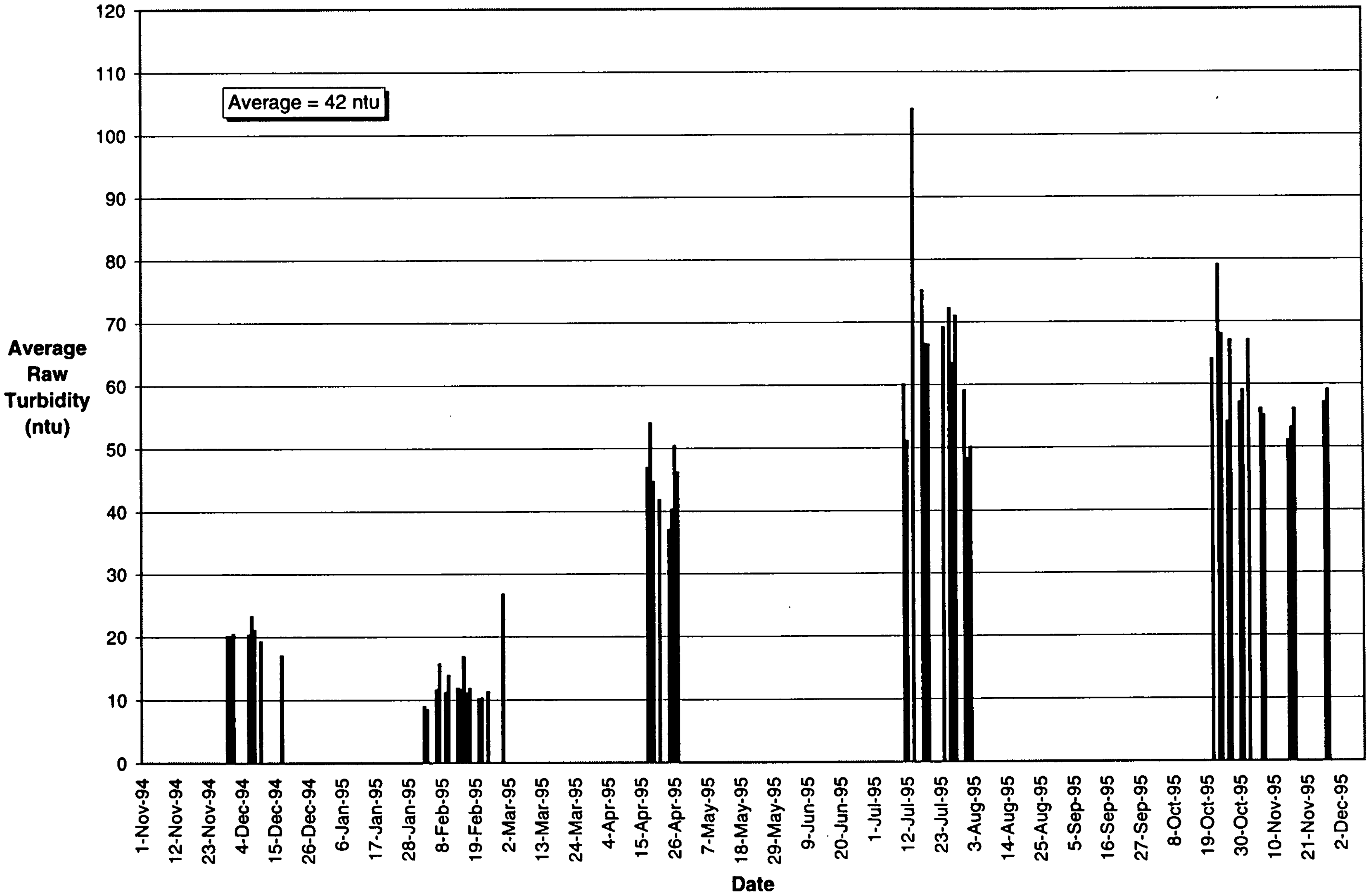


Figure 2-3
Little Arkansas River
Raw Water Turbidity

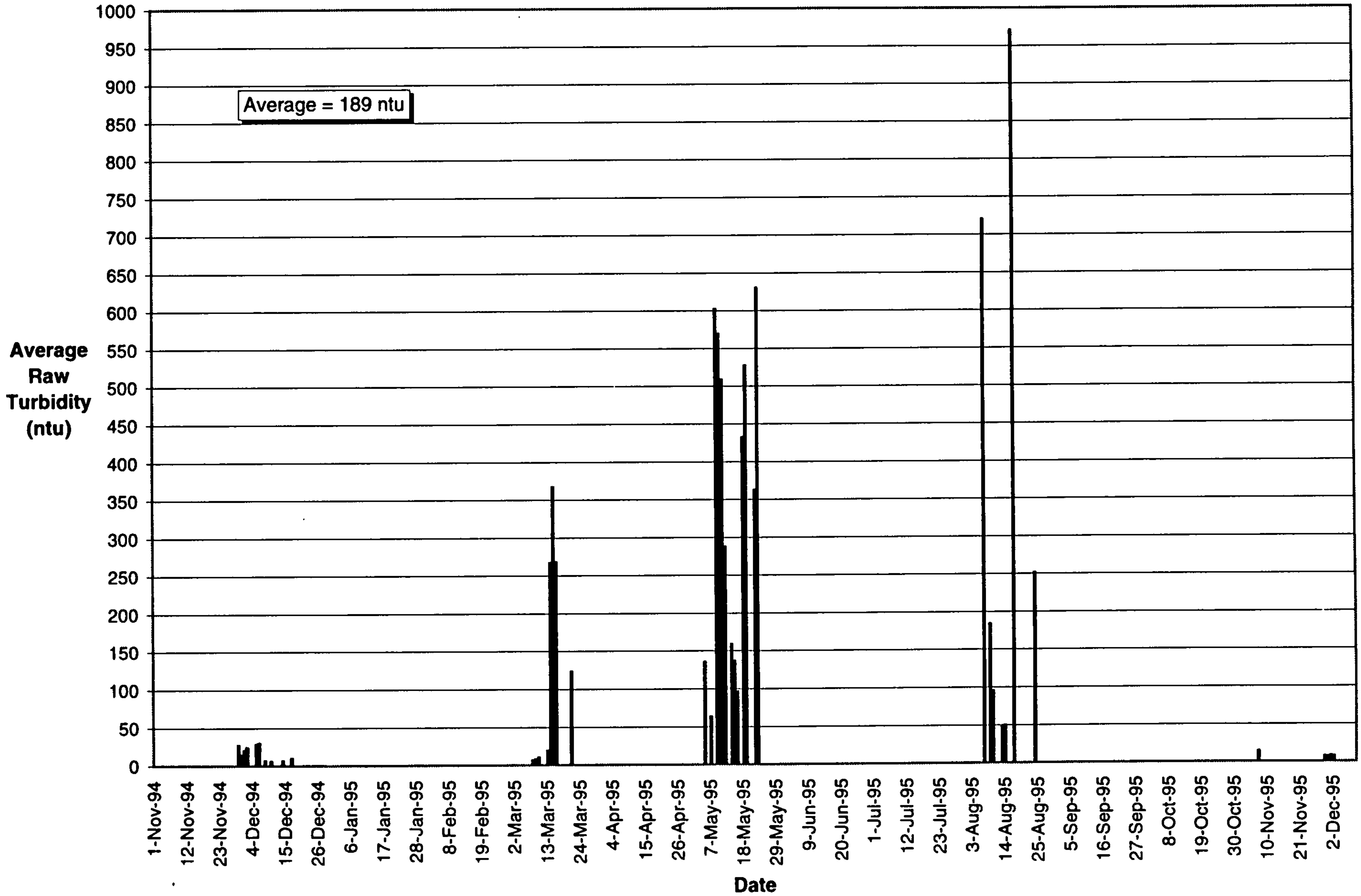


Figure 2-4
Cheney Reservoir
Raw Water TOC

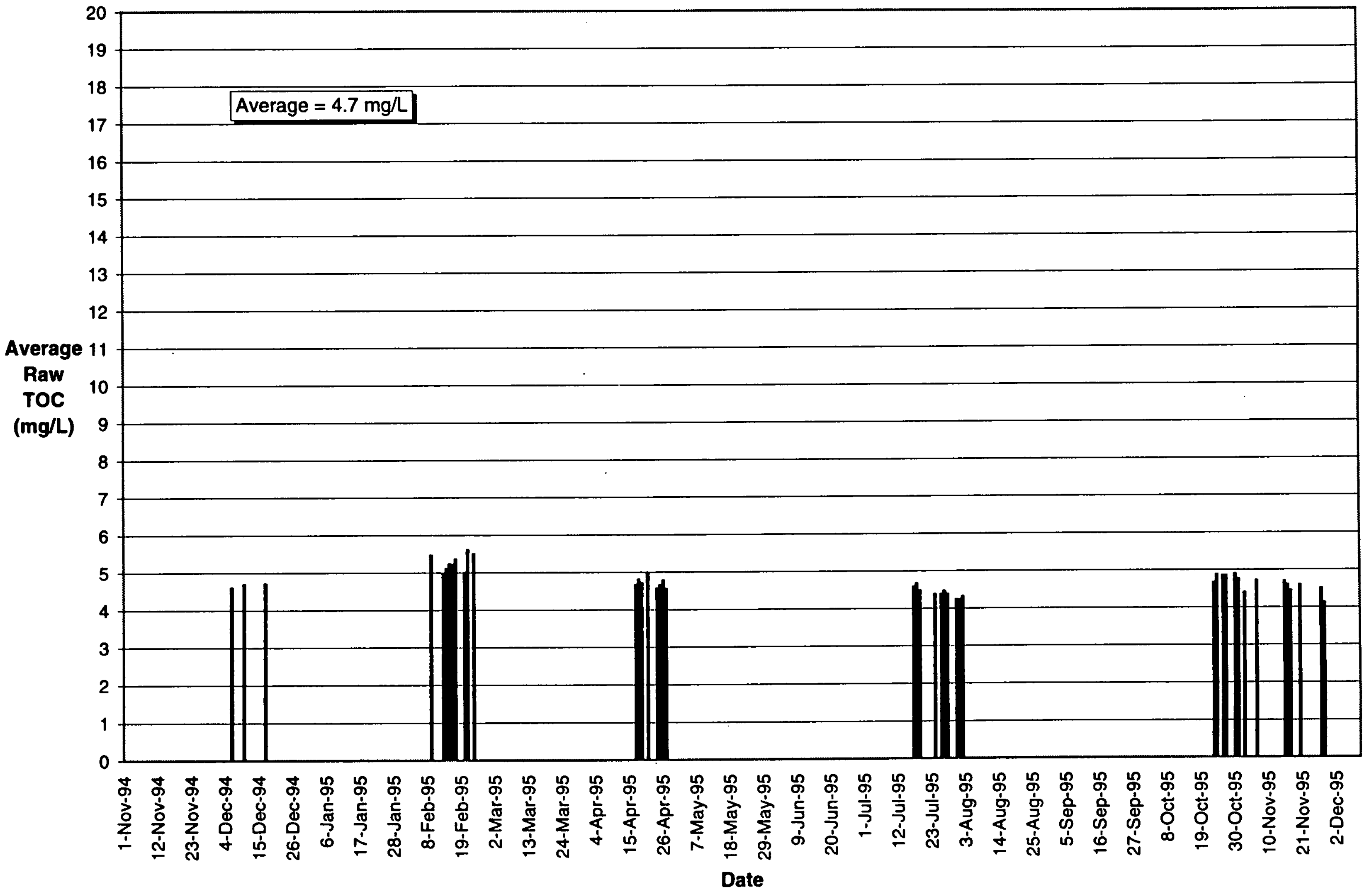


Figure 2-5
Little Arkansas River
Raw Water TOC

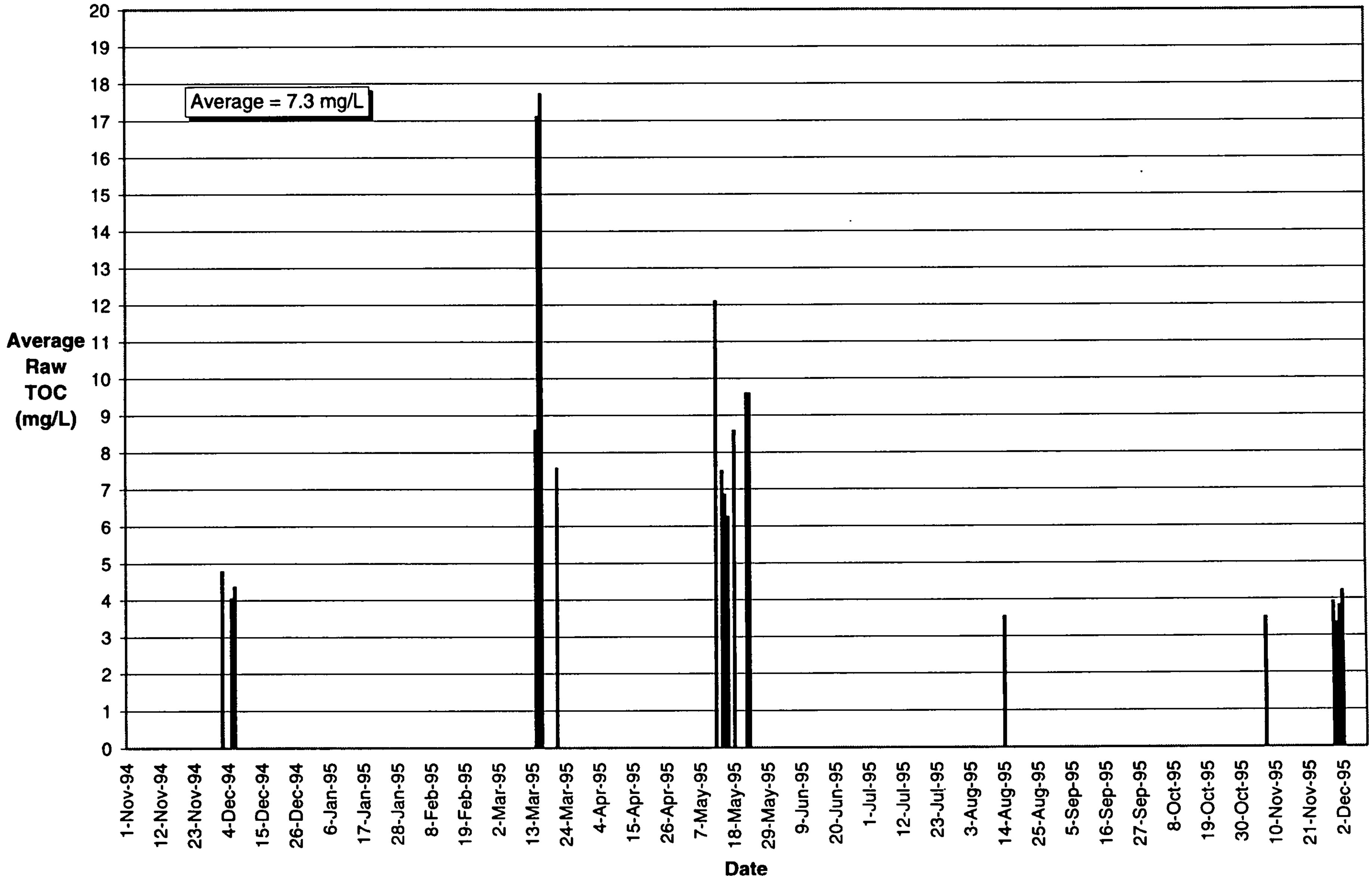


Figure 2-6
Cheney Reservoir
Raw Water Hardness

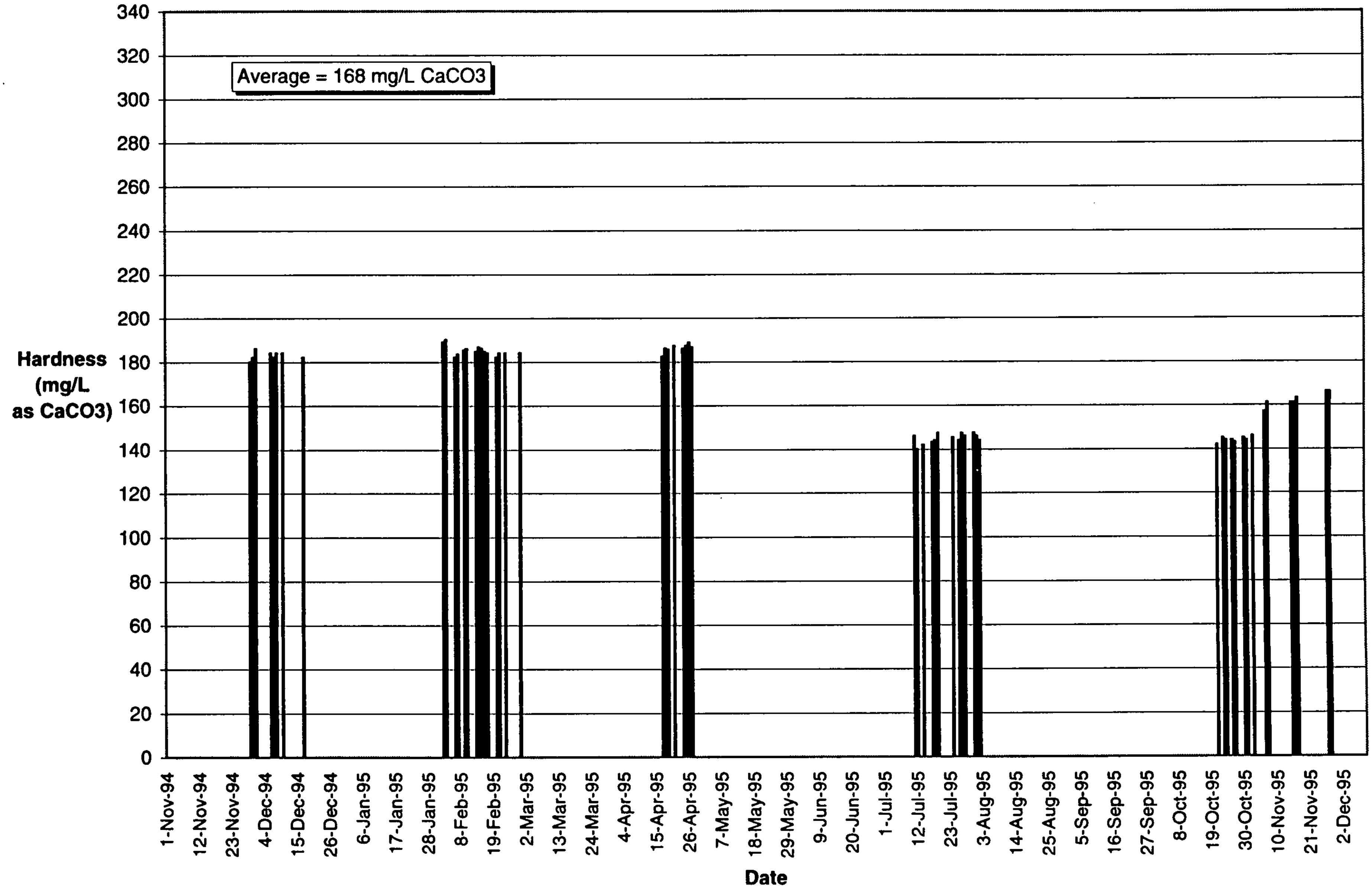


Figure 2-7
Little Arkansas River
Raw Water Hardness

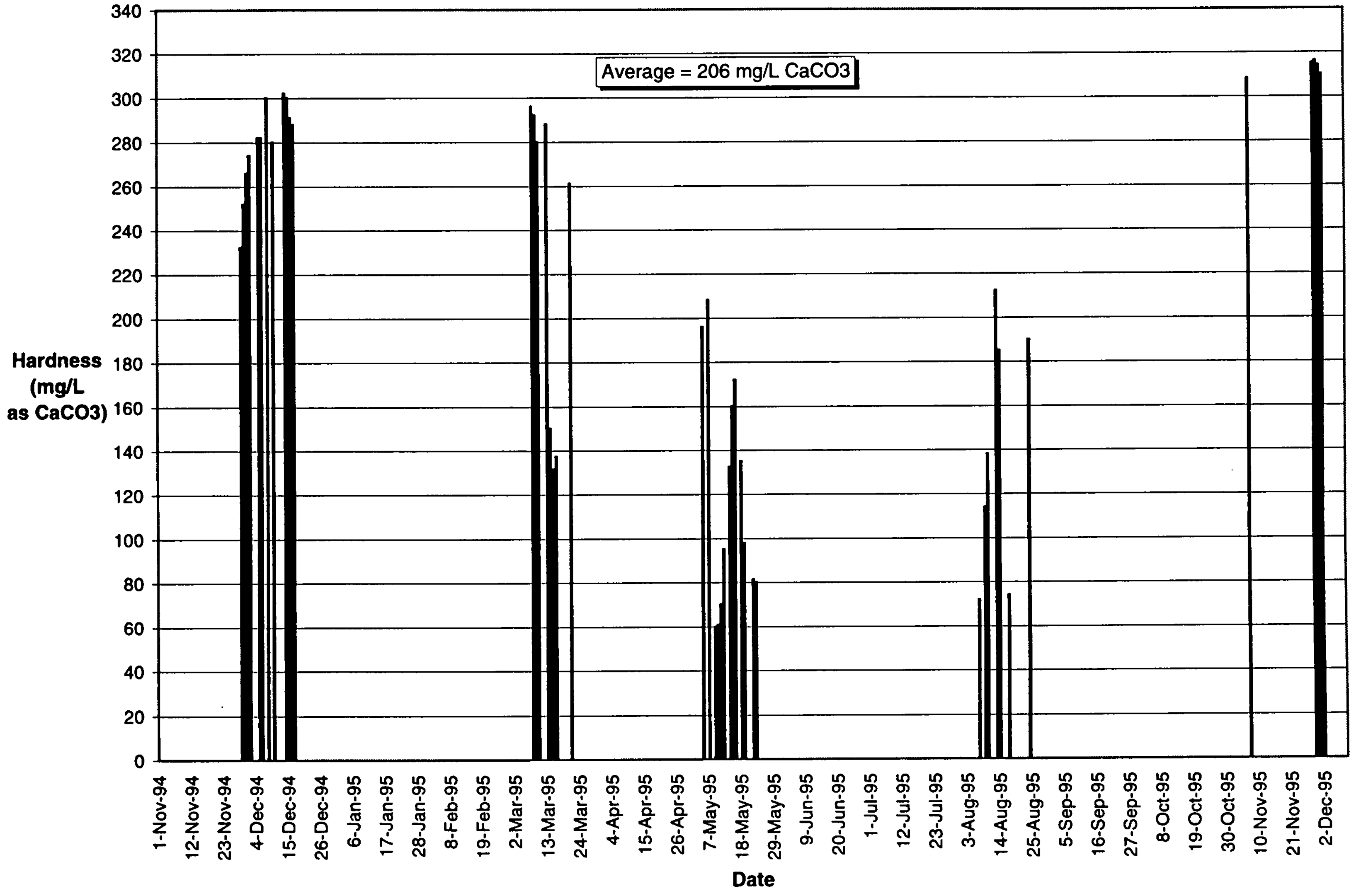


Figure 2-8
Cheney Reservoir
Raw Water Alkalinity

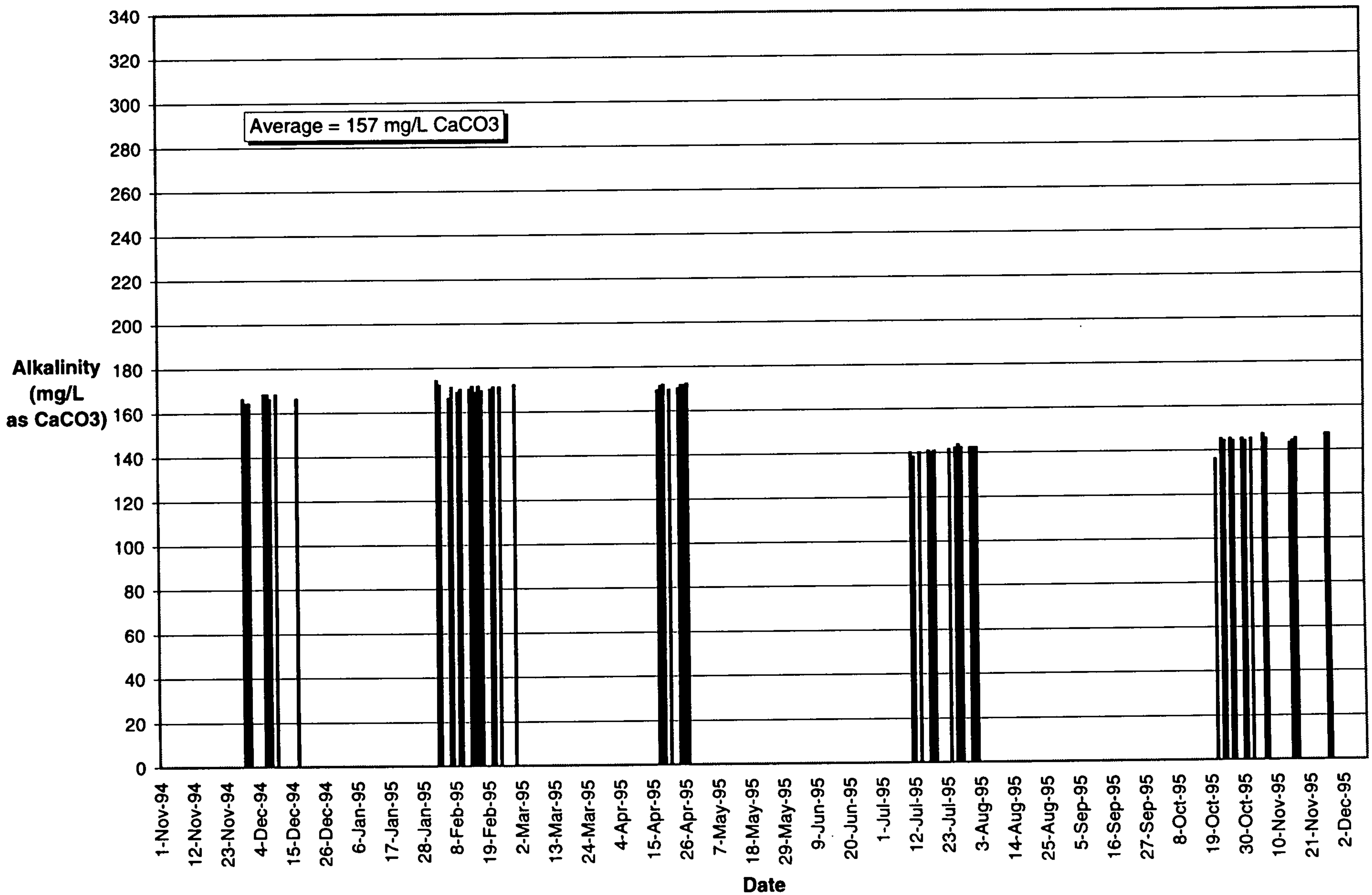
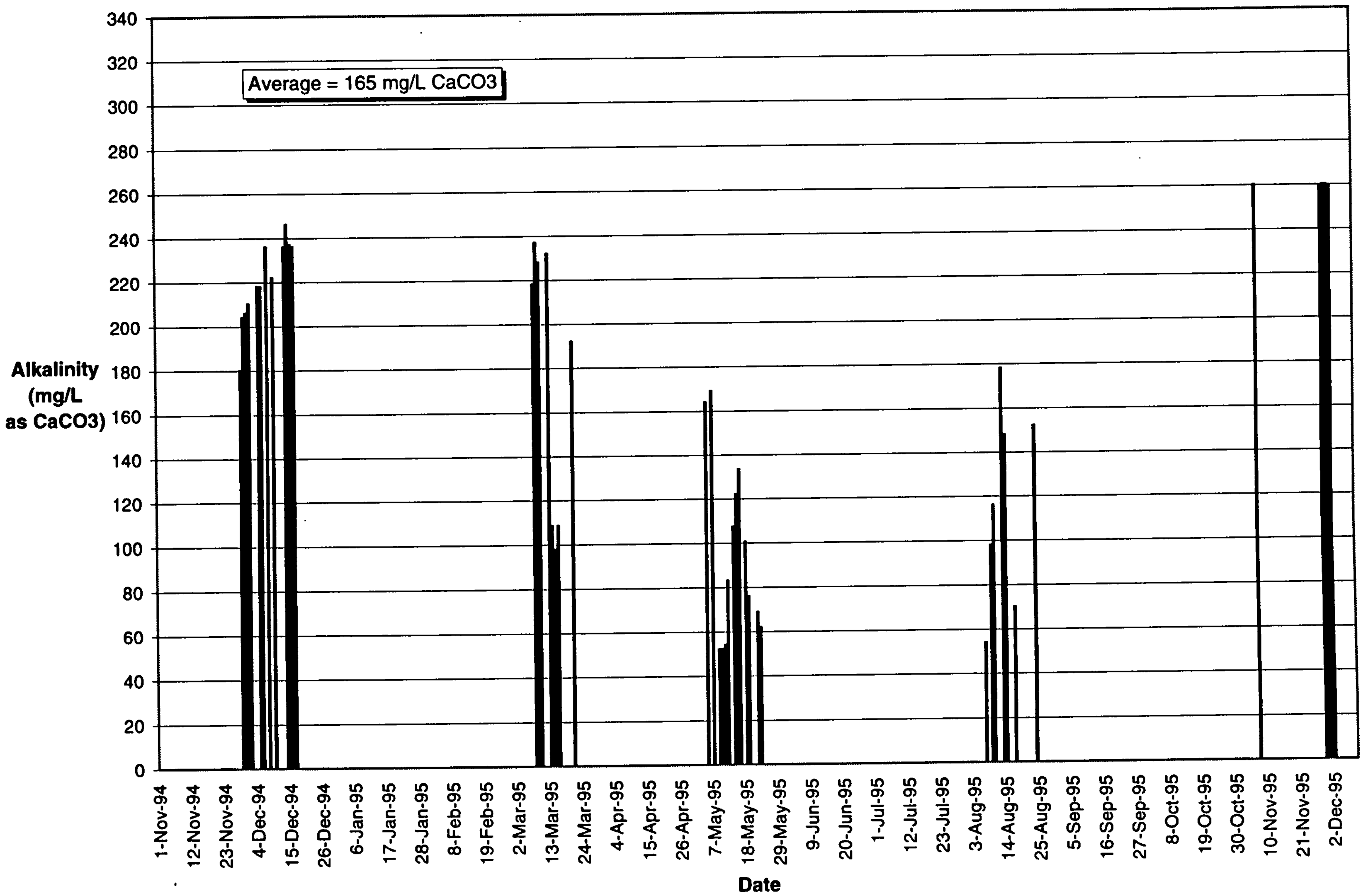


Figure 2-9
Little Arkansas River
Raw Water Alkalinity



Section 3
Equipment and Test Procedures

3.1 Jar Test Equipment and Procedures

Jar testing equipment used throughout the duration of this study included:

- a six-paddle Phipps & Bird™ jar testing apparatus, which includes a 300 rpm mixer and illuminated base, and
- six two-liter square beaker jars.

Analytical equipment consisted of a Hach 2100N™ turbidimeter and portable Fisher Scientific™ pH meter. Additional analytical equipment provided by the City included a bench-top pH meter (for use at the Wichita WTP) and hardness and alkalinity titration apparatuses.

Jar testing served several purposes for this study. The first being to conduct a preliminary evaluation of the softening requirements for the Little Ark supply. The second purpose was to evaluate alternative coagulants, and the third purpose was to evaluate various disinfectant schemes. Additional jar tests were conducted throughout the duration of the study, as required, to assist with the pilot plant evaluations.

The general jar test procedure used for each of the tests is outlined below:

1. Two-liters of raw water were added to each of the jars. Analyses of the raw water included turbidity, pH, temperature, hardness, alkalinity, and TOC.

2. The jar stirrer was turned on and set to 300 rpm to simulate rapid mixing. The selected coagulant(s) and lime (as $Ca(OH)_2$) or lime and soda ash were added to each of the jars via pipet. The samples were then rapid mixed for 10 seconds to simulate rapid mixing at the Wichita WTP. Note: $Ca(OH)_2$ was fed at the jar and pilot level, in lieu of CaO, to bypass the slaking process. All lime doses are reported on the jar and pilot data sheets as $Ca(OH)_2$.

3. The mixer speed was then reduced to simulate three-stage flocculation, similar to the Wichita plant. Flocculation times and mixing intensities generally were as follows:

   - First-Stage Flocculation = 5-11 minutes at 75 rpm
   - Second-Stage Flocculation = 5-11 minutes at 60 rpm
   - Third-Stage Flocculation = 5-11 minutes at 30 rpm

   The shorter, 5-minute, mixing times were used during warm water conditions to simulate summertime treatment (i.e., high flows = shorter detention times). Longer, 7-11 minute, mixing times were used during cold water conditions to simulate wintertime treatment (i.e., low flows = longer detention times).

4. After flocculation, the jars were allowed to settle for 30 minutes at quiescent conditions.

5. After settling, enough sample was decanted from each of the jars to perform selected analyses. These analyses included turbidity, pH, hardness, alkalinity, and TOC.

3.2 Pilot Plant Equipment

The pilot plant modules used to conduct this study were designed and constructed by CDM. Two pilot plant treatment trains were used — one pilot plant was located at the Cheney Pump Station to evaluate Cheney Reservoir and the other pilot plant was located at the Wichita WTP filter gallery to evaluate the Little Ark water. Each pilot plant train included the following:

- Raw Water Aeration Module
- Inlet Module
- Rapid Mix/Flocculation Module
- Sedimentation Module
- Recarbonation Module
- Filter Module
- Backwash Module
- Electrical Module

Additionally, an ozone module was located at the Cheney Pump Station to evaluate pre-ozonation on the Cheney supply. A brief description of each the pilot plant modules follows and an overall schematic of the pilot plant is shown in Figure 3-1. For more in-depth discussions of these modules, refer to the *Pilot Plant Operations and Maintenance Manual, Volume 1*, February 1996.

3.2.1 Raw Water Aeration Module

The raw water aeration module consists of a 55-gallon polyethylene tank into which the raw water is pumped. A fine bubble air diffuser is located in the bottom of the tank and air is pumped to the diffuser via a small air compressor. Water flow through the tank is countercurrent to air flow such that water enters the tank at the top and discharges at the bottom.

3.2.2 Inlet Module

The inlet module consists of several distribution lines — each with a diaphragm valve and rotameter for measuring influent flow. The module is provided with several taps for spiking various constituents into the raw water (e.g., geosmin, MIB). Additionally, raw water turbidity is continuously measured at this module and recorded on a strip-chart.

3.2.3 Ozone Module

The ozone module was located at the Cheney Pump Station for testing with the Cheney Reservoir supply. The module includes an oxygen-fed ozone generator, four counter-current contact columns, and an ozone analyzer for monitoring ozone feed-gas and off-gas concentrations. Additionally, sample taps are located throughout the depth of each contact column to collect samples for analyzing dissolved ozone residuals. The ozone module can be plumbed to ozonate either the raw, settled, or filtered waters. For this study, only raw water ozonation was evaluated.

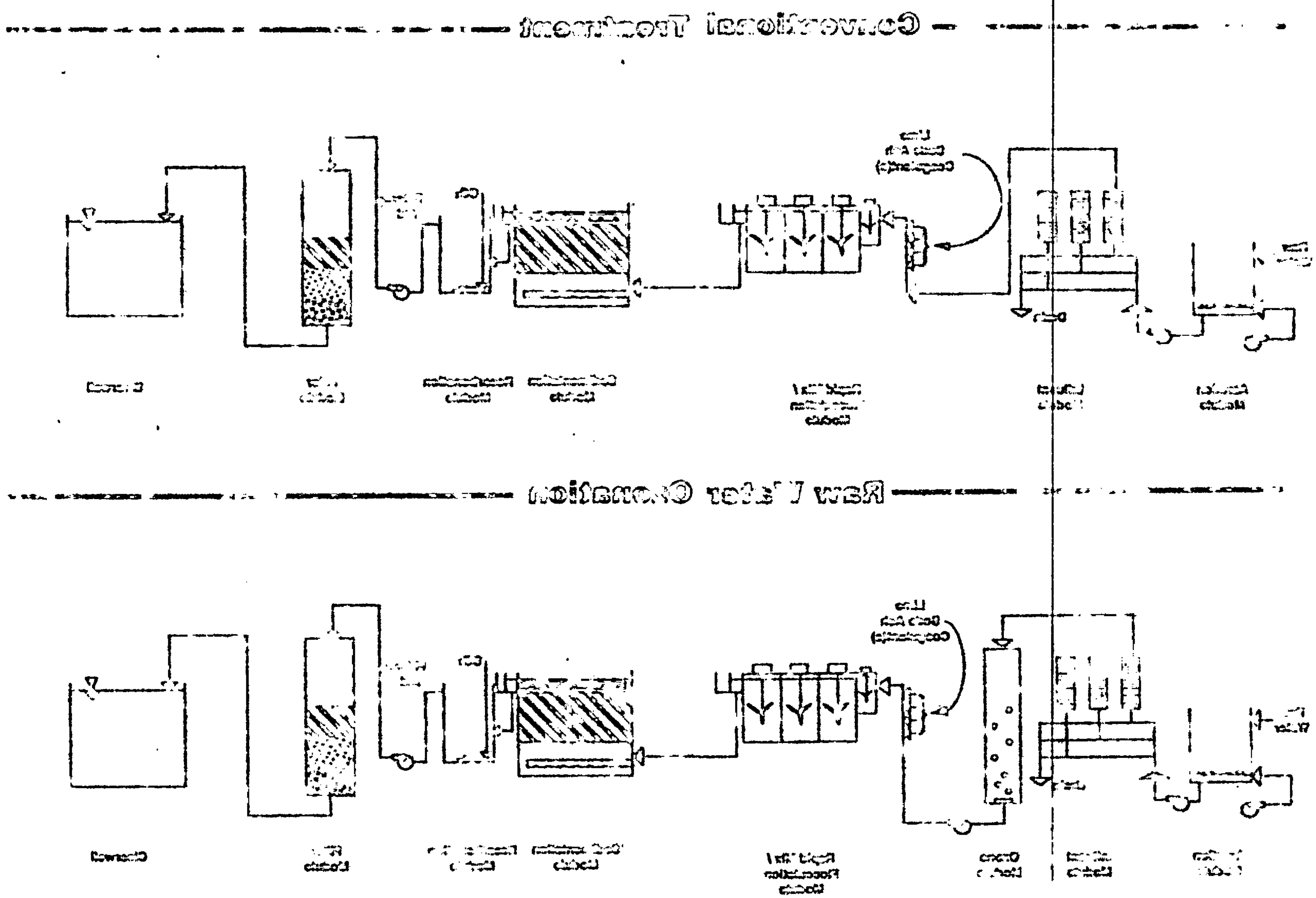


Figure 3-1
Process Schematics

3.2.4 Rapid Mix/Flocculation Module

The rapid mix/flocculation module consists of compartmentalized Plexiglas™ basins with variable speed mixers. Raw or pre-ozonated water feeds this module and the flocculated water flows to the sedimentation module. Chemical addition taps are located prior to the rapid mix portion of the module for chemical addition (e.g., coagulants, lime, soda ash, PAC). After initial rapid mixing in the rapid mix compartment, flocculation, or slow, controlled mixing, is performed in order to create large settleable floc particles. The flocculation portion of the module includes three flocculation compartments, each with a vertical shaft variable speed mixer.

3.2.5 Sedimentation Module

The sedimentation module consists of a rectangular Plexiglas™ basin with tube settlers. Flocculated water enters near the bottom of the sedimentation module through a pair of perforated inlet pipes and flows upward through the tube settlers. Water exits the module through another pair of perforated pipes located above the tube settlers. Settled water turbidity is continuously monitored on the effluent of the sedimentation modules and is recorded on a strip-chart.

3.2.6 Recarbonation Module

The recarbonation module consists of a 30-gallon polyethylene tank into which the settled water flows by gravity. A fine bubble air diffuser is located in the bottom of the tank and air is pumped to the diffuser via a small air compressor. Carbon dioxide (CO_2) gas is bled into the air stream in order to depress the pH further. Water flow through the tank is countercurrent to the CO_2/air flow such that water enters the tank at the top and discharges at the bottom. Recarbonation is monitored by manual pH readings.

3.2.7 Filter Modules

Two filter modules were provided for each pilot plant treatment train. These two modules are mounted on a common support module. The filter media in one of the columns consisted of 22-inches of 1.0 mm anthracite over 12-inches of 0.5 mm silica sand. This filter column simulates the existing Wichita WTP plant filters and the media was obtained from the surplus filter media stocked at the plant. The media in the second filter column consisted of 22-inches of 1.0 mm granular activated carbon (GAC) over 12-inches of 0.5 mm silica sand. The sand in this second filter column was also obtained from the plant surplus inventory and the GAC was provided by Calgon Carbon™.

The filter modules include a variety of equipment to operate as independent pressure filters in a constant rate mode. The recarbonated water flows to each filter module where chemicals (e.g., filter aid) can be added at the influent of the module. Water is pumped to the top of the filter column with a variable speed pump and forced through the column at a constant flow rate. Filtration rates can range from 4 to 20 gpm/ft^2 and the rate is controlled by a programmable process control system which measures the flow and automatically adjusts the pump output to maintain constant flow.

Filtered water turbidity and accumulated headloss through the filter are continuously monitored at each filter and the data is recorded on strip-charts. The filtered water flows to a clearwell located on the backwash module.

3.2.8 Backwash Module

The backwash module consists of a 55-gallon polyethylene clearwell tank, a progressing cavity pump, and an air compressor. Water and air hoses with disconnect couplings are provided on the pump and air compressor for connection to each of the filters for backwashing. Compressed air and/or washwater is introduced to the bottom of the filter column. Air and water flowrates are manually controlled by the operator to provide adequate removal of accumulated solids from the filter media.

3.2.9 Electrical Module

The electrical module distributes power to all of the other pilot plant modules. Power is supplied to the electrical module from the main circuit panel. Dual 30 amp breakers supply the module with 220 volts alternating current (VAC). The electrical module distributes power to six pairs of 110 VAC ground fault indicator (GFI) outlets. Each GFI outlet will instantly shut off in the event of a short circuit or overload.

3.2.10 Analytical Equipment

Analytical equipment used to assist with the pilot plant testing included the Hach 2100N™ turbidimeter, Fisher Scientific™ pH meter, hardness and alkalinity titration apparatuses, and a Met One Model WGS267™ particle counter. The particle counter is a batch sampler that was used to measure particle counts on the filtered water.

3.3 Pilot Plant Operating Procedures

The operation of the pilot plant was dependent on a few key operational decisions being made before each pilot plant run. In most cases, the pilot plants were plumbed as shown in Figure 3-1 for "Conventional Treatment." The general pilot plant operating procedures used for each pilot plant run are listed below.

- Determine testing objectives and operating parameters. The objectives of each pilot run (e.g., enhanced coagulation evaluation, taste and odor evaluation, DBP evaluation) were determined and the operating parameters (e.g., flow rate, chemicals and dosages, filtration rate) were selected.

- Configure the pilot plant modules. The pilot plant treatment modules were plumbed to achieve the desired treatment process configuration. For ozonation pilot runs on the Cheney Reservoir, the pilot plant was plumbed such that the ozone module immediately preceded the rapid mix/flocculation module in order to test pre-ozonation.

- Prepare the treatment chemical feed solutions and spiking compound solutions. Once the chemical treatment scheme was determined, stock feed solutions of the various chemicals (e.g., coagulant, lime, soda ash, PAC) and spiking compounds (e.g., geosmin/MIB) were prepared.

- Start raw water flow to the pilot plant and apply chemicals at proper feed rates. The flowrate to the pilot plant treatment train was set on the rotameter at the influent module. Typically, 2 to 4 gpm was treated through the pilot plant with the lower flow being used in the winter and the higher flow being used in the summer. Chemical feed rates were set to apply proper dose according to plant flow.

- Backwash filter modules. The filters to be used were backwashed prior to being put in-service.
- Allow run to stabilize prior to putting filters on-line. The settled water quality was monitored and the pilot run allowed to stabilize (about 2 to 3 hours) prior to putting the filters in-service.
- Start flow through filter columns. Flow was started through each of the filters at the selected flow rate.
- Monitor pilot run and collect data. The following data was recorded for the duration of each pilot run:

  Raw Water: Turbidity was monitored continuously; additionally, grab samples were collected every four hours, while the pilot plant operator was present, and temperature, pH, turbidity, hardness, and alkalinity were measured.

