STRATEGIES FOR COMPLIANCE WITH STAGE 2 DISINFECTANTS AND DISINFECTION BYPRODUCTS RULE FOR SURFACE WATER TREATMENT FACILITIES IN NORTHEASTERN OKLAHOMA

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Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTORATE OF PHILOSOPHY
July 2012

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACH	Aluminum Chlorohydrate
AMW	Apparent Molecular Weight
AOP	Advanced Oxidation Process
AWWA	American Water Works Association
CCI	Consumer Cost Index
CCL 3	Contaminant Candidate List 3
CFR	Code of Federal Regulations
CFATS	Chemical Facility Anti-Terrorism Standards
COT	City of Tulsa
CT	Concentration-Time
Da	Dalton
D/ DBP	Disinfectants and Disinfection Byproducts
DBP	Disinfection Byproduct
DHS	Department of Homeland Security
DIC	Dissolved Inorganic Carbon
DNA	Deoxyribonucleic Acid
EHS	Extremely Hazardous Substance
ENR	Engineering News Record
EPA	Environmental Protection Agency
GAC	Granular Activated Carbon
HAA5	Haloacetic Acids
HMS	Hydrolyzed Metal Salts
HPC	Heterotrophic Plate Count

HPSEC	High Performance Size Exclusion Chromatography
HRT	Hydraulic Retention Time
LOX	Liquid Oxygen
LRAA	Locational Running Annual Average
LTLCR	Long Term Lead and Copper Rule
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
MCL	Maximum Contaminant Level
MGD	Million Gallons Per Day
MIB	Methylisoborneol
MOR	Monthly Operating Report
MRL	Minimum Reporting Level
NDMA	N-Nitroso-dimethylamine
NOM	Natural Organic Matter
NTU	Nephelometric Turbidity Unit
OAC	Oklahoma Administrative Code
ODEQ	Oklahoma Department of Environmental Quality
OEL	Operational Evaluation Level
ORP	Oxidation Reduction Potential
OSHA	Occupational Safety and Health Administration
OWRB	Oklahoma Water Resources Board
PAC	Powdered Activated Carbon
PACl	Polyaluminum Chloride
PLC	Programmable Logic Controller
PPCP	Pharmaceuticals and Personal Care Products
PPE	Personal Protective Equipment

PVC	Polyvinyl Chloride
RED	Reduction Equivalent Dose
RNA	Ribonucleic Acid
RMP	Risk Management Plan
RTCR	Revised Total Coliform Rule
STP	Standard Temperature and Pressure
SWTR	Surface Water Treatment Rule
TOC	Total Organic Carbon
TTHM	Total Trihalomethanes
UCMR	Unregulated Contaminant Monitoring Regulation
UV	Ultraviolet
UVT	Ultraviolet Light Transmittance
WEF	Water Environment Federation

CHAPTER I

INTRODUCTION

The Environmental Protection Agency (EPA) recently created new regulations that better protect human health but that also make achieving compliance more difficult for existing water treatment facilities. These new regulations deal primarily with disinfection byproducts (DBPs) and are the result of concerns that a lifetime of consuming treated drinking water could increase the chances of developing cancer. Compliance with the Stage 2 Disinfectants and Disinfection Byproducts (D/ DBPs) Rule will become increasingly more difficult for surface water treatment facilities in northeastern Oklahoma. This dissertation will evaluate the effectiveness of various technologies that can be used to be in compliance with the new rule. These technologies will include: the use of alternative disinfectants, such as chlorine dioxide, ozone, and ultraviolet light; the use of chloramines as a microorganism barrier in the distribution system; and the use of total organic carbon removal technologies.

Stage 1 Disinfectants and Disinfection Byproducts Rule went into effect January 1, 2002 for systems serving greater than 10,000 people that utilize surface water or ground water under the influence of surface water. This rule has been relegated to the State of Oklahoma. The Oklahoma Department of Environmental Quality (ODEQ) regulated that the maximum contaminant level (MCL) for total trihalomethanes (TTHMs) is 0.080 mg/L (80 µg/L) and for five (5) haloacetic acids (HAA5s) is 0.060 mg/L (60 µg/L). TTHMs are comprised of four (4) individual compounds which include chloroform, bromoform, bromodichlormethane, and dibromodichlormethane. The HAA5 are made up of five (5) individual compounds which include monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid and dibromoacetic acid. (EPA 2006[b]) (ODEQ 2011[a])

Compliance was based on an annual running average. This allowed utilities to average all the sampling sites in the system in order to obtain a system-wide average DBP concentration. The water utilities are allowed to average their quarterly DBP concentration with the previous three quarters. A visual representation is presented in Table 1.1. This is example data and not representative of any specific water authority.

Table 1.1 – Example of Running Annual Average for TTHMs (µg/L)

	Location 1	**Location 2**	**Location 3**	**Location 4**	**Quarterly Average**
Quarter 1	100	40	50	50	60.00
Quarter 2	75	50	40	100	66.25
Quarter 3	55	45	55	110	66.25
Quarter 4	60	55	40	75	57.50
Running Annual Average					**62.50**

(EPA 2006[b])

A surface water treatment facility is also required to obtain a minimum reduction in total organic carbon (TOC). The percentages will vary depending on the source water alkalinity and raw water TOC. (EPA 2006[b]) (ODEQ 2011[a])

Stage 2 Disinfectants and Disinfection Byproducts Rule goes into effect as follows; April 1, 2012 for systems that serve greater than 100,000 people; October 1, 2012 for systems that serve 50,000 to 99,999 people; and October 1, 2013 for systems serving fewer than 50,000 people. The compliance date is based on the largest system served (either wholesaler or consecutive system). This rule has not been relegated to the State of Oklahoma. The regulation continues the same MCL as found in Stage 1 Disinfectants and Disinfection Byproducts Rule, but essentially changes the manner in which the samples are averaged. Water utilities will no longer be able to average sites found within the distribution system. Each sampling location will be averaged individually, and each must be in compliance. As demonstrated in Table 1.1, the running annual average for TTHMs at the example site is in compliance. As demonstrated in Table 1.2, the locational running annual average (LRAA) is not in compliance for TTHMs at location 4. This is example data and not representative of any specific water authority.

Table 1.2 – Example of Locational Annual Average for TTHMs (µg/L)

	Location 1	**Location 2**	**Location 3**	**Location 4**
Quarter 1	100	40	50	50
Quarter 2	75	50	40	100
Quarter 3	55	45	55	110
Quarter 4	60	55	40	75
Locational Running Annual Average (LRAA)	72.50	47.50	46.25	**83.75**

(EPA 2006[b])

The Stage 2 D/ DBP Rule also contains an operational evaluation requirement. This section of the rule states that the water authority must evaluate their TTHM and HAA5 LARR quarterly utilizing the Stage 2 D/ DBP compliance monitoring results and the following calculation:

(Previous Quarter + Previous Quarter + 2(Current Quarter))/ 4 = OEL

Figure 1.1 – Operational Evaluation Level (OEL) Calculation (EPA 2006[b])

Table 1.3 – Example OEL Calculation for TTHMs

	Location 1 (µg/L)	**OEL (µg/L)**
Quarter 1	60	-
Quarter 2	75	-
Quarter 3	55	71.25
Quarter 4	100	**82.5**
Locational Running Annual Average (LRAA)	72.50	-

In the example calculation shown in Table 1.3, as calculated in accordance with Figure 1.1, it is shown that location 1 is in compliance for the Stage 2 D/ DBP Rule, but the OEL exceeds the established MCL for TTHMs during quarter 4. If at any monitoring location the OEL exceeds the MCL for TTHMs or HAA5s, the authority must complete an evaluation of the treatment and distribution systems. The water authority has ninety (90) days after notification of the analytical results to submit the operational evaluation. The distribution system evaluation must include an evaluation of storage tank operation and excess storage capacity. Additionally, an evaluation must be conducted to determine if there have been changes in the source water quality. The purpose of this section of the regulation is to address EPA concerns with regard to major deviations from the TTHMs or HAA5s MCL. (EPA 2006[b])

The regulation also will now enforce TTHMs and HAA5 standards on consecutive systems. A consecutive system is a system that receives some or all of its finished water from a wholesaler. Any public water supply system that utilizes a disinfectant must also monitor for DBPs in accordance with the regulation. Essentially, all systems in the State of Oklahoma fall into these categories, thereby increasing the regulated systems in the State of Oklahoma from approximately 600 to 1200 entities.

Chlorinated DBPs are formed when organic compounds (i.e. TOC) react with hypochlorite, which is formed by adding free chlorine (or sodium hypochlorite). Water temperature, co-reactants (bromide, hydroxide, etc.), reaction time, and other variables aid in the reaction between TOC and free chlorine. Typically, TOC and reaction time are the only variables that can be controlled by a water treatment facility if not alternative disinfectant exists at the site. Free chlorine applied dosage can not be varied because it is needed to disinfect (i.e. inactivation of *Giardia lambia* and viruses) treated water, and it is also used as a microorganism barrier in the distribution system. When free chlorine is used as a microorganism barrier in the distribution system, a minimum of 0.2 mg/L of free chlorine residual is required by ODEQ and EPA guidelines. (EPA 2011[e]) (ODEQ 2011[a])

Objectives

This paper will evaluate current technologies that have been employed to comply with Stage 2 Disinfectants and Disinfection Byproducts (DBPs) Rule for surface water public water systems. These technologies include the use of ozone, chlorine dioxide, ultraviolet (UV) light, as well as total organic carbon or dissolved organic carbon (DOC) removal technologies. During the evaluation of the different compliance technologies, it will be determined which variables are the most critical to consider when evaluating technologies for compliance with the Stage 2 D/ DBPs Rule. The evaluation and development of critical variables will then be used to develop a decision tree. The decision tree can be used by small municipalities to aid in their selection of a compliance technology, and can also be an effective tool to substantiate the choice of compliant technologies. The decision model should not be used as a substitution for bench and pilot scale testing. Representative water treatment facilities will be used to determine the effectiveness of the decision tree. Presented in Table 1.4 – Dissertation Objectives, is an outline of the intentions of this dissertation.

Table 1.4 – Dissertation Objectives

- Evaluate the use of the following technologies for compliance with Stage 2 Disinfectants and Disinfection Byproducts (D/ DBPs) Rule for small surface water public water systems in northeastern Oklahoma:
    - Ozone
    - Chlorine Dioxide
    - Ultraviolet light (UV) technologies
    - Chloramines (monochloramine)
    - Total organic carbon (TOC) and/ or dissolved organic carbon removal technologies (DOC) which include enhanced coagulation, granular activated carbon, powdered activated carbon, fixed bed anion exchange, and fluidized bed anion exchange
- Determine which variables are the most important factors to consider when evaluating technologies for compliance with Stage 2 D/ DBPs Rule
- Develop a rating system for each variable and its potential for impacting compliance with Stage 2 D/ DBPs Rule
- Develop guidelines and a paper decision model from the above objectives to aid small public water systems in northeastern Oklahoma

To accomplish the above objectives, an evaluation will need to be conducted for each of the technologies, which will include statements and supporting information for the following:

- Compliance with DBPs or ability for compliance with DBPs
    - Utilize ODEQ drinking water watch website to compile testing data on DBPs and TOC
    - Evaluate the test data set for each authority by utilizing basic statistics
- Surface water constituents that impact technology
    - Discuss bromide, iron, manganese, turbidity, UVT, temperature, taste/ odor

compounds, nature of DOC, pathogens and their impact on equipment
    - Request MORs from authority
    - If possible, perform testing at individual facilities to identify variables that impact the concentration of DBPs
- Age and condition of current facility
    - Determine materials that are compatible with equipment
    - Determine if the technology is appropriate for an existing facility
    - Consult authority of the age of the facility and when the last upgrade was performed
    - Review materials used in construction
    - Possibly tour existing facilities
- Impact on other processes
    - Evaluate equipment for the potential for corrosion
    - Evaluate if equipment will require additional processes
- Impact on current ODEQ, EPA, DHS and OSHA regulations
    - Review existing EPA, ODEQ, DHS, and OSHA regulations dealing with the handling, storage, and use of compounds pertaining to each of the above technologies
    - Consider security concerns
    - Discuss new bioterrorism legislation
- Capital cost
    - Develop an approximate equipment purchase and install cost in U.S. dollars ($) per one million gallons (MG) treatment capacity
    - Contact equipment suppliers and contractors
- Operational cost
    - Develop an approximate cost associated with the operations of the equipment in U.S. dollars per million gallons treated
- Unit Process Operations and Maintenance Issues
    - Determine if the equipment requires special training
    - Determine if the equipment requires special maintenance tools
    - Determine if the equipment requires additional staff
- Impact on current or future primary or secondary drinking water standards
    - Review current primary drinking water standards that specifically pertain to surface water facilities
    - Review current secondary drinking water standards
    - Review contaminant candidate list 3
    - Review unregulated contaminant monitoring regulation

CHAPTER II

MATERIALS AND METHODS

The primary source of data was compiled from the State of Oklahoma Drinking Water Watch Website. Five (5) years worth of TOC, alkalinity, and DBP data was gathered (when available) for all surface water treatment facilities that serve a population greater than 1000 persons. Basic statistics (mean, standard deviation, minimum, maximum) were determined from the data. This information is shown in Appendix 1 – Drinking Water Watch Website Information and Statistics Analysis.

Field inspections (visual) were conducted for seven (7) water treatment facilities in northeastern Oklahoma. These facilities serve the communities of Tulsa, Sand Springs, Skiatook, Tahlequah, Gove, Coweta, and Claremore. The total population of the inspected communities represent approximately 601,460 persons. These water treatment facilities use source water from seven (7) different water bodies. The water bodies represented are Oologah Lake, Spavinaw Lake, Skiatook Lake, Illinois River, Grand Lake, Verdigris River, and Claremore Lake.

The City of Tulsa utilizes two (2) water impoundments for sources of water (Oologah Lake and Spavinaw Lake). Sand Springs and Skiatook utilize the same source water (Skiatook Lake). The water treatment facilities inspected utilize surface waters from the largest impoundments and watersheds in northeastern Oklahoma and are representative of the desired geographical area. An inspection was conducted to become familiar with the current treatment practices and to determine the current state (age, condition, materials of construction, adaptability of technology) of each water treatment facility.

Characterization of the dissolved organic carbon (DOC) was conducted on the Oologah Lake, Spavinaw Lake, Verdigris River, Ft. Gisbon Lake, Lake Hudson, Grand Lake, Skiatook Lake and Lake Tenkiller source waters. High performance size exclusion chromatography (HPSEC) was selected as the method to determine the distribution of the DOC for the two different source waters. HPSEC utilized a Dionex HPLC system with Ultimate 3000 diode array detector. The DOC was segregated by apparent molecular weight (AMW) by the use of an Agilent GPC/SEC column (PL aquagel-OH mixed, 300 mm × 7.5 mm ID, 8 μm particle size). The testing was conducted by the Environmental Engineering Department at the University of Washington under the supervision of Dr. Gregory Korshin. The purpose of the characterization was to develop apparent molecular weight (AMW) distributions of the DOC to be used to aid in the development selection of the best treatment technology for those source waters. The HPSEC was conducted at 210, 230, 254, 272, 300 and 350 nm wave lengths. AMW distribution research has been conducted for the most part outside of the United States. (Allpike et al. 2005) (Fabris et al. 2008) (Fang et al. 2010) (Huber et al. 2011) (Kawasaki et al. 2011) (Korshin et al. 2009) (Liu et al. 2010) (Valencia et al. 2012)

Prior to gathering the raw water samples, the sample bottles/ teflon lined caps were autoclaved and sealed. All filtering equipment was washed with soap and tap water. The filtering equipment was then again washed with distilled water.

The DOC characterization sampling was conducted on March 11, 2012 Verdigris River, Ft. Gisbon Lake, Lake Hudson, Grand Lake, Skiatook Lake and Lake Tenkiller. Samples for A.B. Jewell Water Treatment Facility were gathered on March 12, 2012 at the raw water junction box. At this location the operators have the ability to bring raw water directly from Oologah Lake into the water treatment facility, or to utilize Lynn Lane Reservoir, or to combine water. Lynn Lane Reservoir is the onsite reservoir for A.B. Jewell Water Treatment Facility. The same pump station that brings raw water from Oologah Lake into the junction box is also used to fill the Lynn Lane Reservoir. At the time of sampling, raw water was being brought only from Lynn Lake Reservoir. This is typically how the facility is operated.

Samples from the Mohawk Water Treatment Facility were gathered on March 12, 2012 at the typical sample site for the raw water. At this junction box, the operators have the ability to utilize water directly from Spavinaw Lake, or from Lake Yahola, or some percentage of both. Lake Yahola is the onsite reservoir for the water treatment facility and is filled by water from Spavinaw Lake. At the time of sampling, according to the operators, both sources were being utilized by the water treatment facility; however, the percentage from each source was unclear.

Samples for Verdigris River, Ft. Gisbon Lake, Lake Hudson, Grand Lake, Skiatook Lake and Lake Tenkiller were grabbed via the shore. The locations did not necessarily correspond to any particular water treatment facility intake. The raw water from these locations was stored overnight in a refrigerator.

All samples were gathered using a 250 mL glass sample bottle that had been autoclaved prior to use. The samples were then filtered using a 0.45 millpore filter by using a vacuum assisted filter assembly. The filtered water samples were then sealed in a 150 mL sample bottle. The filtered water samples filled their respective container entirely with no head space.

The filtered water samples were immediately packed in ice for shipment. Samples were shipped overnight to the University of Washington in Seattle, WA via United Parcel Service of America, Inc. (UPS).

Analysis was also completed to determine the concentration of N-Nitroso-dimethylamine (NDMA) found in potable water within the distribution system. Underwriters Laboratory, Inc. (UL) performed EPA method 521, which uses solid phase extraction (SPE) gas chromatography for concentration determination.

The NDMA sampling was conducted on Monday, October 10, 2011. Water samples were taken from the distributions systems of Skiatook, Sand Springs and Tulsa (Oklahoma). In Skiatook, the sample site was Skiatook Park (at the intersection of W Oak St. and S Osage Ave), which is located approximately in the geographical center of the distribution system. The water samples (2 – 1 L glass bottles provided by UL) were gathered from the bathroom hose bib. In Sand Springs, the sample site was the Sav-A-Trip (at the intersection of W 2nd St. and N Wilson Ave.) which is located 1 mile north of the water treatment facility. The water samples (2 – 1 L glass bottles provided by UL) were gathered from the bathroom faucet. In Tulsa, the sample site was Lafortune Park (at the intersection of E 61st St. S and S Yale Ave.) which is located approximately in the geographical center of the distribution system. The water samples (2 – 1 L glass bottles provided by UL) were gathered from an outside hose bib. All of the sample sites were flushed for ten (10) minutes at a high flow rate prior to the gathering of the samples. All of the samples were immediately placed in an iced cooler. Unfortunately, the shipped samples were misplaced in transit by United Parcel Service of America, Inc. (UPS) and stored for eight (8) days; thus the October 10, 2011 sampling event was eliminated from sample set. Another round of NDMA sampling was conducted on Wednesday, November 2, 2011 and Tuesday, November 15, 2011. Another single sample was collected for Tulsa, OK on November 30, 2011. These water samples were successfully delivered to Underwriters Laboratory, Inc. in South Bend, IN. The November 2, 2011 samples arrived at the lab at 2.6 degrees C on November 4, 2011. The November 15, 2011 samples arrived at the lab at 2.6 degrees C on November 17, 2011. The November 30, 2011 sample arrived at the lab at 2.6 degrees C on December 2, 2011. The purpose of collecting multiple samples (three (3) samples for Tulsa; two (2) samples for Skiatook;

two (2) samples for Sand Springs) at the same location was to develop a baseline for the NDMA concentration in the geographical center of the communities.

CHAPTER III

RESULTS AND DISCUSSION

Background and Raw Water Constituents Impact on Compliance Technologies

Ozone

Ozone formation is relatively complicated; however, for the purpose of this paper, it is as follows:

Energy is used to convert pure oxygen into elemental oxygen.

$$O_2 + \text{Energy} \rightarrow O + O$$

Figure 3.1 – Initial Ozone Production

(AWWA 1999)

Ozone generation is usually completed by passing pure oxygen (free of impurities) through a small gap. In this small gap there is a peak voltage electric discharge. Some of the pure oxygen will convert to elemental oxygen and combine with molecular oxygen to produce ozone. Different ozone generators can produce varying ranges of ozone concentrations, but all ranges typically utilize this basic concept.

$$O + O_2 \rightarrow O_3$$

Figure 3.2 – Final Ozone Production

(AWWA 1999)

Once ozone has been produced, it typically ranges from 5 to 15 % by volume (STP). The mixture of ozone and pure oxygen travels from the ozone generator to the ozone diffuser. The mixture of ozone and oxygen is transferred from a gaseous state to an aqueous solution through the use of the ozone diffuser. Ozone will immediately undergo a spontaneous auto-decomposition reaction. This may be initiated by many different constituents found in water. The auto-decomposition initiated by the hydroxide ion is presented as follows:

$$OH^- + O_3 \rightarrow HO_2 + O_2^-$$
$$HO_2 = H+ + O_2^-$$
$$O_2^- + O_3 \rightarrow O_2 + O_3^-$$
$$O_3^- + H^+ \rightarrow HO_3$$
$$HO_3 \rightarrow O_2 + OH\cdot$$
$$OH\cdot + O_3 \rightarrow HO_2 + O_2$$

Figure 3.3 – Auto-Decomposition of Ozone

(AWWA 1999)

The reactions above are a chain due to the production of the hydroperoxyl radical ($OH\cdot$) and the superoxide ion (O_2^-). These species produce new chain reactions that may lead to additional auto-decomposition of ozone. Due to auto-decomposition, a host of free radical species can be produced. Therefore, ozone has multiple reaction mechanisms. A direct pathway is the result of a contaminant reacting directly with ozone. The indirect pathway is the result of a contaminant reacting indirectly with a free radical species.

Ozone is a very strong oxidant which can easily inactivate bacteria and viruses. Ozone can also easily inactivate some protozoa. In Table 3.1, ozone is compared to other chemical disinfectants for 2 log (99%) inactivation of target disease causing organisms.

Table 3.1 – 2 log Inactivation of Various Disease Causing Organisms by Various Chemical Disinfectants

Disinfectant	**Bacteria (mg-min/ L)[1]**	**Viruses (mg-min/ L)[1]**	***Giardia lambia* (mg-min/ L)[1]**	***Cryptosporidium* (mg-min/ L)[1]**
Ozone	0.02	0.60	1.30	32
Chlorine Dioxide	0.19	5.60	17.00	858
Free Chlorine[2]	3.30	4.00	162.00[2]	Not Inactivated
Monochloramine[3]	278.00	857	1470	Not Inactivated

[1] Above comparison is completed with the water temperature at 5 degrees C and pH = 8. CT calculations based on residual measurement. [2] 2 mg/L residual dose of free chlorine.
[3] Not an approved ODEQ disinfectant.

(EPA 1999) (WHO 2011)

As shown, ozone is at least nine (9) times more effective for inactivating most disease causing organisms. This is one of the main reasons ozone is attractive to water authorities.

Due to the production of unregulated ozone byproducts, such as formaldehyde, acetaldehyde, and acetic acid, ozone is recommended for use before filtration. (AWWA 2011[c]) Ozone is typically utilized prior to coagulant addition, resulting in an increase in the ozone demand. An additional benefit to ozone is the ability to oxidize dissolved inorganics (iron and manganese) and organics (taste/odor compounds; geosmin and MIB (methylisoborneol)). Surface waters in Northeastern Oklahoma contain iron and manganese in sufficient quantities to create consumer complaints if not removed. If the dissolved iron concentration exceeds the EPA secondary standard of 0.3 mg/L, the consumer will notice a red tint to the water. If the dissolved manganese concentration exceeds 0.05 mg/L, the consumer will notice a black tint to the water. Ozone oxidizes dissolved manganese as shown in the following reaction:

$$O_3 + Mn^{2+} \rightarrow MnO_2 + O_2 + OH^-$$

Figure 3.4 – Ozone Oxidation of Dissolved Manganese

(AWWA 2011[c])

Ozone has been found to work effectively on taste and odor compounds. The most common taste and odor compounds are MIB and geosmin. These compounds cause odor and taste complaints at very low concentrations (levels less than 100 ng/L). Free chlorine has had very little success in removing these compounds; therefore, utilities have moved towards ozone. Oxidation of MIB and geosmin are directly related to pH and residual ozone dose. The higher the pH and residual ozone, the more effective the removal rate of MIB and geosmin. MIB is more difficult to oxidize than geosmin.

The major problem with ozone is that it reacts with bromide to produce brominated compounds. It has been recommended that ozone not be used in waters that contain any bromide. (Metcalf et al. 2003) Ozone reacts directly with bromide in two different reactions as follows:

$O_3 + Br^- + H^+ \rightarrow HOBr + O_2$

Figure 3.5 – Ozone to produce Hypobromous Acid

(AWWA 1999)

$O_3 + Br^- \rightarrow OBr^-$
$OBr^- + O_3 \rightarrow BrO_2^-$
$BrO_2^- + O_3 \rightarrow BrO_3^-$

Figure 3.6 – Ozone to produce Bromate

(AWWA 1999)

Hypobromous acid reacts with organic constituents to produce bromoform, dibromoacetic acid, and other regulated DBPs. The reaction in Figure 3.5 occurs very rapidly at a rate of 160 $M^{-1}S^{-1}$. Bromate is also a suspected carcinogen and must be regulated to very low levels. (EPA 2009) If ozone is added to water that contains bromide, a chemical reaction can occur that leads to the production of bromate. Bromate is a regulated DBP with a maximum contaminant level (MCL) of 0.010 mg/L (10 µg/L). Therefore, very small amounts of bromide (>0.020 mg/L) can lead to violations.

Additional factors account for the formation of ozone DBPs, two (2) of which are ozone dose and pH. Raw water pH can be controlled through the use of common acids or bases, such as sulfuric acid and sodium hydroxide. It has been found that lowering the pH can depress the hypobromite (OBr^-) concentration, thereby controlling the formation of bromate. (AWWA 2011[c]) As previously discussed, for the purposes of eliminating taste and odor compounds, a lower pH is undesirable. Applied ozone dosage is a very important factor to consider when trying to control bromate formation. As stated, surface waters in Northeastern Oklahoma contain high amounts of dissolved inorganic (iron and manganese) and organic material (TOC). Therefore, large amounts of ozone are required to maintain the desired residual ozone necessary to obtain the correct CT for protozoa and virus inactivation.

Free chlorine is still used as a barrier in a distribution system, which can result in the formation of chlorinated DBPs. Typically, the concentrations of chlorinated DBPs are lowered after the use of ozone as a primary disinfectant. Ozone reacts with organic material, which can decrease (mineralize) or alter the concentrations of DOC that readily react with free chlorine to form halogenated byproducts. Ozone has also been found, by some facilities, to assist in the removal of DOC through coagulation. For facilities that are very close to compliance with the D/ DBP MCLs, ozone could be a successful alternative. Additionally, for waters that contain low concentrations of inorganics and organics, ozone could be a successful strategy for compliance with Stage 2 D/ DBP Rule.

Chlorine Dioxide

Chlorine dioxide is formed when sodium chlorite reacts with gaseous chlorine under an acidic condition. Chlorine dioxide is almost never generated offsite and shipped, due to its unstable properties. Chlorine dioxide gas can explode when exposed to such external factors as shock, sunlight, and sparks. The formation chemistry for the reaction is presented as follows:

$$2NaClO_2 + Cl_2\ (g) \rightarrow 2ClO_2 + Na^+ + 2Cl^-$$

Figure 3.7 – Chlorine Dioxide Formation

(AWWA 1999)

Typically, excessive chlorine is added to react the chlorite fully in order to form chlorine dioxide, causing residual free chlorine to be inadvertently added to the receiving waters. This can lead to the formation of some regulated chlorinated DBPs. The more acidic the conditions during the reaction, the lower the chlorite concentrations will be and the higher the concentrations of chlorate will be. Once the chlorine dioxide solution is injected into the receiving water it can degrade to chlorite (ClO_2^-) or chlorate (ClO_3^-), depending on the pH, temperature, and light. The formation of chlorite is a concern because it is a regulated DBP with a MCL of 1.0 mg/L. Due to these factors the practical maximum applied chlorine dioxide concentration is 1.4 to 1.5 mg/L as 50 % to 70 % of the reacted chlorine dioxide will form chlorite. A discussion of chlorate will be conducted in future sections of this paper.

Chlorine dioxide will not react with DOC to form TTHMs or HAA5. Chlorine dioxide reacts slowly with bromide and is unlikely to form brominated compounds. This is a major advantage in complying with current regulated DBPs; however, chlorine dioxide will form unregulated DBPs that will be discussed in a future section of this paper. Chlorine dioxide has been shown to work well in the reduction of taste and odor compounds, due to the increased electrochemical oxidation potential (EOP) of chlorine dioxide, which allows the bonds of taste and odor organic compounds to be disrupted. The EOPs of some common oxidants are presented below.

Table 3.2 – Electrochemical Oxidative Potentials for Common Oxidants

Oxidant	**Electrochemical Oxidation Potential (EOP), V**
Ozone	+2.07
Hydrogen Peroxide	+1.78
Permanganate	+1.67
Chlorine Dioxide	+1.50
Chlorine	+1.36

(Metcalf et al. 2003)

As shown in Table 3.1 – 2 log Inactivation of Various Disease Causing Organisms by Various Chemical Disinfectants, chlorine dioxide is more effective for inactivating *Giardia lambia* than free chlorine and monochloramine. Chlorine dioxide also can inactivate *Cryptosporidium*, whereas free chlorine will not. For all practical purposes, it is unlikely that chlorine dioxide would be selected for the inactivation of *Cryptosporidium*, due to the required hydraulic retention time (HRT). ODEQ has indicated that it is hesitant to approve the use of chlorine dioxide post filtration. When chlorine dioxide is used pre-filtration, it will react with organic and inorganic constituents in the water, making it difficult to maintain a residual. It may be difficult to add sufficient amounts of chlorine dioxide for use in the primary inactivation of protozoa and viruses. (EPA 2011[b]) (ODEQ 2011[a]) (AWWA 1999)

Another consideration is that free chlorine is still used as a barrier in the distribution system, and the potential remains to allow for the formation of chlorinated DBPs. Typically, the concentrations of chlorinated DBPs are lowered after the use of chlorine dioxide as a primary disinfectant. As stated, chlorine dioxide reacts with organic material, which can decrease the concentrations of DOC that readily react with chlorine to form halogenated byproducts. For facilities that are very close to compliance with the TTHM or HAA5 MCLs, chlorine dioxide could be a successful alternative. For waters that contain low concentrations of inorganics and organics, chlorine dioxide could also be a successful strategy for compliance with Stage 2 D/ DBPs.

UV Light

A disinfection option that has recently gained popularity is ultraviolet (UV) disinfection. Its popularity in the treatment of drinking water is a direct result of the implementation of LT2ESWTR. The rule requires that all surface water treatment facilities in the United States meet a minimum 2 log inactivation or removal of *Cryptosporidium*. Surface water treatment facilities that provide unfiltered water to their customers often select UV disinfection as the most cost effective solution. UV is also selected by filtered water authorities that are required to provide additional treatment based on their LT2ESWTR Bin Classification. (EPA 2006[a]) (AWWA 2011[c]) LT2ESWTR Bin Classification is risk-based treatment, meaning the level of removal or inactivation is specifically based on the risk that is presented by the protozoa. Essentially, the higher the bin classification, the higher the risk. Thus more inactivation and/ or removal is required. Presented below is the bin classification (based on the 1st round of source water monitoring) for various water treatment facilities of interest in northeastern Oklahoma.

Table 3.3 – LT2ESWTR Testing and Results for Northeastern Oklahoma

Water Authority	**12 Consecutive Sample Set with Highest Raw Water *Cryptosporidium* Concentration**[2] **(oocysts/ L)**	**Bin Classification**	**Additional Minimum Removal/ Inactivation (log)**
Tulsa - Mohawk WTP	0.000	1	0
Bartlesville	Unknown		
Sapulpa	0.000		0
Tahlequah	0.175	2	1
Claremore	0.042	1	0
Okmulgee	0.000	1	0
Checotah[1]	-	1	0
Jay[1]	-	1	0
Tulsa - A.B. Jewell	0.000		0
Collinsville[1]	-	1	0
Nowata[1]	-	1	0
Broken Arrow	0.038	1	0
Oklahoma Ordnance Works Authority	0.000	1	0
Ft. Gibson[1]	-	1	0
Muskogee	0.000	1	0
Wagoner[1]	-	1	0
Sand Springs	0.000	1	0
Skiatook[1]	-	1	0
Vinita[1]	-	1	0
Grove[1]	-	1	0
Afton[1]	-	1	0
Locust Grove[1]	-	1	0
Salina[1]	-	1	0
Wagoner County Rural Water District #4	0.115	2	1
Coweta[1]	-	1	0

[1] *E.coli* sampling only. [2] Data set courtesy of EPA Region 6.

As shown in Table 3.3, only three water authorities are required to complete additional removal/ inactivation of *Cryptosporidium*. Considering the mixed use (agricultural, residential, industrial) of most of the watersheds within the region, it is expected that there would be the presence of the protozoa within the source waters.

UV light is generated when an electrical voltage is applied across a mercury-containing gas mixture. Mercury-containing gas mixtures have been used because they emit wavelengths of UV light (photons) with the maximum germicidal effect. (EPA 2006[c])

Germicidal effects occur when UV light interferes with the nucleic acid of a microbe, thus causing deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) damage. The damage then prevents the microbe from reproducing, eliminating its ability to infect a host (the customer). Maximum DNA damage occurs between the wavelengths of 250 to 260 nm. The damage to the DNA is directly related to the UV dose; the higher the dose, the more damage that occurs. Damage to the microorganism DNA occurs primarily by disrupting pyrimidine dimers which form when adjacent pyrimidines (DNA sequence) form covalent bonds. Other actions of DNA damage disrupt the pyrimidine (6-4), pyrimidine photoproducts, and the protein-DNA cross-links. (EPA 2006[c]) Presented in Table 3.4 is the inactivation of various target microorganisms for drinking water treatment.

Table 3.4 – UV Inactivation Credit for Targeted Microorganisms

Log Inactivation	***Cryptosporidium* UV Dose (mJ/cm^2)**	***Giardia lamblia* UV Dose (mJ/cm^2)**	**Virus UV Dose (mJ/cm^2)**
0.5	1.6	1.5	39
1.0	2.5	2.1	58
1.5	3.9	3	79
2.0	5.8	5.2	100
2.5	8.5	7.7	121
3.0	12	11	143
3.5	15	15	163
4.0	22	22	186

(EPA 2006[a])

Presented in Table 3.5 is the inactivation of common disease causing bacteria. The inactivation table is based on research conducted by multiple sources.

Table 3.5 – UV Inactivation for Bacteria Based on Research

Organism	**Required UV Dose (mJ/cm^2) for 4 log inactivation**
E. coli 0157:H7 CCUG29193	7
Salmonella spp.	7
Staphylococcus aureus ATCC25923	10.4
Streptococcus faecalis ATCC29212	11.2
Legionella pneumophila ATCC43660	9.4
Campylobacter jejuni ATCC43429	4.6
Shigella sonnei ATCC9290	8.2
Vibrio cholerae ATCC25872	2.9

(Chevrefils et al. 2006)

As shown in Table 3.4, the required UV dose for inactivation of viruses is very high, thus requiring large amounts of energy input. This makes inactivating viruses to the level required by the 1986 Surface Water Treatment Rule (SWTR) cost prohibitive. Chemical disinfectants, such as free chlorine, are used for the inactivation of viruses. Therefore, UV does not completely eliminate the use of chemical disinfectants, like free chlorine; thus halogenated compounds can still form.

The main raw water constituent associated with UV disinfection is ultraviolet light transmittance (UVT). UVT is the measure of a specific wavelength, typically 254 nm, based on a 1 cm path length. UVT is measured from 0 to 100 %. The higher the percentage, the more light that is transmitted through the water with a given bulb output. Therefore, water with a very high UVT requires lower energy input, thus lowering operating costs. Constituents found in raw water that effect UVT are dissolved organic compounds (humic, fulvic, and phenolic) and particles.

Dissolved organic compounds absorb the light, whereas particles, such as turbidity, scatter the light. It has been found that even in waters up to 10 NTU, there is limited affect on disinfection. Most manufacturers of UV disinfection equipment require the water that is being irradiated to be less than 5 NTU. Typically, turbidity is not an issue because most applications of UV disinfection occur post filtration, since the maximum single turbidity reading is determined by LT1ESWTR at 1 NTU. Dissolved organic compounds can be more of a problem for UV disinfection, but the UV disinfection process is usually located after coagulation. Coagulation removes some of the dissolved organic compounds, thereby increasing the UVT; however, coagulants can impact UVT if used excessively. Coagulants and algae are not a concern for UV disinfection if the UV reactor is placed after filtration. Chemical oxidants can also be used to control algae formation, although chemical oxidants must be used cautiously. Permanganate and ozone have low impact thresholds on UV absorbance. Therefore, these oxidants will absorb UV light, thus reducing the germicidal effectiveness. This is another reason for a UV reactor to be placed after filtration. It is unlikely that ozone and permanganate will be unreacted after passing through a filter bed.

