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Evaluation and Optimization of Control Strategies for Management of Disinfection Byproduct Precursors Within the Northeast Mississippi Water District

By

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EVALUATION AND OPTIMIZATION OF CONTROL STRATEGIES FOR MANAGEMENT OF DISINFECTION BYPRODUCT PRECURSORS WITHIN THE NORTHEAST MISSISSIPPI WATER DISTRICT

By

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As a result of the EPA's Disinfection Byproduct Rule, the Northeast Mississippi Regional Water Supply District requested that the Environmental Technology and Applications Laboratory at Mississippi State University conduct a study to develop techniques to comply with new TOC regulations. This study involved the use of jar testing and Enhanced Coagulation in a laboratory setting over a period of twelve months to optimize the various coagulants evaluated in this study. Iron (III) sulfate, aluminum sulfate, aluminum chloride, aluminum chlorohydrate, and a number of polyaluminum chlorides were evaluated in this study. Coagulants were evaluated on both a treatment effectiveness and economical basis. It was determined that an acidified alum solution performed best at meeting EPA standards for total organic carbon reduction, as well as being economically feasible.

DEDICATION

I would like to dedicate this body of work to my brilliant, beautiful, loving wife Tori, who has always been there for me throughout the past three years of graduate school. She has been a constant source of inspiration and support during this process, and I never could have done it without her. This is for you.

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Before I start thanking people, I would like to thank God for blessing me with drive, motivation, and the ability to excel in academics. The completion of my Master's degree is proof that all things are possible if you have but the faith of a mustard seed.

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Last, but certainly not least, I would like to thank my parents, William F. and Jacqueline Horne. The two of you have supported me my entire life, and it is because of you that I am where I am today. Thank you for your love and guidance.

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CHAPTER I

Introduction

Throughout history, mankind has always flocked to areas with abundant water supplies. Whether it is a river, lake, or ocean, people have always known about the importance of water. As early as 400 B.C., Hippocrates, the father of medicine, stated that "water contributes much to health" (Baker, 1981). His early studies were not highly focused on purifying water as they were aimed at finding the highest quality water. Even at this early point in human history, it was recognized that certain water sources resulted in maintaining quality health, while others promoted infection. However, water treatment at this time was for aesthetic purposes only, to make better looking and tasting water. As time progressed, cities grew larger and the demand for clean water grew accordingly. The first municipal water filtration plant began operation in Scotland during 1832 (Baker, 1981). It was during this time that people began to realize that water quality could not be judged solely on sensory perception. As a result, in 1852, a law was passed in London stating that all water must be filtered (Pontius, 1990). Scientists during the 19th century began to discover many things about drinking water, such as Dr. John Snow's empirical proof that cholera was a water borne disease, and Louis Pasteur's studies pertaining to the germ theory of disease (Cotruvo, 1990). However, it was not until 1908 that chlorine was first introduced as a disinfectant for municipal water supplies.

Disinfection is the term applied to the selective destruction of disease-causing organisms (Tchobanoglous and Schroeder, 1987). Disinfection in water treatment systems involves the exposure of said organisms to one or more destructive agents. These may be classified as chemical, physical, mechanical, electromagnetic, acoustic, or radiative. The most common method for disinfection in the United States and throughout the world is chemical disinfection via chlorination (Vogt, 1987).

Chlorination is required for virtually all domestic waters supplied from surface waters and groundwater. Disinfection in water and wastewater treatment typically involves the destruction of viruses, bacteria, and protozoans (Tchobanoglous and Schroeder, 1987). Because chlorine is an oxidant, the amount required for disinfection is a function of the organic and NH_3-N concentration. Therefore, more chlorine is required for the disinfection of wastewater (40-60 g/m^3) than for domestic water supplies (2-5 g/m^3). Chlorine is usually added in the form of Cl_2 gas, chlorine dioxide (ClO_2), sodium hypochlorite (NaOCl), and/or calcium hypochlorite [$Ca(OCl)_2$] (Tchobanoglous and Schroeder, 1987). While chlorine is an excellent disinfectant, it can form compounds that are undesirable after dissolving in water. These compounds usually arise due to the amount of organic compounds found in the raw water. Trihalomethanes (THM's) and haloacetonitriles can be formed in the water system (Tate and Arnold, 1990). This reaction is discussed further in the Literature Survey section of this study.

Due to the occurrence of these potentially carcinogenic and toxic compounds, the United States Environmental Protection Agency (USEPA) decided to establish standards for drinking water pertaining to these materials. In 1986, the USEPA was required to set maximum containment level (MCL) goals for many drinking water contaminants as a result of amendments made to the Safe Drinking Water Act. Their first course of action was to develop a list of disinfectants and disinfectant byproducts (DBP) for regulation. The disinfectant byproduct rule (DBPR) was agreed upon in meetings during 1992-1993. This included MCL's for selected DBP's and maximum residual disinfectants levels (MRDL) for certain disinfectants, including chlorine. However, it was realized that the new MCL's and MRDL's alone might not account for all hazardous DBP's, including those which have not been identified. It was therefore determined that it was necessary to remove natural organic matter (NOM), the primary precursor for DBP formation, via coagulation prior to disinfection. By removing NOM from the water, DBP's in the form of THM's will not have a chance to form during disinfection. The removal of NOM from a water supply is the focus of this study.

Pending EPA regulations may require that the maximum level of total organic carbon (TOC) be no higher than 2.0 mg/L in the water before the chlorination step (EPA, 1999). This organic carbon comes from the amount of NOM found in the water supply. Using a real water source from a water treatment facility, the goal of this study was to apply new techniques in order to keep the system in compliance. Optimization of the current coagulant, alum, as well as utilization of other coagulants were tried as methods to reduce TOC levels.

1.1 Background

The Northeast Mississippi Regional Water Supply has been providing water to the residents of the Tupelo area since 1991. The source water for this district is the Tombigbee River. The Water Supply sells water to 8 water supplier customers in Itawamba and Lee counties with a customer base of nearly 60,000. The treatment plant was designed by Ondeo Industrial, consisting of a flash mixer, 4 upflow pulsating clarifiers, and 12 Greenleaf filters. The filters are mixed media with anthracite and sand. The finished water storage capacity is 4.5 million gallons. The facility is capable of providing 18 million gallons per day. The yearly water sales volume varies between 8 - 10 million gallons a day depending on seasonal factors.

Figure 1.1 shows a PFD of the water treatment facility. The treatment plant uses many chemicals throughout the treatment process. Potassium permanganate is added after water is drawn into the system to oxidize iron and manganese to improve taste and odor. A side benefit of this chemical addition is that it helps control algae growth in the clarifiers. The chemical is fed based on demand with a set point goal of a 0.15 mg/L residual at the flash-mix. The typical feed dose is between 1 - 3 mg/L.

Aluminum Sulfate (Alum) is added as the primary coagulant. Lime is added at the flash-mix to maintain a coagulate pH of 6.8 due to the acidic nature of the alum solution. The lime feed rate varies from 0 - 25 mg/L. Cationic polymer is added to the system just beyond the flash-mix point to help control the sludge blanketing in the clarifiers. Chlorine is added just prior to the filters to disinfect the water. Sodium silica fluoride is also added at this point to provide systemic fluoride treatment to the customers, which promotes tooth and gum health. Lime is added to achieve a finished pH between 7.2 - 7.5. Finally, an ortho-phosphate blend is added at a feed dose of 1.25 mg/L to help with corrosion control.

The Tombigbee River watershed that provides water to the plant has a yearly turbidity average between 50 - 65 Nephelometric Turbidity Units (NTU). The raw alkalinity varies from 15 - 40 mg/L as $CaCO_3$ with a typical level of 30 mg/L. The total organic carbon in the raw water can vary from 3 - 12 mg/L. Iron, manganese and TOC levels are increased by 100-300% during rainfall events in the watershed. After a heavy rainfall the TOC level increases considerably due to runoff. TOC levels can vary widely as large amounts of precipitation occur throughout the year. A stream and current monitor is used to aid the operators with coagulant feed dose settings. Raw water turbidity can change from 30 to over 2,000 NTU in less than 24 hours during significant rain events. The most difficult water to treat in terms of TOC reduction is after the turbidity begins to recede. This is due to high levels of dissolved organic carbon (DOC) that is more difficult to remove than organic carbon that is suspended in the water. At that time, TOC levels remain high and color remains unsatisfactory even though turbidity has already returned to normal levels. Experience has shown that it is important to keep the coagulant at higher levels until the TOC levels return to those present before the rain event.

1.2 Objectives

The objective of this project is to assist the Northeast Mississippi Water District in obtaining and maintaining compliance with the EPA's current and pending Disinfection Byproduct Rules. According to these regulations, the Northeast Mississippi Water District must reduce their TOC levels in their finished water to below 2 ppm. The use of enhanced coagulation and precipitation to remove the NOM from the raw water using various coagulants from different companies was proposed as a means of achieving the treatment goal. The coagulation process was modeled using lab scale jar testing and NOM removal verified using TOC analysis. Although the primary objective was to remove NOM from the raw water supply to an acceptable level, the secondary objective was to do this in an economically feasible way. All coagulants and methods were evaluated on an economic basis as well as a technical effectiveness basis. To be considered technically effective, the coagulant was expected to reduce TOC levels to below 2 ppm. A technically ineffective coagulant was considered unacceptable regardless of price; likewise, a technically effective coagulant that is cost prohibitive is also unacceptable.

Twelve months of data were collected from the experiments described later within this study. Jar testing was utilized as a means to determine turbidity, hardness, alkalinity, TOC and DOC. Water was received on a semi-weekly basis and treated with varying coagulants and coagulant doses, then analyzed in the Mississippi State University Environmental Technology Research and Applications Laboratories. Samples were collected on a semi-weekly basis in order to evaluate all the candidate coagulants as well as the initial coagulant used by the Northeast Mississippi Water District, and to obtain data which would account for seasonal changes in the water quality as well as major rainfall events. All economic comparisons were based on the price of the Northeast Mississippi Water District's current coagulant. All tests run on the water were run in duplicate to determine the accuracy of our results.

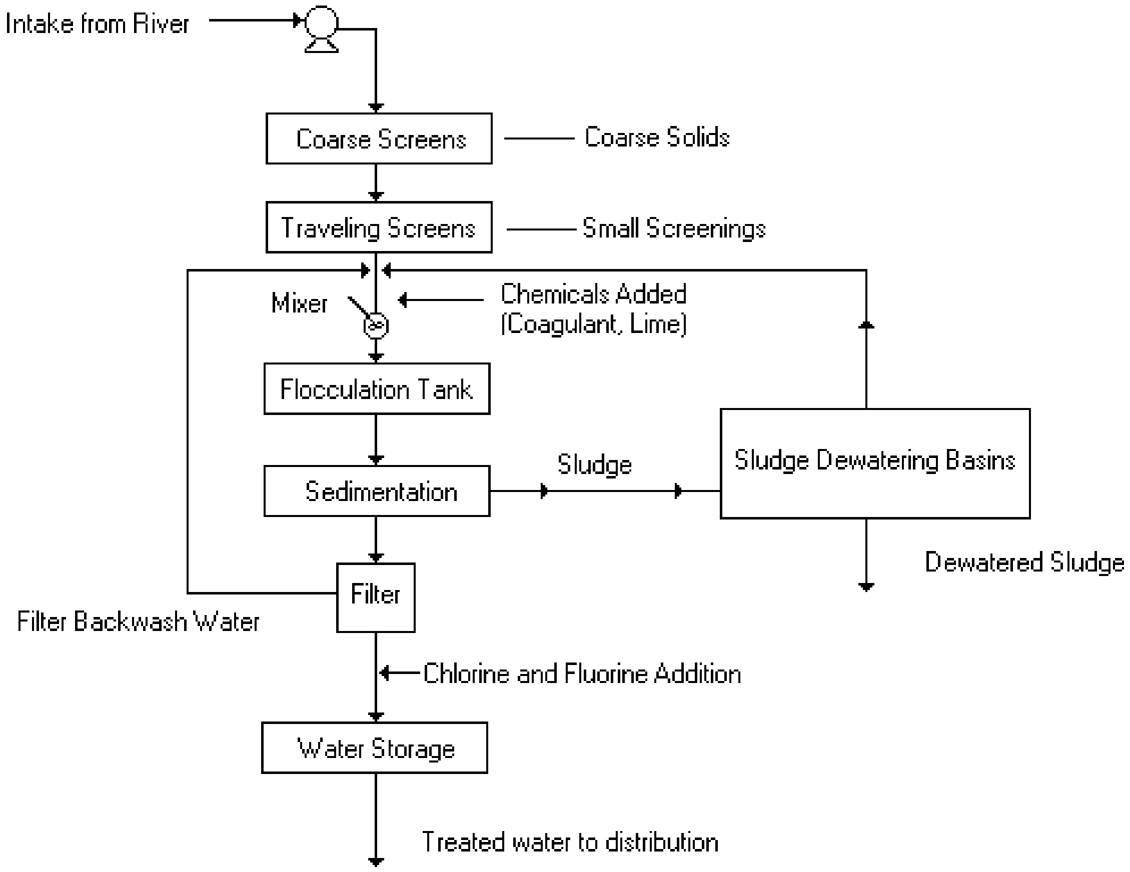


Figure 1.1 - PFD of the Water System (adapted from Tchobanoglous, 1987)

CHAPTER II

Literature Survey

In 1986, amendments were made to the Safe Drinking Water Act (SDWA) requiring that maximum contaminant level goals (MCLGs) be set for many contaminants found in drinking water. Acting on these amendments, the EPA developed a list of disinfectants and disinfectant byproducts (DBPs) for possible regulation. In 1994, the Disinfectant Byproduct Rule was established, forming MCLs for selected DBPs and maximum residual disinfectant levels (MRDLs) for selected disinfectants. The MCLs and MRDLs will provide security against potential health risks brought on by DBPs and disinfectants. However, it was realized that these levels imposed on drinking water standards may not be sufficient to address the risks associated with all DBP’s, including those that are yet to be identified. As a result, it was determined that natural organic matter (NOM), the primary precursor for DBPs, should be removed as well (EPA, 1999). Typically, removal of NOM is accomplished through coagulation and flocculation. Laboratory-scale jar testing is often used to determine the optimal coagulation scheme for the water treatment facility being observed.

The Northeast Mississippi Water District is not the only water district in the country dealing with this problem. Various systems across the United States have either recently undergone or are currently undergoing studies involving enhanced precipitation in order to reduce TOC in their water in accordance with the DBPR (Miltner et al., 1994). One such district is the City of Houston, Texas. Houston's researchers have tested several coagulants in the past few years hoping to find one that would meet the new standards without increasing raw material costs (Reavis et al., 2002). The coagulant being replaced, as in this study, is aluminum sulfate, or Alum. Evaluation of the data collected during the plant trial suggests that an acidified alum product can be used to achieve higher quality water at a reduced overall operating cost.