  Settled Water: Turbidity was monitored continuously. Grab samples were collected every four hours, while the pilot plant operator was present, and pH, turbidity, hardness, and alkalinity were measured.

  Filtered Water: Turbidity and head loss were monitored continuously. Grab samples were collected every four hours, while the pilot plant operator was present, and pH, turbidity, hardness, and alkalinity were measured. Particle counts were also taken periodically throughout the pilot run.

- Termination of pilot plant run. The termination of a pilot run was contingent on several criteria. These included:
  - High filtered water turbidity — 0.5 ntu or greater.
  - High filter head loss — 8 feet or greater.
  - Time — 24 hours.

3.4 Chemicals

The chemicals used during the jar and pilot plant testing included the following:

Softening

- Calcium Hydroxide from Van Waters & Rogers
- Soda Ash from Advance Chemical

Coagulants

- Liquid Alum from Advance Chemical
- Liquid Ferric Chloride from Midland Resources
- Liquid Ferrous Chloride from Midland Resources
- Liquid Ferric Sulfate from the Wichita WTP (also Midland Resources)
- Dry Ferrous Sulfate from QC Corporation
- Liquid Cationic Polymer from the Wichita WTP (also fed as a filter aid)

All liquid coagulant doses are recorded as "liquid delivered" and do not take into account the product's percent solution concentration. This is similar to how the WTP records their chemical dosages.

Recarbonation

- Carbon Dioxide from the Wichita Welding Supply

Carbon

- WPH Powdered Activated Carbon from Calgon Carbon
- Filtersorb 820 Granular Activated Carbon from Calgon Carbon

Disinfectants

- Chlorine Dioxide from Vulcan
- Sodium Hypochlorite (household bleach)
- Ammonium Hydroxide from the Wichita WTP
- Ozone (generated on-site)

Section 4
Testing Chronology

4.1 Introduction

Jar and pilot plant testing was conducted from November 29, 1994 to December 2, 1995. For the most part, testing was not continuous but was conducted over a two-month time frame for each of the four seasons throughout the year. In order to keep track of the various jar and pilot tests, each test was given a particular series number. Each series corresponds to a specific type of test. The series identification numbers and their descriptions are provided below. Note that all hundred series tests are jar tests and all thousand series tests are pilot tests.

Series Identification Number	Description
100	Jar test — Softening
200	Jar test — Coagulants/Enhanced Coagulation
300	Jar test — Disinfection
400	Jar test — Raw Water Blends for Disinfection
500	Jar test — Taste and Odor
1000	Pilot test — Coagulants/Enhanced Coagulation
2000	Pilot test — Adsorption
3000	Pilot test — Disinfection

4.2 Jar Tests

A total of 115 jar tests were conducted throughout the duration of the study. All jar tests results are included in Appendix A. A summary of each of the jar tests is provided in Table 4-1. The pilot plant data included in Table 4-2 are averages for the pilot plant run.

4.3 Pilot Tests

A total of 58 pilot runs were conducted on the Cheney and Little Ark waters. All pilot run results are included in Appendix B and a summary of each of the pilot runs is included in Table 4-2. The pilot plant data included in Table 4-2 are averages for the pilot plant run.

Table 4-1
Summary of Jar Tests

100 Series - Softening

Test No.	Date	Test Objective	Source	RAW WATER QUALITY Temp (C)	pH	Turbidity (ntu)	TOC (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)
J100	11/29/94	Lime/Soda Ash softening	Little Ark	20.0	7.8	29.0	-	222	180
J101	11/29/94	Lime/Soda Ash softening	Little Ark	20.0	7.8	28.1	-	226	180
J102	11/29/94	Lime Softening	Little Ark	19.0	7.9	27.0	-	238	180
J103	11/29/94	Lime Softening	Little Ark	12.0	7.9	25.0	-	238	180
J104	11/29/94	Lime/Soda Ash softening	Cheney/LA	20 / 15	8.4 / 7.9	20 / 27	-	180 / 238	166 / 180
J105	11/30/94	Lime Softening	Cheney/GW	20 / 20	8.2 / 7.7	20 / 7.4	-	182 / 230	164 / 214
J106	11/30/94	Lime/Soda Ash softening	Little Ark	13.0	7.9	18.0	-	252	202
J107	11/30/94	Lime/Soda Ash softening	Little Ark	9.0	7.9	17.0	-	252	198
J108	11/30/94	Lime/Soda Ash softening	LA/GW	13 / 21	7.9 / 7.6	13.8 / 7.2	-	252 / 230	198 / 214
J109	11/30/94	Lime/Soda Ash softening	LA/Chen/GW	-	-	-	-	-	-
J110	12/1/94	Lime Softening	Cheney	21.0	8.2	20.4	-	186	164
J111	12/1/94	Lime Softening	Cheney	21.0	8.2	20.4	-	186	164
J112	12/1/94	Lime/Soda Ash softening	Little Ark	8.0	7.9	18.3	-	266	206
J113	12/1/94	Lime/Soda Ash softening	Little Ark	12.0	7.9	18.9	-	266	206
J114	12/1/94	Lime/Soda Ash softening	Little Ark	9.0	7.9	23.1	-	266	208
J115	12/13/94	Lime/Soda Ash softening	Little Ark	21.5	8.1	7.0	-	300	236
J116	12/13/94	Temp. effect on settling	Little Ark	5.5 / 20	8.1	6.2	-	300	236
J117	12/14/94	Lime/Soda Ash softening	Little Ark	21.0	8.0	6.3	-	300	236
J118	12/14/94	Lime/Soda Ash softening	Little Ark	-	8.0	-	-	302	236
J119	12/14/94	Lime/Soda Ash softening	Little Ark	19.0	8.0	-	-	304	236
J120	12/15/94	Lime/Soda Ash softening	Little Ark	22.0	8.0	-	-	300	246
J121	12/16/94	Lime/Soda Ash softening	Little Ark	18.0	8.1	-	-	294	236
J122	12/16/94	Lime/Soda Ash softening	Little Ark	16.0	8.1	-	-	294	236
J123	12/16/94	Lime/Soda Ash softening	Little Ark	16.0	8.1	-	-	284	240
J124	12/17/94	Lime/Soda Ash softening	Cheney/LA	21.5 / 21	8.2 / 7.9	16.9 / 9.5	-	182 / 288	166 / 236
J125	3/8/95	Lime/Soda Ash softening	Little Ark	5.0	8.4	6.5	-	296	218
J126	3/9/95	Lime Softening	Little Ark	5.0	8.4	7.3	-	294	240
J127	3/9/95	Lime/Soda Ash softening	Little Ark	7.0	8.4	8.0	-	290	234
J128	3/10/95	Lime Softening	Little Ark	7.5	8.4	8.9	-	280	228
J129	3/10/95	Lime/Soda Ash softening	Little Ark	7.5	8.4	9.9	-	280	226
J130	3/10/95	Lime/Soda Ash softening	Little Ark	8.0	8.3	11.0	-	278	230
J131	3/13/95	Lime/Soda Ash softening	Little Ark	13.0	8.3	19.3	-	288	232
J132	5/7/95	Lime/Soda Ash softening	Little Ark	15.0	8.1	64.0	-	196	162
J133	11/2/95	Enhanced softening	Cheney	12	8.4	63	-	146	146

Table 4-1 (cont.)
Summary of Jar Tests

200 Series - Coagulants/Enhanced Coagulation

Test No.	Date	Test Objective	Source	RAW WATER QUALITY Temp (C)	pH	Turbidity (ntu)	TOC (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)
J200	12/2/94	Ferric Sulfate	Little Ark	8.0	8.0	23.5	4.8	274	210
J201	12/2/94	Ferric Chloride	Little Ark	9.0	8.0	23.5	4.8	274	210
J202	12/5/94	Ferrous Chloride	Little Ark	8.5	7.8	30.6	4.1	282	218
J203	12/5/94	Ferrous Sulfate	Little Ark	12.0	7.8	27.0	4.2	282	218
J204	12/5/94	Alum	Little Ark	16.0	7.8	27.0	3.8	282	218
J205	12/6/94	Polymer	Little Ark	22.0	7.8	29.6	3.9	282	218
J206	12/6/94	Ferrous Sulfate	Cheney	7.0	8.1	20.3	4.8	184	168
J207	12/6/94	Ferrous Chloride	Cheney	12.0	8.1	20.3	4.3	184	168
J208	12/10/94	Ferric Chloride	Cheney	20.0	8.2	19.2	4.8	184	168
J209	12/10/94	Polymer	Cheney	20.0	8.1	19.0	4.6	184	168
J210	12/10/94	Ferric Sulfate	Cheney	20.0	8.2	18.9	4.6	184	168
J211	12/11/94	Alum	Cheney	20.0	8.2	20.1	-	184	168
J212	2/2/95	Ferric Sulfate	Cheney	5.5	8.0	8.9	-	188	174
J213	2/2/95	Ferric Sulfate	Cheney	7.5	8.1	8.9	-	190	174
J214	2/2/95	Polymer	Cheney	7.0	8.1	8.9	-	190	174
J215	2/3/95	Ferric Sulfate	Cheney	16.0	8.3	8.4	-	190	172
J216	2/3/95	Polymer	Cheney	19.0	8.3	8.4	-	190	172
J217	2/6/95	Ferric Chloride	Cheney	7.5	8.6	12.1	-	182	166
J218	2/6/95	Ferr. Sulfate - Detention Time	Cheney	8.0	8.4	11.2	-	182	166
J219	2/9/95	Polymer - Detention Time	Cheney	5.5	8.3	10.9	-	186	168
J220	2/13/95	Alum - Detention Time	Cheney	6.0	8.2	11.9	-	182	172
J221	2/14/95	Ferric Chloride	Cheney	5.0	8.1	11.9	-	186	170
J222	2/15/95	Ferrous Chloride	Cheney	5.0	8.1	11.9	-	186	170
J223	2/16/95	Ferrous Sulfate	Cheney	5.0	8.1	11.1	-	184	170
J224	2/20/95	Ferr. Sulfate - Enhanced	Cheney	5.5	8.3	10.1	5.0	182	170
J225	2/21/95	Polymer - Enhanced	Cheney	5.0	8.3	10.3	5.7	182	172
J226	2/21/95	Alum - Enhanced	Cheney	5.0	8.3	10.4	5.3	182	172
J227	2/21/95	Ferric Chloride - Enhanced	Cheney	5.0	8.2	10.2	5.5	186	170
J228	2/21/95	Ferrous Chl. - Enhanced	Cheney	5.5	8.3	10.1	5.9	186	170
J229	2/23/95	Ferrous Sulf. - Enhanced	Cheney	6.5	8.3	12.6	5.5	184	170
J230	3/8/95	Ferric Chloride	Little Ark	6.0	8.4	9.3	-	290	214
J231	3/9/95	Ferrous Chloride	Little Ark	7.5	8.3	9.5	-	292	234
J232	3/15/95	Ferrous Sulfate	Little Ark	13.0	8.0	390	-	126	96
J233	3/16/95	Ferric Chloride	Little Ark	15.0	7.5	308	-	134	104
J234	3/16/95	Ferric Chloride	Little Ark	14.5	7.6	276	-	134	106
J235	3/16/95	Ferric Chloride	Little Ark	14.0	7.8	277	-	136	108
J236	3/21/95	Ferric Sulfate	Little Ark	16.0	7.9	78.0	-	258	192
J237	3/21/95	Ferric Sulfate	Little Ark	17.0	7.9	78.0	7.4	258	192
J238	3/21/95	Ferrous Sulfate	Little Ark	18.0	8.0	157	7.9	262	192
J239	3/21/95	Ferric Chloride	Little Ark	18.0	8.0	179	7.3	264	196
J240	4/19/95	Polymer	Cheney	13.0	8.2	51.0	-	186	170
J241	5/5/95	Ferric Sulfate	Little Ark	14.0	8.1	135	-	196	164
J242	5/9/95	Ferric Sulfate	Little Ark	15.5	7.4	602	-	60	52
J243	5/18/95	Polymer	Little Ark	18.0	8.0	370	-	150	110
J244	5/18/95	Polymer	Little Ark	18.0	8.0	376	-	170	118
J245	5/19/95	Polymer - Ferric Sulfate	Little Ark	17.5	7.7	527	-	98	76
J246	5/22/95	Polymer	Little Ark	-	-	300	-	-	-
J247	5/22/95	Polymer - Ferric Sulfate	Little Ark	18.0	7.7	286	-	100	90
J248	7/11/95	Ferric Sulfate	Cheney	24.0	8.2	60.0	-	146	140
J249	7/12/95	Polymer - Ferric Sulfate	Cheney	24.0	8.2	51.0	-	140	138
J250	7/14/95	Polymer - Ferric Sulfate	Cheney	24.0	8.1	104	-	142	140
J251	7/24/95	Polymer - Ferric Sulfate	Cheney	24.0	8.0	71.0	-	146	140
J252	8/7/95	Polymer	Little Ark	26.5	7.2	720	-	72	54
J253	8/9/95	Presed. - Ferric Sulfate	Little Ark	-	-	251	-	-	-
J254	8/9/95	Presed. - Ferric Sulfate	Little Ark	28.0	7.7	161	-	-	-
J255	8/9/95	Presed. - Polymer	Little Ark	28.0	7.7	141	-	114	98
J256	8/10/95	Presed. - Ferric Sulfate	Little Ark	27.0	7.6	95.0	-	138	116
J257	8/13/95	Ferric Sulfate	Little Ark	28.5	8.0	48.0	-	212	178
J258	8/17/95	Ferric Sulfate	LA/GW	27 / 19	7.4 / 7.6	970 / 0.7	-	74 / 296	70 / 250
J259	8/24/95	Ferric Sulfate	LA/GW	27 / 27	7.4 / 7.8	251 / 1.9	-	190 / 306	152 / 240
J260	10/21/95	Ferric Sulfate	Cheney	16.0	8.5	64.0	-	142	136
J261	10/24/95	Ferric Sulfate - Alum	Cheney	14.0	8.6	76.0	-	146	142
J262	10/31/95	Ferric Sulfate - Alum	Cheney	13.0	8.5	59.0	4.8	144	144
J263	11/2/95	Ferric Chloride	Cheney	12.0	8.4	68.0	-	146	142
J264	11/2/95	Aluminum Chlorohydrate	Cheney	12.0	8.4	65.0	4.4	146	148

Table 4-1 (cont.)
Summary of Jar Tests

200 Series - Coagulants/Enhanced Coagulation

Test No.	Date	Test Objective	Source	RAW WATER QUALITY Temp (C)	pH	Turbidity (ntu)	TOC (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)
J265	11/6/95	Ferric Sulfate - 2 Stage Soft.	Cheney	11.0	8.3	63.0	4.2	148	146
J266	11/7/95	Ferric Sulfate - Alum	Little Ark	-	8.4	14.1	3.5	308	260
J267	11/7/95	Ferric Sulfate - 2 Stage Soft.	Little Ark	15.0	8.4	15.0	3.5	308	258

300 Series - Disinfection

Test No.	Date	Test Objective	Source	RAW WATER QUALITY Temp (C)	pH	Turbidity (ntu)	TOC (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)
J300	12/7/94	Chlorine Residual	Cheney	14.0	8.3	23.2	-	182	168
J301	12/8/94	Chloramine Residual	Cheney	20.0	8.1	21.0	-	184	166
J302	12/8/94	Chlorine Residual	Little Ark	6.0	8.0	14.1	-	280	226
J303	12/10/94	Chloramine Residual	Little Ark	5.0	8.0	5.6	-	280	222
J304	12/17/94	Disinfection Schemes	Cheney/LA	-	-	-	4.7 / 5.1	-	-
J305	2/28/95	Chlorine Dioxide	Cheney	7.5	8.3	26.7	-	184	172
J306	4/21/95	Chlorine Dioxide	Cheney	13.0	8.3	45.0	4.6	186	170
J307	5/23/95	Chlorine Dioxide	Little Ark	18.0	7.8	630	9.6	80	62

400 Series - Raw Water Blends for Disinfection

Test No.	Date	Test Objective	Source	RAW WATER QUALITY Temp (C)	pH	Turbidity (ntu)	TOC (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)
J400	11/27/95	Chlorine/Chloramines	Cheney/GW	15 / 19	8.2 / 7.5	65.0 / 0.4	4.5 / 0.8	168 / 252	142 / 258
J401	12/2/95	Chlorine/Chloramines	LA/GW	13 / 23	8.4 / 7.7	10.9 / 2.7	4.1 / 2.1	316 / 250	262 / 262

500 Series - Taste and Odor

Test No.	Date	Test Objective	Source	RAW WATER QUALITY Temp (C)	pH	Turbidity (ntu)	TOC (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)
J500	11/20/95	Geosmin & MIB - PAC mix	Cheney	-	-	-	4.6	-	-
J501	11/20/95	Geosmin & MIB - PAC mix	Cheney	-	-	-	4.6	-	-
J502	11/30/95	Geosmin & MIB - PAC mix	Little Ark	-	-	-	3.5	-	-

Table 4-2
Summary of Pilot Tests

1000 Series
Coagulants/Enhanced Coagulation

Source	Cheney	Cheney	Cheney	Cheney	Cheney	Cheney	Cheney	Cheney
Run Number	1001	1002	1003	1004	1005	1006	1007	1008
Date	2/7/95	2/9/95	2/10/95	2/13/95	2/14/95	2/15/95	2/16/95	2/17/95
Run Hours	23.5	7.0	4.0	6.0	9.0	8.0	8.0	8.0
Lime (mg/L)	120	123	120	110	133	120	132	108
Soda Ash (mg/L)	-	-	-	-	-	-	-	-
Ferric Sulfate (mg/L)	23	35	-	-	-	-	-	-
Polymer (mg/L)	-	-	1.8	3.3	-	-	-	-
Alum (mg/L)	-	-	-	-	54	-	-	-
Ferric Chloride (mg/L)	-	-	-	-	-	25	-	-
Ferrous Chloride (mg/L)	-	-	-	-	-	-	50	-
Ferrous Sulfate (mg/L)	-	-	-	-	-	-	-	60
Filter Aid Polymer (mg/L)	-	0.1	0.3	0.1	0.2	0.4	0.5	0.5
Filter Aid Ferric Sulfate (mg/L)	-	-	-	-	-	-	-	-
Filter Aid Ferric Chloride (mg/L)	-	-	-	-	-	-	-	-

RAW

Pilot Plant Flowrate (gpm)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Temp. (deg. C)	5.4	5.5	5.5	5.0	4.3	4.2	4.2	4.3
pH (units)	8.4	8.3	8.3	8.2	8.1	8.0	8.2	8.1
Grab Turbidity (ntu)	18.2	11.0	13.2	11.8	11.5	16.9	11.1	11.5
On-Line Turbidity (ntu)	15.6	11.1	13.8	11.8	11.6	16.7	11.0	11.7
T. Hardness as CaCO3 (mg/L)	184	185	186	185	187	186	185	184
T. Alkalinity as CaCO3 (mg/L)	171	169	170	170	171	169	171	169

SETTLED

pH (units)	9.7	9.9	10.4	9.9	9.4	9.8	9.5	9.5
Grab Turbidity (ntu)	17.5	6.1	22.2	26.4	17.6	7.1	3.9	3.9
On-Line Turbidity (ntu)	10.4	5.6	23.6	23.1	13.6	4.9	3.4	3.9
T. Hardness as CaCO3 (mg/L)	114	122	99	104	127	115	119	121
T. Alkalinity as CaCO3 (mg/L)	95	98	88	96	97	95	94	100

22" GAC / 12" Sand Media

Filtration Rate (gpm/sf)	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Avg. Headloss (in/hr)	1.5	3.8	2.8	2.3	7.8	2.7	3.1	4.0
pH (units)	8.2	8.5	8.5	8.2	8.5	8.5	8.2	8.2
Grab Turbidity (ntu)	-	0.44	1.30	1.55	1.75	0.69	0.52	0.55
On-Line Turbidity (ntu)	0.64	0.39	1.65	1.57	1.67	0.61	0.46	0.50
Particles <5 um (counts/mL)	-	-	-	-	-	-	-	-
Particles 5-15 um (counts/mL)	-	-	-	-	-	-	-	-

22" Anth / 12" Sand Media

Filtration Rate (gpm/sf)	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Avg. Headloss (in/hr)	1.3	1.8	5.2	2.1	6.0	2.4	2.6	3.3
pH (units)	8.2	8.5	8.5	8.2	8.5	8.5	8.2	8.2
Grab Turbidity (ntu)	-	0.52	1.60	1.65	1.90	0.72	0.59	0.64
On-Line Turbidity (ntu)	0.66	0.51	2.05	1.83	1.89	0.66	0.52	0.55
Particles <5 um (counts/mL)	-	-	-	-	-	-	-	-
Particles 5-15 um (counts/mL)	-	-	-	-	-	-	-	-

TOC (mg/L)

Raw	-	5.5	-	5.0	5.1	5.2	5.2	5.4
Settled	-	4.4	-	4.4	4.3	4.3	4.3	4.5
22" GAC / 12" Sand Media	-	2.8	-	2.9	3.3	2.9	3.0	3.2
22" Anth / 12" Sand Media	-	4.1	-	4.1	4.2	3.9	3.9	4.0

Table 4-2 (cont.)
Summary of Pilot Tests

1000 Series
Coagulants/Enhanced Coagulation

Source	Little Ark	Little Ark	Little Ark	Cheney	Cheney	Cheney	Cheney	Cheney
Run Number	1009	1010	1011	1012	1013	1014	1015	1016
Date	3/14/95	3/15/95	3/16/95	4/17/95	4/19/95	4/20/95	4/21/95	4/24/95
Run Hours	19.0	6.0	10.0	24.0	24.0	15.0	24.0	24.0
Lime (mg/L)	154	23	44	83	100	115	115	115
Soda Ash (mg/L)	104	-	11	-	-	-	-	-
Ferric Sulfate (mg/L)	70	-	-	40	45	60	60	60
Polymer (mg/L)	-	-	-	-	-	-	-	-
Alum (mg/L)	-	-	-	-	-	-	-	-
Ferric Chloride (mg/L)	-	-	100	-	-	-	-	-
Ferrous Chloride (mg/L)	-	-	-	-	-	-	-	-
Ferrous Sulfate (mg/L)	-	113	-	-	-	-	-	-
Filter Aid Polymer (mg/L)	-	-	-	-	-	-	-	-
Filter Aid Ferric Sulfate (mg/L)	2.2	-	-	-	-	-	-	-
Filter Aid Ferric Chloride (mg/L)	-	-	1.5	-	-	-	-	-

RAW

Pilot Plant Flowrate (gpm)	2.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0
Temp. (deg. C)	13.0	13.0	14.5	12.9	13.1	-	12.8	12.8
pH (units)	8.0	7.9	7.8	8.1	8.3	8.3	8.4	8.5
Grab Turbidity (ntu)	267	367	268	48.5	38.7	-	42.0	37.5
On-Line Turbidity (ntu)	-	-	-	46.8	44.6	42.9	41.7	37.0
T. Hardness as CaCO3 (mg/L)	150	132	137	183	186	-	187	186
T. Alkalinity as CaCO3 (mg/L)	109	98	109	169	172	-	169	170

SETTLED

pH (units)	10.4	8.3	8.2	9.3	9.5	9.3	9.7	9.6
Grab Turbidity (ntu)	29.6	185	142	5.5	5.1	-	3.6	5.8
On-Line Turbidity (ntu)	17.4	-	21.8	5.1	5.0	5.5	3.4	4.0
T. Hardness as CaCO3 (mg/L)	123	158	139	123	120	120	120	122
T. Alkalinity as CaCO3 (mg/L)	96	121	91	99	94	94	89	96

22" GAC / 12" Sand Media

Filtration Rate (gpm/sf)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Avg. Headloss (in/hr)	3.0	-	2.2	0.9	0.7	0.8	0.8	0.8
pH (units)	8.3	-	8.4	8.2	8.4	8.4	8.4	8.6
Grab Turbidity (ntu)	4.60	-	-	0.14	0.13	-	0.11	0.12
On-Line Turbidity (ntu)	5.74	-	3.20	0.11	0.11	0.17	0.09	0.09
Particles <5 um (counts/mL)	-	-	-	-	89	-	41	43
Particles 5-15 um (counts/mL)	-	-	-	-	18	-	11	14

22" Anth / 12" Sand Media

Filtration Rate (gpm/sf)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Avg. Headloss (in/hr)	5.2	-	2.4	0.8	0.7	0.8	0.7	0.8
pH (units)	8.3	-	8.4	8.2	8.4	8.4	8.4	8.6
Grab Turbidity (ntu)	4.10	-	-	0.18	0.13	-	0.11	0.14
On-Line Turbidity (ntu)	4.94	-	3.25	0.10	0.11	0.16	0.09	0.10
Particles <5 um (counts/mL)	-	-	-	-	61	-	36	43
Particles 5-15 um (counts/mL)	-	-	-	-	14	-	11	15

TOC (mg/L)

Raw	8.6	17.1	17.7	4.7	4.7	-	5.0	4.6
Settled	6.7	13.1	7.9	4.4	4.8	-	4.0	4.1
22" GAC / 12" Sand Media	3.2	-	5.8	3.2	4.3	-	3.2	3.2
22" Anth / 12" Sand Media	6.1	-	8.7	4.5	4.7	-	4.1	3.9

Table 4-2 (cont.)
Summary of Pilot Tests

1000 Series
Coagulants/Enhanced Coagulation

Source	Cheney	Cheney	Little Ark	Little Ark	Little Ark	Little Ark	Little Ark	Little Ark
Run Number	1017	1018	1019	1020	1021	1022	1023	1024
Date	4/25/95	4/27/95	5/7/95	5/10/95	5/11/95	5/12/95	5/14/95	5/15/95
Run Hours	24.0	24.0	16.0	14.0	5.0	24.0	24.0	24.0
Lime (mg/L)	140	135	140	40	45	45	35	40
Soda Ash (mg/L)	-	-	25	35	45	65	20	30
Ferric Sulfate (mg/L)	80	100	60	235	220	255	170	154
Polymer (mg/L)	-	-	-	-	-	-	-	-
Alum (mg/L)	-	-	-	-	-	-	-	-
Ferric Chloride (mg/L)	-	-	-	-	-	-	-	-
Ferrous Chloride (mg/L)	-	-	-	-	-	-	-	-
Ferrous Sulfate (mg/L)	-	-	-	-	-	-	-	-
Filter Aid Polymer (mg/L)	-	-	-	-	-	-	-	-
Filter Aid Ferric Sulfate (mg/L)	-	-	-	-	-	-	-	-
Filter Aid Ferric Chloride (mg/L)	-	-	-	-	-	-	-	-

RAW

Pilot Plant Flowrate (gpm)	3.0	3.0	2.5	3.0	3.0	3.0	3.0	3.0
Temp. (deg. C)	13.0	12.5	15.0	16.0	15.5	16.4	18.1	19.0
pH (units)	8.3	8.4	8.1	7.3	7.6	7.8	8.1	8.2
Grab Turbidity (ntu)	44.0	40.7	64.5	569	509	288	159	136
On-Line Turbidity (ntu)	40.2	46.1	63.7	-	-	-	-	-
T. Hardness as CaCO3 (mg/L)	187	187	208	61	70	95	133	160
T. Alkalinity as CaCO3 (mg/L)	171	172	169	52	54	83	108	122

SETTLED

pH (units)	9.6	9.7	9.7	7.3	7.3	7.5	8.0	7.8
Grab Turbidity (ntu)	2.5	2.0	2.7	4.8	3.8	2.4	3.7	2.8
On-Line Turbidity (ntu)	2.9	2.3	3.3	5.2	4.5	2.4	2.9	2.2
T. Hardness as CaCO3 (mg/L)	117	118	119	95	120	138	161	174
T. Alkalinity as CaCO3 (mg/L)	79	78	80	39	66	93	110	122

22" GAC / 12" Sand Media

Filtration Rate (gpm/sf)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Avg. Headloss (in/hr)	0.7	0.6	0.9	1.2	1.0	0.7	0.9	0.6
pH (units)	8.3	8.3	8.4	-	7.3	7.5	8.0	7.9
Grab Turbidity (ntu)	0.10	0.09	0.56	-	-	0.16	0.26	0.16
On-Line Turbidity (ntu)	0.07	0.07	0.54	0.53	0.38	0.14	0.21	0.13
Particles <5 um (counts/mL)	24	35	-	-	-	-	-	639
Particles 5-15 um (counts/mL)	7	12	-	-	-	-	-	359

22" Anth / 12" Sand Media

Filtration Rate (gpm/sf)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Avg. Headloss (in/hr)	0.6	0.6	0.8	1.2	1.0	0.6	0.8	0.5
pH (units)	8.3	8.3	8.4	-	7.3	7.5	8.0	7.9
Grab Turbidity (ntu)	0.10	0.08	0.59	-	-	0.17	0.18	0.15
On-Line Turbidity (ntu)	0.08	0.07	0.58	0.62	0.38	0.13	0.18	0.13
Particles <5 um (counts/mL)	21	32	-	-	-	-	-	475
Particles 5-15 um (counts/mL)	14	13	-	-	-	-	-	323

TOC (mg/L)

Raw	4.7	4.6	-	-	-	12.1	7.5	6.8
Settled	3.8	3.9	-	-	-	7.8	5.4	5.6
22" GAC / 12" Sand Media	3.1	3.2	-	-	-	7.3	3.7	4.6
22" Anth / 12" Sand Media	3.9	3.8	-	-	-	9.2	4.8	5.5

Table 4-2 (cont.)
Summary of Pilot Tests

1000 Series
Coagulants/Enhanced Coagulation

Source	Little Ark	Little Ark	Cheney	Cheney
Run Number	1025	1026	1027	1028
Date	5/16/95	5/18/95	7/17/95	7/19/95
Run Hours	24.0	24.0	24.0	24.0
Lime (mg/L)	100	139	100	100
Soda Ash (mg/L)	20	44	-	-
Ferric Sulfate (mg/L)	140	247	65	61
Polymer (mg/L)	-	-	0.3	0.2
Alum (mg/L)	-	-	-	-
Ferric Chloride (mg/L)	-	-	-	-
Ferrous Chloride (mg/L)	-	-	-	-
Ferrous Sulfate (mg/L)	-	-	-	-
Filter Aid Polymer (mg/L)	-	-	-	-
Filter Aid Ferric Sulfate (mg/L)	-	-	-	-
Filter Aid Ferric Chloride (mg/L)	-	-	-	-

RAW

Pilot Plant Flowrate (gpm)	3.0	3.0	4.0	4.0
Temp. (deg. C)	19.0	17.9	23.8	24.7
pH (units)	8.2	7.9	7.9	8.0
Grab Turbidity (ntu)	114	432	80.0	70.5
On-Line Turbidity (ntu)	96.3	-	75.0	66.4
T. Hardness as CaCO3 (mg/L)	172	135	143	147
T. Alkalinity as CaCO3 (mg/L)	133	101	141	141

SETTLED

pH (units)	9.0	9.1	9.0	9.0
Grab Turbidity (ntu)	2.4	1.7	4.1	6.0
On-Line Turbidity (ntu)	2.1	1.6	4.8	4.8
T. Hardness as CaCO3 (mg/L)	137	117	115	123
T. Alkalinity as CaCO3 (mg/L)	82	52	90	102

22" GAC / 12" Sand Media

Filtration Rate (gpm/sf)	4.0	4.0	6.0	6.0
Avg. Headloss (in/hr)	0.4	0.5	1.0	0.9
pH (units)	8.0	8.2	8.2	8.4
Grab Turbidity (ntu)	0.15	0.23	1.30	0.26
On-Line Turbidity (ntu)	0.13	0.20	0.50	0.21
Particles <5 um (counts/mL)	438	437	-	1303
Particles 5-15 um (counts/mL)	248	250	-	188

22" Anth / 12" Sand Media

Filtration Rate (gpm/sf)	4.0	4.0	6.0	6.0
Avg. Headloss (in/hr)	0.3	0.4	0.9	0.7
pH (units)	8.0	8.2	8.2	8.4
Grab Turbidity (ntu)	0.16	0.26	0.91	0.26
On-Line Turbidity (ntu)	0.15	0.24	0.39	0.18
Particles <5 um (counts/mL)	455	464	-	1153
Particles 5-15 um (counts/mL)	265	269	-	192

TOC (mg/L)

Raw	6.2	8.6	4.6	4.5
Settled	5.1	6.1	3.9	3.8
22" GAC / 12" Sand Media	3.5	4.9	3.4	3.0
22" Anth / 12" Sand Media	4.9	5.9	3.8	3.4

Table 4-2 (cont.)
Summary of Pilot Tests

2000 Series
Adsorption

Source	Cheney	Cheney	Cheney	Cheney	Cheney	Little Ark	Cheney	Cheney	Cheney
Run Number	2000	2001	2002	2003	2004	2005	2006	2007	2008
Date	7/18/95	7/24/95	7/26/95	7/27/95	7/28/95	8/14/95	10/23/95	10/24/95	10/26/95
Run Hours	16.0	24.0	22.0	22.0	23.0	24.0	24.0	24.0	22.0
Lime (mg/L)	110	105	110	117	120	140	128	120	115
Soda Ash (mg/L)	-	-	-	-	-	27	-	-	-
Ferric Sulfate (mg/L)	65	60	69	69	60	54	79	62	57
Polymer (mg/L)	0.3	0.2	0.2	0.2	0.2	0.1	-	-	-
Geosmin (ng/L)	100	100	100	100	100	100	61	93	94
MIB (ng/L)	100	100	100	100	100	100	83	98	75
PAC (mg/L)	-	-	10.0	20.0	30.0	-	-	-	10.0
Filter Aid Polymer (mg/L)	-	-	-	-	-	-	-	-	-

RAW

Pilot Plant Flowrate (gpm)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Temp. (deg. C)	24.0	24.8	25.2	25.0	25.5	27.0	14.4	14.2	14.0
pH (units)	7.9	8.0	8.0	8.0	8.1	7.9	8.5	8.5	8.5
Grab Turbidity (ntu)	75.0	73.0	76.3	74.0	72.3	53.0	108.5	75.0	58.3
On-Line Turbidity (ntu)	66.5	69.1	72.1	63.4	70.9	49.7	78.6	68.3	53.6
T. Hardness as CaCO3 (mg/L)	144	145	144	147	146	185	145	144	144
T. Alkalinity as CaCO3 (mg/L)	140	141	142	143	142	148	145	144	145

SETTLED

pH (units)	8.9	8.9	8.9	8.8	8.9	9.1	9.4	9.5	9.6
Grab Turbidity (ntu)	3.7	3.4	4.7	4.4	2.8	5.2	5.8	3.9	3.2
On-Line Turbidity (ntu)	4.4	3.0	4.3	4.2	2.6	4.1	5.2	4.1	2.5
T. Hardness as CaCO3 (mg/L)	115	119	124	129	116	112	116	106	108
T. Alkalinity as CaCO3 (mg/L)	97	99	106	110	97	82	96	87	89

22" GAC / 12" Sand Media

Filtration Rate (gpm/sf)	6.0	6.0	6.0	6.0	6.0	4.2	6.0	6.0	6.0
Avg. Headloss (in/hr)	1.0	0.9	1.2	1.0	8.3	0.6	0.8	0.8	2.6
pH (units)	8.3	8.2	8.2	8.2	8.3	8.6	8.2	8.4	8.3
Grab Turbidity (ntu)	0.43	0.33	0.34	0.37	0.36	0.64	0.21	0.16	0.23
On-Line Turbidity (ntu)	0.28	0.26	0.47	0.44	0.22	0.71	0.43	0.35	0.23
Particles <5 um (counts/mL)	4810	3999	1829	808	2612	-	-	258	700
Particles 5-15 um (counts/mL)	995	914	294	228	616	-	-	54	191

22" Anth / 12" Sand Media

Filtration Rate (gpm/sf)	6.0	6.0	6.0	6.0	6.0	4.2	6.0	6.0	6.0
Avg. Headloss (in/hr)	0.8	0.7	0.9	0.8	0.8	0.5	0.8	0.8	2.2
pH (units)	8.3	8.2	8.2	8.2	8.3	8.6	8.2	8.4	8.3
Grab Turbidity (ntu)	0.36	0.37	0.29	0.29	0.38	0.64	0.19	0.19	0.22
On-Line Turbidity (ntu)	0.23	0.23	0.40	0.37	0.20	0.76	0.38	0.32	0.21
Particles <5 um (counts/mL)	3787	2995	1697	248	432	-	-	257	626
Particles 5-15 um (counts/mL)	747	617	252	56	69	-	-	48	169

TOC (mg/L)

Raw	4.7	4.4	4.4	4.5	4.4	3.5	4.7	4.9	4.8
Settled	3.9	3.9	3.7	3.3	2.8	2.5	3.5	3.8	3.5
22" GAC / 12" Sand Media	3.6	3.4	3.1	3.0	2.7	2.0	3.2	3.4	3.1
22" Anth / 12" Sand Media	3.9	3.8	3.6	3.3	2.9	2.8	3.7	3.8	3.4

LAB ANALYSIS - 22" GAC / 12" Sand

Geosmin (ng/L)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	12	17	-
MIB (ng/L)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	27	33	-

LAB ANALYSIS - 22" Anth / 12" Sand

Geosmin (ng/L)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	-	-	43
MIB (ng/L)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	-	-	53

Table 4-2 (cont.)
Summary of Pilot Tests

2000 Series
Adsorption

Source	Cheney	Cheney	Little Ark	Little Ark
Run Number	2009	2010	2011	2012
Date	10/27/95	10/30/95	11/29/95	12/1/95
Run Hours	24.0	24.0	24.0	24.0
Lime (mg/L)	115	120	230	225
Soda Ash (mg/L)	-	-	30	30
Ferric Sulfate (mg/L)	57	53	19	15
Polymer (mg/L)	-	-	-	-
Geosmin (ng/L)	73	140	104	59
MIB (ng/L)	67	130	114	67
PAC (mg/L)	20.0	30.0	-	-
Filter Aid Polymer (mg/L)	-	-	0.1	0.1

RAW

Pilot Plant Flowrate (gpm)	4.0	4.0	3.0	3.0
Temp. (deg. C)	13.8	13.1	11.7	11.0
pH (units)	8.5	8.5	8.4	8.3
Grab Turbidity (ntu)	66.0	59.8	6.7	7.6
On-Line Turbidity (ntu)	67.2	56.6	6.9	7.6
T. Hardness as CaCO3 (mg/L)	143	145	315	314
T. Alkalinity as CaCO3 (mg/L)	144	145	259	260

SETTLED

pH (units)	9.5	9.4	9.5	9.4
Grab Turbidity (ntu)	3.3	2.9	4.6	4.5
On-Line Turbidity (ntu)	2.6	3.6	4.6	4.5
T. Hardness as CaCO3 (mg/L)	107	114	113	114
T. Alkalinity as CaCO3 (mg/L)	89	92	87	91

22" GAC / 12" Sand Media

Filtration Rate (gpm/sf)	6.0	6.0	4.0	4.0
Avg. Headloss (in/hr)	1.2	1.2	1.3	1.3
pH (units)	8.3	8.2	8.3	8.3
Grab Turbidity (ntu)	0.25	0.30	0.24	0.24
On-Line Turbidity (ntu)	0.23	0.25	0.22	0.19
Particles <5 um (counts/mL)	675	546	222	465
Particles 5-15 um (counts/mL)	186	153	51	107

22" Anth / 12" Sand Media

Filtration Rate (gpm/sf)	6.0	6.0	4.0	4.0
Avg. Headloss (in/hr)	1.0	1.2	1.2	1.2
pH (units)	8.3	8.2	8.3	8.3
Grab Turbidity (ntu)	0.26	0.28	0.23	0.17
On-Line Turbidity (ntu)	0.22	0.25	0.18	0.15
Particles <5 um (counts/mL)	647	548	198	387
Particles 5-15 um (counts/mL)	167	144	57	71

TOC (mg/L)

Raw	4.8	4.9	3.9	3.8
Settled	3.2	3.0	3.7	3.0
22" GAC / 12" Sand Media	3.1	2.8	2.4	2.7
22" Anth / 12" Sand Media	3.4	3.1	3.4	3.1

LAB ANALYSIS - 22" GAC / 12" Sand

Geosmin (ng/L)	-	-	5.5	-
MIB (ng/L)	-	-	12	-

LAB ANALYSIS - 22" Anth / 12" Sand

Geosmin (ng/L)	37	36	-	51
MIB (ng/L)	51	47	-	66

Table 4-2 (cont.)
Summary of Pilot Tests

3000 Series
Disinfection

Source	Cheney	Cheney	Cheney	Cheney	Little Ark	Cheney	Cheney	Cheney	Cheney	Cheney
Run Number	3000	3001	3002	3003	3004	3005	3006	3007	3008	3009
Date	2/23/95	2/23/95	4/18/95	4/26/95	5/22/95	7/31/95	8/1/95	8/2/95	11/6/95	11/7/95
Run Hours	6.0	5.0	24.0	24.0	23.0	24.0	24.0	20.0	24.0	24.0
Pre-Ozone (mg/L)	-	-	-	-	-	2.0	2.0	-	2.0	2.0
Lime (mg/L)	120	120	90	135	40	120	116	120	132	140
Soda Ash (mg/L)	-	-	-	-	20	-	-	-	-	-
Ferric Sulfate (mg/L)	35	-	40	80	130	60	55	60	47	45
Polymer (mg/L)	-	-	-	-	7.9	0.2	0.1	0.1	-	-
Ferric Chloride (mg/L)	-	30	-	-	-	-	-	-	-	-
Filter Aid Polymer (mg/L)	-	-	-	-	-	-	-	-	0.1	0.1
Filter Aid Ferric Sulfate (mg/L)	0.9	-	-	-	-	-	-	-	-	-
Filter Aid Ferric Chloride (mg/L)	-	3.3	-	-	-	-	-	-	-	-

RAW

Pilot Plant Flowrate (gpm)	2.0	2.0	3.0	3.0	3.0	4.0	4.0	4.0	3.0	3.0
Temp. (deg. C)	6.0	6.8	13.0	13.0	18.0	25.8	25.5	25.5	11.0	10.5
pH (units)	8.3	8.3	8.3	8.4	7.6	8.2	8.3	8.1	8.3	8.4
Grab Turbidity (ntu)	11.5	11.8	54.8	50.7	362.6	64.0	51.3	57.5	59.5	59.5
On-Line Turbidity (ntu)	11.2	12.2	53.9	50.3	-	59.0	48.2	50.0	55.8	54.9
T. Hardness as CaCO3 (mg/L)	184	185	186	189	81	147	146	144	157	161
T. Alkalinity as CaCO3 (mg/L)	171	170	171	171	69	142	142	142	147	145

SETTLED

pH (units)	9.7	9.7	9.3	9.9	8.8	8.9	9.1	9.0	9.5	9.4
Grab Turbidity (ntu)	4.8	5.1	5.2	1.8	4.7	3.6	3.9	5.8	3.5	3.6
On-Line Turbidity (ntu)	3.2	3.6	5.1	2.2	3.0	4.1	4.3	6.9	3.2	4.2
T. Hardness as CaCO3 (mg/L)	115	115	124	108	104	122	111	111	113	117
T. Alkalinity as CaCO3 (mg/L)	94	92	101	71	73	105	94	92	87	94

22" GAC / 12" Sand Media

Filtration Rate (gpm/sf)	4.0	4.0	4.0	4.0	4.0	6.0	6.0	6.0	4.0	4.0
Avg. Headloss (in/hr)	2.3	2.1	0.7	0.7	1.2	1.8	2.2	1.0	1.4	2.0
pH (units)	8.3	8.1	8.2	8.5	8.2	8.2	8.3	8.4	8.4	8.3
Grab Turbidity (ntu)	0.54	0.47	0.15	0.09	0.24	0.19	0.13	0.23	0.11	0.10
On-Line Turbidity (ntu)	0.38	0.38	0.12	0.07	0.20	0.24	0.12	0.43	0.05	0.09
Particles <5 um (counts/mL)	-	-	79	35	290	1532	438	257	39	27
Particles 5-15 um (counts/mL)	-	-	20	9	247	445	110	37	6	5

22" Anth / 12" Sand Media

Filtration Rate (gpm/sf)	4.0	4.0	4.0	4.0	4.0	6.0	6.0	6.0	4.0	4.0
Avg. Headloss (in/hr)	1.6	1.6	0.7	0.7	1.0	1.3	1.8	1.0	1.2	2.0
pH (units)	8.3	8.1	8.2	8.5	8.2	8.2	8.3	8.4	8.4	8.3
Grab Turbidity (ntu)	0.46	0.46	0.14	0.09	0.23	0.17	0.11	0.21	0.12	0.08
On-Line Turbidity (ntu)	0.41	0.42	0.11	0.07	0.20	0.26	0.10	0.41	0.06	0.09
Particles <5 um (counts/mL)	-	-	116	26	239	969	218	239	10	15
Particles 5-15 um (counts/mL)	-	-	32	9	134	197	51	33	2	4

TOC (mg/L)

Raw	-	-	4.8	4.8	9.6	4.2	4.2	4.3	4.8	-
Settled	-	-	4.5	3.8	6.8	3.6	3.7	3.8	3.7	-
22" GAC / 12" Sand Media	-	-	3.4	3.1	4.7	2.7	3.0	3.3	3.2	-
22" Anth / 12" Sand Media	-	-	4.2	3.8	6.1	3.3	3.3	3.9	3.6	-

DISINFECTION ANALYSIS
22" GAC / 12" Sand

TTHM (ug/L)	25	23	29	31	66	3	-	53	6	-
HAA5 (ug/L)	-	-	23	20	79	9	-	38	3	-

DISINFECTION ANALYSIS
22" Anth / 12" Sand

TTHM (ug/L)	39	35	43	38	57	3	-	58	7	-
HAA5 (ug/L)	-	-	28	25	64	14	-	41	5	-

Table 4-2 (cont.)
Summary of Pilot Tests

3000 Series
Disinfection

Source	Cheney	Cheney	Cheney	Cheney	Cheney	Little Ark	Little Ark
Run Number	3010	3011	3012	3013	3014	3015	3016
Date	11/15/95	11/16/95	11/17/95	11/27/95	11/28/95	11/30/95	12/2/95
Run Hours	24.0	24.0	24.0	24.0	24.0	24.0	24.0
Pre-Ozone (mg/L)	2.0	-	-	-	-	-	-
Lime (mg/L)	136	132	135	140	140	221	225
Soda Ash (mg/L)	-	-	-	-	-	30	30
Ferric Sulfate (mg/L)	46	48	45	49	52	19	20
Polymer (mg/L)	-	-	-	-	-	-	-
Ferric Chloride (mg/L)	-	-	-	-	-	-	-
Filter Aid Polymer (mg/L)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Filter Aid Ferric Sulfate (mg/L)	-	-	-	-	-	-	-
Filter Aid Ferric Chloride (mg/L)	-	-	-	-	-	-	-

RAW

Pilot Plant Flowrate (gpm)	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Temp. (deg. C)	9.0	9.0	8.9	9.0	9.0	11.2	10.5
pH (units)	8.3	8.3	8.4	8.3	8.3	8.4	8.4
Grab Turbidity (ntu)	54.8	56.5	58.3	60.5	62.0	6.8	7.1
On-Line Turbidity (ntu)	51.2	53.3	55.8	57.2	58.9	6.7	7.0
T. Hardness as CaCO3 (mg/L)	161	161	163	166	166	316	310
T. Alkalinity as CaCO3 (mg/L)	143	144	145	147	147	260	259

SETTLED

pH (units)	9.4	9.4	9.4	9.4	9.4	9.4	9.4
Grab Turbidity (ntu)	4.1	4.6	4.0	4.3	4.7	4.9	4.5
On-Line Turbidity (ntu)	3.8	3.7	4.1	3.7	4.4	4.4	4.4
T. Hardness as CaCO3 (mg/L)	115	118	118	118	117	116	112
T. Alkalinity as CaCO3 (mg/L)	86	90	89	95	92	92	91

22" GAC / 12" Sand Media

Filtration Rate (gpm/sf)	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Avg. Headloss (in/hr)	1.5	1.5	1.6	1.7	1.7	1.2	1.2
pH (units)	8.3	8.3	8.3	8.4	8.3	8.2	8.2
Grab Turbidity (ntu)	0.09	0.10	0.15	0.18	0.17	0.15	0.20
On-Line Turbidity (ntu)	0.09	0.09	0.11	0.12	0.14	0.14	0.16
Particles <5 um (counts/mL)	58	86	72	102	-	197	-
Particles 5-15 um (counts/mL)	18	27	21	26	-	49	-

22" Anth / 12" Sand Media

Filtration Rate (gpm/sf)	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Avg. Headloss (in/hr)	1.6	1.5	1.5	1.7	1.7	1.3	1.2
pH (units)	8.3	8.3	8.3	8.4	8.3	8.2	8.2
Grab Turbidity (ntu)	0.09	0.12	0.15	0.16	0.14	0.20	0.22
On-Line Turbidity (ntu)	0.08	0.08	0.10	0.11	0.11	0.18	0.19
Particles <5 um (counts/mL)	48	76	69	124	-	241	-
Particles 5-15 um (counts/mL)	16	26	21	34	-	63	-

TOC (mg/L)

Raw	3.9	4.6	4.4	5.4	4.1	4.1	4.2
Settled	3.1	3.9	4.1	4.8	3.7	3.8	4.5
22" GAC / 12" Sand Media	2.7	3.7	3.6	4.0	3.3	2.7	2.9
22" Anth / 12" Sand Media	2.9	3.8	4.2	4.5	3.7	3.7	4.3

DISINFECTION ANALYSIS
22" GAC / 12" Sand

TTHM (ug/L)	0	43	44	42	41	76	84
HAA5 (ug/L)	4	18	18	17	18	14	18

DISINFECTION ANALYSIS
22" Anth / 12" Sand

TTHM (ug/L)	1	51	53	50	51	52	66
HAA5 (ug/L)	4	24	25	21	23	12	14

Section 5
TOC Reduction

5.1 Introduction

TOC is one of the surrogates commonly used to predict DBP concentrations. Because of the TOC reduction requirements of the proposed D/DBPR (discussed in Section 2), evaluations of various coagulants and alternative TOC reduction methods were required to determine what, if any, process modifications would have to made to the Wichita WTP in order to treat the Cheney Reservoir and Little Arkansas River. The average raw water TOC over the duration of the treatability study was 4.7 mg/L for Cheney and 7.3 mg/L for the Little Ark. The average raw water alkalinity for Cheney was 157 mg/L (as $CaCO_3$) and 165 mg/L (as $CaCO_3$) for the Little Ark. Based on the raw water alkalinities and TOC, a minimum 25% TOC reduction would be required for either surface water supply. This value is equivalent to the TOC reduction goal established for the treatability study.