Other potential raw water constituents of concern are pH, oxidation reduction potential (ORP), hardness, alkalinity, temperature, and ion concentration. These raw water constituents can combine to foul the UV reactor sleeve. The sleeve physically separates the UV generating bulb from the water that is to be disinfected. The UV reactor bulb will heat up the sleeve, which will in turn heat up a thin layer of water that surrounds the sleeve. As the water is heated, it increases the likelihood that inorganics will precipitate. A low ORP will make the inorganics more likely to precipitate once they also come in contact with the UV reactor sleeve. Raw water hardness has not been found to foul a UV reactor when the hardness is less than 140 mg/L as

$CaCO_3$. (EPA 2006[c]) Scale will build up over time on the UV reactor sleeve with waters that are high in inorganics. Fouling of the reactor sleeve will reduce the UV output, thus reducing disinfection. Regular cleanings of the UV reactor will reduce the fouling experienced on the sleeve of the UV reactor. During design of the UV reactor, the reduced UV output is taken into account by using a fouling factor. Additionally, as a UV lamp ages, the UV output decreases. To alleviate the reduced output from an aged bulb, the bulb is simply replaced. During design of the UV reactor, the decrease in UV output due to age is taken into account by using an aging factor. The fouling factor and aging factor are combined in the following equation:

$$\text{UV Dose with Clean Lamps} * \text{Fouling Factor} * \text{Aging Factor} \geq \text{Required UV Dose}$$

Figure 3.8 – Equation for Fouling and Aging Factor

(EPA 2006[c])

The ODEQ required combined aging and fouling factor is 0.7. (ODEQ 2006[c])

Taste and odor compounds are not affected by photolysis. Therefore, a standard UV disinfection reactor will not remove taste and odor compounds. Currently, there is an advanced oxidation process (AOP) that utilizes UV light and hydrogen peroxide to produce the hydroxyl radical. The process in which the hydroxyl radical is formed is as follows:

$$H_2O_2 + uv \rightarrow 2\ OH\cdot$$

Figure 3.9 – Production of the Hydroxyl Radical Using UV/ Hydrogen Peroxide

(AWWA 2011[c])

Once the hydroxyl radical has been propagated, it will auto decompose hydrogen peroxide to produce additional hydroxyl radicals in the following manner:

$H_2O_2 + OH\cdot \rightarrow H_2O + HO_2\cdot$
$HO_2\cdot + H_2O_2 \rightarrow H_2O + O_2 + OH\cdot$

Figure 3.10 – Reaction Continuation for the production of the Hydroxyl Radical Using UV/ Hydrogen Peroxide

(AWWA 2011^c)

Hydroxyl radicals are nonselective oxidants that very rapidly degrade taste and odor compounds. Unlike ozone, the above reaction will not react with bromide to form bromate. Excessive hydrogen peroxide and UV light are required to produce the hydroxyl radical, making this process less efficient than other AOPs. Research has recently been conducted into the feasibility and ability of UV/ HOCl (Cl_2) AOPs to degrade microcontaminants (like taste/ odor). The research indicates that this type of AOP is successful at degrading microcontaminants and has a lower operational cost than other forms of AOPs. (Sichel et al. 2011) (Zhao et al. 2011)

UV disinfection will not remove inorganics such as iron and manganese. These inorganics must be removed prior to the UV reactor, as they can interfere with UVT, thereby decreasing disinfection. Oxidants such as permanganate (sodium/ potassium) and ozone can be used to precipitate inorganics prior to the UV reactor. This is another reason why UV disinfection must be placed post filtration.

Chloramines

Another option for a drinking water utility is to investigate the use of chloramines. Chloramines are formed when free chlorine and ammonia react to form the desired chloramine, monochloramine.

$$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$$

Figure 3.11 – Chlorine and Ammonia to produce Monochloramine

(AWWA 1999)

Small amounts of organochloramines (undesirable) are produced during monochloramine production. The maximum production of monochloramine is reached when the theoretical ratio of 5:1 (hypochlorite to ammonia) by weight is reached. In practice this is typically not observed. Organic or inorganic compounds found in the water will exert a chlorine demand which will skew the ratio. The water temperature and pH will also skew the desirable ratio for the production of monochloramine. If the 5:1 ratio is exceeded, then undesirable chloramines (dichloramine and trichloramine) will form.

$$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$$

Figure 3.12 – Chlorine and Ammonia to produce Dichloramine

$$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$$

Figure 3.13 – Chlorine and Ammonia to produce Trichloramine

(AWWA 1999)

Undesirable chloramines can lead to taste and odor complaints. If the correct process control is not maintained in the distribution system, undesirable biochemical reactions (nitrification) can occur that lead to the production of nitrate and a reduction in chloramine residual. Nitrate will consume the chloramine residual in the distribution system, which can lead to reduced chloramine residual found in the distribution system. These issues can lead to difficulties in operations for the water treatment facility operators. Chloramines are a weak disinfectant and not approved by ODEQ for the primary inactivation of *Giardia lambia* and viruses. (ODEQ 2011[a]) Free chlorine, UV, chlorine dioxide and ozone are the only disinfectants approved for primary inactivation of protozoa and viruses. Chloramines can only be used as a microorganism barrier in the distribution system. Chloramines are one-hundred (100) to one-thousand (1000) times less effective for inactivating bacteria, viruses, and protozoa than free chlorine. Therefore, if contamination were to occur in the distribution system, consumers would be more likely to ingest viable disease-causing microorganisms. Typically, when chloramines are used as a microorganism barrier for the distribution system, free chlorine will be used for primary inactivation purposes. In EPA 40 CFR Parts, 9, 141 and 142 – Stage 2 Disinfectants and Disinfection Byproducts Rule, it is stated that chloramines are not a recommended best available technology (BAT) for utilities that serve less than 10,000 persons. (Environmental Protection Agency 2010) As previously stated, the treated water TOC reacts very quickly with free chlorine, forming DBPs during disinfection. Adding chloramines may do little to alleviate chlorinated DBPs. Currently, there are no regulated DBPs associated with the use of chloramines. In the near future that may change, since compounds that are associated with chloramines, such as NDMA, are on the EPA's Contaminant Candidate List 3. (EPA 2011[a])

The only water treatment facility in northeastern Oklahoma that currently uses chloramines is Sand Springs. Sand Springs utilizes a 4:1 ammonia (as N) to free chlorine ratio for the creation of monochloramine. The ammonia to free chlorine ratio is currently not adjusted based on temperature or pH.

TOC or DOC Removal Technologies

There are multiple TOC/ DOC removal technologies. This paper will focus on three (3) technologies. The technologies are enhanced coagulation, activated carbon (granular/ powdered), and anion exchange.

Historically, coagulants were added to target turbidity removal in a process called coagulation. A sufficient amount of coagulant was added to remove most of the insoluble fraction of the TOC, which, if not removed during coagulation, was removed during filtration. Enhanced coagulation is the process of adding a coagulant for the purpose of removing TOC. Enhanced coagulation typically requires additional coagulants to target the dissolved organic fraction of the TOC. Coagulants are made up of hydrolyzing metal salts (HMS) which result from the use iron and aluminum. (AWWA 2011[c]) (AWWA 1999) Common coagulants used in Northeastern Oklahoma are aluminum sulfate (alum), ferric chloride, ferric sulfate, polyaluminum chloride (PACl), and aluminum chlorohydrate (ACH).

In northeastern Oklahoma, the majority of the TOC is insoluble DOC. Historically, humic acid has been the targeted DOC constituent of concern. (AWWA 2011[c]) Humic acid has a high affinity for the absorption of 254 nm UV wavelength. This is why UV 254 nm has been used as an indicator for the likelihood of the raw water DOC to form DBPs. However, DBPs have been formed to unacceptable levels with waters that have very low UV 254 nm absorbance. (Lui et al. 2010) Therefore, more effort has been made to better understand the DOC composition. Humic acid has a molecular weight of 1000 to 3000 Da in size. (Allpike et al. 2005) Fulvic acid has been defined as having a molecular weight of 540 to 900 Da. (AWWA 2011[c]) Amino acids, aliphatic amines, and proteins have a molecular weight of 0 to 400 Da. Different constituents of raw water DOC have been shown to absorb various wavelengths. (Fang et al. 2010)

The soluble DOC compound is removed from the interaction with the HMS through three (3) mechanisms. The first mechanism is to form complexes between the cation and the high molecular weight compound of the DOC. The second mechanism is for the HMS to form a metal ion/ DOC precipitate. The third mechanism is for DOC to be adsorbed onto the metal hydroxide precipitant. (AWWA 2011^c) (AWWA 1999) Enhanced coagulation has been shown to target specifically the removal of high molecular weight organic compounds with an apparent molecular weight greater than 10,000 Daltons (Da). (Allpike et al. 2005) (Korshin et al. 2009) It has also been observed that increasing concentrations of coagulant will lead to increasing removal of DOC. As the HMS concentration increases, destabilization and floc formation occurs, which results in adsorption of the DOC. It has also been observed that as the HMS concentration increases, the adsorption of DOC per unit area of floc decreases as a result of hydroxide microcrystals. Therefore, the addition of HMS to target DOC can be a very inefficient process (mg coagulant/ mg of DOC) that requires large amounts of coagulant to remove a very small amount of DOC. The initial concentration of DOC is a critical component of enhanced coagulation. (AWWA 2011^c) (AWWA 1999)

Another factor critical to DOC removal is the initial pH and alkalinity. It has been observed that DOC removal efficiency is increased at a lower pH. (AWWA 2011^c) The ratio of coagulant to DOC will decrease (mg coagulant/ mg of DOC) from approximately 2 to 0.5 as the pH is suppressed from 7.5 to 6.5. It has also been shown that the DOC removal percentage will increase as the pH is decreased. Optimal pH for an HMS is less than 7; and in order to decrease the pH to this point, reduction or removal of the alkalinity is required.

Inorganics such as iron and manganese have little effect on enhanced coagulation. Soluble iron and manganese will not be affected by the HMS. Precipitated iron and manganese can reduce the effectiveness of the coagulant, since the precipitant will reduce the charge interaction between the coagulant and the DOC. Precipitated coagulant acts in a similar manner as other particles found in the water therefore, the required dosage of coagulant will increase as the concentration of precipitated iron and manganese increases. Current research indicates that bromide has no impact on enhanced coagulation. (AWWA 2011[c]) (AWWA 1999)

As the raw water turbidity increases, the required coagulant dosage for the purposes of coagulation increases. The increase in coagulant dosage causes charge neutralization of the suspended particles for destabilization. Destabilized particles allow particles to interact and to form floc for settling purposes. HMS charge neutralization of suspended particles interferes with DOC adsorption; in order for enhanced coagulation to occur, charge neutralization needs to occur first. The required dosage of coagulant will increase as the concentration of turbidity increases.

Current research indicates that taste and odor compounds have no effect on enhanced coagulation. (AWWA 2011[c]) (AWWA 1999) Taste and odor compounds are associated with algae blooms. Algae blooms increase the raw water turbidity, affecting enhanced coagulation in the manner described above.

Water temperature can also effect the rate of DOC adsorption. The rate of reaction for the formation of the metal hydroxide precipitant is slowed in colder waters. The metal hydroxide precipitant has the greatest capacity for adsorption of the DOC. Therefore, in colder water, the required time for DOC adsorption is increased.

Raw surface waters in northeastern Oklahoma have moderate to high concentration of TOC, the majority of which is DOC. Presented in Table 3.6 is the raw water TOC concentration for various surface water treatment facilities in northeastern Oklahoma.

Table 3.6 – Raw Water TOC Analysis from 07/01/2006 to 06/30/2011 Data Set

Water Authority	**Mean (as $CaCO_3$) (mg/L)**	**Standard Deviation (as $CaCO_3$) (mg/L)**	**95% Confidence (X+2SD) (mg/L)**	**Source**
Tulsa - Mohawk WTP	2.36	0.40	3.16	Spavinaw Lake
Bartlesville	6.01	1.05	8.11	Hulah Lake/ Caney River
Sapulpa	4.66	0.80	6.26	Sahoma Lake/ Skiatook Lake
Tahlequah	1.51	0.48	2.47	Illinois River
Claremore	6.75	1.16	9.07	Claremore Lake
Okmulgee	5.55	1.04	7.63	Okmulgee Lake
Checotah	5.93	1.43	8.79	Lake Eufaula
Jay	1.98	0.42	2.82	Eucha Lake
Tulsa - A.B. Jewell	4.16	0.39	4.94	Oologah Lake
Collinsville	4.26	0.60	5.46	Oologah Lake
Nowata	5.28	1.25	7.78	Oologah Lake
Broken Arrow	5.96	1.22	8.40	Grand River
Oklahoma Ordnance Works Authority	4.11	0.50	5.11	Grand River
Ft. Gibson	4.61	1.36	7.33	Grand River
Muskogee	4.37	0.49	5.35	Ft. Gibson Lake
Wagoner	4.19	0.98	6.15	Ft. Gibson Lake
Sand Springs	4.77	0.82	6.41	Skiatook Lake/ Shell Creek Lake
Skiatook	4.62	0.59	5.80	Skiatook Lake
Vinita	4.22	0.62	5.46	Grand Lake
Grove	4.17	0.58	5.33	Grand Lake
Afton	4.81	0.99	6.79	Grand Lake/ Bernice
Locust Grove	4.04	0.70	5.44	Lake Hudson
Salina	4.29	0.49	5.27	Lake Hudson
Wagoner County Rural Water District #4	6.32	1.26	8.84	Verdigris River
Coweta	6.92	1.75	10.42	Verdigris River

(ODEQ 2011[c])

Statistical analysis was completed to determine the average and standard deviation of the data set. Obvious unreasonable data was omitted from the data set of Skiatook. Some of the samples had DOC concentrations of greater than 20 mg/L. This was either a situation where the data was improperly input into the data set, or the TOC test was improperly conducted. The statistical analysis was completed to determine the 95 % confidence interval TOC value. The 95 % confidence interval is an important value when considering compliance technologies. If a water authority is going to make an investment in a compliance technology, then the treatment component or scheme must allow Stage 2 D/ DBP Rule compliance to be maintained at least 95% of the time.

The apparent molecular weight distribution of the DOC for various waters in northeastern Oklahoma at a wave length of 254 nm is presented in Figure 3.14.

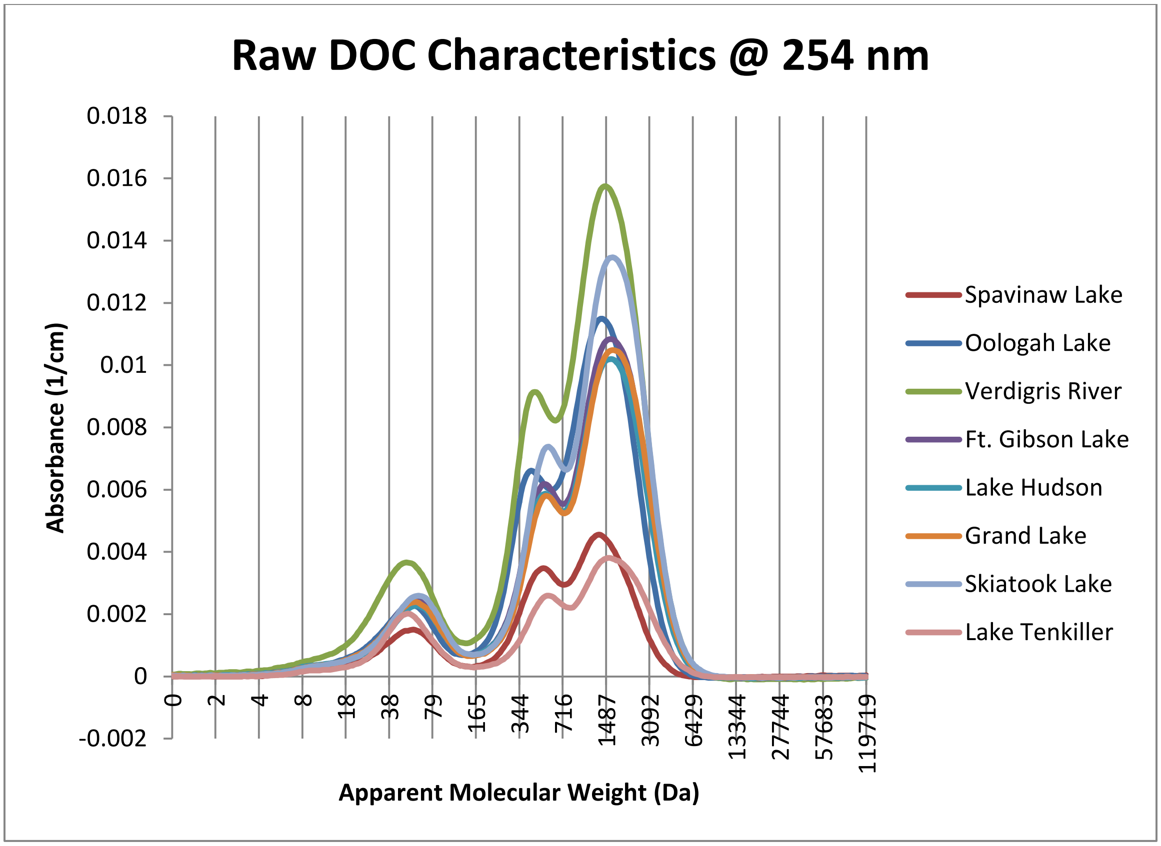

Figure 3.14 – DOC Characterization at 254 nm for Various Surface Waters in Northeastern Oklahoma

(Wintle et al. 2012)

As shown above, the general shape of the curves is consistent with other waters previously identified in the research. The general consistencies are the initial peak that is observed at low apparent molecular weights and then a decline. The curve recovers and reaches a peak between 1000 to 1500 Daltons (Da). The absorbance then rapidly declines and approaches zero at apparent molecular weights greater than 4000 Da. (Allpike et al. 2005) (Fabris et al. 2008) (Fang et al. 2010) (Huber et al. 2011) (Kawasaki et al. 2011) (Korshin et al. 2009) (Liu et al. 2010) (Valencia et al. 2012) Fulvic acid is natural organic matter (NOM) that typically has a molecular weight between 540 to 900 Da, whereas humic acid is a natural organic matter (NOM) that typically has molecular weights greater than 1000 Da. (AWWA 2011) Humic acid is more aromatic due to the carbon double bond which allows it to react with disinfectants to form DBPs. (AWWA 2011)

At first glance the curves seem similar; but upon closer inspection, there are slight variations. The distributions for Tenkiller, Hudson, Grand, Ft. Gibson, and Skiatook Lakes have a slightly higher percentage of the higher molecular weight compounds which tend to be more aromatic in nature. It would be expected that these waters would produce a higher TTHM/ DOC (ug/ mg) yield. TTHM analysis conducted on Oologah and Spavinaw Lakes indicates that a slight shift in the curve can lead to an increased yield ratio. (Wintle et al. 2012)

Another interesting aspect of the information is that Skiatook Lake has a higher peak absorbance than other waters with similar levels of TOC. It would be expected that Skiatook Lake would have a higher concentration of DBPs than other lakes with similar levels of TOC.

The apparent molecular weight distribution of the DOC for various waters in northeastern Oklahoma at a wave length of 230 nm is presented in Figure 3.15.

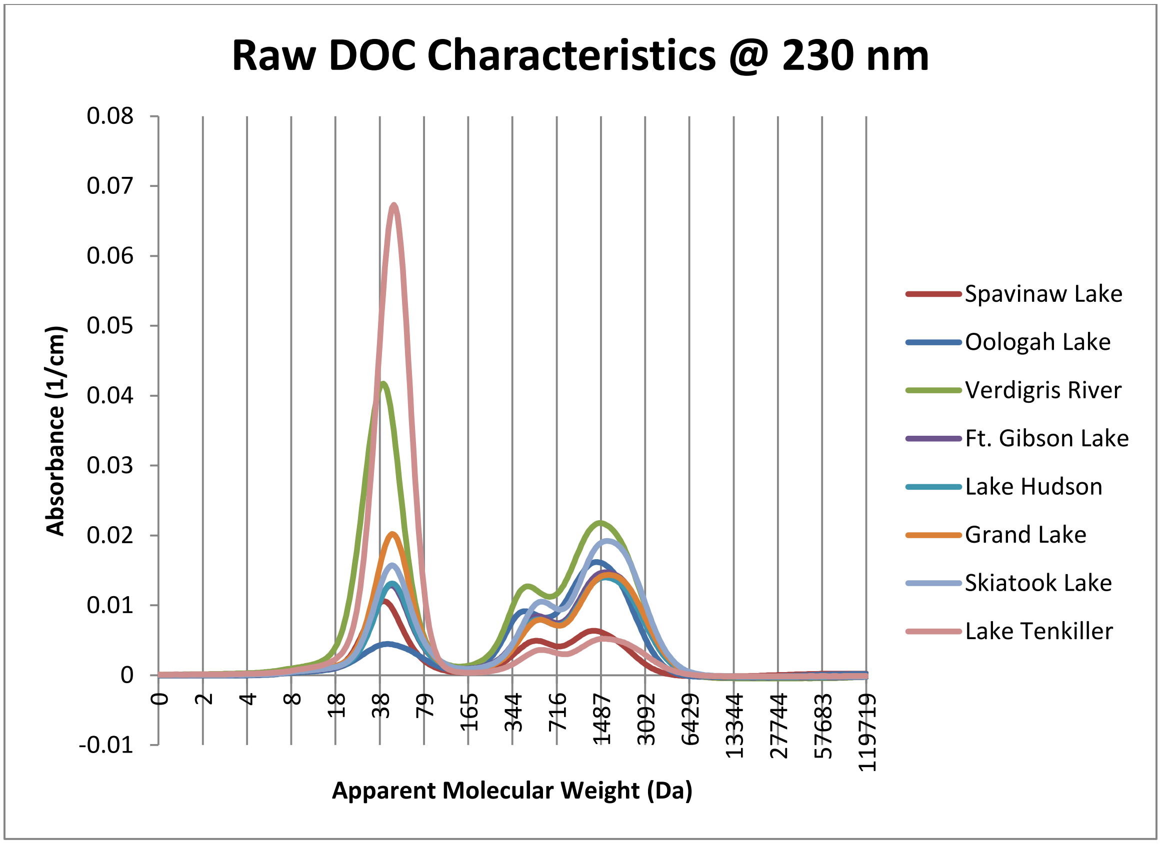

Figure 3.15 – DOC Characterization at 230 nm for Various Surface Waters in Northeastern Oklahoma

(Wintle et al. 2012)

As shown in the above graph, there is a high peak absorbance of low molecular weight compounds at an absorbance wavelength of 230 nm. Research indicates that amino acids have an affinity for absorbance at 230 nm wavelength. Research further indicates that algal-derived organic material is typically comprised mostly of amino acids. (Fang et al. 2010) Algal-derived amino acids are mostly arginine, lysine, and glycine. (Fang et al. 2010) It has also been shown that waters high in low molecular weight compounds can still form unacceptable levels of DBPs. (Liu et al. 2010) As shown above, Lake Tenkiller has the highest absorbance for low molecular weight compounds. This is interesting considing that Lake Tenkiller has one of the lowest DOC concentrations when compared to other impoundments in northeastern Oklahoma. Figure 3.15 indicates that the DOC of Lake Tenkiller is comprised mostly of low molecular weight algal derived compounds, thus leading to high absorbency at 230 nm. This corresponds to Lake Tenkiller's high concentrations of algae that have been the focus of recent litigation. Another interesting aspect is that aliphatic amines, such as dimethylamine, methylamine, ethylamine, methylethylamine and diethylamine are commonly found in waters high in algae. (Fang et al. 2010) Aliphatic amines are considered precursors for chloraminated DBPs (NDMA). (Bond et al. 2011) (Wintle et al. 2012)

As with the 254 nm wave length, the Verdigris River also has a fairly high absorbance at 230 nm. This is an indication that the Verdigris River could have high concentrations of aromatic humic acid and algae derived amino acids. This also corresponds to the high concentrations of chlorinated DBPs that have been observed by water authorities that utilize the Verdigris River. Utilizing chloramines to comply with Stage 2 D/ DBP Rule may aid in the compliance of chlorinated DBPs. However, the utilization of chloramines may also lead to the formation of chloraminated DBPs, due to the high concentrations of algal derived amino acids.

HPSEC can also be used to determine the effectiveness of a water treatment facility in the removal of the various constituents that make up the DOC. Presented in Figure 3.16 is the removal of DOC through the water treatment facility.

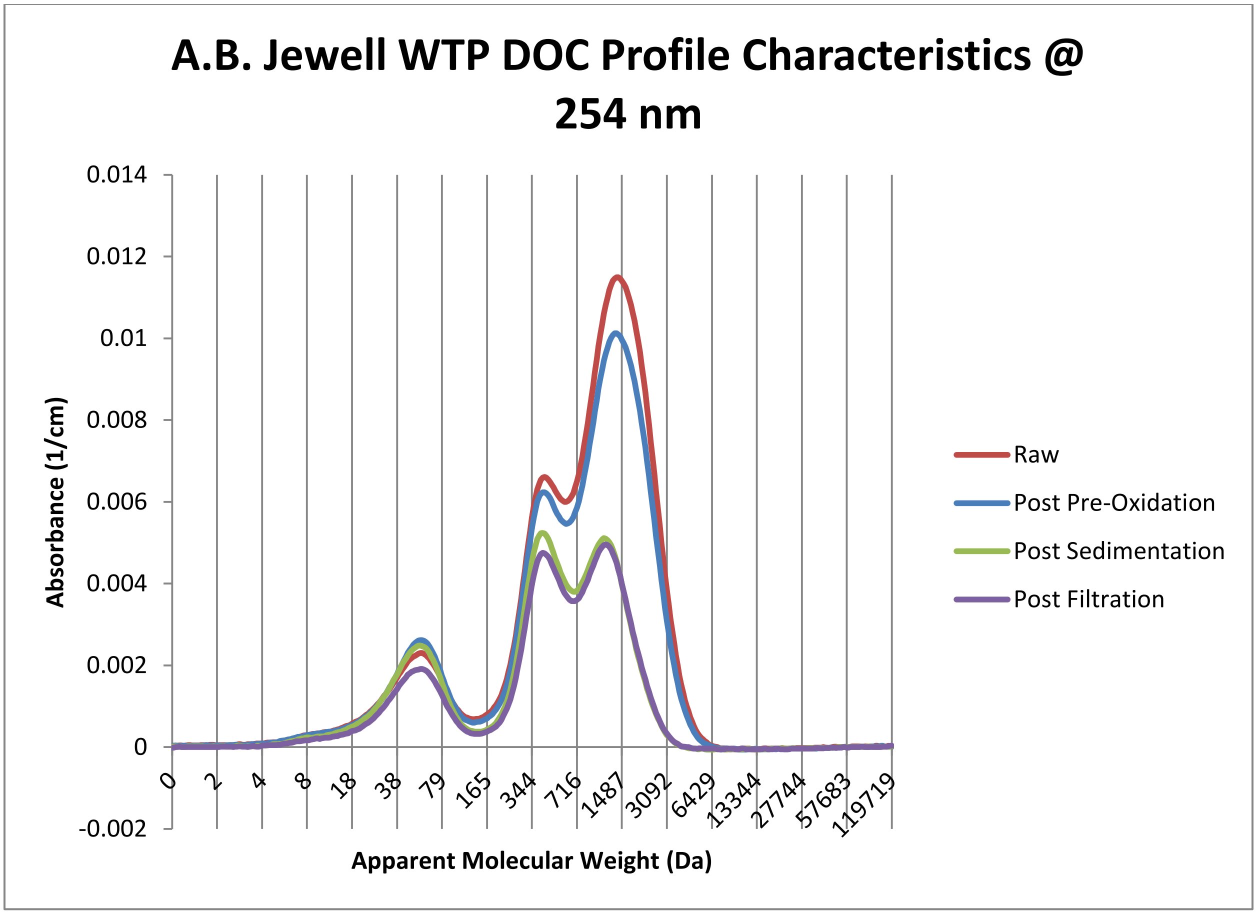

Figure 3.16 – DOC Characterization at 254 nm for A.B. Jewell Water Treatment Plant (Wintle et al. 2012)

As shown in the above DOC characterization curve, the majority of the aromatic compounds (humic acid) are removed by coagulation, flocculation and sedimentation. This is expected considering that HMS can remove soluble DOC through three mechanisms. It is also expected that some aromatic compounds would be removed from pre-oxidation. It is recommended that continued research be conducted in the area of HPSEC and DOC reduction.

Raw surface waters in northeastern Oklahoma have moderate to low alkalinity. Presented in Table 3.7 is the raw water alkalinity for various surface water treatment facilities in northeastern Oklahoma.

Table 3.7 – Raw Water Alkalinity Data and Analysis from 07/01/2006 to 06/30/2011 Data Set

Water Authority	Mean (mg/L)	Standard Deviation (mg/L)	95% Confidence (X-2SD) (mg/L)
Tulsa - Mohawk WTP	96	14	68
Bartlesville	75	32	11
Sapulpa	68	7	54
Tahlequah	98	18	62
Claremore	58	15	28
Okmulgee	31	4	23
Checotah	96	22	52
Jay	83	20	43
Tulsa - A.B. Jewell	96	14	68
Collinsville	112	17	78
Nowata	140	38	64
Broken Arrow	93	14	65
Oklahoma Ordnance Works Authority	98	17	64
Ft. Gibson	97	15	67
Muskogee	95	15	65
Wagoner	107	14	79
Sand Springs	71	7	57
Skiatook	65	7	51
Vinita	97	15	67
Grove	103	16	71
Afton	96	14	68
Locust Grove	89	19	51
Salina	105	14	77
Wagoner County Rural Water District #4	96	13	70
Coweta	67	13	41

(ODEQ 2011^{c})

As previously stated, the importance of determining the 95 % confidence interval is to determine the technology that allows compliance to be maintained 95 % of the time.

Presented below is Stage 1 D/ DBP rule minimum TOC removal based on the 95 % confidence interval values of the raw water TOC and alkalinity. Although it may seem unlikely that the raw water TOC and minimum alkalinity would occur at the same instant, that is simply not the case. For the water authorities identified, the majority of the watersheds are mixed use with residential, agricultural and industrial sources of pollution. This is one of the main reasons why the surface waters in northeastern Oklahoma are eutrophic. During eutrophic conditions, nitrification (conversation of ammonia to nitrate) occurs, which consumes alkalinity. The low alkalinity conditions typically occur during the spring and fall, which correlates with higher than average TOC concentrations. Water bodies that have higher raw water TOC standard deviations may also be most affected by residential and/ or agricultural pollution. Table 3.8 presents the raw water TOC, alkalinity and minimum TOC removal percentages based on 95% confidence values.

Table 3.8 – Stage 1 D/ DBP TOC Removal Percentages based on the Raw Water TOC and Alkalinity Data/ Analysis from 07/01/2006 to 06/30/2011 Data Set

Water Authority	**Raw Water TOC (95% Confidence (X+2SD)) (mg/L)**	**Raw Water Alkalinity (95% Confidence (X-2SD)) (mg/L)**	**Minimum TOC Removal Percentages (Based on 95% Confidence Values and Stage 1 D/ DBP Rule) (%)**
Tulsa - Mohawk WTP	3.16	68	25
Bartlesville	8.11	11	50
Sapulpa	6.26	54	45
Tahlequah	2.47	62	25
Claremore	9.07	28	50
Okmulgee	7.63	23	45
Checotah	8.79	52	50
Jay	2.82	43	35
Tulsa - A.B. Jewell	4.94	68	35
Collinsville	5.46	78	35
Nowata	7.78	64	35
Broken Arrow	8.40	65	40
Oklahoma Ordnance Works Authority	5.11	64	35
Ft. Gibson	7.33	67	35
Muskogee	5.35	65	35
Wagoner	6.15	79	35
Sand Springs	6.41	57	45
Skiatook	5.80	51	45
Vinita	5.46	67	35
Grove	5.33	71	35
Afton	6.79	68	35
Locust Grove	5.44	51	45
Salina	5.27	77	35
Wagoner County Rural Water District #4	8.84	70	40
Coweta	10.42	41	50

The minimum TOC removal percentages identified above would be used to assess TOC removal technologies. If the TOC removal technology can meet the above removal requirements, then the authority would be in compliance with Stage 1 D/ DBP Rule 95% of the time. This minimum TOC removal percentage would also aid in compliance with the Stage 2 D/ DBP Rule. If the minimum TOC removal percentages for each facility identified in Table 3.8 are met, then compliance during the quarters when the water temperature is colder should be obtainable. During the quarters when the water temperature is warmer, additional TOC may need to be removed for compliance purposes.

The surface water treatment facilities presented in Table 3.8 typically have a pH of 8 to 8.5. The mean alkalinity can range from 30 to 140 mg/L depending on the water source. At high concentrations of alkalinity (>130 mg/L as $CaCO_3$), the water contains a large buffering capacity. Utilizing coagulant hydrolysis to reduce the pH to optimal levels requires a high concentration of coagulant. Waters high in alkalinity would require high concentrations of acid to lower the pH if the coagulant were not utilized for hydrolysis. Therefore, enhanced coagulant for the removal of DOC can be very inefficient process.

Enhanced coagulation receives no direct removal credits (as defined by the 1986 SWTR) for the removal of viruses and protozoa. When used in conjunction with flocculation, sedimentation, and filtration (sequential and separate), the entire unit process receives 2 log of virus removal and 2.5 log removal of *Giardia lamblia*. (EPA 1999) The combination of unit processes receives a 3 log removal credit of *Cryptosporidium*. (EPA 2006[a]) It should be noted that dissolved air flotation (DAF) as a clarification technology is not being investigated in great detail as a part of this paper. DAF has been identified as a technology that is more consistent at removing of *Cryptosporidium*. At low water temperatures, the plate sedimentation removal efficiency of *Cryptosporidium* is reduced by 50%. (Edzwald et al. 2011) (AWWA 2011[c]) As previously identified, surface water impoundments in northeastern Oklahoma are eutrophic and therefore, high in algae. DAF is a very effective technology for removing algae, typically achieving an additional 1 log removal when compared to sedimentation. (AWWA 2011^c) (Edzwald et al. 2011) There are currently no DAF treatment systems in the State of Oklahoma. Further investigations should be conducted to determine the viability of this technology for clarification of surface waters in northeastern Oklahoma.

Activated carbon can be another TOC removal technology. Activated carbon is a form of carbon that has been processed to make it extremely porous, maximizing surface area available for adsorption. The carbon is activated through exposure to an oxidizing agent, which is usually steam or carbon dioxide at very high temperatures. This process produces very porous carbon particles. The organic compounds in the water adsorb, or attach, themselves to the activated carbon, due to charge and energy differentials. As a result of the porosity, the activated carbon has a large surface area, which provides more opportunity for the organic compounds to adsorb. Therefore, this technology is generally very effective for removing micro contaminants from water. (AWWA 2011^c)

Turbidity can interfere with the contact between the DOC and activated carbon (granular/ powdered). Turbidity can physically plug a granular activated carbon (GAC) contactor bed; therefore, GAC contactors are typically placed after filtration. GAC can also be placed into a mixed media filter bed, but this arrangement causes operational difficulties. Once the carbon has been exhausted, the mixed media filter bed would need to be taken off-line and the spent GAC would need to be vacuumed out. Replacing activated carbon thereby becomes labor intensive. In a GAC contactor bed, the unit process is specific to the removal of the DOC. By placing the GAC contactor post filtration, there is limited interference with turbidity. Turbidity can also shield the DOC from contact with powdered activated carbon (PAC). PAC is generally less effective for removing DOC when compared to GAC (site specific for the effectiveness). PAC has primarily been used for taste and odor control, but has been shown to remove some amounts of DOC. The DOC removal percentages are highly dependent upon the type of PAC and the location where it is added. The longer the contact times between the DOC and the PAC, the more DOC that is removed. (AWWA 2011[c])

For both activated carbon technologies, DOC removal can be inhibited by interference with other compounds. Oxidizing agents, such as ozone, free chlorine, permanganate, monochloramine, and chlorine dioxide can interfere with the adsorption of DOC onto the activated carbon. The oxidizing chemical exhausts the activated carbon, preventing the adsorption of the DOC. Also, sometimes when oxidizing compounds are applied once the activated carbon has adsorbed the DOC; this can actually cause the DOC to desorb.

Activated carbon can also adsorb some inorganics. Common inorganics, such as bromide, iron and manganese, are unaffected by activated carbon. One particular inorganic of interest is chromium (III and VI). This will be discussed in more detail later in this paper.

pH can effect the overall adsorption capacity of the activated carbon. Lower pH is desirable for DOC adsorption for PAC and GAC. One study indicated that by lowering the pH by one pH unit, the adsorption capacity of the activated carbon was increased by 6 percent. As previously stated, in waters that have high pH and high alkalinity, decreasing the pH may not be efficient for the purposes of activated carbon adsorption. (AWWA 2011[c])

Activated carbon provides no direct removal credits (ODEQ/ EPA) for removal of viruses or protozoa; although, as previously stated, GAC can be used in a mixed media filter bed, which provides for the removal of viruses and protozoa. The sequential and separate unit processes of coagulation, flocculation, sedimentation, and filtration receive log removal credit as identified in the previous section. (EPA 2006[a])

Anion exchange has become a more viable option for the removal of DOC in recent years. The process removes the negatively charged DOC (more specifically the humic acid fraction) by exchanging DOC for chloride. (AWWA 2011[c])

The anion exchange technology is a physical/ chemical unit process. There are two (2) configurations currently being employed for the removal of DOC. The most common type of ion exchanger is a packed bed type which consists of a charged resin and a pressure vessel. Raw water is pumped through the packed resin bed, allowing the necessary contact associated with the ion exchange process. The less common type of anion exchanger is a fluidized bed which consists of resin beads, up flow contact basin, and settling zone. This type of anion exchanger allows raw water to be pumped into the upflow contactor where the contact between the raw water and resin beads occurs. The resin beads are then separated from the now DOC treated water. Once all the resin exchange sites are exhausted, the resin must be regenerated. For a fixed bed reactor, regeneration is completed in a batch system. This requires that the reactor be taken out of service and that a regenerate be pumped into the contactor. The regenerate typically used is sodium chloride, commonly called brine. The fluidized bed anion exchange system does not have to be taken off-line for regeneration. This is accomplished by continuously taking a portion of the settled resin out of the contractor, regenerating it, and then injecting it back into the contactor. Also a small amount of fresh resin is added continuously to the contractor while a small amount of resin is hydraulically washed out of the contactor. The spent regenerate (brine waste) is then sent to holding tanks after regeneration. Brine waste handling is one of the difficulties of the anion exchange technology. The characteristics of typical brine waste are presented as follows in table 3.9.