In the state of North Carolina, UNC-Chapel Hill performed a study pertaining to the DBPR where water samples from 22 water systems across the state were evaluated to see if they would meet the new standards set out by the EPA (Singer et al., 1995). It was found that only 7 of the 22 met the requirements of the proposed enhanced coagulation. It was determined that the remaining facilities would require significant transitional costs to obtain compliance with the proposed rules. However, effective turbidity removal was achieved in all cases where enhanced coagulation was used.

Facilities using surface water are not the only ones under the scrutiny of the EPA. The City of Long Beach, California uses groundwater as its main drinking water source (Cheng et al., 2000). The Long Beach Water Department has been treating this water with conventional filtration methods since the 1950's, but due to relatively high levels of naturally occurring organics in the groundwater, the DBPR requires a new methodology to be implemented. Several methods were tested and evaluated, and enhanced coagulation was found to be both cost effective and technically effective.

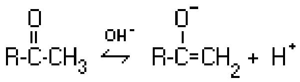
The desire to reduce DBP's is not just a problem in the United States. In Salerno, Italy, a study was performed on the city's municipal water system to determine how to reduce the production of THM's (Rizzo et al., 2004). Aluminum sulfate, iron chloride, iron sulfate, and polyaluminum chloride were evaluated to determine how their performance compared to one another. It was found that 30-50 mg/L of alum, 30-50 mg/L of $FeCl_3$, and less than 20 mg/L of PAC were required to meet desired TOC levels in their water. It was recommended that PAC be used in their treatment system.

Alum is the most common coagulant used in municipal water treatment, with iron salts coming in a close second (Pontius, 1990). However in recent years, preformed alumina species, such as polyaluminum chloride, have been touted for their ability to coagulate quickly and thoroughly (Amirtharajah, 1990). Preformed alumina species are synthetically produced compounds containing aluminum as the main coagulating element. Aluminum oxide, aluminum chloride, and aluminum chlorohydrate are examples. The biggest issue facing polyaluminum chloride blends is their basicity, or tendency to raise pH. It was found in the study performed by the City of Houston that a pH of around 6.5-6.8 was best for optimal coagulation (Reavis et al., 2002). This is consistent with data reported in other studies as well (Lee et al., 2000; Gregory and Carlson, 2003). When using alum, calcium carbonate, or lime, can be used to adjust the pH. However, the polyaluminum chloride blends are of varying basicity, making the need for pH adjustment irrelevant. Due to PAC's basic nature, the water to which it is added increases in pH.

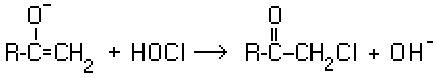
2.1 Disinfection Byproducts

The purpose of this project is to remove disinfection by-product precursors from the water supply. These DBP's are found in the form of organic carbon in the NOM. Organic carbon in the form of NOM combines with chlorine to form carcinogens and suspected carcinogens in the form of trihalomethanes (THM) and other molecules (Snoeyink and Jenkins, 1980). Trihalomethanes have the general form CHX_3, where X is Cl in this case. $CHCl_3$, chloroform, is a clear, colorless liquid with a characteristic odor. It was one of the earliest general anesthetics, but it is no longer used for this purpose due to its toxic effects. The recommended limit by the National Institute for Occupational Safety and Health (NIOSH) is 2 ppm based on a 1-hour sample collected at 750 L/min. Chloroform may produce burns if left in contact with the skin. It can also cause death due to liver damage and cardiac arrest. Exposure can cause lassitude, digestive disturbance, dizziness, mental dullness, and coma. Chronic overexposure has been shown to cause enlargement of the liver as well as kidney damage (Sittig, 1979). There is also evidence showing that chloroform is a carcinogen. Following long-term oral intubation at maximum tolerated and half maximum tolerated doses, chloroform was shown to be carcinogenic in rats and mice (Powers and Welker, 1976). In rats, malignant and benign primary kidney tumors were found while chloroform treated mice showed significant incidences of hepatocellular carcinomas.

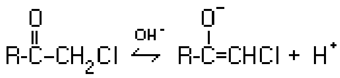
Organic carbon comes from natural organic matter found in the raw river water. NOM in rivers and lakes is a complex mixture of molecules with varying molecular weight and chemical nature and originates from a variety of sources, including the degradation of terrestrial and aquatic organisms, biological activity in the body of water, as well as inputs by humans (Masion et al., 2000). NOM includes all dissolved organic compounds, ranging from low molecular weight molecules, such as amino acids and urea, to high molecular weight compounds, collectively called humic substances (Egeberg and Roberts, 2002). The series of reaction steps which lead to chloroform formation during water treatment are (Snoeyink and Jenkins):



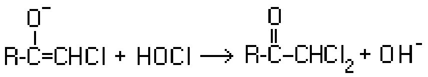
$$R\text{-}\overset{\overset{O}{\|}}{C}\text{-}CH_3 \overset{OH^-}{\rightleftarrows} R\text{-}\overset{\overset{O^-}{|}}{C}{=}CH_2 + H^+ \tag{1}$$



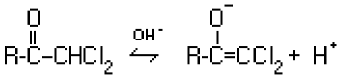
$$R\text{-}\overset{\overset{O^-}{|}}{C}{=}CH_2 + HOCl \longrightarrow R\text{-}\overset{\overset{O}{\|}}{C}\text{-}CH_2Cl + OH^- \tag{2}$$



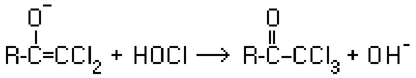
$$R\text{-}\overset{\overset{O}{\|}}{C}\text{-}CH_2Cl \overset{OH^-}{\rightleftarrows} R\text{-}\overset{\overset{O^-}{|}}{C}{=}CHCl + H^+ \tag{3}$$



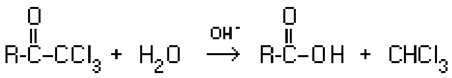
$$R\text{-}\overset{\overset{O^-}{|}}{C}{=}CHCl + HOCl \longrightarrow R\text{-}\overset{\overset{O}{\|}}{C}\text{-}CHCl_2 + OH^- \tag{4}$$



$$R\text{-}\overset{\overset{O}{\|}}{C}\text{-}CHCl_2 \overset{OH^-}{\rightleftarrows} R\text{-}\overset{\overset{O^-}{|}}{C}{=}CCl_2 + H^+ \tag{5}$$



$$R\text{-}\overset{\overset{O^-}{|}}{C}{=}CCl_2 + HOCl \longrightarrow R\text{-}\overset{\overset{O}{\|}}{C}\text{-}CCl_3 + OH^- \tag{6}$$



$$R\text{-}\overset{\overset{O}{\|}}{C}\text{-}CCl_3 + H_2O \xrightarrow{OH^-} R\text{-}\overset{\overset{O}{\|}}{C}\text{-}OH + CHCl_3 \tag{7}$$

The kinetically slow steps in the reaction series are (1), (3), and (5). These three steps are favored in the presence of OH^-, therefore the overall reaction proceeds more quickly at high pH (Snoeyink and Jenkins, 1980). Not all compounds with an acetyl group,

$COCH_3$, react rapidly enough to pose a problem during water treatment. For example, acetone does not react rapidly enough to be a major concern (Morris, 1978). However, the functional groups on most natural organic matter found in raw water undergo attack by chlorine to form chloroform very quickly. The major source for these groups is the humic substances found in the river water (Snoeyink and Jenkins, 1980.) Organic compounds in water and sediments are a mixture of biopolymers such as carbohydrates, lipids, and proteins, as well as complex and less well characterized macromolecules, generally referred to as humic substances (Vilge-Ritter et al., 1999). It is recommended that for the most accurate results, water samples from the actual source be used when trying to determine the optimal method for removing NOM from a specific source. This NOM can be removed from the raw water through processes called coagulation and flocculation.

Due to its complexity and heterogeneity, the chemistry of NOM is not well understood. It is for this reason that NOM is often characterized by one or several of its overall chemical properties. For example, pyrolysis-gas chromotography-mass spectrometry (Py-GC-MS) yields a fingerprint of the NOM and allows its classification into major categories of biopolymers (polysaccharides, polyhydroxy aromatics, amino sugars, proteins, etc.), thus giving an overview of the overall chemical nature of the NOM (Masion, 2000). As a result of this, it is possible to model a water system in the laboratory without ever acquiring water from the actual source. Synthetic waters made from concentrates of humic substances from reservoir and river waters can be tested in the laboratory and correlated to actual river conditions (Bolto et al., 2002). However, it is recommended that for the most accurate results, actual water from the source be used when trying to determine the optimal method for removing NOM from a specific source.

2.2 Coagulation

Coagulation is the destabilization of colloids by neutralizing the forces that keep them apart. Cationic coagulants provide positive charges to reduce the negative charge (zeta potential) of the colloids. As a result of this neutralization, the particles collide and form flocs, or clumps of particles. The coagulant works much like a magnet attracting tiny particles of metal. Once the particles are all stuck to the coagulant, the now heavier particle will settle to the bottom. During this stage of the process, rapid mixing is required to ensure complete dispersion of the coagulant through the liquid. Incomplete dispersion of the coagulant can lead to sections that have either too little coagulant to be effective or too much coagulant. Overdosing of coagulants can cause charge reversal and restabilize the colloid complex, causing the flocs to break apart and redisperse in the water. Overmixing in this stage of the process will not change the effectiveness of the coagulant, but insufficient mixing will.

Coagulation in water treatment is a process of combining small particles into larger aggregates for better settling characteristics. This best occurs in a pH range of 6.0-7.5 (Gregory and Carlson, 2003). Two mechanisms occur in this range: charge neutralization and the sweep-floc mechanism (Lee et al., 2000). Charge neutralization results from a specific chemical reaction between positively charged coagulants and the negatively charged colloids, thus leading to precipitation. This occurs at the low end of the pH range. The sweep-floc mechanism happens as the particles are destabilized by the aluminum and form large solid particles that will settle out or form flocs. Aluminum is commonly used as a coagulant due to its strong positive charge as an ion which helps neutralize the negatively charged colloid. A diagram describing the actions that transpire during coagulation can be found in Figure 2.1.

2.3 Flocculation

The flocculation step is a key process in drinking water treatment plants (Bouyer et al., 2001). The reliability of plant operation and the final water quality together with the problems of cost control are the most important issues facing water treatment, all of which hinge almost solely on the coagulation/flocculation process.

Flocculation is the action of polymers to form bridges between the flocs and other particles into larger clumps. Using a slow-mixing process, as was utilized in this project, the flocs and other particles bump into each other forming larger particles. Floc size continues to build due to the inclusion of anionic polymers that bridge the now positively charged particles into even larger blocks. Overdosing of the polymer can cause settling problems, since most polymers have a specific gravity of less than one. This can cause the newly-formed flocs to float. Mixing too rapidly can break the newly formed polymer chains and cause clarification problems, which can be as big a problem as TOC removal. Figure 2.2 shows how the flocs take in more particles as they settle out after the flocculation step.

The coagulation/flocculation process has been studied for many years. Smoluchowski first proposed a global description of the particle collision in 1917. The analysis was restricted to simple laminar flow and Brownian motion was not considered (Bouyer et al., 2001). Different systems with varying vessel or impeller geometries can have the same velocity gradient, but the floc particle size distribution can be different due to local stress and strain rates. It is for this reason that the jar test must be modeled as closely as possible to the conditions of the water treatment facility (Bouyer et al., 2001).

2.4 Jar Testing

Jar testing is a very common method used to simulate the conditions at an actual water treatment facility. Jar tests have been used globally to assess the effects of various coagulants and coagulant aides on local water sources (Ma and Liu, 2002). Jar testing is an experimental method where optimal conditions are determined empirically rather than theoretically, meaning that data are obtained via experimentation rather than using a theoretical calculation. The jar test is universally recognized as the most valuable and most commonly used tool for coagulation control. Jar testing in its earliest form was introduced as long ago as the 1930's (O'Melia, 1990).

Jar testing has been used in many states as the primary means of determining acceptable methods for attaining compliance with the DBPR. The Metropolitan Water District for Southern California used jar testing in its experiments to come up with a means of complying with the DBP precursor removal criteria (Krasner and Amy, 1995).

The Kentucky-American Water Company of Lexington, Kentucky worked with two small contiguous water systems experiencing elevated DBP levels to identify key factors and take actions to improve the water quality (Routt and Pizzi, 2000). Jar testing was implemented both on- and off-site in the study in order to attain a better understanding of the problems that were arising in the systems.

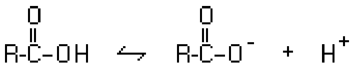
The City of Calgary, Alberta, Canada was studying the differences between their current alum and the proposed polyaluminum chloride at a large conventional water treatment plant to see if the PAC would perform better at reducing TOC levels, especially in cold water conditions (Elford, 2003). These experiments relied heavily on laboratory scale jar testing in order to make their final decision to implement the PAC in their system.

Jar tests are meant to copy the conditions and processes that take place in the clarification portion of water and wastewater treatment plants. In this case, the mixing speeds used in the laboratory tests were set to be modeled after the system currently used by the Northeast Mississippi Water District's treatment facility. The values that are obtained through the experiment are correlated and adjusted in order to account for the actual treatment system. The Northeast Mississippi Water district has done a considerably amount of jar testing in the past, and has determine that the values used in their studies, as well as those used in this study, best account for the current system. All jar tests were run in duplicate and all data represented in this study represent the mean value of the determinations.

2.5 pH Depression as a Coagulant Aid

In the 1980's, iron salts were introduced as an alternative to alum as a coagulating compound. They were shown to reduce TOC levels with dosages equivalent to that of alum. However, the reduction in TOC was more than likely due to the amount of sulphuric acid in the solutions. In order for an iron salt solution to have 10% Fe^{3+} in solution, excess H_2SO_4 was required to be in solution as well. While this acid does not act as a coagulant itself, it aids in coagulation in a number of ways.

First, humic acids, the main source of organic carbon in raw water, are less soluble in water at lower pH. The humic acids, denoted by R-COOH, are only slightly soluble, whereas the ionized form, $R\text{-}COO^- + H^+$, is far more soluble. Once solubilized, the humic substances are far more difficult to remove. By adding protons to the water in the form of an acid, the ionized form of these humic substances is far less likely to form (Steelhammer, 2000). This can be attributed to LeChatelier's Principle. This principle states that a system in chemical equilibrium responds to an imposed change in any of the factors governing the equilibrium, such as the concentration of one of the species (Sandler, 1999). In this case, the reaction is as follows:



$$R\text{-}\overset{\overset{\displaystyle O}{\|}}{C}\text{-}OH \leftrightharpoons R\text{-}\overset{\overset{\displaystyle O}{\|}}{C}\text{-}O^- + H^+$$

As protons are added in the form of acid, the reaction is pushed to the left, therefore keeping the humic substances in their non-ionized form. This form is far less soluble then the ionized form, and therefore easier to remove.

Secondly, it is well known that adsorption of soluble anions onto metal hydroxide surfaces occurs more readily in solutions with a pH of less than 7. Therefore, as the water pH is lowered, more organic anions are adsorbed onto the metal hydroxide flocs and removed via the sweep-floc mechanism.