Jar and pilot tests evaluated the following process alternatives:

- Coagulants/Enhanced Coagulation
- Softening/Enhanced Softening
- Adsorption
- Oxidation
- Source Water Control

5.2 Coagulants/Enhanced Coagulation

5.2.1 Preliminary Jar Tests

Initial jar tests were conducted to evaluate various coagulants in terms of both turbidity and TOC reduction. Four iron coagulants — ferric sulfate, ferrous sulfate, ferric chloride, and ferrous chloride — as well as alum and cationic polymer were tested. Lime (for Cheney) or lime/soda ash (for the Little Ark) was added as necessary to each of the waters in order to meet the softening goals.

Figures 5-1 through 5-6 show the jar tests results for the various coagulants for both Cheney and the Little Ark. For the tests on Cheney, ferric chloride and ferric sulfate provided the best results in terms of turbidity reduction and ferrous chloride provided the best TOC reduction. Doses of at least 40 mg/L were required to meet the settled water turbidity goal of 5 ntu. In general, increased doses provided increased TOC reduction; however, the TOC reduction provided by ferrous chloride did not meet the 25% TOC reduction goal. Initial jar tests on the Little Ark showed that alum provided the best turbidity reduction. In terms of TOC reduction on the Little Ark, polymer provided the highest TOC reduction but was not capable of achieving the 25% TOC reduction goal.

Because of the changes in water quality (e.g., turbidity) for both water sources seen over the duration of the treatability study, jar tests were also conducted using combinations of ferric sulfate and alum. Ferric sulfate/alum combinations have been known to be effective in treating certain river supplies in Kansas that experience high turbidities. Figures 5-7 and 5-8 show the turbidity and

Figure 5-1
Cheney Jar Tests
Settled Water Turbidity

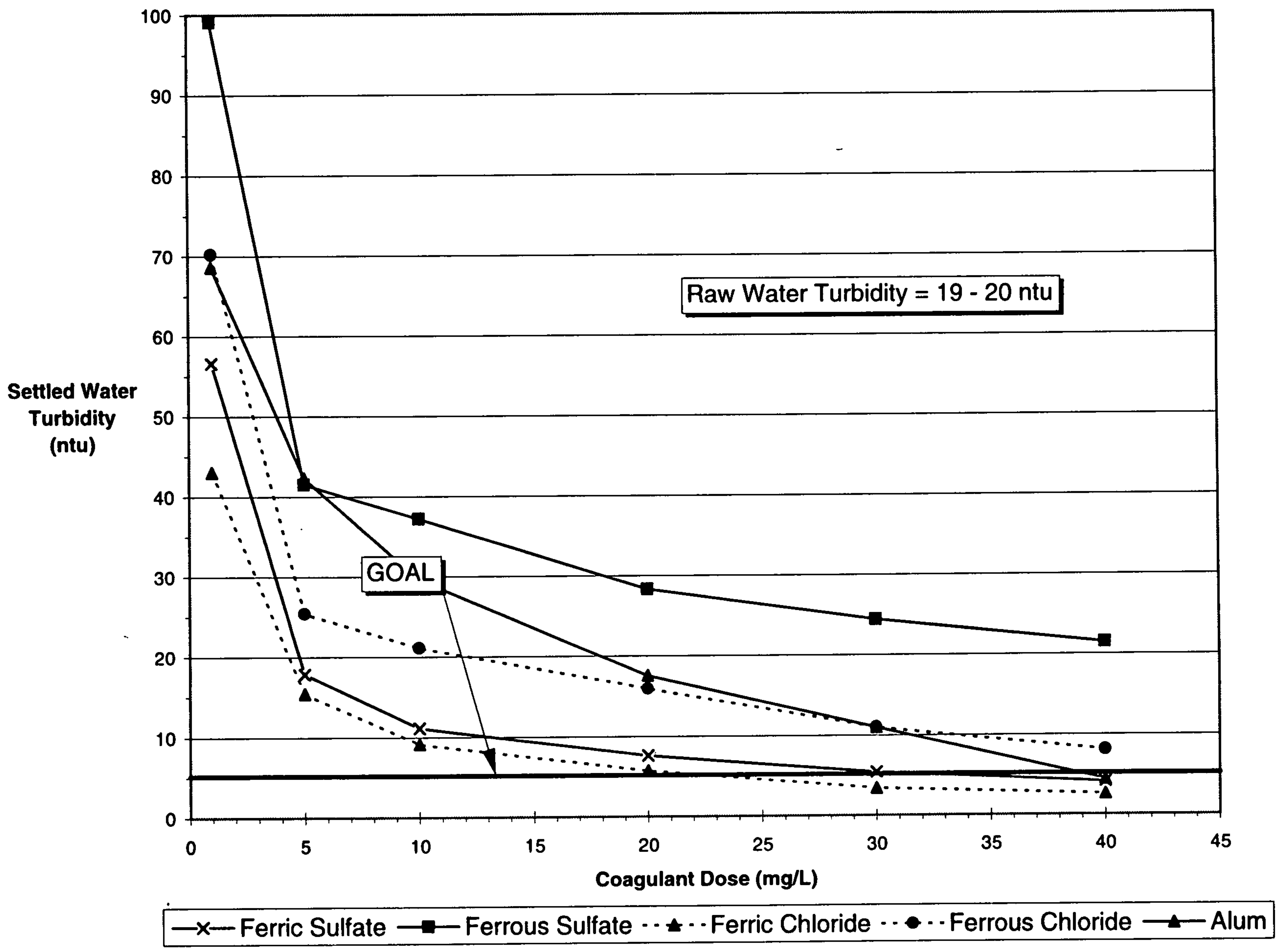


Figure 5-2
Cheney Jar Tests
TOC Reduction

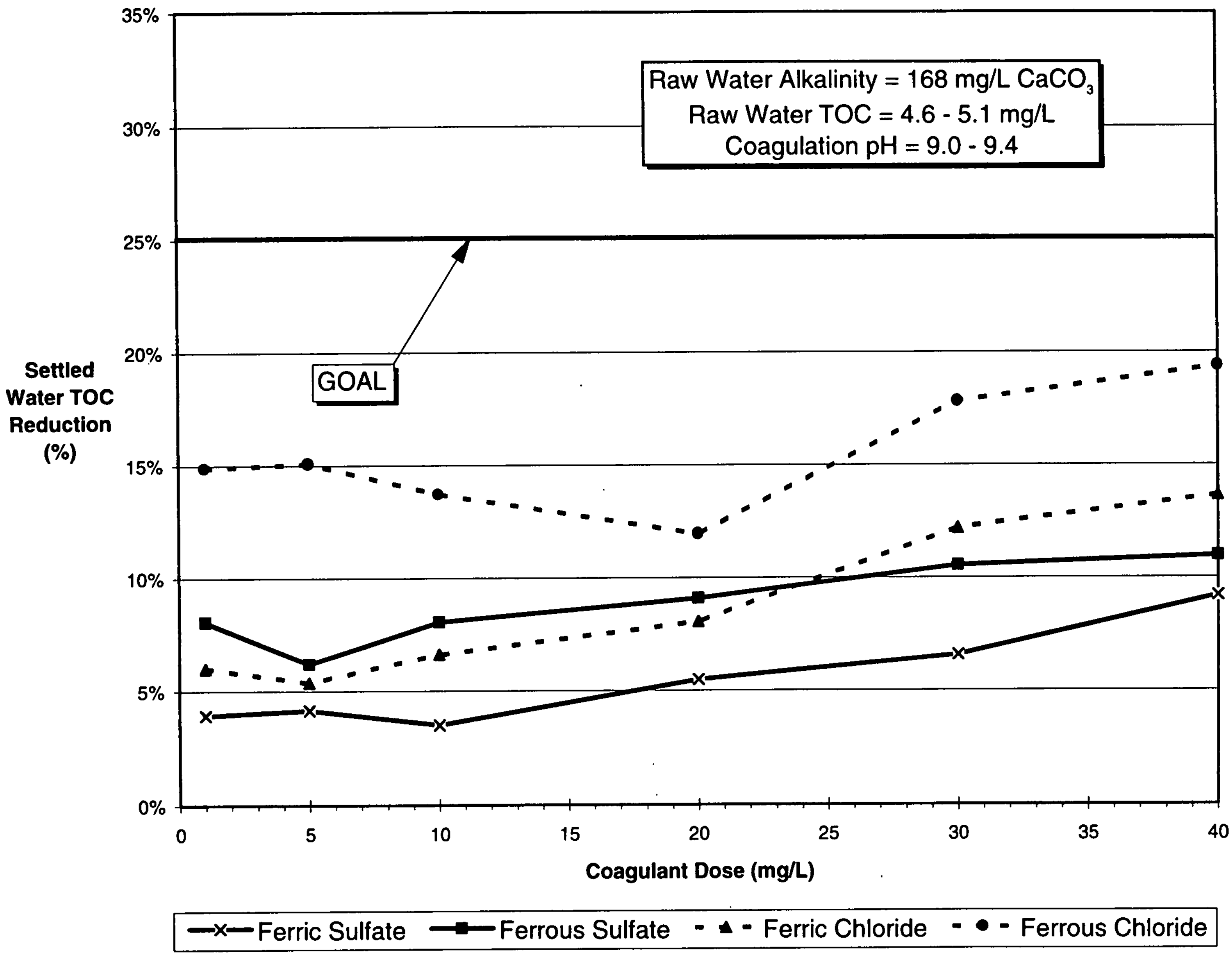


Figure 5-3
Little Arkansas Jar Tests
Settled Water Turbidity

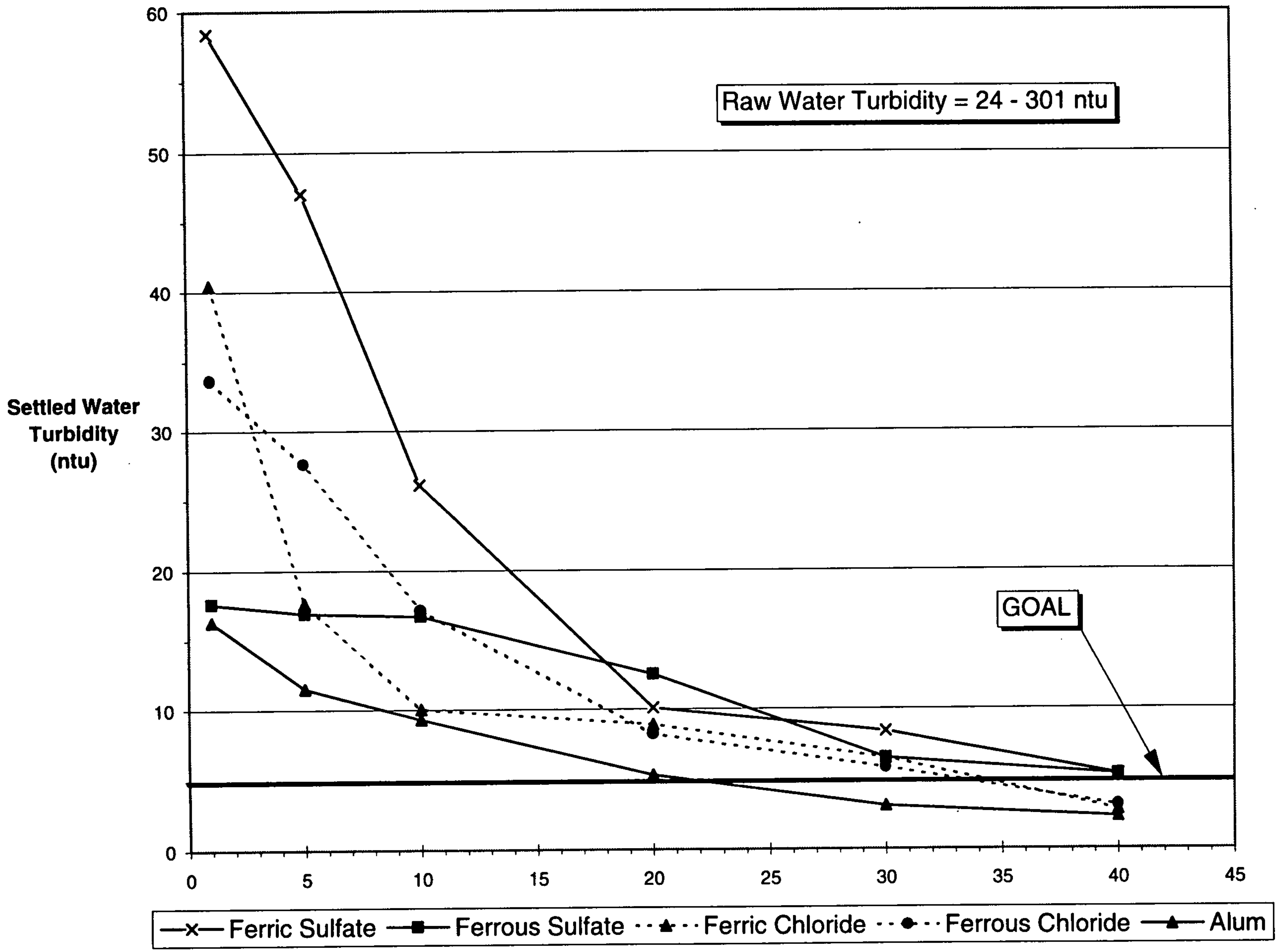


Figure 5-4
Little Arkansas Jar Tests
TOC Reduction

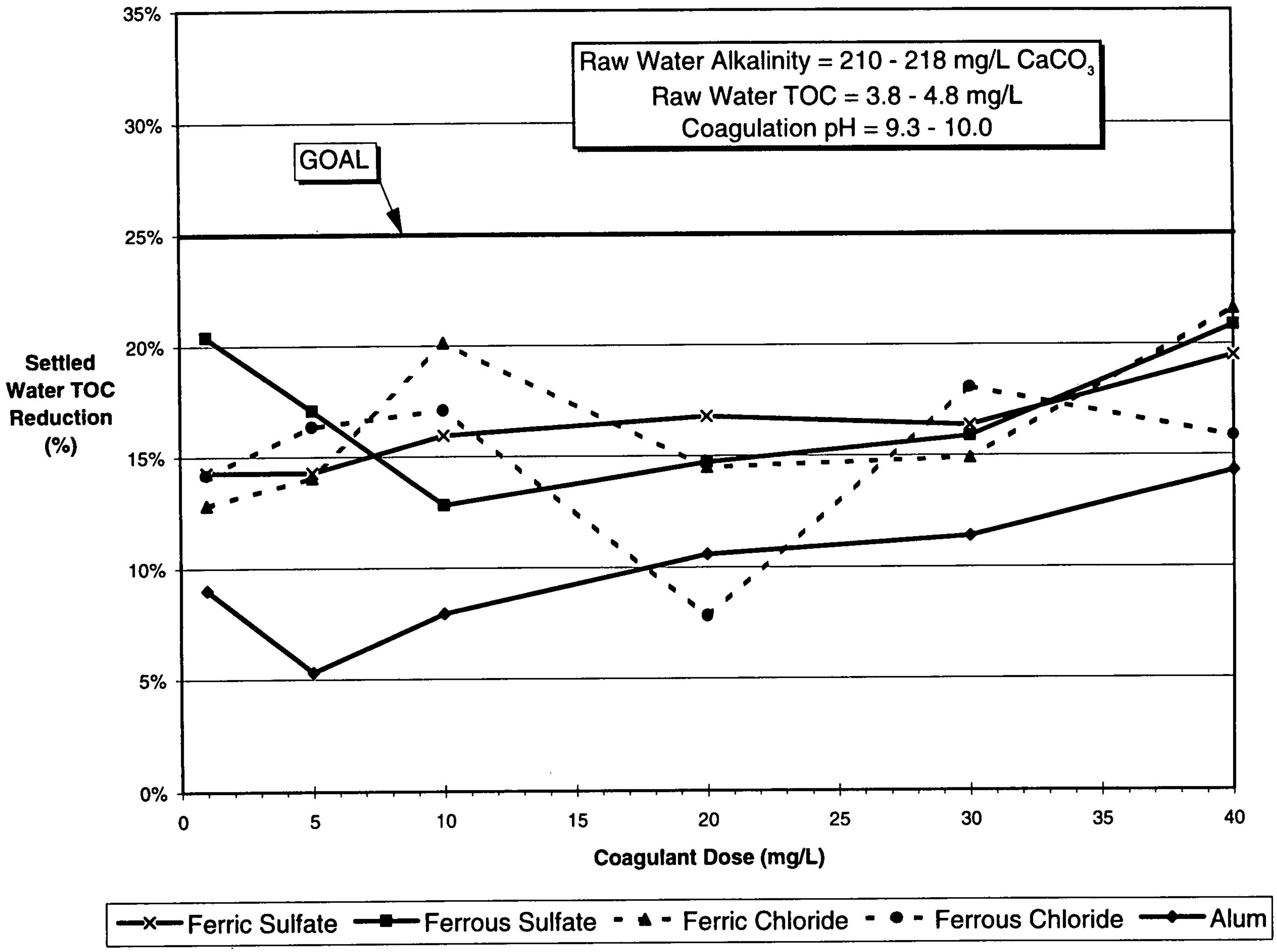


Figure 5-5
Polymer Jar Tests
Settled Water Turbidity

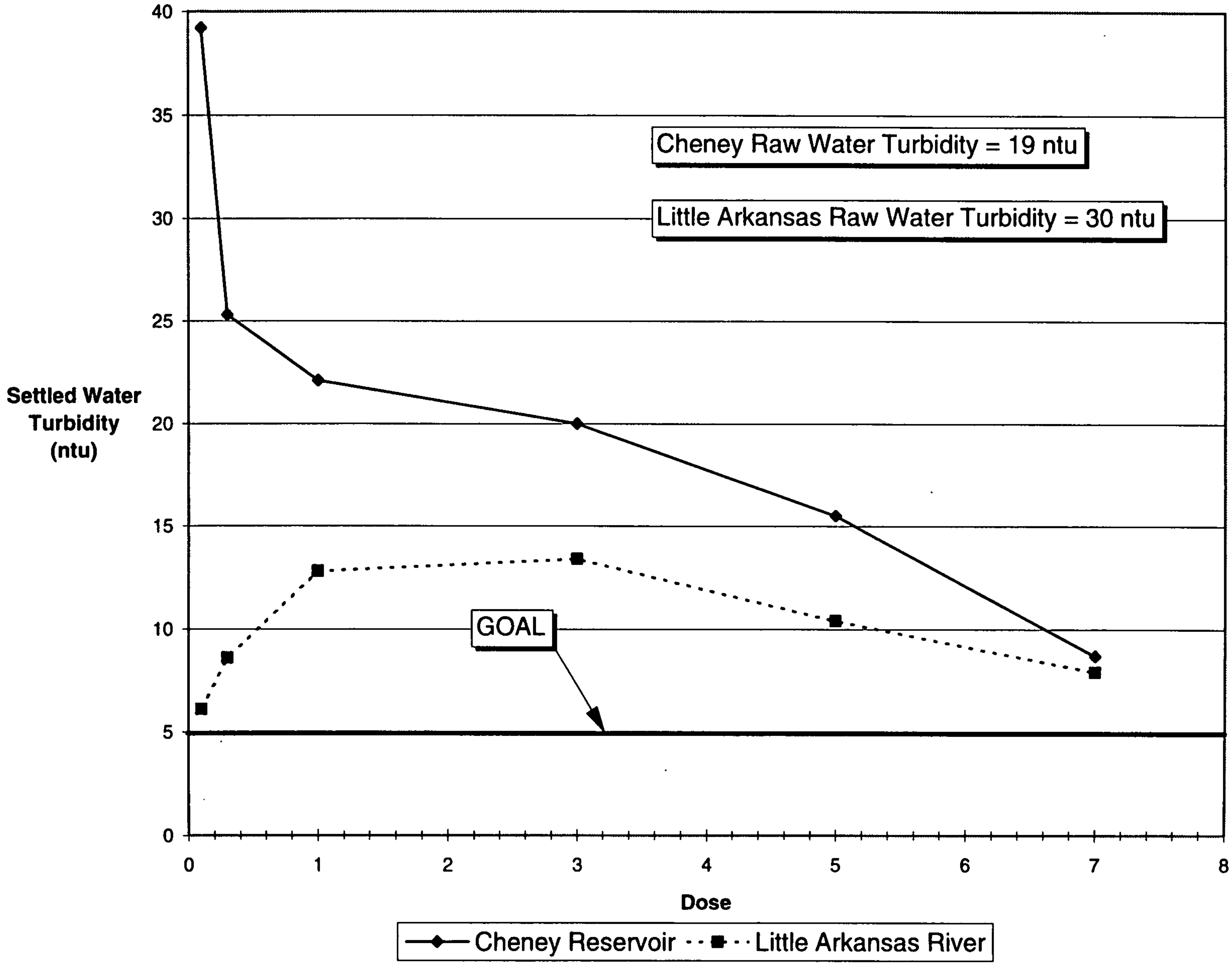


Figure 5-6
Polymer Jar Tests
TOC Reduction

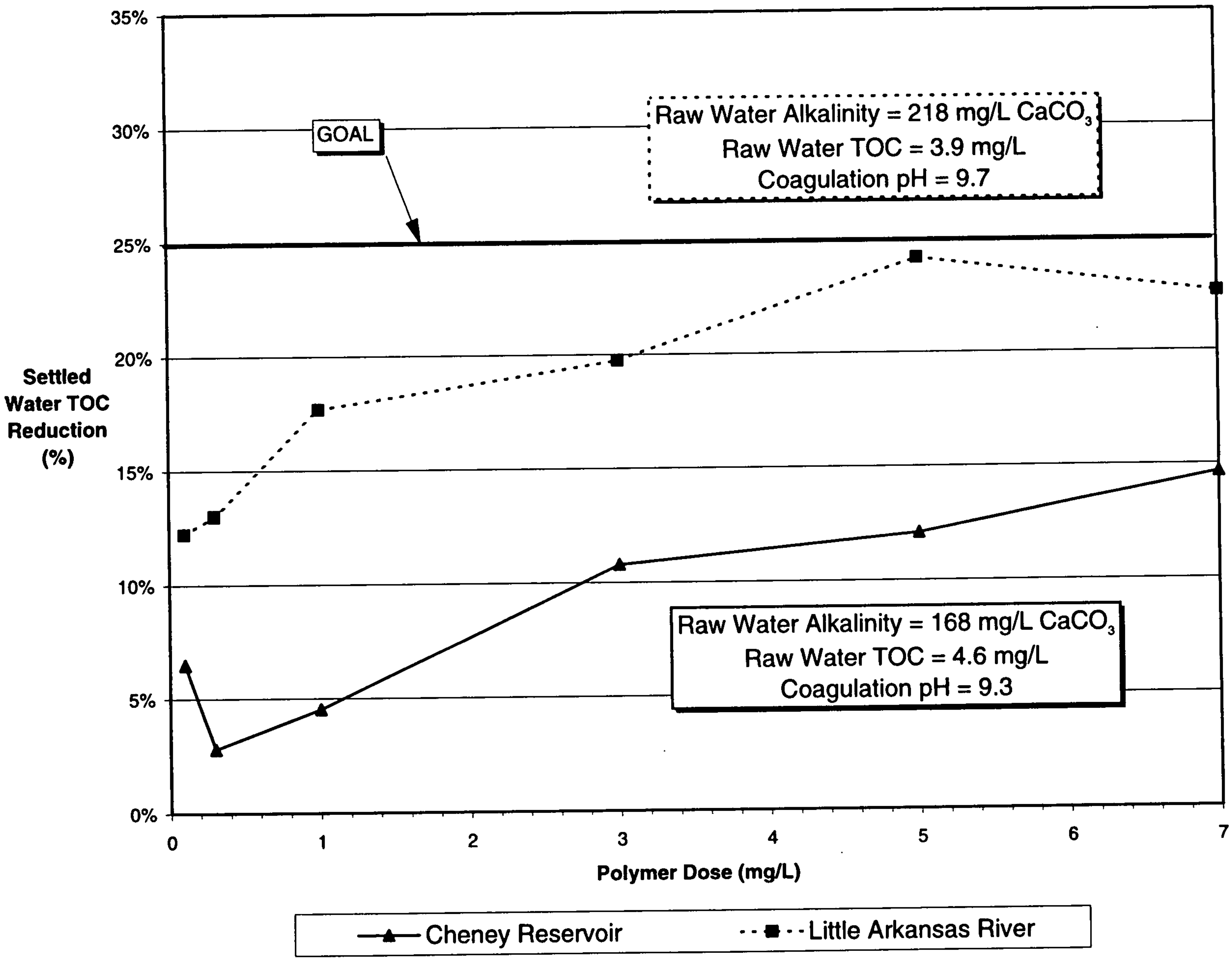


Figure 5-7
Settled Water Turbidity Using
Ferric Sulfate and Alum Combinations

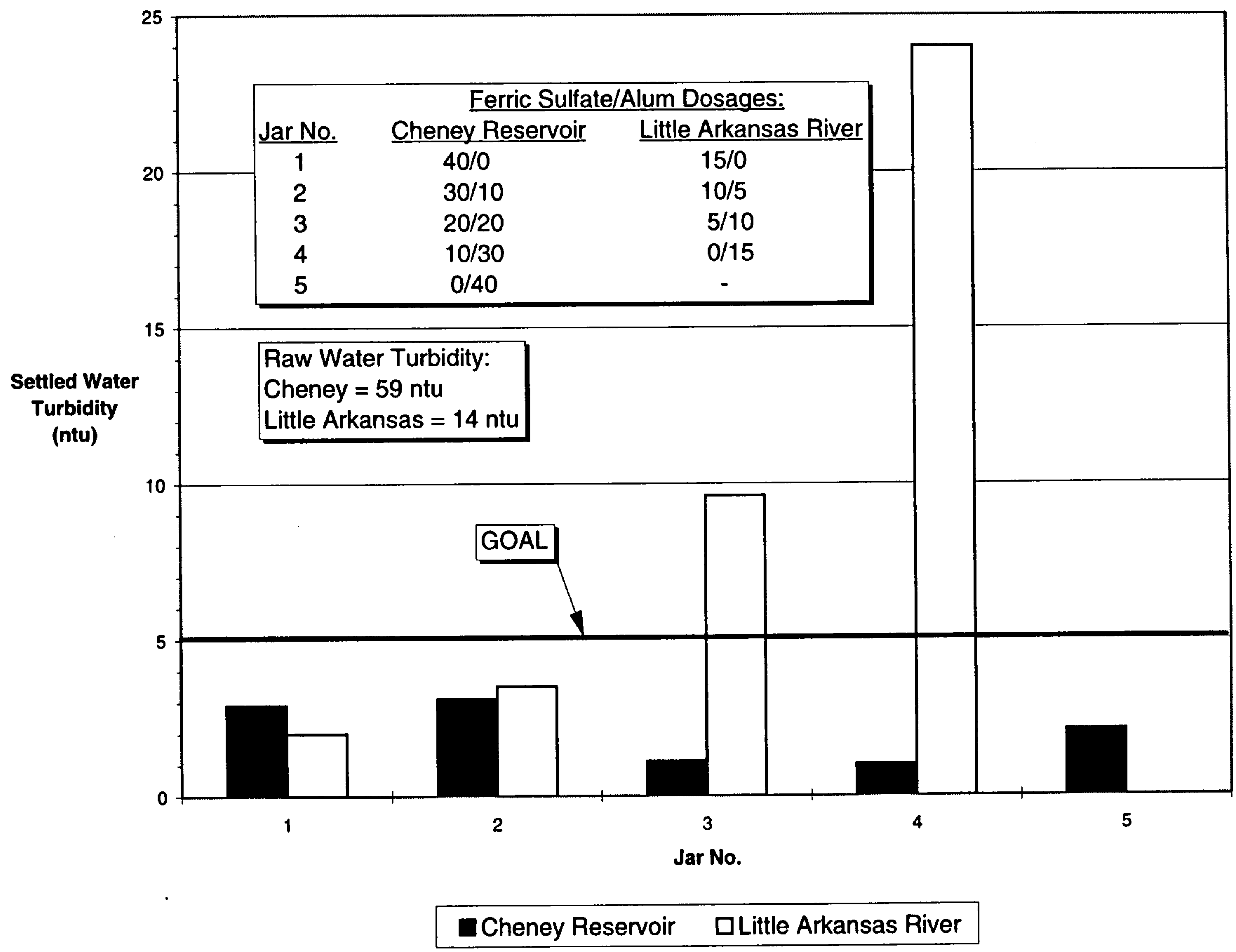
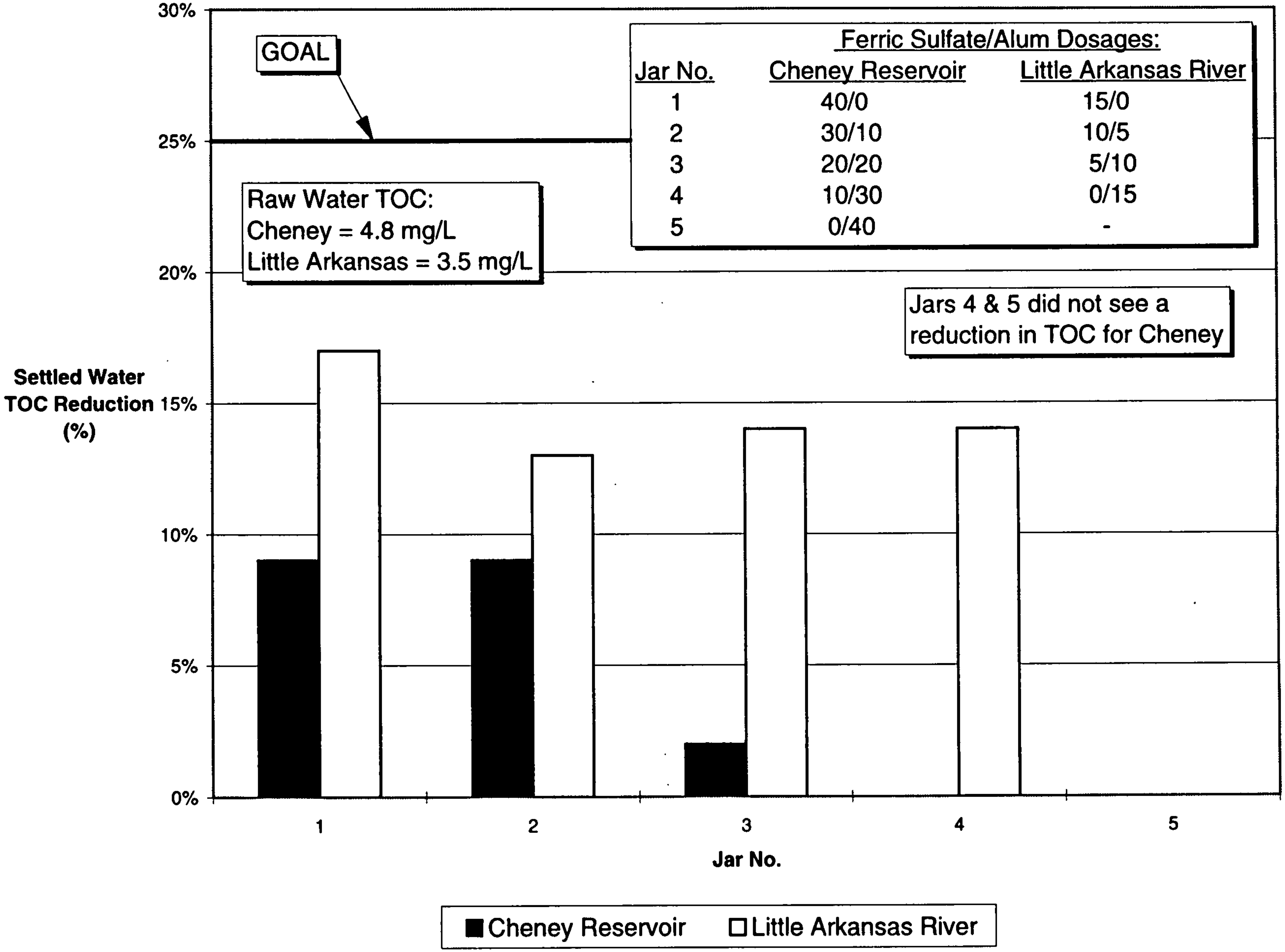


Figure 5-8
Settled Water TOC Reduction Using Ferric Sulfate and Alum Combinations



TOC results, respectively, for the ferric sulfate/alum jar tests. For Cheney, doses of 50% ferric sulfate and 50% alum provided the best settled water turbidity, although all coagulant combinations exceeded the 5 ntu settled water turbidity goal. Settled water TOC results for Cheney, however, indicated that ferric sulfate, alone, provided the highest TOC removal, however, 25% TOC reduction was not achieved. For the Little Ark, ferric sulfate, by itself, provided the best turbidity and TOC reduction, although 25% TOC reduction was not achieved. Previous jar tests did show good turbidity reduction with alum. Over the duration of the treatability study, however, alum was not capable of providing consistent settled water turbidities.

While it is accepted that the coagulation process is temperature-dependent, some incidental jar tests results revealed the degree to which temperature affects coagulation for both Cheney and the Little Ark. Figures 5-9 and 5-10 show jar tests results for Cheney with ferric sulfate and polymer, respectively. With respect to ferric sulfate, a 15°F lower water temperature requires a 67% increased dosage in order to achieve roughly the same settled water turbidity. For polymer, improved turbidities also occur at higher coagulation temperatures, however, at both cold and warm water temperatures, polymer was not capable of meeting the settled water turbidity goal. Figure 5-11 illustrates polymer coagulation results for the Little Ark. Like Cheney, polymer coagulation on the Little Ark water proved to be more effective at warm water temperatures, and for a dose of 0.10 mg/L, came very close to meeting the settled water turbidity goal.

5.2.2 Pilot Tests and Additional Jar Tests

Coagulant Evalutions

Pilot runs were conducted with each of the six coagulants to determine which coagulants provided the best turbidity and TOC reduction at the pilot level. Figures 5-12 and 5-13 show settled water turbidities and TOC reduction, respectively. For each of the pilot runs, enough coagulant was added to produce a settled water turbidity of about 5 ntu, or less; however, alum and polymer were not capable of meeting this goal. Figure 5-12 shows that all of the iron coagulants performed reasonably well in terms of turbidity — settled water turbidity for ferric sulfate was slightly higher than 5 ntu but this was due to some initial pilot plant operational problems during the run. TOC results are shown in Figure 5-13. Generally, the iron coagulants provided better TOC reduction than either alum or polymer. Ferric sulfate, however, was the only coagulant capable of meeting the 25% TOC reduction goal for the anthracite/sand filtered watered. Additionally, all coagulants were capable of meeting the 25% TOC reduction with the GAC/sand filter.

Ferric Sulfate Evaluations

Because of the acceptable turbidity and TOC reduction results achieved with ferric sulfate, as well as the fact that ferric sulfate is currently fed at the Wichita WTP, the majority of the remaining pilot tests were conducted with ferric sulfate as the primary coagulant.

Cheney Turbidity Results

Figures 5-14 and 5-15 show settled and filtered water turbidities, respectively, for the Cheney pilot runs with ferric sulfate. Ferric sulfate doses tended to increase with increasing raw water turbidity. Additionally, any ferric sulfate doses listed that are 80 mg/L or greater were used only to evaluate enhanced coagulation at a higher coagulant dose and were not required for turbidity reduction.