Table 3.9 – Typical Brine Waste Characteristics Associated with Anion Exchange

Parameter	**Concentration**[1]
TDS (mg/L)	120,000
Conductivity (umhos/cm)	220,000
Chloride (mg/L)	65,000
Sodium (mg/L)	52,000
COD (mg/L)	34,820
BOD (mg/L)	1,958
Sulfate (mg/L)	9,800

[1] Data set courtesy of Coweta Public Works Authority in conjunction with ORICA Watercare MIEX™.

Depending on the amount generated, it may be possible to send the brine waste to the backwash lagoon. However, experience has indicated that it is unlikely that this waste can be disposed of in that manner. A second option for disposal is to discharge into the waste to the sanitary sewer system, if all pretreatment requirements are in compliance and the wastewater treatment facility has the capability. A third option is to evaporate the brine waste liquid onsite and dispose of the solids in a landfill. Evaporation can be accomplished either by mechanical methods (such as a natural gas evaporator) or by evaporation pond. Experience has shown that northeastern Oklahoma receives too much rainfall for an evaporation pond to work effectively. (ODEQ 2011[d])

The fixed bed anion exchange system must be used on low turbidity water because turbidity will build up on the resin and cause excessive hydraulic head loss. Therefore, the resin contactor is typically placed downstream of the filtration unit.

Turbidity is not a concern for a fluidized bed anion exchanger. The reason is that the fluidized bed only occupies approximately 20 % of the volume of the contactor. This allows the raw water to flow easily through the contactor with minimal head loss even during high turbidity events. Due to this consideration, a fluidized bed anion exchange reactor is typically placed upstream of rapid mix, flocculation, sedimentation, and filtration. A major advantage to placing an anion exchanger in this configuration is that it can reduce the enhanced coagulation dosage. When the anion exchanger removes the negatively charged DOC, the overall charge of the DOC becomes unstable (more positively charges compounds than negatively). This creates a greater force between the soluble compounds and the coagulant that allows the coagulant to adsorb more easily the DOC, increasing the efficiency of the applied coagulants. Another advantage of the fluidized bed anion exchanger is that it can be continuously operated due to the fact that the resin is continuously regenerated. A small portion of the resin beads are continuously pulled from the contactor and placed in a resin regeneration vessel where the exchange capacity of the resin bead is once again achieved. (AWWA 2011[c])

Inorganics, such as iron and manganese, have little effect on anion exchange. These particles are cations which will not affect the anion exchange capacity of the resin. Precipitated iron and manganese could affect a fixed bed ion exchange reactor in the same way turbidity does. (AWWA 2011[c])

Research does indicate that bromide (an anion) is removed by anion exchange. It was observed through bench scale testing from a source water in northeastern Oklahoma that bromide was reduced by 25 to 50 % (depending on bed volumes of the reactor). (Data courtesy of Coweta Public Works Authority in conjunction with ORICA Watercare MIEX™) This has promising implications for the reduction of surface waters high in bromide and could play a major role in reducing brominated disinfection byproducts. It is recommended that continued research into the effectiveness of anion exchange on bromide removal be conducted in future research projects.

An important inorganic constituent to the proper function of an anion exchange reactor is sulfate. Sulfate competes with DOC for exchange sites on the resin. Therefore, the sulfate raw water concentration is an important design consideration when evaluating anion exchange. (AWWA 2011^{c})

Intuitively negatively charged taste and odor compounds could be removed by an anion exchange reactor. Limited research has been conducted on the topic. Another possible side benefit to the anion exchange system is that it removes taste and odor compounds. It is recommended that direct removal of taste and odor compounds from an anion exchange reactor be evaluated in the future. Indirectly, anion exchange will increase the removal of taste and odor compounds. This is due to the fact that it has been observed that anion exchange enhances the total removal of DOC. If competing adsorption DOC is reduced, processes like GAC and PAC can more effectively remove MIB and geosmin through oxidation or adsorption. (AWWA 2011^{c})

An important consideration for anion exchange systems is algae. Algae blooms can be a concern when utilizing a fluidized bed anion exchange reactor, can coat the resin and prevent contact to the raw water. Continuous regeneration minimizes the effect of algae (due to the high concentrations of brine used during regeneration). If anion exchange is going to be used for the removal of DOC, provisions should be made to minimize algae growth within the source water or to utilize oxidants to minimize algae growth on the resin. (AWWA 2011^{c})

Water temperature has been found to have limited effect on the exchange capacity of the resin. (AWWA 2011^{c}) Anion exchange receives no inactivation or removal credit for any pathogens. (EPA 1999) (EPA 2006)

Materials Compatibility, Corrosion Concerns and Technology Adaptability

It is critical to evaluate the impact of an alternative disinfection technology on other water treatment unit processes. Alternative disinfectants can result in accelerated corrosion within the distribution system or of downstream processes. TOC removal technologies can also increase the corrosion of downstream processes or play a role in accelerated corrosion of the distribution system.

Material compatibility is a major concern of any water authority. Large water treatment facilities consist of concrete structures with steel piping. Mohawk and A.B. Jewel Water Treatment Facilities of Tulsa, OK are the largest water treatment facilities in northeastern Oklahoma. Each water treatment facility is sized for approximately one-hundred (100) MGD. The water treatment facilities are conventional water treatment facilities that consist of rapid mix, flocculation, sedimentation, and rapid rate gravity sand filtration. The materials of construction for these unit processes consist of structural concrete and metallic equipment. This is compared to the Coweta Water Treatment Facility located in Coweta, OK, which is one of the smaller water treatment facilities in northeastern Oklahoma. This water treatment facility currently uses a U.S. General Filter™ package water treatment facility. These higher rate treatment units utilize steel basin construction materials.

Other specific facilities evaluated were Sand Springs and Skiatook. These facilities are examples of systems that utilize high rate clarification and rapid rate gravity sand filtration. The high rate clarification uses metallic materials (plates, bolts, etc.) inside a concrete basin. Similar combinations of materials are utilized at Claremore and Tahlequah. These facilities utilize a solids contact clarifier in combination with rapid rate gravity sand filtration. The solids contact clarifier is made of metallic materials which are susceptible to corrosion.

Ozone

If ozone is used pre-filtration, it can cause excessive corrosion of other water treatment facility components. ODEQ requires that ozone shell and tubing material be 316L stainless steel. (ODEQ 2011[a]) Ozone should not come in contact with rubber, most plastics, or aluminum. Additionally, ozone reacts with carbon steel structural components, dramatically reducing the life of those components. The maximum allowable atmospheric concentration of ozone exposure to a worker is 0.1 ppm. (United States Department of Labor 2011) This is not a concern if the proper ozone destruction unit has been installed. It has been found that small off gassing over time by an ozone contactor can corrode components directly above or adjacent to the ozone contactor. It is recommended that the ozone contactor be placed in a location where there are no structures directly above or adjacent to the contactor. Ozone residual can also corrode downstream components and create a hazard to worker health if not properly addressed. If the ozone residual is required to be 0.50 mg/L at the end of the contactor in order to provide for the desired CT, then ozone off gassing can occur in a downstream component. A larger contactor may be necessary in order to achieve a lower residual for the desired CT to minimize ozone residual carry over. A quenching agent, such as hydrogen peroxide, may also be necessary. The reaction between ozone and hydrogen peroxide produces superoxide ion and the hydroxyl radical, known as free radicals. The reaction chemistry is presented in Figure 3.17 to produce the free radical products. (AWWA 1999)

$$H_2O_2 = HO_2^- + H_2$$
$$HO_2^- + O_3 \rightarrow OH\cdot + O_2^- + O_2$$

Figure 3.17 – Ozone and Hydrogen Peroxide to produce the Hydroxyl Radical

(AWWA 1999)

The hydroxyl radical and the superoxide ion contribute to additional auto-decomposition reactions of ozone, thereby creating additional free radicals that scavenge for constituents to oxidize and reduce. These free radicals exist for only a short period of time and react with constituents in the water, eliminating the residual ozone. It may be necessary to have a small reaction chamber after the ozone residual monitor in order to allow these reactions to occur before the treated water leaves the contactor. Another benefit to adding hydrogen peroxide is that the hydroxyl radical is very efficient in oxidizing taste and odor compounds.

As previously stated, pH levels are very important for the control of bromate. The use of chemicals to control the pH can consume alkalinity. A decrease in total alkalinity can cause corrosion in the distribution system to increase. Corrosion can lead to issues associated with the aesthetic of the delivered water, as well as the longevity of the distribution system piping and pumping systems. More importantly, a utility may experience an increase in lead and copper violations. (AWWA 1999) (AWWA 2005)

Additional variables include the age and condition of the facility as well as materials used during construction. If the utility wishes to use ozone with a pre-packaged treatment system, such as the Siemens Water Trident™ (previously called U.S. Filter Trident or U.S. General Filter Trident), the ozone system could cause corrosion to the main structure of the facility. These units have been commonly sold in northeastern Oklahoma during the last 20 to 40 years. A package system usually consists of a painted carbon steel shell that is placed on a concrete slab. Typically, components inside the basin are painted carbon steel. Evidence of corrosion in these units is very common when chlorine has been used for pretreatment or aggressive coagulants have been used as turbidity removal aids. Ozone could further exacerbate corrosion of the treatment system when adopting ozone as pretreatment.

Chlorine Dioxide

Long term use of any oxidant can accelerate the corrosion of the materials downstream of the injection point. As previously discussed, chlorine dioxide is a stronger oxidant than free chlorine, but not as strong as ozone. The materials of concern for chlorine dioxide are similar to free chlorine. Polyvinyl chloride (PVC) is typically used for conveyance lines when handling concentrated solutions of chlorine dioxide.

As stated, the concentration of applied chlorine dioxide is limited to approximately 1.4 mg/L. Therefore, the concentrations that are observed in contact basins are relatively low. Due to the reduced amounts of chlorine dioxide, the accelerated corrosion risk to painted carbon steel and other metallic objects is reduced to levels similarly observed with free chlorine. (AWWA 2005)

UV Light

UV light can disrupt the bonds that are found between organic compounds. Over time UV light can break down PVC piping. Caution must be exercised when determining the upstream and downstream piping from the UV reactor. UV resistant ductile iron pipe is typically used.

The UV disinfection reactor does not leave a residual in the receiving waters; therefore, concern is only warranted in the immediate vicinity of the reactor.

Chloramines

Monochloramine can not be used as a primary disinfectant, thus there is no concern with corrosion within a water treatment facility.

Monochloramine is gaining popularity in northeastern Oklahoma as a disinfectant barrier in the distribution system. When the barrier in the distribution system is converted from free chlorine to monochloramine, the ORP of the water in the distribution will change. This change in the ORP is associated with the oxidation strength of free chlorine compared to monochloramine. Due to the lower ORP that is associated with monochloramine, a decrease in iron corrosion is expected within the distribution system. This can lead to an increase in the life expectancy of the distribution system piping. (AWWA 2011[b])

The decrease in finished water ORP (associated with switching from free chlorine to monochloramine) can also lead to increased concentrations of lead found in delivered water. As the ORP decreases, it has been observed that the precipitated lead based scale ($PbCO_3$ and $Pb_3(CO_3)_2)(OH)_2$) detach from the pipe walls. These lead-based particles then increase the concentrations of lead found in the delivered water. (AWWA 2011[b])

TOC or DOC Removal Technologies

Enhanced coagulation can effect corrosion within a water treatment facility. As previously discussed, enhanced coagulation is most effective at pH less than 7. Therefore, at acidic conditions, corrosion will occur within the treatment facility.

As stated, some HMS, when added to the raw water, will consume alkalinity. This consumption of alkalinity is due to the formation of acidic compounds associated with the disassociation of the HMS. The acidic compounds can locally suppress the pH, corroding materials adjacent to the injection point (such as the propeller on a rapid mixer). By consuming alkalinity and decreasing the pH, the water becomes aggressive towards metallic materials, specifically iron. This occurs when electrons flow from the anodes to the cathode sites within the metallic material (due to the interaction between water and metal). Alkalinity is a source of dissolved inorganic carbon (DIC), which is an important constituent in the prevention of corrosion of metallic surfaces. As previously discussed, surface waters in northeastern Oklahoma are typically low in alkalinity, thus small amounts of HMS can make the water aggressive toward metallic materials. Additional corrosion can occur within the distribution system if the water is not properly stabilized. The HMS is aggressive towards chemical conveyance lines. Close attention to the chemical conveyance line material is necessary during the design of the facility.

GAC corrosion is limited within a water treatment facility. GAC can be slightly abrasive towards the rapid rate gravity filter basin (if being utilized as a media) and a pressure vessel during a backwash. Backwashing is completed so infrequently that this is of little concern.

On the other hand PAC can be very abrasive towards the materials that are utilized during slurry creation and conveyance to the injection point. Stainless steel is recommended to be used in all materials to come in contact with PAC.

Anion exchange can be potentially corrosive towards the distribution system. This is because anion exchange increases the concentration of chloride and decreases the concentration of sulfate. When an increase occurs, the chloride to sulfate mass ratio can increase to above 0.58. Once this occurs it can lead to increase concentrations of lead and copper within the finished water. The combined role that chloride and sulfate plays in corrosion is not fully understood at this time. (AWWA 2011[b])

Impact on Current ODEQ, EPA, DHS and OSHA Regulations

The use of alternative disinfection technologies can affect other regulations not associated with the Stage 2 D/ DBPs Rule. Compliance with other regulations is important to a water authority when evaluating alternative disinfection technologies. When implementing recommended compliance technology, researchers and design engineers sometimes do not consider the impact from other regulations.

Ozone

A downside to the use of ozone as a disinfectant is the associated operational danger of producing ozone onsite. Pure oxygen is required to produce ozone, and pure oxygen is usually generated offsite and brought to the facility. Therefore, it would be necessary to store large amounts of pure oxygen onsite. Oklahoma Administrative Code (OAC) 252:626-11-3 requires that a 30 day supply of chemicals be stored. Special considerations must be incorporated into the design in order to comply with Occupational Safety and Health Administration (OSHA) regulations. OSHA states that all compressed gasses must be visually inspected and stored in a safe manner, covered under 29 CFR Part 1910.101. OSHA also has special requirements for oxygen, covered under 29 CFR Part 1910.104. The threshold quantity for compliance with 29 CFR Part 1910.104 is 13,000 scf. In the unlikely event a water authority in northeastern Oklahoma needed to comply with this regulation, the oxygen container would need a spill containment dike, the oxygen container would also be located at least 50 ft from combustible structures. (U.S. Department of Labor 2011) (AWWA 1999) (AWWA 2005) (ODEQ 2011[a])

Ozone is also listed on EPA 40 CFR Part 355 Appendix A – The List of Extremely Hazardous Substances and Their Threshold Planning Quantities (CAS 10028-15-6). Ozone is also listed on OSHA 29 CFR Part 1910.119 App A List of Highly Hazardous Chemicals, Toxics and Reactives. A water authority must comply with these requirements when more than one-hundred (100) pounds (lbs) of gaseous ozone is stored onsite. Typically, a water authority can not store ozone onsite; therefore, it is unlikely that a facility would need to comply with the above regulations.

A Toxic Release Inventory (TRI) Form R is needed each year if the entity manufactures (converts oxygen to ozone) more than 25,000 lbs or uses greater than 10,000 lbs onsite annually. (EPA 2011[e]) Most facilities in northeastern Oklahoma would not meet this threshold. If the facility has a release of one-hundred (100) lbs of ozone in a 24 hour period, the required actions are listed in Table 3.10.

Table 3.10 – EPA 40 CFR Part 355.40

a) Immediate notification. The notice required under this section shall include as much of the following information known at the time. However, the retrieval of this information should not cause a delay in the notification on the emergency response.
(1) The chemical name or identity of any substance involved in the release.
(2) Indicate whether the substance is an EHS.
(3) Provide an estimate of the quantity of any such substance that was released into the environment.
(4) State the time and duration of the release.
(5) The medium or media into which the release occurred.
(6) Any known or anticipated acute or chronic health risks associated with the emergency and, where appropriate, advice regarding medical attention necessary for exposed individuals.
(7) Proper precautions to take as a result of the release, including evacuation (unless such information is readily available to the community emergency coordinator pursuant to the emergency plan).
(8) The name and telephone number of the individual (or individuals) to be contacted for further information.
(b) Written follow-up emergency notification. Except for releases that occur during transportation or from storage incident to transportation, you must provide a written follow-up emergency notice (or notices, as more information becomes available), as soon as practicable after the release. In the written follow-up emergency notice, you must provide and update the information required in the immediate notification and include additional information with respect to all of the following:
(1) Actions taken to respond and contain the release.
(2) Any known or anticipated acute or chronic health risks associated with the release.
(3) Where appropriate, advice regarding medical attention necessary for exposed individuals.
(c) You are not required to submit a written follow-up notification for a release that occurred during transportation or from storage incident to transportation. See §355.42(b) for requirements for reporting such releases.

(EPA 2011^{e})

As shown, in Table 3.10, the use of ozone can create new compliance issues for a water authority. There are dangers associated with the storage and handling of oxygen for workers. Ozone is a dangerous gas that has the potential to cause injury if released.

Chlorine Dioxide

As previously discussed, chlorine dioxide is very dangerous due to the fact that it can react with external energy input such as shock, sunlight, and sparks. This is why chlorine dioxide is almost never generated offsite and shipped, due to its unstable properties. Interestingly, chlorine dioxide is not listed in EPA 40 CFR Part 355 Appendix A – The List of Extremely Hazardous Substances and Their Threshold Planning Quantities (CAS 10049-04-4), nor is it listed in EPA 40 CFR Part 302 Hazardous Substances and Reportable Quantities. It is listed in EPA 40 CFR Part 68.130 List of Regulated Toxic Substances and Threshold Quantities for Accidental Release Prevention and OSHA 29 CFR Part 1910.119 App A List of Highly Hazardous Chemicals, Toxics and Reactives. (United States Department of Labor 2011) The utility must store 1,000 lbs or greater in order to be required to comply with the above two regulations. Typically, a water authority produces only what is needed at the time of injection and no chlorine dioxide is stored onsite; therefore, it is unlikely that a facility would need to comply with EPA and OSHA regulations. A TRI Form R is needed each year if the entity uses more than 10,000 lbs annually. (EPA 2011[e]) The storage and use of chlorine dioxide is regulated under OAC 252:626-11-4 by ODEQ.

As discussed, sodium chlorite and chlorine gas are used to manufacture chlorine dioxide onsite. Sodium chlorite is considered non-hazardous by EPA and OSHA. Therefore, storage of sodium chlorite does not impact any additional EPA and OSHA regulations. ODEQ regulates the storage of sodium chlorite under OAC 252:626-11-4. See Appendix 2 – Chemical Regulations Review for the regulation associated with chlorine dioxide, sodium chlorite and chlorine gas.

UV Light

Ultraviolet light uses no chemicals, thus requiring no onsite storage of chemicals. UV disinfection poses limited potential dangers to workers. The hazards associated with a UV system are electrical, heat, and UV exposure. Prolonged UV light exposure can cause health effects; however, the UV reactor is a closed vessel, thus preventing exposure. When performing maintenance on the system, a worker should use personal protective equipment (PPE), similar to that worn during maintenance on chemical feed pumps. Depending on the materials used in construction of the reactor bulbs, there could be additional EPA solid waste regulations. UV bulbs can have high concentrations of mercury that could potentially limit their disposal in a landfill. It would be necessary to investigate the disposal of the UV bulbs with the manufacturer of the equipment prior to purchasing the system.

Chloramines

Anhydrous ammonia is also listed on EPA 40 CFR Part 355 Appendix A – The List of Extremely Hazardous Substances and Their Threshold Planning Quantities (CAS 7664-41-7). According to this section, if more than five-hundred (500) lbs is stored onsite, then the entity must comply with EPA 40 CFR Part 355.20. Oklahoma Administrative Code (OAC) 252:626-11-3.a requires that a 30 day supply of chemicals be provided; therefore, even small water authorities will need to comply with EPA 40 CFR Part 355.20, as shown in Table 3.11.

Table 3.11 – EPA 40 CFR Part 355.20

What types of emergency planning notification are required?	**What information must I provide?**	**To whom must I provide the information**	**When must I provide the information?**
(a) Emergency planning notification	You must provide notice that your facility is subject to the emergency planning requirements of this subpart	To the SERC and the LEPC	Within 60 days after your facility first becomes subject to the requirements of this subpart. If no LEPC exists for your facility at the time you are required to provide emergency planning notification, then you should report to the LEPC within 30 days after an LEPC is established for the emergency planning district in which your facility is located.
(b) Facility emergency coordinator	You must designate a facility representative who will participate in the local emergency planning process as a facility emergency response coordinator. You must provide notice of this facility representative	To the LEPC (or the SERC if there is no LEPC, or the Governor if there is no SERC)	Within 60 days after your facility first becomes subject to the requirements of this subpart. If no LEPC exists when you first report, then provide an additional report to the LEPC within 30 days after such LEPC is established for the emergency planning district in which your facility is located.
(c) Changes relevant to emergency planning	You must provide notice of any changes occurring at your facility that may be relevant to emergency planning	To the LEPC	Within 30 days after the changes have occurred.
(d) Requested information	You must provide any information necessary for developing or implementing the local emergency plan if the LEPC requests it	To the LEPC	Promptly. Note: The LEPC may specify a time frame for this information.

(EPA 2011[e])

Furthermore, if the facility has a release of one-hundred (100) lbs of anhydrous ammonia in a 24 hour period, the following actions are required:

a) *Immediate notification.* The notice required under this section shall include as much of the following information known at the time. However, the retrieval of this information should not cause a delay in the notification on the emergency response.
(1) The chemical name or identity of any substance involved in the release.
(2) Indicate whether the substance is an EHS.
(3) Provide an estimate of the quantity of any such substance that was released into the environment.
(4) State the time and duration of the release.
(5) The medium or media into which the release occurred.
(6) Any known or anticipated acute or chronic health risks associated with the emergency and, where appropriate, advice regarding medical attention necessary for exposed individuals.
(7) Proper precautions to take as a result of the release, including evacuation (unless such information is readily available to the community emergency coordinator pursuant to the emergency plan).
(8) The name and telephone number of the individual (or individuals) to be contacted for further information.
(b) *Written follow-up emergency notification.* Except for releases that occur during transportation or from storage incident to transportation, you must provide a written follow-up emergency notice (or notices, as more information becomes available), as soon as practicable after the release. In the written follow-up emergency notice, you must provide and update the information required in the immediate notification and include additional information with respect to all of the following:
(1) Actions taken to respond and contain the release.
(2) Any known or anticipated acute or chronic health risks associated with the release.
(3) Where appropriate, advice regarding medical attention necessary for exposed individuals.
(c) You are not required to submit a written follow-up notification for a release that occurred during transportation or from storage incident to transportation. See §355.42(b) for requirements for reporting such releases.

Figure 3.18 – EPA 40 CFR Part 355.40

(EPA 2011[e])

If greater than ten-thousand (10,000) lbs is used annually, the entity must comply with EPA 40 CFR Part 372.25. This requires the entity to submit the Toxic Release Inventory (TRI) Form R each year. (EPA 2011[e])

Anhydrous ammonia is also listed on OSHA 29 CFR 1910.111 Storage and Handling of Anhydrous Ammonia. Due to this designation, OSHA has specific requirements when workers are present at a facility that stores any amount of anhydrous ammonia. These requirements deal with the construction of the storage facility, labeling of containers, labeling of conveyance lines, type of conveyance lines, safety relief devices, and electrical equipment. If greater than 10,000 lbs of anhydrous ammonia is stored onsite, then the entity must comply with the OSHA 29 CFR

1910.119 and EPA 40 CFR Part 68. Most water treatment facilities located in northeastern Oklahoma will not need to comply with these requirements as they will not meet the minimum threshold. (EPA 2011^{e})

Facilities that store and feed anhydrous ammonia would need to meet ODEQ requirements as described in OAC 252:626-11-4. These regulations deal with the storage and handling of anhydrous ammonia at the water treatment facility. For more details associated with the storage and handling of anhydrous ammonia see Appendix 2 – Chemical Regulations Review.

Due to the special storage and handling considerations associated with anhydrous ammonia, most water authorities have selected to use aqua ammonia (19% solution) to create monochloramine. At 19 % solution aqua ammonia is not considered an extremely hazardous substance. Aqua ammonia is defined a hazardous substance, thus the storage and handling is similar to that of common coagulants, such as ferric chloride or aluminum sulfate. ODEQ regulates the storage and feed of aqua ammonia as described in OAC 252:626-11-4.

The disadvantages of using aqua ammonia are similar to sodium hypochlorite. These liquid chemicals are comprised mostly of water and require large storage tanks. Also, liquid chemicals typically cost more, since the chemical supplier must transport mostly water.

Gaseous chlorine is also listed on EPA 40 CFR Part 355 Appendix A – The List of Extremely Hazardous Substances and Their Threshold Planning Quantities. A water authority must comply with the EPA requirements if it stores greater than one-hundred (100) lbs of gaseous chlorine onsite. A water authority must comply with EPA 40 CFR Part 355.40 if a release of ten (10) lbs of gaseous chlorine occurs in a 24-hour period. A TRI Form R is needed each year if the entity uses more than 10,000 lbs annually. (EPA 2011^{e})

Anhydrous ammonia and gaseous chlorine are also regulated under EPA 40 CFR Part 68. Unlike anhydrous ammonia, gaseous chlorine at a typical surface water treatment facility in northeastern Oklahoma would be stored in quantities sufficient to meet the threshold requirements as defined by the regulation. A facility that stores greater than 2,500 lbs of gaseous chlorine must have a Risk Management Plan (RMP). An RMP requires the water authority to evaluate the hazard to the public in the event of a release. An RMP also establishes a plan for first responders. (EPA 2011[e])

Gaseous chlorine is also regulated by OSHA 29 CFR Part 1910.119 App A List of Highly Hazardous Chemicals, Toxics and Reactives. Due to this regulation, the water authority must meet requirements that deal with the storage and handling of gaseous chlorine as defined by OSHA. These requirements deal with the storage, handling, notification, medical testing, and training of employees that have direct contact with the gaseous chlorine. For more details associated with the storage and handling of gaseous chlorine, see Appendix 2 – Chemical Regulations Review**.** (United States Department of Labor 2011)

Gaseous chlorine has widespread acceptance and use in northeastern Oklahoma. Gaseous chlorine has been safely used in northeastern Oklahoma for nearly one-hundred (100) years. Due to recent incidents involving chlorine gas, the EPA is encouraging water authorities to convert to sodium hypochlorite (either onsite generation or bulk delivery). Additionally, H.R. 2868 was passed by the 111th (2009 to 2010) House of Representative to deal with regulation of water and wastewater treatment facilities by Department of Homeland Security (DHS) 6 CFR Part 27 Chemical Facility Anti-Terrorism Standards (CFATS). This bill was not brought up in the 111th Senate and is currently dead. However, if passed, the regulation would require facilities (that meet the threshold) to implement security measures, security plan, vulnerability assessments, and security inspections by DHS. It also would require water authorities to decrease the quantities of extremely hazardous substances at their facilities. By not doing so, water authorities could face enforcement action by the EPA. (United States House of Representatives 2010).

Due to these considerations, water authorities should exercise caution when adding additional hazardous substances (such as anhydrous ammonia) at their facilities. Adding additional hazards can create a level of complexity for a water authority. Typically, water authorities pursue actions that minimize the use of hazardous substances and the associated OSHA requirements.

TOC or DOC Removal Technologies

Enhanced coagulation simply requires the water authority to feed additional coagulant. Therefore, the water authority will only need to store and handle coagulants. Common coagulants used in northeastern Oklahoma are ferric chloride (40 % solution), alum (aluminum sulfate) (50 % solution), and ACH (an alum derivative regulated similarly to alum) (50 % solution). These chemicals are considered hazardous chemicals. If 1000 lbs of ferric chloride or 5000 lbs of alum is released in a twenty-four (24) hour period, the water authority must report the release in accordance with EPA 40 CFR Part 302. Additionally, spill containment (to hold 100 % of the largest container or 10 % of the aggregate) must be provided for the storage of these chemicals. Also, the water authority must comply with EPA 40 CFR Part 370 Hazardous Chemical Reporting: Community Right to Know if greater than 10,000 lbs of any of the coagulants is stored onsite. The water authority may need to comply with this regulation for enhanced coagulants, depending on the dosage required. For information associated with the regulation of these coagulants see Appendix 2 – Chemical Regulations Review. (EPA 2011[e])

If the water authority practices pH suppression (prior to the addition of the coagulant for enhanced coagulation), then an acid must be added. Common acids found at water treatment facilities in northeastern Oklahoma are sulfuric acid (98% solution) and hydrochloric acid (38 % solution). The major difference associated with the regulation of these acids is that sulfuric acid is a listed in EPA 40 CFR Part 355 Appendix A – The List of Extremely Hazardous Substances and Their Threshold Planning Quantities (CAS 7664-93-9 / 8014-95-7). The water authority must comply with this regulation (as previously discussed) if greater than 1000 lbs of sulfuric acid is stored onsite. Interestingly, sulfuric acid is not listed in EPA 40 CFR Part 68; therefore, no RMP is required for the storage of sulfuric acid. Also, the water authority must comply with EPA 40 CFR Part 370 Hazardous Chemical Reporting: Community Right-to-Know if greater than 1,000 lbs of sulfuric acid is stored onsite. The water authority may need to comply with this regulation for enhanced coagulation depending on the dosage required. If more than 10,000 lbs is used onsite during a year, then the water authority must comply with EPA 40 CFR Part 372 Toxic Chemical Release Reporting: Community Right-to-Know requirements by submitting a TRI Form R annually. Hydrochloric acid is not listed in 40 CFR Part 355 and does not require the level of regulation that sulfuric acid does.

GAC and PAC are not considered hazardous materials, and the impact to current regulations associated with the use of GAC or PAC is limited. GAC and PAC are flammable, which requires proper storage and handling methods for the materials. GAC and PAC are not to be stored with other chemicals (especially oxidants). GAC and PAC should be stored in a fire resistant room with fire suppression equipment. Any carbon dust should be cleaned up and not allowed to collect within the room. The electrical designation for the space should be Class II Division 1, which limits the flammability or explosion potential of the space.

GAC pressure filter use is regulated by ODEQ under OAC 252:626-9-5, which requires a pilot study to be completed prior to its use. The pilot study aids in the determination of the adsorption isotherm, minimum empty bed contact time, and service time (time to exhaustion). ODEQ also regulates the design of the GAC pressure filter through this regulation. (ODEQ 2011[a])

PAC is also regulated by ODEQ under OAC 252:626-11-4.d. ODEQ construction standards require that dust collection equipment, fireproof room and corrosion resistant materials be designed into the storage facility. (ODEQ 2011[a])

PAC and GAC can be dewatered and then disposed in a landfill. It is unlikely that PAC and GAC will adsorb enough heavy metals to prevent passing the Toxicity Characteristic Leaching Procedure (TCLP) test. (Tchobanoglous et al. 1993)

Anion exchange process is not currently in ODEQ construction standards. To use the anion exchange process for the treatment of a public water supply requires a variance from ODEQ construction standards as defined by OAC 252:626-3-8.

Anion exchange systems utilize resin and regenerate. Resin and brine (sodium chloride) are not considered hazardous and have not been the object of regulation. Resins are specific to the manufacturer of the anion exchanger. The manufacturer would need to provide the MSDS that is specific to its system. Brine (sodium chloride) is not considered hazardous and poses little hazard to workers. Anion exchange will remove other anions including chromium VI, which will be discussed in more detail in a later section. It is unlikely that surface waters in northeastern Oklahoma have sufficient quantities of chromium VI that, once removed by an anion exchange system, would make the waste product a hazardous waste. It may be prudent to test the raw water and then conduct a mass balance to determine the maximum possible concentration found in the waste product.

A pilot test should also be conducted to determine the amount of chromium VI that is adsorbed onto the resin and not removed during a regeneration cycle. The resin will adsorb chromium VI, which can make the resin a hazardous material. Studies will need to be conducted at each facility to determine the bed volumes until the resin became a hazardous material.

Capital and Operational Costs Estimate

Capital and operational costs are very important when considering specific treatment strategies to best achieve compliance with Stage 2 DBP Rule. Estimated costs associated with the installation of a new treatment unit are presented.

Chemical costs as provided by water treatment facilities. Construction costs were determined based on verbal conversations with equipment suppliers and contractors located in northeastern Oklahoma. Capital Cost were also compared to published information contained within the literature. (McGivney et al. 2008)

Ozone

Presented in Table 3.12 and 3.13 are the estimated capital and operational costs associated with an ozone treatment process.

Table 3.12 – Estimated Ozone Capital Costs per 1 MGD

Ozone	
Equipment	$425,000
Construction	$500,000
Project Costs	$138,750
Contingency	$185,000
Total[2]	[1]$1,248,750
Total Estimated Cost per Gallon	$1.25

[1] Enginering News Record Consumer Cost Index (ENR CCI) for February 2011: 8998.

[2] Estimated cost is intended to provide an approximate cost per 1 MGD. As in the above literature, many site specific factors can have a dramatic impact on the cost of a treatment component.

Table 3.13 – Estimated Monthly Ozone Operational Costs

Ozone	
Oxygen Usage (scf)	1,210
Liquid Oxygen (LOX) ($/ scf)	$0.55
Monthly LOX Cost	$666
Electricity Usage (kWh)	5,500
Electricity Costs ($/kWh)	$0.10
Monthly Electricity Cost	$550
Monthly Maintenance	$500
Monthly Intangibles	$250
Total[2]	$1,966
Operational Cost per 1000 gal[1]	$0.07

[1] Estimated cost using 30E6 gal/ month. [2] Estimated cost is intended to provide an approximate operational cost. As stated in the above literature, many site specific factors can have a dramatic impact on the operational cost of a treatment component.

Operational costs can be difficult to estimate. Many site specific factors can impact the monthly cost of a treatment strategy. One of the main operational costs of ozone generation is liquid oxygen (LOX). Only very large systems will generate oxygen onsite due to the associated capital and operational costs. Typically, LOX can be stored onsite and used as needed. The cost of electricity is another operational expense in ozone generation. The price of electricity is fairly low in northeastern Oklahoma when compared to the rest of the country; therefore, ozone generation and delivery has a potentially lower operating cost in northeastern Oklahoma than other regions. (U.S. Energy Information Administration: Independent and Statistics Analysis 2011)

Chlorine Dioxide

Presented in Table 3.14 and 3.15 are the estimated capital and operational costs associated with chlorine dioxide treatment process.

Table 3.14 – Estimated Chlorine Dioxide Capital Costs per 1 MGD

Chlorine Dioxide	
Equipment	$250,000
Construction	$150,000
Project Costs	$60,000
Contingency	$80,000
Total[2]	[1]$540,000
Total Estimated Cost per Gallon	$0.54

[1]Enginering News Record Consumer Cost Index (ENR CCI) for February 2011: 8998. [2]Estimated cost is intended to provide an approximate cost per 1 MGD. As in the above literature, many site specific factors can have a dramatic impact on the cost of a treatment component. [3]Cost includes concrete pre-sedimentation basin.

Table 3.15 – Estimated Monthly Chlorine Dioxide Operational Costs

Chlorine Dioxide	
Chemical Usage - Sodium Chlorite (lbs)	250
Chemical Cost ($/lbs)	$0.50
Chemical Usage - Chlorine Gas (lbs)	125
Chemical Cost ($/lbs)	$0.65
Monthly Chemical Cost	$206
Monthly Maintenance	$350
Monthly Intangibles	$200
Total[2]	$756
Operational Cost per 1000 gal[1]	$0.03

[1]Estimated cost using 30E6 gal/ month. [2]Estimated cost is intended to provide an approximate operational cost. As stated in the above literature, many site specific factors can have a dramatic impact on the operational cost of a treatment component.

Chlorine dioxide generating equipment, including installation, is relatively inexpensive when compared to other alternatives. The operational cost of chlorine dioxide is also relatively inexpensive since chlorine gas is used to generate chlorine dioxide. EPA and OSHA requirements associated with having chlorine gas onsite have not been factored into the above costs.

UV Light

Presented in Table 3.16 and 3.17 are the estimated capital and operational costs associated with UV light treatment process.