Lastly, the charge neutralization method of coagulation can occur more readily in the presence of extra protons in the water being treated. Again, this is due to LeChatelier's Principle. When the aluminum coagulants are added to the water, they begin to undergo a hydrolysis reaction, as shown here:

$$Al^{3+} + H_2O \rightleftharpoons Al(OH)^{2+} + H^+$$

Once again, when protons are added to the water in the form of an acid, the reaction is pushed toward the reactants. The Al^{3+} ion has a greater positive charge than the $Al(OH)^{2+}$ ion, and therefore is better at performing charge neutralization. Also, the $Al(OH)^{2+}$ ion will continue to undergo similar hydrolysis reactions until reaching $Al(OH)_3$, which precipitates out of solution.

There is a considerable amount of research showing that pH depression aids in coagulation. Much of this research is not in the field of drinking water treatment, but rather, in wastewater treatment. A project where an olive oil-water suspension is used as a model for wastewater was conducted in 2004. Various coagulation techniques were implemented, but all were found to perform best at a pH of 6 (Meyssami and Kasaeian, 2005). pH depression was achieved in this study by the addition of sulfuric acid. In the paper manufacturing industry, it is widely understood that a pH under 7 is preferable for the coagulation of wastewater streams (Hatano, 2001). This information is not new, as papers dating as far back as 25 years state this as fact (Lickso, 1979).

There are also a few studies pertaining to pH reduction as a coagulation aid in drinking water treatment. A Korean study compared the coagulation potential of polyaluminum chloride sulfate (PACS) in water that had been preadjusted to a reduced pH via sulfuric acid to the coagulation of PACS in water with no pH adjustment (Lee et al., 2003). It was determined that a preadjusted pH of 6 before the addition of PACS provided the optimal performance of the coagulant.

In a study performed in South Africa, researchers determined that higher levels of organic matter were removed from the water when pretreated with acid. It was also found that the same amount of organics could be removed with less coagulant when the water was pretreated with acid (Freese et al., 2001). The City of Houston, Texas, also found that pH reduction by acid addition improved the ability of their alum to reduce TOC in their water (Reavis et al., 2002). The City of Houston evaluated a number of coagulants, including an acidified alum. Their report stated that not only did the acidified alum reduce TOC levels to the desired levels, but equivalent alum dosages were reduced by up to 40%, depending on water conditions.

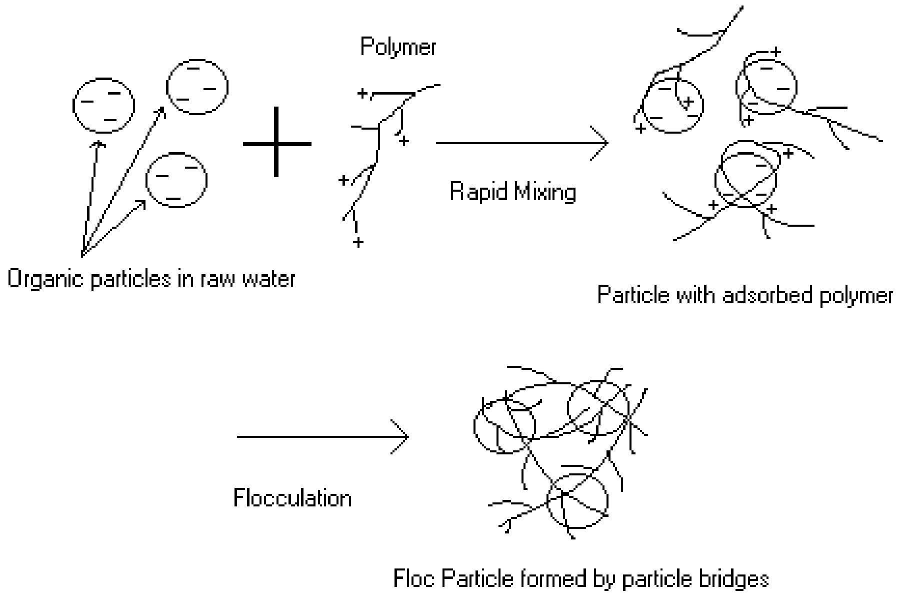


Figure 2.1 - Coagulation (adapted from Tchobanoglous, 1987)

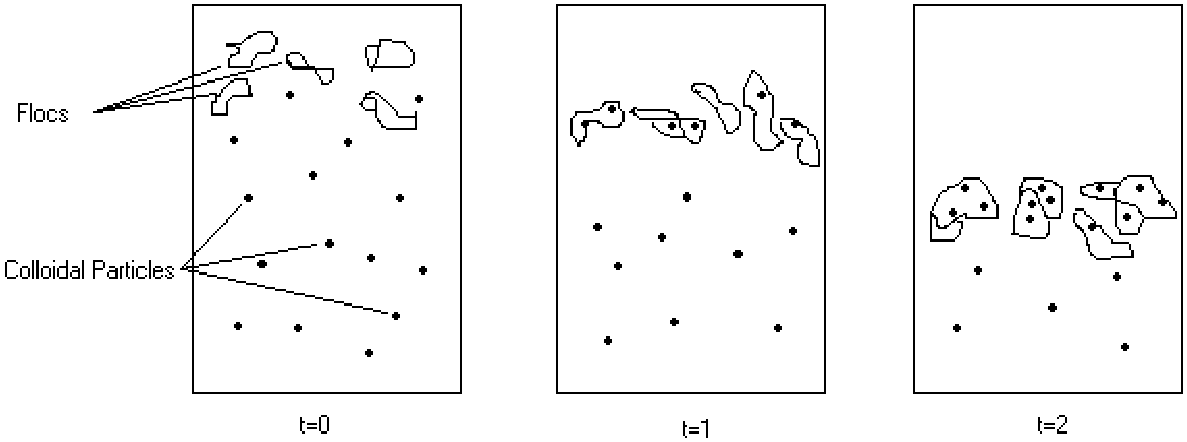


Figure 2.2 - Flocculation (adapted from Tchobanoglous, 1987)

CHAPTER III

Methods and Materials

This study utilized a number of pieces of analytical equipment, including a turbidimeter, a pH meter, and a TOC analysis machine. This chapter of the thesis describes in detail these pieces of equipment. This chapter also contains information pertaining to the coagulants and other materials used in this study. The coagulants included alum, acidified alum, iron (III) sulfate, hydroxoaluminum chloride sulfate, aluminum chloride, aluminum chlorohydrate, and three different polyaluminum chlorides. A brief description of each coagulant is shown in Table 3.1. This chapter also describes the water that was tested in the study, as well as the methods used in the study, including the statistical analysis program used to analyze the data.

3.1 Equipment

Laboratory Turbidimeter

Turbidity is the measure of the relative cloudiness of the water, using units of NTU's, or Nephelometric Turbidity Units. The instrument and standards used in this study were made by HF Scientific (Ft. Myers, Florida). The Micro 1000 Laboratory Turbidimeter utilizes five separate detectors to calculate an average reading in NTU's.

The turbidimeter was calibrated every day using standards ranging from 0.02 NTU to 1750 NTU. A picture of this instrument is given in Figure 3.1.

pH meter

The pH meter used in this study was an UltraBasic Benchtop UB-10, made by Denver Instrument (Arvada, Colorado). Its range is from 0-14 and was calibrated every day using standards of 4, 7, and 10 pH. A picture of this instrument is shown in Figure 3.2.

Jar Testing Apparatus

The two jar testing systems used in this study were built specifically for MSU by EC Engineering (Edmonton, Alberta, Canada). Each machine consists of 6 one-liter rectangular jars being mixed by stirrers powered by an electric motor. The mixing speed can be controlled by a knob, which changes the revolutions per minute (RPM) of the mixing blades. Injections of coagulant and lime were made via syringes which were held in place by a plastic rack above the jars. This rack also included baffles which were placed in the jars to aid in thorough mixing. The jars are lit from below by a fluorescent bulb, illuminating the reaction in the jars so that the user is able to get a good view of what is occurring. Two mixers were implemented in this experiment to get all the data in duplicate. A picture of the mixers is given in Figure 3.3.

Total Organic Carbon Analyzer

The instrument used to test for total organic and dissolved organic carbon (DOC) concentration was a TOC-5000A made by Shimadzu Corporation (Kyoto, Japan). This unit uses the combustion/non-dispersive infrared gas analysis method for TOC analysis. The combustion temperature is 680 °C and the range of analysis is from 4 ppb to 4,000 ppm. Analysis time per sample ranges from 5-10 minutes. Both solid and liquid modules are available to analyze samples. A picture of this piece of equipment is shown in Figure 3.4.

The TOC analyzer can test solid or liquid samples. However, the liquid analysis part of the machine was used exclusively in this experiment, since all samples consisted of water from the Northeast Mississippi Water District. The machine has an autosampler attached, and it was in this that all samples were placed for analysis. The TOC machine would then inject a needle into the vial and draw out a sample. A minimum of three samples were drawn from each vial and their values averaged.

Calibration curves were made using total carbon (TC) and inorganic carbon (IC) standards from SCP Scientific (Quebec, Canada). First, calibration standards were mixed from a 1000 ppm TC standard and a 1000 ppm IC standard. Values for the mixtures ranged from 10 ppm to 0.625 ppm. These values were used because the estimated TOC level range for the water was thought to be below 10 ppm under most circumstances. Total organic carbon (TOC) was measured by subtracting the measured IC value from the measured TC value. Similarly, dissolved organic carbon (DOC) was determined by taking water from the jar testing systems and filtering it through a 0.45 µm filter before testing. These methods of TOC and DOC analysis were used on all samples of the Tupelo water.

3.2 Materials

The concentration of all coagulant solutions was determined using the method described in the Enhanced Coagulation and Enhanced Softening Guidance Manual (EPA, 1999). Appendix A provides an example of how this value was determined using the EPA's method of equivalent alum dosages.

Alum

Alum, or aluminum sulfate, is a common coagulant used in municipal water treatment. This chemical is currently being used by the Northeast Mississippi Water District in their facilities. It is produced by Geo Specialty Chemicals (Cleveland, Ohio). It has a specific gravity of 1.33 g/mL. When used with the water from the NE MS Water District, it requires the addition of lime to return the pH to the optimal level of around 6.8. The alum that was used in this experiment was diluted to 10 mL of concentrate per liter in order to match the conditions at the plant.

Lime

Lime, or calcium oxide, is a widely used commodity in the water industry. It is mostly used to aid in the optimization of pH levels during coagulation of raw water. Powdered lime from the NE MS Water District was delivered to the MSU E-Tech

Laboratory at the beginning of the experiment to be used in conjunction with the alum as well as any other coagulants that might need pH adjustment. It is produced by Arkansas Lime Corporation (Batesville, Arkansas). The lime solution had a concentration of 1 g/L.

SternPAC

SternPAC is the product name of one of the commercial coagulants used in this study. It is produced by Eaglebrook Inc. (Brantford, Ontario, Canada). It is an aqueous solution of hydroxoaluminum and hydroxosulphatoaluminum chlorides. It has a specific gravity of 1.205. The solution used in the experiment was diluted at a ratio of 3.65 mL/L. Since the pH of the solution is 3, SternPAC did not require the use of lime to adjust the pH in the finished water. This chemical was chosen as to include a different type of polyaluminum chloride than those provided by the other manufacturers in the study. It was chosen to determine if a hydroxoaluminum chloride would sufficiently meet TOC standards as a coagulant for this water system.

Ferriclear

Ferriclear is the product name of another coagulant provided by Eaglebrook. Its active ingredient is $Fe_2(SO_4)_3$, or iron (III) sulfate. It is a commonly used coagulant in the water industry used to remove turbidity and NOM from raw water. It has a specific gravity of 1.49 and is a stable compound under normal laboratory conditions. The solution used in the experiment was diluted to a ratio of 16.9 mL/L. When used in conjunction with water from the NE MS Water District, Ferriclear requires the addition of lime to aid in the optimization of the pH for coagulation, due to the pH of solution being less than 1. Ferriclear was chosen for evaluation due to its popularity among water treatment facilities and the relative inexpensiveness of iron salts as coagulants.

SI-AA

SI-AA is the product name for the first of the coagulants from Southern Ionics (West Point, MS). It is a blend of aluminum sulfate, sulfuric acid, and water. It has a specific gravity of 1.30 g/mL and is considered a stable compound. This product is very similar to the alum that the NE MS Water district is currently using, with the exception of the addition of sulphuric acid. The solution evaluated in the laboratory was diluted by a ratio of 10 mL/L, identical to that of the initial alum from Tupelo. When used with water from the NE MS Water District, SI-AA required the addition of lime to adjust the pH to optimal conditions due to the solution having a pH of less than 1. This chemical was chosen to determine how acid added to a coagulant affects TOC removal properties of a coagulant.

SI-ACH

SI-ACH is the second of the coagulants tested from Southern Ionics. It consists of only two components: aluminum chlorohydrate and water. It has a specific gravity of 1.30 and is a stable compound. The concentration of the SI-ACH solution used in the laboratory was diluted at a ratio of 13.7 mL/L. Due to this coagulant having a pH of 4, no lime was required when using this coagulant with water from the NE MS Water District. This is important due to coagulation occurring in a narrow pH range, and this experiment utilized coagulants of varying pH in order to determine the effect of coagulant pH on TOC reduction.

SI-AC

SI-AC is the third and final coagulant used from Southern Ionics. It is a solution of aluminum chloride ($AlCl_3 \cdot 6H_2O$) in water. It has a specific gravity of 1.27 and is stable under normal conditions. The solution used in our experiments was diluted at a ratio of 13.6 mL/L. SI-AC has a pH of less than 1, and requires the use of a substantial amount of lime to adjust the pH in coagulation when used with water from the NE MS Water District. Its highly acidic nature was one of the reasons it was chosen for the study, since this study was evaluating varying pH coagulants in order to determine their TOC removal abilities.

PAX-XL31

XL31 is the first of three coagulants from Kemiron Atlantic (Savannah, GA) evaluated in this study. It is a polyaluminum chloride blend with a polymer premixed. It has a specific gravity of 1.35 and is yellow in color. The solution was diluted at a ratio of 13.9 mL/L. XL31 has a pH of l.2, and requires the use of lime to adjust the pH accordingly during coagulation. Again, varying pH coagulants, in this case, varying pH polyaluminum chlorides, were evaluated to determine their effect on the final coagulation pH of the treated water.

PAX-XL37

XL37 is the second of the coagulants from Kemiron that was evaluated. Like XL31, it is a polyaluminum chloride blend with polymer premixed. It has a specific gravity of 1.25 and is also yellow in color. The main difference between XL31 and XL37 is the basicity. XL37 is far less acidic than XL31, having a pH of 3.3. It does not require lime to adjust the pH during coagulation when used with water from the NE MS Water District. The solution used in the experiment was diluted at a ratio of 13.7 mL/L.

PAX-4505

4505 is the last of the three coagulants from Kemiron. It is a polyaluminum chloride blend with a polymer premixed. It has a specifc gravity of 1.20 and is a clear liquid. Again, the pH increases in the 4505 to a value of 4. No lime is required when used with water from the NE MS Water District as a result of this. The solution used in the study was diluted at a ratio of 13.5 mL/L.