Figure 5-9
Cheney Jar Tests
Temperature Effect on Ferric Sulfate

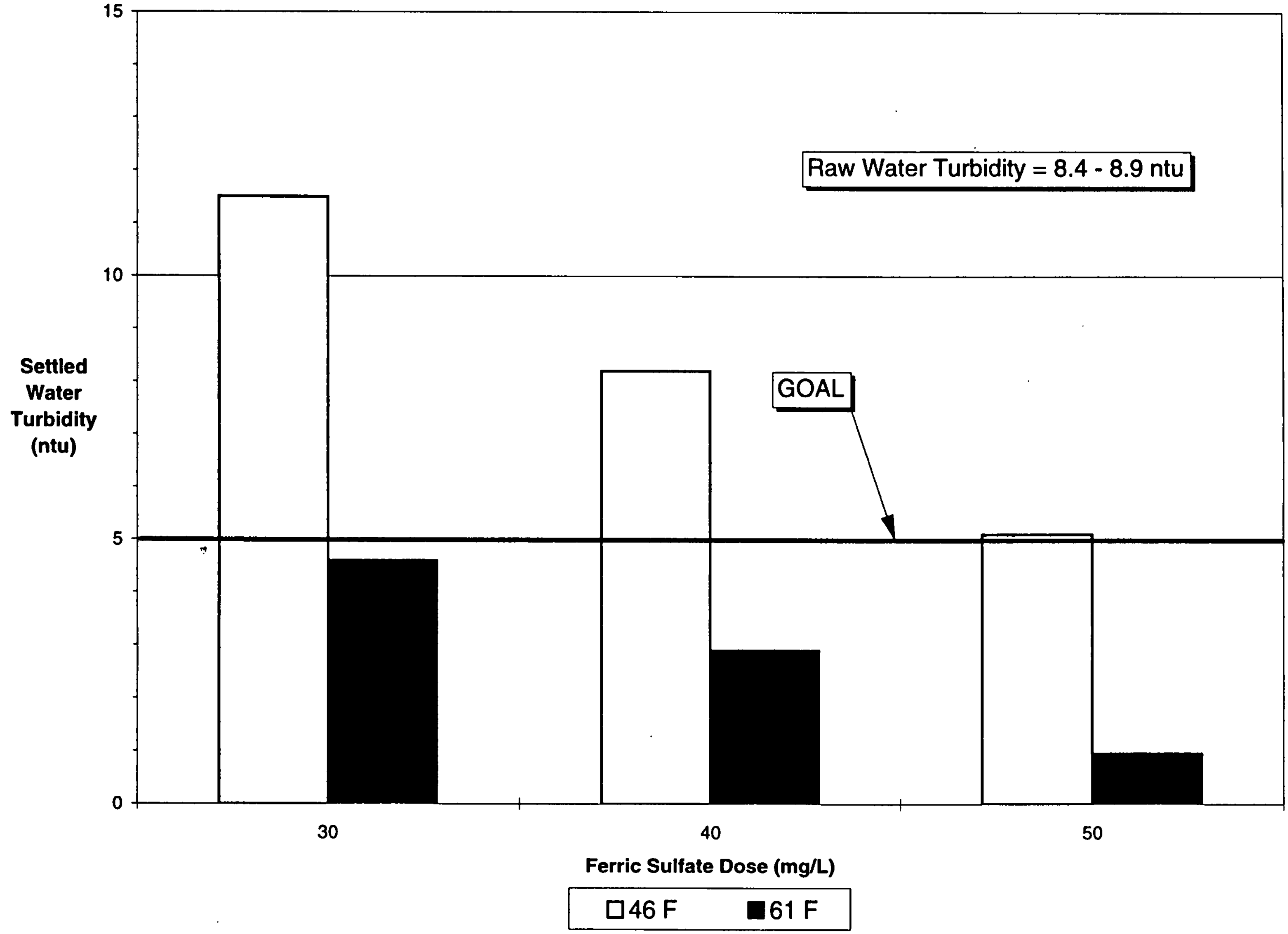


Figure 5-10
Cheney Jar Tests
Temperature Effect on Polymer

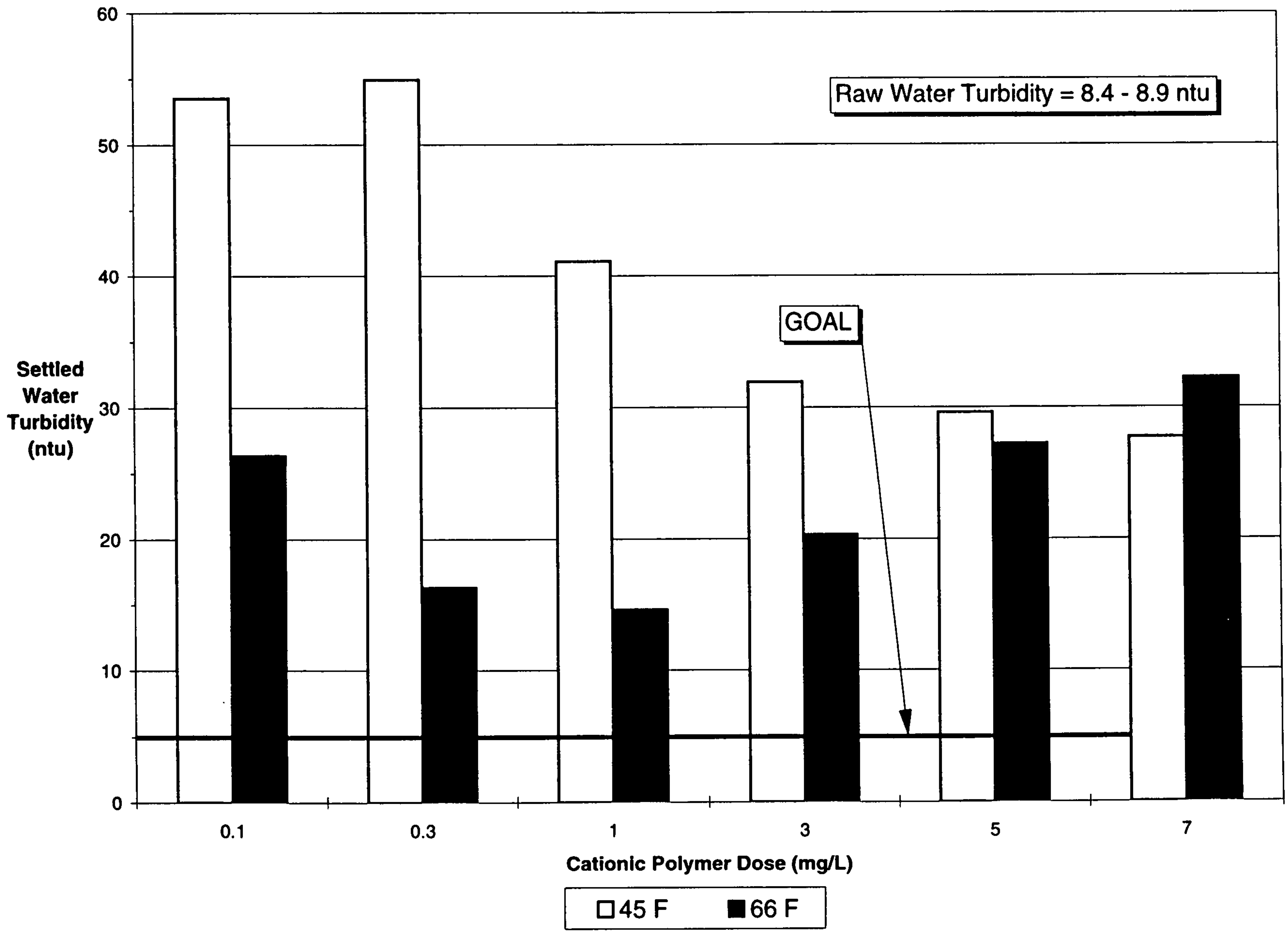


Figure 5-11
Little Arkansas Jar Tests
Temperature Effect on Polymer

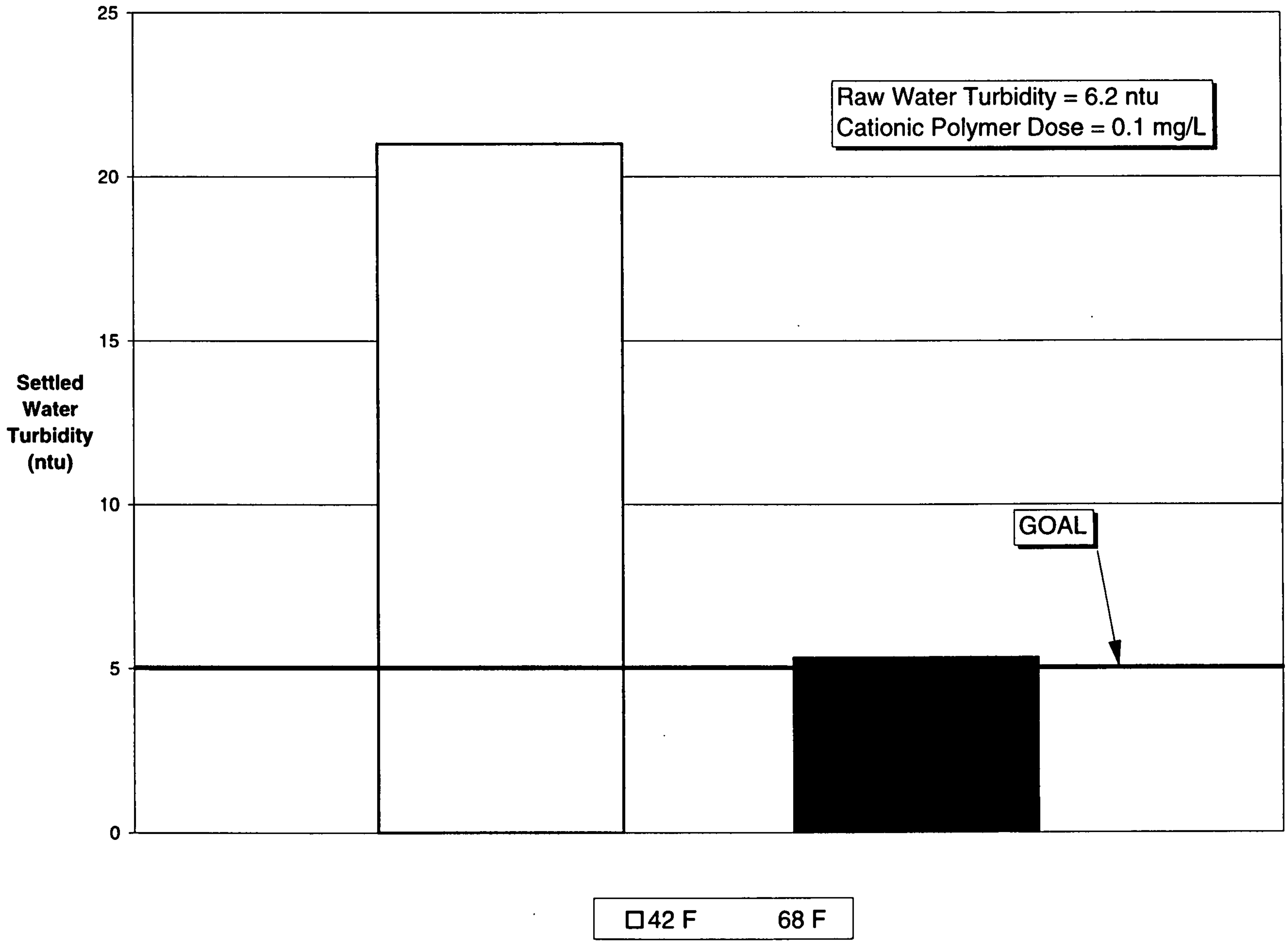


Figure 5-12
Cheney Pilot Runs
Alternative Coagulants Turbidity Reduction

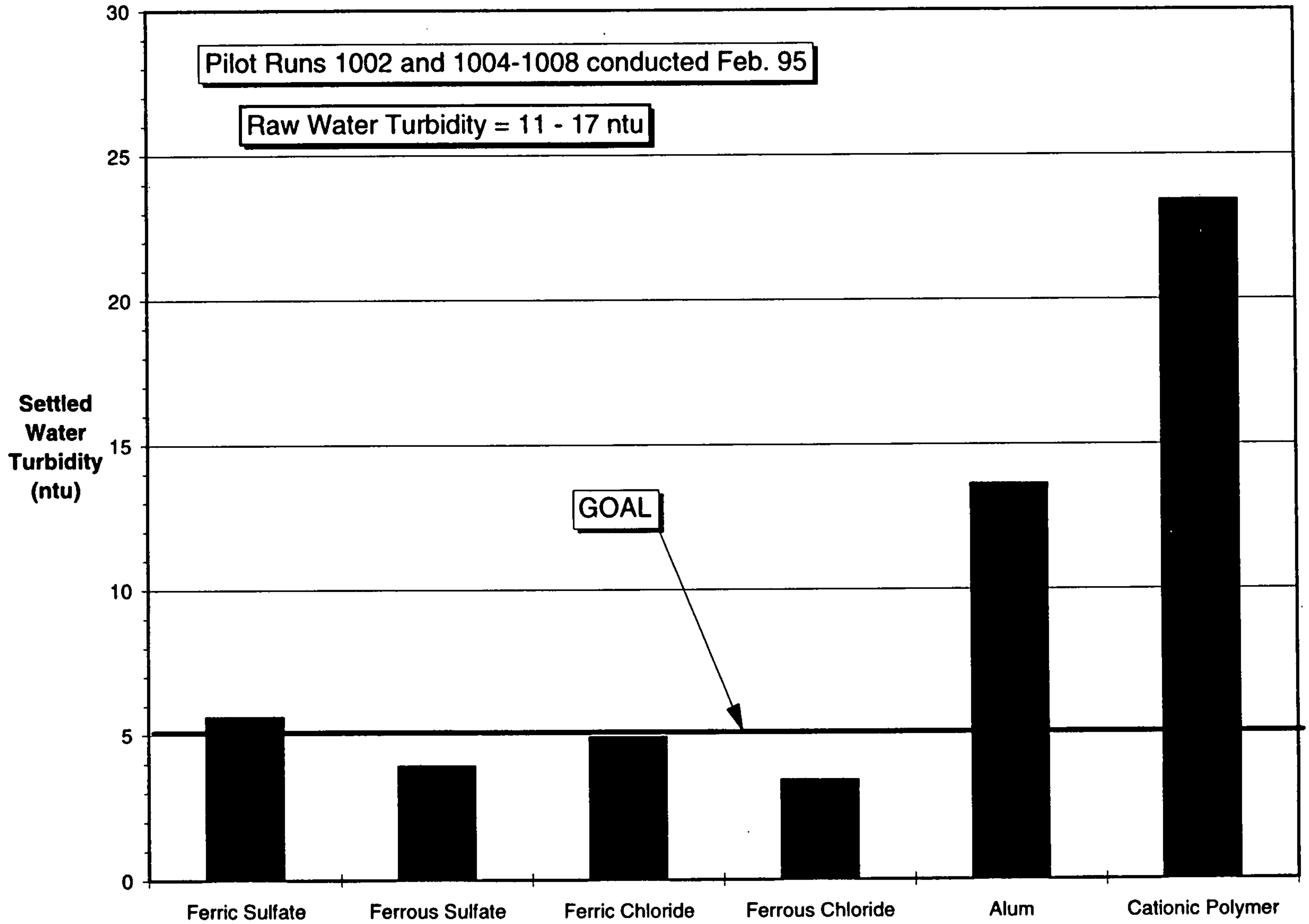


Figure 5-13
Cheney Pilot Runs
Alternative Coagulants TOC Reduction

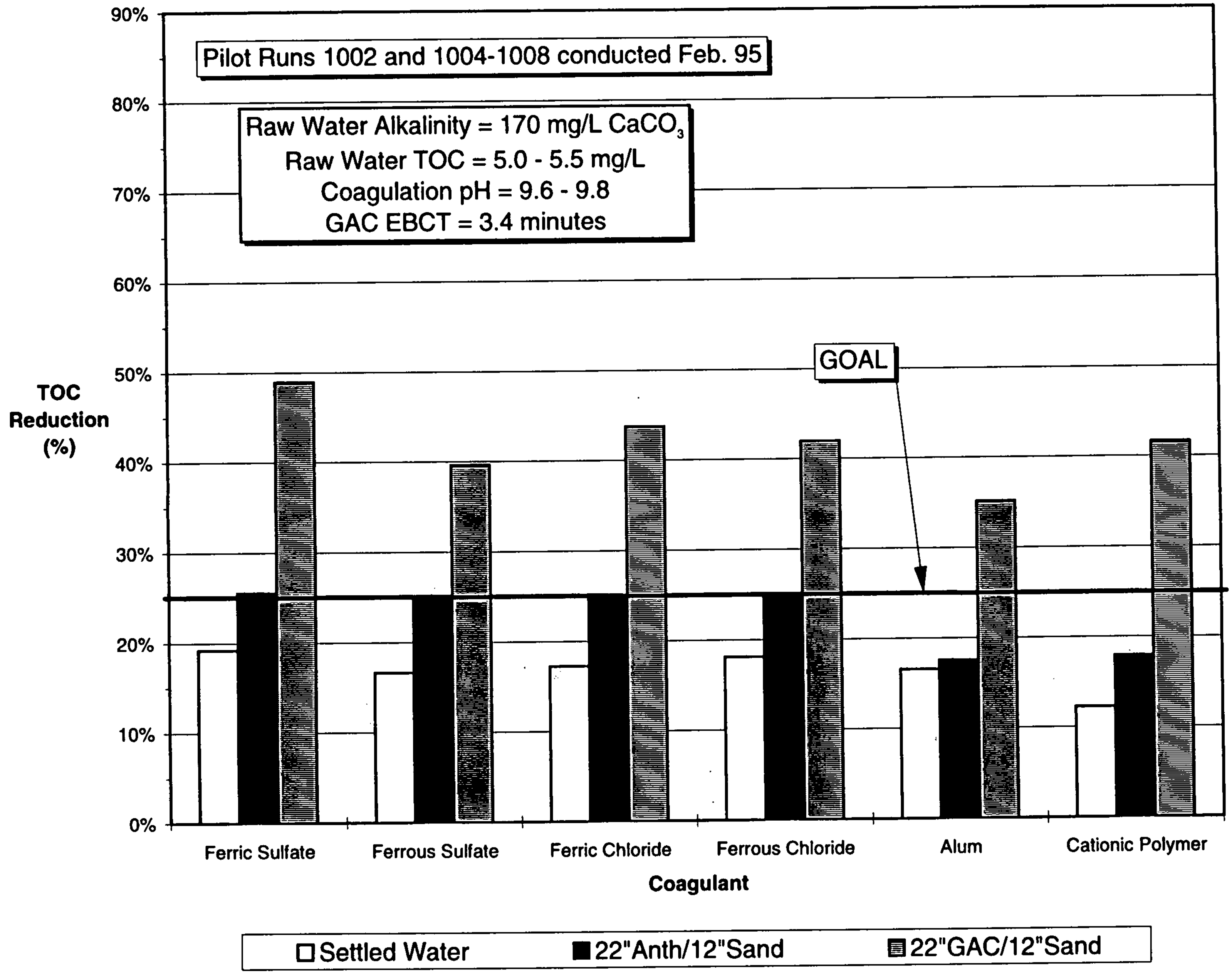
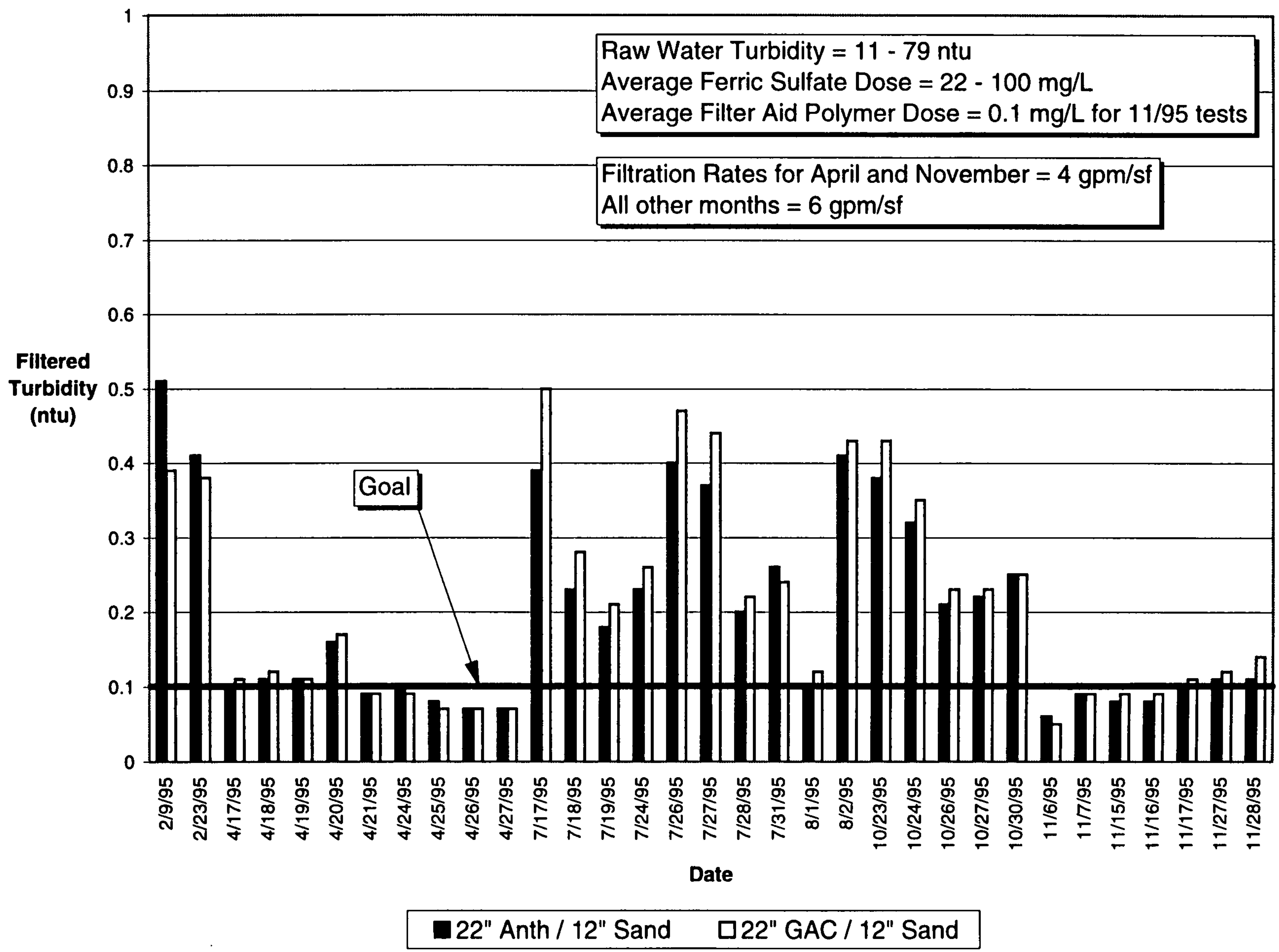


Figure 5-15
Cheney Pilot Runs
Average Filtered Water Turbidity Using Ferric Sulfate



The highest ferric sulfate dose required for turbidity reduction was about 70 mg/L. For the most part, settled water turbidities of 5 ntu were easily achieved. Filtered water turbidities, as shown in Figure 5-15, however, varied somewhat. This variation is most likely due to several contributing factors, which include: applied water quality, whether or not a filter aid was used, and, to some extent, filtration rate. The impact of filtration rate, however, is believed to be small based on the 1991 Filter Pilot Study conducted for the City of Wichita. The 1991 Filter Pilot Study evaluated filtration rates of 4-10 gpm/sf, and found that filtration rate had little impact on filtered water quality.

Little Ark Turbidity Results

Due to the high, and often sporadic, raw water turbidities for the Little Ark, fewer pilot runs on this water source were able to be completed when compared to Cheney. Nevertheless, pilot runs that were completed on the Little Ark are shown in Figures 5-16 and 5-17. With the exception of May 7, 1995, all pilot runs for May 1995 were conducted during very high raw water turbidities (114-569 ntu) and, given the constraints of the existing treatment train (pilot plant and full-scale WTP), very high ferric sulfate doses (140-255 mg/L), which are impractical on a full-scale, were required in order to treat the water using a conventional rapid mix, flocculation, sedimentation, and filtration process. For the tests conducted on the Little Ark, most pilot runs were capable of meeting or exceeding the 5 ntu settled water turbidity goal, as shown in Figure 5-16. Figure 5-17, however, illustrates that no pilot runs were capable of achieving the 0.10 ntu filtered water goal, and a few pilot runs exceeded 0.50 ntu on average. All filter runs on the Little Ark were conducted at filtration rates of 4 gpm/sf, so it is unclear why filtered turbidities of 0.10 ntu could not be achieved — even when feeding a filter aid polymer.

Cheney TOC Results

TOC reduction for the Cheney pilot plant runs with ferric sulfate is shown in Figure 5-18. With the exception of the one pilot plant run conducted February 9, 1995, conventional softening and filtration with the anthracite/sand filter was not capable of consistently meeting the 25% TOC reduction goal. Filtration with the GAC/sand filter did achieve 25% TOC reduction, however, degradation of the GAC bed was noticed in the third month of intermittent operation.

A comparison of the effect higher ferric sulfate doses had on TOC reduction is illustrated in Figure 5-19. For an increase in ferric sulfate of 150%, there was only a 10% improvement in TOC reduction for the anthracite/sand filtered water. Additionally, even with the increase in ferric sulfate dosages, conventional softening and filtration with the anthracite/sand filter was not capable of achieving the 25% TOC reduction requirement. However, GAC/sand filtration did meet the 25% TOC reduction goal.

Dissolved organic carbon (DOC) samples were collected and analyzed for several pilot plant runs. The fraction of DOC/TOC for the raw water varied from 82% - 96%, which is fairly typical for most water supplies. Percent DOC removal was similar to TOC removal for Cheney.

Figure 5-16
Little Arkansas Pilot Runs
Average Settled Water Turbidity Using Ferric Sulfate

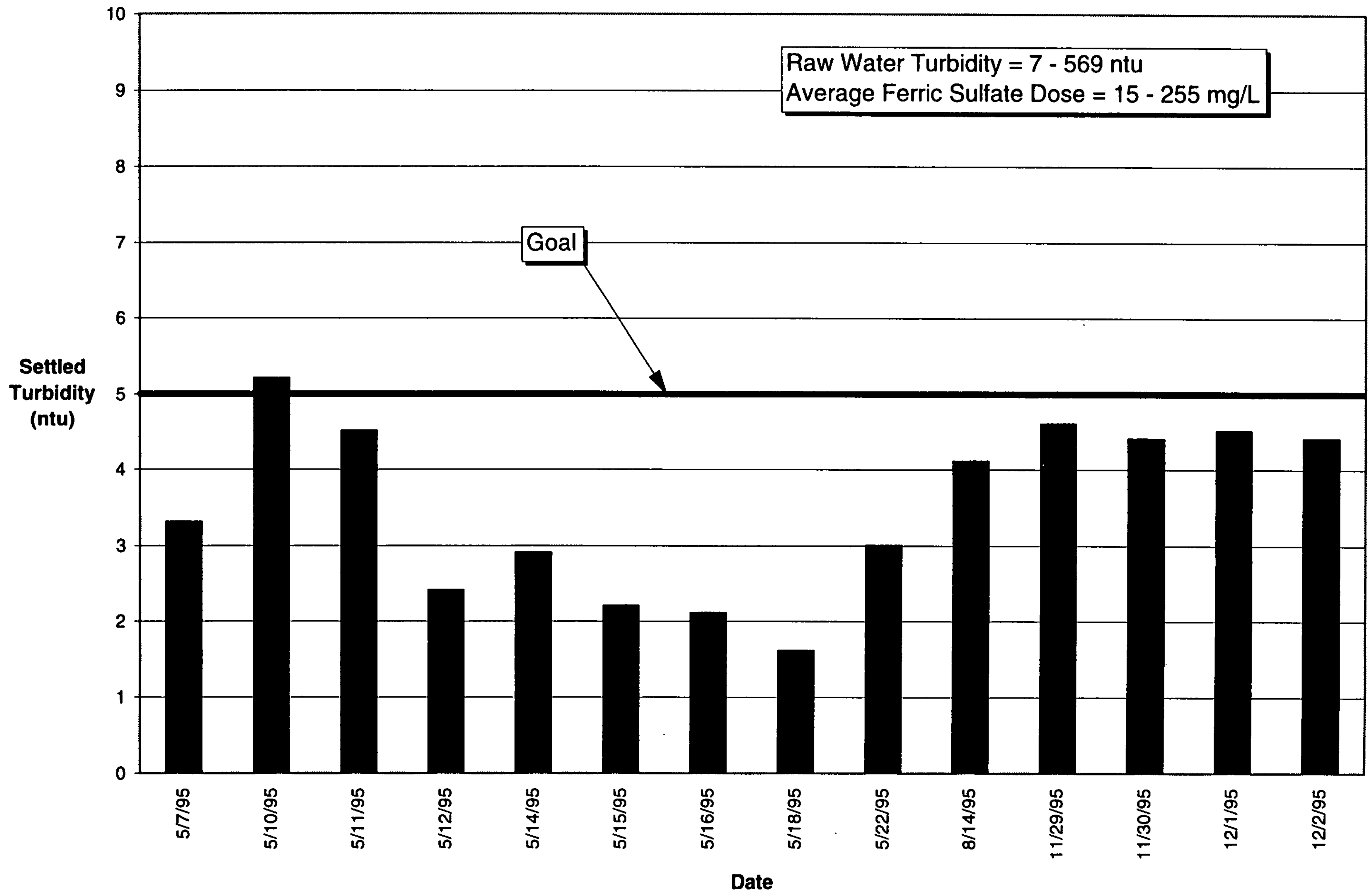


Figure 5-17
Little Arkansas Pilot Runs
Average Filtered Water Turbidity Using Ferric Sulfate

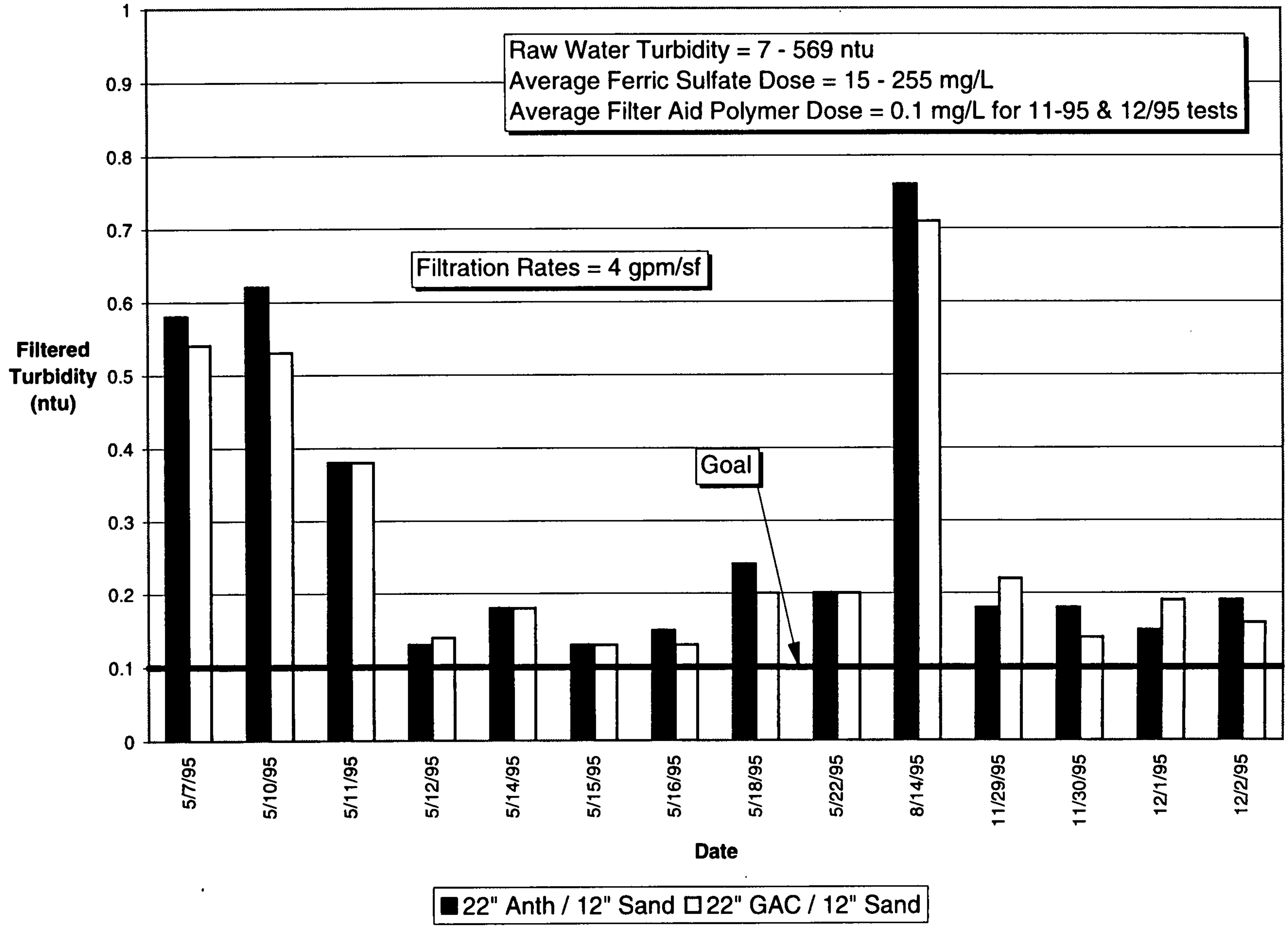


Figure 5-18
Cheney Pilot Runs
TOC Reduction Using Ferric Sulfate

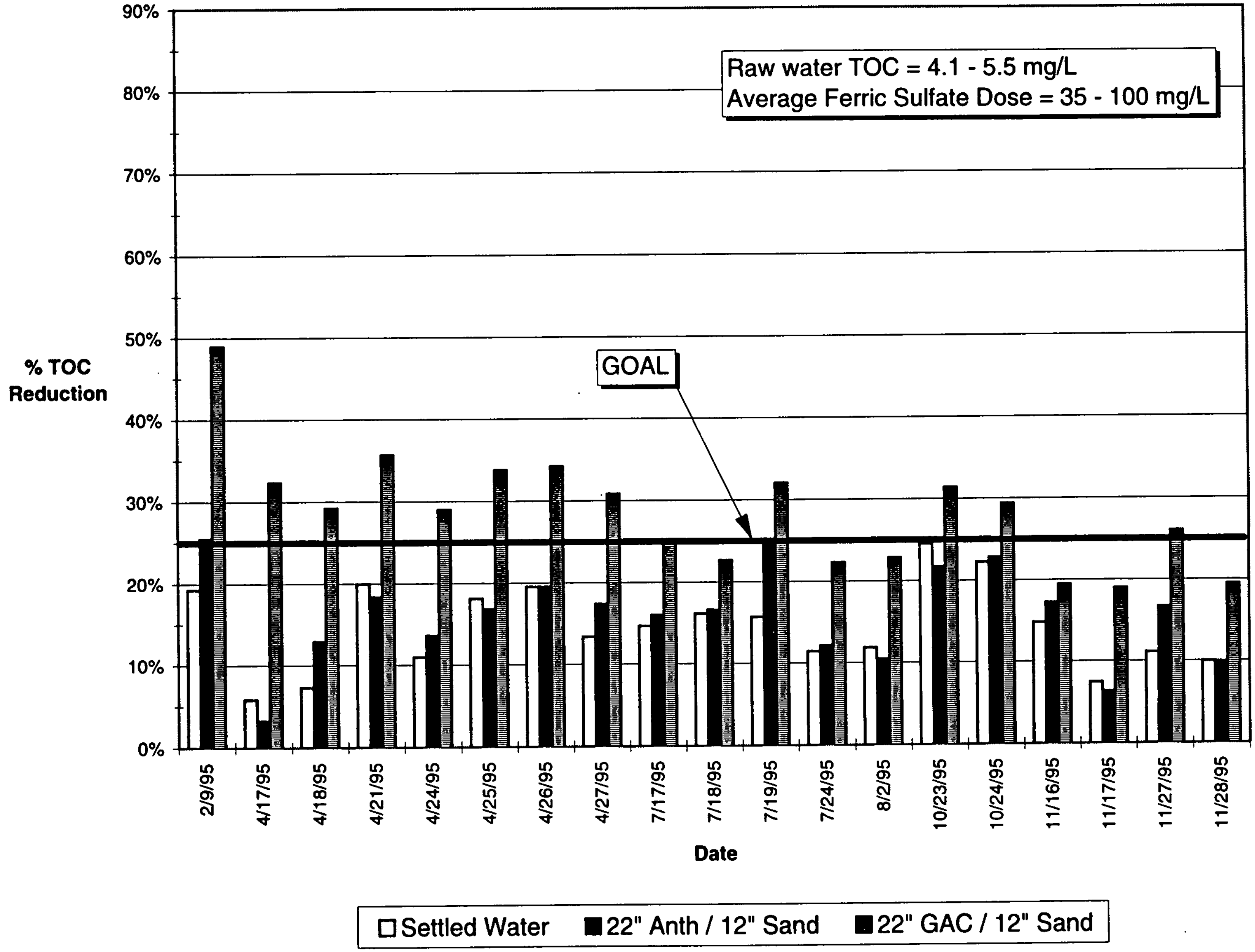
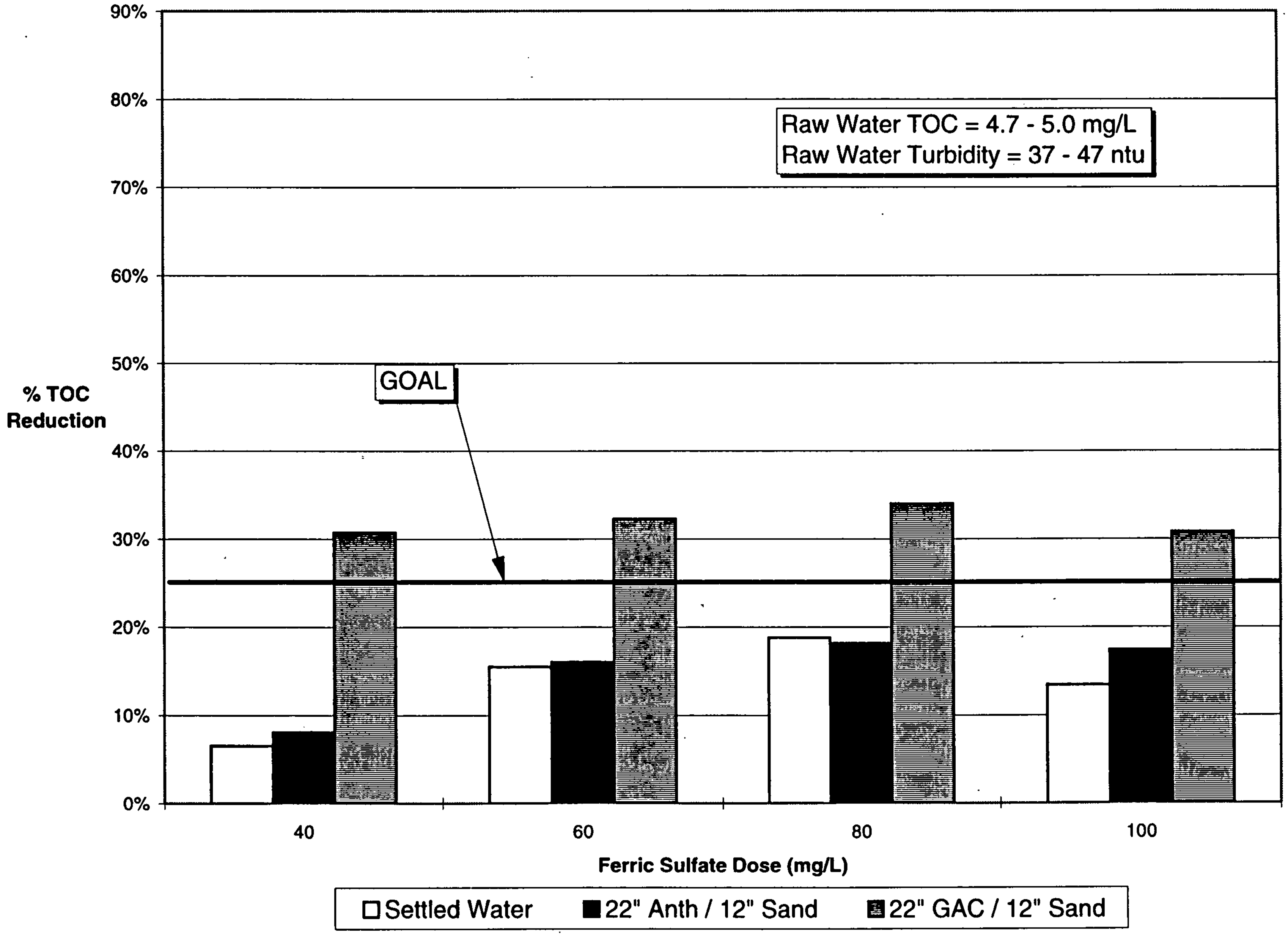


Figure 5-19
Cheney Pilot Runs
TOC Reduction For Various Ferric Sulfate Doses



Little Ark TOC Results

Figure 5-20 shows TOC reduction for the Little Ark pilot plant runs. In four of the pilot plant runs, conventional softening followed by anthracite/sand filtration exceeded the 25% TOC reduction requirement. However, for the three runs in May that exceeded 25%, a very high (130 mg/L or greater) ferric sulfate dose was used. For the one run in March that exceeded 25% TOC reduction with the anthracite/sand filter, a coagulation pH of 10.4 was observed which may have helped contribute to higher removal of magnesium hardness to simulate enhanced precipitative softening. For the November and December pilot runs shown on Figure 5-20, the Little Ark raw water quality was relatively stable, with low turbidity (less than 10 ntu) and low raw water TOC (about 4 mg/L). Ferric sulfate doses during these winter runs ranged from about 15 to 20 mg/L, however, TOC reduction for these pilot tests did not meet the 25% TOC reduction criteria unless GAC filtration was used.

Similar to Cheney, DOC samples were analyzed for several pilot plant runs. The fraction of DOC/TOC for the raw water varied from 85% - 95% and percent DOC removal was similar to TOC removal.

Presedimentation Jar Tests

Because of the high turbidities on the Little Ark and the fact that treating the Little Ark with a conventional rapid mix, flocculation, sedimentation, and filtration process was not proving sufficient, CDM decided to conduct a few jar tests simulating a presedimentation basin. Little Ark water was collected, rapid mixed with selected coagulants at various dosages for 10 seconds, then allowed to settled over a time period of 15 to 60 minutes. Results from these jar tests with ferric sulfate and polymer are shown in Figures 5-21 and 5-22, respectively. In all cases, the addition of coagulant did not improve turbidity. Additionally, when no coagulant was added and settled water turbidities were measured over 60 minutes, only a slight drop in turbidity — from a raw water turbidity of 161 ntu to settled water turbidity at 60 minutes of 155 ntu — was noticed. From these results, it appears that most of raw water turbidity in the Little Ark is of a suspended nature and requires rapid mixing and flocculation in order to form floc particles large enough to settle.

TOC Correlations

The linear correlation coefficient, r, between coagulation pH and TOC reduction is shown in Figure 5-23. These correlations are shown for the Little Ark water since the softening requirement varied considerably. For the most part, there was only a small correlation between settled water and anthracite/sand filtered water TOC reduction and coagulation pH, with r = - 0.480 and r = - 0.314, respectively. While it appears the lower pH waters provided better TOC reduction, further investigation of these results show that the raw water TOCs during these low pH periods was fairly high (i.e., 6.8 - 17.7 mg/L). Thus, the improved TOC reduction at the lower coagulation pHs may have more to do with the high raw water TOC than the lower pH. This phenomena seems to be fairly constant for the Little Ark in that during rain events, turbidity and TOC increase while pH, hardness, and alkalinity decrease (as would be expected).