Table 3.16 – Estimated UV Disinfection Capital Costs per 1 MGD

UV Disinfection	
Equipment	$140,000
Construction	$175,000
Project Costs	$47,250
Contingency	$63,000
Total[2]	[1]$425,250
Total Estimated Cost per Gallon	$0.43

[1]Enginering News Record Consumer Cost Index (ENR CCI) for February 2011: 8998. [2]Estimated cost is intended to provide an approximate cost per 1 MGD. As in the above literature, many site specific factors can have a dramatic impact on the cost of a treatment component. [3]Cost includes concrete pre-sedimentation basin.

Table 3.17 – Estimated Monthly UV Disinfection Operational Costs

UV Disinfection	
Electricity Usage (kWh)	4,672
Electricity Costs ($/kWh)	$0.10
Monthly Electricity Cost	$467
Bulb Replacement	$145
Monthly Maintenance	$250
Monthly Intangibles	$200
Total[2]	$1,062
Operational Cost per 1000 gal[1]	$0.04

[1]Estimated cost using 30E6 gal/ month. [2]Estimated cost is intended to provide an approximate operational cost. As stated in the above literature, many site specific factors can have a dramatic impact on the operational cost of a treatment component.

UV disinfection equipment, including installation, is one of the least costly alternatives for the disinfection of treated water. UV disinfection also has a low operating cost, which is one of the reasons it has been selected as the alternative of choice for compliance with LT2ESWTR.

Chloramines

Presented in Table 3.18 and 3.19 are the estimated capital and operational costs associated with chloramines treatment process.

Table 3.18 – Estimated Chloramines Capital Costs per 1 MGD

Chloramines	
Equipment/ Basin	$100,000
Construction	$125,000
Project Costs	$33,750
Contingency	$45,000
Total[2]	[1]$303,750
Total Estimated Cost per Gallon	$0.30

[1] Enginering News Record Consumer Cost Index (ENR CCI) for February 2011: 8998.
[2] Estimated cost is intended to provide an approximate cost per 1 MGD. As in the above literature, many site specific factors can have a dramatic impact on the cost of a treatment component. [3] Cost includes concrete pre-sedimentation basin.

Table 3.19 – Estimated Monthly Chloramines Operational Costs

Chloramines	
Chemical Usage - Aqua Ammonia (lbs)	250
Chemical Cost - Aqua Ammonia ($/lbs)	$0.20
Monthly Chemical Cost	$50
Additional Chlorine Usage (lbs)	500
Chlorine Costs ($/lbs)	$0.65
Monthly Additional Chlorine Cost	$325
Monthly Maintenance	$100
Monthly Intangibles	$500
Total[2]	$975
Operational Cost per 1000 gal[1]	$0.03

[1] Estimated cost using 30E6 gal/ month. [2] Estimated cost is intended to provide an approximate operational cost. As stated in the above literature, many site specific factors can have a dramatic impact on the operational cost of a treatment component.

The use of chloramines is a low cost alternative. Low capital and operational costs are the main reasons chloramines are the strategy of choice for compliance with Stage 2 D/ DBP Rule for large water authorities in northeastern Oklahoma. Operational costs do not include additional maintenance of the distribution system associated with nitrification. The cost of storing the aqua ammonia associated with the use of chloramines is also not included.

TOC or DOC Removal Technologies

Presented in Table 3.20 and 3.21 are the estimated capital and operational costs associated with the enhanced coagulation treatment process.

Table 3.20 – Estimated Enhanced Coagulation Capital Costs per 1 MGD

Enhanced Coagulation	
Equipment/ Basin	$275,000
Construction	$300,000
Project Costs	$86,250
Contingency	$115,000
Total[2]	[1]$776,250
Total Estimated Cost per Gallon	$0.78

[1] Enginering News Record Consumer Cost Index (ENR CCI) for February 2011: 8998.
[2] Estimated cost is intended to provide an approximate cost per 1 MGD. As in the above literature, many site specific factors can have a dramatic impact on the cost of a treatment component. [3] Cost includes concrete pre-sedimentation basin.

Table 3.21 – Estimated Monthly Enhanced Coagulation Operational Costs

Enhanced Coagulation	
Chemical Usage - $FeCl_3$ (lbs)	15,000
Chemical Cost - $FeCl_3$ ($/lbs)	$0.19
Monthly Chemical Cost	$2,850
Alkalinity Usage (lbs)	8,757
Alkalinity Costs ($/lbs)	$0.25
Monthly Alkalinity Cost	$2,189
Residuals Handling	$1,000
Monthly Maintenance	$100
Monthly Intangibles	$50
Total[2]	$6,189
Operational Cost per 1000 gal[1]	$0.21

[1] Estimated cost using 30E6 gal/ month. [2] Estimated cost is intended to provide an approximate operational cost. As stated in the above literature, many site specific factors can have a dramatic impact on the operational cost of a treatment component.

The selected coagulant for the above chemical cost analysis is ferric chloride. This is one of the lowest cost coagulants available in northeastern Oklahoma. Additional maintenance associated with corrosion from the injection of ferric chloride is not factored into the cost. The above maintenance costs include labor and parts that are associated with the maintenance of the chemical feed pumps.

Presented in Table 3.22 and 3.23 are the estimated capital and operational costs associated with the granular activated carbon treatment process.

Table 3.22 – Estimated GAC Capital Costs per 1 MGD

GAC	
Equipment	$330,000
Construction	$350,000
Project Costs	$102,000
Contingency	$136,000
Total[2]	[1]$918,000
Total Estimated Cost per Gallon	$0.92

[1]Enginering News Record Consumer Cost Index (ENR CCI) for February 2011: 8998.
[2]Estimated cost is intended to provide an approximate cost per 1 MGD. As in the above literature, many site specific factors can have a dramatic impact on the cost of a treatment component. [3]Cost includes concrete pre-sedimentation basin.

Table 3.23 – Estimated Monthly GAC Operational Costs

GAC	
GAC Usage (lbs)	2,500
GAC Cost ($/lbs)	$2.00
Monthly GAC Cost	$5,000
Electricity Usage (kWh)	3,200
Electricity Costs ($/kWh)	$0.10
Monthly Electricity Cost	$320
Residuals Handling	$330
Monthly Maintenance	$250
Monthly Intangibles	$150
Total[2]	$6,050
Operational Cost per 1000 gal[1]	$0.20

[1]Estimated cost using 30E6 gal/ month. [2]Estimated cost is intended to provide an approximate operational cost. As stated in the above literature, many site specific factors can have a dramatic impact on the operational cost of a treatment component.

As demonstrated above, over 80 % of the monthly operational costs is associated with replacement GAC. The time to exhaustion (or breakthrough) is dependent on the site specific characteristics of the raw water; therefore, this is a difficult number to estimate. In order to determine more accurate estimated costs, it is recommended that a pilot study be completed. Experience has shown that the cost of GAC is also difficult to predict, as the cost can be volatile.

Presented in Table 3.24 and 3.25 are the estimated capital and operational costs associated with powdered activated carbon treatment process.

Table 3.24 – Estimated PAC Capital Costs per 1 MGD

PAC	
Equipment	$75,000
Construction	$90,000
Project Costs	$24,750
Contingency	$33,000
Total[2]	[1]$222,750
Total Estimated Cost per Gallon	$0.22

[1] Enginering News Record Consumer Cost Index (ENR CCI) for February 2011: 8998.
[2] Estimated cost is intended to provide an approximate cost per 1 MGD. As in the above literature, many site specific factors can have a dramatic impact on the cost of a treatment component. [3] Cost includes concrete pre-sedimentation basin.

Table 3.25 – Estimated Monthly PAC Operational Costs

PAC	
Chemical Usage (lbs)	5,000
Chemical Cost ($/lbs)	$2.30
Monthly Chemical Cost	$11,500
Residuals Handling	$250
Monthly Maintenance	$100
Monthly Intangibles	$50
Total[2]	$11,900
Operational Cost per 1000 gal[1]	$0.40

[1] Estimated cost using 30E6 gal/ month. [2] Estimated cost is intended to provide an approximate operational cost. As stated in the above literature, many site specific factors can have a dramatic impact on the operational cost of a treatment component.

PAC has a low capital cost but a high operational cost. As with GAC, the price of PAC can be volatile depending on market forces. Also, jar testing is needed to determine a more precise estimated cost associated with the use of PAC.

Presented in Table 3.26 and 3.27 are the estimated capital and operational costs associated with the anion exchange – fixed bed treatment process.

Table 3.26 – Estimated Anion Exchange – Fixed Bed Capital Costs per 1 MGD

Anion Exchange - Fixed Bed	
Equipment	$550,000
Construction	$350,000
Project Costs	$135,000
Contingency	$180,000
Total[2]	[1]$1,215,000
Total Estimated Cost per Gallon	$1.22

[1]Enginering News Record Consumer Cost Index (ENR CCI) for February 2011: 8998. [2]Estimated cost is intended to provide an approximate cost per 1 MGD. As in the above literature, many site specific factors can have a dramatic impact on the cost of a treatment component. [3]Cost includes concrete pre-sedimentation basin.

Table 3.27 – Estimated Monthly Anion Exchange – Fixed Bed Operational Costs

Anion Exchange - Fixed Bed	
Salt Usage (lbs)	13,500
Salt Cost ($/lbs)	$0.10
Monthly Regeneration Cost	$1,350
Electricity Usage (kWh)	3,500
Electricity Costs ($/kWh)	$0.10
Monthly Electricity Cost	$350
Residuals Handling	$360
Monthly Maintenance	$250
Monthly Intangibles	$200
Total[2]	$2,510
Operational Cost per 1000 gal[1]	$0.08

[1]Estimated cost using 30E6 gal/ month. [2]Estimated cost is intended to provide an approximate operational cost. As stated in the above literature, many site specific factors can have a dramatic impact on the operational cost of a treatment component.

The main operational cost difference of the fixed anion exchange bed reactors is the resin replacement. There is no resin loss with the fixed bed reactor, thus there is no cost associated with replacing lost resin. It should be noted that replacing the fixed bed anion exchange resin is a maintenance item and is included in the maintenance line item cost estimate.

Presented in Table 3.28 and 3.29 are the estimated capital and operational costs associated with the anion exchange – fluidized bed treatment process.

Table 3.28 – Estimated Anion Exchange – Fluidized Bed Capital Costs per 1 MGD

Anion Exchange - Fluidized Bed	
Equipment	$775,000
Construction	$450,000
Project Costs	$183,750
Contingency	$245,000
Total[2]	[1]$1,653,750
Total Estimated Cost per Gallon	$1.65

[1] Enginering News Record Consumer Cost Index (ENR CCI) for February 2011: 8998.
[2] Estimated cost is intended to provide an approximate cost per 1 MGD. As in the above literature, many site specific factors can have a dramatic impact on the cost of a treatment component. [3] Cost includes concrete pre-sedimentation basin.

The anion exchange fluidized bed reactor is the most expensive alternative investigated. However, a cost advantage of this system is that it typically decreases the applied coagulant dosages. Additionally, as the system increases in size, the capital cost per gallon decreases. There will also be some operational cost offsets with this system. For example, at the proposed installation location in northeastern Oklahoma (Coweta, OK), jar testing was conducted that indicates the applied coagulant dosage could be reduced by six (6) times.

Table 3.29 – Estimated Monthly Anion Exchange – Fluidized Bed Operational Costs

Anion Exchange - Fluidized Bed	
Salt Usage (lbs)	15,000
Salt Cost ($/lbs)	$0.10
Monthly Regeneration Cost	$1,500
Resin Loss (5.70 L/ MG)	171.00
Resin Cost ($13.85/ L)	$13.85
Monthly Resin Costs	$2,368
Monthly Maintenance	$300
Monthly Intangibles	$200
Total[2]	$4,382
Operational Cost per 1000 gal[1]	$0.15

[1] Estimated cost using 30E6 gal/ month. [2] Estimated cost is intended to provide an approximate operational cost. As stated in the above literature, many site specific factors can have a dramatic impact on the operational cost of a treatment component.

As shown in Table 3.30, chloramines are the lowest cost alternative with an approximate capital cost of $0.30 per gallon and $0.03 per 1000 gallons for operational costs.

Table 3.30 – Estimated Capital and Operational Costs Summary

Alternative	Total Capital Cost Per Gallon[1]	Operational Cost Per 1000 Gallons[2]
Ozone	$1.25	$0.07
Chlorine Dioxide	$0.54	$0.03
UV Disinfection	$0.43	$0.04
Chloramines	$0.30	$0.03
Enhanced Coagulation	$0.78	$0.21
GAC	$0.92	$0.20
PAC	$0.22	$0.40
Anion Exchange - Fixed Bed	$1.22	$0.08
Anion Exchange - Fluidized Bed	$1.65	$0.15

[1] Estimated cost using 30E6 gal/ month. [2] Estimated cost is intended to provide an approximate operational cost. As in the above literature, many site specific factors can have a dramatic impact on the operational cost of a treatment component.

Unit Process Operational and Maintenance Difficulties

It is imperative that investigations be completed on the operation and maintenance difficulties that may be associated with the compliance technology. A new unit process may require additional labor costs to train an operator. Qualified operators may cost more per month than the treatment unit. Also access to qualified operators may be limited in northeastern Oklahoma.

Ozone

Currently, there are no installations of ozone in northeastern Oklahoma. Ozone has had limited use in the United States, including the state of Oklahoma. A good training and start-up program can alleviate some of the concerns associated with a new unit process.

Storage of oxygen is similar to the storage of chlorine. Oxygen, as stated, requires special handling and storage considerations. Operators must be properly trained to handle LOX.

The generation of ozone is relatively simple; however, the equipment required to do so is fairly complicated. A small water authority will not have a person on the maintenance staff that can work on an ozone generator. Ozone generators are usually proprietary systems that can require special maintenance. An operator could possibly repair piping used to support the ozone generator. Electrical maintenance associated with the ozone generator requires a licensed electrician. If ozone is selected as the best alternative for compliance with Stage 2 DBP, it may be necessary to select a manufacturer that has local representation. It may also be in the best interest of the water authority to purchase a maintenance agreement with the manufacturer to assure the equipment is properly serviced (not included in Chapter 5). (Lauer et al. 2009)

Once ozone has been generated, it is injected through a fine bubble diffuser in a manner similar to the injection of oxygen into an aeration basin for an activated sludge process. Fine bubble diffusers have been used extensively at activated sludge waste water treatment facilities across Northeastern Oklahoma.

An ozone unit process is simple and easy to understand and has been used extensively in Europe for over a hundred years. (AWWA 2011[c]) It is expected that operators in northeastern Oklahoma could assimilate the required information to operate the system. It is not expected that special or new staff would be required. It is the maintenance or troubleshooting of the ozone generator that can present difficulties for the staff of a water treatment facility. For large systems, the authority may want to consider additional staff for the operation and maintenance of the system. Additional staff is probably not necessary for a small system.

Chlorine Dioxide

Chlorine dioxide has experienced popularity in northeastern Oklahoma for its ability to aid in TOC removal, oxidation of taste/ odor, and oxidation of iron/ manganese. The largest water authority in northeastern Oklahoma, Tulsa, uses chlorine dioxide at one (1) of its water treatment facilities.

The generation and injection of chlorine dioxide is relatively easy to understand. It has been safely used in large and small water authorities in northeast Oklahoma.

On the other hand, the technology that is used to generate chlorine dioxide, according to operators, has been found to be operationally difficult. The majority of the generators that were installed in northeast Oklahoma were unreliable and prone to maintenance issues, due in part to the manufacturer that provided the majority of the generators. Also, the corporation that manufactured and sold the majority of the equipment installed in northeastern Oklahoma went out of business in 2008. Therefore, it is difficult to find parts and to repair the generators.

It was found difficult for operators to use chlorine dioxide, due to chlorite, the regulated disinfection byproduct. Operators were limited by the amount of chlorine dioxide that could be applied to the raw water, making it difficult to maintain the desired level of treatment at all times. If the oxidant demanding inorganic or organic compounds spike in the raw water, the desired levels of residual chlorine dioxide may not be maintained. This is especially concerning if chlorine dioxide is being used to meet the required CT as defined by the 1986 SWTR. Operators must closely monitor applied dosages to balance the concentrations of chlorite, chlorine dioxide, and residual free chlorine. If chlorine dioxide injected into raw water contains high concentrations of free chlorine, then TTHMs and HAA5 will be formed. Also, the operator needs to monitor the injection of sodium chlorite closely. Equipment malfunctions can lead to a chlorite violation.

In northeastern Oklahoma, the source water can rapidly change with spikes of oxidant-demanding inorganic and organic compounds, which can make chlorine dioxide difficult to operate. Also, the equipment used to generate chlorine dioxide has been prone to maintenance issues. For these reasons, the unit process has fallen out of favor for use for water treatment in recent years.

UV Light

As discussed, UV light has gained in popularity for water treatment across the United States, due to its ability to inactivate C*ryptosporidium*. However, LT2ESWTR raw water testing has found limited concentrations of *Cryptosporidium* in northeastern Oklahoma, and thus very few water authorities have implemented its use. Currently, there are no installations of UV disinfection on public water supplies in northeastern Oklahoma, but two (2) water authorities have plans to install the technology in the coming years.

UV light has been used in northeastern Oklahoma for the disinfection of wastewater. Wastewater operators have a familiarity with its maintenance and operation, and the technology would not be difficult to adapt to water treatment.

From an operational standpoint, the operator simply needs to monitor the RED and flow rates. Typically, these parameters are programmed into the PLC, automatically sending an alarm to the operator when the desired parameters are exceeded. Special operational care needs to be taken when feeding chemicals directly upstream of the reactor. As previously discussed, certain chemicals can interact with UV light, limiting its ability to inactivate microorganisms.

The UV disinfection system requires minimal maintenance. Unlike the wastewater UV disinfection systems, the water treatment UV system is a closed conduit system. The reactors re very small and typically contain a limited number of bulbs. The most important aspect of maintaining a UV disinfection system is to ensure the sleeves receive the necessary cleaning. All UV disinfection systems contain mechanical wiping, which is monitored automatically by the equipment PLC. If a mechanical wiper were to fail, the system would automatically alarm the operator. The mechanical wiper is the only moving part found in a UV disinfection system. UV generating bulbs need to be replaced in accordance with the manufacturer’s requirements. The technology is relatively easy to understand, operate, and maintain on a day to day basis.

In case of a major failure associated with the UV disinfection system, the manufacturer would need to be utilized for repair. Major maintenance on the system requires personnel with knowledge of the manufacturer’s specific equipment. Most manufacturers have representatives that can respond to a system issue within twenty-four (24) hours. It is important to have the correct contact information for all UV disinfection system support personnel.

In general, operators in northeastern Oklahoma can complete the tasks associated with properly operating a UV disinfection system, although there is some special training required. For large systems, the authority may want to consider additional staff for the operation and maintenance of the system. Additional staff is probably not necessary for a small system.

Chloramines

Chloramines are formed from the interaction of ammonia and free chlorine. Although this concept is simple to understand, the operation of chloramines is complicated. The recommended desired free chlorine to ammonia ratio is 4.5:1 to 5:1 (weight basis). (AWWA 2006) The minimum amount of total chlorine residual required at the point of entry is 2 mg/L and at least one (1) mg/L total chlorine residual at all points within the distribution system. (ODEQ 2011[b]) The correct molar ratio needed to meet the levels of monochloramine is temperature and pH dependent. Therefore, corrections need to be made to the ratio depending on these parameters. The applied levels of ammonia need to be adjusted depending on the raw water ammonia levels. Raw water ammonia may fluctuate and must be tested daily by the operator. The finished water must also contain sufficient amounts of alkalinity in order to buffer pH changes in the distribution system. Nitrification will occur naturally within a chloraminated distribution system. As chloramines react with inorganic and organic material in the distribution system, ammonia is released. This ammonia is utilized by nitrifying bacteria for energy, which in turn converts ammonia to nitrate. Within a distribution system, nitrification is at its peak when the water temperature is at its highest and the residual chloramine levels are at their lowest. (AWWA 2006)

If these parameters are not closely monitored and operation is not maintained, excessive nitrification can occur within the distribution system. Excessive nitrification leads to taste/ odor problems, loss of residual, and increased heterotrophic plate count (HPC). Controlling the free ammonia leaving the water treatment facility is the first step in minimizing nitrification in the distribution system. Free ammonia should never exceed 0.10 mg/L; thus, finished water ammonia levels must be continuously monitored. Free chlorine and ammonia injection points must also be properly mixed to ensure complete conversion to chloramines.

The next step in minimizing excessive nitrification in the distribution system is water age management. As water ages in the distribution system, it loses chloramine residual, which allows for nitrifying bacteria to grow. Storage towers are notorious for residual loss and are prime locations for excessive nitrification. It is recommended that storage towers be properly designed and cycled. Also, flushing within the distribution system can increase the overall residual, which will decrease the concentrations of nitrifying bacteria. Chloramination booster stations can be installed that will maintain the proper levels of residual within the distribution system.

The equipment used to inject free chlorine and ammonia is common to water treatment facilities. Operations and maintenance staff should be familiar with its use.

The equipment associated with chloramination is easy to operate and maintain. There is no need to acquire additional staff or to require special training. Successful water treatment and distribution system operation is imperative for the use of chloramines. If close operation is not maintained, then violations within the distribution system can occur. In addition, customer complaints can result.

TOC or DOC Removal Technologies

The addition of coagulants is well understood by operators within northeastern Oklahoma. There is no need for additional operators or maintenance staff. The operator is limited in the amount of coagulant that can be added according to the design of the sedimentation basin. U.S. General Filters™ typically can not handle high concentrations of coagulants without having operational issues with excessive backwashing and turbidity spikes. Conventional water treatment facilities can process solids generated by enhanced coagulation. If the facility does not have mechanical solids removal equipment, the basin may fill up with solids faster than expected, which leads to increased maintenance of the basin. If the sedimentation basin is not equipped with a solids removal system, it may not be properly sized to handle the additional generated solids. Increased use of solids removal equipment can lead to increased maintenance on the equipment.

If an acid is used to suppress the pH for enhanced coagulation, then operational difficulties may arise from the feeding of this chemical. Acid can quickly degrade conduits and pump parts if the proper materials are not selected. Additionally, acids are found in strong solutions; therefore, if the improper amount is fed, a dramatic decrease in the water's pH can result. This can lead to decreased turbidity removal by filtration, causing a turbidity violation.

As previously discussed, HMS will consume alkalinity; therefore, provisions need to be made to ensure that the finished water contains a sufficient amount of alkalinity. The operator will need to add carbonate or bicarbonate alkalinity after sedimentation. This is usually accomplished by adding lime (calcium oxide), soda ash (sodium carbonate), or baking soda (sodium bicarbonate). The pH will need to be adjusted through the use of sodium hydroxide. Sodium hydroxide is typically found at strong solutions, which can lead to a dramatic increase in the pH if the improper amount is fed. If the saturation pH of the water is exceeded, then calcium carbonate can deposit on conduit walls, decreasing the effective size of piping. This can decrease the hydraulic capacity of conduits and cause excessive wear on pumps.

Enhanced coagulation sludge can rapidly fill backwash lagoons. Once a backwash lagoon is full, special equipment and staff is required to dewater the lagoon, which could be a major expense for a water treatment facility.

GAC and PAC have also been used extensively in northeastern Oklahoma. GAC has been placed into existing dual or mixed media filtration basin. As discussed, GAC can be rapidly exhausted, which will lead to the replacement of the GAC. Existing rapid sand filtration basins are not conducive to replacement of media (on a monthly or bi-monthly basis). Replacement of filter media is a labor intensive endeavor for water treatment staff; therefore, GAC has been used more commonly with pressure filters. Pressure filters have drains that allow spent GAC to be easily wasted and new carbon to be placed into the filter. Pressure filters require backwashing and feed pumps, causing increased maintenance for staff. However, pressure filters are comprised of common types of pumps and require no special staff for the maintenance of the equipment.

The PAC feed system requires a slurry mix system, dust control system, feed pump, and conduit. Careful operation is dependent on the location of the PAC feed. If PAC is fed onto the filter, it can lead to excessive backwashing and effluent turbidity problems. The operator must also be cautious when feeding PAC in locations where HMS, polymers, or oxidants are present. HMS and polymer will blind adsorption sites, which will lead to decreased adsorption efficiency, thus increasing the required amount of PAC. Oxidants such as permanganate, free chlorine, chlorine dioxide, and hydrogen peroxide will react, or adsorb, with PAC, decreasing the efficiency of the PAC and increasing the required amount. Adding PAC in a location where oxidants are present will lead to an increase in the dosage, which leads to increased operational costs.

PAC will also increase the amount of sludge to be removed from the sedimentation basin. As with enhanced coagulation, this can lead to a multitude of issues that have maintenance and operational implications.

PAC feed equipment and dust control can require extra maintenance. Peristaltic feed pumps function best with slurries in order to avoid contact with the abrasive substance. The wear tubing will need to be monitored and replaced as necessary. The dust collection equipment will also need to be properly maintained by removing the fine PAC dust. Fine PAC dust can be a fire hazard if allowed to collect. PAC feed systems are comprised of common equipment found at water treatment facilities and require no special staff for their maintenance.

Currently there are no anion exchange systems (for DOC removal) in use in northeastern Oklahoma. One (1) anion exchange system is expected to be constructed in the coming year at a water treatment facility. As with ozone, there is no operator familiarity with this process in the study area.

A fixed bed anion exchange system is similar in operation to a pressure GAC filter. The fixed bed anion exchange system is a pressure system that requires feed pumps. The fixed bed needs to be regenerated when exhausted, which requires that regenerate (sodium chloride solution or brine) be pumped into the contactor. Regenerate must be stored at the site, which is typically accomplished by a salt saturator and a saturated brine tank. Pumps are required to transfer the saturated brine from the storage tank to the contactor. Therefore, maintenance is similar to that of a GAC pressure filter. Fixed bed anion exchange systems are comprised of common equipment found at water treatment facilities and require no special staff for maintenance.

A fluidized bed anion exchange system is comprised of mixers, pumps, contactors, and storage tanks. The system requires that anion exchange resin be continuously regenerated; thus, pumps must be turned on and off to transfer brine and resin from and into various contactors. The operation of the system is heavily controlled by a PLC.

It is important to have controls personnel on call for troubleshooting a GAC pressure filter and the fixed and fluidized bed anion exchange systems. There are various personnel in northeastern Oklahoma that can support the PLC for these systems. There is no need for additional operational personnel for any of the TOC removal technologies. There may be additional maintenance staff needed for larger systems with the GAC pressure filter and the fixed and fluidized bed anion exchange systems. A good start up and training program is imperative to the operation of the GAC pressure filter and the fixed and fluidized bed anion exchange systems

Potential Future Safe Drinking Water Regulations and Compliance Concerns

A water authority usually receives funding through the OWRB State Revolving Funds program, where the capital investment repayment period for a water authority is 20 to 30 years. It is imperative that the authority stay in compliance during the debt repayment period. Each water authority should investigate the ability of the proposed unit process to comply with potential future regulations. What follows is a discussion of what these future regulations are likely to be and how they affect each process considered in this paper.

Ozone

Ozone can aid in compliance with future regulations; however, the assurance of success depends upon the contaminant of concern. Contaminants can be classified into three categories: microbial, organic and inorganic.

Ozone will aid in compliance with potential future microbial contaminants. Currently, LT2ESWTR requires water authorities that serve less than 10,000 persons to sample for *E.coli*. If an authority is above the action level (average of all 24 samples) of 10 MPN per 100 mL for lake/ reservoir water sources and 50 MPN per 100mL for flowing stream water sources, water authorities are required to sample for *Cryptosporidium*. All authorities that serve more than 10,000 persons are required to sample for *Cryptosporidium* every six (6) years and are placed into a bin classification based on the raw water concentration of *Cryptosporidium*. The bin classification depends entirely on the most recent raw water concentration of *Cryptosporidium*. The second round of source water monitoring is slated to begin in the near future. It is expected that EPA will not allow *E.coli* to be used as an action level organism for the second round of monitoring. As stated in LT2ESWTR, each sampling cycle is expected to become more rigorous. (EPA 2006[a]) If an authority is placed in bin 1 for the first sampling round, it does not mean that the authority will not be placed into a higher bin in six (6) years. Depending on the bin classification (bin 1, bin 2, bin 3 and bin 4), water authorities can be required to provide up to an additional three (3) log removal/ inactivation of *Cryptosporidium*. Ozone disinfection technology can achieve some of the additional treatment requirements by changing the inactivation target organism to *Cryptosporidium*. This may require the authority to increase ozone residual or to increase contact time. This can sometimes be accomplished with an existing ozone generator and contactor. It was also recommended that the MCL for bromate be lowered to 0.005 mg/L (5 µg/L) in EPA 40 CFR Parts, 9, 141 and 142 – Stage 2 Disinfectants and Disinfection Byproducts Rule; however, EPA has decided to review the MCL for bromate during the six (6) year review process. It is expected that bromate will be reduced in the future. If the standard is lowered to 5 µg/L, it will be very difficult for water authorities to maintain compliance if the water source contains bromide.

Ozone also can allow the utility to comply with some secondary standards. As previously discussed, ozone can aid in the removal of iron and manganese, which are two (2) of the fifteen (15) contaminants listed in the National Secondary Drinking Water Standards. Ozone can also oxidize color and odor compounds, which are also listed as secondary standards. (EPA 2011[b])

The Final Contaminant Candidate List 3 (CCL 3) was released in October 2009 and contains twelve (12) microbial contaminant candidates. The CCL 3 is one of the last steps in issuing a new proposed rule. (AWWA 2011[c]) Each of the proposed microbial contaminants (four (4) virus, two (2) protozoan, and six (6) bacteria) can be inactivated by ozone. If the microbial contaminants are regulated at the water treatment facility, ozone will allow the water authority to maintain compliance. If the microbial contaminants were to be regulated in the distribution system, ozone treatment at the water treatment facility could have little effect. This is especially true for microbial contaminants that have an affinity for growing in the distribution system.

The CCL 3 also contains 104 chemicals or chemical groups. Formaldehyde, acrolein, and acetaldehyde, which are found in CCL3, are formed when ozone reacts with NOM found in the water. Therefore, waters that contain high concentrations of NOM will likely have higher concentrations of acetaldehyde, acrolein and formaldehyde. The formation of these byproducts is the main reason for locating ozone before filtration. Biological activity in the filtration unit process can remove some of these byproducts. Currently, some treatment facilities employ biologically active filtration units to remove the maximum amount of unregulated byproducts. If these byproducts are regulated, it may be necessary to place the ozone unit process between clarification and filtration to minimize the amount of NOM that is oxidized by ozone. It may also be necessary to place a biologically active filter directly downstream of the ozone unit process. If these byproducts are regulated, ozone technologies will be more complicated to implement in northeastern Oklahoma. Additionally, biologically active filters will be more difficult and more expensive to operate. Additional investigations in biologically active filters should be conducted into the removal of ozone produced by products like acetaldehyde, acrolein and formaldehyde.

It also should be noted that a large number of contaminants listed in the CCL 3 are microcontaminants, such as cyanotoxins, endocrine disrupters, and pharmaceuticals and personal care products (PPCP). Ozone has been found to oxidize over 80 percent of the microcontaminants under normal operating conditions (CT). (AWWA 2011[c]) It may be possible to comply with potential future microcontaminant regulations with the use of ozone. The reaction rate of ozone can be limited depending on the targeted microcontaminant. For example, Table 3.31 presents various organic compounds and their reaction rates with ozone.

Table 3.31 – Ozone Reaction Rate

Contaminant	**Ozone ($M^{-1}S^{-1}$)**
Phenol	1300
Naphthalene	3000
Benzene	2
PCE	0.1
TCE	10-20
Atrazine	10-20

(AWWA 1999)

Analysis of the EPA Unregulated Contaminant Monitoring Regulation (UCMR) program has established some preliminary findings of occurrence and concentrations for some of the contaminants listed in CCL 3. (EPA 2011[d]) UCMR 1 was conducted over a 12 month period from 2001 to 2003 and sampled for 24 contaminants listed on CCL 3. The contaminants sampled were primarily pesticides, herbicides, and industrial solvents. Unregulated ozone byproducts were not sampled under the UCMR 1. The sampling set consisted primarily of large water treatment facilities serving more than 10,000 persons. In the state of Oklahoma, only one (1) contaminant out of the 24 listed was found at a concentration above the minimum reporting level (MRL). Perchlorate was found above the MRL in two (2) analyses from two (2) public water supplies with an average concentration of 14 µg/L. The prevalence of the contaminants that were sampled under UCMR 1 and UCMR 2 is limited in Northeastern Oklahoma. (EPA 2011[d])

The use of ozone may achieve compliance with Stage 2 DBP, but it may also be worth noting that EPA has indicated that the MCLs for TTHMs and HAA5s may not be sufficient to protect human health. It was indicated 13 years ago that future regulations were going to lower the regulations for TTHMs and HAA5s to 40 µg/L and 30 µg/L respectively (commonly called the 40/30 limit). (Davis et al. 1998) Stage 2 DBP also states that if a water authority is consistently below the 40/30 limit (40 µg/L of TTHMs and 30 µg/L HAA5s), it can qualify for reduced monitoring of DBPs, as long as those limits are not exceeded during any LRAA testing or as long as the source water (raw) annual average TOC levels do not exceed 4 mg/L. (EPA 2006[b]) Therefore, EPA already encourages water authorities to strive for the 40/30 limit. In the future, it is expected that EPA will lower the chlorinated DBPs to the 40/30 limit.

Chlorine Dioxide

As previously discussed, chlorine dioxide has associated DBPs. Currently, only chlorite is regulated. Chlorite is formed under basic conditions during the generation of chlorine dioxide. To minimize the formation of chlorite, the pH is reduced, but in doing so the concentrations of chlorate are increased. Once in solution, chlorine dioxide solution can degrade to chlorite or chlorate depending on the pH, temperature, and light.

Chlorate may be regulated in the future, since it is listed on the CCL 3. Therefore, caution needs to be exercised when selecting chlorine dioxide as an alternative to comply with Stage 2 D/DBP Rule. It is expected that if chlorate were to be regulated, it would further curtail the practical maximum applied dosage of chlorine dioxide (current practical maximum applied chlorine dioxide concentration is 1.4 to 1.5 mg/L). In June 2011 EPA held a public meeting on the preliminary regulation determinations. During that meeting, thirty-two (32) contaminates were discussed that defined the short list. The short list was distilled from the CCL 3. From that short list, regulatory determinations will be made on at least five (5). (EPA 2011[a]) Chlorate is listed on the short list, as shown in Table 3.32and future regulation is likely.

Table 3.32 – EPA Contaminant Candidate Short List

Contaminant	Contaminant
N-nitrosodiethylamine (NDEA)	RDX
N-nitrosodimethylamine (NDMA)	Dimethoate
N-nitroso-di-n-propylamine (NDPA)	Disulfoton
N-Nitrosodiphenylamine	Diuron
N-nitrosopyrrolidine (NPYR)	Molinate
Chlorate	Terbufos
Molybdenum	Terbufos Sulfone
Strontium	Acetochlor
Vanadium	Acetochlor ethanesulfonic acid (ESA)
1,1,1,2-Tetrachloroethene	Acetochlor oxanilic acid (OA)
1,2,3-Tetrachloropropane	Acrolein
1,3-Dinitrobenzene	Alachlor ethanesulfonic acid (ESA)
1,4-Dioxane	Alachlor oxanilic acid (OA)
MTBE	Metolachlor
Nitrobenzene	Metolachlor ethanesulfonic acid (ESA)
PFOS and PFOA	Metolachlor oxanilic acid (OA)

(EPA 2011[a])

Chlorine dioxide, as discussed, is a stronger disinfectant than free chlorine and monochloramine. Therefore, it would be expected to have the potential ability to comply with microbial contaminants that are listed on the CCL 3. The bacteria and viruses should be easily inactivated by chlorine dioxide. It may be more difficult to inactivate the two (2) protozoan that are listed in the CCL 3 (if similar CT requirements when compared to *Cryptosporidium*).

Limited research has been conducted into the ability of chlorine dioxide to oxidize microcontaminants. It is expected that chlorine dioxide will oxidize some micorcontaminants, as it is a stronger oxidant than free chlorine. Some pesticides (such as atrazine) are very resistant to some types of oxidants; therefore, it is anticipated that chlorine dioxide would not easily oxidize some potential contaminants.

If the 40/ 30 limit were instituted, chlorine dioxide may not allow the water authority to comply with the lower regulations. Additionally, if chlorate were added to the list of regulated DBPs, it may become more difficult to comply with future D/ DBPs Rules. Due to this consideration, chlorine dioxide is expected to have limited use for compliance with future safe drinking water act regulations.

Chlorine dioxide can allow the utility to comply with some secondary standards. As previously discussed, chlorine dioxide can aid in the removal of iron and manganese, which are two (2) of the fifteen (15) contaminants listed in the National Secondary Drinking Water Standards. Chlorine dioxide can also oxidize color and odor compounds, which are also listed as secondary standards, more effectively than free chlorine. (EPA 2011[b])

UV Light

UV light has been found to easily inactivate protozoa that are resistant to chemical disinfectants. UV light has also been found to easily inactivate bacteria at commonly applied UV dosages. Therefore, of the twelve (12) microbial contaminants listed in the CCL 3, all but four (4) viruses should be inactivated by UV disinfection technology at common UV dosages (Dose < 40 mJ/cm^2). (Chevrefils et al. 2006)

UV disinfection technology does not react with constituents in the water to produce DBPs at common disinfection levels. At very high levels of applied UV energy, photolysis of the NOM found in water can occur. The change to the structure of the NOM does not have an effect on the formation of TTHMs or HAA5. Therefore, there is little concern with the production of any compounds found on the CCL 3. (AWWA 2011[c])

At typical disinfection levels, little photolysis of microcontaminants occurs. The standard UV disinfection reactor does not apply enough required energy for the production of the hydroxyl radical. As discussed in the report previously, UV disinfection can be adapted into an AOP. It has been well documented that an AOP will remove microcontaminants through the production of the hydroxyl radical. Presented in Table 3.33 is the reaction rate for the hydroxyl radical.