Water Samples

The water samples evaluated in this study were collected from the Tombigbee River near the Tupelo-Fulton area, which is located in the Northeast Mississippi Water District. The water samples were taken by a technician as the water entered the treatment facility so that the actual conditions of the treatment facility could be duplicated within the laboratory environment. Water was transported via 8-liter plastic jugs and delivered to MSU by a courier approximately every two weeks. Initial water turbidity ranged from 30 NTUs to 350 NTUs and initial TOC concentration ranged from 4 ppm to 12 ppm. Alkalinity of the water ranged from 20 to 50 mg/L as $CaCO_3$. Alkalinity, TOC, and turbidity varied with the season, as well as the amount of rainfall occurring over the time prior to sampling. When not being used, the sample bottles were stored in the refrigerator at 4°C to keep algae and other microorganisms from growing in the water samples. After each use, the jugs were scrubbed and rinsed with soap and water, rinsed with 2 M nitric acid, and then rinsed again with distilled water. The jugs were then sent back to Tupelo to receive further samples.

3.3 Experimental Procedures

All experimentation, when applicable, follow the methods laid out in the Enhanced Coagulation and Enhanced Softening Guidance Manual (EPA, 1999). All jar tests were run in duplicate, and all data represented in this study represent the mean value of the two determinations.

The jar testing procedure utilized is as follows: first, jars were rinsed with 2 M nitric acid to remove any excess carbon; they were then rinsed with distilled water and allowed to dry. Next, one liter of raw water was poured in each of the six jars on the two mixers. The water was allowed to reach room temperature since it had been kept in the refrigerator at 4°C. The water was brought to room temperature due to the facts that coagulation does not occur readily at low temperatures, and it was desired to reproduce the conditions of the plant as well as possible. Once the water reached 25°C, the mixers were set to the rapid mix speed of 80 rpm. The mixing speeds used in the laboratory tests were selected as to mimic the system currently used by the Northeast Mississippi Water District's treatment facility. Varying concentrations of coagulant test doses were added to each jar, starting with zero in the first and the highest concentration in the sixth. The jars were subjected to a three minute rapid mix time. This was done to ensure complete dispersion of the coagulant throughout the mixture. After the rapid mix stage, the mixer speed was set to 30 rpm, thus allowing for the flocculation stage of the experiment to occur. The mixers ran for fifteen minutes at this setting. After fifteen minutes, the mixers were turned off and the sample allowed to settle for two hours.

After a two hour settling time, the sampling portion of the procedure was initiated. First, 50 mL samples were drawn into acid-washed plastic measuring cups. Samples were drawn from these cups into acid-washed glass syringes and placed in TOC analysis vials. Approximately 6 mL of water was used in each TOC sample. Samples were taken for both TOC and DOC. DOC samples were taken in the same method as TOC samples, except that they were passed through filters that had been rinsed with distilled deionized (DDI) water. Filters were 0.45 µm, constructed of nylon, and manufactured by Ionics Inc. (Waterton, MA). Twelve samples per mixer were generated for TOC analysis during each run, yielding a duplicate set for each condition tested.

Turbidity was also evaluated at this point. Three vials specifically made for use in the turbidimeter were filled with approximately 20 mL of treated water and placed in the turbidimeter for analysis. Two raw samples and 10 treated samples were evaluated for each run. The turbidimeter vials did not require acid washing, since they never came into contact with anything involved with the TOC analyzer.

Another element of the testing was pH analysis. Raw water and treated water from each jar were analyzed using the pH meter. The pH meter probe was placed into each of the 50-mL plastic measuring cups and a reading was taken and recorded.

After all of the above detailed sampling efforts were completed, alkalinity analysis was performed. This was done in accordance to methods in Standard Methods for the Examination of Water and Wastewater (Clesceri, 1998). The water was titrated with 1 M HCl to determine its alkalinity and the value recorded. Values were determined for both raw and treated water. The following formula was used in the calculation of alkalinty:

$$\text{Alkalinity (mg/L CaCO}_3\text{)} = (A * N * 50000) / \text{mL sample}$$

where

A= mL acid used in the titration
N= the normality of the acid used

Statistical analysis was also performed on the data. Data were analyzed using an analysis of variance statistics procedure. This was conducted using Statistical Analysis System (SAS) Version 8.02 and utilized an ANOVA computation with a Waller-Duncan statistical function (SAS, 2005). The independent variables utilized for this analysis were the coagulant, sample date, coagulant dose, and replica. Separate analysis was performed for each dependent variable. These included TOC, DOC, and turbidity. Results of the analysis are presented in the Results chapter of this study.

Figure 3.1 - Laboratory Turbidimeter

Figure 3.2 - pH meter

Figure 3.3 - Jar Testing Apparati

Figure 3.4 - Shimadzu TOC-5000A

Table 3.1 - Coagulants Utilized in Study

Coagulant Name	Dilution Used (mL/L)	pH	Specific Gravity g/mL
Alum	10.0	1	1.33
Ferriclear	16.9	<1	1.49
SternPAC	3.65	3	1.21
PAX-XL31	13.9	1.2	1.35
PAX-XL37	13.7	3.3	1.25
PAX-4505	13.5	4	1.2
SI-AA	10.0	<1	1.3
SI-ACH	13.7	4	1.3
SI-AC	13.6	<1	1.27

CHAPTER IV

Results

Data were accumulated starting in May of 2002 and ending April of 2003. The TOC values for the raw water analyzed over the course of the year are shown in Figure 4.1. Figure 4.2 shows TOC and turbidity throughout the year of testing. As evident from this figure, turbidity and TOC levels tend to rise together, but turbidity tends to recede before TOC levels. This shows that a direct correlation between turbidity and TOC is not always apparent.

It was expected that turbidity and TOC values would increase as precipitation accumulated and drained into the Tombigbee River. As a result, rainfall amounts were compared to the TOC and turbidity data collected in the laboratory. The total rainfall in the 72 hours previous to sampling was acquired from the National Climatology Laboratory Website (NCL, 2004) for the sampling dates in question and are plotted versus initial TOC and turbidity in Figure 4.3. This plot clearly shows the correlation between precipitation and initial water characteristics. As expected, turbidity and TOC levels rose as precipitation increased.

4.1 Summer 2002

On June 17, 2002, the first jar tests were implemented using the water from the Northeast Mississippi Water District. The initial samples had an average pH of approximately 7 and an initial turbidity of 31 NTU. Four candidate coagulants as well as the current coagulant being used by the Northeast Mississippi Water District were evaluated for their performance with this water. They were the alum from Tupelo, PAX-XL31, PAX-XL37, PAX-4505, and Ferriclear. Results typical of the water received during the summer of 2002 are shown in Figures 4.4-4.9. Initial average TOC levels were determined to be 5.04 ppm. As can been seen from the plots, four of the five coagulants performed well, with the polyaluminum chloride blend performing the best. The superior performance of the polyaluminum chloride is consistent with previous research cited in the literature survey section of this report (Rizzo et al., 2004). All three of the PAX products lowered the TOC levels below the desired 2 ppm limit, and two of them, XL-37 and 4505, required no addition of lime to control pH due to their high level of basicity. The higher basicity, or inclusion of hydroxide ions, of the XL-37 and 4505 is the reason for their superior performance in terms of TOC reduction. These larger molecules would perform better in the sweep-floc mechanism of coagulation while performing as well or better than the other PAC products due to their highly positive charge on the aluminum atoms. The sweep-floc mechanism was described in detain in the literature survey chapter of this thesis.

More water was received every week for a month, and each of the five coagulants were evaluated each time, with the addition of a sixth coagulant, SternPAC, after the first few weeks. This coagulant was added to the evaluations due to the desire to add an additional polyaluminum chloride compound to the study to determine if a different type of compound would perform well with the Northeast Mississippi Water District's water. Much success has been found in previous studies dealing with polyaluminum chloride compounds in terms of TOC reduction (Rizzo et al., 2004).

Due to the dry summer that North Mississippi experienced during 2002, TOC and turbidity levels were considered relatively low for the months of June, July, and August. Initial turbidity stayed around 25 NTUs for the first half of the summer, and spiked at 60 NTU on July 17 after a significant amount of precipitation fell in the days previous to sampling. However, turbidity dropped back into the 20's the following week, and declined to levels below 20 NTUs for the remainder of the summer. Initial TOC levels followed a similar pattern. Initial TOC levels for the summer were at 4.0-4.5 ppm, but dropped to levels between 3 and 3.5 ppm for this period. A maximum of 4.76 ppm was recorded on July 24, one week after the maximum turbidity for the summer was recorded. A maximum initial pH level of 7.93 was recorded on August 15. The pH range for the summer was typically between 7.0 and 7.5. A comparison of TOC and turbidity levels to the initial pH and alkalinity levels is given in Figure 4.10. There was no discernable pattern as to how the fluctuations of initial pH affected TOC and turbidity levels. Initial alkalinity levels ranged from 28-36 for the time period. Like pH, no pattern was detected for the effect of initial alkalinity on TOC or turbidity.

At this point in the research, the polyaluminum chloride products seemed to be the clear choices for attaining sufficient TOC removal in this process. They required only 75% as much product as compared to alum, and the higher pH coagulants required no lime addition for pH adjustment. However, it was clear at this point that the iron sulfate coagulant, Ferriclear, was not going to meet sufficient removal standards, having been unable to reduce turbidity levels to below 1 NTU. Many systems around the world had met with considerable success using iron salts as coagulants (Hamann et al., 1990). However, there are also documented situations where the iron salts do not perform as well as needed (Rizzo, 2004). The Ferriclear coagulant was unable to reduce TOC to the desired level consistently, and in most cases, the turbidity levels were also unacceptable after treatment, failing to reduce turbidity to below 1 NTU. The SternPAC coagulant, while doing a sufficient job at clarification, was also unable to reduce TOC levels to below 2 ppm. Typical results for these coagulants are found in Figures 4.5 and 4.6. A few runs were made during the fall using these coagulants, but it was determined that more coagulants should be evaluated in the future in lieu of continuing to evaluate these two coagulants. Comparisons of Ferriclear and SternPAC to the PAX products in terms of TOC and turbidity reduction are found in Figures 4.11 and 4.12.

4.2 Fall 2002

In September of 2002, Southern Ionics provided the project team with three coagulants to evaluate. These three coagulants were SI-AA (acidified alum), SI-ACH (aluminum chlorohydrate), and SI-AC (aluminum chloride). These three coagulants were immediately worked into the testing sequence. These coagulants were selected due to their range of basicity, or inclusion of hydroxide ions in the molecule, and because of the different coagulating compounds contained therein. This wide range of pH was expected to prove useful in obtaining the optimal coagulation pH in the finished water. The City of Houston, Texas had much success with these coagulants as well (Reavis et al., 2000).

The first few weeks of the fall were much like the summer; low initial turbidity and TOC. Initial turbidity ranged from 10 to 15 NTUs. Initial TOC ranged from 3.5-4.0 ppm. However, this all changed when a tropical storm came through North Mississippi, resulting in record amounts of rain. The first samples received after the tropical storm had an initial turbidity of 300 NTUs and an initial TOC of nearly 12 ppm. This new shipment of water pushed the abilities of the coagulants. Figures 4.13-4.17 show plots of the coagulants performance during the tropical storm. Only one of the coagulants evaluated, the aluminum chlorohydrate, was able to reduce the TOC levels to below 2 ppm, although the polyaluminum chloride blends came very close and probably would have met the reduction standards had more product been used. Reasoning as to why these particular coagulants performed best on this high-TOC water is two-fold. First, the PAC coagulants, such as SI-ACH and PAX-XL37, are made up of very large polymeric compounds that can attach themselves to a large amount of humic substances in the water due to their highly positive charges. This gives them an advantage in the coagulation step of charge destabilization. Secondly, once the flocs have formed, they are considerably larger than those of alum or aluminum chloride, and therefore a greater ability to adsorb organic material to their surfaces during the sweep-floc mechanism and flocculation steps.

Within a week of the major rain event, the initial turbidity levels dropped to between 100 and 150 NTUs; however, initial TOC levels remained at levels around 11 ppm. Typical plots of the coagulants evaluated in the fall of 2002 are shown in Figures 4.18-4.23. Alum still was unable to reduce TOC levels to below the 2 ppm limit, but the polyaluminum chlorides performed very well, achieving the goal of reducing TOC to below 2 ppm. This is, again, more than likely due to the polymeric nature of these coagulants. It had been shown in our previous experimentation prior to the major precipitation event that these polyaluminum chloride blends with polymer had been able to perform to the desired level with smaller doses under normal conditions. This is typical of synthetic organic coagulants utilizing a premixed polymer (Hamann et al., 1990). After seeing the results of their performance after the major precipitation event, it was assumed that these compounds were better at reducing TOC and turbidity during high TOC and turbidity loads. Within another week, initial turbidity levels had dropped to new lows of 5-10 NTU, but initial TOC levels continued to be above average at 8 ppm. All coagulants remaining in the study performed well on the remainder of water for the year.

It was determined at this time that an economic comparison of the coagulants should be made to determine which of the well performing coagulants was economically feasible. This comparison is found in the next section of the thesis. As a result of these findings, it was determined that SI-AA and SI-ACH should continue to be evaluated due to their performance and reduced cost. These coagulants, as well as the original alum from the NE MS Water District, would continue to be evaluated through the Spring of 2003.

4.3 Winter - Spring 2003

Winter in Mississippi is usually cold and wet, and 2003 was no exception. Due to the increased seasonal precipitation, initial turbidity levels were between 60 and 70 NTU and initial TOC levels were above 8. This gave data pertaining to high initial TOC water that was needed for a complete evaluation of the two top coagulants as well as the alum. Typical plots for alum and SI-AA during the spring are shown in Figures 4.24 and 4.25. Alum failed to sufficiently remove TOC to below the desired 2 ppm level, but reduced turbidity sufficiently. SI-AA and SI-ACH continued to perform well, removing TOC and reducing turbidity as desired. Due to the slightly basic nature of the water in the Northeast Mississippi Water District, coupled with coagulation's desire to occur at a pH of around 6.5 (Gregory and Carlson, 2003), acidified alum performed better than the normal alum. This is consistent with the performance of the low pH Southern Ionics aluminum chloride coagulant, SI-AC, and also the low pH PAX-XL31. However, the reduction of pH by the coagulant itself is not as dramatic as the reduction found when SI-AA is utilized. This increased pH reduction helps drive the hydrolysis reactions that occur when alum is introduced to water back toward the more positively charge Al^{3+} ion, instead of aluminum hydroxide, as described in the literature survey. Since more of the aluminum remains more positively charged, coagulation occurs more readily via charge neutralization and the destabilization of the negative colloid suspension in the water.

After all the data were recorded, a Duncan statistical analysis was performed on the data, as described in the Materials and Methods chapter of this study. SI-AA was found to be significantly better at reducing TOC, DOC, and turbidity. Results from this analysis are found in Tables 4.1, 4.2, and 4.3. According to the analysis, SI-AA was, with a 99% confidence interval, found to be significantly better at lowering TOC than the other coagulants. This statistical analysis reinforces the conclusion that SI-AA was better at removing NOM than the other candidate coagulants.