What is apparent from Figure 5-23 is the softening pHs of 9.0 - 9.5 provided the lowest TOC removal. However, when high pH (i.e., 10.4), enhanced softening was practiced, TOC reduction for

Figure 5-20
Little Arkansas Pilot Runs
TOC Reduction Using Ferric Sulfate

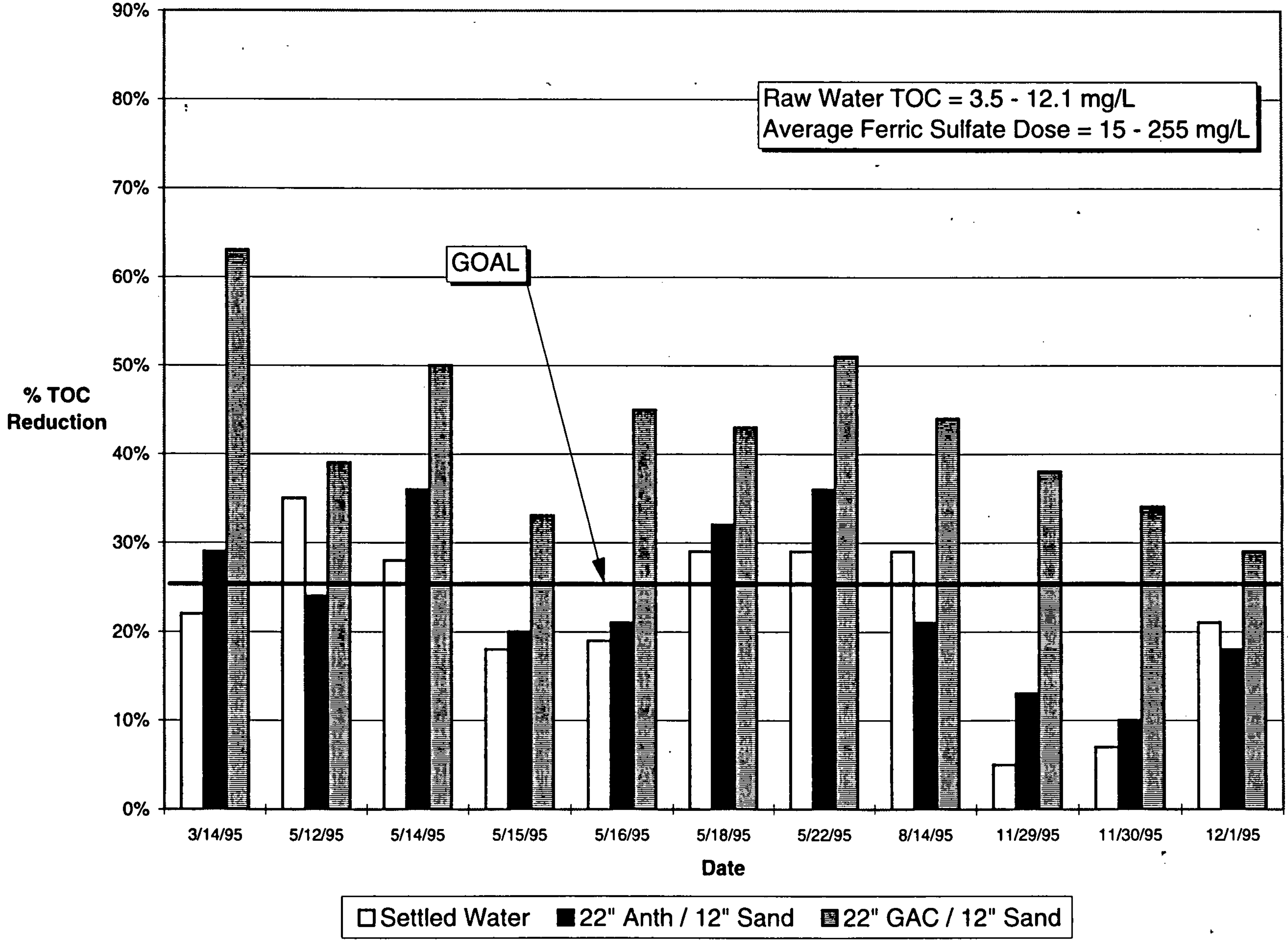


Figure 5-21
Little Arkansas River
Presedimentation Jar Tests with Ferric Sulfate

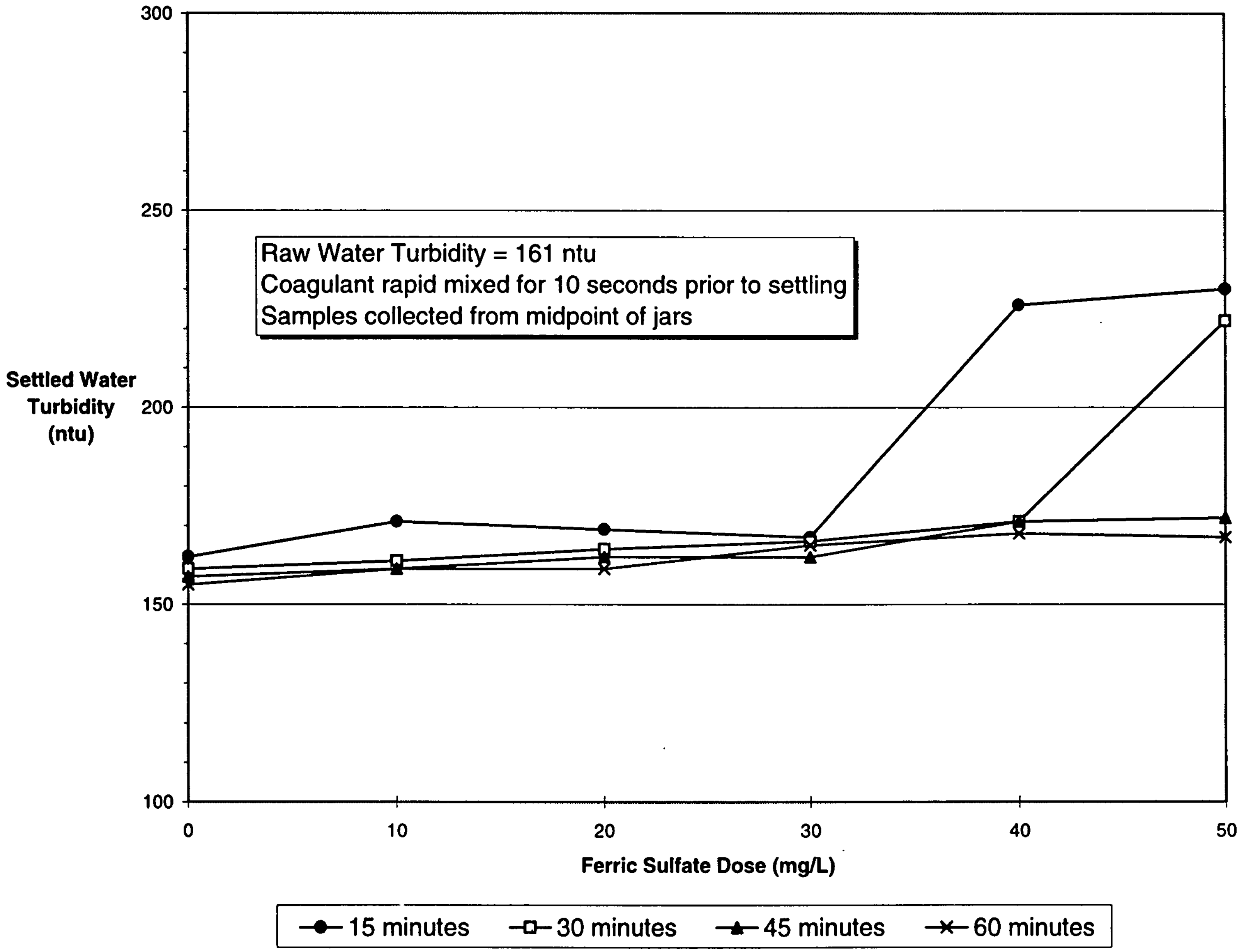


Figure 5-22
Little Arkansas River
Presedimentation Jar Test with Polymer

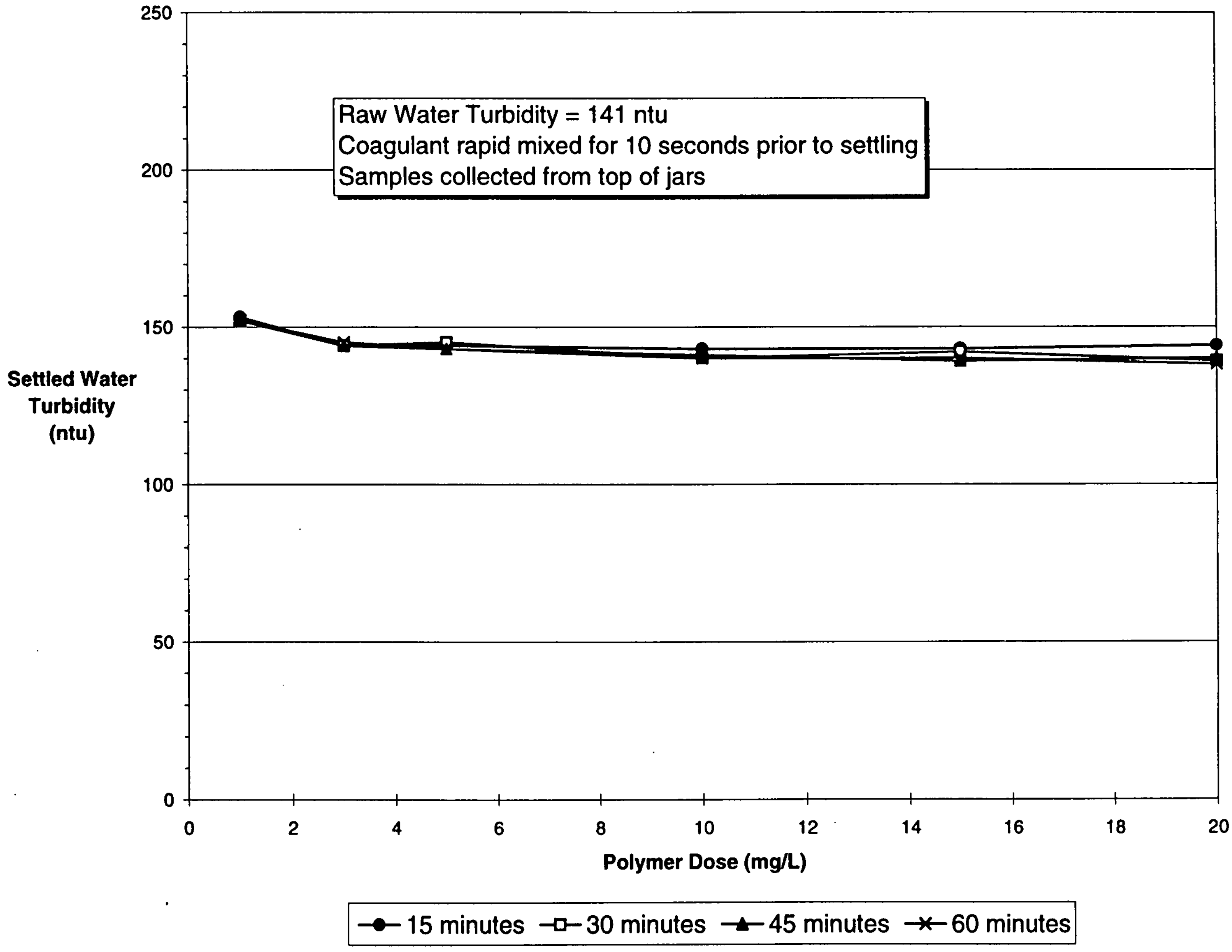
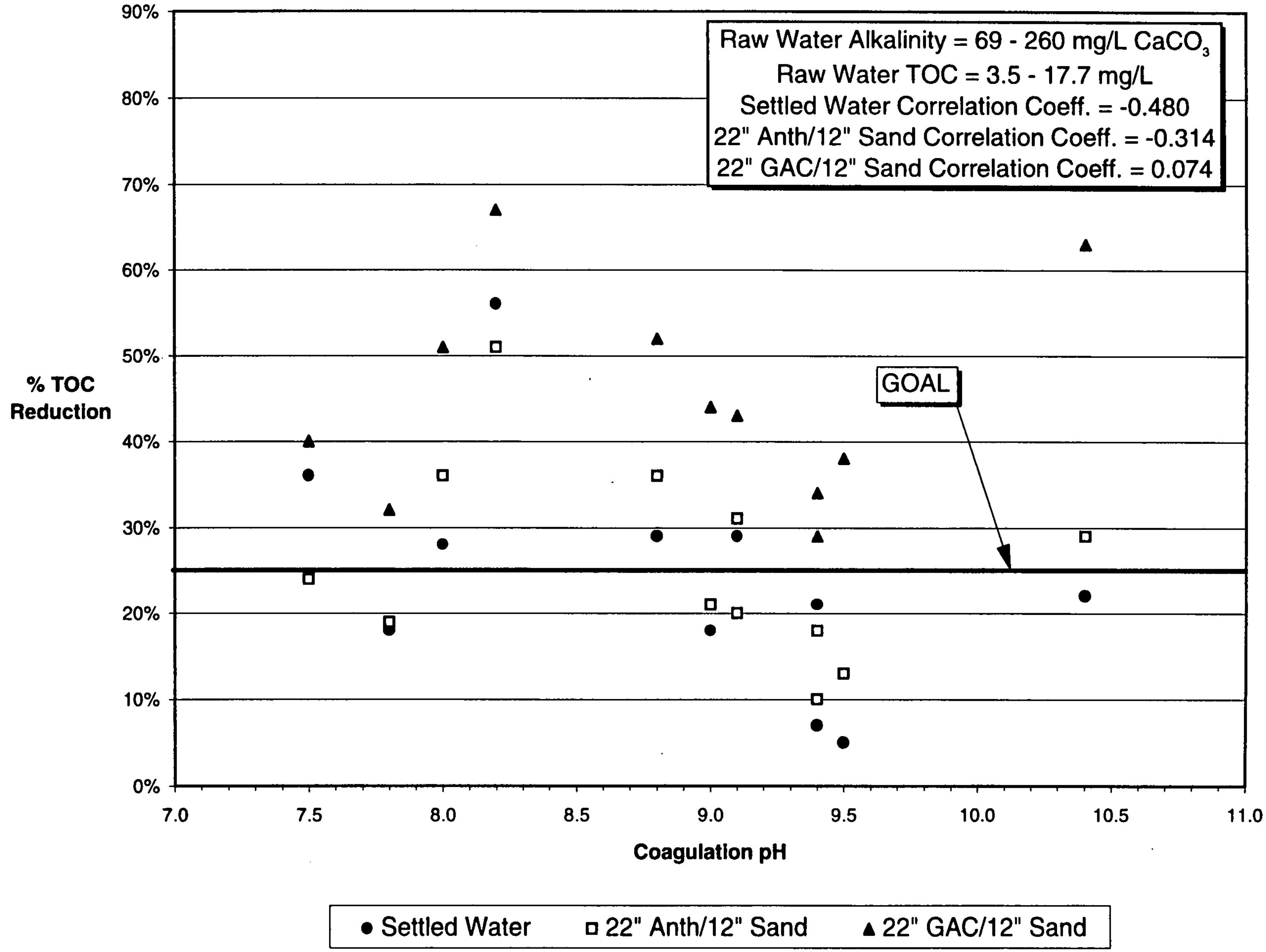


Figure 5-23
Little Arkansas River Pilot Runs
Correlation Between TOC Reduction and Coagulation pH



the anthracite/sand filtered water was 29%. As expected, there was very little correlation between coagulation pH and TOC reduction for the GAC/sand filter (r = 0.074), since the GAC/sand filter tended to provide good TOC reduction regardless of coagulation pH. Figure 5-24 shows the correlation between ferric sulfate dose and TOC reduction. With an increasing ferric sulfate dose, there was a slight improvement in TOC reduction — particularly for the settled water (r = 0.572) and anthracite/sand filtered water (r = 0.529). However, TOC reduction generally stayed below the 25% reduction goal. Similar to varying coagulation pH, there tended to be a smaller correlation between ferric sulfate dose and TOC reduction for the GAC/sand filter (r = 0.446), and, in most cases, TOC reduction with GAC remained above 25%.

5.3 Softening/Enhanced Softening

5.3.1 Cheney Reservoir

Softening for Cheney varied somewhat with the change in water quality due to high spring runoff into Cheney which caused a drop in both hardness and alkalinity of about 40 mg/L $CaCO_3$. For the duration of the pilot testing, lime doses (as $Ca(OH)_2$ and equivalent CaO) were as shown in Table 5-1 in order to meet the softening goals:

Table 5-1
Cheney Reservoir Lime Doses

	$Ca(OH)_2$ (mg/L)	Equivalent CaO (mg/L)
Minimum	83	63
Average	116	88
Maximum	140	106

During the pilot tests, sludge from the sedimentation module was recycled back to the rapid mix. Sludge at 5% - 9% solids concentration was recycled at about 1% of total pilot plant flow. As discussed previously, conventional softening followed by anthracite/sand filtration is not capable of consistently meeting the TOC reduction requirement for Cheney.

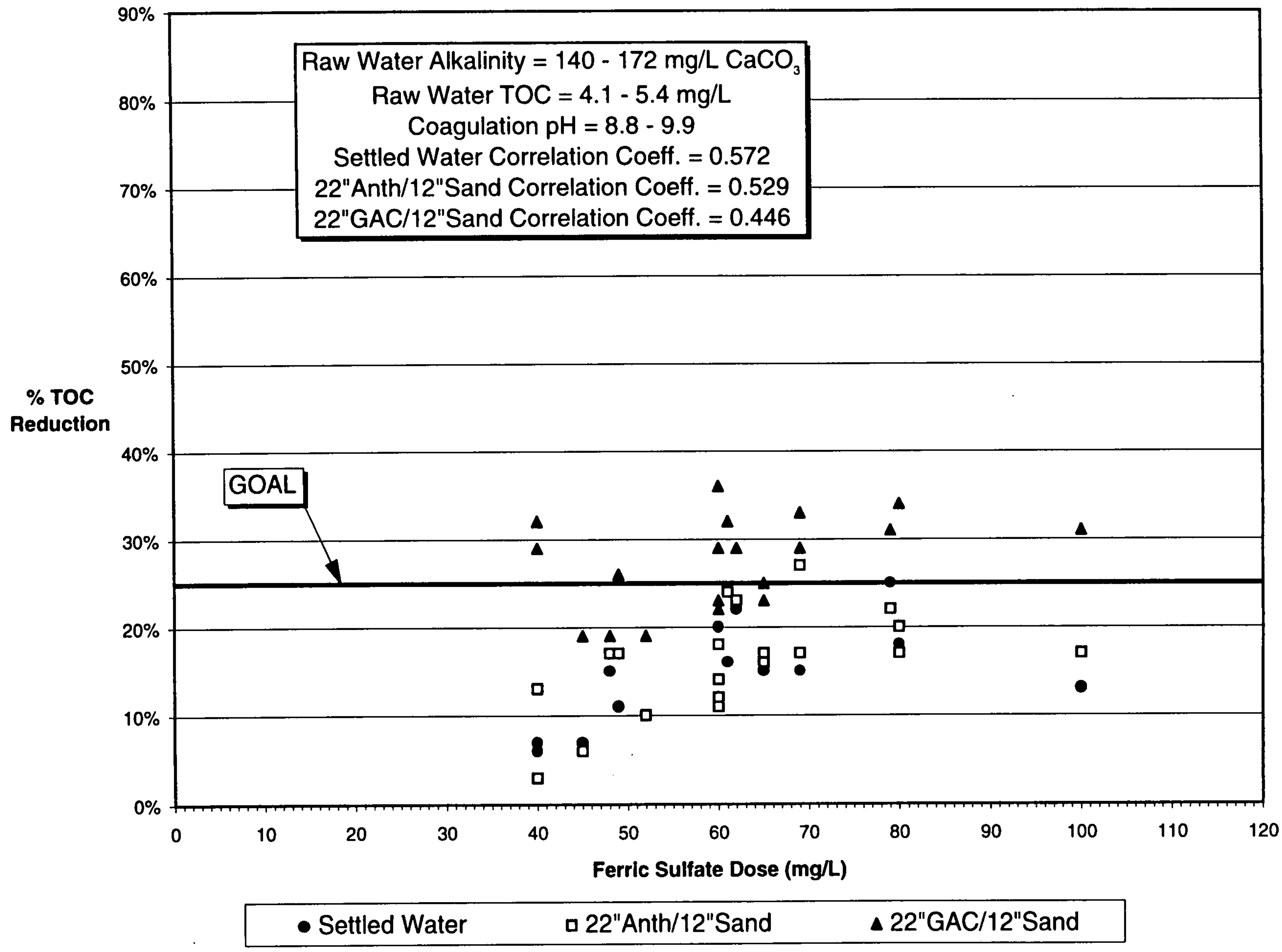
In order to achieve enhanced softening on Cheney, a $Ca(OH)_2$ dose of at least 200 mg/L (151 mg/L CaO) is required in order to raise the pH high enough to remove at least 10 mg/L of magnesium hardness so that the TOC reduction requirements will not have to be met.

5.3.2 Little Arkansas River

For the Little Ark, both lime and lime/soda ash combinations were required due to highly variable raw water quality. The lime and soda ash doses required during the pilot testing phase varied considerably and were as shown in Table 5-2.

Sludge was recycled for the Little Ark pilot plant in a manner similar to that described above for Cheney. When the softening pH varied from 9.0 to 9.5, it was difficult to achieve the minimum 25%

Figure 5-24
Cheney Pilot Runs
Correlation Between TOC Reduction and Ferric Sulfate Dose



TOC reduction with anthracite/sand filtration. However, when enhanced softening was practiced (pH = 10.4), TOC reduction for the anthracite/sand filtered water was 29%.

Table 5-2
Little Ark River Lime and Soda Ash Doses

	$Ca(OH)_2$ (mg/L)	Equivalent CaO (mg/L)	Soda Ash (mg/L)
Minimum	23	17	0
Average	111	84	35
Maximum	230	174	65

5.3.3 Single-Stage Softening vs. Two-Stage Coagulation and Softening/Coagulation

Because of the difficulties with TOC reduction for conventional softening at coagulation pHs of 9.0 to 9.5, a jar test was conducted to simulate:

- Conventional Single-Stage Softening with Coagulation (as practiced at the Wichita WTP), and
- Two-Stage Treatment with Coagulation Followed by Softening/Coagulation.

For the conventional single-stage softening with coagulation, ferric sulfate and lime/soda ash were added during rapid mixing, followed by flocculation and sedimentation. For the two-stage treatment scenario, ferric sulfate was added prior to flocculation and sedimentation. Decant from the jars was then taken and second-stage treatment with ferric sulfate and lime/soda ash followed by flocculation and sedimentation was performed. The overall ferric sulfate dose for each of the jar tests was the same; hence, for two-stage treatment, half the ferric sulfate dose was added in the first stage and the other half was added with lime/soda ash during second-stage treatment. Figure 5-25 shows the results from these jar tests conducted on the Little Ark. As this figure illustrates, the two-stage treatment scenario provided significantly better TOC reduction. Moreover, two-stage treatment was capable of achieving a settled water TOC reduction of 27%.

5.4 Adsorption

Two applications of carbon adsorption were evaluated for TOC reduction: powdered activated carbon (PAC) and granular activated carbon (GAC) as a filter media. The PAC evaluations consisted of jar tests which simulated feeding PAC ahead of the water treatment plant — termed "pre-PAC" — as well as pilot tests with PAC fed at the rapid mix module. The GAC tests evaluated 22-inches of GAC as a filter medium.

Figure 5-26 shows the jar tests results for various pre-PAC doses for both Cheney and the Little Ark. Pre-PAC doses for Cheney were mixed for six hours to simulate the detention time in the Cheney Reservoir raw water pipeline during average flows. The pre-PAC mixing time for the Little Ark was one hour. No further treatment of the water was conducted, so the pre-PAC jar tests simply evaluated TOC removal with PAC alone. As Figure 5-26 illustrates, pre-PAC doses of 10 to 30

Figure 5-25
Comparison of Single-Stage Softening (with Coagulation) and Two-Stage (Coagulation/Softening) Treatment

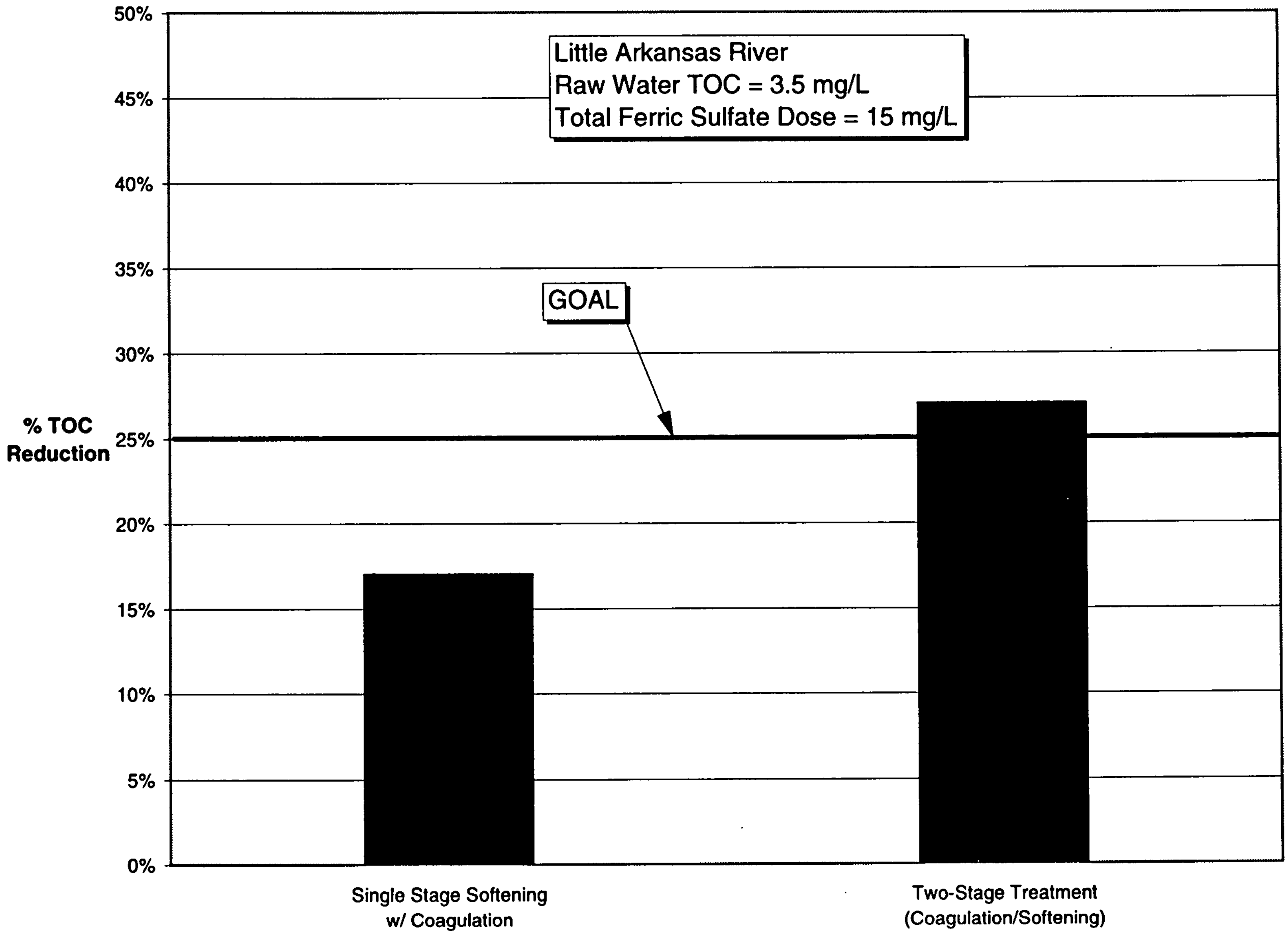
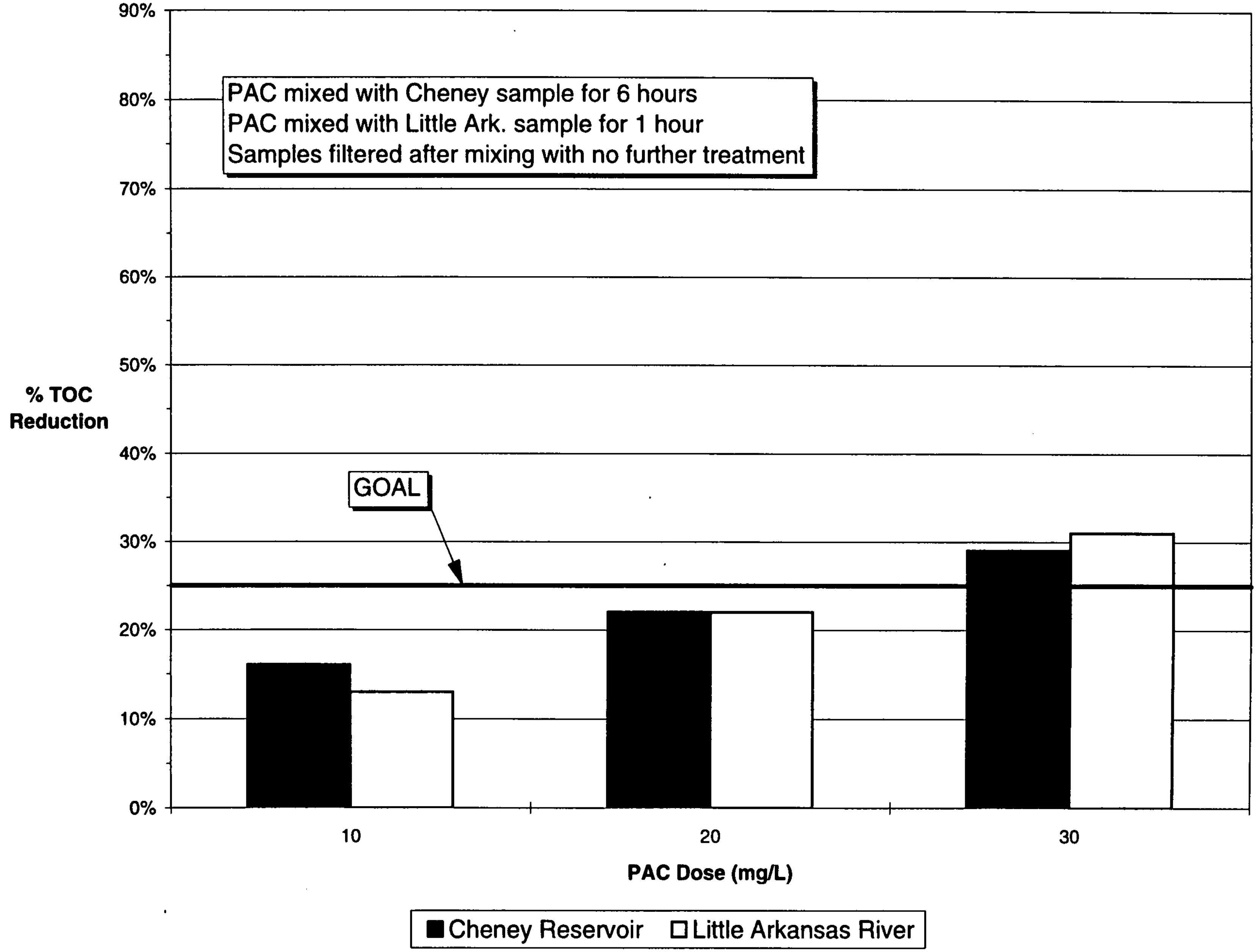


Figure 5-26
TOC Removal Using Pre-PAC



mg/L provided good TOC reduction. TOC removal increased for both waters with the increasing pre-PAC dose, and a dose of 30 mg/L was capable of achieving the 25% TOC reduction goal. Note that a pre-PAC dose of 10 mg/L provided similar TOC removal to conventional coagulation, flocculation, sedimentation, and filtration. Thus, it can be assumed that pre-PAC followed by coagulation, flocculation, sedimentation, and filtration would provide even better TOC reduction and would easily exceed the 25% TOC reduction requirement. It is also worth noting that there appears to be little difference in the length of PAC mixing time. That is, the six-hour PAC mixing time for Cheney did not provide significantly better TOC removal than the one-hour mixing time for the Little Ark.

Various adsorption process alternatives were evaluated at the jar and pilot level. These processes included:

- GAC Filtration
- Pre-PAC
- PAC Fed at the Rapid Mix (PAC at RM)
- PAC at RM followed by GAC Filtration

Figure 5-27 shows the various adsorption alternatives as well as anthracite/sand filtration and oxidation with ozone. In terms of adsorption, PAC fed at the rapid mix followed by GAC filtration provided the best TOC reduction. Additionally, pre-PAC, PAC fed at the rapid mix, and GAC filtration provided good results that met or exceeded the 25% TOC reduction goal. As stated previously, the pre-PAC results shown only reflect treatment with PAC. Thus, it is reasonable to assume the pre-PAC followed by coagulation, flocculation, sedimentation, and anthracite/sand filtration would easily achieve the 25% TOC reduction requirement. Although GAC filtration, on average, provided excellent TOC reduction, it was observed over the course of the treatability study, that the 22-inch GAC bed appears to have a relatively short bed life of about three to four months.

5.5 Oxidation

Oxidation was evaluated to determine its effectiveness in reducing TOC. Pilot tests with ozone and jar tests with chlorine dioxide were conducted. Figure 5-27 shows the pilot results with pre-ozonation followed by conventional treatment and anthracite/sand filtration and pre-ozonation followed by conventional treatment and GAC/sand filtration. For pre-ozonation doses of 2 mg/L, pre-ozonation followed by anthracite/sand filtration did not consistently achieve the 25% required TOC removal. Pre-ozonation followed by GAC/sand filtration, however, was capable of meeting the 25% minimum TOC reduction.

Figure 5-28 shows settled water TOC reduction for the chlorine dioxide jar tests with ferric sulfate for both the Cheney and Little Ark waters. Chlorine dioxide did not improve TOC reduction for Cheney. However, it appears that chlorine dioxide may have been effective in oxidizing TOC for the Little Ark. Because the raw water TOC for the Little Ark was rather high (i.e., 9.6 mg/L), it is difficult to say how much of the TOC reduction was due to the high raw water TOC and how much was due to the chlorine dioxide oxidation.

Figure 5-27
Cheney Reservoir
Comparison of TOC Reduction Alternatives

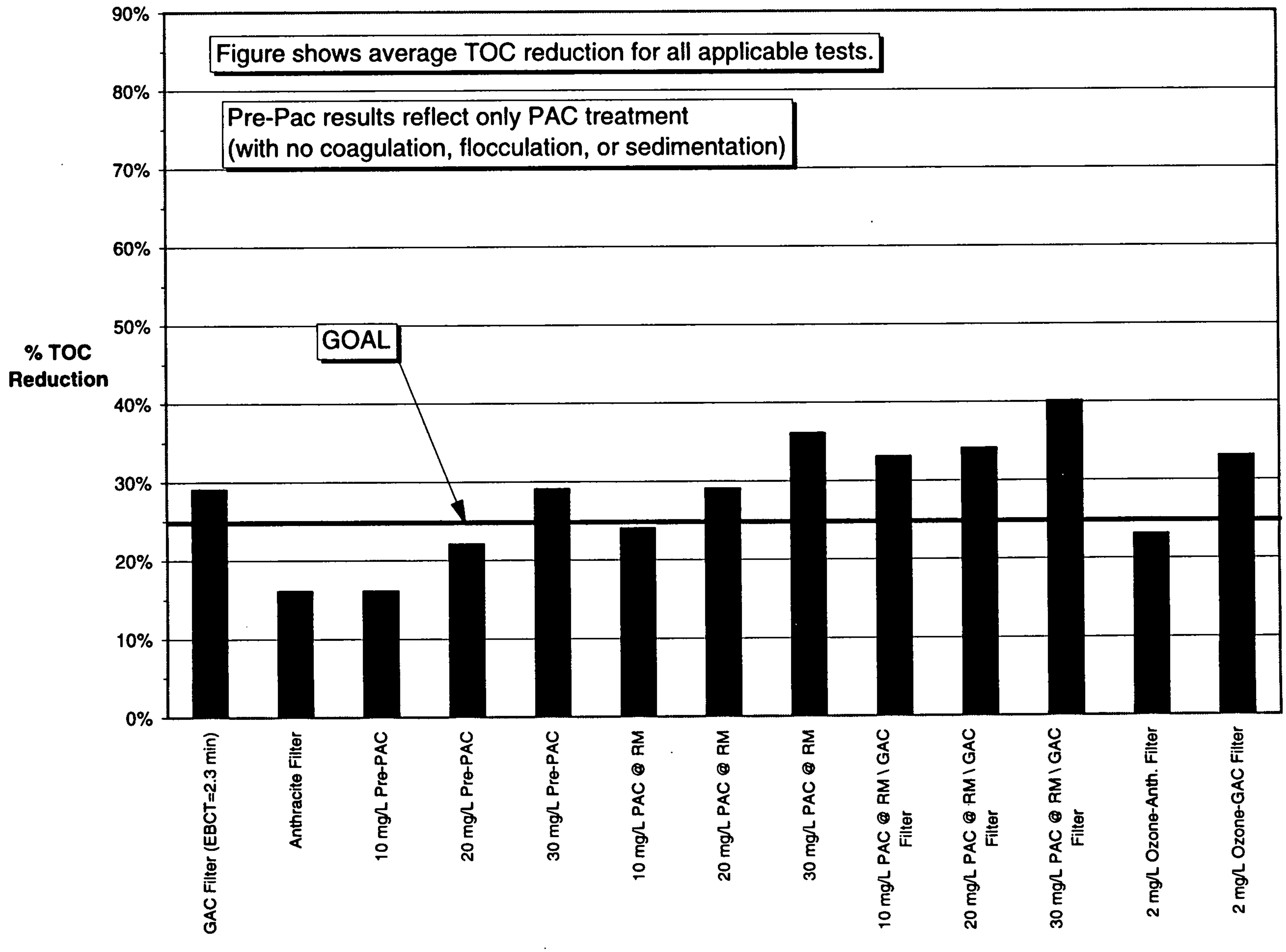
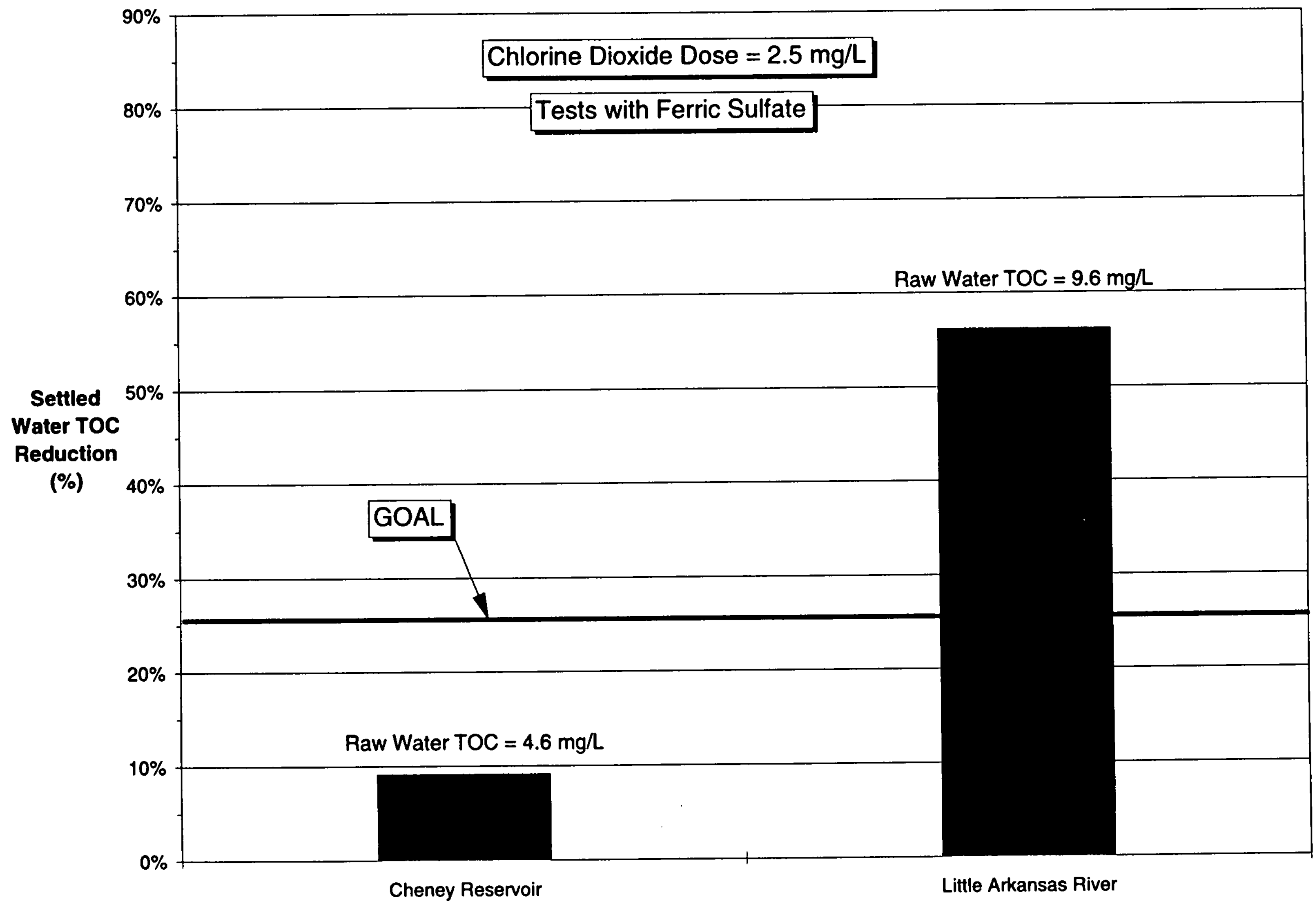


Figure 5-28
TOC Reduction with Chlorine Dioxide



5.6 Source Water Control

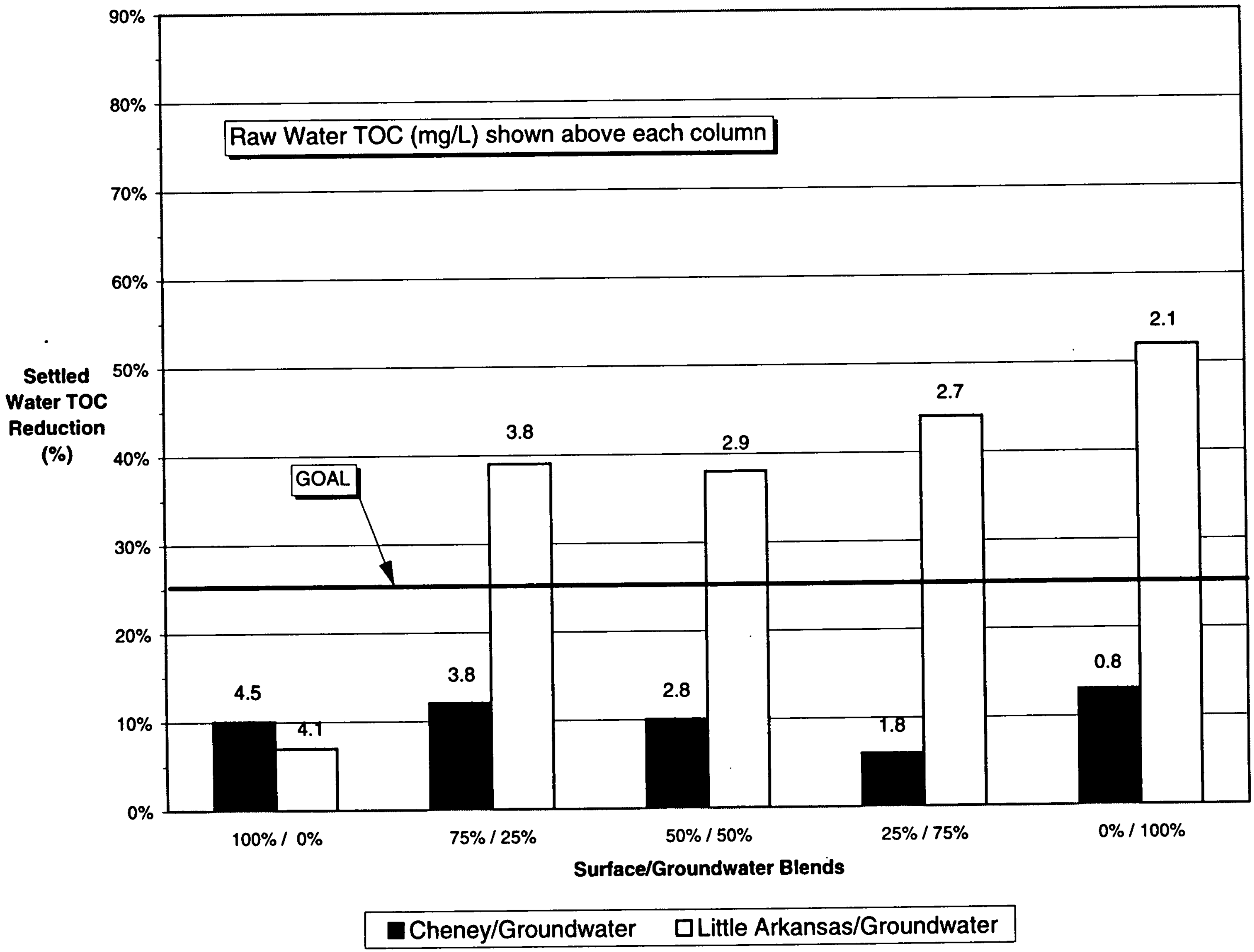
Various blends of Cheney/groundwater and the Little Ark/groundwater were evaluated to determine the effect of source water control on TOC reduction. Figure 5-29 shows the various blend percentages for each of the supplies in terms of settled water TOC reduction. For the Cheney/groundwater blends, an increased percentage of groundwater does not appear to improve TOC reduction, although groundwater percentages of 75% and greater produced raw water TOC of less than 2 mg/L. For the Little Ark/groundwater blends, an increased percentage (25% and greater) of groundwater improved TOC reduction significantly and exceeded the 25% TOC reduction goal.

5.7 Summary

The following can be summarized from the various TOC reduction alternatives evaluated:

- Of the six coagulants evaluated, ferric sulfate provided the best results in terms of both turbidity and TOC reduction for both surface waters.
- Significantly higher doses of ferric sulfate will be required during cold water temperatures when treating a large percentage of surface water .
- For Cheney, conventional softening and ferric sulfate coagulation followed by anthracite/sand filtration is capable of meeting the settled water and finished water turbidity goals. Although the pilot filters experienced some high turbidities (> 0.10 ntu), treatment optimization at the full-scale (e.g., filter aid polymer, coagulant dose, sludge recirculation) should be capable of meeting these goals.
- Lime doses for Cheney varied from 63 - 106 mg/L CaO with an average of 88 mg/L CaO.
- For Cheney, conventional softening and ferric sulfate coagulation followed by anthracite/sand filtration was not capable of achieving 25% TOC reduction. Additionally, increased ferric sulfate doses, by as much as 150%, did not achieve the 25% TOC reduction goal.
- For the Little Ark, conventional softening and ferric sulfate coagulation followed by anthracite/sand filtration is capable of meeting the settled water and finished water turbidity goals only when raw water turbidities remain below 100 ntu. Although the pilot filters experienced some high turbidities(> 0.10 ntu), treatment optimization at the full-scale (e.g., filter aid polymer, coagulant dose, sludge recirculation) should be capable of meeting these goals. The largest issue for treating the Little Ark is the extreme raw water variability, which can vastly change in a matter of hours. The pilot plant experienced many problems with treatment optimization due to the fact that once one treatment scheme (lime/soda ash and coagulant) was established, the raw water quality would again change — requiring significantly different chemical doses.
- Pre-sedimentation does not appear to be effective in treating the highly variable raw water turbidities of the Little Ark.

Figure 5-29
TOC Reduction For Surface/Groundwater Blends



- Lime doses for the Little Ark varied from 17 - 174 mg/L CaO with an average of 84 mg/L CaO. Soda ash doses varied from 0 - 65 mg/L with an average of 35 mg/L.

- For the Little Ark, conventional softening and ferric sulfate coagulation followed by anthracite/sand filtration was not capable of consistently achieving 25% TOC reduction; although, very high ferric sulfate doses (i.e., 130 - 255 mg/L) did achieve the 25% TOC reduction goal.