Table 3.33 – Hydroxyl Radical Reaction Rate

Contaminant	**Ozone ($M^{-1}S^{-1}$)**
Phenol	$1x10^7$ - $1x10^{10}$
Naphthalene	$1x10^7$ - $1x10^{10}$
Benzene	$1x10^7$ - $1x10^{10}$
PCE	$1x10^7$ - $1x10^{10}$
TCE	$1x10^7$ - $1x10^{10}$
Atrazine	$1x10^7$ - $1x10^{10}$

(AWWA 1999)

As demonstrated above, the hydroxyl radical is a non-selective oxidant. It has a fairly uniform rate of reaction and can oxidize at a rapid rate for almost all organic containments found in wastewater. It has been shown that the removal efficiency is proportional to the oxidant strength. Therefore, higher degrees of removals of microcontaminants are expected for the UV/ AOP processes than for other oxidants (ozone, chlorine dioxide, free chlorine, and monochloramine). (AWWA 1999) (AWWA 2011[c]) (Rosenfeldt et al. 2004) At the high dosages of applied UV energy that are required for AOPs, photolysis of NDMA will occur, thus potentially allowing utilities to comply with potential nitrosamines regulations. (AWWA 2011[c])

UV disinfection technology is not expected to allow the utility to gain compliance with all potential future regulations. It is another available treatment technology that can be utilized with little concern for negative side effects warrenting compliance with future regulations.

Chloramines

One compound found on the Contaminant Candidate List 3 is N-Nitroso-dimethylamine (NDMA). NDMA has been classified as a B2 by the EPA, which indicates that there is sufficient evidence to believe that NDMA is a probable human carcinogen. The drinking water unit risk has been established as 7 ng/L for 1 person in 100,000 to develop cancer from the consumption of drinking water at this concentration over a lifetime. The State of California has established 10 ηg/L of NDMA as the level of maximum concentration before the water utility is required to notify the public. The World Health Organization has established 100 ng/L as a guidance value for 1 person in 100,000 to develop cancer from the consumption of drinking water over a lifetime. Currently, there is no European Union Standard for NDMA. NDMA forms when ammonia, free chlorine and precursors (dimethylamine) are combined in water, which is why NDMA has been found to be more prevalent in chloraminated drinking water than free chlorine. (EPA 2011[a]) Typically, chloraminated drinking water contains between 5 to 30 ng/L of NDMA with levels sometimes as high as 140 ng/L. (EPA 2011[d]) (WHO 2011)

As previously stated, EPA defined the short list in June 2011. NDMA and four (4) other nitrosamines were on the short list. (EPA 2011[a]) Results released from the public meeting have indicated a high prevalence of NDMA in the sample set (17,900 samples from 1,200 Public Water Supplies). NDMA was to be found present (at least one detect) in 38.6 % of all surface water treatment plants tested that use chloramines. This is compared to the fact that NDMA was found present (at least one detect) in 4.3 % of all surface water treatment plants tested that use free chlorine. (EPA 2011[a]) (EPA 2011[d])

An investigation of NDMA was conducted to determine if NDMA is a concern for public water supplies in northeastern Oklahoma. Skiatook, Sand Springs, and Tulsa (Oklahoma) were selected for NDMA testing. Skiatook and Sand Springs were selected because the source water for both water treatment facilities is Skiatook Lake. Although different sizes, the water treatment facilities also utilize the same process treatment (ferric sulfate coagulation, anionic polymer (acrylamide), Degrmont Technologies Superpulsator™ flocculation/ sedimentation, mixed media filtration, and chlorination disinfection). The Sand Springs WTP is sized for a peak flow of eight (8) MGD, and the Skiatook WTP is sized for three (3) MGD. The main difference between the facilities is that Sand Springs WTP utilizes chloramines as a barrier in the distribution system, whereas Skiatook WTP utilizes hypochlorite (chlorination). Also, as of November 15, 2011 Sand Springs is the only water authority using chloramines as the barrier in the distribution system in the study area. Sampling sites were chosen in the approximate geographical middle of the distribution system to obtain samples that could be used to represent an average NDMA concentration for the distribution system. Literature has stated that NDMA formation is similar to other disinfection byproducts, wherein the concentration increases with the increased detention time. (Knight et al. 2011) The results of the NDMA concentration comparison between Sand Springs, OK and Skiatook, OK is presented in Table 3.34.

Table 3.34 – NDMA Testing Results for Sand Springs, OK and Skiatook, OK

Public Water Supply	Location	Sampling Date: 11/2/2011	Sampling Date: 11/15/2011	Units
Sand Springs, Ok	Sav-A-Trip (W 2nd St./ Wilson Ave) - Bathroom Faucet	5.3	3.2	ng/L
Skiatook, Ok	Skiatook Park - (W Oak St./ S Osage Ave) - Bathroom Faucet	<2	<2	ng/L

The results above indicate that chloramine use can increase NDMA concentrations. This is similar to the results of the UCMR. Continued research should be conducted into the production of NDMA from chloraminated water authorities in northeastern Oklahoma.

Tulsa was selected for investigation because it is currently in the process of changing the barrier in the distribution system from free chlorine to chloramines. This change is expected to occur in July2012. The results of the NDMA formation are presented in Table 3.35.

Table 3.35 – NDMA Testing Results for Tulsa, OK

Public Water Supply	Location	Sampling Date: 11/2/2011	Sampling Date: 11/15/2011	Sampling Date: 11/30/2011	Units
Tulsa, OK	LaFortune Park (East 61st St. S/ S Yale Ave) - Outside Faucet	<2	<2	<2	ng/L

As stated in earlier in this paper, four (4) of the twelve (12) microorganisms listed on the CCL 3 are viruses (or virus groups). (EPA 2011[d]) In Europe, recent investigations were conducted on the prevalence of adenoviruses and noroviruses in surface waters, and it was found that thirty-nine (39%) percent of the samples taken from recreational surface waters were positive for one or both viruses (553 positive samples of 1410 samples gathered). Adenoviruses were found to be most prevalent and common in 513 positive samples when compared to 132 positive samples for noroviruses. (Wyn-Jones et al. 2011) In New Zealand, it was found that ninety-seven (97%) percent of the samples taken from two (2) drinking water sources were positive for enteric viruses. (Williamson et al. 2011) The fact that literature shows viruses have a very high pervasiveness in the environment is a concern. Additional research should be conducted into the concentrations of viruses found in waters in northeastern Oklahoma.

As shown in Table 3.1 of this report, the required CT for 2 log inactivation for viruses, as published by EPA, is 857 mg-min/L monochloramine (at 5 degrees C; pH = 8). (EPA 1999) Due to the increased regulation of chlorinated DBPs, many utilities have begun to switch to monochloramine for the barrier in the distribution system. A review was conducted on the ability of monochloramine to inactivate various viruses commonly found in the environment and found on the CCL 3. A review was also conducted to determine the ability of free chlorine to inactivate the same viruses. The results of the study are presented below.

Table 3.36 – Determined CT (mg-min/L) for 2 log Inactivation at 5 degrees C

	Monochloramine[2]		Free Chlorine[1]	
Virus	pH 7	pH 8	pH 7	pH 8
Adenoviruses 2	600	990	0.02	0.04
Adenoviruses 40	90	360	<0.02	<0.02
Adenoviruses 41	58	190	0.005	<0.02
Coxsackieviruses B3	270	240	0.97	0.65
Coxsackieviruses B5	510	670	3.6	4.7
Echoviruses 1	8	8	0.96	0.99
Echoviruses 11	1000	880	0.82	0.54
Murine norovirus	26	36	<0.02	<0.02

[1] 0.2 mg/L of free chlorine. [2] 1.0 mg/L of monochloramine.
(Cromeans et al. 2010)

An interesting part of this study is that it was conducted at the minimum residual dosage (monochloramine = 1 mg/L; free chlorine = 0.2 mg/L) that can be found in the distribution system. (ODEQ 2011[b]) (EPA 2011[e]) Therefore, the above data represents the potential ability of monochloramine to inactivate viruses if contamination were to occur in the distribution system. According to the above information, free chlorine is between 8 and 30,000 times more effective at inactivating viruses than monochloramine. It should also be noted that the published 2 log EPA inactivation values for viruses have little to no safety factor (Adenoviruses 2 = 990/ Echoviruses 11= 880/ Echoviruses 11= 1000 mg-min/L > 857 mg-min/L).

Currently, the EPA is revising the total coliform rule (RTCR) and lead/ copper rule (LTLCR). As previously stated, lead and copper release may be facilitated by switching from free chlorine to chloramines. Therefore, it may be more difficult for systems to comply with this future rule if chloramines are used as a barrier in the distribution system. It is also expected that the RTCR will place more emphasis on *E. coli* sampling and testing. As discussed in the previous sections, monochloramine is approximately eighty-four (84) times less effective as a disinfectant than free chlorine when inactivating bacteria. (WHO 2011) Other research indicates that chloramines contribute to an increase in the Heterotrophic Plate Count (HPC) by increasing the concentration of nitrifying bacteria found in the distribution system. (AWWA 2006)

Considering the prevalence and health effects associated with NDMA, it is expected that the contaminant (including other nitrosamines) will be regulated in the future. This is in agreement with the Director of Federal Agencies, Alan Roberson of AWWA. (AWWA 2011[a]) EPA is on record stating that “regulating nitrosamines could constrain chloramines use”. (EPA 2011[a]) Careful consideration must also be given to the impact of chloramines on compliance with the RTCR and LTLCR. Therefore, caution must be exercised if a water authority is considering chloramines.

If the 40/ 30 limit were instituted, chloramines may not allow the utility to comply with the lower regulations. This is because free chlorine is typically used as a primary disinfectant, thus allowing the formation of DBPs before the addition of ammonia to form chloramines. Also, chloramines will form DBPs at long detention times in the distribution system. (AWWA 2011[c])

Chloramines may assist in the formation of future regulated compounds. Monochloramine may not inactivate viruses if contamination were to occur in the distribution system. Therefore, caution must be exercised by a water authority when determining the viability of chloramines for compliance with Stage 2 D/ DBP Rule.

TOC or DOC Removal Technologies

. It is unlikely that enhanced coagulation will remove microcontaminants. The microcontaminants contained within the CCL 3 are hydrophilic and, at very low concentrations, would be difficult to remove with HMS. It is doubtful that enhanced coagulation will allow a water authority to comply with contaminants that are found on the CCL 3. (EPA 2011[a])

GAC and PAC can adsorb may organic and inorganic compounds found on CCL 3 and may not be cost effective to use due to the rapid breakthrough that has been observed with other microcontaminants. Research will need to be conducted into the removal efficiency of GAC and PAC for the targeted microcontaminants that may be found in northeastern Oklahoma.

As discussed previously, an anion exchanger will remove other anions like bromide and chromium VI (although truly not an anion, it exhibits the characteristics of an anion). Bromide is an inorganic found in bromoform, bromodichlormethane, dibromodichlormethane, monobromoacetic acid, and dibromoacetic acid. (EPA 2011[b]) (EPA 2011[c]) Bromide is not expected to be regulated by EPA; however, since bromide is a precursor for certain DBPs, its removal would be an additional benefit. Additional research should be conducted into anion exchange system's ability to remove bromide. Recently, attention has been drawn to chromium VI. The EPA MCL is 0.1 mg/L for total chromium, which includes chromium III and chromium VI combined. (EPA 2011[b]) It is expected that chromium VI will have its own MCL in the future. (AWWA 2011[a]) The MCL is expected to be regulated between 0.000005 mg/L (current California Public Health Goal) and 0.001 mg/L. (California Department of Public Health 2012) Chromium VI could be found at these leveld in surface waters in northeastern Oklahoma. Anion exchange systems could remove some chromium VI as well as DOC. Additional research should be conducted into anion exchange system's ability to remove chromium VI. Anion exchange systems could also remove DOC to levels lower than other technologies. This could be a major benefit for DBPs that may be regulated in the future. Moreover, the removal of DOC by anion exchange systems will allow GAC to remove microcontaminants more efficiently. Additional research will need to be conducted into adding anion exchange systems upstream of the GAC to improve the removal of the targeted compound or to increase the number of bed volumes of the GAC prior to exhaustion.

It is expected that anion exchange systems may remove negatively charged microcontaminants. Additional research will need to be conducted into the ability of anion exchange systems to remove microcontaminants.

Anion exchange resins have been a cause of concern for the potential formation of NDMA. This has been found to occur when free chlorine interacts with certain anion exchange resins. It may be prudent for the manufacturer to provide research information that may be associated with NDMA formation. Also, caution must be exercised when adding free chlorine upstream of an anion exchange reactor.

Anion exchange systems may assist the water authority when complying with the potential future 40/30 level for DBPs. This may be possible due the ability of the anion exchange systems to remove excessive amounts of DOC and bromide.

Enhanced coagulation, GAC, PAC, and anion exchange systems will not receive any inactivation or removal credits of the twelve (12) potentially regulated microorganisms that can be found on the CCL 3. However, they may assist in removal of microorganisms when used in combination with other processes. (EPA 1999) (EPA 2006[a]) (EPA 2011[b]) (AWWA 2011[c])

CHAPTER IV

CONCLUSIONS

The amount of TOC that is found in northeastern Oklahoma will require most water authorities to investigate compliance technologies for Stage 2 D/ DBP Rule. Due to capital and operational costs, chloramines will be the most likely selected compliance technology for water authorities in northeastern Oklahoma. The selection of a compliance technology should not be based exclusively on cost, but rather selection should incorporate all facets discussed in this paper. Selection of a compliance technology should be based on the best solution specific to each individual water authority. Decision trees were developed that can be used by ODEQ and water authorities in northeastern Oklahoma for preliminary determination of compliance technologies. When determining the compliance technology, the areas that are reviewed in this paper should be investigated.

Water authorities should strive to meet a LRAA that is consistently below the 40/ 30 limit (40 µg/L of TTHMs and 30 µg/L HAA5s). Water authorities should also be aware of the potential future regulations for drinking water, especially the DBPs that are more likely to be formed by chloramines.

Ozone offers the ability for some water authorities in northeastern Oklahoma to gain compliance with Stage 2 D/ DBP Rule. Ozone also allows a water authority the potential to comply with LT2ESWTR, as well as potential future regulated microcontaminants. Ozone is nine (9) times more effective for disinfection than chlorine dioxide. Ozone can also be used to facilitate the removal of DOC and taste/ odor organic compounds, iron and manganese. Ozone produces no waste products that need to be removed from the treated water, but DBPs will form when reacted with bromide. Therefore, ozone should not be used on waters that contain bromide. Ozone can be hazardous to workers, requiring additional OSHA and EPA compliance. Free chlorine, or chloramines, is still needed as a barrier in the distribution system; therefore, formation of TTHMs and HAA5 can still occur. Ozone can increase corrosion of carbon steel components at a treatment facility. Maintenance of an ozone system can require special service technicians and equipment. Ozone has a high capital cost ($1.25/ gallon) and medium to low operational cost ($0.07/ 1000 gallons). Ozone may not allow a water authority to comply with a 40/ 30 limit, as it may not facilitate enough DOC removal to allow for continued use of free chlorine in the distribution system.

The chlorine dioxide unit process produces limited amounts of TTHMs and HAA5. Free chlorine and chloramines will still be needed as a barrier in the distribution system, thus TTHMs and HAA5 can still be formed in the distribution system. The use of chlorine dioxide produces chlorite, which is a regulated DBP, and chlorate a likely future regulated DBP. Chlorine dioxide is a stronger disinfectant than free chlorine, thus allowing compliance with the 1986 SWTR. It is unlikely that sufficient HRT exists to allow chlorine dioxide to inactivate C*ryptosporidium* for compliance with LT2ESWTR. Chlorine dioxide can also be used to facilitate the removal of taste/ odor organic compounds, iron and manganese. Research that has been completed, suggests that chlorine dioxide is more effective than free chlorine at removing microcontaminants. Historically, chlorine dioxide equipment has been maintenance intensive and unreliable. Chlorine dioxide has a medium capital cost ($0.54/ gallon) and a low operational cost ($0.03/ 1000 gallons). Chlorine dioxide may not allow a water authority to comply with a 40/ 30 limit as it may not facilitate enough DOC removal to allow for continued use of free chlorine in the distribution system.

UV disinfection unit processes easily inactivates *Giardia lambia* and C*ryptosporidium* while not producing TTHMs and HAA5. UV technology can be used to aid an authority for compliance with LT2ESWTR and 1986 SWTR without a possible detrimental impact to Stage 2 DBP. It is typically not feasible to utilize UV disinfection for the inactivation of viruses, thus chemical disinfection (ozone, chlorine dioxide and free chlorine) must still be used, which can form DBPs. Also free chlorine or chloramines must be used as a barrier in the distribution system, which can still form TTHMs or HAA5. Maintenance of a UV reactor can require special service technicians and equipment.   UV disinfection has a low capital cost ($0.43/ gallon) and a low operational cost ($0.04/ 1000 gallons). UV disinfection may not allow a water authority to comply with a 40/ 30 limit as it will not facilitate DOC removal to allow for continued use of free chlorine in the distribution system.

Chloramines can only be used as a barrier in the distribution system; however, DBPs can still be formed during disinfection. Chloramine injection equipment is relatively easy to operate and maintain. Monochloramine is much less effective as a disinfectant than free chlorine. Operation of a distribution system that uses chloramines can be difficult. Poor operation can result in taste, and odor issues and HPC violations. The use of chloramines requires the storage and handling of hazardous chemicals. Compliance with potential future regulated DBPs may be difficult with the use of chloramines. It is doubtful that chloramines will assist in compliance with microcontaminants. Use of chloramines has a low capital cost ($0.30/ gallon) and a low operational cost ($0.03/ 1000 gallons).

Enhanced coagulation can be used to remove DOC, which is a precursor for the formation of TTHMs and HAA5. Removing the precursor more effectively allows the free chlorine to be used as a disinfectant and a barrier in the distribution system. HPSEC is a useful tool at determining the DOC characteristics of the source waters in northeastern Oklahoma. By characterizing the DOC, the user can make an assessment of the potential DBPs yield. DOC characterization can be used to determine the effectiveness of coagulants to remove aromatic compounds. It is doubtful that enhanced coagulation will assist in the removal of microcontaminants. Enhanced coagulation can increase the corrosion of a water treatment facility. Enhanced coagulation generates large amounts of solids. Enhanced coagulation can require the storage and handling of some hazardous chemicals. Enhanced coagulation has a medium capital cost ($0.78/ gallon) and a medium operational cost ($0.21/ 1000 gallons).

GAC can be used to remove DOC for compliance with TTHMs and HAA5. GAC can be used to remove some microcontaminants and taste/ odor compounds. GAC is not considered a hazardous chemical, but storage can create a fire hazard. GAC has a medium capital cost ($0.92/ gallon) and a medium operational cost ($0.20/ 1000 gallons). GAC may allow a water authority to comply with a 40/ 30 limit, but may significantly increase the operational costs in doing so.

PAC can be used to remove DOC for compliance with TTHMs and HAA5. PAC can be used to remove some microcontaminants and taste/ odor compounds. PAC is not considered a hazardous chemical, but storage and use can create a fire hazard. PAC can be adapted to an existing facility. PAC has a low capital cost ($0.22/ gallon) and a high operational cost ($0.40/ 1000 gallons). PAC may allow a water authority to comply with a 40/ 30, but may significantly increase the operational costs in doing so.

Anion exchange technologies exist that can selectively remove hydrophilic (dissolved) negatively charged NOM and bromide. Anion exchange offers the ability to remove compounds that are the largest contributors to DBPs. Anion exchange technologies allow the use of free chlorine, thus decreasing the potential for formation of future regulated DBPs. Fixed bed anion exchangers have a high capital cost ($1.22/ gallon) and a medium operational cost ($0.08/ 1000 gallons). Fluidized bed anion exchangers have a high capital cost ($1.65/ gallon) and a medium operational cost ($0.15/ 1000 gallons). Anion exchange system may allow a water authority to comply with a 40/ 30 limit, due to the system's ability to facilitate excessive DOC removal.

CHAPTER V

FUTURE RESEARCH

Further investigations should be conducted to determine the viability of DAF for clarification of surface waters in northeastern Oklahoma. It is recommended that continued research be conducted in the area of HPSEC and DOC reduction. Research should be conducted on the direct removal of taste and odor compounds from an anion exchange reactor. Investigations using biologically active filters should be conducted in the removal of ozone produced by products such as acetaldehyde, acrolein and formaldehyde. Research should be conducted into the production of NDMA from chloraminated water authorities in northeastern Oklahoma. Investigations should be conducted to determine if a correlation exists between HPSEC absorbance curves and algae counts. Additional research should be conducted into the concentrations of viruses found in waters in northeastern Oklahoma. Additional research should also be conducted into the ability of an anion exchange system to remove bromide and chromium VI. Research should be conducted to determine the effectiveness of the use of paper decision trees for water authorities in northeastern Oklahoma.

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APPENDIX 1

DRINKING WATER WATCH WEBSITE INFORMATION AND STATISTICAL ANALYSIS

Name: Tulsa OK1020418
Population Served: 504613
Source (s): Oologah Lake
Spavinaw Lake Chlorine Dioxide Mohawk - No
AB Jewell - Yes

	Mohawk			AB Jewell			6500 W Charles Page DBP MAX		13100 S Elwood DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	RAW TOC (	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	1.90	1.10	98	4.00	2.30	110	**74.90**	11.50	**97.90**	34.20
Aug-06	2.10	1.50	87	4.20	2.60	110				
Sep-06	2.30	1.10	82	4.00	2.40	110				
Oct-06	3.10	1.30	101	4.00	2.50	110				
Nov-06	2.80	1.50	120	3.80	2.40	130	46.70	9.00	53.10	15.10
Dec-06	3.10	2.10	110	3.90	2.40	120				
Jan-07	3.00	2.00	110	3.80	2.40	110	36.30	6.80	37.60	17.90
Feb-07	2.70	1.60	110	3.80	2.20	110				
Mar-07	2.20	1.50	108	3.60	2.30	110				
Apr-07	1.80	1.30	92	3.60	2.40	94				
May-07	1.90	1.30	100	4.00	2.40	110	55.10	11.60	65.20	**35.30**
Jun-07	1.50	1.20	92	4.70	2.40	100				
Jul-07	1.80	1.30	85	4.40	2.70	95				
Aug-07	2.10	1.40	75	4.10	2.30	83	**78.10**	13.90	76.20	**42.90**
Sep-07	2.30	1.50	83	3.90	2.20	89				
Oct-07							41.00	9.10	76.80	37.30
Nov-07	2.50	1.50	98	3.40	1.70	120				
Dec-07	2.10	1.30	100	3.70	2.00	110				
Jan-08	2.80	1.20	100	3.50	2.20	120				
Feb-08	2.40	1.50	100	3.80	2.20	100	24.70	8.20	42.10	19.50
Mar-08	2.20	1.50	89	3.90	2.20	120				
Apr-08	2.60	1.60	120	4.20	2.70	130	41.70	11.90	54.90	27.60
May-08	3.30	1.70	78	4.20	2.50	120				
Jun-08	2.60	1.50	80	4.40	2.50	110	**77.50**	**16.90**	**103.90**	**42.60**
Jul-08	2.30	1.50	78	4.40	2.10	93				
Aug-08	2.60	1.50	90	4.30	2.50	99	67.10	**19.70**	**110.40**	**57.20**
Sep-08	2.60	1.40	82	4.00	2.30	110				
Oct-08	2.30	1.30	84	4.00	2.20	100				
Nov-08	2.50	0.98	85	4.40	2.30	110	39.40	11.50	69.30	28.60
Dec-08	2.40	0.86	98	4.60	2.30					
Jan-09	2.30	1.00	110	4.70	2.50	120				
Feb-09	2.50	1.20	110	4.80	2.70	110	21.20	7.20	54.50	25.90
Mar-09	2.70	1.50	120	4.70	2.80	130				
Apr-09	2.20	1.40	120	4.50	2.70	150				
May-09	2.30	1.20	110	4.40	2.80	130	33.90	5.70	42.90	17.50
Jun-09	2.10	1.30	99	4.50	2.80	120				
Jul-09	2.00	1.10	98	4.40	2.50	110				
Aug-09	2.30	1.20	83	4.10	2.80	120	53.60	**33.00**	58.00	22.90
Sep-09	2.50	1.30	81	4.20	2.60	110				
Oct-09	2.30	1.30	93	4.00	2.00	110				
Nov-09	2.40	1.40	91	3.80	1.70	110	49.10	11.30	69.40	18.70
Dec-09	2.40	1.40	100	3.90	2.10	99				
Jan-10	2.80	1.50	100	4.70	2.90	120				
Feb-10	2.10	1.40	100	4.30	2.80	120	24.40	9.20	38.20	23.00

Tulsa, OK

Mar-10	1.70	1.10	94	5.40	2.90	120				
Apr-10	1.50	1.00	100	4.20	2.60	150				
May-10	1.60	0.91	113	5.30	2.70	156	28.40	4.50	71.00	28.00
Jun-10	1.70	1.00	88	4.00		140				
Jul-10	2.20	1.40	83	4.10	2.40	120				
Aug-10	2.40	1.80	74	4.10	3.00	140	65.60	13.50	61.90	16.60
Sep-10	2.40	1.30	74	3.80	2.10	110				
Oct-10	2.50	1.40	77	4.20	2.10	100				
Nov-10	2.30	1.30	78	4.00	2.30	92	35.20	8.90	51.50	25.30
Dec-10	2.60	1.50	89	4.10	2.40	120				
Jan-11	2.80	1.50	94	4.20	2.30	120				
Feb-11	2.70	1.60	100	4.20	2.50	130	18.40	4.40	37.30	14.40
Mar-11	2.50	1.60	130	4.20	2.30	130				
Apr-11	2.10	1.40	110	3.70	2.20	120				
May-11	2.30	1.50	100	3.90	2.40	120				
Jun-11	2.90	1.90	83	4.30	3.40	120	**76.60**	**14.60**	**91.50**	24.70
Mean	2.36	1.39	96	4.16	2.43	116	47.10	11.55	64.94	27.40
SD	0.40	0.25	14	0.39	0.31	15	19.75	6.28	21.85	10.92
Min	1.50	0.86	74	3.40	1.70	83	18.40	4.40	37.30	14.40
Max	3.30	2.10	130	5.40	3.40	156	78.10	33.00	110.40	57.20
Four (4) Highest Quarters							76.78	21.05	100.93	44.50

Bartlesville, OK

Name: Bartlesville
Population Served: 43371 OK1021401
Source (s): Hulah Lake/ Caney River
Chlorine Dioxide No

	Bartlesville WTP			Fire Station #3 DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	5.69	3.23	113		
Aug-06	5.70	3.37	123		
Sep-06	5.75	4.25	130	**113.00**	**74.92**
Oct-06	5.63	4.28	135		
Nov-06	5.55	4.15	134		
Dec-06	5.42	3.96	132	**116.50**	27.63
Jan-07	5.54	4.13	137		
Feb-07	5.63	4.05	132		
Mar-07	5.83	4.12	127	**79.20**	**46.92**
Apr-07	8.01	5.12	5		
May-07	8.36	5.19	62		
Jun-07	7.39	3.73	35	**115.30**	**110.10**
Jul-07	8.71	3.35	39		
Aug-07	7.69	4.09	38		
Sep-07	6.61	3.43	58	44.60	**35.80**
Oct-07	6.07	3.10	73		
Nov-07	5.55	3.49	84		
Dec-07	4.83	2.67	88	26.93	13.35
Jan-08	4.96	2.78	96		
Feb-08	4.95	2.86	99		
Mar-08	5.62	3.12	87	32.43	16.06
Apr-08	7.25	3.18	67		
May-08	7.40	3.38	55		
Jun-08	7.17	2.61	37	32.30	25.77
Jul-08	6.37	2.73	40		
Aug-08	6.36	2.99	45		
Sep-08	6.36	2.86	59	36.69	17.96
Oct-08	6.29	2.87	57	29.66	18.28
Nov-08	6.15	2.77	49		
Dec-08	6.01	2.87	48		
Jan-09	5.90	2.62	44	25.20	12.50
Feb-09	6.90	3.08	45		
Mar-09	6.57	3.10	48		
Apr-09	7.76	3.02	39	30.40	20.90
May-09	7.70	2.53	35		
Jun-09	7.47	2.97	35		
Jul-09	6.35	2.78	46	42.70	28.40
Aug-09	5.87	2.65	65		
Sep-09	4.86	2.39	82		
Oct-09	5.26	2.47	80	28.40	11.30
Nov-09	4.85	2.89	77		
Dec-09	5.34	2.53	84		
Jan-10	4.82	2.42	98	19.10	8.50

Feb-10	4.84	2.23	90		
Mar-10	4.83	2.30	80		
Apr-10	5.33	2.83	71	25.00	11.30
May-10	6.24	2.84	71		
Jun-10	5.86	2.67	66		
Jul-10	7.05	2.27	36	28.20	19.30
Aug-10	7.09	2.83	42		
Sep-10	5.51	2.37	60		
Oct-10	4.99	2.33	68	29.40	12.90
Nov-10	4.74	2.39	80		
Dec-10	4.88	2.34	91		
Jan-11	4.55	2.40	98	27.80	11.70
Feb-11	4.22	2.36	110		
Mar-11	4.60	2.24	100		
Apr-11	5.06	2.32	86	33.00	12.10
May-11	5.96	2.53	76		
Jun-11	5.97	2.83	79		
Mean	6.01	3.04	75	45.80	26.79
SD	1.05	0.70	32	32.21	25.07
Min	4.22	2.23	5	19.10	8.50
Max	8.71	5.19	137	116.50	110.10
Four (4) Highest Quarters				106.00	66.94

Sapulpa, OK

Name: Sapulpa OK1020404
Population Served: 35352
Source (s): Sahoma Lake/ Skiatook Lake
Chlorine Dioxide No

				Bishops Auto Sales DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	3.78	2.68	71	**123.40**	22.00
Aug-06	3.82	2.63	75		
Sep-06	3.79	2.52	82		
Oct-06	4.01	2.65	81	73.70	34.00
Nov-06	3.99	2.94	80		
Dec-06	3.82	2.57	77		
Jan-07	4.05	2.92	82		
Feb-07	4.07	2.78	73		
Mar-07	7.04	4.78	65	83.70	
Apr-07	3.85	2.49	78		23.00
May-07	4.26	3.01	73		
Jun-07	4.69	3.31	68	99.40	
Jul-07	5.80	3.05	71		
Aug-07	5.73	3.66	68		35.00
Sep-07	7.27	4.62	65	**184.40**	41.00
Oct-07	5.02	2.95	65		
Nov-07	4.85	3.41	70	99.50	**55.00**
Dec-07	5.44	3.69	74		
Jan-08	5.11	3.87	69		
Feb-08	4.93	3.89	70	60.30	33.00
Mar-08	5.30	3.82	66		
Apr-08	5.37	3.12	68		
May-08	5.38	2.97	63	**107.00**	**44.00**
Jun-08	5.29	3.69	62		
Jul-08	4.76	3.81	59		
Aug-08	5.04	3.65	62	**137.70**	**70.00**
Sep-08	3.55	3.18	60		
Oct-08	4.63	3.01	64		
Nov-08				69.70	34.00
Dec-08	4.33	2.60	62		
Jan-09	4.32	2.61	62		
Feb-09	4.47	2.75	60	48.50	30.00
Mar-09	4.13	2.57	57		
Apr-09	4.21	2.74	61		
May-09	4.23	2.77	61	85.90	26.00
Jun-09	4.44	2.69	60		
Jul-09	4.57	2.68	65		
Aug-09	4.57	3.02	64		
Sep-09	4.32	3.01	64	**105.20**	30.00
Oct-09	4.97	3.49	66		
Nov-09	5.59	3.35	58		
Dec-09	5.39	3.55	56	87.70	**52.00**
Jan-10	5.70	3.81	62		

Feb-10	5.41	3.50	65	71.30	34.00
Mar-10	4.41	3.17	65		
Apr-10	4.33	2.59	60		
May-10	4.42	2.75	64		
Jun-10	4.25	2.48	61	78.70	28.00
Jul-10	4.53	2.65	65		
Aug-10	4.80	2.95	67		
Sep-10	4.27	2.59	67	93.90	33.00
Oct-10	4.12	2.64	66		
Nov-10	4.34	2.76	74		
Dec-10	3.94	2.26	68	59.50	13.00
Jan-11	4.27	2.66	72	58.90	30.00
Feb-11	4.04	2.28	73		
Mar-11	6.48	3.81	82		
Apr-11	3.79	2.10	76		
May-11	3.68	2.25	76	60.10	22.00
Jun-11	3.81	2.42	78		
Mean	4.66	3.04	68	89.43	34.45
SD	0.80	0.57	7	32.14	13.00
Min	3.55	2.10	56	48.50	13.00
Max	7.27	4.78	82	184.40	70.00
Four (4) Highest Quarters				138.13	55.25

Tahlequah, OK

Name:	Tahlequah	OK1021701			
Population Served:	18431				
Source (s):	Illinois River				
		Chlorine Dioxide	No		
	Tahlequah WTP			Welling Store DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	1.32	1.09	104		
Aug-06	1.31	101.00	104		
Sep-06	1.96	1.15	105	**60.92**	29.88
Oct-06	1.40	1.17	113		
Nov-06	1.71	1.39	110		
Dec-06	1.37	1.24	96	58.80	**51.17**
Jan-07	1.54	1.20	96		
Feb-07	1.33	1.07	91		
Mar-07	1.88	1.43	93	39.55	32.27
Apr-07	1.73	1.48	101		
May-07	1.65	1.53	98		
Jun-07	2.00	1.93	89	**107.26**	38.56
Jul-07	1.80	1.44	108		
Aug-07	1.37	1.22	105		
Sep-07	1.65	1.47	107	**71.53**	**40.50**
Oct-07	1.48	1.20	112		
Nov-07	1.41	1.13	116		
Dec-07	1.28	1.08	125	34.82	27.90
Jan-08	1.51	1.26	97		
Feb-08	3.58	2.26	65		
Mar-08	1.58	1.23	91	47.50	**48.09**
Apr-08	1.85	1.45	78		
May-08	1.51	1.03	85		
Jun-08	2.56	1.89	64	64.41	36.44
Jul-08	2.18	1.45	82		
Aug-08	1.69	1.39	90		
Sep-08	1.82	1.44	103	**80.42**	**69.55**
Oct-08	1.32	1.04	98		
Nov-08	1.29	1.06	109		
Dec-08	1.29	0.89	106	21.93	12.00
Jan-09	1.04	0.84	104		
Feb-09	1.90	1.44	90		
Mar-09	1.36	1.02	98	32.60	21.20
Apr-09	2.36	1.88	81		
May-09	1.92	1.52	0		
Jun-09	1.60	1.21	96	51.80	25.00
Jul-09	1.15	0.86	103		
Aug-09	1.20	0.98	107		
Sep-09	1.15	0.94	108	45.30	21.40
Oct-09	1.11	0.85	109		
Nov-09	1.75	1.47	82		
Dec-09	1.06	0.84	97	21.00	12.60
Jan-10	1.09	0.95	108		

Feb-10	1.42	1.17	102		
Mar-10	1.09	0.92	115	34.10	20.70
Apr-10	1.23	0.91	92		
May-10	2.56	1.86	80		
Jun-10	1.30	0.96	98	38.00	15.70
Jul-10	1.09	0.84	101		
Aug-10	1.10	0.91	104		
Sep-10	1.24	0.89	106	51.90	26.30
Oct-10	0.84	0.68	111		
Nov-10	0.80	0.67	109		
Dec-10	0.99	0.80	96	20.40	14.90
Jan-11	1.07	0.89	102		
Feb-11	0.97	0.79	93		
Mar-11	1.78	1.29	107	39.60	30.70
Apr-11	1.64	1.30	105		
May-11	1.26	1.02	96		
Jun-11	1.10	0.82	88	37.20	19.30
Mean	1.51	2.86	98	47.96	29.71
SD	0.48	12.89	18	21.57	14.56
Min	0.80	0.67	0	20.40	12.00
Max	3.58	101.00	125	107.26	69.55
Four (4) Highest Quarters				80.03	52.33

Claremore, OK

Name: Claremore OK1021512
Population Served: 20043
Source (s): Claremore Lake
Chlorine Dioxide Yes