It was at this point that the SI-AA coagulant was determined to be the best product for the money. Not only was it less expensive than all the other products, but it sufficiently reduced TOC levels below the 2 ppm limit as desired. A direct comparison of the acidified alum versus the original alum on identical water from the Northeast Mississippi Water District can be found in Figure 4.26. This figure shows how the original alum fails to meet TOC removal goals while the acidified alum succeeds.

Results found in this project are consistent with trials run using SI-AA on different water systems. The City of Houston, Texas found SI-AA to reduce TOC and turbidity better than their previous alum, as well as reduce costs (Reavis et al., 2002). The reason for the SI-AA's superior performance is more than likely due to its low pH. This lower pH allows coagulation to occur within the low end of the optimal coagulation pH range, which better allows for charge neutralization to occur (Lee et al., 2000). This charge neutralization destabilizes the colloid complex, resulting in precipitation. Also, it is well known that adsorption of soluble anions onto metal hydroxide floc surfaces occurs more readily at pH's below 7 (Steelhammer, 2000). This allows for the sweep-floc mechanism of coagulation to occur more readily.

A filtered turbidity test was run on the water at this time to determine what the turbidity of the water treated with SI-AA would be after filtering. This test was suggested by people from the Northeast Mississippi Water District in order to make sure that the finished water would meet turbidity level standards. Treated water was run through a 0.45 µm filter and tested in the turbidimeter. The value was so low that it was below the calibration limits of the analyzer, and therefore was low enough to meet turbidity standards of 0.1 NTU in the finished water.

Table 4.1 - Analysis of Variance Using TOC as the Dependent Variable

Dependent Variable: TOC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	31	3236.46	104.4	90.92	< 0.0001
Error	784	900.206	1.148		
Corrected Total	815	4136.66			

R-Square	Coeff Var	Root MSE	TOC Mean
0.7824	36.618	1.072	2.926

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Coagulant	8	338.33	42.292	36.83	< 0.0001
Date	17	1966.1	115.66	100.73	< 0.0001
Dose	5	931.69	186.34	162.28	< 0.0001
Replica	1	0.29401	0.29401	0.26	0.6130

Table 4.2 - Analysis of Variance Using DOC as the Dependent Variable

Dependent Variable: DOC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	31	2551.2	82.296	112.86	< 0.0001
Error	784	571.68	0.7292		
Corrected Total	815	3122.9			

R-Square	Coeff Var	Root MSE	DOC Mean
0.8169	35.32	0.8539	2.418

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Coagulant	8	283.14	35.392	48.54	< 0.0001
Date	17	1587.9	93.405	128.09	< 0.0001
Dose	5	679.20	135.84	186.29	< 0.0001
Replica	1	0.96957	0.96957	1.33	0.2492

Table 4.3 - Analysis of Variance Using Turbidity as the Dependent Variable

Dependent Variable: Turbidity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	31	911502.4	29403.3	46.19	< 0.0001
Error	784	499105.6	636.614		
Corrected Total	815	1410608			

R-Square	Coeff Var	Root MSE	Turbidity Mean
0.6462	167.9	25.23	15.02

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Coagulant	8	130723.9	16340.5	25.67	< 0.0001
Date	17	675084.7	39710.9	62.38	< 0.0001
Dose	5	105191.0	21038.2	33.05	< 0.0001
Replica	1	502.877	502.877	0.79	0.3744