- Two-stage treatment with coagulation followed by softening/coagulation provides better TOC removal than single-stage softening/coagulation. However, two-stage treatment is not currently available at the Wichita WTP.

- There does not appear to be a strong correlation between coagulation pH and TOC reduction; however, enhanced softening at a coagulation pH of 10.4 did exceed the 25% TOC reduction goal for anthracite/sand filtration (as well as GAC/sand filtration). For enhanced softening of Cheney, a lime dose of at least 151 mg/L CaO would be required.

- While TOC reduction improved slightly with higher ferric sulfate doses, these higher coagulant doses combined with anthracite/sand filtration could not meet the 25% TOC reduction requirement.

- Adsorption with both PAC and GAC proved to be very effective in TOC reduction. PAC fed at the rapid mix followed by GAC/sand filtration provided the best TOC reduction (33% - 40%). Additionally, pre-PAC, PAC at the rapid mix, and GAC filtration also exceeded the 25% TOC reduction goal.

- While GAC filtration proved effective for TOC reduction, degradation of the GAC filter bed occurred after the third month of operation.

- Oxidation with either ozone or chlorine dioxide did not meet the TOC reduction goal for Cheney; however, chlorine dioxide may be effective for the Little Ark.

- For the Cheney/groundwater blends, an increased percentage of groundwater does not appear to improve TOC reduction, although groundwater percentages of 75% and greater produced raw water TOC of less than 2 mg/L.

- For the Little Ark/groundwater blends, an increased percentage (25% and greater) of groundwater improved TOC reduction significantly and exceeded the 25% TOC reduction goal.

Section 6
Disinfection By-Product Control

6.1 Introduction

Because of the Stage 1 and Stage 2 MCLs for both THMs and HAA5 proposed in the D/DBPR, alternative disinfection schemes were evaluated for both the Cheney Reservoir and Little Ark River to determine each disinfection scheme's effectiveness for complying with Stage 1 and Stage 2 of the D/DBPR. Three primary disinfectants were tested:

- *Chlorine* — Chlorine is currently used by the City as a primary disinfectant. While chlorine has been effective in preventing waterborne disease outbreaks, concern over disinfection by-products will limit its use. Conditions of the D/DBPR will limit chlorination at the Wichita WTP to the filtered water.

- *Ozone* — Ozone is highly effective against *Giardia* and viruses. Additionally, research shows that ozone is effective for *Cryptosporidium* inactivation. Research continues on defining disinfection CT requirements for *Cryptosporidium*. For disinfection CT credit with ozone for the D/DBPR, biological filtration must be practiced.

- *Chlorine Dioxide* — Chlorine dioxide is also a highly effective disinfectant against *Giardia* and viruses. It is of limited effectiveness against *Cryptosporidium*. Disinfection CT credit with chlorine dioxide under the D/DBPR requires that the chlorine dioxide generators be 95% efficient.

Since chloramines are currently used for residual disinfection in the distribution system, secondary disinfection with chloramine was paired with each of the above primary disinfectants. Thus, the disinfection schemes evaluated were:

- Chlorine/Chloramines
- Ozone/Chloramines
- Chlorine Dioxide/Chloramines

In addition to oxidation, adsorption with GAC was also assessed. Like the other pilot tests, 22-inches of GAC was evaluated as a filter medium.

DBP treatment goals established for the treatability study are as follows:

- TTHM 80 μg/L
- HAA5 60 μg/L
- Bromate 10 μg/L
- Chlorite 1.0 mg/L

The following DBP policy standards are also established for the study:

- TTHM 40 μg/L
- HAA5 30 μg/L

6.2 Alternative Disinfectants

6.2.1 THM Formation

Before each of the alternative disinfectants was evaluated, THM formation with free chlorine was determined for Cheney and the Little Ark over a 24-hour timeframe. Figures 6-1 and 6-2 show the chlorine residuals over time for free chlorine doses of 1, 2, 3, 4 and 5 mg/L for Cheney and the Little Ark, respectively. Based on this data, a 4 mg/L chlorine dose was selected to determine THM formation over 24 hours. Figure 6-3 shows the 24-hour THM formation for each of the waters. After 24 hours, THM formation for the Little Ark was about 25% higher than Cheney. It should be noted, when THM formation was conducted on both Cheney and the Little Ark, raw water turbidities were fairly low.

6.2.2 Cheney Reservoir

Figures 6-4 and 6-5 illustrate the simulated distribution system TTHM (SDSTTHM) and SDSHAA5 results for the three disinfection schemes. A hold time of 24-hours was used for all SDS analyses. Both the chlorine/chloramine and ozone/chloramine disinfection schemes were conducted on pilot plant treated water; however, the chlorine dioxide/chloramine evaluations were conducted at the jar test level. All three disinfection schemes were capable of meeting the proposed Stage 1 TTHM and HAA5 MCLs of 80 μg/L and 60 μg/L, respectively. Additionally, both the chlorine dioxide/chloramine and ozone/chloramine schemes were capable of meeting the proposed Stage 2 TTHM and HAA5 MCLs of 40 μg/L and 30 μg/L, respectively. Disinfection with chlorine/chloramines and anthracite/sand filtration averaged TTHMs around 46 μg/L, thus falling short of meeting the 40 μg/L policy standard. However, chlorine/chloramine disinfection coupled with GAC/sand filtration met the proposed Stage 2 TTHM MCL. With respect to HAAs, the chlorine/chloramine disinfection scheme met the Stage 2 HAA5 MCL.

While the THM and HAA results with chlorine dioxide were promising, one major concern when feeding this disinfectant is the formation of the chlorine dioxide by-products chorite and chlorate. EPA has proposed an MCL for chlorite of 1.0 mg/L. Previous research has shown chemical reduction with ferrous chloride to be effective for minimizing chlorite formation. Thus, several jar tests were conducted to compare both ferric sulfate and ferrous chloride for chlorite reduction. Figure 6-6 shows the chlorine dioxide DBP results for ferric sulfate and ferrous chloride coagulation. As this figure illustrates, neither coagulant was effective in keeping chlorite to less than 1.0 mg/L, although the ferrous chloride did reduce chlorite somewhat. Because of the inherent difficulties in minimizing chlorite formation, no further testing with chlorine dioxide was performed on Cheney.

Total organic halogen (TOX) — a surrogate for total (identified and unidentified) halogenated DBPs — is shown in Figure 6-7 for the chlorine/chloramine and ozone/chloramine disinfection schemes.

Figure 6-1
Cheney Reservoir
Chlorine Residuals

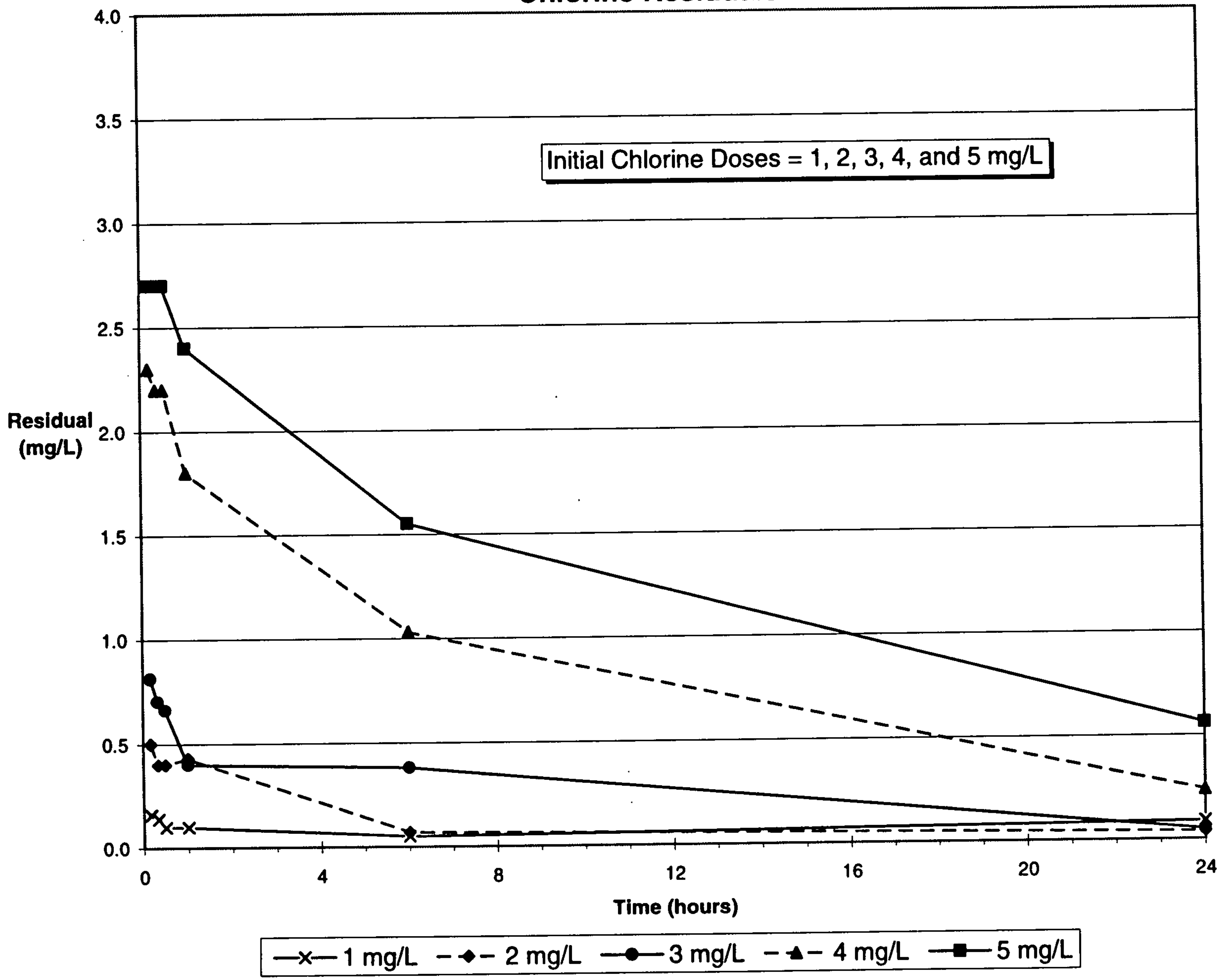


Figure 6-2
Little Arkansas River
Chlorine Residuals

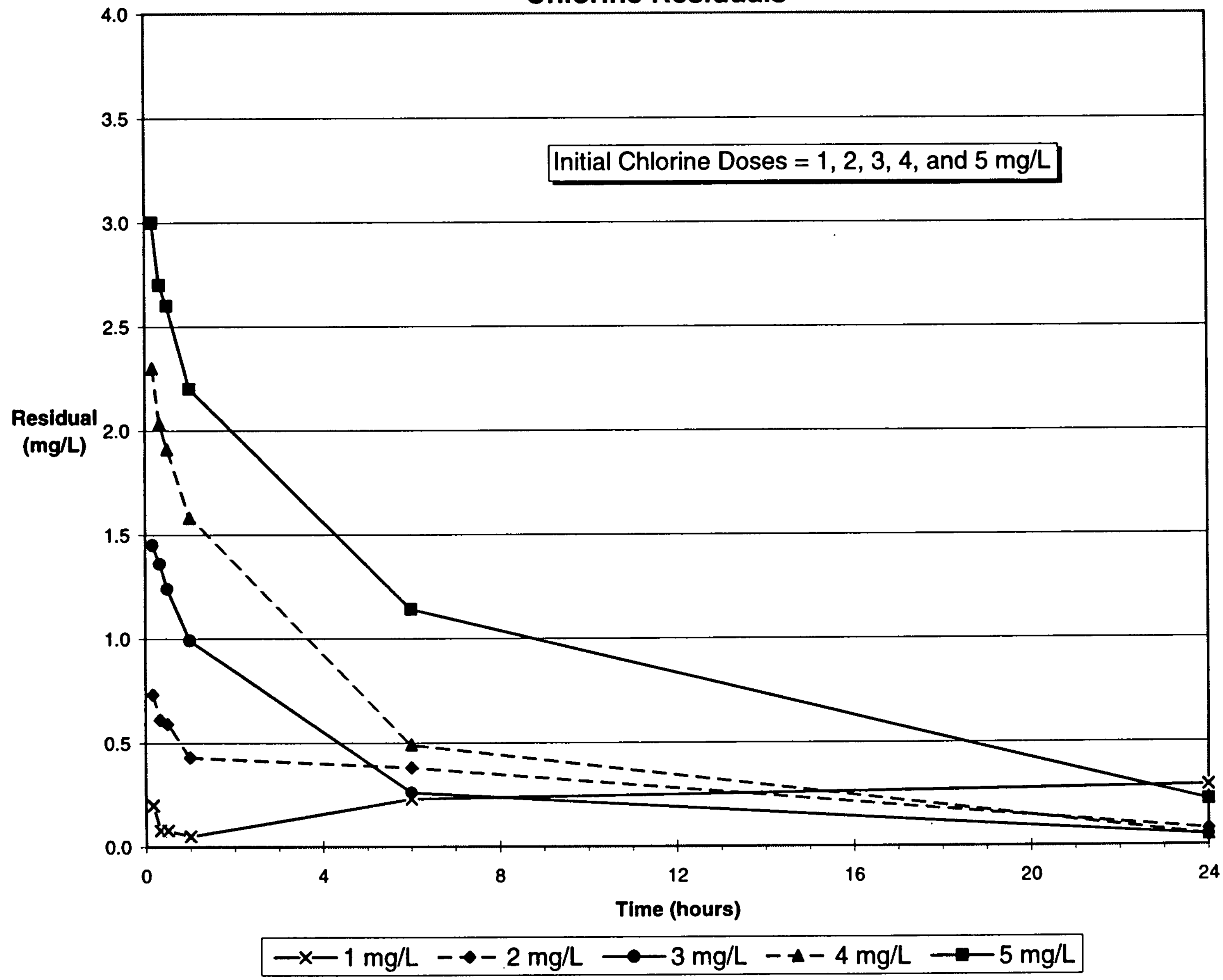


Figure 6-3
TTHM Formation

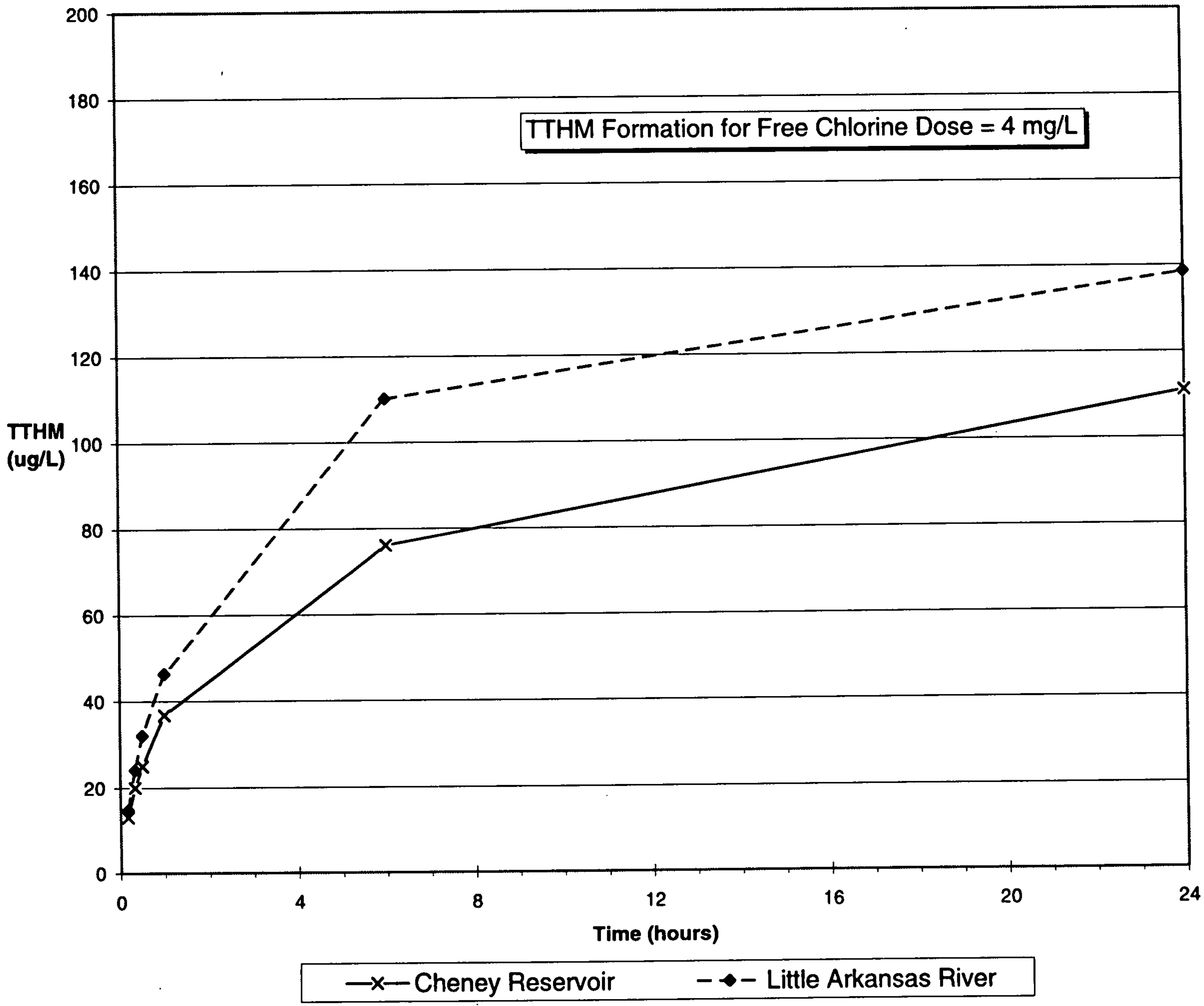


Figure 6-4
Cheney Reservoir
SDSTTHM

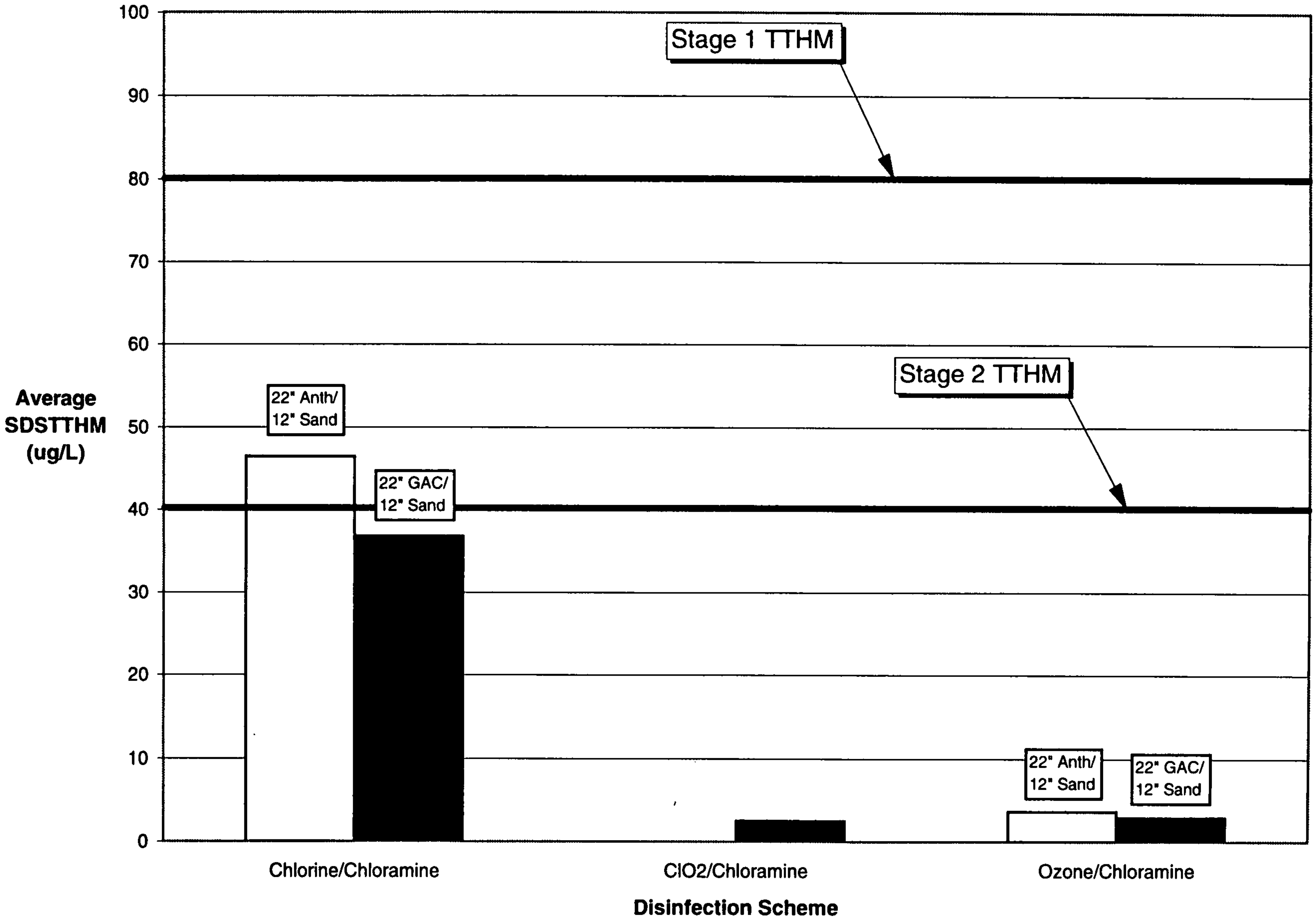


Figure 6-5
Cheney Reservoir
SDSHAA5

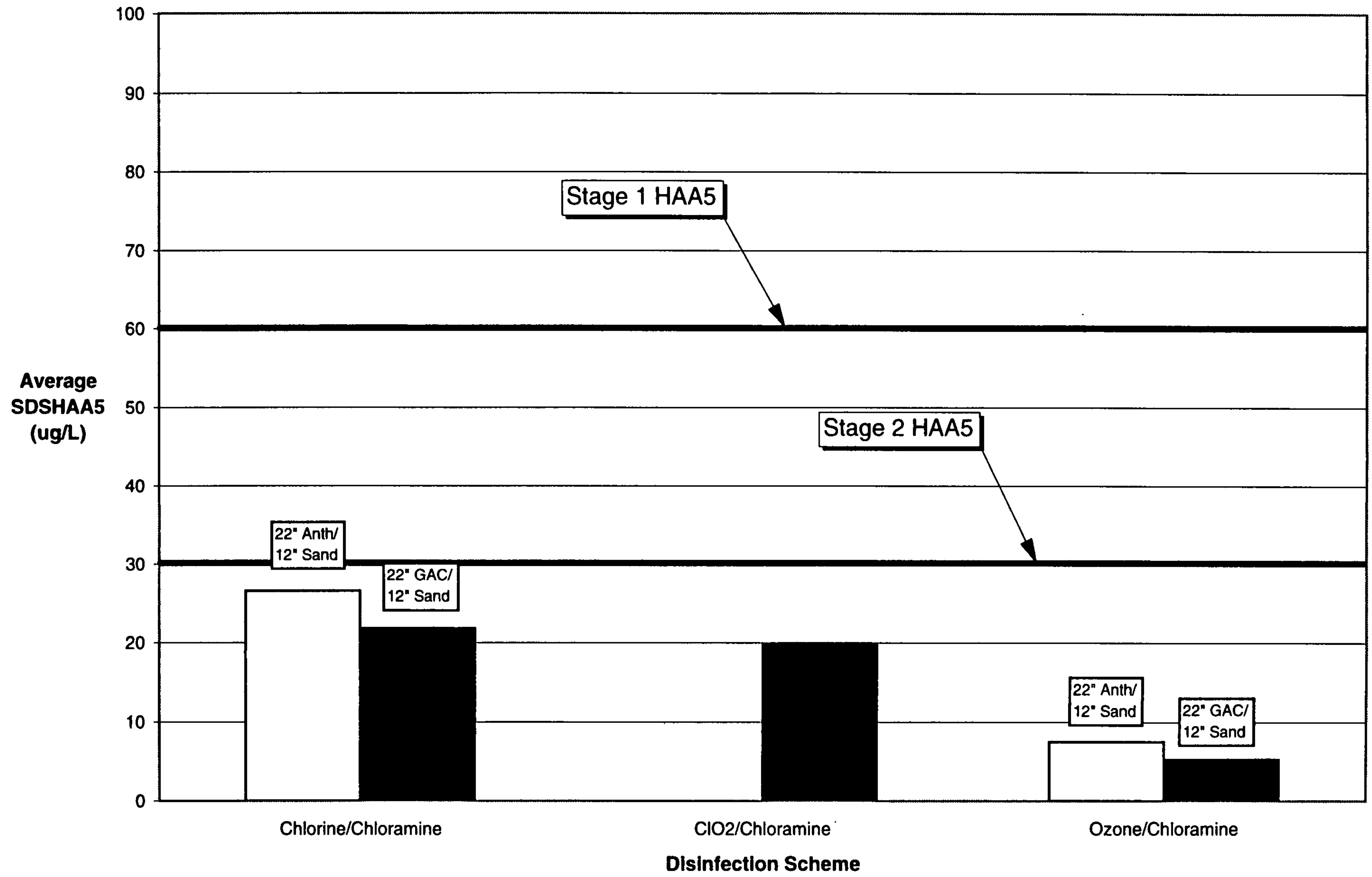


Figure 6-6
Cheney Reservoir
Chlorine Dioxide Disinfection By-Products

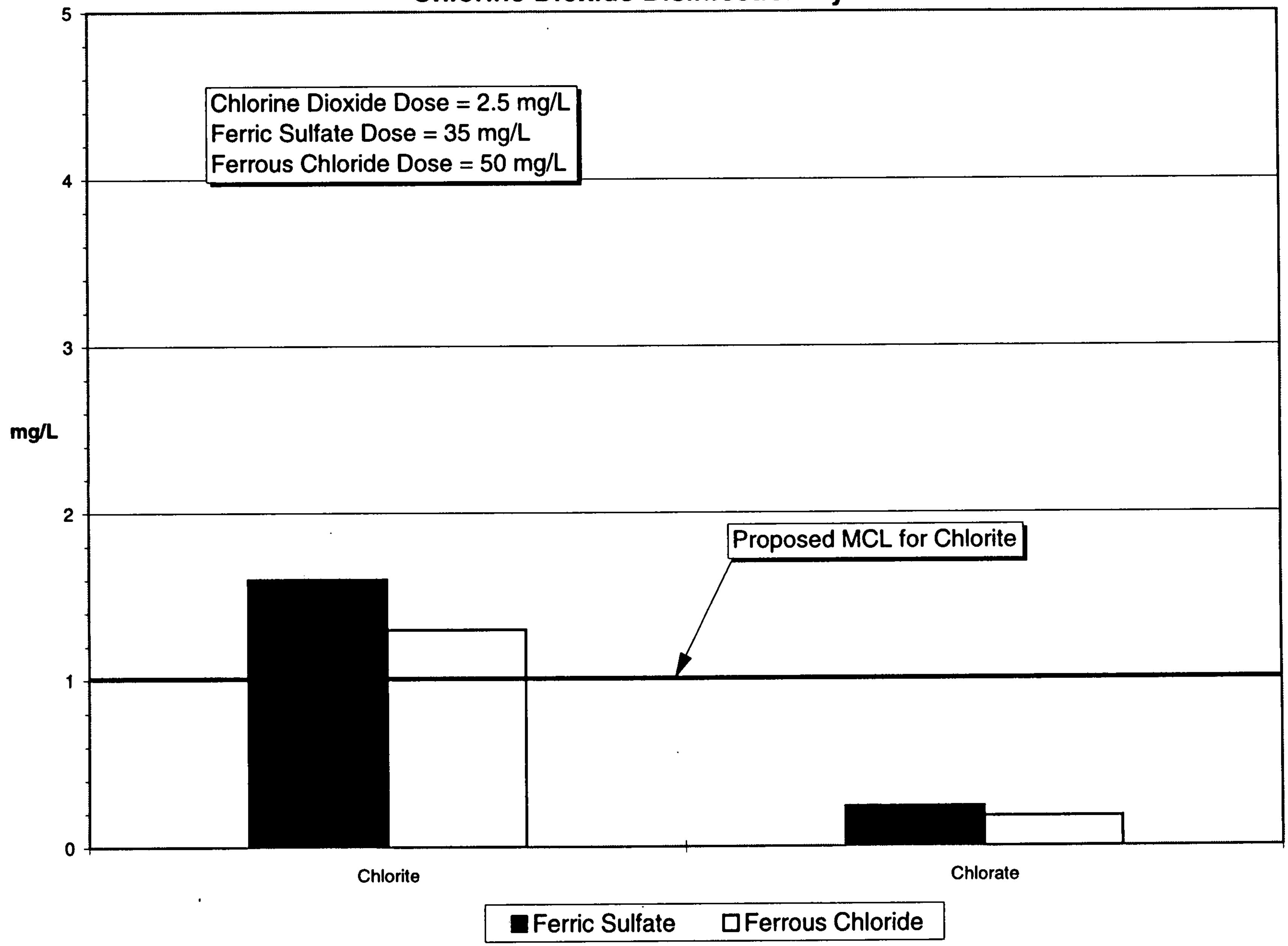
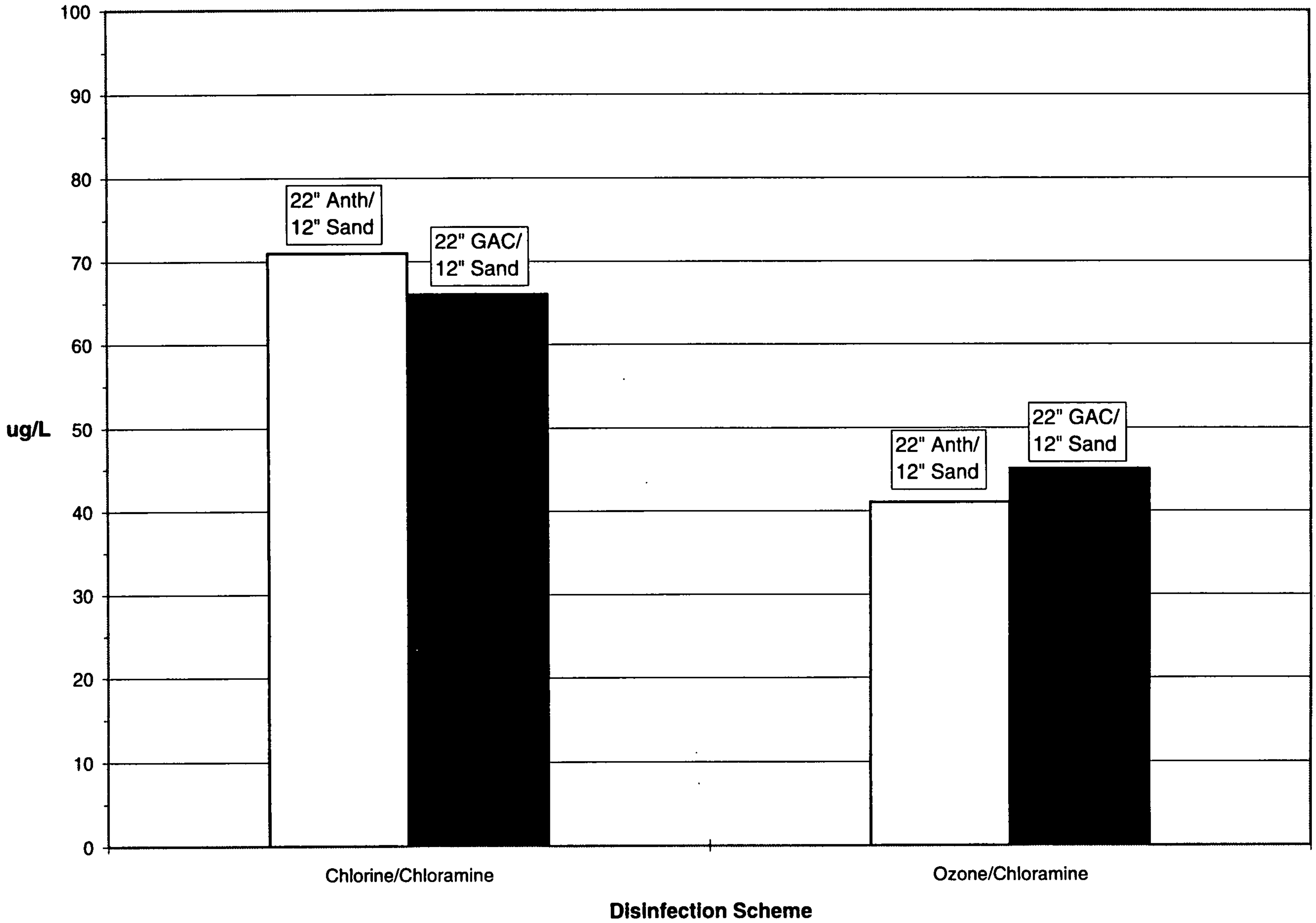


Figure 6-7
Cheney Reservoir
Total Organic Halogen (TOX)



While ozone was capable of reducing TOX by as much as 40%, adsorption with GAC did not provide significant TOX reduction.

Ozonation DBPs are shown in Figure 6-8. No bromide was detected in the raw water for Cheney so it is not suprising that bromate was not detected in the ozonated water. Aldehydes — measured as formaldehyde, acetaldehyde, butanal, propanal, pentanal, glyoxal, and methyl glyoxal — are also shown in Figure 6-8 and were 52 μg/L for anthracite/sand filtration and 41 μg/L for GAC/sand filtration. Assimilable organic carbon (AOC), which is a measure of bacterial regrowth potential, is shown in Figure 6-9. AOC values of 290 μg/L for anthracite/sand filtered water and 275 μg/L for GAC/sand filtered water were detected. Raw water AOC was not measured, so it is not known whether additional AOC was created during the ozonation process and then removed during filtration. However, the high filtered water AOCs are an indiction that the filters were not sufficiently biologically active at the time of sample collection to aid in the reduction of AOC.

6.2.3 Little Arkansas River

SDSTTHM and SDSHAA5 for the chlorine/chloramine and chlorine dioxide/chlorine disinfection schemes is shown in Figures 6-10 and 6-11. Chlorine/chloramine was capable of meeting the Stage 1 MCLs for TTHMs and HAA5, but not Stage 2 — even with GAC filtration. Chlorine dioxide/chloramine was also capable of meeting the Stage 1 MCLs for TTHMs and HAA5; however, it came short of meeting the Stage 2 HAA5 MCL. Ozone was not tested on the Little Ark due to the extreme water quality variations and corresponding treatment problems; however, it can be assumed that DBP formations with ozone would be similar to those produced for Cheney. Additionally, no bromide was detected in the Little Ark raw water, so bromate formation with ozonation should not be a problem.

Similar to the Cheney investigations with chlorine dioxide, jar tests with ferric sulfate and ferrous chloride were conducted to determine their effectiveness in reducing the chlorite. The chlorine dioxide DBP results are shown in Figure 6-12. Unlike Cheney, ferrous chloride was found to be effective in reducing chlorite to non-detectable levels. One reason this may have occurred is the ferrous chloride, as well as ferric sulfate, dose for the Little Ark water was very high — 140 mg/L for ferrous chloride. This high dose was required due to the high raw water turbidity (630 ntu). Thus, it is unlikely that lower doses of ferrous chloride would be as effective in reducing chlorite formation during lower raw water turbidity events.

TOX results are shown in Figure 6-13 for the chlorine/chloramine scheme. Unlike Cheney, adsorption with GAC was capable of reducing TOX by as much as 70%.

6.2.4 Source Water Control

Various blends of Cheney and groundwater and Little Ark and groundwater were evaluated to determine the effect of source water control on SDSTTHM and SDSHAA5 formations. All tests were conducted with chlorine/chloramines at the jar test level, since groundwater was not fed through the pilot plants. SDSTTHM results are shown in Figure 6-14. Every blend of surface water/groundwater easily met the Stage 1 TTHM MCL. For the Cheney/groundwater blends, a ratio of 50:50 was required to achieve the Stage 2 TTHM MCL. For the Little Ark/groundwater

Figure 6-8
Cheney Reservoir
Ozone Disinfection By-Products

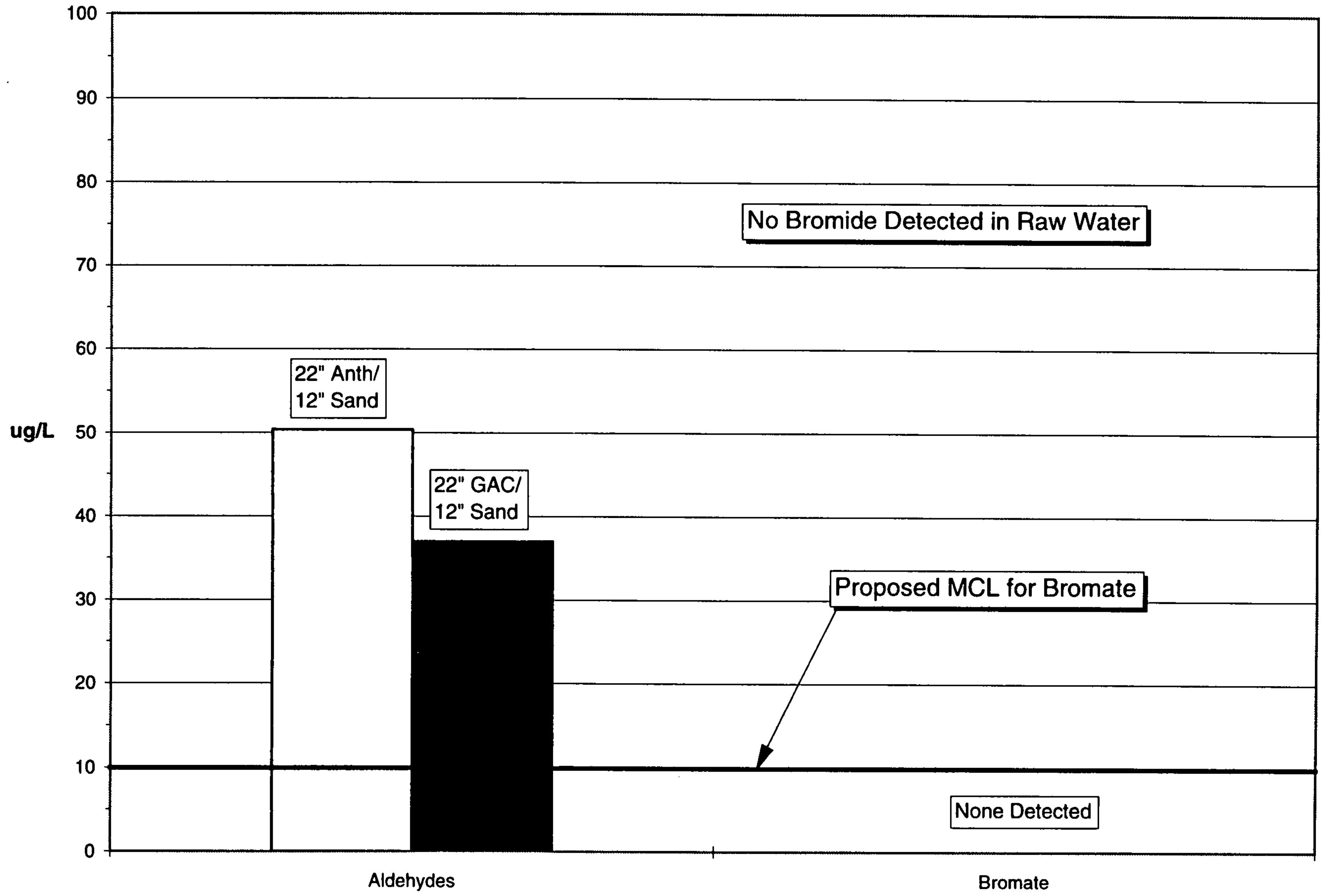


Figure 6-9
Cheney Reservoir
Assimilable Organic Carbon (AOC)