				2119 Holly DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	6.03	3.33	90		
Aug-06	7.29	3.87	95	111.00	42.00
Sep-06	6.75	3.72	93		
Oct-06	7.44	3.78	92		
Nov-06	7.97	4.39	90		
Dec-06	6.19	3.52	86	62.80	
Jan-07	7.52	3.80	67		**88.00**
Feb-07	7.53	3.97	56		
Mar-07	6.26	3.04	56	61.60	78.00
Apr-07	6.40	3.38	62		
May-07	10.60	5.71	50	**142.10**	**135.00**
Jun-07	8.63	3.53	42		
Jul-07	10.00	4.10	61		
Aug-07	8.88	4.05	69	**148.70**	59.00
Sep-07	7.91	3.92	70		
Oct-07	7.76	3.86	64		
Nov-07	6.60	3.36	60		
Dec-07	6.87	3.54	56	68.10	46.00
Jan-08	7.42	3.53	56		
Feb-08	7.11	3.45	53		
Mar-08	7.19	2.84	46	73.10	57.00
Apr-08	6.06	2.49	37		
May-08	7.32	3.01	44	88.40	56.00
Jun-08	8.56	2.91	28		
Jul-08	6.23	2.85	44		
Aug-08	7.71	3.44	48	**122.20**	64.00
Sep-08	7.49	3.59	49		
Oct-08	6.18	3.08	52		
Nov-08	6.03	3.42	53	77.30	54.00
Dec-08	5.94	3.14	54		
Jan-09	5.68	2.85	57		
Feb-09	6.18	2.94	50	47.20	**81.00**
Mar-09	6.36	3.32	48		
Apr-09	6.14	3.05	49		
May-09	8.54	2.92	35	97.40	**93.00**
Jun-09	6.50	3.21	56		
Jul-09	6.31	3.18	62		
Aug-09	6.62	3.58	70		
Sep-09	6.50	3.50	71	96.70	23.00
Oct-09	5.61	2.92	60		
Nov-09	5.93	3.10	51		
Dec-09	5.30	2.58	52	61.60	39.00
Jan-10	4.84	3.12	50		

Feb-10	5.25	2.53	47	61.00	55.00
Mar-10	5.12	2.61	47		
Apr-10	5.64	2.62	42		
May-10	5.00	2.50	56	106.60	24.00
Jun-10	6.61	2.94	47		
Jul-10	6.60	2.81	58		
Aug-10	6.84	3.76	59	**128.80**	35.00
Sep-10	6.89	3.59	66		
Oct-10	7.04	3.59	64		
Nov-10	5.90	3.55	63	92.10	37.00
Dec-10	6.40	3.56	61		
Jan-11	6.86	3.69	64		
Feb-11	5.75	3.39	62		
Mar-11	5.48	3.10	58	67.10	41.70
Apr-11	5.12	3.03	60		
May-11	6.40	3.04	41		
Jun-11	7.56	3.98	42	87.30	54.70
Mean	6.75	3.36	58	90.06	58.12
SD	1.16	0.55	15	29.03	26.60
Min	4.84	2.49	28	47.20	23.00
Max	10.60	5.71	95	148.70	135.00
Four (4) Highest Quarters				135.45	99.25

Okmulgee, OK

Name:	Okmulgee	OK1020708			
Population Served:	20673				
Source (s):	Okmulgee Lake				
		Chlorine Dioxide	No		
				New Water Tower DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	4.75	2.70	32		
Aug-06	4.55	2.56	32	113.90	33.00
Sep-06	4.76	2.90	33		
Oct-06	4.61	3.28	36		
Nov-06	4.46	3.03	35	113.90	14.00
Dec-06	4.49	3.18	33		
Jan-07	5.20	3.34	30		
Feb-07	6.29	3.53	28	75.00	40.00
Mar-07	4.86	3.08	26		
Apr-07	5.89	2.79	27		
May-07	10.20	2.97	23		
Jun-07	6.75	3.16	26	**170.00**	**59.00**
Jul-07	7.44	3.09	25		
Aug-07	7.56	3.46	29	**191.50**	**82.00**
Sep-07	6.09	2.74	28		
Oct-07	6.48	3.26	29		
Nov-07	6.09	3.10	31		
Dec-07	5.28	2.65	30	64.29	42.84
Jan-08	5.96	3.11	31		
Feb-08	5.44	2.73	29	82.57	45.51
Mar-08	5.46	2.70	30		
Apr-08	5.88	2.43	28	105.19	63.37
May-08	6.05	2.45	24		
Jun-08	5.77	2.37	24		
Jul-08	6.53	2.74	25		
Aug-08	5.93	2.74	32	**125.00**	34.10
Sep-08	5.62	2.78	31		
Oct-08					
Nov-08	5.46	2.60	31	88.70	51.84
Dec-08					
Jan-09	4.84	2.55	30		
Feb-09	5.31	2.58	31	53.00	46.50
Mar-09	5.04	2.52	30		
Apr-09	5.40	3.10	33		
May-09	5.65	2.72	30	99.7	51
Jun-09	6.50	3.09	33		
Jul-09	6.24	3.25	33		
Aug-09	5.72	3.15	37	90.80	54.20
Sep-09	6.44	3.49	36		
Oct-09	6.41	3.04	33		
Nov-09	6.06	2.96	29	71.00	45.10
Dec-09	5.20	2.61	30		
Jan-10	5.64	2.60	28		

Feb-10	4.67	2.77	26	88.70	48.70
Mar-10	4.96	2.78	28		
Apr-10	5.15	2.60	30		
May-10	4.80	2.21	27	**144.00**	**51.90**
Jun-10	5.14	2.68	27		
Jul-10	4.89	2.68	28		
Aug-10	4.72	2.52	30	117.00	30.30
Sep-10	4.49	2.45	30		
Oct-10	4.38	2.59	32		
Nov-10	3.76	1.93	34	70.10	34.90
Dec-10	4.48	2.55	34		
Jan-11	4.39	2.50	32		
Feb-11	4.66	2.38	32	34.20	27.70
Mar-11	7.19	2.68	32		
Apr-11	4.34	2.50	31		
May-11	5.78	2.36	28	66.70	**56.60**
Jun-11	5.80	2.93	29		
Mean	5.55	2.80	31	98.27	45.63
SD	1.04	0.34	4	38.67	14.75
Min	3.76	1.93	23	34.20	14.00
Max	10.20	3.53	37	191.50	82.00
Four (4) Highest Quarters				157.63	62.38

Chectah, OK

Name: Checotah OK1020515
Population Served: 8250
Source (s): Lake Eufaula
Chlorine Dioxide Yes
503 NW Second
DBP MAX

	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	5.23	4.51	136		
Aug-06	5.59	4.85	130	264.90	102.00
Sep-06	6.26	5.34	136		
Oct-06	5.96	4.58	138		
Nov-06	5.69	4.40	132	216.80	99.00
Dec-06	4.97	4.17	128		
Jan-07	5.90	4.73	122		
Feb-07	6.66	4.69	108	121.40	55.00
Mar-07	5.81	4.81	98		
Apr-07	5.77	4.48	84	286.40	157.00
May-07	10.20	8.02	80		
Jun-07	10.10	7.22	84		
Jul-07	9.95	6.69	66		
Aug-07	7.96	5.80	94	**446.60**	87.00
Sep-07	6.54	4.90	94		
Oct-07	5.83	4.46	88		
Nov-07	5.86	4.76	90	200.50	**241.00**
Dec-07	6.06	4.70	100		
Jan-08	5.83	4.58	118		
Feb-08	6.02	4.69	110	170.20	167.00
Mar-08	5.80	4.33	98		
Apr-08	7.07	4.86	64		
May-08	7.54	4.78	54	**318.10**	**439.00**
Jun-08	6.90	4.79	84		
Jul-08	6.18	4.27	98		
Aug-08	6.92	5.76	90	**423.30**	**181.00**
Sep-08	5.97	4.75	94		
Oct-08	5.45	4.55	100		
Nov-08	5.57	4.47	106	**312.50**	**231.57**
Dec-08	5.39	4.27	104		
Jan-09	4.77	4.17	62		
Feb-09	5.32	4.25	102	100.00	58.00
Mar-09	5.36	4.01	116		
Apr-09	4.42	3.59	116		
May-09	5.66	2.89	114	147.80	56.00
Jun-09	7.62	3.90	80		
Jul-09	6.89	3.94	96		
Aug-09	6.71	3.98	98	155.40	21.00
Sep-09	6.98	4.18	98		
Oct-09	6.23	4.04	108		
Nov-09	5.91	3.05	60	72.80	16.00
Dec-09	6.02	2.23	56		
Jan-10					

Feb-10	6.18	3.10	80	92.90	37.00
Mar-10	6.89	3.94	80		
Apr-10	5.94	3.49	80	113.60	50.00
May-10	6.00	2.20	92		
Jun-10	5.20	1.36	90		
Jul-10	6.57	2.19	68		
Aug-10	4.05	2.87	54	161.80	35.00
Sep-10	4.85	2.83	106		
Oct-10	4.44	1.21	106		
Nov-10	3.06	0.74	100	50.30	13.00
Dec-10	4.65	0.76	106		
Jan-11	3.66	0.79	92		
Feb-11	4.30	1.19	124	25.90	13.00
Mar-11	3.01	0.74	102		
Apr-11	3.27	2.22	100		
May-11	5.42	1.96	90	50.20	47.00
Jun-11	5.49	2.44	56		
Mean	5.93	3.86	96	186.57	105.28
SD	1.43	1.56	22	121.22	106.06
Min	3.01	0.74	54	25.90	13.00
Max	10.20	8.02	138	446.60	439.00
Four (4) Highest Quarters				375.13	273.14

Jay, OK

Name:	Jay	OK1021674			
Population Served:	2980				
Source (s):	Eucha Lake				
		Chlorine Dioxide	No		
				OHT Gary Earp DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	2.62	1.34	85		
Aug-06	2.70	1.66	76		
Sep-06	2.42	1.52	89	82.80	55.00
Oct-06	2.34	1.44	99		
Nov-06	2.07	1.90	111		
Dec-06	1.18	1.16	111	42.10	36.00
Jan-07	1.71	1.28	87		
Feb-07	1.87	1.32	96		
Mar-07	1.73	1.30	112	36.70	
Apr-07	2.66	1.50	80	65.90	
May-07	1.50	1.39	89		
Jun-07	2.00	1.45	75		**99.00**
Jul-07	2.52	2.19	66		**86.00**
Aug-07				**92.10**	
Sep-07	1.84	1.33	95		
Oct-07	1.81	1.33	96		
Nov-07	1.59	1.17	111		
Dec-07	1.83	1.09	107	53.10	29.00
Jan-08	1.60	1.09	71		
Feb-08	1.45	1.06	75	47.90	22.00
Mar-08	3.41	1.97	70		
Apr-08	1.64	0.90	55		
May-08	2.13	1.37	62	54.20	35.00
Jun-08	1.84	1.09	65		
Jul-08	1.62	1.10	88		
Aug-08	2.03	1.12	77	59.00	42.00
Sep-08	2.21	1.60	88		
Oct-08	1.87	1.21	96		
Nov-08	1.92	1.29	100	**93.20**	11.28
Dec-08	1.80	1.30	99		
Jan-09					
Feb-09	1.30	0.85	0	17.10	9.00
Mar-09	2.04	1.03	98		
Apr-09			108		
May-09	1.92	1.08	87	55.20	30.00
Jun-09	1.91	1.08	73		
Jul-09	1.83	1.11	52		
Aug-09	2.10	1.38	78	32.20	21.00
Sep-09	2.17	1.45	69		
Oct-09	2.45	1.80	75		
Nov-09				70.70	45.00
Dec-09	1.53	1.19	86		
Jan-10	1.12	1.11	80		

Feb-10	1.56	>1		84	21.10	12.00
Mar-10	1.69	>1		87		
Apr-10	2.39		1.86	86		
May-10	2.02		1.57	83		
Jun-10	2.14		1.03	62		
Jul-10	2.15		1.64	63		
Aug-10	2.53		1.87	54	**93.70**	**81.00**
Sep-10	2.06		1.82	70		
Oct-10	1.98		1.92	78		
Nov-10	1.86		1.41	89	53.50	**76.00**
Dec-10	2.43		1.50	105		
Jan-11	1.78		1.20	95		
Feb-11	1.72		1.02	93	12.90	8.00
Mar-11	1.49	>1		100		
Apr-11	1.65			96		
May-11	2.24		1.51	68	**86.30**	72.00
Jun-11	2.52		1.89	58		
Mean	1.98		1.39	83	56.30	42.74
SD	0.42		0.32	20	25.69	28.97
Min	1.12		0.85	0	12.90	8.00
Max	3.41		2.19	112	93.70	99.00
Four (4) Highest Quarters					91.33	85.50

Collinsville, OK

Name:	Collinsville	OK1021505			
Population Served:	4680				
Source (s):	Oologah Lake				
		Chlorine Dioxide	No		
				Wastewater Facility	
				DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	4.50	2.62	90	**97.10**	58.30
Aug-06	4.47	3.02	94		
Sep-06	4.38	2.88	98		
Oct-06	4.85	3.12	106	63.29	50.67
Nov-06	6.25	2.99	110		
Dec-06	4.07	3.02	114		
Jan-07	4.55	3.13	118	55.20	64.71
Feb-07	4.76	2.90	116		
Mar-07	4.43	2.98	118		
Apr-07	4.47	3.12	118	65.80	36.11
May-07	4.19	3.00	122		
Jun-07	4.85	2.81	116		
Jul-07	4.91	2.60	100	**105.02**	**90.82**
Aug-07	4.72	2.85	9		
Sep-07	4.33	3.16	100		
Oct-07	4.03	2.94	98	**112.45**	**102.40**
Nov-07	4.64	2.89	102		
Dec-07	4.80	2.73	108		
Jan-08	5.18	2.83	110	52.21	47.87
Feb-08	4.36	2.60	112		
Mar-08	4.61	2.86	112		
Apr-08	4.95	3.27	112	63.80	59.70
May-08	4.83	3.16	114		
Jun-08	5.49	3.43	114		
Jul-08	4.99	2.99	100	63.58	56.47
Aug-08	4.27	2.70	88		
Sep-08	4.24	3.01	98		
Oct-08	5.32	2.79	110	60.58	54.25
Nov-08	4.49	3.15	118		
Dec-08	4.69	3.07	110		
Jan-09	3.91	2.96	122	44.10	42.50
Feb-09	4.16	2.86	124		
Mar-09	4.00	2.83	128		
Apr-09	3.98	2.79	126	52.80	49.00
May-09	4.09	2.67	122		
Jun-09	4.63	3.07	124		
Jul-09	4.26	2.84	118	**87.00**	**77.80**
Aug-09	4.43	3.49	116		
Sep-09	3.81	2.52	118		
Oct-09	3.74	2.60	114	68.20	**66.30**
Nov-09	3.78	2.74	116		
Dec-09	3.96	2.43	116		
Jan-10	4.06	2.70	114	39.40	38.80

Feb-10	3.97	2.96	114		
Mar-10	3.63	2.74	120		
Apr-10	3.87	3.07	122	60.80	63.30
May-10	4.33	3.03	132		
Jun-10	3.60	2.94	130		
Jul-10	3.98	2.88	116	78.50	60.00
Aug-10	3.72	2.84	100		
Sep-10	3.62	2.42	104		
Oct-10	3.62	2.34	110	50.10	39.40
Nov-10	3.80	2.29	110		
Dec-10	3.64	2.43	126		
Jan-11	3.76	2.36	114	30.10	27.70
Feb-11	3.41	2.71	124		
Mar-11	3.15	2.38	122		
Apr-11	2.99	2.35	126	43.10	32.70
May-11	3.41	2.30	122		
Jun-11	3.57	2.44	122		
Mean	4.26	2.83	112	64.66	55.94
SD	0.60	0.28	17	21.80	18.85
Min	2.99	2.29	9	30.10	27.70
Max	6.25	3.49	132	112.45	102.40
Four (4) Highest Quarters				100.39	84.33

Nowata, OK

Name:	Nowata	OK1021503			
Population Served:	5566				
Source (s):	Oologah Lake				
		Chlorine Dioxide	No		

				Nursing Home DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	5.00	2.99	120		
Aug-06	5.41	3.58	128		
Sep-06	4.83	3.11	128	**89.40**	36.16
Oct-06	5.21	3.07	126		
Nov-06	5.30	3.64	132		
Dec-06	6.56	4.92	144	**110.00**	42.39
Jan-07	5.69	3.30	118		
Feb-07	5.93	3.62	126	52.20	**58.90**
Mar-07	10.10	4.76	94		
Apr-07	6.02	3.63	138	**90.98**	**63.28**
May-07	5.86	2.81	126		
Jun-07	5.29	2.35	124		
Jul-07	4.54	1.78	86	46.92	**53.70**
Aug-07	4.51	2.12	116		
Sep-07	5.05	3.08	136		
Oct-07	5.96	3.58	146		
Nov-07	5.21	3.58	154		
Dec-07	6.76	3.40	132	66.18	**52.55**
Jan-08	4.37	2.97	178		
Feb-08	6.35	3.60	126	53.47	41.44
Mar-08					
Apr-08	6.43	3.06	114	80.45	45.56
May-08	6.67	2.41	62		
Jun-08	5.35	2.28	100		
Jul-08	5.08	2.31	96		
Aug-08	4.20	1.90	110		
Sep-08	5.68	2.61	110	**94.14**	65.22
Oct-08	4.47	2.51	148		
Nov-08	7.16	3.86	168		
Dec-08	4.00	2.46	228	63.69	12.69
Jan-09	4.32	2.50	182		
Feb-09	6.72	4.32	148		
Mar-09	5.01	2.86	212		
Apr-09	7.88	4.35	142	64.80	45.10
May-09	4.87	2.16	116		
Jun-09	5.24	2.59	120		
Jul-09	3.91	2.08	164	74.00	24.10
Aug-09	3.60	1.82	134		
Sep-09	4.00	1.62	88		
Oct-09	6.93	2.32	102	42.60	29.80
Nov-09	6.88	3.61	126		
Dec-09	4.21	2.44	230		
Jan-10	3.97	2.48	210	35.30	20.30

Feb-10	3.76	2.44	180		
Mar-10	6.45	2.66	140		
Apr-10	3.94	2.28	174	57.50	28.80
May-10	5.35	2.53	140		
Jun-10	4.03	1.67	96		
Jul-10	4.14	1.74	94	70.60	35.00
Aug-10	3.40	1.90	164		
Sep-10	4.97	2.25	96		
Oct-10	4.17	2.02	150	64.90	25.70
Nov-10	3.92	2.18	160		
Dec-10	4.48	3.10	182		
Jan-11	4.58	2.98	198	60.40	22.10
Feb-11	5.19	3.66	194		
Mar-11	5.64	2.82	146		
Apr-11	4.76	2.64	178	87.70	46.40
May-11	7.67	3.26	62		
Jun-11	4.46	2.66	166		
Mean	5.28	2.84	140	68.70	39.44
SD	1.25	0.77	38	19.50	15.21
Min	3.40	1.62	62	35.30	12.69
Max	10.10	4.92	230	110.00	65.22
Four (4) Highest Quarters				96.13	57.11

Broken Arrow, OK

Name:	Broken Arrow				
Population Served:	81730	OK1021508			
Source (s):	Grand River	Purcuse from Oklahoma Ordnance Works Authority			
		Chlorine Dioxide	Yes		
				14500 E 131st South	
	Broken Arrow WTP			DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	6.56	2.14	92		
Aug-06	5.90	2.52	76	48.10	23.67
Sep-06	5.38	2.40	68		
Oct-06	6.04	2.56	76		
Nov-06	5.29	2.30	98	36.70	20.29
Dec-06	5.27	2.31	90		
Jan-07	5.68	2.29	86		
Feb-07	6.22	2.54	88	23.66	16.54
Mar-07	5.68	2.64	90		
Apr-07	9.46	2.52	92		
May-07	7.40	2.69	100	40.19	34.88
Jun-07	7.64	2.35	92		
Jul-07	8.01	2.17	82		
Aug-07	5.79	2.37	78	**64.62**	**90.44**
Sep-07	6.61	2.64	82		
Oct-07	6.03	2.17	98		
Nov-07	5.52	2.17	106	38.10	24.80
Dec-07	5.45	2.07	108		
Jan-08	6.19	2.05	86		
Feb-08	5.68	1.93	96	22.90	20.73
Mar-08	6.14	2.11	94		
Apr-08	6.87	2.07	80		
May-08	6.97	1.86	82	46.70	**45.93**
Jun-08	4.39	2.10	46		
Jul-08	7.47	2.71	78		
Aug-08	7.55	2.18	78	**75.58**	**75.67**
Sep-08	6.18	2.29	84		
Oct-08	6.00	2.82	84		
Nov-08	5.70	2.31	136	50.79	43.76
Dec-08	5.33	2.27	112		
Jan-09	4.96	2.70	98		
Feb-09	4.24	2.21	98	30.50	33.10
Mar-09	4.14	2.25	98		
Apr-09	4.44	2.97	94		
May-09	6.33	2.55	82	**54.80**	39.60
Jun-09	6.99	2.40	92		
Jul-09	5.02	2.24	106		
Aug-09	5.62	2.20	112	**56.00**	35.00
Sep-09	5.22	2.27	98		
Oct-09	5.17	2.29	80		
Nov-09	9.20	2.30	80	49.50	**46.00**
Dec-09	5.75	2.59	86		
Jan-10	6.38	2.71	108		

Broken Arrow, OK

Feb-10	7.30	2.89	90	35.90	40.90
Mar-10	6.66	2.74	96		
Apr-10	7.82	2.58	98		
May-10	5.84	2.57	112	50.00	45.40
Jun-10	6.47	2.33	104		
Jul-10	4.10	2.62	108		
Aug-10	5.15	2.06	86	61.30	44.50
Sep-10	4.98	2.22	102		
Oct-10	4.00	2.12	102		
Nov-10	4.40	2.16	100	37.60	26.20
Dec-10	4.54	2.32	106		
Jan-11	4.24	2.27	110		
Feb-11	4.08	2.18	102	21.70	22.10
Mar-11	6.18	2.10	88		
Apr-11	5.90	2.66	110		
May-11	5.91	1.93	92	22.40	32.50
Jun-11	7.89	1.92	68		
Mean	5.96	2.35	93	43.36	38.11
SD	1.22	0.26	14	15.09	18.29
Min	4.00	1.86	46	21.70	16.54
Max	9.46	2.97	136	75.58	90.44
Four (4) Highest Quarters				62.75	64.51

Oklahoma Ordnance Works Authority, OK

Name:	Oklahoma Ordnance Works Authority		OK1021602	
Population Served:	100623			
Source (s):	Grand River			
		Chlorine Dioxide	Yes	
				Mayes County Health Department DBP MAX

	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	3.77	2.34	109		
Aug-06	4.12	2.36	111	**50.26**	25.79
Sep-06	3.77	2.24	112		
Oct-06	3.70	2.25	114		
Nov-06	3.71	2.32	115	29.96	4.63
Dec-06	3.92	2.36	114		
Jan-07	3.60	2.31	122		
Feb-07	3.79	2.35	113	21.28	15.92
Mar-07	4.21	2.37	134		
Apr-07	3.81	2.32	119		
May-07	4.27	2.36	110	48.36	**39.07**
Jun-07	5.69	2.32	95		
Jul-07	5.11	1.82	68		
Aug-07	4.58	1.77	67		
Sep-07	4.38	2.13	76	**73.57**	**46.28**
Oct-07	4.12	2.18	76		
Nov-07	3.97	2.05	87	41.74	21.56
Dec-07	3.94	2.12	87		
Jan-08	3.75	1.89	89		
Feb-08	3.83	1.82	96	23.00	20.09
Mar-08	3.82	1.97	100		
Apr-08	4.74	1.81	76		
May-08	4.58	1.97	78	42.32	34.82
Jun-08	4.94	2.21	52		
Jul-08	4.96	2.37	70		
Aug-08	4.42	2.17	80	**54.54**	36.94
Sep-08	4.20	2.10	98		
Oct-08	4.59	2.59	94		
Nov-08	4.04	2.28	98	40.80	28.82
Dec-08	3.99	2.19	94		
Jan-09	3.95	2.12			
Feb-09	4.35	2.44		24.40	23.80
Mar-09	3.98	2.35	104		
Apr-09	4.96	3.09	114		
May-09	4.90	2.40	96	44.60	**47.60**
Jun-09	5.00	2.46	85		
Jul-09	4.18	2.11	94		
Aug-09	3.84		100	45.07	**41.90**
Sep-09	4.02	2.12	105		
Oct-09	3.82	2.31	82		
Nov-09	4.33	2.24	66	43.30	36.10
Dec-09	4.21	2.22	81		
Jan-10	4.81	2.81	90		

Feb-10	4.48	2.58	108	32.10	34.20
Mar-10	3.96	2.34	112		
Apr-10	3.42	2.11	123		
May-10	3.84	2.34	112	44.00	38.90
Jun-10	3.95	2.21	102		
Jul-10	3.89	2.15	92		
Aug-10	3.62	1.69	98	**54.40**	31.90
Sep-10	3.48	2.03	95		
Oct-10	3.98	2.32	114		
Nov-10	3.41	2.02	100	32.80	19.70
Dec-10	3.39	2.06	116		
Jan-11	3.52	2.16	108		
Feb-11	3.78	2.11	108	15.10	14.30
Mar-11	3.57	2.06	104		
Apr-11					
May-11	3.65	1.96	95	35.90	26.20
Jun-11	3.45	1.61			
Mean	4.11	2.21	98	39.88	29.43
SD	0.50	0.26	17	13.65	11.33
Min	3.39	1.61	52	15.10	4.63
Max	5.69	3.09	134	73.57	47.60
Four (4) Highest Quarters				58.19	43.71

Ft. Gibson, OK

Name:	Ft. Gibson	OK1021622
Population Served:	8847	
Source (s):	Grand River	
	Chlorine Dioxide	No

Charlies Chicken
DBP MAX

	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug	HAA5 (ug/L)
Jul-06	4.47	3.56	120		
Aug-06	4.54	3.75	120		
Sep-06	4.37	3.22	120	**69.37**	47.60
Oct-06	4.24	3.60	116		
Nov-06	4.45	3.48	118		
Dec-06	4.64	3.85	106		
Jan-07	4.31	3.75	108		
Feb-07	4.13	3.21	100		
Mar-07	4.86	3.54	104	37.50	45.60
Apr-07	11.88	3.09	110		
May-07	6.62	4.50	84		
Jun-07	8.81	6.38	82	**77.74**	**80.08**
Jul-07	7.24	3.57	82		
Aug-07	4.41	2.88	72		
Sep-07	4.02	2.00	73	45.36	15.60
Oct-07	3.54	3.37	86		
Nov-07	6.35	4.09	96		
Dec-07	4.27	5.08	98	**77.65**	**69.01**
Jan-08	3.74	2.90	86		
Feb-08	3.17	2.64	92		
Mar-08	3.76	2.51	92		
Apr-08	5.20	2.07	88		
May-08	3.85	2.44	78		
Jun-08	4.41	3.92	79	47.88	**78.09**
Jul-08	4.67	3.56	77		
Aug-08	4.49	2.20	84		
Sep-08	4.87	2.50	88		
Oct-08	4.88	2.18	82		
Nov-08	4.49	2.40	92	47.93	35.18
Dec-08	4.43	2.27	92		
Jan-09	3.91	2.12	108		
Feb-09	5.66	2.78	94		
Mar-09	5.36	1.70	95	41.50	43.30
Apr-09	5.28	2.62	121	41.00	41.20
May-09	4.58	2.11	123		
Jun-09	4.85	2.42	121		
Jul-09	4.35	1.90	75	46.90	41.20
Aug-09	4.05	1.97	92		
Sep-09	4.11	2.09	101		
Oct-09	3.87	1.38	66	51.90	**63.70**
Nov-09	4.60	2.42	71		
Dec-09	3.92	1.50	75		

Jan-10	4.26	1.90	86	44.90	55.80
Feb-10	4.90	2.44	82		
Mar-10	3.84	2.24	95		
Apr-10	3.85	1.63	115	68.20	51.90
May-10	3.58	2.39	110		
Jun-10	4.05	1.68	115		
Jul-10	4.13	2.65	91	65.30	46.70
Aug-10					
Sep-10					
Oct-10	3.60	2.22	100	**71.40**	54.50
Nov-10	3.61	2.23	101		
Dec-10	3.74	2.61	98		
Jan-11	3.81	2.41	104	33.10	29.10
Feb-11	3.92	2.39	103		
Mar-11	3.49	2.05	103		
Apr-11	3.56	1.90	108	46.30	48.40
May-11	4.98	2.29	104		
Jun-11	4.17	2.14	103		
Mean	4.61	2.74	97	53.77	49.83
SD	1.36	0.93	15	14.52	16.55
Min	3.17	1.38	66	33.10	15.60
Max	11.88	6.38	123	77.74	80.08
Four (4) Highest Quarters				74.04	72.72

Muskogee, OK

Name:	Muskogee	OK1021607			
Population Served:	45044				
Source (s):	Ft. Gibson Lake				
		Chlorine Dioxide	Yes		
	Muskogee WTP			Cum and Go DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	4.30	2.54	110		
Aug-06	4.36	2.84	110		
Sep-06	4.39	2.62	113	36.13	35.32
Oct-06	4.26	2.53	115		
Nov-06	4.34	2.56	112		
Dec-06	4.22	2.50	115	22.29	17.37
Jan-07	4.46	2.72	109		
Feb-07	4.26	2.86	103	17.21	19.80
Mar-07	4.76	2.86	103		
Apr-07	4.18	2.38	111		
May-07	4.07	2.23	107	34.97	28.93
Jun-07	5.26	2.64	114		
Jul-07	5.61	2.87	77		
Aug-07	4.92	2.99	74	**83.66**	**86.43**
Sep-07	4.56	2.28	78		
Oct-07	4.24	2.26	75		
Nov-07	4.48	2.48	74	38.61	42.54
Dec-07	4.25	2.31	80		
Jan-08	4.00	2.23	83		
Feb-08	3.65	2.36	91	23.56	22.20
Mar-08	4.07	2.51	97		
Apr-08	4.58	2.38	80		
May-08	4.66	1.98	69	34.29	40.42
Jun-08	5.13	2.96	74		
Jul-08	5.05	2.63	75		
Aug-08	4.48	2.86	78		
Sep-08	5.21	2.59	91	**47.85**	50.30
Oct-08	4.51	2.92	91		
Nov-08	4.49	2.49	89		
Dec-08	4.21	2.57	74	29.58	41.17
Jan-09	3.86	2.55	103		
Feb-09	4.79	3.17	97		
Mar-09	4.49	2.62	98	35.40	35.90
Apr-09	4.55	2.82	108		
May-09	5.56	3.61	91		
Jun-09	4.96	3.27	115	**65.50**	**76.60**
Jul-09	4.40	2.69	93		
Aug-09	3.80	2.52	100		
Sep-09	3.74	2.53	102	**60.30**	**49.60**
Oct-09	4.27	2.45	75		
Nov-09	4.04	2.25	70		
Dec-09	4.10	2.29	75	19.80	34.00
Jan-10	4.35	2.91	87		

Feb-10	4.04	2.60	100	35.70	42.40
Mar-10	3.89	2.56	118		
Apr-10	3.78	2.34	82	36.60	34.80
May-10	3.69	2.67	115		
Jun-10	4.04	3.13	99		
Jul-10	4.22	2.67	95		
Aug-10	5.51	3.83	95		
Sep-10	3.47	2.56	99	45.60	**46.50**
Oct-10	4.07	3.55	101		
Nov-10	4.01	2.68	100		
Dec-10	4.04	2.27	106	42.70	46.40
Jan-11	4.34	2.58	111		
Feb-11	3.99	2.51	106		
Mar-11	3.43	2.27	104		
Apr-11	4.74	2.20	98	40.70	38.20
May-11	4.51	2.42	88		
Jun-11	4.27	3.10	83		
Mean	4.37	2.65	95	39.50	41.52
SD	0.49	0.36	15	16.35	17.02
Min	3.43	1.98	69	17.21	17.37
Max	5.61	3.83	118	83.66	86.43
Four (4) Highest Quarters				64.33	64.78

Wagoner, OK

Name:	Wagoner	OK1021649			
Population Served:	8699				
Source (s):	Ft. Gibson Lake				
		Chlorine Dioxide	No		
	Wagoner WTP			Mike Blair DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	4.63	3.28	128		
Aug-06	4.56	3.50	122	**94.60**	39.20
Sep-06	4.45	3.15	120		
Oct-06	4.40	3.58	120		
Nov-06	4.68	3.23	122	77.60	41.57
Dec-06	4.53	3.24	126		
Jan-07	4.00	2.74	116		
Feb-07	3.98	2.74	118		
Mar-07	2.93	2.04	118	46.50	35.40
Apr-07	2.68	1.57	126		
May-07	6.11	4.00	110		
Jun-07	9.00	3.76	92	**92.72**	**99.59**
Jul-07	4.66	2.96	78		
Aug-07	4.44	2.75	78		
Sep-07	3.79	2.28	82	**98.29**	**89.07**
Oct-07	3.73	2.50	84		
Nov-07	3.57	2.55	90		
Dec-07	4.37	2.62	98	62.36	49.70
Jan-08	3.31	2.18	94		
Feb-08	3.43	2.10	104		
Mar-08	2.87	1.65	102	40.66	31.40
Apr-08	4.33	2.43	94		
May-08	4.75	2.56	82		
Jun-08	4.01	2.44	90		
Jul-08	4.78	2.50	84	**103.80**	**69.08**
Aug-08	4.01	1.98	94		
Sep-08	3.43	1.98	98		
Oct-08	3.65	1.92	106		
Nov-08	3.72	2.15	106		
Dec-08	3.40	1.91	112	44.50	44.28
Jan-09	3.42	1.93	110		
Feb-09	3.42	2.02	104		
Mar-09	3.28	2.16	104	45.10	49.20
Apr-09	4.30	2.34	124		
May-09	6.02	3.75	106	50.10	48.40
Jun-09	5.06	3.03	106	70.40	**64.00**
Jul-09	4.11	2.40	110		
Aug-09	4.10	2.59	112		
Sep-09	4.55	2.40	120	68.00	58.10
Oct-09	3.69	2.20	106		
Nov-09	4.72	2.60	96		
Dec-09	4.62	2.39	100	42.00	41.70
Jan-10	4.59	2.98	102		

Feb-10	6.95	2.86	106	41.60	42.30
Mar-10	4.05	2.57	116	43.70	46.30
Apr-10	4.05	2.33	120		
May-10	3.94	2.39	120	55.10	42.40
Jun-10	4.27	2.40	124	67.30	43.80
Jul-10	3.83	2.31	102		
Aug-10	4.04	2.56	100		
Sep-10	3.75	2.26	118	78.40	50.00
Oct-10	3.54	2.07	106		
Nov-10	3.72	2.24	110		
Dec-10	3.25	2.04	116	42.50	31.10
Jan-11	3.63	2.61	120		
Feb-11	3.85	2.52	122		
Mar-11	4.01	2.52	108	49.70	42.70
Apr-11	3.48	2.12	114		
May-11	4.12	2.49	112		
Jun-11	4.26	2.44	105	54.20	49.00
Mean	4.19	2.54	107	62.24	50.38
SD	0.98	0.52	14	20.63	16.97
Min	2.68	1.57	78	40.66	31.10
Max	9.00	4.00	128	103.80	99.59
Four (4) Highest Quarters				97.35	80.44

Sand Springs, OK

Name: Sand Springs OK1020420
Population Served: 22223
Source (s): Skiatook Lake/ Shell Creek Lake
Chlorine Dioxide No

	Sand Springs WTP			308 S 209 DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	3.68	2.42	79	45.50	14.00
Aug-06	3.85	2.76	80		
Sep-06	4.03	2.72	82		
Oct-06	4.25	2.92	86	42.70	17.00
Nov-06	4.06	2.68	84		
Dec-06	3.86	2.81	80		
Jan-07	4.45	3.27	80		
Feb-07	4.29	3.16	80	28.90	16.00
Mar-07	4.49	3.38	80		
Apr-07	4.50	3.11	78	38.30	21.00
May-07	5.44	3.61	74		
Jun-07	5.68	3.94	74		
Jul-07	5.59	3.57	76	**69.60**	**70.00**
Aug-07	6.15	4.09	76		
Sep-07	5.79	3.66	70		
Oct-07	5.94	3.08	74		
Nov-07	5.84	4.09	76	**78.80**	**27.00**
Dec-07	5.88	4.16	74		
Jan-08	5.76	3.73	74		
Feb-08	5.29	3.72	68	44.38	17.96
Mar-08	5.15	3.63	70		
Apr-08	5.97	3.59	70	40.91	25.39
May-08	5.12	3.39	71		
Jun-08	5.25	3.25	66		
Jul-08	5.16	3.21	62	**58.27**	**28.68**
Aug-08	5.46	3.27	64		
Sep-08	7.57	3.12	64		
Oct-08	5.89	2.95	64	**59.30**	**25.40**
Nov-08	4.93	2.97	64		
Dec-08	4.43	2.72	64		
Jan-09	4.52	2.86	64		
Feb-09	4.46	2.84	64	36.80	17.40
Mar-09	4.43	2.80	60		
Apr-09	4.49	2.77	64		
May-09	4.19	2.84	64	38.20	14.00
Jun-09	4.53	2.77	68		
Jul-09	4.87	2.89	64		
Aug-09	4.65	2.73	66	48.20	17.30
Sep-09	4.31	2.63	66		
Oct-09	4.47	2.71	68	42.20	15.50
Nov-09	4.50	2.86	68		
Dec-09	4.52	2.78	66		
Jan-10	4.93	2.69	68	33.30	14.60