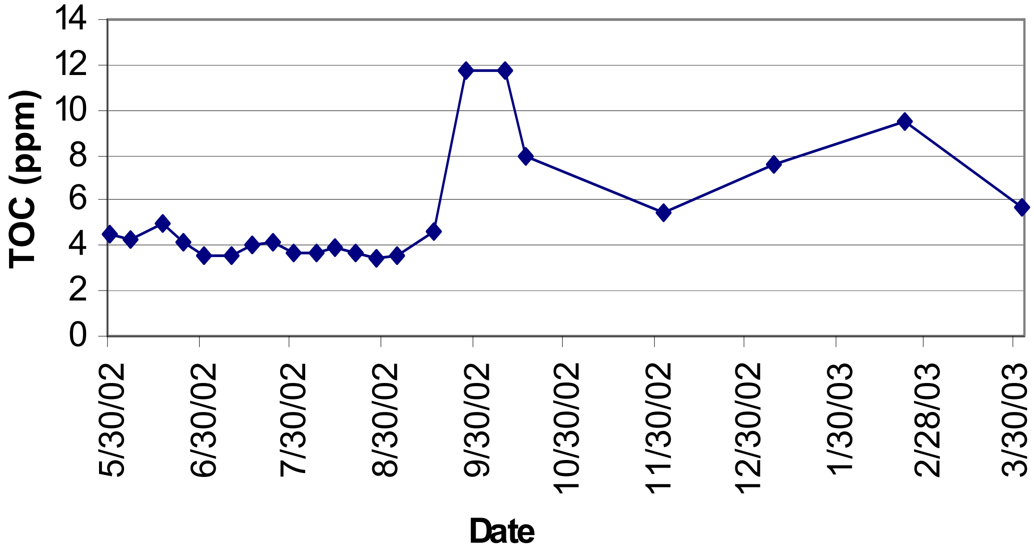


Figure 4.1 - Initial TOC Data for Raw Water, 5/30/02 - 4/6/03

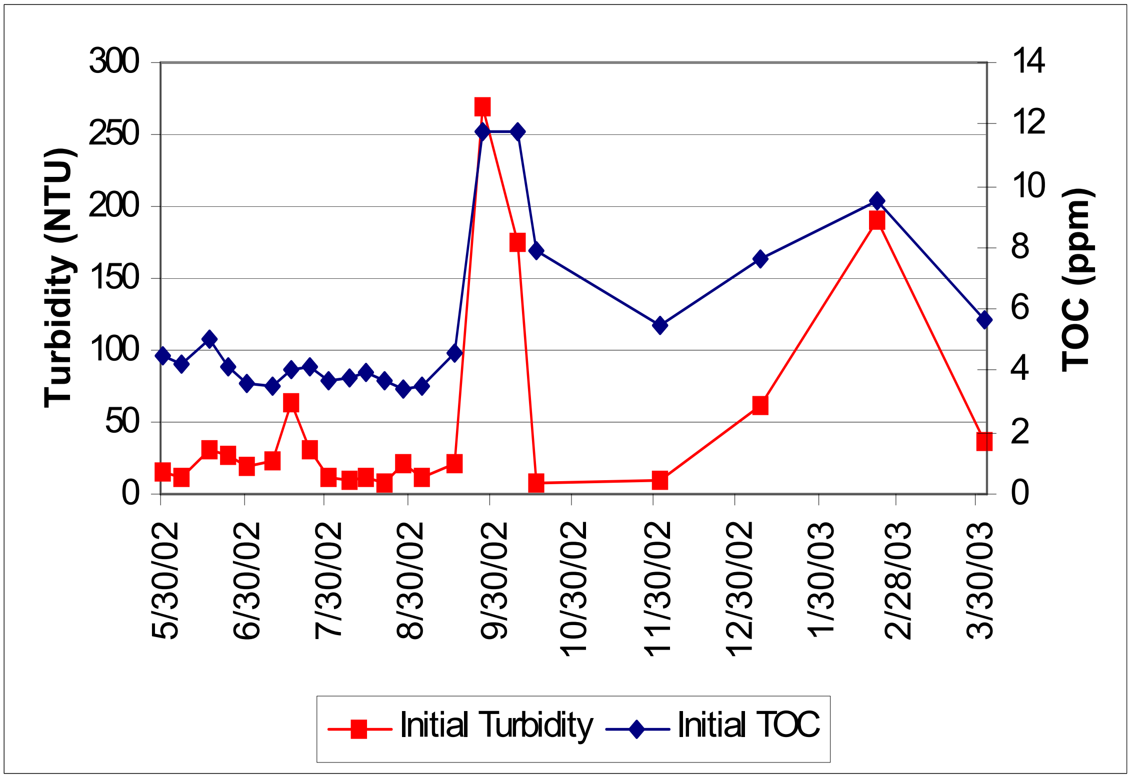


Figure 4.2 - Initial TOC and Initial Turbidity for Raw Water

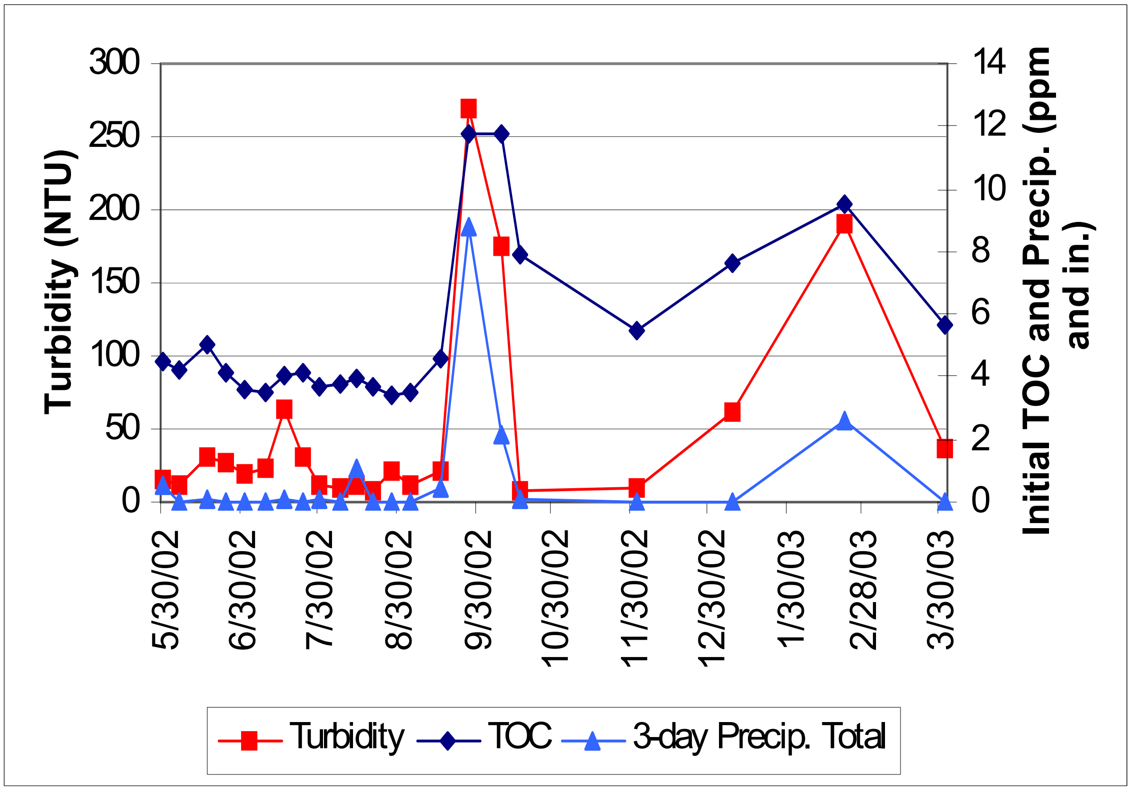


Figure 4.3 - Turbidity and TOC for Raw Water Compared to Precipitation Levels

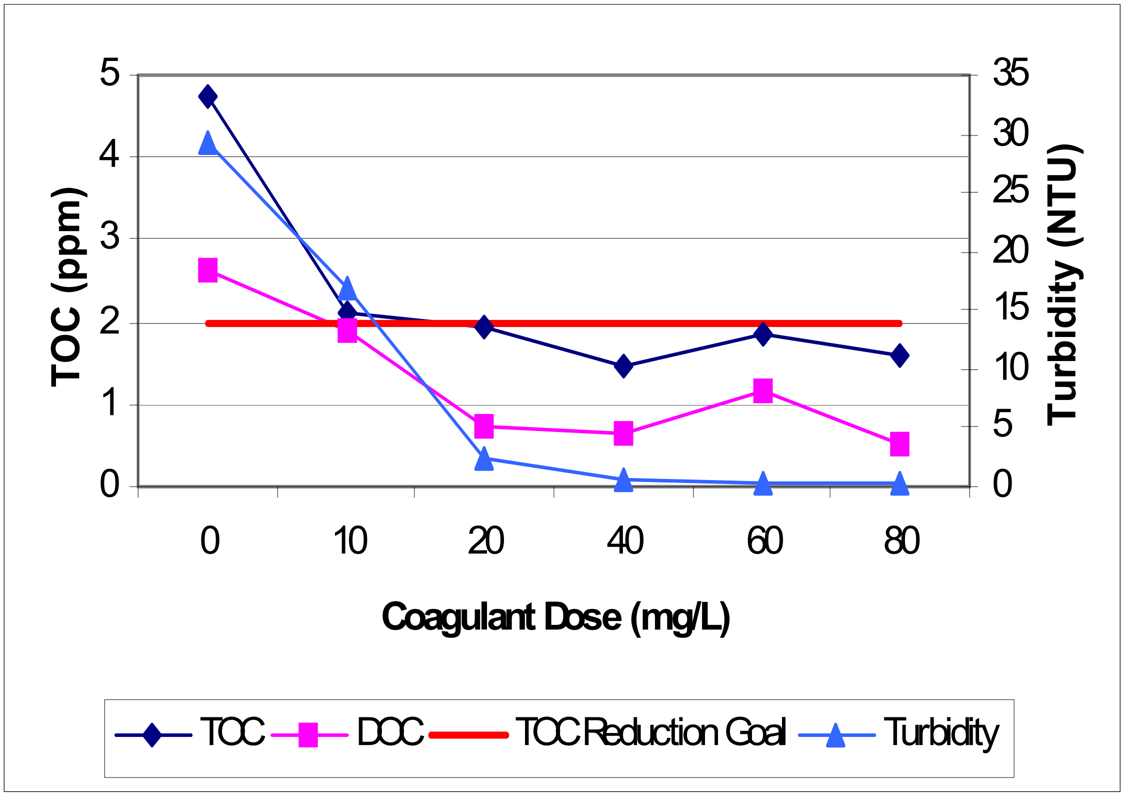


Figure 4.4 - Typical plot for Alum, Summer 2002

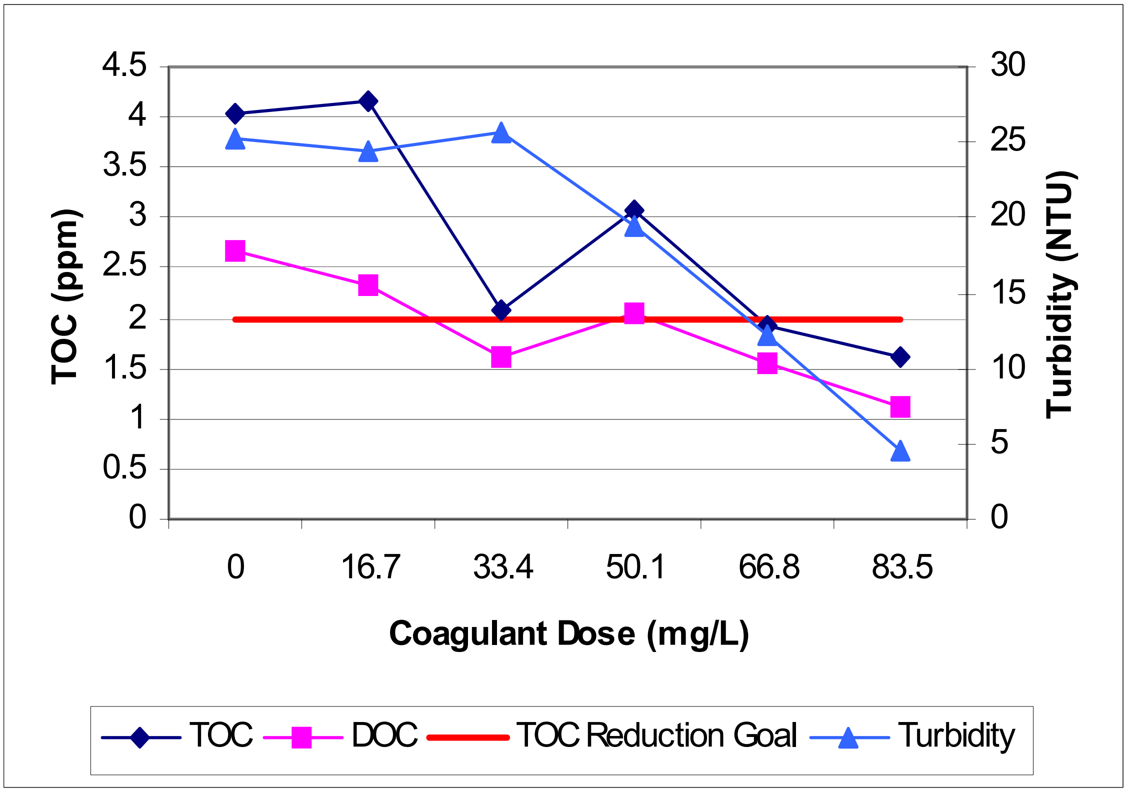


Figure 4.5 - Typical plot for Ferriclear, Summer 2002

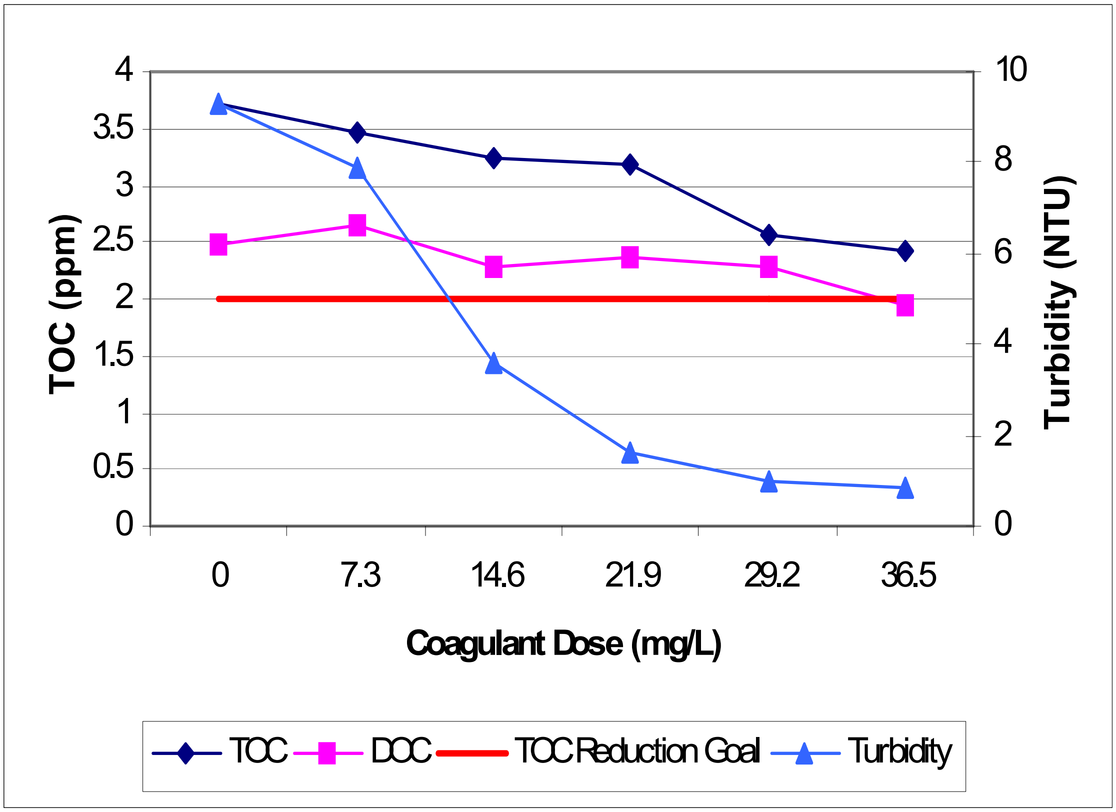


Figure 4.6 - Typical plot for SternPAC, Summer 2002

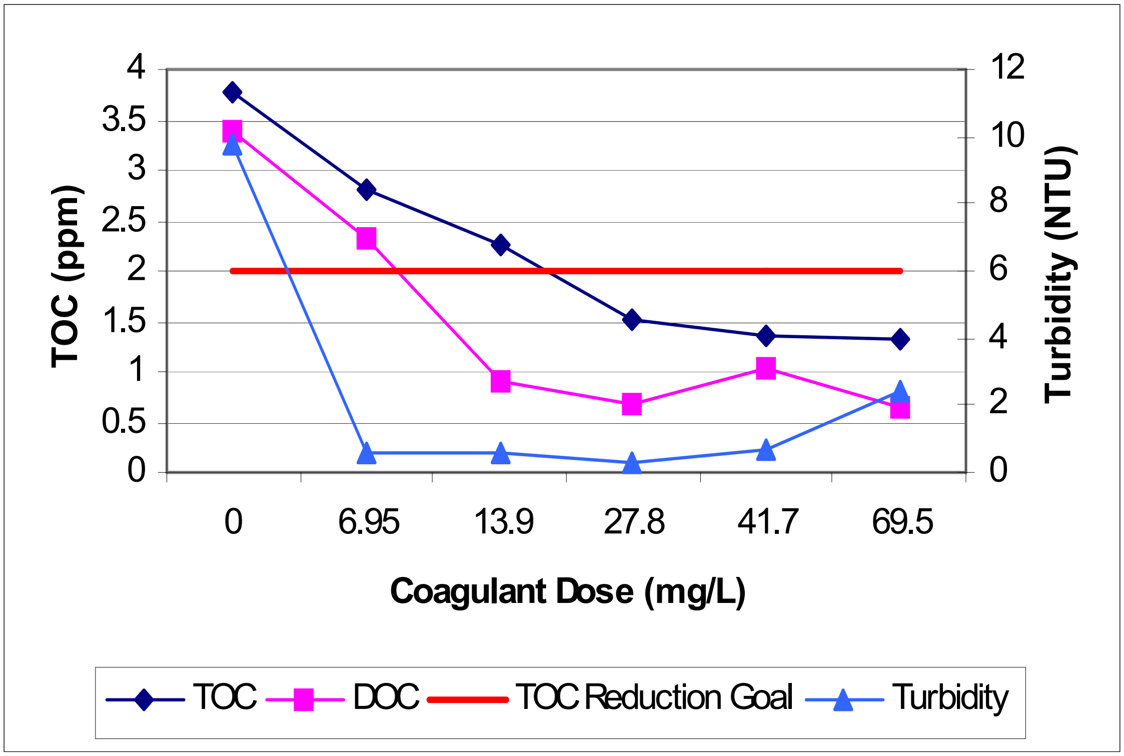


Figure 4.7 - Typical plot for PAX-XL31, Summer 2002

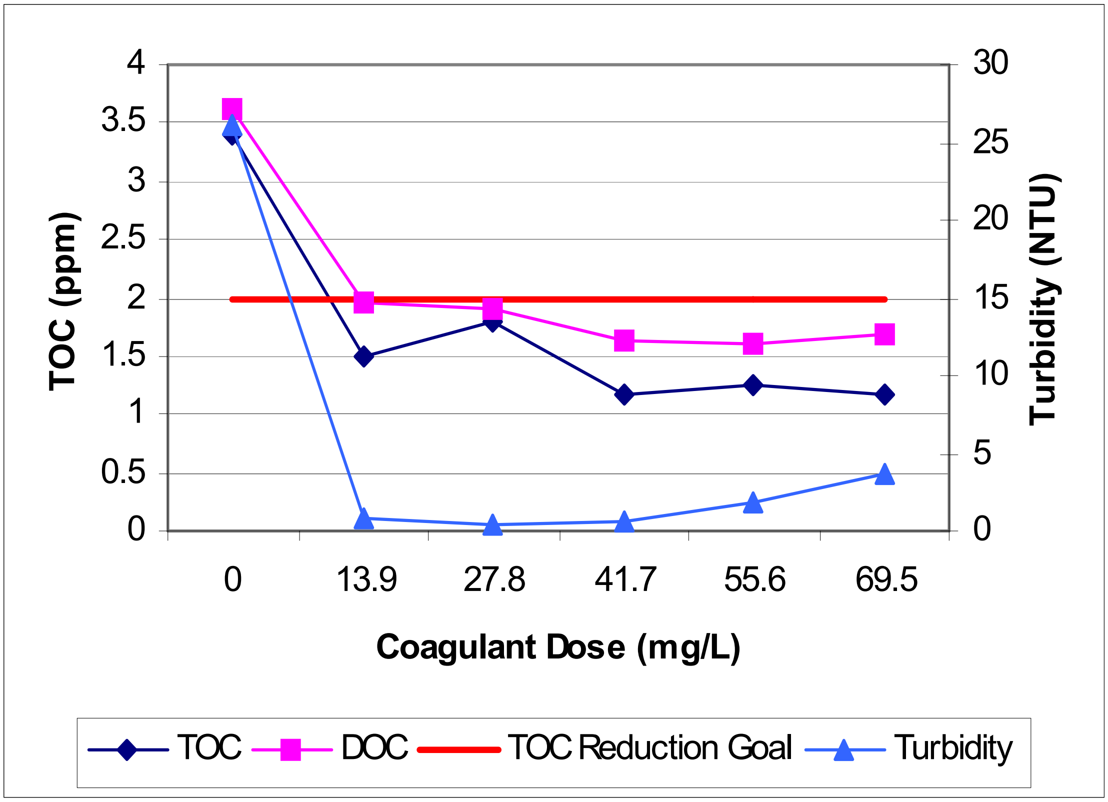


Figure 4.8 - Typical plot for PAX-XL37, Summer 2002

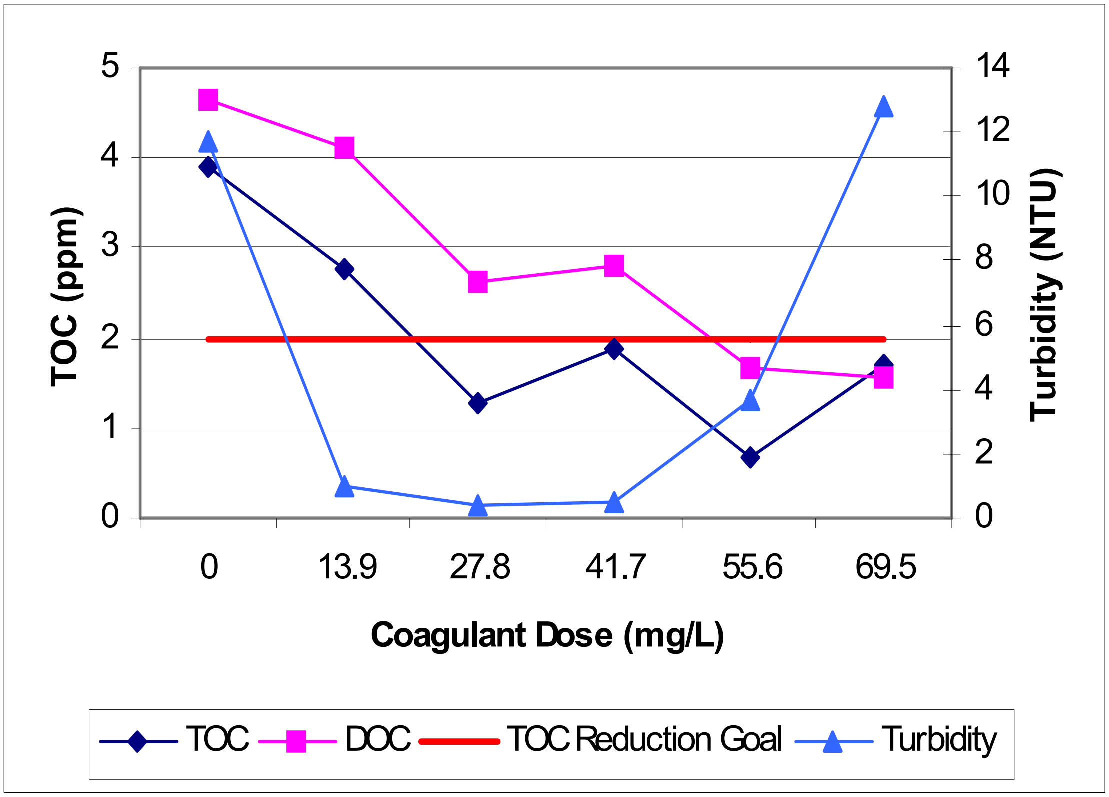


Figure 4.9 - Typical plot for PAX-4505, Summer 2002

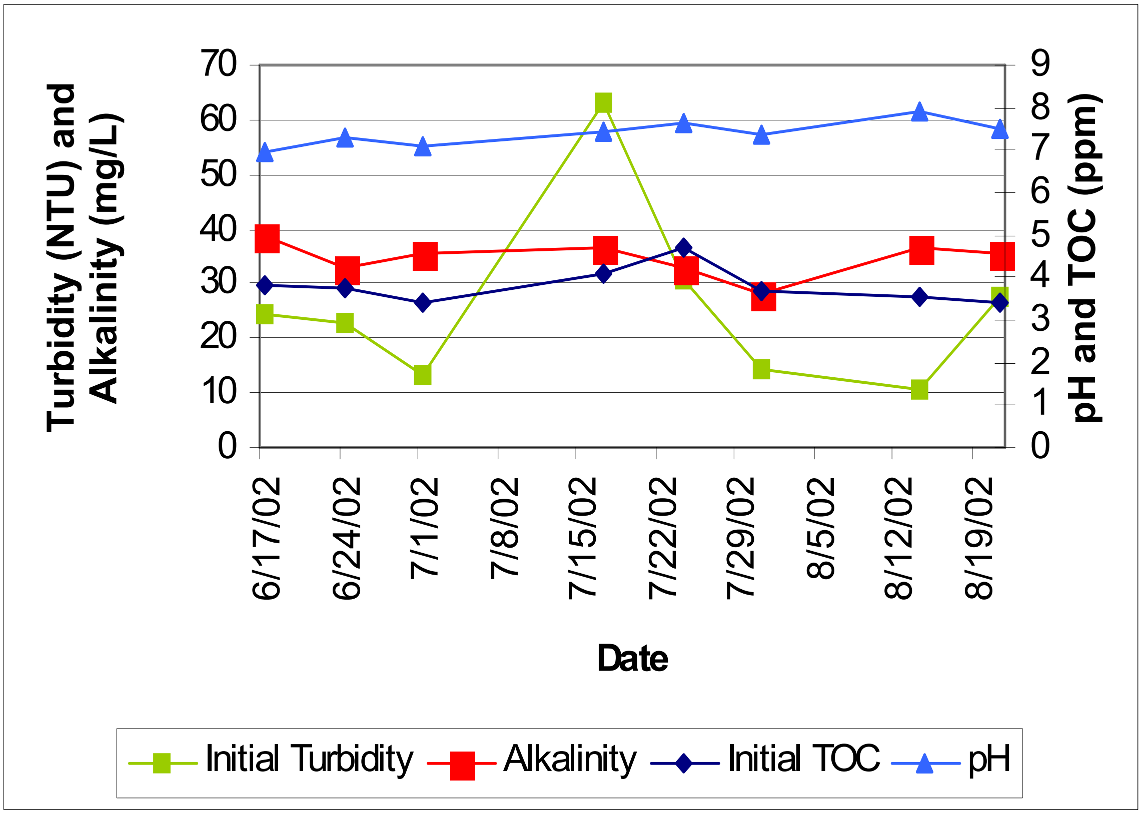


Figure 4.10 - Comparison of TOC and Turbidity levels to Initial pH and Alkalinity Levels