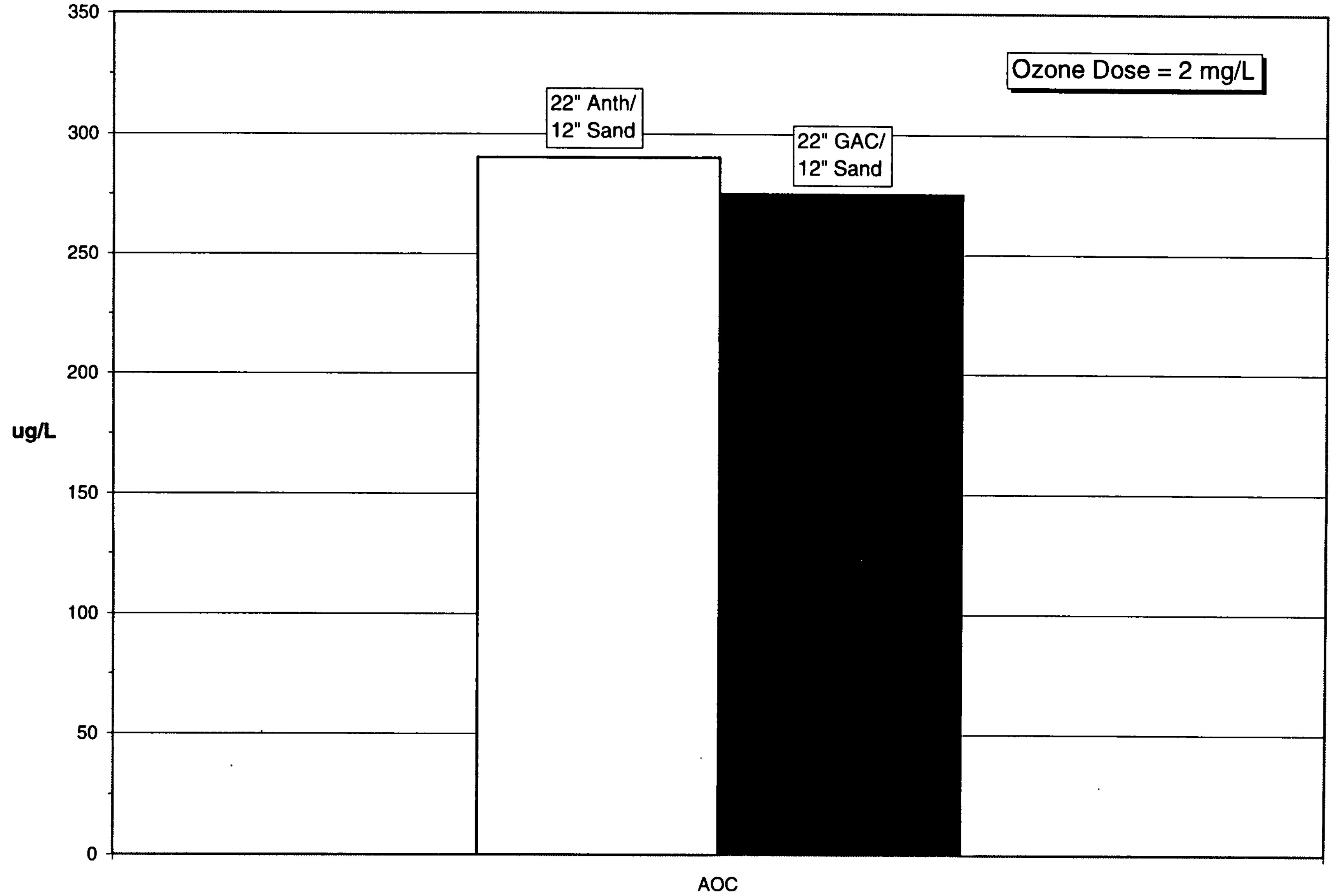


Figure 6-10
Little Arkansas River
SDSTTHM

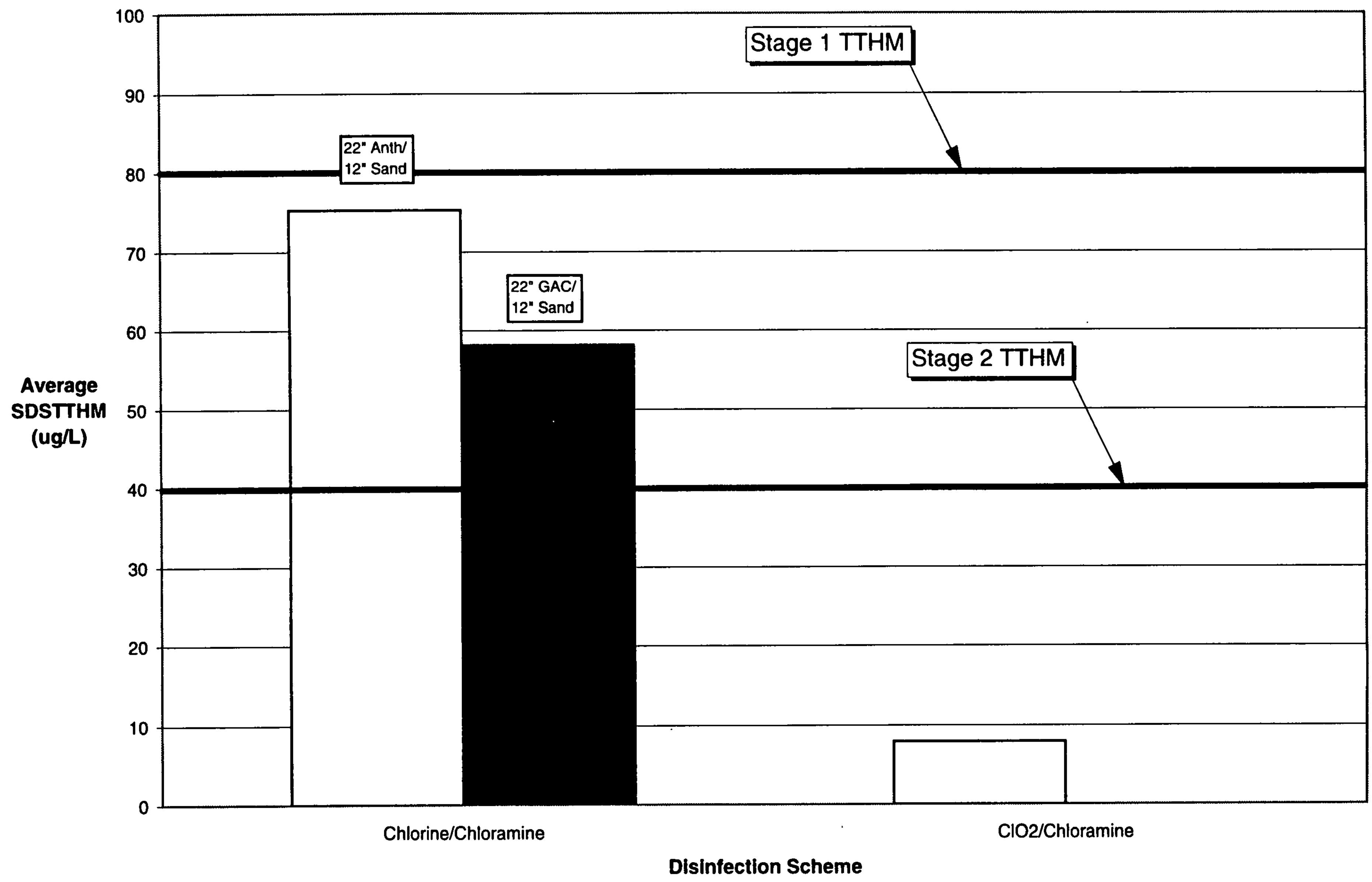


Figure 6-11
Little Arkansas River
SDSHAA5

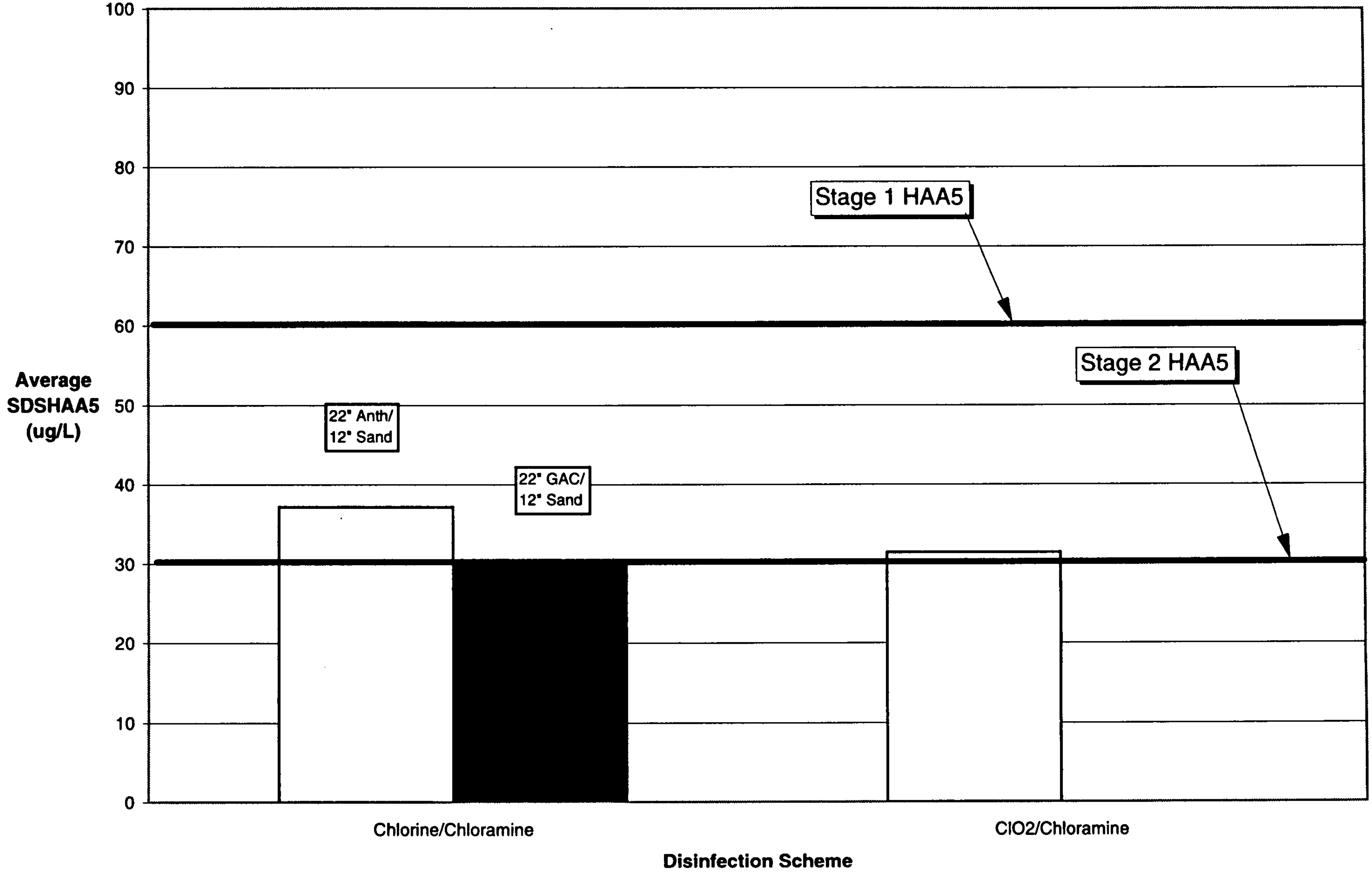


Figure 6-12
Little Arkansas River
Chlorine Dioxide Disinfection By-Products

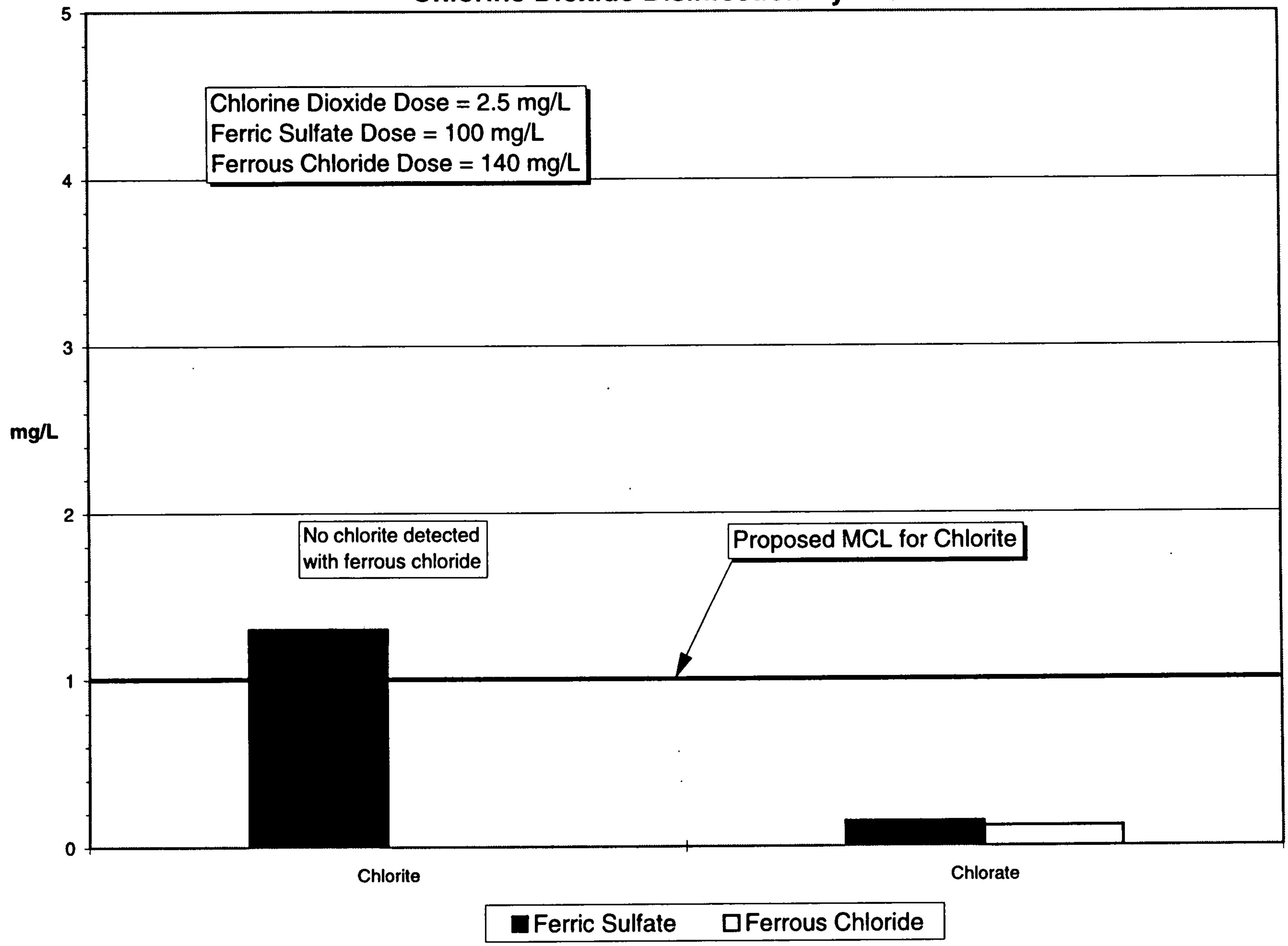


Figure 6-13
Little Arkansas River
Total Organic Halogen (TOX)

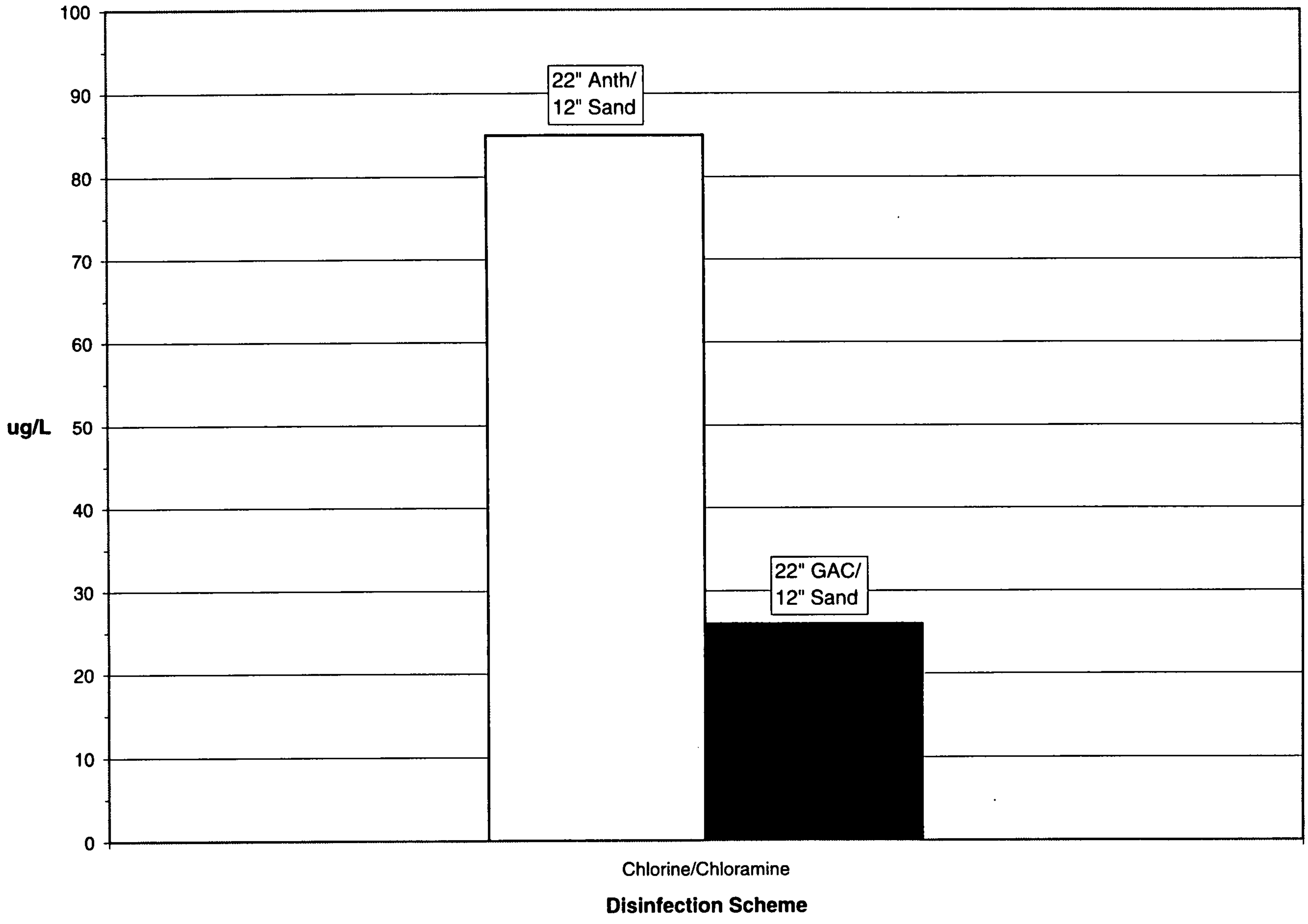
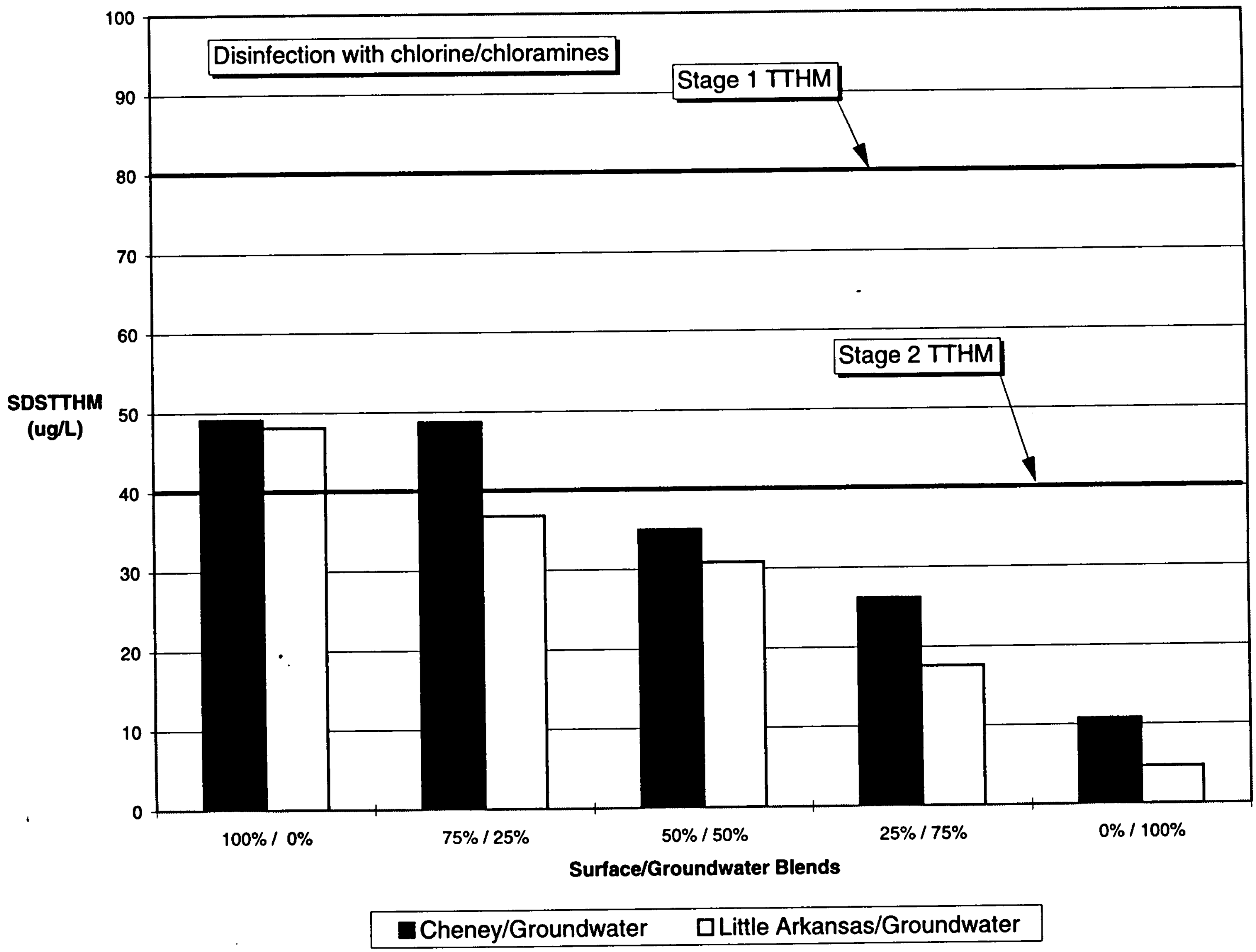


Figure 6-14
SDSTTHM Formation For Surface/Groundwater Blends



blends, a ratio of 75:25 was required to achieve the Stage 2 TTHM MCL. Although this data does not exactly correspond with the pilot-scale data for 100% surface water, it can be assumed that groundwater percentages of 25% - 50% may be required for either surface water if source water control is used as a means for meeting the Stage 2 TTHM MCL.

SDSHAA5 results for each of the surface water/groundwater blends is shown in Figure 6-15. Similar to the pilot plant results, any blend of surface water/groundwater should be capable of meeting both the Stage 1 and Stage 2 HAA5 MCLs.

6.2.5 DBP Correlations

Because of the TOC reduction requirements affiliated with the D/DBPR, it is important to know what, if any, correlations exist between SDSTTHM and TOC as well as SDSHAA5 and TOC. Figure 6-16 shows the linear correlation coefficients, r, for each of these comparisons. With respect to SDSTTHMs and TOC, there was a fairly good positive linear trend, with r = 0.628. The correlation between SDSHAA5 and TOC was somewhat better, with r = 0.726. Correlations between SDSTTHM and SDSHAA5 are plotted in Figure 6-17 and show r = 0.137. Thus, for the Cheney supply, there does not appear to be any significant correlation between TTHMs and HAA5.

Figure 6-18 shows the SDSTTHM and TOC and SDSHAA5 and TOC correlations for the Little Ark. The correlation between SDSTTHM and TOC gives an r = 0.188, which shows a poor correlation. One explanation for this may be the changes in Little Ark water quality. Two data points for the Little Ark were during high turbidity events (>350 ntu), and during this time raw water TOC was 9.6 mg/L — which was more than twice the TOC during low raw water turbidity events. The correlation between SDSHAA5 and TOC, however, was much better with r = 0.889. The correlation between SDSTTHM and SDSHAA5 is illustrated in Figure 6-19. In reviewing all the data, including low and high raw water turbidities, there is little correlation between TTHMs and HAA5 (r = -0.254). However, considering only the low raw water turbidity data, there is a good correlation between SDSTTHMs and SDSHAA5 with r = 0.893.

6.3 Summary

The following can be summarized from the various DBP control alternatives:

- TTHM and HAA5 formations on the Little Ark tended to be higher than Cheney. This is not surprising since TOC for the Little Ark is generally higher and much more variable than Cheney.

- Of the three disinfectant schemes evaluated for Cheney, ozone/chloramines provided the lowest TTHMs and HAA5. Additionally, since no bromide was detected in the raw water, ozonation did not create bromate. Chlorine dioxide also produced low TTHMs and HAA5, however, chlorite formation remained above the 1.0 mg/L proposed MCL. Chlorine/chloramines is easily capable of meeting the proposed Stage 1 MCLs for TTHMs and HAA5, although adsorption with GAC or PAC would be required to meet the Stage 2 TTHM MCL if 100% Cheney is treated.

- Of the two disinfectant schemes evaluated for the Little Ark, chlorine dioxide produced low TTHMs and HAA5, however, removal of chorite would most likely require very high doses of ferrous chloride (e.g., > 100 mg/L) to keep chorite below the 1.0 mg/L proposed MCL. CDM believes these high dosages to be impractical on a full-scale treatment plant. Chlorine/chloramines is capable of meeting the proposed Stage 1 MCLs for TTHMs and HAA5; however, this disinfection scheme does not appear capable of consistently meeting the Stage 2 MCLs for 100% Little Ark water — even with carbon adsorption.

- Source water control may be the most cost-effective means for controlling DBPs if chlorine/choramines use is continued and the Stage 2 MCLs are promulgated. Groundwater percentages up to 50% may be required to meet the Stage 2 TTHM and HAA5 MCLs.

- If the running average for TTHMS and HAA5 can be kept below 40 μg/L and 30 μg/L, respectively, using free chlorine for primary disinfection, the City will not be required to meet the TOC reduction requirements of the D/DBPR.

- Correlations between SDSTTHM and TOC as well as SDSHAA5 and TOC was good for Cheney. Thus, it can be assumed that increased reductions in TOC will reduce THM and HAA5 formations.

- There was no observed correlation between SDSTTHM and SDSHAA5 formations for Cheney.

- The correlation between SDSHAA5 and TOC was very good for the Little Ark. The correlation between SDSTTHM and TOC, however, was less promising — this may have been due to highly variable raw water quality.

- Similar to Cheney, there was no osbserved correlation between SDSTTHM and SDSHAA5 formations for the Little Ark when all the data was considered.

Figure 6-15
SDSHAA5 Formation For Surface/Groundwater Blends

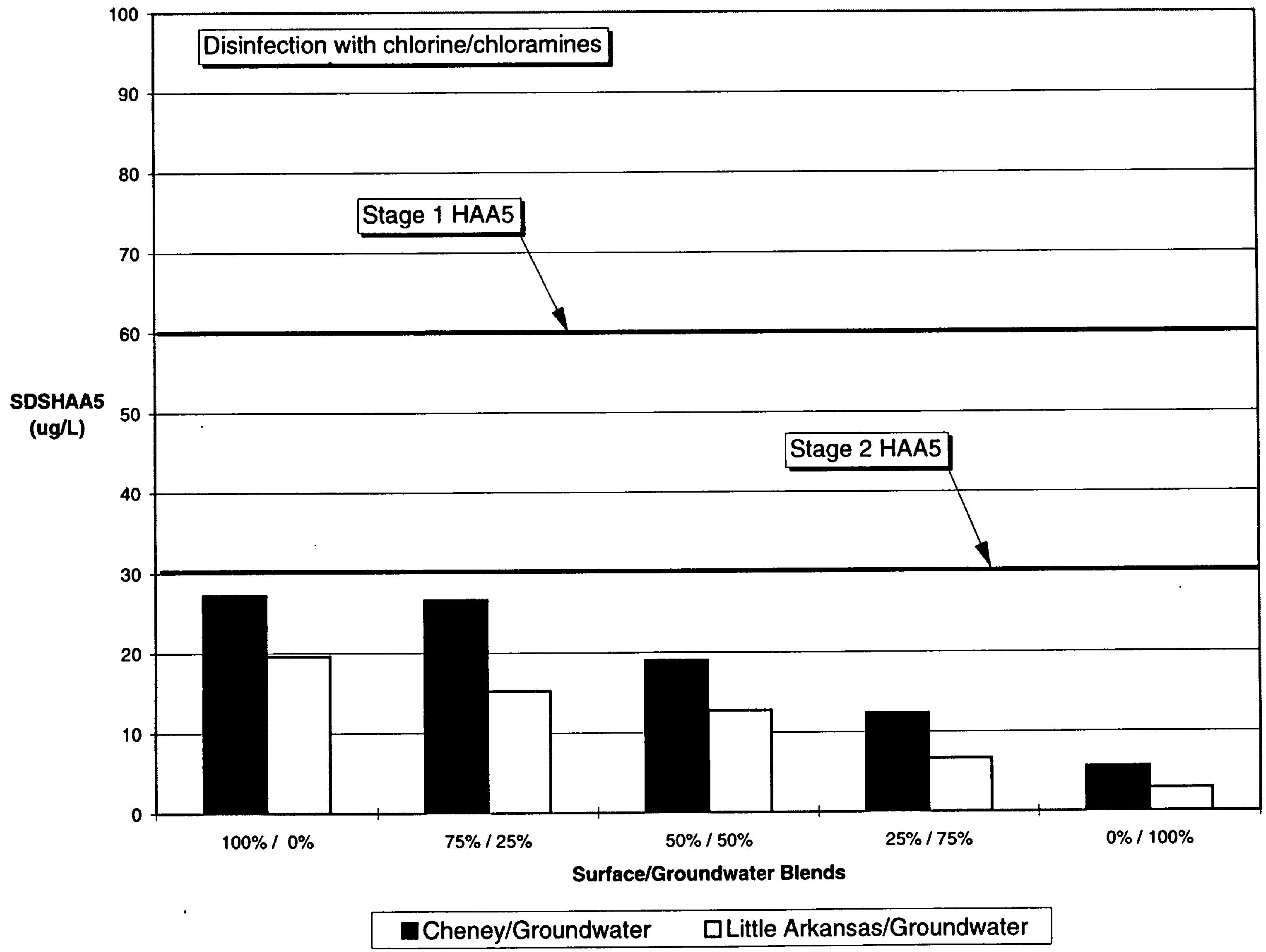


Figure 6-16
Cheney Reservoir
Correlation Between SDSTTHM/SDSHAA5 and TOC

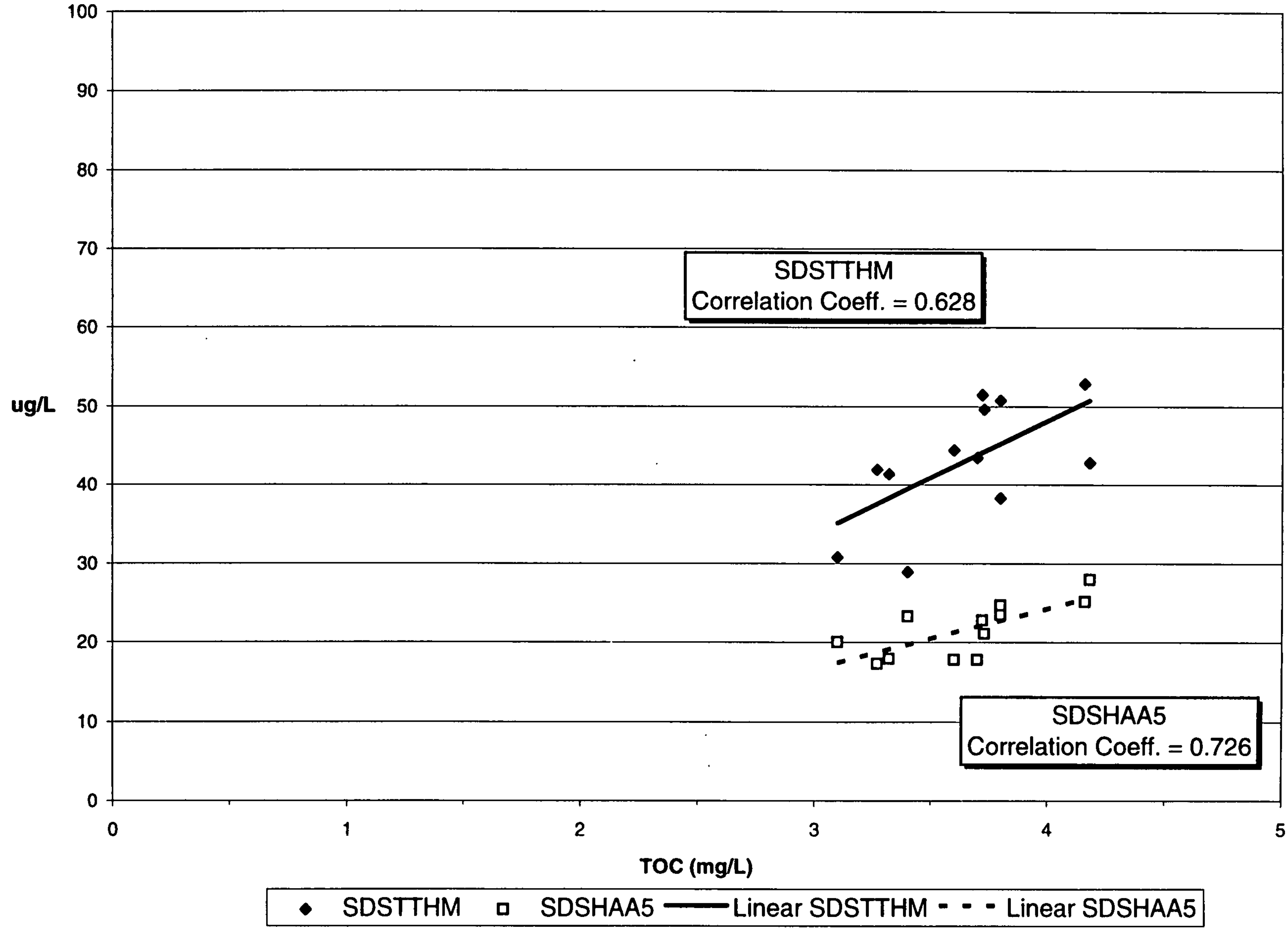


Figure 6-17
Cheney Reservoir
Correlation Between SDSHAA5 and SDSTTHM

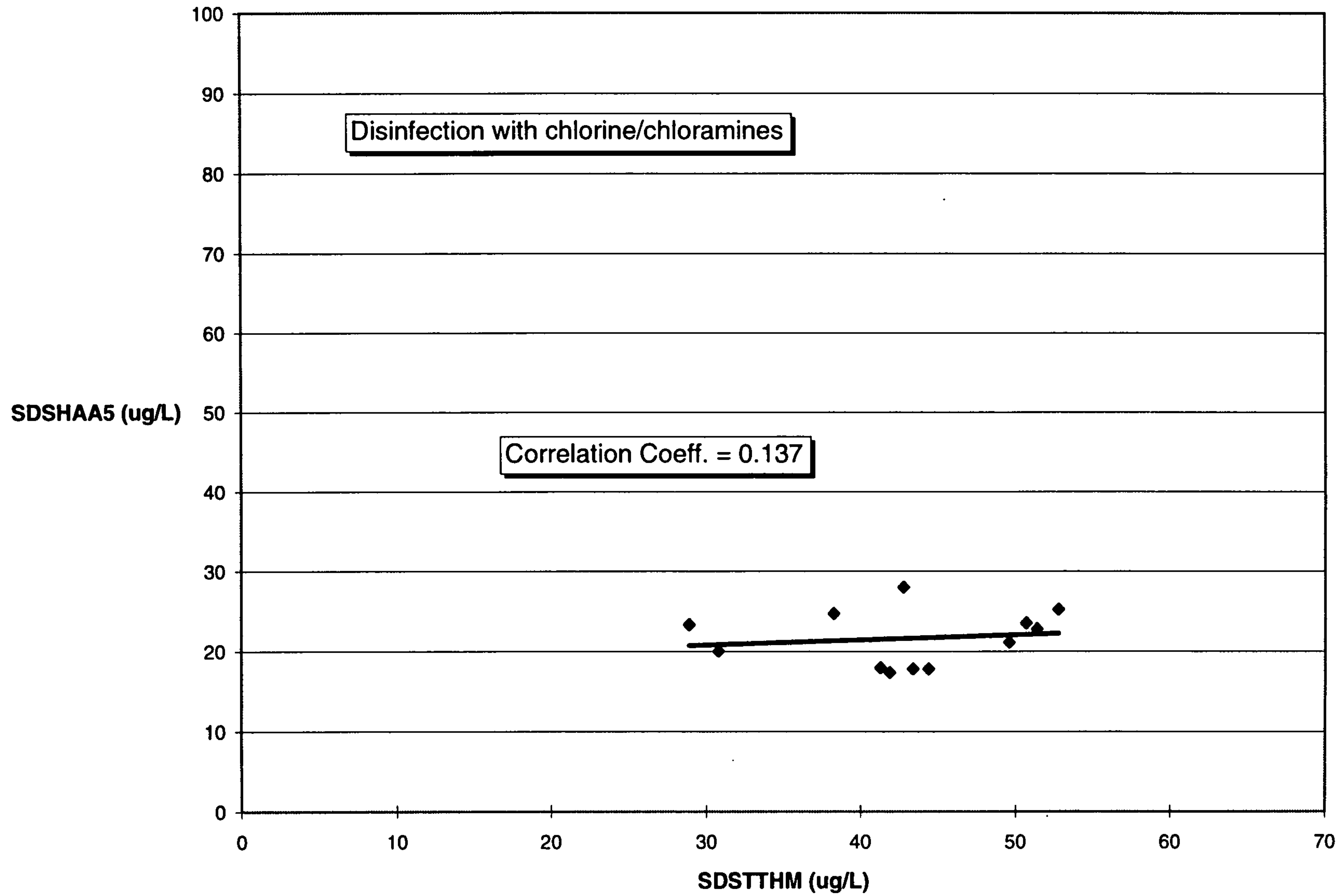


Figure 6-18
Little Arkansas River
Correlation Between SDSTTHM/SDSHAA5 and TOC

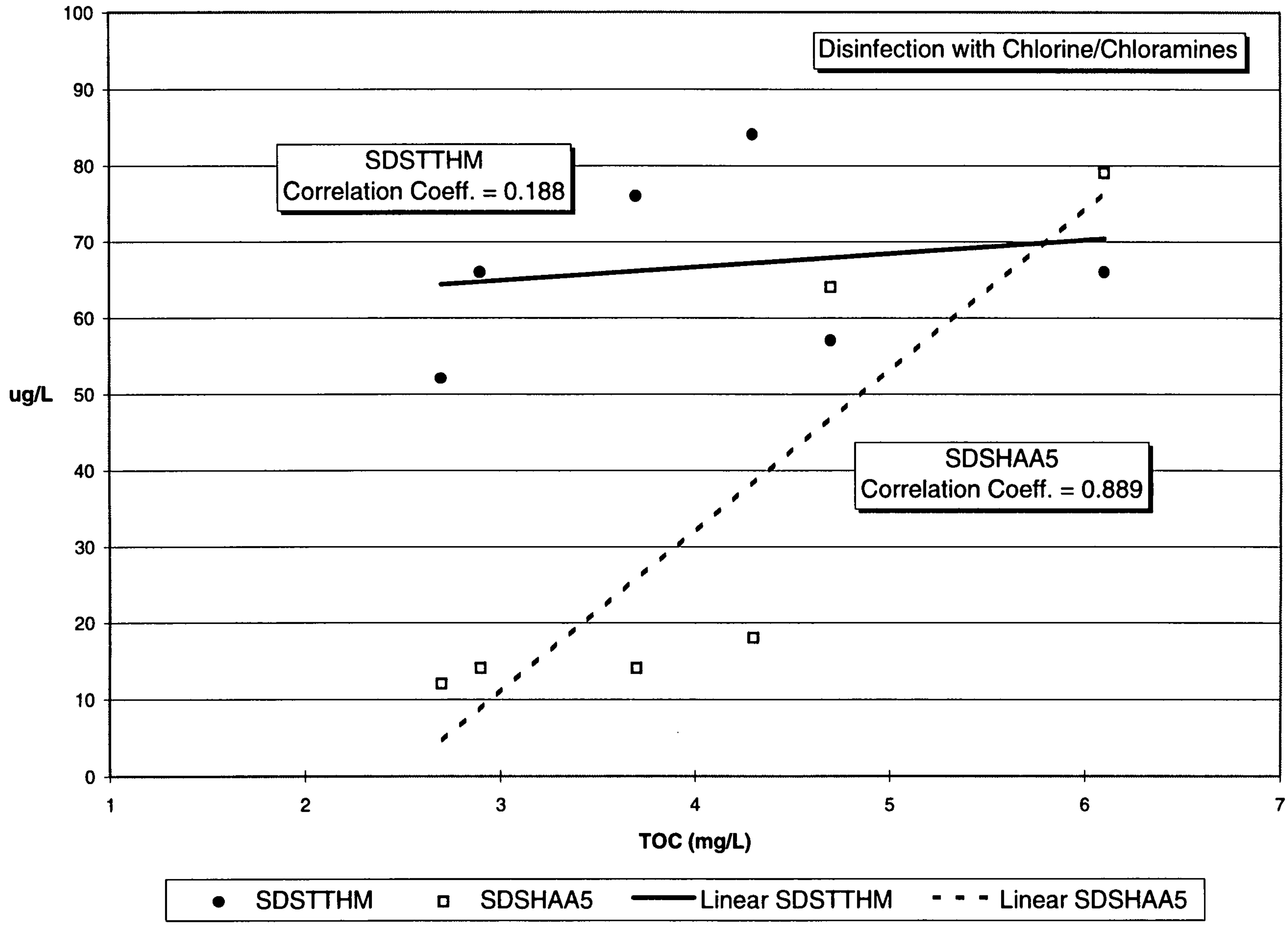
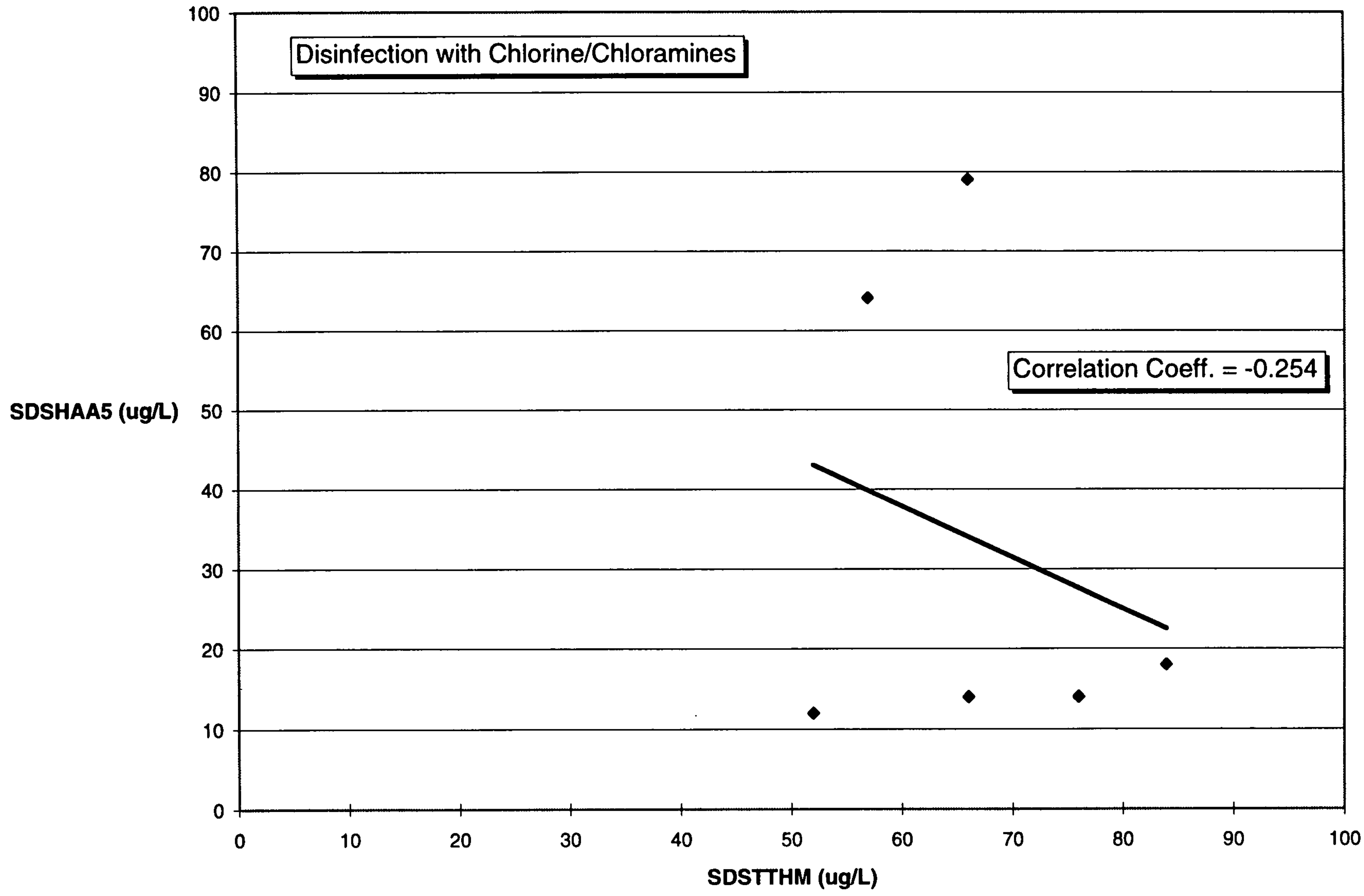


Figure 6-19
Little Arkansas River
Correlation Between SDSHAA5 and SDSTTHM



Section 7
Taste and Odor Control

7.1 Introduction

The City of Wichita currently experiences intermittent taste and odor (T&O) episodes from the Cheney Reservoir supply — primarily in late spring, summer, and/or early fall. No historical data is available on the actual T&O causing compounds present in the Cheney supply; however, the City has relayed that when the T&O events occur, an "earthy/musty" odor in the water is detectable. A policy standard of "no objectionable tastes and odors" has been established by the City.

7.2 Classification of T&O Compounds

Classification of T&O in drinking waters can be attributed to three primary sources: inorganic constituents, organic constituents, and biological constituents. Each is summarized below.

- *Inorganic Constituents* — Inorganic constituents are most commonly detected by taste since they are typically present in much higher concentrations than are organic pollutants. Examples of inorganic constituents are salts, such as sodium chloride, and metals, such as iron, manganese, and zinc.

- *Organic Constituents* — Organic constituents can be classified into six major groups: humic substances, hydrophilic acids, carboxylic acids, peptides and amino acids, carbohydrates, and hydrocarbons. Organic contaminants are generally associated with industrial water sources. Examples of organic constituents include phenolic compounds and pesticides.

- *Biological Constituents* — Biological constituents, by far, contribute to the majority of T&O causing problems occurring in drinking water supplies. Decay of algae, actinomycetes, and other microorganisms are the principal biological sources for T&O. Two common compounds associated with biological tastes and odors are geosmin and 2-methylisoborneol (MIB). Both geosmin and MIB have been identified as a product of actinomycete cultures and various blue green algae species. Each is known for producing "earthy/musty" type odors.

A closed-loop stripping analysis was conducted on the Cheney Reservoir when a minor T&O episode occurred in late February 1995. However, no geosmin or MIB was detected in the sample. CDM planned to conducted some pilot tests during natural T&O events, unfortunately no pronounced T&O episodes occurred during the testing phase. Because the T&O events that occur in the Cheney Reservoir are seasonal and produce "earthy/musty" type odors, we believe that most of the tastes and odors experienced at the Wichita WTP are biological in nature.

7.3 Processes Tested and Results

Jar and pilot tests were conducted on both the Cheney and Little Ark supplies and synthetic samples of geosmin and MIB were spiked into the raw water. Detection limits for each of these constituents is 2 nanograms per liter (ng/L). The lowest typical threshold odor concentrations for geosmin and MIB are about 10 ng/L and 30 ng/L, respectively. A "target" spike dose of 100-125 ng/L was set for both geosmin and MIB to ensure that enough geosmin and MIB would be dosed in the raw water. The artificial spiking produced raw water geosmin and MIB concentrations ranging from 59-140 ng/L and 42-130 ng/L, respectively.