Sand Springs, OK

Feb-10	4.18	2.43	66		
Mar-10	4.17	2.54	66		
Apr-10	4.11	2.67	66		
May-10	4.57	2.40	68	45.40	19.30
Jun-10	4.45	2.16	70		
Jul-10	4.19	2.57	70		
Aug-10	4.35	2.58	74	52.80	19.10
Sep-10	4.05	2.49	70		
Oct-10	3.99	2.47	70	47.00	24.80
Nov-10	4.16	2.52	72		
Dec-10	4.06	2.61	72		
Jan-11	4.22	2.69	72	35.80	14.90
Feb-11	4.22	2.77	72		
Mar-11	3.89	2.46	74		
Apr-11	3.82	2.38	72		
May-11	6.97	2.51	72	35.10	13.10
Jun-11	3.99	2.56	78		
Mean	4.77	2.97	71	46.08	21.63
SD	0.82	0.49	7	12.46	12.35
Min	3.68	2.16	60	28.90	13.10
Max	7.57	4.16	86	78.80	70.00
Four (4) Highest Quarters				66.49	37.77

Skiatook, OK

Name:	Skiatook	OK1021313		
Population Served:	10580			
Source (s):	Skiatook Lake	Spavinaw Lake	Purchuse Water from Tulsa - Mowhawk WTP	
		Chlorine Dioxide	No	
				Spoonfork Bridge
	Skiatook WTP			DBP MAX

	RAW TOC (mg/L)	FINISHED TOC (mg/L	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06		3.82	71		
Aug-06		3.68	69		
Sep-06		4.16	71	118.40	**44.27**
Oct-06		3.90	76		
Nov-06	4.17	3.69	79		
Dec-06	4.00	3.58	78	64.40	22.09
Jan-07		3.90	80		
Feb-07	4.17	3.75	76		
Mar-07	3.98	3.57	78	71.20	25.72
Apr-07	4.16	3.86	71		
May-07		4.71	70		
Jun-07		4.34	67	**165.65**	30.90
Jul-07	5.33	5.17	68		
Aug-07	6.50	5.86	65		
Sep-07	6.18	5.56	65	**223.50**	18.95
Oct-07		5.65	67		
Nov-07	5.49	5.27	75	**141.60**	**56.56**
Dec-07	5.52	5.13	73		
Jan-08		5.17	70		
Feb-08	5.28	5.15	70	123.00	**81.00**
Mar-08		5.29	70		
Apr-08	5.22	4.91	68		
May-08		4.92	67		
Jun-08	5.35	5.19	63	99.56	12.38
Jul-08		4.88	65		
Aug-08		5.10	63		
Sep-08	4.16	3.59	64	**190.10**	**54.59**
Oct-08	5.23	4.08	64		
Nov-08	3.76	2.78	64		
Dec-08	4.97	2.88	64	58.60	33.70
Jan-09	4.10	3.17	60		
Feb-09	4.42	2.37	61		
Mar-09	4.45	2.82	61	69.10	35.80
Apr-09	4.94	3.08	60		
May-09	4.30	2.74	58		
Jun-09	5.02	2.46	57	45.90	14.30
Jul-09	4.87	2.75	52		
Aug-09	4.91	2.63	59		
Sep-09	4.61	2.54	61	81.40	24.90
Oct-09	4.66	2.25	58		
Nov-09	4.58	2.35	61		

Dec-09	4.64	2.58	58	79.60	**58.10**
Jan-10	4.81	2.46	61		
Feb-10	4.95	2.58	61		
Mar-10	4.10	2.32	60	69.20	15.50
Apr-10	4.42	2.52	59		
May-10	4.35	2.45	61		
Jun-10	4.76	2.71	55	115.00	12.60
Jul-10	4.56	2.63	57		
Aug-10	4.39	2.58	58		
Sep-10	4.21	2.23	56	102.00	25.60
Oct-10	4.11	2.20	62		
Nov-10	4.17	1.98	65		
Dec-10	4.14	1.96	60	63.60	12.30
Jan-11	4.46	2.72	67		
Feb-11	4.29	2.34	66		
Mar-11	4.22	2.57	61	58.70	20.90
Apr-11	3.77	2.30	60		
May-11	4.12	2.26	66		
Jun-11	4.19	2.52	60	73.60	13.30
Mean	4.62	3.48	65	100.71	30.68
SD	0.59	1.17	7	47.92	19.11
Min	3.76	1.96	52	45.90	12.30
Max	6.50	5.86	80	223.50	81.00
Four (4) Highest Quarters				180.21	59.11

Vinita, OK

Name:	Vinita	OK1021611	
Population Served:	12330		
Source (s):	Grand Lake		
		Chlorine Dioxide	No

	Vinita WTP			Dist 2 Master Meter DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	5.29	3.38	109		
Aug-06	4.63	3.15	109		
Sep-06	4.17	2.99	104	90.20	**79.31**
Oct-06	4.05	2.94	109		
Nov-06	4.26	3.11	113		
Dec-06	3.93	3.10	112	53.20	35.05
Jan-07	4.00	2.86	113		
Feb-07	3.90	3.01	113		
Mar-07	4.16	3.00	112	46.80	31.50
Apr-07	4.16	2.76	108		
May-07	7.01	4.34	80		
Jun-07	5.36	3.17	77	91.00	**117.56**
Jul-07	5.15	2.81	59		
Aug-07	4.46	2.56	63		
Sep-07	4.58	2.55	80	69.18	61.39
Oct-07	4.62	2.54	88		
Nov-07	4.26	2.70	88	57.97	51.70
Dec-07	3.74	2.88	91		
Jan-08	3.71	2.86	95	55.27	44.30
Feb-08	3.85	2.62	96		
Mar-08	4.95	3.06	99		
Apr-08	4.71	2.95	78		
May-08	4.81	3.09	73		
Jun-08	4.94	3.17	83	**114.03**	**119.49**
Jul-08	4.28	2.70	82		
Aug-08	4.21	2.36	90		
Sep-08	4.30	2.54	100	73.40	55.97
Oct-08	4.41	2.89	92		
Nov-08	4.24	2.86	93	73.98	50.01
Dec-08	4.10	2.82	101		
Jan-09	4.24	3.07	103		
Feb-09	3.90	2.97	105		
Mar-09	4.02	3.04	114	67.40	56.80
Apr-09	4.82	3.28	123		
May-09	5.12	3.44	87	77.40	54.20
Jun-09	4.54	2.36	85		
Jul-09	4.23	2.44	64		
Aug-09	4.16	2.36	102	80.90	55.10
Sep-09	3.44	2.06	102		
Oct-09	4.39	2.62	79		
Nov-09	4.30	2.62	73	56.10	55.40
Dec-09	4.32	3.10	89		
Jan-10	4.36	3.30	90		

Feb-10	3.89	3.01	116	62.40	60.30
Mar-10	3.88	3.13	115		
Apr-10	4.20	2.97	104		
May-10	3.85	2.87	104	84.80	64.30
Jun-10	4.19	2.60	95		
Jul-10	3.30	2.10	100		
Aug-10	3.75	2.25	92	**102.00**	56.60
Sep-10	3.57	2.44	100		
Oct-10	3.48	2.41	107		
Nov-10	3.39	2.62	107	**91.70**	50.20
Dec-10	3.73	3.06	108		
Jan-11	3.64	3.10	109		
Feb-11	3.61	2.94	111	62.20	53.70
Mar-11	3.11	2.70	115		
Apr-11	3.71	3.03	110		
May-11	3.79	2.90	90	**94.10**	**97.50**
Jun-11	3.86	2.70	71		
Mean	4.22	2.86	97	75.21	62.52
SD	0.62	0.37	15	18.13	23.66
Min	3.11	2.06	59	46.80	31.50
Max	7.01	4.34	123	114.03	119.49
Four (4) Highest Quarters				100.46	103.47

Grove, OK

Name:	Grove	OK1021614		
Population Served:	18431			
Source (s):	Grand Lake			
		Chlorine Dioxide	No	
	Grove WTP			67000 E 260 Road DBP MAX

	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	4.86	3.12	106		
Aug-06	4.06	2.76	102		
Sep-06	4.25	2.64	104	102.00	54.60
Oct-06	4.28	2.67	110		
Nov-06	3.94	2.73	112		
Dec-06	3.84	2.53	110	76.02	46.16
Jan-07	3.70	2.46	112		
Feb-07	3.78	2.39	110		
Mar-07	3.55	2.27	116	65.04	35.10
Apr-07	4.01	2.60	102		
May-07	5.84	3.51	94		
Jun-07	5.51	3.46	88	**108.39**	**95.50**
Jul-07	5.09	3.17	82		
Aug-07	4.31	2.40	70		
Sep-07	4.35	2.73	90	77.37	**75.24**
Oct-07	4.23	2.53	92		
Nov-07	3.83	2.46	94		
Dec-07	3.67	2.23	96	67.77	51.94
Jan-08	3.69	2.27	104		
Feb-08	3.62	2.05	100		
Mar-08	3.59	2.10	106	64.26	56.75
Apr-08	4.16	2.01	70		
May-08	4.01	1.98	74		
Jun-08	4.59	2.53	88	**103.80**	**78.88**
Jul-08	5.37	3.32	78		
Aug-08	4.65	3.10	80		
Sep-08	4.31	2.55	110	**111.22**	60.99
Oct-08	4.17	2.42	100		
Nov-08	4.18	2.37	102		
Dec-08	4.05	2.40	106	**116.98**	**77.39**
Jan-09	3.91	2.25	110		
Feb-09	4.71	2.76	150		
Mar-09	3.83	2.37	130	60.60	42.40
Apr-09	4.12	2.56	128		
May-09	5.51	3.24	110		
Jun-09	5.14	2.90	88	97.40	74.10
Jul-09	4.30	2.29	96		
Aug-09	4.09	2.37	108		
Sep-09	4.21	2.42	106	60.60	49.80
Oct-09	3.75	2.01	82		
Nov-09	3.88	2.15	96		
Dec-09	4.30	2.40	108	60.60	39.50
Jan-10	4.67	2.70	116		

Feb-10	4.73	2.79	126		
Mar-10	3.74	2.02	124	37.10	29.80
Apr-10	3.20	1.79	104		
May-10	3.68	2.20	112		
Jun-10	4.65	2.90	88	90.30	63.50
Jul-10	4.33	3.04	98		
Aug-10	3.99	2.80	94		
Sep-10	3.91	2.44	110	93.20	67.80
Oct-10	3.70	2.06	114		
Nov-10	3.79	2.10	116		
Dec-10	3.44	2.29	112	48.50	31.70
Jan-11	3.56	2.11	116		
Feb-11	3.52	2.14	118		
Mar-11	3.10	1.85	124	54.40	34.70
Apr-11	4.69	3.09	110		
May-11	3.85	1.96	82		
Jun-11	3.88	1.86	86	75.70	47.20
Mean	4.17	2.50	103	78.57	55.66
SD	0.58	0.42	16	22.97	18.23
Min	3.10	1.79	70	37.10	29.80
Max	5.84	3.51	150	116.98	95.50
Four (4) Highest Quarters				110.10	81.75

Afton, OK

Name:	Afton	OK1021696	
Population Served:	1428		
Source (s):	Grand Lake/ Bernice		
		Chlorine Dioxide	No

				Buffelo Ranch DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	4.69	2.32	104	0.00	0.00
Aug-06	4.15	2.18	96		
Sep-06	4.65	2.24	105		
Oct-06	4.20	2.16	109	**72.90**	62.80
Nov-06	4.18	2.35	112		
Dec-06	3.88	2.31	117		
Jan-07	4.18	2.46	116	64.00	57.44
Feb-07	4.93	2.68	110		
Mar-07	4.47	2.31	114		
Apr-07	4.48	2.14	104	61.42	43.40
May-07	5.36	2.59	88		
Jun-07	5.89	2.10	85		
Jul-07	6.01	2.51	81	94.86	**127.62**
Aug-07	4.87	2.05	70		
Sep-07	4.62	1.84	79		
Oct-07	4.43	2.29	92	**114.17**	**109.16**
Nov-07	4.06	1.94	91		
Dec-07	3.69	2.03	91		
Jan-08	4.15	2.08	97	61.51	52.52
Feb-08	4.19	2.09	100		
Mar-08	5.29	2.38	93		
Apr-08	5.44	1.91	78	70.08	**70.06**
May-08	4.87	1.49	73	49.27	46.23
Jun-08	6.77	1.79	63	**120.28**	**72.35**
Jul-08	5.58	1.81	76		
Aug-08	4.99	1.79	81		
Sep-08	4.45	1.82	103		
Oct-08	4.80	1.20	97		
Nov-08	4.09	1.45	98		
Dec-08	4.20	1.63	100		
Jan-09	4.90	1.48	97	34.50	21.40
Feb-09	6.14	1.82	100		
Mar-09	5.24	1.75	103		
Apr-09	4.87	1.85	119	54.50	34.90
May-09	7.65	2.01	87		
Jun-09	5.86	1.85	89		
Jul-09	4.55	1.46	96	**113.00**	49.80
Aug-09	4.22	1.43	100		
Sep-09	4.03	1.15	87		
Oct-09	5.27	1.90	59	55.90	62.00
Nov-09	5.27	1.96	65		
Dec-09	4.37	2.02	89		
Jan-10	4.66	2.51	97		

Feb-10	9.11	3.22	104		
Mar-10	6.50	2.86	109	64.70	70.00
Apr-10	5.06	2.37	100		
May-10	4.60	1.91	106		
Jun-10	4.78	1.69	87	53.30	43.00
Jul-10	5.14	1.95	87		
Aug-10	3.78	1.58	99		
Sep-10	4.04	1.64	103	67.20	55.00
Oct-10	3.84	1.65	106		
Nov-10	3.77	1.81	108	58.20	40.30
Dec-10	5.31	1.76	107		
Jan-11	3.79	1.95	111		
Feb-11	3.84	1.89	112		
Mar-11	4.20	1.76	99	41.20	32.40
Apr-11	4.02	1.80	107		
May-11	4.06	1.80	85	50.80	43.70
Jun-11	4.06	1.29	72		
Mean	4.81	1.97	96	65.09	54.71
SD	0.99	0.40	14	28.41	27.99
Min	3.69	1.15	59	0.00	0.00
Max	9.11	3.22	119	120.28	127.62
Four (4) Highest Quarters				105.09	94.80

Locust Grove, OK

Name:	Locust Grove	OK1021668
Population Served:	1950	
Source (s):	Lake Hudson	
	Chlorine Dioxide	No

				People Residences DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	4.43	2.90	110	**120.27**	7.48
Aug-06	4.25	2.57	110		
Sep-06	3.95	2.10	114		
Oct-06	3.57	2.01	104		
Nov-06	4.15	1.33	116		
Dec-06	3.42	2.57	100	75.26	9.15
Jan-07	4.04	2.02	102		
Feb-07	3.88	2.26	100		
Mar-07	4.19	2.87	98	64.30	37.60
Apr-07	3.92	2.96	128		
May-07	3.80	3.67	72		
Jun-07	6.61	3.46	60	**134.56**	20.36
Jul-07	5.01	2.89	60		
Aug-07	4.96	2.39	46		
Sep-07	4.37	2.68	60		
Oct-07	4.42	2.51	76		
Nov-07	4.13	2.12	68		
Dec-07	3.73	2.19	76	54.10	34.90
Jan-08					
Feb-08	2.43	2.14	78	48.66	43.73
Mar-08	4.44	2.70	84		
Apr-08	2.59	2.43	52	63.44	52.47
May-08	4.38	2.17	44		
Jun-08	5.19	2.71	68	71.61	51.66
Jul-08	5.21	3.17	62		
Aug-08	4.24	2.72	100		
Sep-08	4.35	2.76	76		
Oct-08	4.75	3.07	84		
Nov-08	3.49	2.56	82		
Dec-08	4.02	3.69	92		
Jan-09	3.16	2.41	90		
Feb-09	2.49	2.63	88		
Mar-09	4.42	3.04	98		
Apr-09	4.62	2.99	94		
May-09	4.32	2.50			
Jun-09	5.43	2.65	80		
Jul-09	4.02	2.66	86	**170.00**	**123.00**
Aug-09	4.06	2.66	84		
Sep-09	3.18	2.21	74		
Oct-09	3.74	2.22	80	63.90	49.40
Nov-09	4.11	2.28	76		
Dec-09	4.46	3.02	79	55.40	52.00
Jan-10	4.58	2.49	95	53.70	67.00

Feb-10	3.86	2.25	98	91.30	54.20
Mar-10	4.32	2.75	122	51.50	52.40
Apr-10	3.45	2.23	117	76.40	59.00
May-10	4.03	2.44	118	108.00	**70.90**
Jun-10	4.22	2.52	102	112.00	**83.70**
Jul-10	3.94	2.35	98	**128.00**	27.50
Aug-10	3.90	2.55	96	109.00	7.08
Sep-10	3.66	2.24	94	149.00	6.08
Oct-10	3.77	2.58	99	122.00	49.70
Nov-10	3.48	2.15	100		
Dec-10	3.43	2.80	100		
Jan-11	3.60	2.65	100	82.30	48.90
Feb-11	3.59	2.56	98		
Mar-11	3.40	2.28	109		
Apr-11	3.66	2.20	95		
May-11	3.77	2.54	93	71.30	**79.30**
Jun-11	3.49	2.05	73		
Mean	4.04	2.56	89	90.27	47.29
SD	0.70	0.42	19	34.78	27.85
Min	2.43	1.33	44	48.66	6.08
Max	6.61	3.69	128	170.00	123.00
Four (4) Highest Quarters				138.21	89.23

Salina, OK

Name:	Salina	OK1021603			
Population Served:	1422				
Source (s):	Lake Hudson				
		Chlorine Dioxide	No		
				Indian Hill DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	4.29	3.45	104		
Aug-06	4.21	3.10	114		
Sep-06	3.55	3.04	116	88.30	**72.72**
Oct-06	4.19	3.24	120		
Nov-06	3.84	3.22	120		
Dec-06	3.69	3.24	118	94.28	53.64
Jan-07	4.14	2.97	120		
Feb-07	3.99	2.98	120		
Mar-07	3.84	3.19	122	87.83	66.32
Apr-07	4.66	3.39	112		
May-07	5.04	3.07	96		
Jun-07	5.11	3.29	76	**134.32**	**86.71**
Jul-07	5.24	3.59	90		
Aug-07	4.30	2.81	74		
Sep-07	4.39	2.84	100	**117.42**	**103.98**
Oct-07	4.65	2.71	94		
Nov-07	4.28	2.63	94		
Dec-07	4.25	2.42	98	61.01	60.17
Jan-08	4.05	2.49	106		
Feb-08	4.59	2.51	96		
Mar-08	4.91	3.83	104	68.04	64.85
Apr-08	4.63	2.56	80		
May-08	4.53	2.73	84		
Jun-08	5.15	3.25	90	**115.90**	**114.09**
Jul-08	4.91	3.44	82		
Aug-08	4.35	2.71	100		
Sep-08	4.64	3.17	102	83.61	73.89
Oct-08	4.64	2.52	90		
Nov-08	4.36	2.56	108		
Dec-08	4.26	2.55	102	62.39	60.82
Jan-09	3.82	2.56	108		
Feb-09	4.92	4.29	108		
Mar-09	4.40	2.98	110	73.70	67.70
Apr-09	4.71	3.17	124	65.00	44.00
May-09	5.49	3.08	94		
Jun-09	4.42	2.98	100		
Jul-09	4.01	2.55	102	191.00	16.50
Aug-09	4.17	2.92	108		
Sep-09	3.61	2.50	102		
Oct-09	4.07	2.22	84		
Nov-09	4.36	2.14	70		
Dec-09				60.60	67.70
Jan-10	4.61	2.78	96		

Feb-10	4.04	2.60	126		
Mar-10	5.06	2.79	114		
Apr-10	3.76	2.74	130		
May-10	4.52	2.45	118		
Jun-10	4.34	2.98	102	**135.00**	19.80
Jul-10	4.02	2.82	110		
Aug-10	3.66	2.88	108		
Sep-10	4.05	2.60	104	98.20	60.00
Oct-10	3.50	3.77	114		
Nov-10	3.44	2.41	110		
Dec-10	4.02	2.70	114	55.20	55.60
Jan-11	4.03	2.92	114		
Feb-11	4.06	3.35	116	76.80	58.10
Mar-11	3.46	2.34	124		
Apr-11	4.00	2.33	114		
May-11	3.68	2.16	100		
Jun-11	3.62	2.10	86	97.00	70.70
Mean	4.29	2.88	105	92.93	64.07
SD	0.49	0.45	14	34.05	23.27
Min	3.44	2.10	70	55.20	16.50
Max	5.49	4.29	130	191.00	114.09
Four (4) Highest Quarters				125.66	94.38

Wagoner County RWD 4, OK

Name:	Wagoner County Rural Water District #4			OK1021529	
Population Served:	23553				
Source (s):	Verdigris River				
		Chlorine Dioxide	No		
	WCRWD4 WTP			101st and 193rd DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	6.17	4.18	98		
Aug-06	6.97	4.14	100	**143.20**	**84.39**
Sep-06	5.55	4.25	82		
Oct-06	5.56	3.96	90		
Nov-06	5.11	1.06	86	14.51	7.60
Dec-06	6.10	1.94	90		
Jan-07	6.66	2.63	76		
Feb-07	5.91	2.29	90	32.95	24.09
Mar-07	6.85	2.72	104		
Apr-07	7.69	2.86	102		
May-07	8.52	3.55	98	**140.55**	40.73
Jun-07	7.64	2.84	106		
Jul-07	7.54	2.38	90		
Aug-07	5.66	1.93	90	67.62	24.06
Sep-07	5.49	1.97	90		
Oct-07	5.02	2.32	72		
Nov-07				71.36	23.59
Dec-07	5.29	2.61	110		
Jan-08	5.57	2.41	94		
Feb-08	6.42	2.36	106	48.96	24.23
Mar-08	7.20	2.25	100		
Apr-08	6.29	2.56	90		
May-08	7.53	2.25	84	65.18	33.31
Jun-08	7.12	2.48	72		
Jul-08	7.97	2.60	86		
Aug-08	6.98	2.39	70	**96.54**	41.12
Sep-08	6.44	2.00	78		
Oct-08	6.52	2.62	96		
Nov-08	6.04	2.19	106	55.56	26.07
Dec-08	5.38	3.28	116		
Jan-09	5.82	2.64	112		
Feb-09	9.15	3.34	90	67.80	30.50
Mar-09	5.86	2.60	116		
Apr-09	8.86	3.14	90		
May-09	8.09	3.14	90	**116.00**	**53.50**
Jun-09	6.25	3.48	102		
Jul-09	5.80	2.34	114		
Aug-09	5.10	1.66	116	67.30	18.60
Sep-09	5.12	2.16	86		
Oct-09	7.20	2.28	74		
Nov-09	7.43	2.27	76	74.00	36.20
Dec-09	6.11	2.75	100		
Jan-10	6.52	2.07	110		

Feb-10	5.85	2.49	98	65.60	40.60
Mar-10	6.00	2.59	100		
Apr-10	6.50	2.76	116		
May-10	8.92	2.56	76	**119.00**	**56.20**
Jun-10	9.68	2.38	80		
Jul-10	6.62	2.29	74		
Aug-10	4.84	2.02	92	73.70	40.70
Sep-10	4.46	2.17	92		
Oct-10	4.68	2.20	104		
Nov-10	4.30	2.29	104	83.60	37.00
Dec-10	4.58	2.64	108		
Jan-11	4.61	2.65	112		
Feb-11	5.13	2.40	94	57.20	26.40
Mar-11	5.20	2.44	104		
Apr-11	4.82	2.17	114		
May-11	5.66	2.73	104	83.60	**43.00**
Jun-11	6.13	2.60	92		
Mean	6.32	2.59	96	77.22	35.60
SD	1.26	0.60	13	32.65	16.40
Min	4.30	1.06	70	14.51	7.60
Max	9.68	4.25	116	143.20	84.39
Four (4) Highest Quarters				124.07	59.27

Coweta, OK

Name: Coweta OK1021509
Population Served: 7139
Source (s): Verdigris River
Chlorine Dioxide No

	Coweta WTP			Tiger Carwash DBP MAX	
	RAW TOC (mg/L)	FINISHED TOC (mg/L)	Alkalinity (mg/L as CaCO3)	TTHM (ug/L)	HAA5 (ug/L)
Jul-06	7.21	5.45	76		
Aug-06	6.84	5.64	64	421.60	321.00
Sep-06	5.62	5.37	68		
Oct-06	5.06	4.44	68	150.00	116.00
Nov-06	5.12	3.92	62		
Dec-06	4.84	3.59	58		
Jan-07	6.11	4.81	58		
Feb-07	6.47	4.94	48	128.60	213.00
Mar-07	5.60	4.64	48		
Apr-07	6.31	5.05	58		
May-07	8.07	6.15	74	278.50	210.20
Jun-07	7.21	5.47	70		
Jul-07	7.45	5.62	62		
Aug-07	7.33	5.79	70	410.53	329.10
Sep-07	7.36	5.85	80		
Oct-07	7.05	5.67	72	254.69	190.07
Nov-07	7.21	5.64	70		
Dec-07	6.78	5.64	70		
Jan-08	6.55	5.22	48		
Feb-08	7.17	4.56	50	118.18	114.10
Mar-08	8.13	5.52	50		
Apr-08	6.31	4.25	69		
May-08	5.24	3.47	50	129.80	121.53
Jun-08	6.32	4.94	58		
Jul-08	6.81	4.95	50	238.60	8.55
Aug-08	6.77	5.56	58		
Sep-08	5.94	4.47	50		
Oct-08	7.20	4.97	50	295.00	31.37
Nov-08	6.17	4.47	58		
Dec-08	5.67	4.20	62		
Jan-09	5.30	3.96	64	108.00	96.70
Feb-09	6.32	4.72	72		
Mar-09					
Apr-09				132.00	130.00
May-09	11.00	7.72	72		
Jun-09	10.20	7.45	74		
Jul-09	7.96	6.16	86	266.00	191.00
Aug-09	7.35	5.76	100		
Sep-09	7.31	7.31	100		
Oct-09	4.87	3.77	66		
Nov-09	5.59	4.25	52	139.00	57.00
Dec-09	5.76	4.46	56		
Jan-10	7.30	5.49	70	123.00	139.00

Feb-10	7.63	5.38	56		
Mar-10	6.55	4.81	64		
Apr-10	15.70	5.06	60	164.00	131.00
May-10	6.07	4.52	78		
Jun-10	7.30	5.79	72		
Jul-10	6.82	5.18	74		
Aug-10	7.99	5.83	66		
Sep-10	6.53	5.37	82	141.00	98.10
Oct-10					
Nov-10					
Dec-10	6.36	4.89	71		
Jan-11	5.45	3.95	80	0.00	0.00
Feb-11	5.47	4.10	78		
Mar-11	8.01	4.81	78		
Apr-11	6.98	7.05	80	89.00	21.00
May-11	5.03	3.10	74		
Jun-11	10.40	4.47	62		
Mean	6.92	5.11	67	188.82	132.57
SD	1.75	0.96	13	109.08	93.68
Min	4.84	3.10	48	0.00	0.00
Max	15.70	7.72	100	421.60	329.10
Four (4) Highest Quarters				345.46	268.33

APPENDIX 2

CHEMICAL REGULATIONS REVIEW

Regulatory Review
Chlorine Gas

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.a	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.179	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Meet DHS 6 CFR 27 (WTP Currently Exempted)	Comply 10 State Standards - Public Water Supplies 4.3	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3	Comply 10 State Standards - Public Water Supplies 5.4.1
Type	**Chlorine Gas Feed**						Yes																									Yes			
Chemical Provider						ANSI/NSF Standard 60/61																											ANSI/NSF Standard 60/61		
Size of Each Unit																																			
No. of Units & 30 Day Supply	2	Yes	Yes					Yes																								Yes			
If change in disinfection must notify ODEQ of change					No																														
Automatic and Manual Proportional Control								Yes																								Yes			
Cross Connection Prevention						Yes																										Yes			
CT Calculations				Yes																												Yes			
Educator																																Yes			
Automatic Switch Over																																Yes			
Injector/ Diffuser																																Yes			
Residual Chlorine																																Yes			
Testing Equipment				Automatic if > 3,300 pop.																												Yes			
Piping Material						Yes				Yes																						Yes			
Housing									Yes																										Yes
Ventilation									Yes																									Yes	Yes
Heat									Yes																										Yes
Storage of Chlorine Cylinders									Yes																										Yes
Scales									Yes																										Yes
Chlorine Gas Line									Yes																										Yes
Water Supply									Yes																										Yes
Handling Equipment									Yes																										Yes
Manifolds									Yes																										Yes
Leak Detection									Yes																									Yes	Yes
Evaporators									Yes																										Yes
Respiratory Protection									Yes							Yes																		Yes	Yes
CAS No.	7782-50-5																									Yes									
Greater than 10 lbs stored onsite																										Yes		Yes							
Must notify LEPC and SERC																													Yes						

Regulatory Review
Chlorine Gas

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.a	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.179	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Meet DHS 6 CFR 27 (WTP Currently Exempted)	Comply 10 State Standards - Public Water Supplies 4.3	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3	Comply 10 State Standards - Public Water Supplies 5.4.1
Greater than 2,500 lbs stored onsite must develop risk management plan																								Yes											
Must report if greater than 10 lbs / 24 hrs released in accordance																									Yes		Yes								
Chemical Labels/ Signage																					Yes								Yes				Yes	Yes	
MSDS																					Yes								Yes						
Eye Wash/ Shower Station																						Yes													
Greater than 10,000 lbs used annually																														Yes					
Must submit Form R annually																														Yes					
Must Institute Respiratory Protection Program																Yes																			
Personal Protective Equipment														Yes	Yes		Yes	Yes																Yes	
Greater than 1,500 lbs onsite, requires special OSHA handling												Yes																							
Provide intended capacity to employee												Yes																							
Provide process flow diagram to employee												Yes																							
Provide safe upper and lower limits (temperature, pressure, flows or compositions) to employee												Yes																							
Provide an evaluation of the consequences for deviations to employee												Yes																							
Provide electrical classification to employee												Yes																							
Provide materials of construction to employee												Yes																							

Regulatory Review
Chlorine Gas

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.a	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.179	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Meet DHS 6 CFR 27 (WTP Currently Exempted)	Comply 10 State Standards - Public Water Supplies 4.3	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3	Comply 10 State Standards - Public Water Supplies 5.4.1
Provide ventilation design to employee												Yes																							
Provide design codes or regulations of the system compliance to employee												Yes																							
Provide material and energy balance to employee												Yes																							
Provide safety systems to employee												Yes																							
Provide written program for operational procedures												Yes																							
Develop employee training program												Yes																							
Develop process hazard evaluation												Yes																							
Must evaluate contractors safety and performance, must notify contractors of hazard, contractor must develop an emergency action plan												Yes																							
Must control entrance, presence, and exit of contractors. Must evaluate performance of the safety of contractors. Must maintain a log of contractors employee illness and injuries when working in process area.												Yes																							
Must ensure proper training, inspection, maintenance of equipment												Yes																							

Regulatory Review
Chlorine Gas

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.a	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.179	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Meet DHS 6 CFR 27 (WTP Currently Exempted)	Comply 10 State Standards - Public Water Supplies 4.3	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3	Comply 10 State Standards - Public Water Supplies 5.4.1
Develop and maintain (every 3 years) an emergency planning and response plan in accordance with 29 CFR 1910.38 & 29 CFR 1910.120												Yes	Yes							Yes															
Provide fire protection																							Yes												
Overhead & Gantry Cranes																			Yes																
Visually Inspect the Safe Condition of Compressed Gas											Yes																								
Bioterrorism Act of 2002 - Must Comply with Chemical Facility Anti-Terrorism Standards (CFATS) if store greater than 2,500 lbs																															No				

Regulatory Review
Anhydrous Ammonia

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.h	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.111	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.179	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Meet DHS 6 CFR 27 (WTP Currently Exempted & Chemical Exempted)	Comply 10 State Standards - Public Water Supplies 4.3	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3	Comply 10 State Standards - Public Water Supplies 5.4.5.3
Type	**Anhydrous Ammonia Feed**						Yes																										No			
Chemical Provider						ANSI/NSF Standard 60/61																												ANSI/NSF Standard 60/61		
Size of Each Unit																																				
No. of Units & 30 Day Supply	2	Yes	Yes					Yes																									Yes			
If change in disinfection must notify ODEQ of change					Yes																															
Chloramines Notification Requirements Compliance					Yes																															
Automatic and Manual Proportional Control								Yes																									Yes			
Cross Connection Prevention						Yes																											Yes			
Chloramines Not an ODEQ Approved Disinfectant - CT Calculations				No																													Yes			
Educator																																	Yes			
Automatic Switch Over																																	Yes			
Injector/ Diffuser																																	Yes			
Residual Chloramines																																	Yes			
Testing Equipment				Automatic if > 3,300 pop.																													Yes			
Piping Material						Yes				Yes																							Yes			
Storage of Ammonia Cylinders									Yes																											Yes
Corrosion Resistant Materials									Yes																										Yes	Yes
Ammonia Gas Feed Lines Must Stay in Storage Room									Yes																											Yes
Emergency Exhaust System									Yes																											Yes
Leak Detection									Yes																											Yes
Removal of Scale and Deposits									Yes																											Yes
Emergency Gas Scrubbing System Required									Yes																											Yes
Respiratory Protection																		Yes																	Yes	Yes
CAS No.	7664-41-7																										Yes									
Greater than 500 lbs stored onsite																											Yes		Yes							

Regulatory Review
Anhydrous Ammonia

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.h	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.111	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.179	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Meet DHS 6 CFR 27 (WTP Currently Exempted & Chemical Exempted)	Comply 10 State Standards - Public Water Supplies 4.3	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3	Comply 10 State Standards - Public Water Supplies 5.4.5.3
Must notify LEPC and SERC																														Yes						
Greater than 10,000 lbs stored onsite must develop risk management plan																									No											
Must report if greater than 100 lbs / 24 hrs released in accordance																										Yes		Yes								
Chemical Labels/ Signage											Yes																			Yes				Yes	Yes	
MSDS											Yes																			Yes						
Eye Wash/ Shower Station																							Yes													
Greater than 10,000 lbs used annually																															No					
Must submit Form R annually																															No					
Must Institute Respiratory Protection Program																		Yes																		
Personal Protective Equipment																Yes	Yes		Yes	Yes															Yes	
Greater than 10,000 lbs onsite, requires special OSHA handling														No																						
Provide intended capacity to employee														No																						
Provide process flow diagram to employee														No																						
Provide safe upper and lower limits (temperature, pressure, flows or compositions) to employee														No																						
Provide an evaluation of the consequences for deviations to employee														No																						
Provide electrical classification to employee														No																						
Provide materials of construction to employee														No																						
Provide ventilation design to employee														No																						
Provide design codes or regulations of the system compliance to employee														No																						

Regulatory Review
Anhydrous Ammonia

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.h	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.111	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.179	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Meet DHS 6 CFR 27 (WTP Currently Exempted & Chemical Exempted)	Comply 10 State Standards - Public Water Supplies 4.3	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3	Comply 10 State Standards - Public Water Supplies 5.4.5.3
Provide material and energy balance to employee														No																						
Provide safety systems to employee														No																						
Provide written program for operational procedures														No																						
Develop employee training program														No																						
Develop process hazard evaluation														No																						
Must evaluate contractors safety and performance, must notify contractors of hazard, contractor must develop an emergency action plan														No																						
Must control entrance, presence, and exit of contractors. Must evaluate performance of the safety of contractors. Must maintain a log of contractors employee illness and injuries when working in process area.														No																						
Must ensure proper training, inspection, maintenance of equipment														No																						
Develop and maintain (every 3 years) an emergency planning and response plan in accordance with 29 CFR 1910.38 & 29 CFR 1910.120														No	No							No														
Provide fire protection																							Yes	Yes												
Overhead & Gantry Cranes																					Yes															
Visually Inspect the Safe Condition of Compressed Gas												Yes																								

Regulatory Review
Anhydrous Ammonia

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.h	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.111	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.179	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Meet DHS 6 CFR 27 (WTP Currently Exempted & Chemical Exempted)	Comply 10 State Standards - Public Water Supplies 4.3	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3	Comply 10 State Standards - Public Water Supplies 5.4.5.3
Bioterrorism Act of 2002 - Must Comply with Chemical Facility Anti-Terrorism Standards (CFATS)																																No				
Basic Rules													Yes																							
Requirements for construction, original test and requalification of nonrefridgerated containers													Yes																							
Marking nonrefridgerated containers													Yes																							
Location of Containers													Yes																							
Container Appuratuces													Yes																							
Piping, tubing and fittings													Yes																							
Hose Specifications													Yes																							
Safety relief devices													Yes																							
Charging of containers													Yes																							
Transfer of liquids													Yes																							
Tank car unloading points													Yes																							
Liquid level gauging devices													Yes																							
Electrical equipment and wiring													Yes																							

Regulatory Review
Ammonium Hydroxide (19% Solution)

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.h.2	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 264.175	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 370.10	Comply 10 State Standards - Public Water Supplies 4.3	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3.4	Comply 10 State Standards - Public Water Supplies 5.4.5
Type	**Aqua Ammonia (19 % Solution) Feed**						Yes														Yes			
Chemical Provider						ANSI/NSF Standard 60/61																ANSI/NSF Standard 60/61		
Size of Each Unit																								
No. of Units & 30 Day Supply	2	Yes	Yes					Yes													Yes			
If change in disinfection must notify ODEQ of change					No																			
Automatic and Manual Proportional Control								Yes													Yes			
Cross Connection Prevention						Yes															Yes			
Chloramines Not an ODEQ Approved Disinfectant - CT Calculations				No																	Yes			
Residual Chlorine																					Yes			
Testing Equipment				Automatic if > 3,300 pop.																	Yes			
Piping Material						Yes				Yes											Yes			
Corrosion Resistant Tank - Closed									Yes															Yes
Tank Vented Through Trap									Yes															Yes
Incompatible/ lockout connection									Yes															Yes
Ability to control temperature of solution									Yes															Yes
Exhaust Fan									Yes															Yes
Conveyance lines fitted with PRV									Yes															Yes
Inject into location with turbulance									Yes															Yes
Provisions to remove calcium deposits									Yes															Yes
Pumped Undiluted to Point of Application									Yes															Yes
Scrubber for Releases																								Yes
CAS No.	1336-21-6																							
Greater than 10,000 lbs stored onsite																				No				
Spill Containment - 10% of total containers or 100 % of largest container																		Yes						