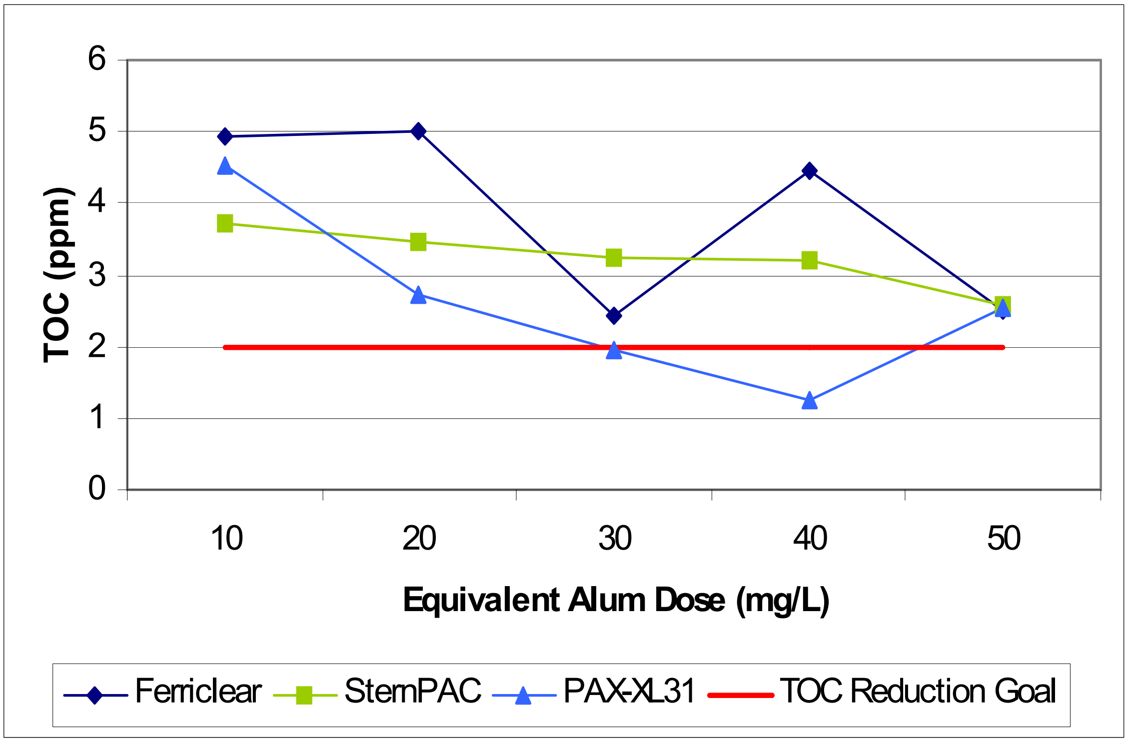


Figure 4.11 - Comparison of TOC reduction by Ferriclear, SternPAC, and PAX-XL31

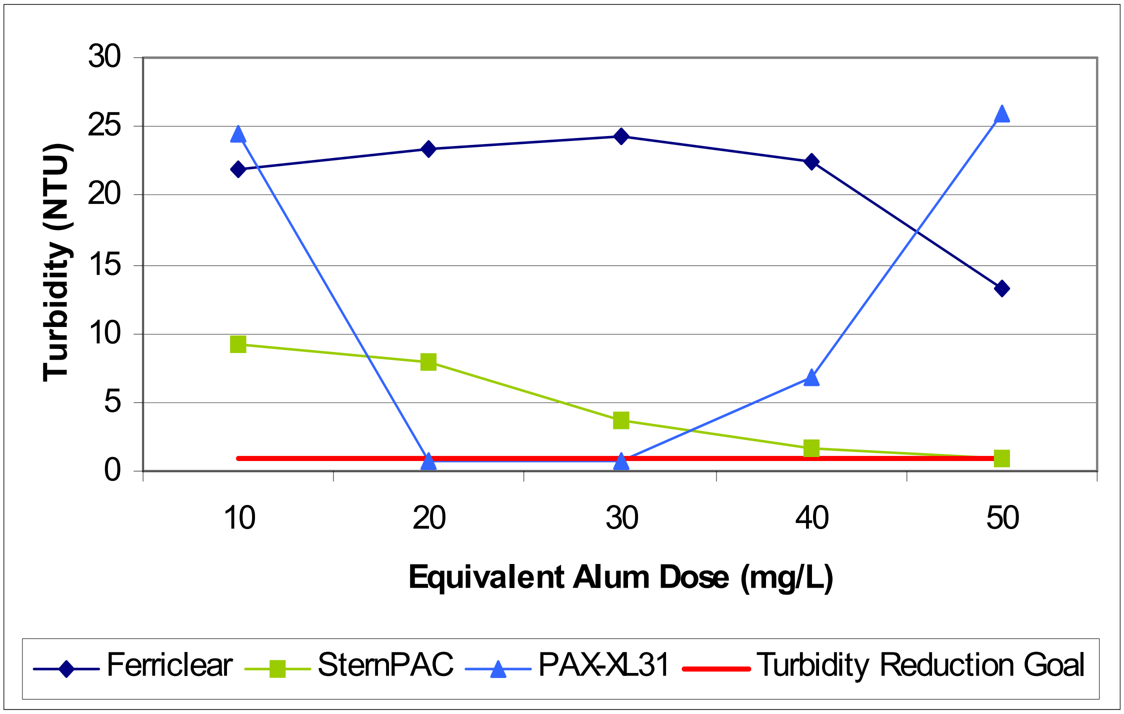


Figure 4.12 - Comparison of Turbidity Reduction: Ferriclear, SternPAC, and PAX-XL31