7.3.1 Adsorption

Two applications of carbon adsorption were evaluated for taste and odor control: PAC and GAC as a filter media. The PAC evaluations consisted of jar tests which simulated feeding PAC ahead of the water treatment plant (termed "pre-PAC") as well as pilot tests with PAC fed at the rapid mix module. The GAC tests evaluated 22-inches of GAC as a filter media.

Figures 7-1 and 7-2 show the jar tests results for various pre-PAC doses for the Cheney and Little Ark supplies, respectively. Pre-PAC doses for Cheney were allowed to mix for six hours in order to simulate the detention time in the Cheney Reservoir pipeline for average flows. The pre-PAC mixing time for the Little Ark supply was one hour. For Cheney, geosmin reduction for pre-PAC doses of 10-30 mg/L ranged from 95-100%. MIB reduction for Cheney was somewhat lower and ranged from 67-91%. Obviously, geosmin and MIB reduction for the Little Ark was not expected to be as great since the pre-PAC mixing time was one-sixth that of Cheney. For the Little Ark, geosmin and MIB reductions ranged from 73-100% and 32-87%, respectively.

Pilot results for PAC fed at the rapid mix module are shown in Figure 7-3. While there is a general improvement in geosmin and MIB reduction for the higher PAC dose, the variation in percent reduction for both geosmin and MIB is most likely due to the variations in raw water geosmin/MIB concentrations. This would explain why the pilot run for the PAC dose of 20 mg/L, which had the lowest raw water geosmin/MIB concentration, did not perform as well as the 10 mg/L dose. As expected, PAC fed at the rapid mix is not as effective in reducing geosmin and MIB as pre-PAC. This is primarily due to the fact that when PAC is fed at the rapid mix, the PAC enmeshes with the lime and coagulant floc, making it less available for adsorption of the taste and odor causing compounds.

Figure 7-4 illustrates percent reductions of geosmin and MIB for the GAC filter pilot runs on both Cheney and the Little Ark. Reduction of geosmin and MIB ranged from 81-95 percent and 67-89 percent, respectively. The discrepancy between the Cheney and Little Ark results is primarily due to the fact the GAC empty bed contact time (EBCT) for the Little Ark was slightly longer (i.e., 3.4 minutes for the Little Ark versus 2.3 minutes for Cheney). Note, the difference in EBCT is due to a difference in filtration rates, not GAC depth.

7.3.2 Oxidation

Oxidative processes alter the chemical structure of T&O causing compounds to neutralize their effect. Of the different oxidative processes, ozonation is known for its significant destruction of geosmin and MIB odors and is also associated with producing fruity or citrus type odors. Ozone pilot runs were conducted on the Cheney Reservoir. Both pre-ozonation and pre-ozonation combined with GAC filtration were evaluated. The results from these pilot tests are outlined below.

Figure 7-1
Cheney Jar Test Results for
Geosmin & MIB Removal Using Pre-PAC

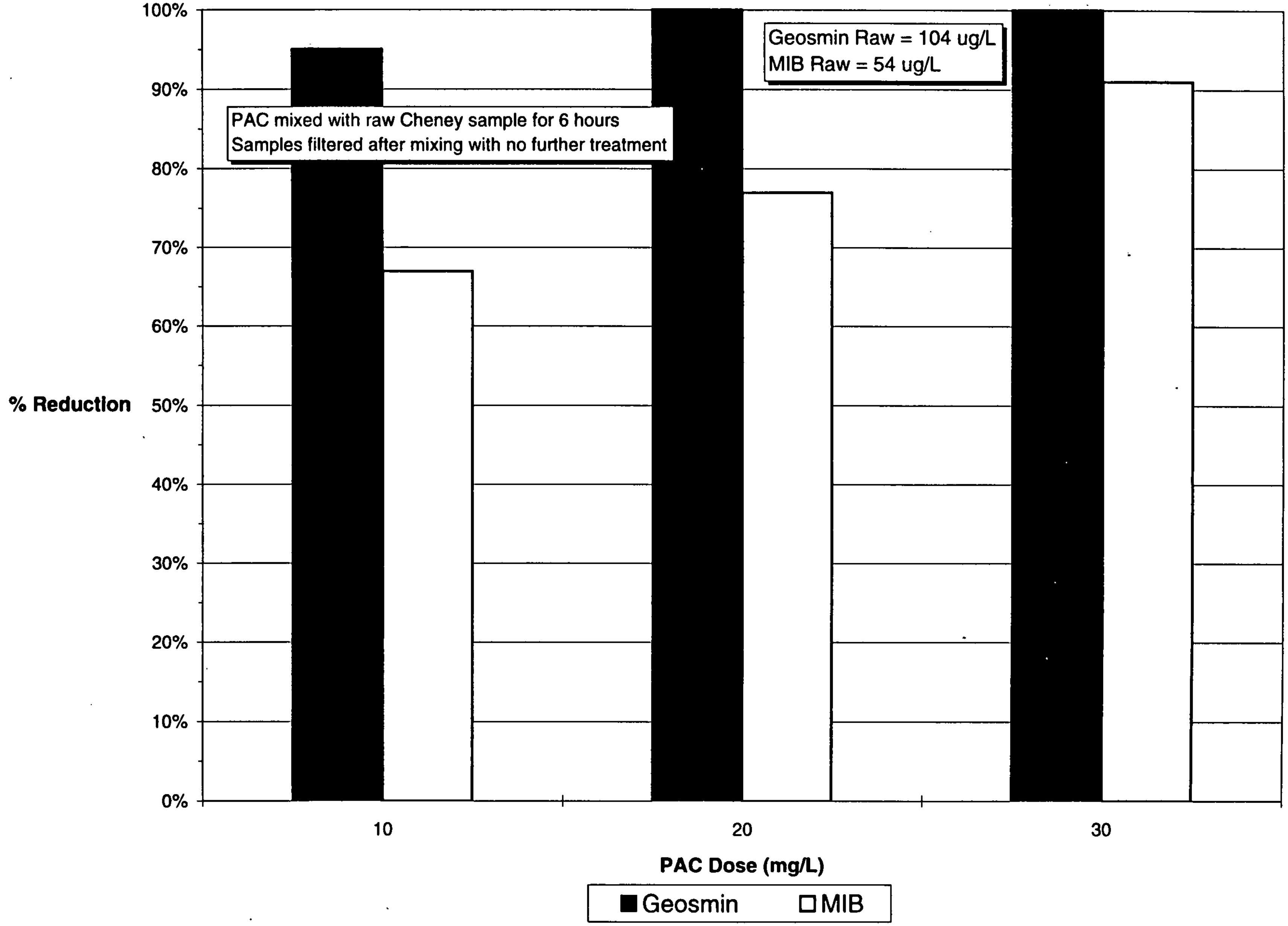


Figure 7-2
Little Arkansas Jar Test Results for Geosmin & MIB Removal Using Pre-PAC

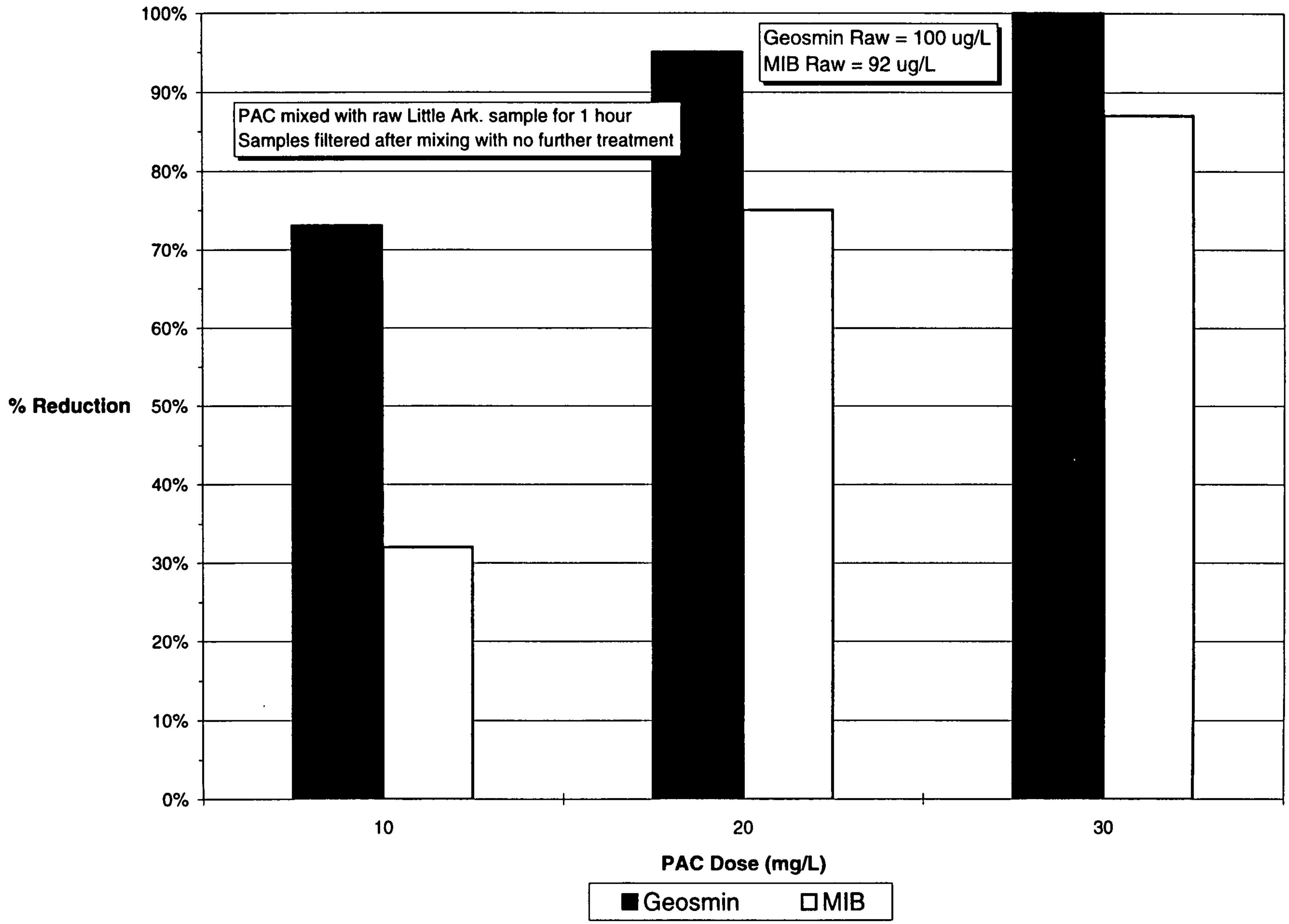


Figure 7-3
Cheney Pilot Runs
Geosmin & MIB Removal with PAC at the Rapid Mix

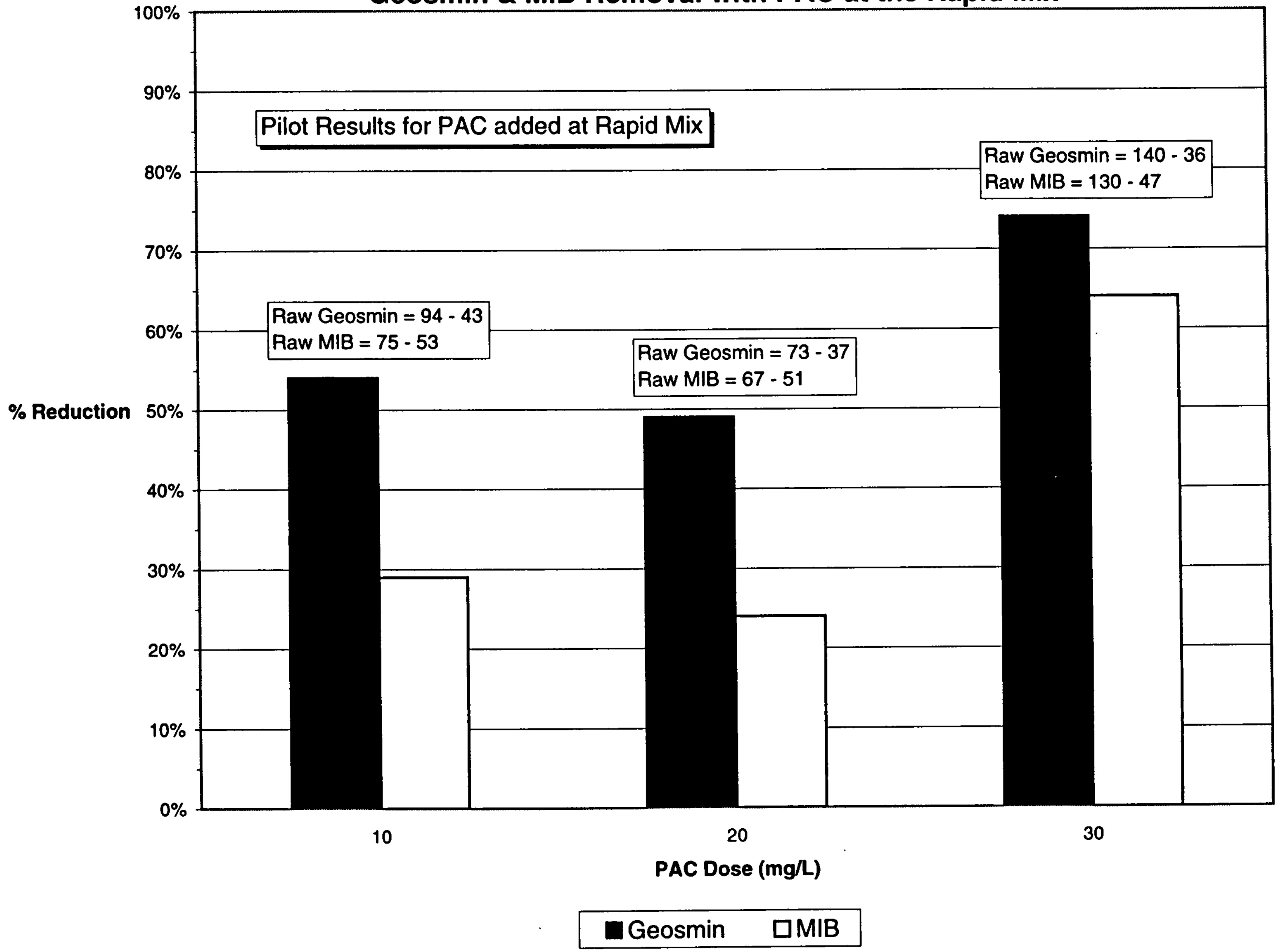
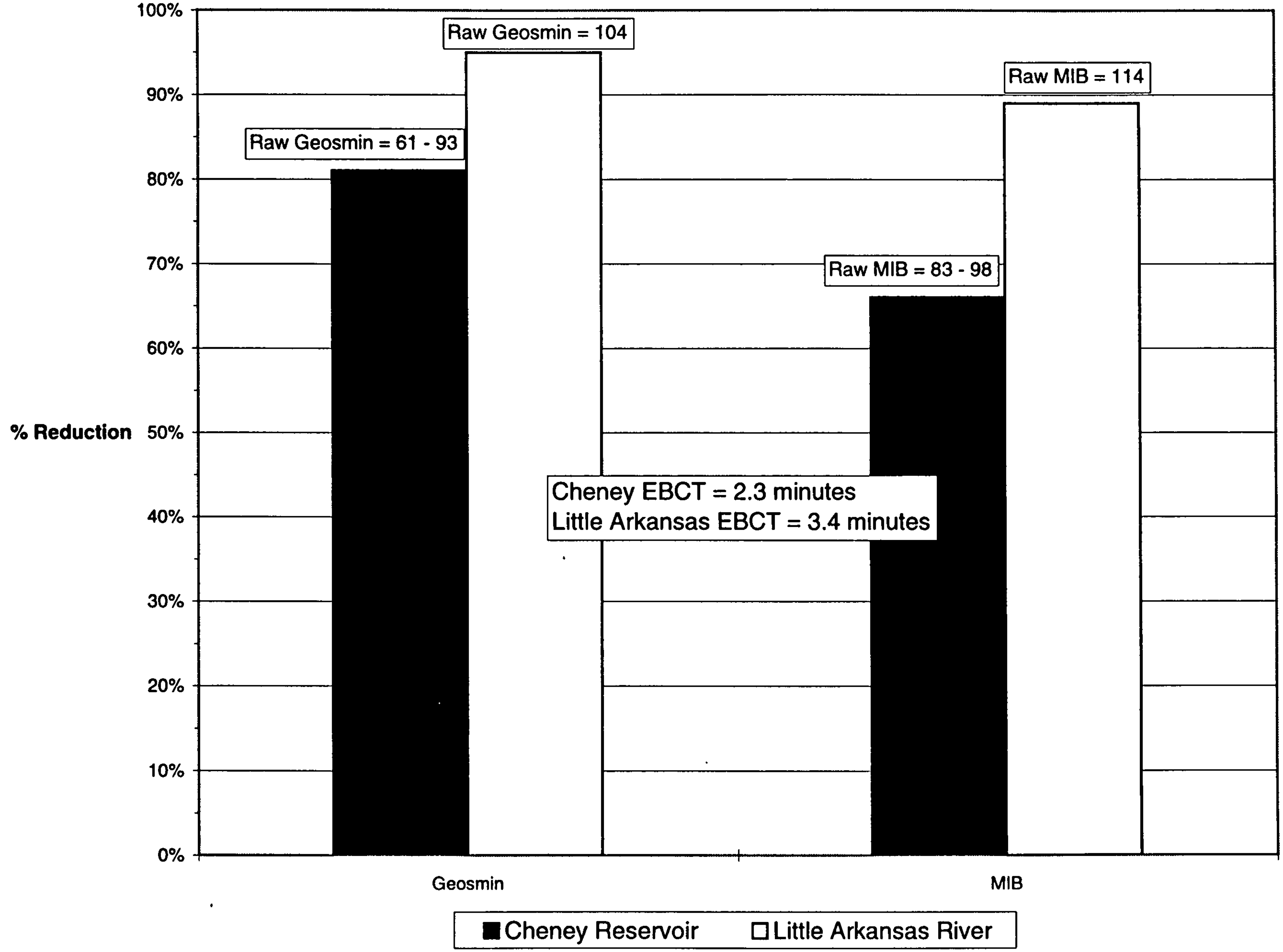


Figure 7-4
Geosmin & MIB Removal with GAC Filter



- A pre-ozone dose of 2 mg/L followed by conventional softening treatment resulted in geosmin and MIB reductions of 94% an 87%, respectively.

- A pre-ozone dose of 2 mg/L followed by conventional softening treatment and GAC filtration (EBCT = 3.5 minutes) resulted in geosmin and MIB reductions of 100% and 94%, respectively.

7.4 Summary

Figure 7-5 shows a comparison of the various T&O control alternatives evaluated for Cheney. Of the processes evaluated, ozone with GAC provided the best results with respect to geosmin and MIB reduction. Following a close second was a pre-PAC dose of 30 mg/L.

A summary of the Little Ark T&O control tests is shown in Figure 7-6; note that no ozone tests were conducted. For these evaluations, a pre-PAC dose of 30 mg/L provided the best results.

Figure 7-5
Cheney Reservoir
Comparison of Geosmin & MIB Removal

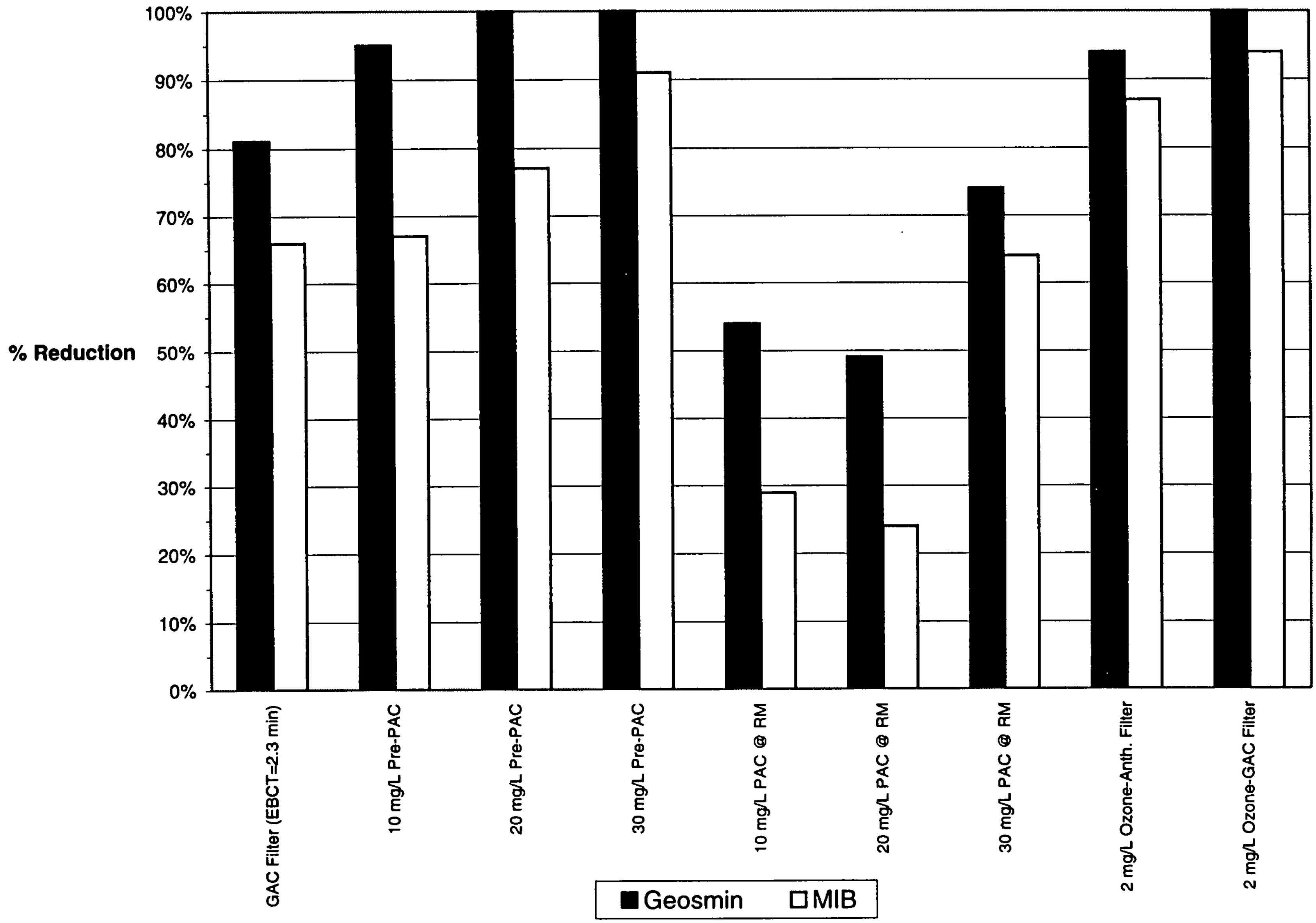
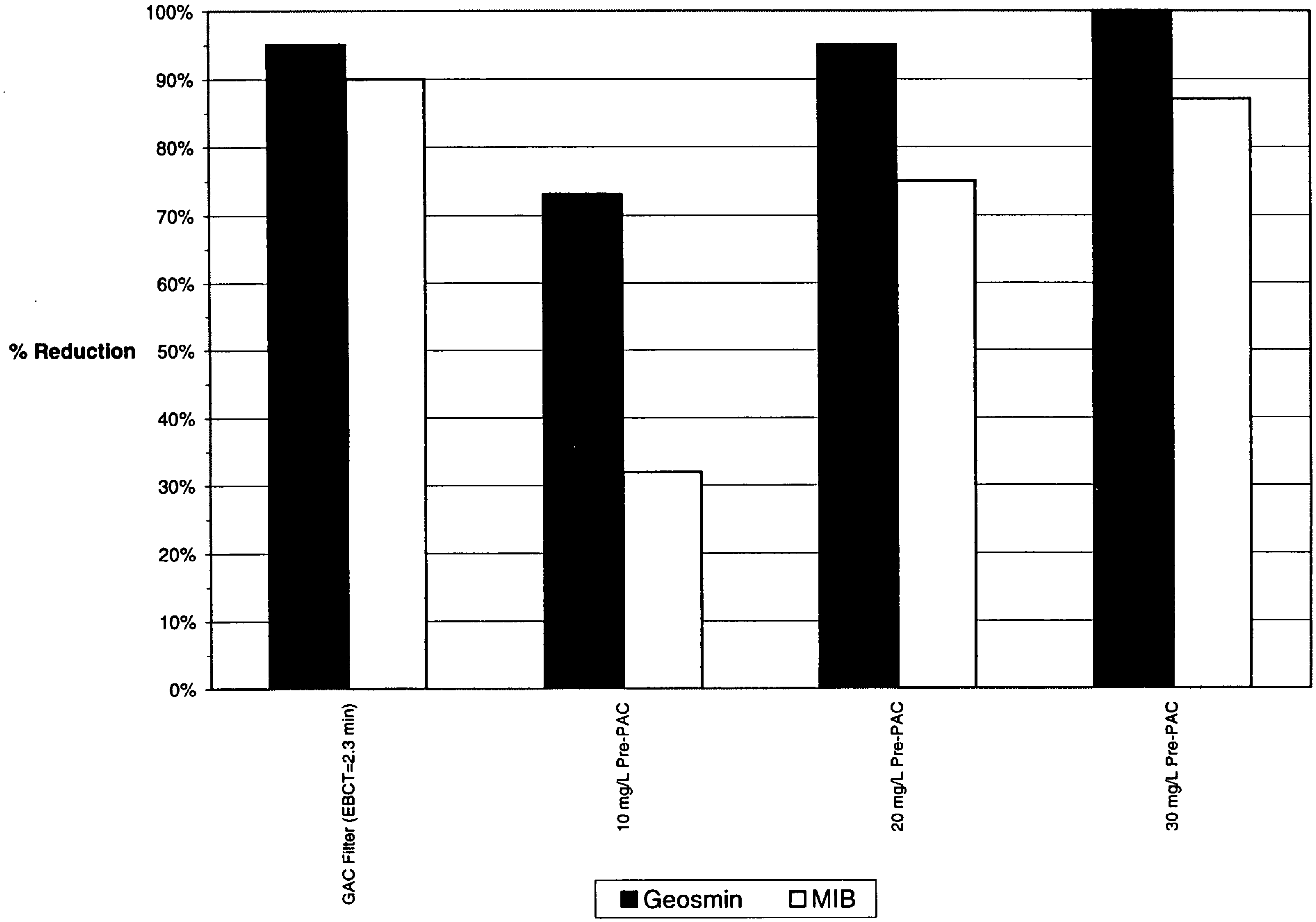


Figure 7-6
Little Arkansas River
Comparison of Geosmin & MIB Removal



Section 8
Treatment Evaluations and Recommendation

8.1 Introduction

In 1993, the City developed a raw water supply plan based on a report prepared by Burns & McDonnell titled *Water Supply Study*, 1993. In this report, not only was the Little Arkansas River identified as a potential second surface water source, but estimated projections of surface water and groundwater use were provided for the year 2050 based on an average-day demand of 125 mgd. These water use projections are provided in Table 8-1 along with the historical water usage.

Recognizing that pilot plant treatment of the Cheney Reservoir, Little Arkansas River, and groundwater was not economically feasible, the treatability study focused on pilot plant treatment of Cheney and the Little Ark, by themselves. Since the groundwater quality is very good, it is reasonable to assume that groundwater blending will only improve treatment. Nevertheless, jar tests of various blends of surface water and groundwater were also performed to better evaluate to what extent groundwater may be needed to meet the treatment goals.

In order to assess the various treatment processes tested, the actual percentages of Cheney, the Little Ark, and the groundwater supplies must be considered so as not to overestimate any required treatment plant modifications. Thus, in evaluating these treatment alternatives, the impact of groundwater blending, according to the percentage shown in Table 8-1 (i.e., 51%), is considered. Note, for the treatability study, Equus Beds Wellfield water was used in the groundwater blending tests. It is assumed that the E & S, Local, Reserve, and Gilbert-Mosley Wellfield water qualities are similar to the Equus Beds.

Evaluations of the various treatment alternatives tested as well as the recommended implementation plan are provided below.

8.2 Evaluation of Treatment Alternatives

Because most of the treatment alternatives evaluated for TOC reduction and T&O reduction overlap, a comparison of the different processes has been combined and is shown in Table 8-2. This table lists the various monetary and non-monetary advantages and disadvantages of each process alternative. From this table, pre-PAC provides good TOC reduction, excellent geosmin/MIB reduction, and relatively low capital cost. GAC filtration provides good TOC and geosmin/MIB reduction, but has a short bed life for TOC reduction and a very high O&M cost. While PAC at the rapid mix provides good TOC reduction, it does not provide efficient geosmin/MIB reduction and the overall dose required is higher than pre-PAC to achieve the same results. Pre-ozonation provides excellent geosmin/MIB reduction, but poor TOC reduction. Additionally, pre-ozonation has the highest capital cost. While both pre-PAC/GAC and pre-ozonation/GAC provide the best TOC and geosmin/MIB reduction, their overall capital and/or O&M costs are very high. Finally, the enhanced softening/pre-PAC option would provide the necessary 10 mg/L removal of magnesium hardness so that the TOC reduction requirements would not have to be met; however, softening to a pH of at least 10.5 would require a significantly higher lime dose than the WTP currently feeds. On the other hand, pre-PAC feed for this option would be intermittent since it would only be required for T&O reduction.

Table 8-1
Historical and Projected Uses of Water Sources for Average Operating Conditions

Supply Source	Current Use	Projected Use in 2050
Surface Water		
Cheney Reservoir	40%	37%
Little Arkansas River	0%	12%
Groundwater		
Equus Beds Wellfield	60%	11%
E&S Wellfield	Peaking Only	12%
Gilbert-Mosley Wellfield	0%	2%
Reserve Wellfield	0%	4%
Local Wellfield	0%	22%

A comparative present worth analysis of the TOC and T&O reduction options is shown in Table 8-3. Note that the "PAC at rapid mix" option is not shown in the present worth analysis since this chemical feed point does not provide an efficient use of PAC and is thus not recommended as a viable option. From the present worth analysis, pre-PAC has the lowest present worth value, assuming a 20-year life.

Table 8-4 shows a comparison of the three disinfection schemes evaluated. The chlorine/chloramines option has the lowest capital and O&M costs; however, carbon adsorption or blending with up to 50% groundwater is required to meet the proposed Stage 2 TTHM and HAA5 MCLs. Pre-ozonation/chloramines produces very low DBPs, although the capital cost is extremely high. Chlorine dioxide/chloramines also produces low TTHMs and HAA5, but chlorite formation is above the 1.0 mg/L proposed MCL. Thus, chlorine dioxide is not considered a viable option. A comparative present worth analysis of the two viable disinfection alternatives is shown in Table 8-3. As expected, chlorine/chloramine has the lowest present worth value — less than one-fourth that of pre-ozonation/chloramines.

The overall treatment options and their respective present worth values are as follows:

- Pre-PAC with Chlorine/Chloramines — $13,612,000
- Pre-Ozonation/Chloramines — $14,173,000
- Enhanced Softening/Pre-PAC with Chlorine/Chloramines — $14,993,000
- GAC Filtration with Chlorine/Chloramines — $19,391,000
- Pre-PAC/GAC with Chlorine/Chloramines — $21,730,000
- Pre-Ozonation/GAC with Chloramines — $22,273,000

Table 8-2
TOC and T&O Reduction Alternatives

Process	Advantages	Disadvantages
Pre-PAC	+ Neglible capital cost for Cheney + Good TOC reduction [(1)] + Excellent geosmin/MIB reduction	- Will not be able to feed PAC when periodically use chlorine to disinfect 60" raw water line from Cheney - High O&M cost
PAC at Rapid Mix	+ Good TOC reduction	- Capital cost for new facilities at WTP to treat surface waters - Poor geosmin/MIB reduction - Requires higher dose than pre-PAC to achieve same results (not efficient PAC feed point) - High O&M cost
GAC Filter	+ Good TOC reduction + Ease of operation + Good geosmin/MIB reduction with 22" bed depth	- Very short bed-life for TOC reduction - Very high O&M cost
Pre-Ozonation	+ Excellent geosmin/MIB reduction + Low O&M cost	- Poor TOC reduction - Very high capital cost - More complex system operation
Pre-PAC/GAC[(2)]	+ Excellent TOC reduction + Excellent geosmin/MIB reduction + Low capital cost	- Very high O&M cost
Pre-Ozonation/GAC	+ Excellent TOC reduction + Excellent geosmin/MIB reduction	- Very high capital cost - Very high O&M cost - More complex system operation
Enhanced Softening/ Pre-PAC	+ As long as removing 10 mg/L magnesium hardness, do not need to meet TOC reduction requirements + Does not require continuous feeding of PAC + Excellent geosmin/MIB reduction w/pre-PAC	- High O&M cost - Will need to increase slaker/feeder capacity at Central plant

(1) Assumes pre-PAC dose of 10 mg/L followed by conventional treatment would acheve 25% TOC reduction.

(2) PAC could either be fed as pre-PAC or PAC at Rapid Mix. Pre-PAC was assumed, since it is more effective for T&O and the capital cost is lower.

Table 8-3
Comparative Present Worth Analysis [1][2][3]

Item	Cheney Reservoir		Little Arkansas River		Total		Present Worth
	Capital	O&M	Capital	O&M	Capital	O&M	
TOC and T&O Reduction Alternatives							
Pre-PAC[4]	$1,000	$731,000	$165,000	$92,000	$166,000	$823,000	**$10,422,000**
GAC Filtration[5]	$0	$650,000	$0	$650,000	$0	$1,300,000	**$16,201,000**
Pre-Ozonation[6]	$6,700,000	$234,000	$2,600,000	$30,000	$9,300,000	$264,000	**$12,590,000**
Pre-PAC/GAC Filtration[4][7]	$1,000	$1,056,000	$165,000	$417,000	$166,000	$1,473,000	**$18,523,000**
Pre-Ozonation/GAC Filtration[6][7]	$6,700,000	$559,000	$2,600,000	$355,000	$9,300,000	$914,000	**$20,690,000**
Enhanced Softening/Pre-PAC[8]	$86,000	$859,000	$165,000	$68,000	$251,000	$927,000	**$11,803,000**
Disinfection Alternatives							
Chlorine/Chloramines[9]	$0	$128,000	$0	$128,000	$0	$256,000	**$3,190,000**
Pre-Ozonation/Chloramines[6][10]	$6,700,000	$297,500	$2,600,000	$93,500	$9,300,000	$391,000	**$14,173,000**

Notes:

(1) Present worth is based on 8% interest rate, 3% inflation, and 20 year life.
(2) Capital costs assume 80 mgd for Cheney and 20 mgd for the Little Ark.
(3) O&M costs assume 40 mgd average day demand for Cheney and 5 mgd average day demand for the Little Ark.
(4) Assumes a 10 mg/L PAC dose all year-around.
(5) Assumes replacement of GAC media once/year as O&M cost equally split between Cheney and the Little Ark.
(6) Assumes an air-fed system and an average ozone dose of 2 mg/L.
(7) Assumes replacement of GAC media once every two years as O&M cost equally split between Cheney and the Little Ark.
(8) Softening cost includes only the additional amount of lime needed to raise pH from 9.0 to 10.5 and additional amount of CO_2 to reduce pH from 10.5 to 8.5. Pre-PAC dose (for T&O reduction) assumed at 10 mg/L for 3 months/year.
(9) Assumes a chlorine dose of 4 mg/L and an ammonia dose of 0.45 mg/L.
(10) Assumes a chlorine dose of 1.8 mg/L and an ammonia dose of 0.45 mg/L.

Table 8-4
Disinfection Alternatives

Process	Advantages	Disadvantages
Chlorine/Chloramines	+ Can easily meet proposed Stage 1 TTHM and HAA5 MCLs with 100% surface water + Since WTP currently practices chlorine/chloramine disinfection, no capital cost + Low O&M cost	- Will require carbon adsorption or blending with up to 50% groundwater to meet proposed Stage 2 TTHM and HAA5 MCLs
Pre-Ozonation/ Chloramines	+ Can easily meet proposed Stage 2 TTHM and HAA5 MCLs with 100% surface water + Bromate not detected in treated water	- Requires biologically active filtration - Very high capital cost - High O&M cost - More complex system operation
Chlorine Dioxide/ Chloramines	+ Can easily meet proposed Stage 2 TTHM and HAA5 MCLs with 100% surface water	- Chlorite in treated water greater than 1.0 mg/L proposed MCL - Requires chlorine dioxide generator be at least 95% efficient - Very high capital cost - High O&M cost - More complex system operation

8.3 Additional Process Improvements

Treatment of Cheney and the Little Ark will require some additional chemical system modifications no matter what DBP and T&O reduction alternative is recommended. These modifications are described below.

8.3.1 Ferric Sulfate System

Because of: 1) the significant change in the water quality (i.e., higher turbidity) of Cheney Reservoir, compared to 1990 when bench-scale testing was last performed, and 2) the City's desire to maximize surface water treatment, modifications to the existing ferric sulfate feed system are recommended. The existing ferric sulfate system is designed to feed 10 mg/L at flows of 130 mgd to Central plant and 30 mgd to East plant.

While future groundwater use may average around 50% for the year, there most likely will be times during the year when the City wishes to treat a majority of surface water — particularly Cheney. Thus, two treatment scenarios will be considered for increasing the capacity of the existing ferric sulfate system: 1) treating 50% surface water and 50% groundwater, and 2) treating 100% surface water.

For the 50% surface water scenario and assuming a 25 mg/L maximum ferric sulfate dose, two additional ferric sulfate metering pumps would be required. One of these pumps would provide additional feed capacity to Central plant and the second pump would serve as a spare. The estimated construction cost for these two pumps as well as related pump appurtenances and piping is $50,000.

For the 100% surface water scenario and assuming a 50 mg/L maximum ferric sulfate dose, two additional ferric sulfate metering pumps would be required — one for Central plant and one spare — and the ferric sulfate transfer pump would need to be replaced with a larger capacity pump. Additionally, we recommend adding a 12,000 gallon bulk ferric sulfate tank, transfer pump, and day tank in order to improve the ferric sulfate storage capabilities. The estimated construction cost for these two new metering pumps, two new transfer pumps, a new 12,000 bulk tank, day tank, tank containment area, and related pump appurtenances and piping is $140,000. Figure 8-1 shows two potential locations for the new ferric sulfate bulk tank and transfer pump.

8.3.2 Soda Ash System

Treatment of the Little Ark may require a new soda ash storage and feed system at the Wichita WTP. The need for soda ash is not only dependent on the hardness and alkalinity of the Little Ark but also the percentage of the Little Ark treated — both which could be highly variable. Assuming that a new soda ash system is required to treat the Little Ark water, the estimated construction cost for this system is $250,000. This cost is for a soda ash package system which includes a minimum 1,000 cubic foot storage hopper, soda ash solution make-up system, metering pumps, piping, appurtenances, and a self-contained building enclosure.

8.4 Recommendation

To comply with the requirements of the proposed D/DBPR and to control tastes and odors at the Wichita WTP, CDM recommends the City incorporate the following process modifications.

- At the Cheney Pump Station, add piping, valves, and appurtenances to the second PAC feed pump. There are a total of two 550 gph PAC feed pumps (only one pump currently has piping). It is our understanding, that the PAC system is in satisfactory condition and will not require further improvements.

- Expand the capacity of the existing ferric sulfate feed system so that the system can treat 100% surface water, if necessary.

- Feed chlorine at the Cheney Pump Station and wellfields only as necessary to keep these lines clean. No disinfection credit (CT) with chlorine will be allowed until after the TOC reduction requirements have been met.

- Begin obtaining disinfection (CT) credit with free chlorine through the modified chlorine contact basin, and ammonia addition at the basin outlet to tie up the remaining free chlorine and form chloramines. If the running average for TTHMs and HAA5 can be kept below 40 μg/L and 30 μg/L, respectively, the City will not be required to meet the TOC reduction requirements of the D/DBPR.

- Process modifications to accommodate treatment of the Little Ark are dependent not only on the amount of Little Ark the City wishes to treat, but also whether the Little Ark water is obtained directly from the river or from recharge injection wells. The treatability study evaluated taking Little Ark water directly from the river. One of the conclusions from this study was treatment of the Little Ark directly from the river would be very difficult due to the wide and rapid variability in raw water quality (e.g., turbidity, hardness, alkalinity, TOC). As a minimum, treatment of Little Ark water directly from the river would require pretreatment facilities to better even out the incoming water quality. A new soda ash system may be required to treat the non-carbonate hardness in the Little Ark raw water. However, the need for this system is dependent on the amount and quality of the Little Ark water to be treated.

The PAC improvements at the Cheney Pump Station and the ferric sulfate system improvements at the water treatment plant should be implemented as soon as possible to provide additional treatment capabilities. Chlorine disinfection in the new chlorine contact basin must be in operation before promulgation of Stage 1 of the D/DBPR. The PAC and soda ash systems for treatment of Little Ark water should be added, as necessary, at the same time as the Little Ark raw water supply system.

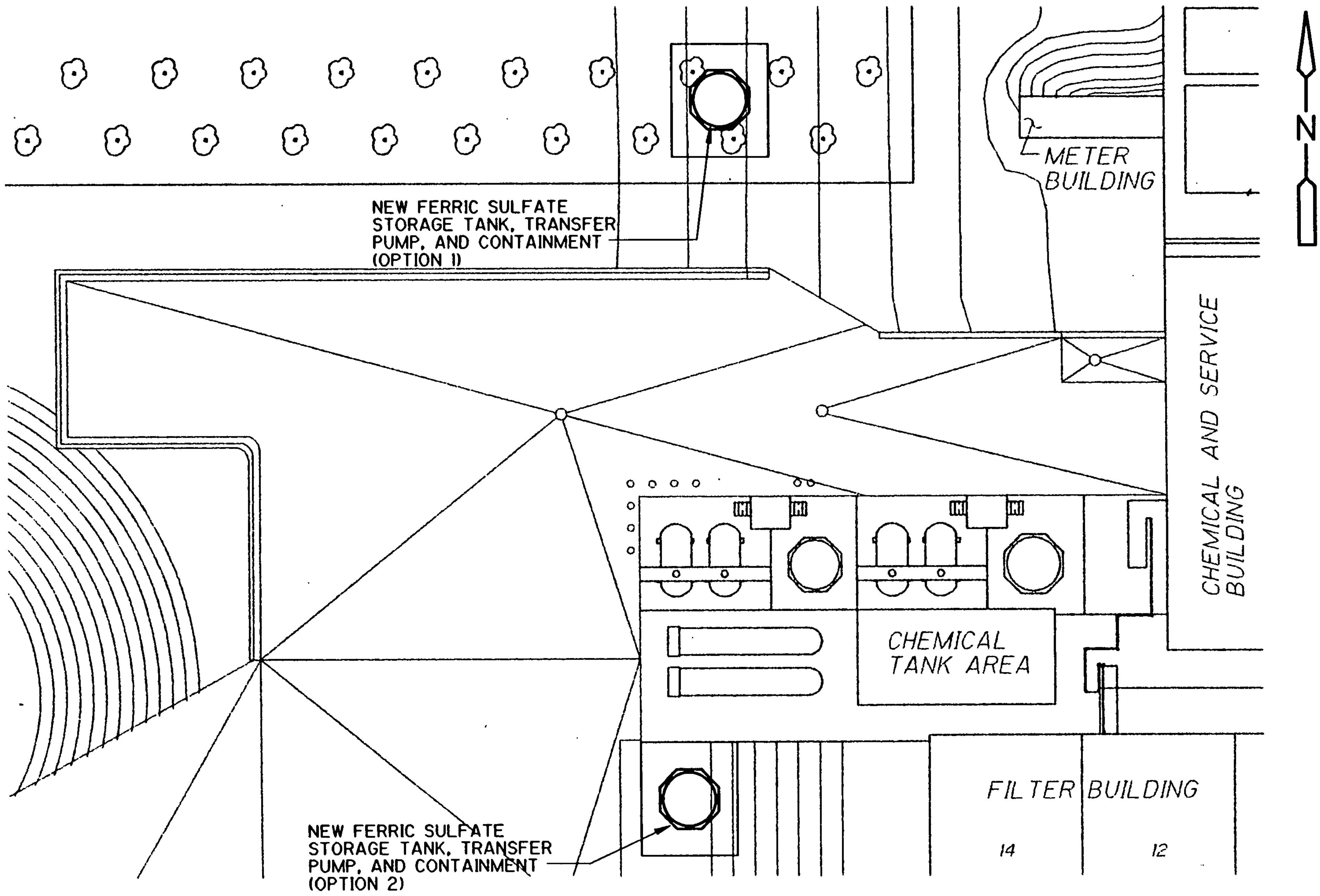


Figure 8-1
NEW FERRIC SULFATE STORAGE TANK AND TRANSFER PUMP

Section 9
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