Regulatory Review
Ozone Gas

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-9-4	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.104	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet OSHA 29 CFR 1910.179	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Comply 10 State Standards - Public Water Supplies 4.3.7	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3
Type	**Ozone Gas Feed**						Yes																									Yes		
Chemical Provider						ANSI/NSF Standard 60/61																											ANSI/NSF Standard 60/61	
Size of Each Unit																																		
No. of Units & 30 Day Supply	2	Yes	Yes					Yes																								Yes		
If change in disinfection must notify ODEQ of change					Yes																													
Automatic and Manual Proportional Control								Yes																								Yes		
Cross Connection Prevention						Yes																										Yes		
CT Calculations				Yes																												Yes		
Educator																																Yes		
Automatic Switch Over																																Yes		
Injector/ Diffuser																																Yes		
Testing Equipment				Automatic if > 3,300 pop.																												Yes		
Housing and Piping Material						Yes			Yes	Yes																						Yes		
Sufficient Capacity									Yes																							Yes		
Cooling									Yes																							Yes		
Materials									Yes																							Yes		
Alarms/ Shut Down									Yes																							Yes		
Safety									Yes																							Yes		
Instrumentation									Yes																							Yes		
Ozone Destruction Unit									Yes																							Yes		
Disinfectant Residual									Yes																							Yes		
Design Considerations																																Yes		
Feed Gas Preparation																																Yes		
Air Compression																																Yes		
Air Drying																																Yes		
Air Filters																																Yes		
Joints/ Connections																																Yes		
Construction Consideration																																Yes		
CAS No.	10028-15-6																										Yes							
Greater than 100 lbs stored onsite																											No		No					
Must notify LEPC and SERC																														No				
Must report if greater than 100 lbs / 24 hrs released in accordance																										No		Yes						
Chemical Labels/ Signage																					Yes									Yes			Yes	Yes

Regulatory Review
Ozone Gas

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-9-4	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.104	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet OSHA 29 CFR 1910.179	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Comply 10 State Standards - Public Water Supplies 4.3.7	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3
MSDS																					Yes									Yes				
Eye Wash/ Shower Station																						Yes												
Greater than 10,000 lbs used annually or manufacturer greater than 25,000 lbs																															Yes			
Must submit Form R annually																															Yes			
Must Institute Respiratory Protection Program																	Yes																	
Personal Protective Equipment															Yes	Yes		Yes	Yes															Yes
Greater than 100 lbs onsite, requires special OSHA handling													No																					
Provide intended capacity to employee													No																					
Provide process flow diagram to employee													No																					
Provide safe upper and lower limits (temperature, pressure, flows or compositions) to employee													No																					
Provide an evaluation of the consequences for deviations to employee													No																					
Provide electrical classification to employee													No																					
Provide materials of construction to employee													No																					
Provide ventilation design to employee													No																					
Provide design codes or regulations of the system compliance to employee													No																					
Provide material and energy balance to employee													No																					
Provide safety systems to employee													No																					
Provide written program for operational procedures													No																					
Develop employee training program													No																					
Develop process hazard evaluation													No																					

Regulatory Review
Ozone Gas

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-9-4	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.104	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet OSHA 29 CFR 1910.179	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Comply 10 State Standards - Public Water Supplies 4.3.7	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3
Must evaluate contractors safety and performance, must notify contractors of hazard, contractor must develop an emergency action plan													No																					
Must control entrance, presence, and exit of contractors. Must evaluate performance of the safety of contractors. Must maintain a log of contractors employee illness and injuries when working in process area.													No																					
Must ensure proper training, inspection, maintenance of equipment													No																					
Develop and maintain (every 3 years) an emergency planning and response plan in accordance with 29 CFR 1910.38 & 29 CFR 1910.120													No	No						No														
Provide fire protection																							Yes											
Visually Inspect the Safe Condition of Compressed Gas											Yes																							
Store more than 13,000 scf of oxygen onsite												No																						
Must provide spill containment												No																						
Must be located 50 ft from any combustible structures												No																						

Regulatory Review
Chlorine Dioxide Gas

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.a	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.179	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Meet DHS 6 CFR 27 (WTP Currently Exempted)	Comply 10 State Standards - Public Water Supplies 4.3	Comply 10 State Standards - Public Water Supplies 4.3.8
Type	**Chlorine Dioxide Feed**						Yes																									Yes	
Size of Each Unit																																	
If change in disinfection must notify ODEQ of change					Yes																												
Automatic and Manual Proportional Control								Yes																								Yes	
Cross Connection Prevention						Yes																										Yes	
CT Calculations				Yes																												Yes	
Residual Chlorine Dioxide																																Yes	
Provide ClO2 demand study prior to selection for primary disinfectant				Yes																													
Testing Equipment				Automatic if > 3,300 pop.																												Yes	
Minimum Efficiency of 95%																																Yes	
Comply with Chlorine Gas and Sodium Chlorite Storage Facilities																																	Yes
Must Comply with Part 4.3																																	Yes
Must notify public of change in disinfection practices																																	Yes
CAS No.	10049-04-04																									No							
Greater than 500 lbs stored onsite																										No		No					
Must notify LEPC and SERC																													No				
Greater than 1000 lbs stored onsite must develop risk management plan																								No									
Must report released																									No		No						
Chemical Labels/ Signage																					Yes								Yes				Yes

Regulatory Review
Chlorine Dioxide Gas

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.a	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.179	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Meet DHS 6 CFR 27 (WTP Currently Exempted)	Comply 10 State Standards - Public Water Supplies 4.3	Comply 10 State Standards - Public Water Supplies 4.3.8
MSDS																					Yes								Yes				
Eye Wash/ Shower Station																						Yes											
Greater than 10,000 lbs used annually																														Yes			
Must submit Form R annually																														Yes			
Must Institute Respiratory Protection Program																Yes																	
Personal Protective Equipment														Yes	Yes		Yes	Yes															
Greater than 1,000 lbs onsite, requires special OSHA handling												No																					
Provide intended capacity to employee												No																					
Provide process flow diagram to employee												No																					
Provide safe upper and lower limits (temperature, pressure, flows or compositions) to employee												No																					
Provide an evaluation of the consequences for deviations to employee												No																					
Provide electrical classification to employee												No																					
Provide materials of construction to employee												No																					
Provide ventilation design to employee												No																					
Provide design codes or regulations of the system compliance to employee												No																					
Provide material and energy balance to employee												No																					
Provide safety systems to employee												No																					

Regulatory Review
Chlorine Dioxide Gas

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.a	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.179	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Meet DHS 6 CFR 27 (WTP Currently Exempted)	Comply 10 State Standards - Public Water Supplies 4.3	Comply 10 State Standards - Public Water Supplies 4.3.8
Provide written program for operational procedures												No																					
Develop employee training program												No																					
Develop process hazard evaluation												No																					
Must evaluate contractors safety and performance, must notify contractors of hazard, contractor must develop an emergency action plan												No																					
Must control entrance, presence, and exit of contractors. Must evaluate performance of the safety of contractors. Must maintain a log of contractors employee illness and injuries when working in process area.												No																					
Must ensure proper training, inspection, maintenance of equipment												No																					
Develop and maintain (every 3 years) an emergency planning and response plan in accordance with 29 CFR 1910.38 & 29 CFR 1910.120												No	No							No													
Provide fire protection																							No										
Visually Inspect the Safe Condition of Compressed Gas											Yes																						

Regulatory Review
Chlorine Dioxide Gas

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11	Meet OAC 252:631-3-3	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.a	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.101	Meet OSHA 29 CFR 1910.119	Meet OSHA 29 CFR 1910.120	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.134	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.179	Meet OSHA 29 CFR 1910.38	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 68.12	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 355.20	Meet EPA 40 CFR 355.40	Meet EPA 40 CFR 370.10	Meet EPA 40 CFR 370.30 through EPA 40 CFR 370.33	Meet EPA 40 CFR 372.25	Meet DHS 6 CFR 27 (WTP Currently Exempted)	Comply 10 State Standards - Public Water Supplies 4.3	Comply 10 State Standards - Public Water Supplies 4.3.8
Bioterrorism Act of 2002 - Must Comply with Chemical Facility Anti-Terrorism Standards (CFATS) if store greater than 1,000 lbs																															No		

Regulatory Review
Sodium Chlorite

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-9-11.d	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-4.f	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Comply 10 State Standards - Public Water Supplies 5.0	Comply 10 State Standards - Public Water Supplies 5.1	Comply 10 State Standards - Public Water Supplies 5.2
Type	**Sodium Chlorite**					Yes													
Chemical Provider					ANSI/NSF Standard 60/61														ANSI/NSF Standard 60/61
Size of Each Unit																			
No. of Units	2	Yes	Yes				Yes										Yes		
General Requirements																		Yes	Yes
Automatic and Manual Proportional Control							Yes										Yes		
Cross Connection Prevention					Yes												Yes		
Devise to Measure Liquid Level							Yes												
Prevent Siphonage							Yes												
Provide ClO2 demand study prior to selection for primary disinfectant				Yes															
Use must be approved by ODEQ in an Engineering Report								Yes											
Store alone in a detached building, non combustable materials								Yes											
Shall be handled to prevent spilling								Yes											
Provide Emergency Operation plan for cleanup								Yes											
Drums shall be washed prior to disposal								Yes											
Positive displacement pumps								Yes											
Check valves to prevent back flow of chlorine into storage container								Yes											
Type 1 PVC or compatabile Feed lines shall prevent gas pocket formation and terminate at a point of positive pressure								Yes											

Regulatory Review
Aluminum Sulfate (50%)

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-3.g	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 264.175	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 370.10	Comply 10 State Standards - Public Water Supplies 5.0	Comply 10 State Standards - Public Water Supplies 5.1	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3
Type	**Aluminum Sulfate**				Yes																	
Chemical Provider				ANSI/NSF Standard 60/61																	ANSI/NSF Standard 60/61	
Size of Each Unit																						
No. of Units & 30 Day Supply	2	Yes	Yes			Yes													Yes			
General Requirements																				Yes	Yes	Yes
Automatic and Manual Proportional Control						Yes													Yes			
Prevent Siphonage						Yes																
Cross Connection Prevention				Yes															Yes			
Piping Material				Yes			Yes	Yes											Yes			
Devise to Measure Liquid Levels						Yes																
30 Day Supply							Yes															
Provide Overflow							Yes															
CAS No.	10043-01-3																					
Greater than 10,000 lbs stored onsite																		No				
Spill Containment - 10% of total containers or 100 % of largest container																Yes						
Must report if greater than 5000 lbs / 24 hrs released in accordance																	Yes					
Chemical Labels/ Signage													Yes						Yes	Yes	Yes	
MSDS													Yes									
Personal Protective Equipment									Yes	Yes	Yes	Yes										Yes
Eyewash/ Shower Station														Yes								Yes
Provide fire protection															Yes							

Regulatory Review
Ferric Chloride (40% Solution)

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-3.g	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Meet EPA 40 CFR 264.175	Meet EPA 40 CFR 302.4	Meet EPA 40 CFR 370.10	Comply 10 State Standards - Public Water Supplies 5.0	Comply 10 State Standards - Public Water Supplies 5.1	Comply 10 State Standards - Public Water Supplies 5.2	Comply 10 State Standards - Public Water Supplies 5.3
Type	**Ferric Chloride**				Yes																	
Chemical Provider				ANSI/NSF Standard 60/61																	ANSI/NSF Standard 60/61	
Size of Each Unit																						
No. of Units & 30 Day Supply	2	Yes	Yes			Yes													Yes			
General Requirements																				Yes	Yes	Yes
Automatic and Manual Proportional Control						Yes													Yes			
Prevent Siphonage						Yes																
Cross Connection Prevention				Yes															Yes			
Piping Material				Yes			Yes	Yes											Yes			
Devise to Measure Liquid Levels						Yes																
30 Day Supply							Yes															
Provide Overflow							Yes															
CAS No.	7705-08-0																					
Greater than 10,000 lbs stored onsite																		No				
Spill Containment - 10% of total containers or 100 % of largest container																Yes						
Must report if greater than 1000 lbs / 24 hrs released in accordance																	Yes					
Chemical Labels/ Signage													Yes						Yes	Yes	Yes	
MSDS													Yes									
Personal Protective Equipment									Yes	Yes	Yes	Yes										Yes
Eyewash/ Shower Station														Yes								Yes
Provide fire protection															Yes							

Regulatory Review
Powdered Activated Carbon

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-3.h	Meet OAC 252:262-11-4.d	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Comply 10 State Standards - Public Water Supplies 4.9.4	Comply 10 State Standards - Public Water Supplies 5.0	Comply 10 State Standards - Public Water Supplies 5.1	Comply 10 State Standards - Public Water Supplies 5.2
Type	**Powdered Activated Carbon**				Yes															
Chemical Provider				ANSI/NSF Standard 60/61																ANSI/NSF Standard 60/61
Size of Each Unit																				
No. of Units	1	No	Yes			Yes												Yes		
General Requirements																			Yes	Yes
Automatic and Manual Proportional Control						Yes												Yes		
Cross Connection Prevention				Yes														Yes		
Devise to Measure Liquid Level						Yes														
Prevent Siphonage						Yes														
Cover Solution Tanks							Yes													
Continuous Agitation							Yes													
Devises to Measure Liquid and Solid when Mixing the Two Together							Yes													
Piping Material				Yes				Yes	Yes									Yes		
Fireproof Compartment with Explosion Proof Electrical Equipment								Yes												
Provide wet carbon storage with dust collectors								Yes												
Provide slurry pumps to transfer carbon								Yes												
Maximum Slurry Concentration = 1 lbs/ gal								Yes												
Chemical Labels/ Signage							Yes							Yes				Yes	Yes	Yes
Add as Early in Process as Possible																	No			
Means to Add 0.1 mg/L to 40 mg/L																	No			
Dust Control																	Yes			
MSDS														Yes						
Personal Protective Equipment										Yes	Yes	Yes	Yes							

Regulatory Review
Powdered Activated Carbon

	Design Parameter	Meet OAC 252:262-9-1.c	Meet OAC 252:262-9-1.d	Meet OAC 252:262-11-1	Meet OAC 252:262-11-2	Meet OAC 252:262-11-3	Meet OAC 252:262-11-3.h	Meet OAC 252:262-11-4.d	Meet OAC 252:262 Appendix A	Meet OSHA 29 CFR 1910.132	Meet OSHA 29 CFR 1910.133	Meet OSHA 29 CFR 1910.136	Meet OSHA 29 CFR 1910.138	Meet OSHA 29 CFR 1910.1200	Meet OSHA 29 CFR 1910 Subpart K	Meet OSHA 29 CFR 1910 Subpart L	Comply 10 State Standards - Public Water Supplies 4.9.4	Comply 10 State Standards - Public Water Supplies 5.0	Comply 10 State Standards - Public Water Supplies 5.1	Comply 10 State Standards - Public Water Supplies 5.2
Eyewash/ Shower Station															Yes					
Provide fire protection																Yes				

APPENDIX 3

DECISION TREES

Decision Tree Scoring Sheet

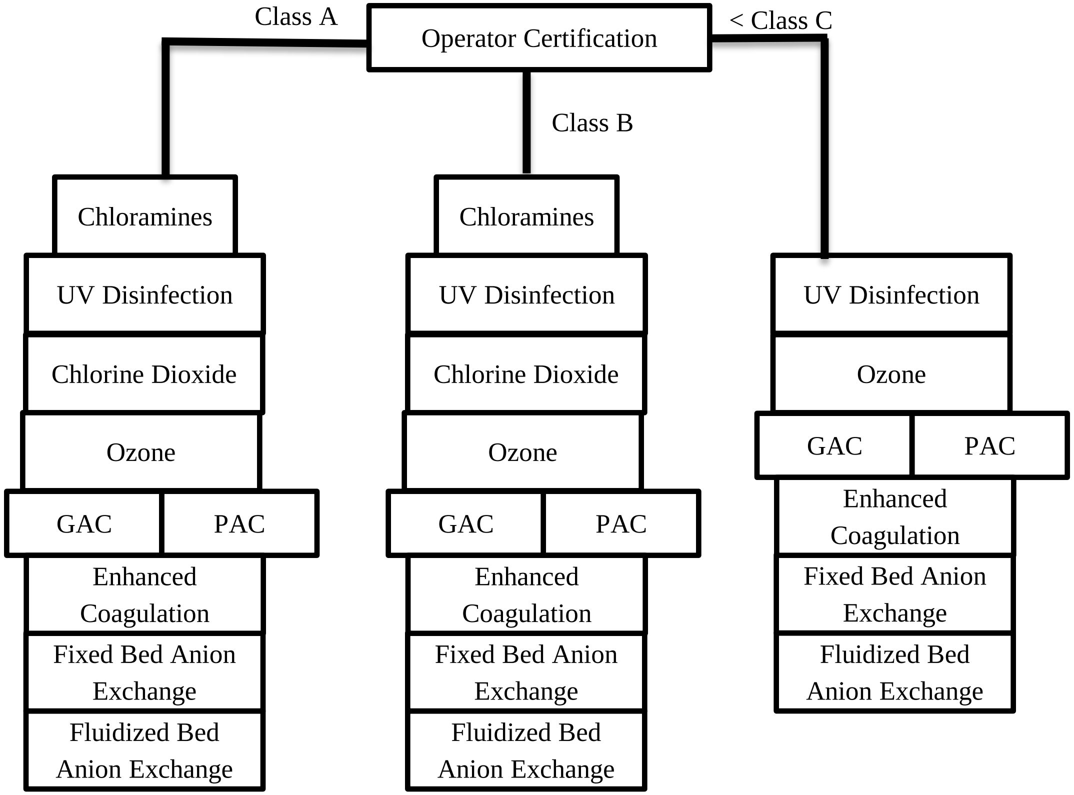
Place a mark next to the adjacent technology from each decision tree. Total up the number of marks in the second to the right column. Rank each technology from 1 to 9 in accordance with the total number of check marks obtained.

Name of Water Authority:____________________

Technology	Operator Certification	Condition of the Existing Water Treatment Facility	Raw Water TOC/ Alkalinity	TTHMs/ HAA5	Disinfectants	Total	Rank
Chloramines							
UV Disinfection							
Chlorine Dioxide							
Ozone							
GAC							
PAC							
Enhanced Coagulation							
Fixed Bed Anion Exchange							
Fluidized Bed Anion Exchange							

Operator Certification

Use Highest License Operator Class



Operator Certification

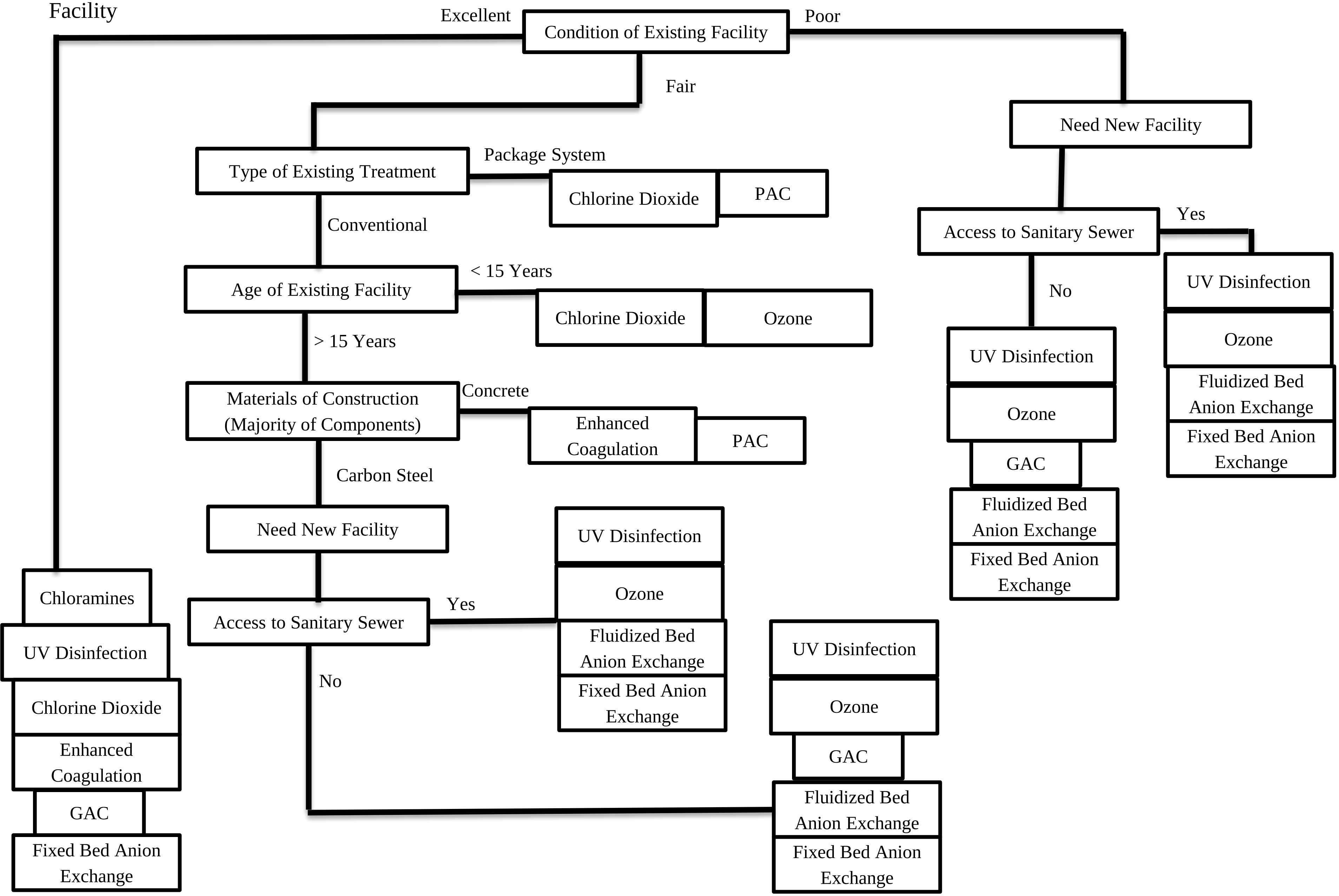
Class A
- Chloramines
- UV Disinfection
- Chlorine Dioxide
- Ozone
- GAC | PAC
- Enhanced Coagulation
- Fixed Bed Anion Exchange
- Fluidized Bed Anion Exchange

Class B
- Chloramines
- UV Disinfection
- Chlorine Dioxide
- Ozone
- GAC | PAC
- Enhanced Coagulation
- Fixed Bed Anion Exchange
- Fluidized Bed Anion Exchange

< Class C
- UV Disinfection
- Ozone
- GAC | PAC
- Enhanced Coagulation
- Fixed Bed Anion Exchange
- Fluidized Bed Anion Exchange

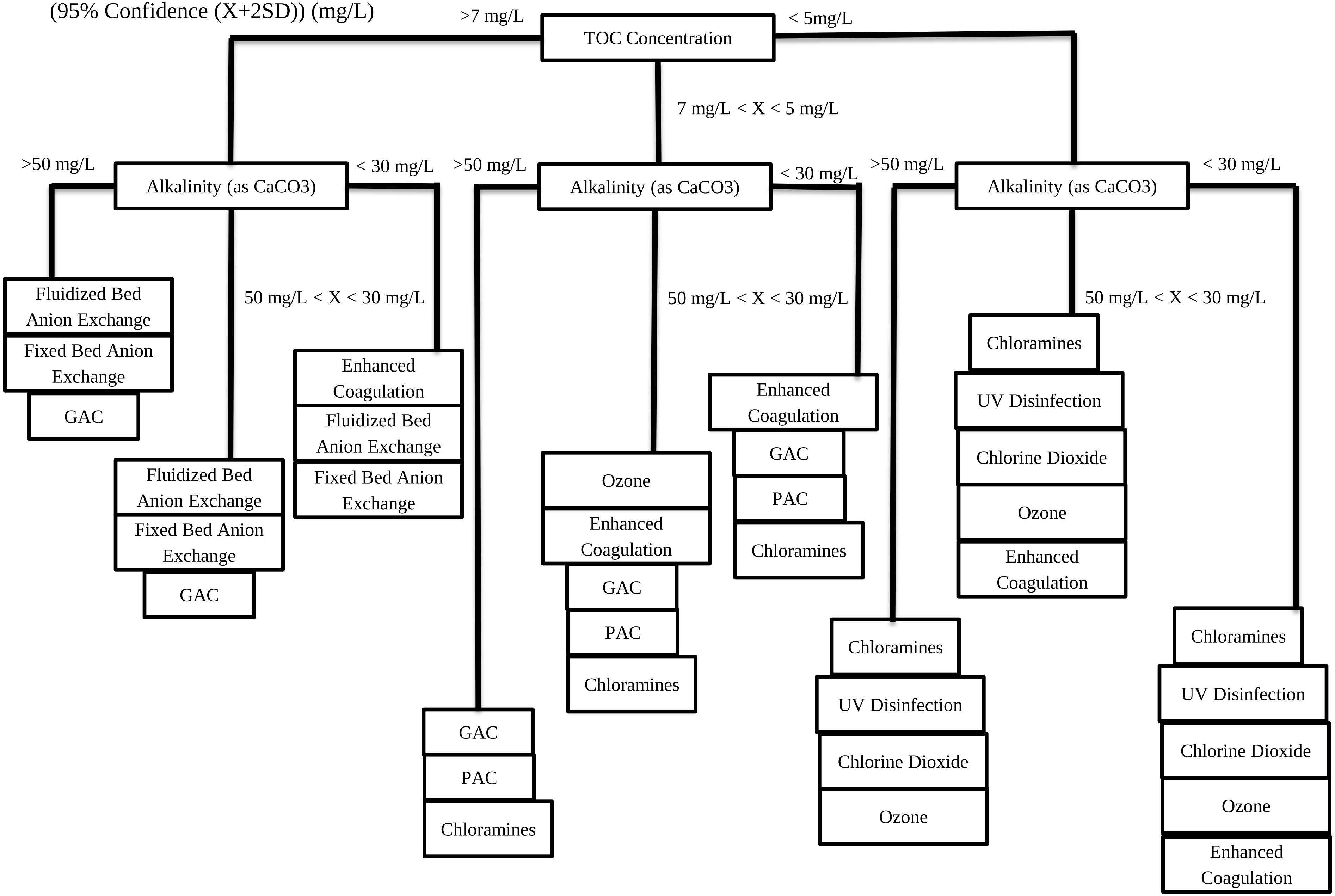
Condition of the Existing Water Treatment Facility

Assess the Current Condition of the Facility



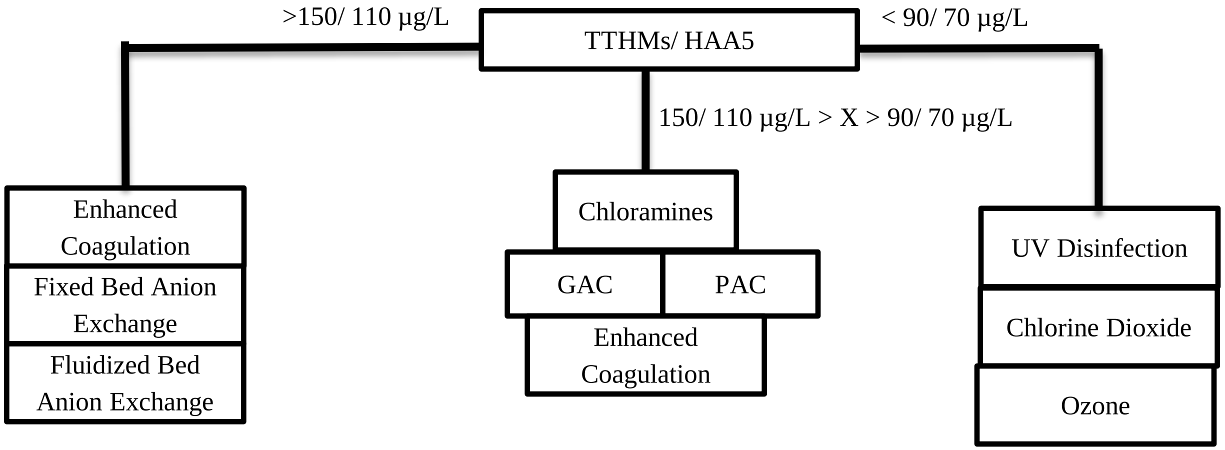
Raw Water TOC/ Alkalinity

Use Raw Water TOC and Alkalinity
(95% Confidence (X+2SD)) (mg/L)



TTHMs/ HAA5

Use four (4) of the highest concentrations for TTHMs over the last five (5) years from a single sample site. Repeat calculation for HAA5.



TTHMs/ HAA5

>150/ 110 µg/L

Enhanced Coagulation

Fixed Bed Anion Exchange

Fluidized Bed Anion Exchange

150/ 110 µg/L > X > 90/ 70 µg/L

Chloramines

GAC

PAC

Enhanced Coagulation

< 90/ 70 µg/L

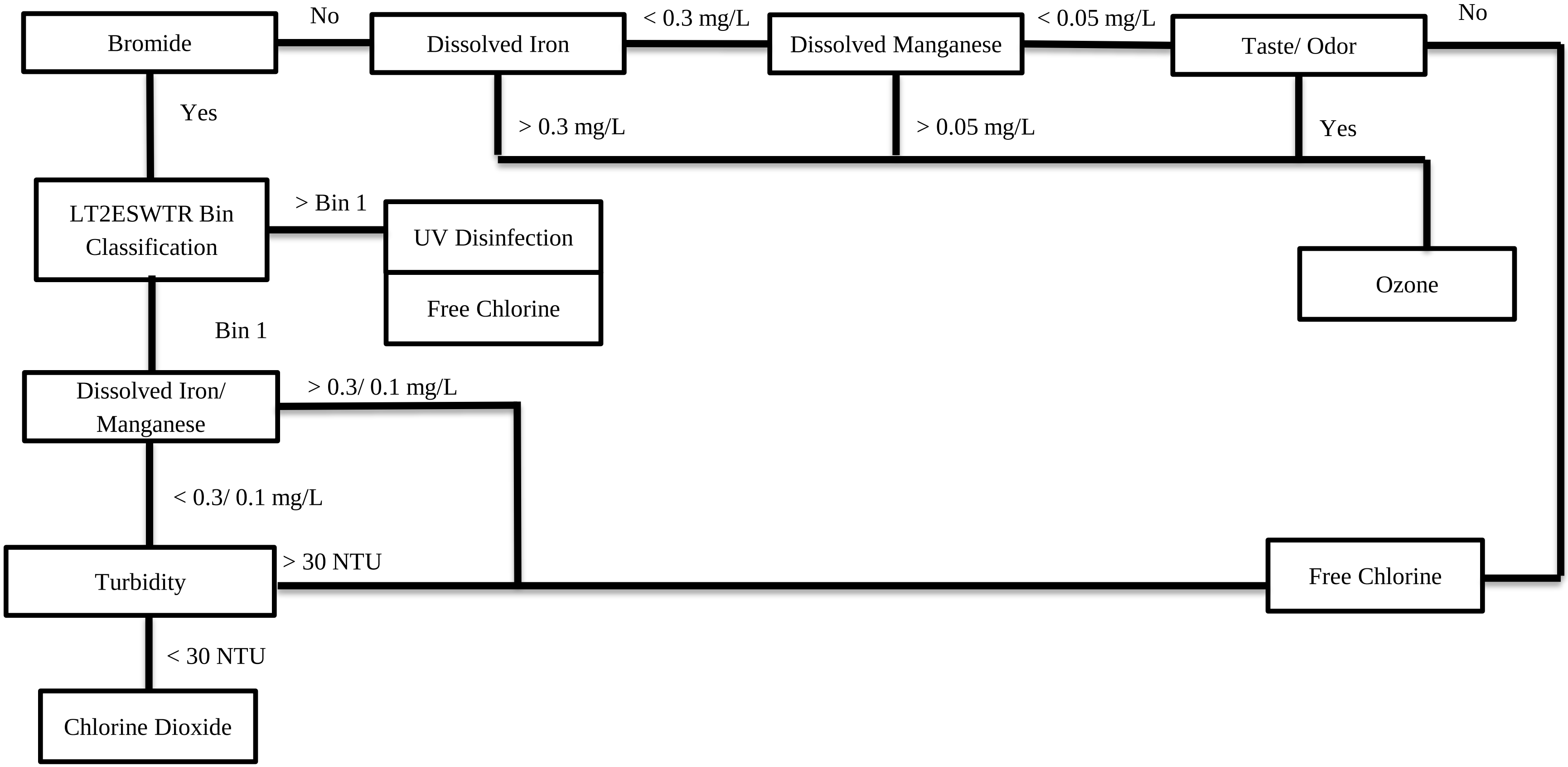
UV Disinfection

Chlorine Dioxide

Ozone

Disinfectants

Use Raw Water Parameters (95% Confidence (X+2SD)) (mg/L)



Decision Tree Scoring Sheet

Place a mark next to the adjacent technology from each decision tree. Total up the number of marks in the second to the right column. Rank each technology from 1 to 9 in accordance with the total number of check marks obtained.

Name of Water Authority:____Coweta PWA_____________

Technology	Operator Certification	Condition of the Existing Water Treatment Facility	Raw Water TOC/ Alkalinity	TTHMs/ HAA5	Disinfectants	Total	Rank
Chloramines						0	5
UV Disinfection	X	X			X	3	2
Chlorine Dioxide	X					1	4
Ozone	X	X				2	3
GAC	X	X	X			3	2
PAC	X					1	4
Enhanced Coagulation	X			X		2	3
Fixed Bed Anion Exchange	X	X	X	X		4	1
Fluidized Bed Anion Exchange	X	X	X	X		4	1

VITA

Brian N. Wintle

Candidate for the Degree of

Doctor of Philosophy

Thesis: STRATEGIES FOR COMPLIANCE WITH STAGE 2 DISINFECTANTS AND DISINFECTION BYPRODUCTS RULE FOR SURFACE WATER TREATMENT FACILITIES IN NORTHEASTERN OKLAHOMA

Major Field: Civil Engineering

Biographical:

Education:
Completed the requirements for the Doctor of Philosophy in Civil Engineering at Oklahoma State University, Stillwater, Oklahoma in July, 2012.

Completed the requirements for the Master of Science in Environmental Engineering at Oklahoma State University, Stillwater, Oklahoma in 2008.

Completed the requirements for the Bachelor of Science in Civil Engineering at University of Maine, Orono, Maine in 2007.

Experience:
Water/ Wastewater Design Engineer – Full Time
Professional Engineering Consultants, P.A. (PEC), Tulsa, OK
Mar. 2009 – Present

Research Assistant – Part Time
Oklahoma State University, Stillwater, OK
Jan. 2007 – Present

Summer Intern – Full Time
Olver Associates, Inc. Winterport, ME
May 2003 – Sept. 2006

Professional Memberships:
Water Environment Federation
Membership No. 17540333-0
Mar. 2012 – Present

American Water Works Association
Membership No. 01154716
Sept. 2011 – Present

Name: Brian N. Wintle Date of Degree: July, 2012

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: STRATEGIES FOR COMPLIANCE WITH STAGE 2 DISINFECTANTS AND DISINFECTION BYPRODUCTS RULE FOR SURFACE WATER TREATMENT FACILITIES IN NORTHEASTERN OKLAHOMA

Pages in Study: 207 Candidate for the Degree of Doctor of Philosophy

Major Field: Civil Engineering

Scope and Method of Study: The Environmental Protection Agency (EPA) recently created new regulations that better protect human health but that also make achieving compliance more difficult for existing water treatment facilities. Compliance with the Stage 2 Disinfectants and Disinfection Byproducts (D/ DBPs) Rule will become increasingly more difficult for surface water treatment facilities in northeastern Oklahoma. Technologies exist for compliance with Stage 2 D/ DBP Rule for all systems in northeastern Oklahoma. Stage 2 D/ DBP Rule compliance strategies that were evaluated were: the use of chlorine dioxide, ozone, and ultraviolet light; the use of chloramines as a microorganism barrier in the distribution system; and the use of total organic carbon removal technologies.

Findings and Conclusions: Due to capital and operational costs, chloramines will be the most likely selected compliance technology for water authorities in northeastern Oklahoma. The compliance technology should not be based exclusively on cost, but rather selection should incorporate all facets of water treatment. Selection of a compliance technology should be based on the best solution specific to each individual water authority. Investigations were conducted into developing decision trees that can be used by water authorities in northeastern Oklahoma and ODEQ for preliminary determination of compliance technologies. Water authorities should strive to meet a LRAA that is consistently below the 40/ 30 limit (40 µg/L of TTHMs and 30 µg/L HAA5s). Water authorities should also be aware of the potential future regulations drinking water regulations, especially the DBPs that are more likely to be formed by chloramines.

ADVISER’S APPROVAL: Dr. Gregory Wilber