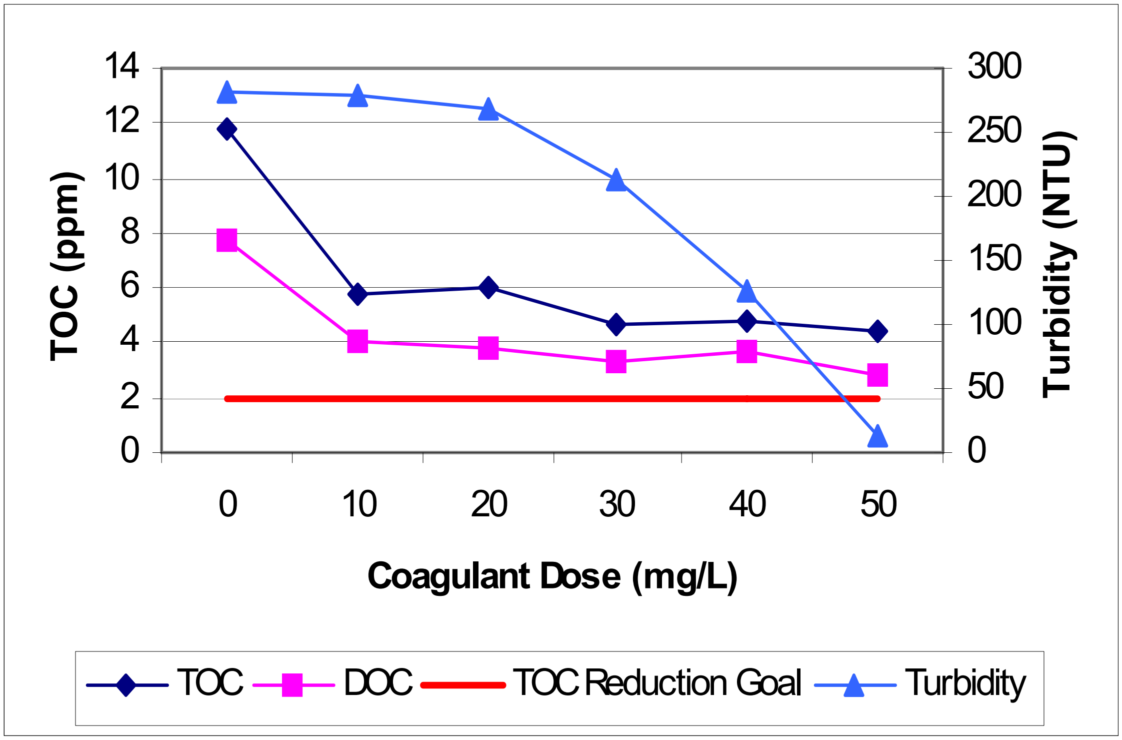


Figure 4.13 - Alum Performance After a Major Rain Event

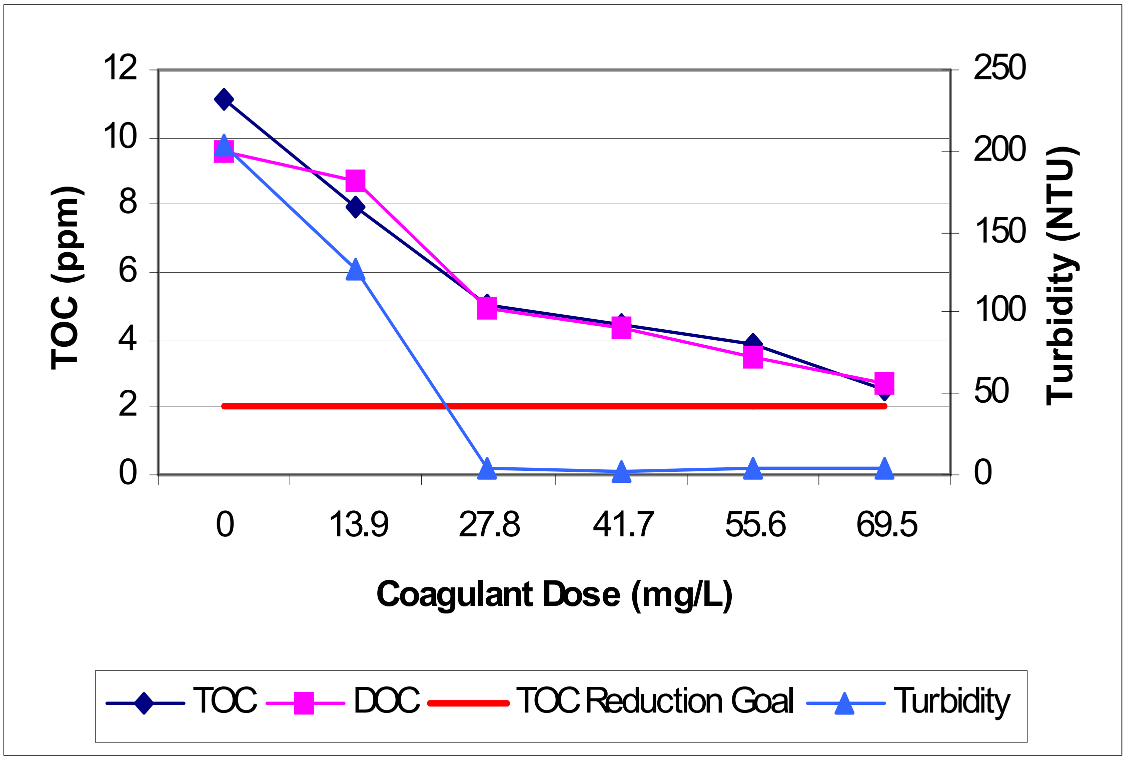


Figure 4.14 - PAX-XL31 Performance After a Major Rain Event

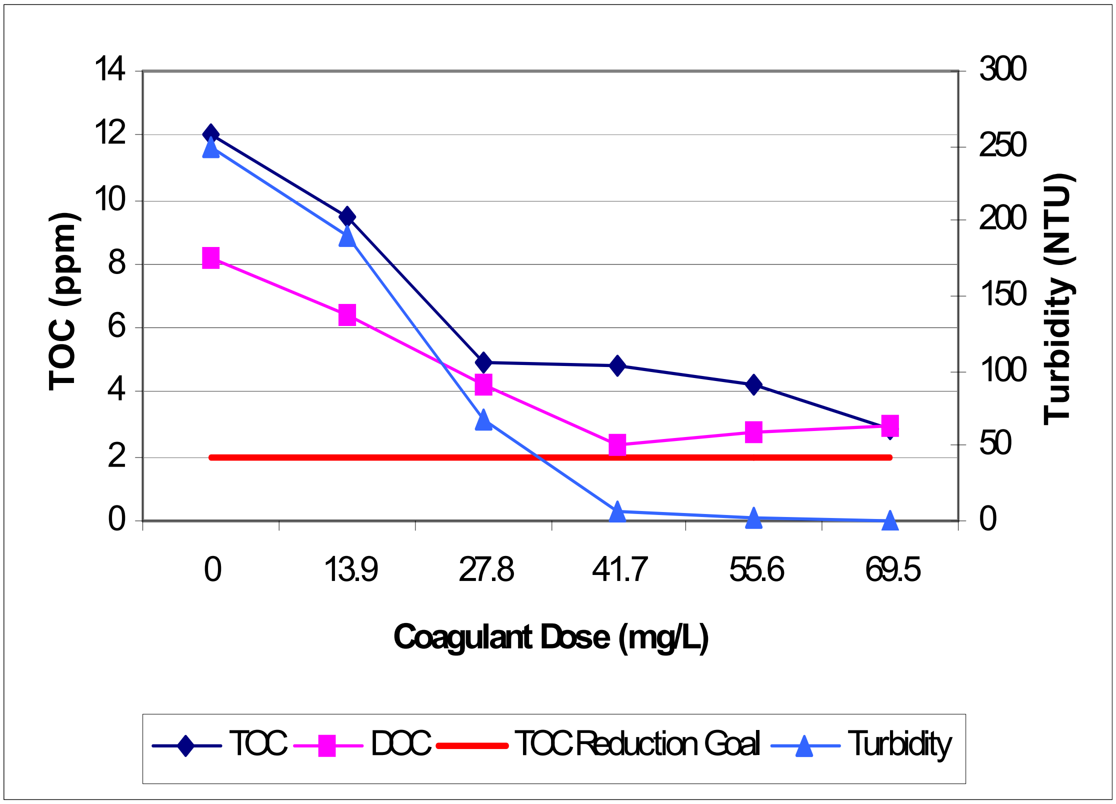


Figure 4.15 - PAX-XL37 Performance After a Major Rain Event

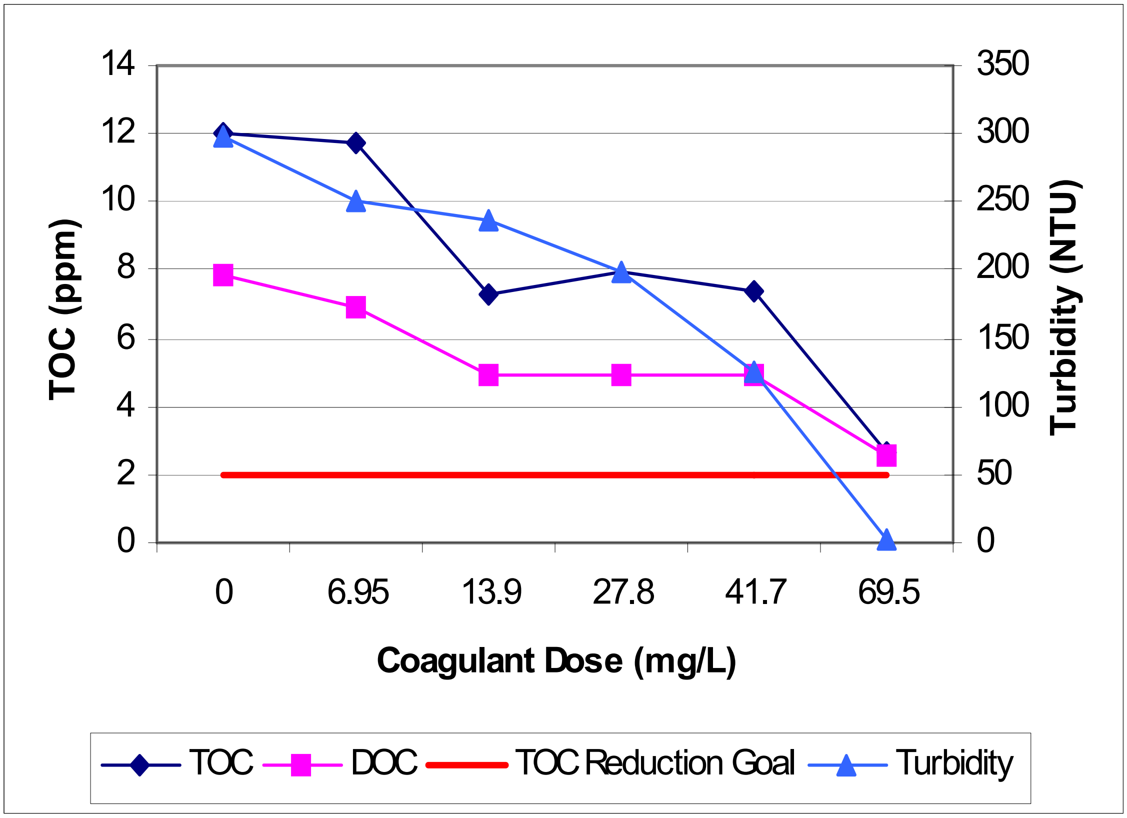


Figure 4.16 - PAX-4505 Performance After a Major Rain Event

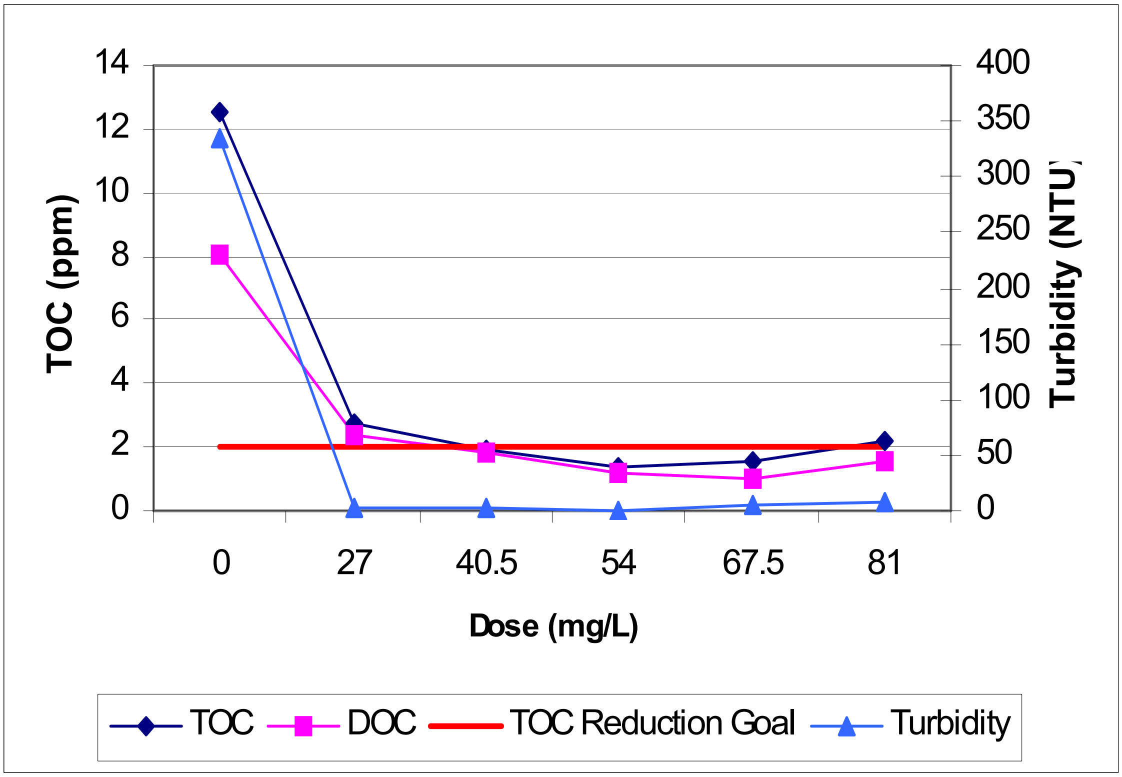


Figure 4.17 - SI-ACH Performance After a Major Rain Event

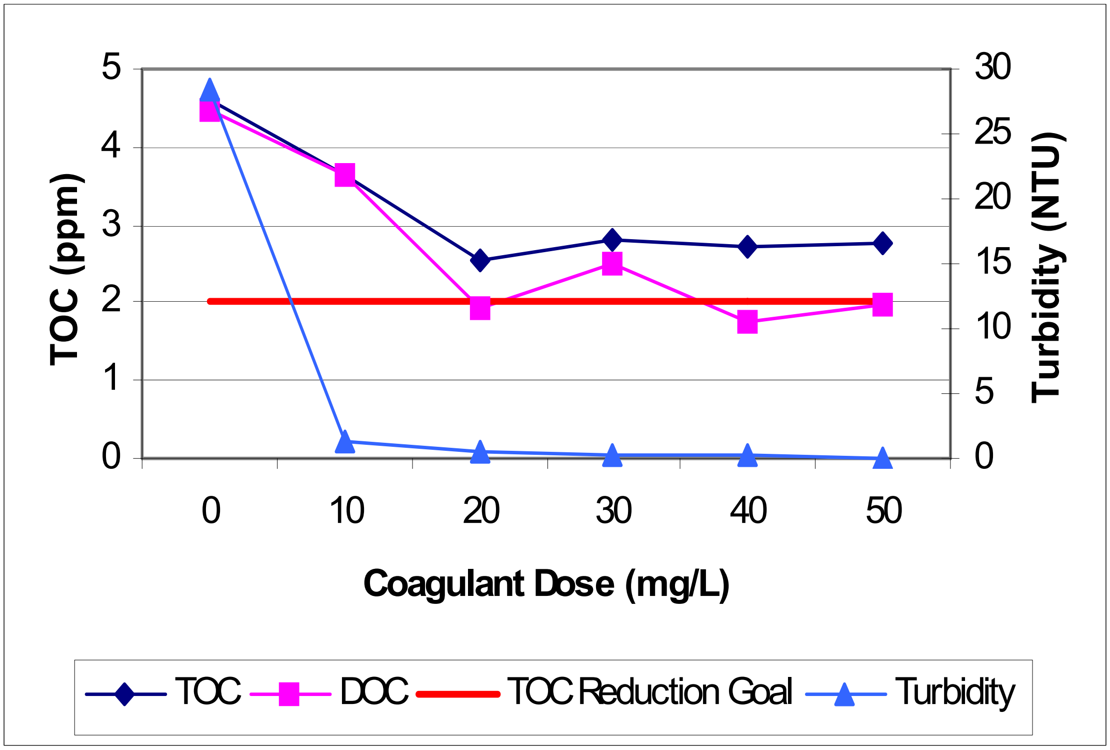


Figure 4.18 - Typical plot for Alum, Fall 2002

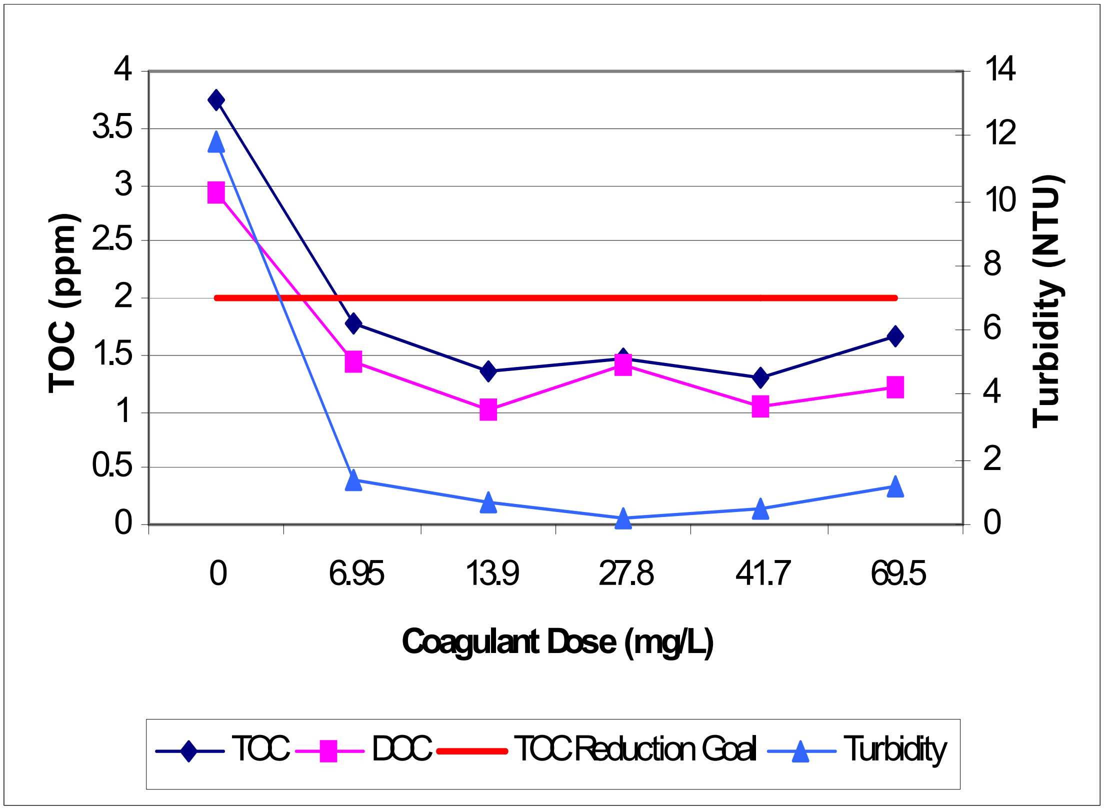


Figure 4.19 - Typical plot for PAX-XL37, Fall 2002

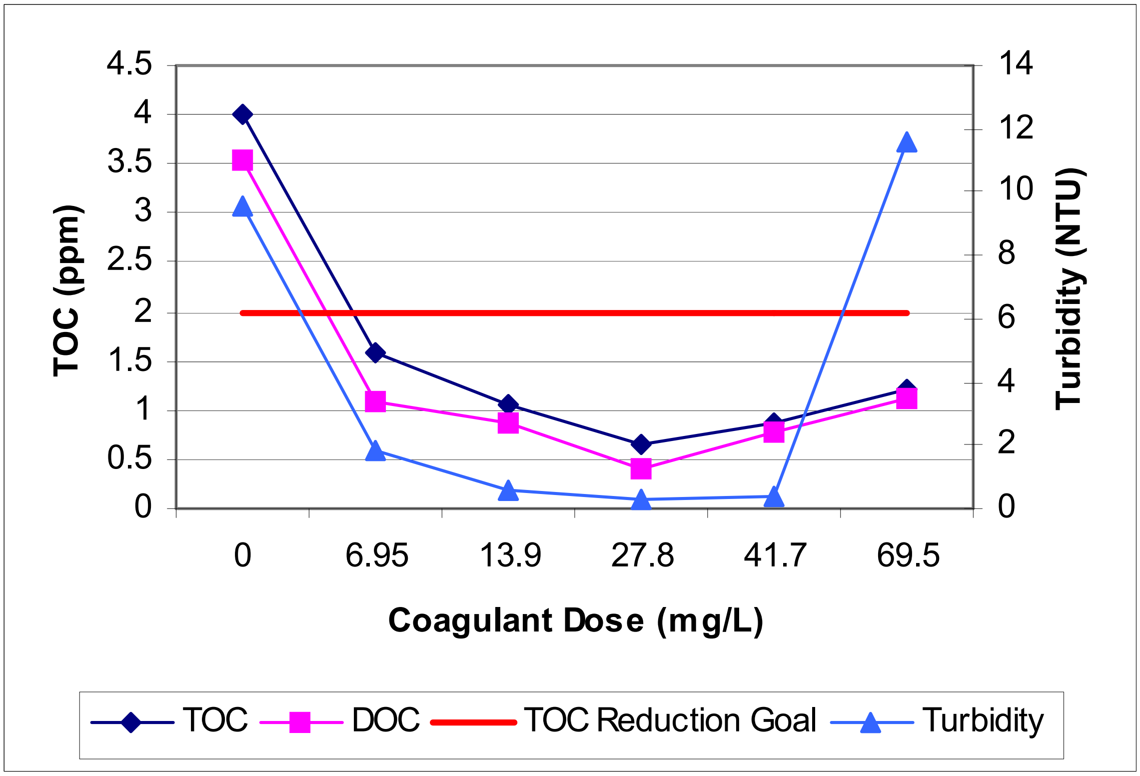


Figure 4.20 - Typical plot for PAX-4505, Fall 2002

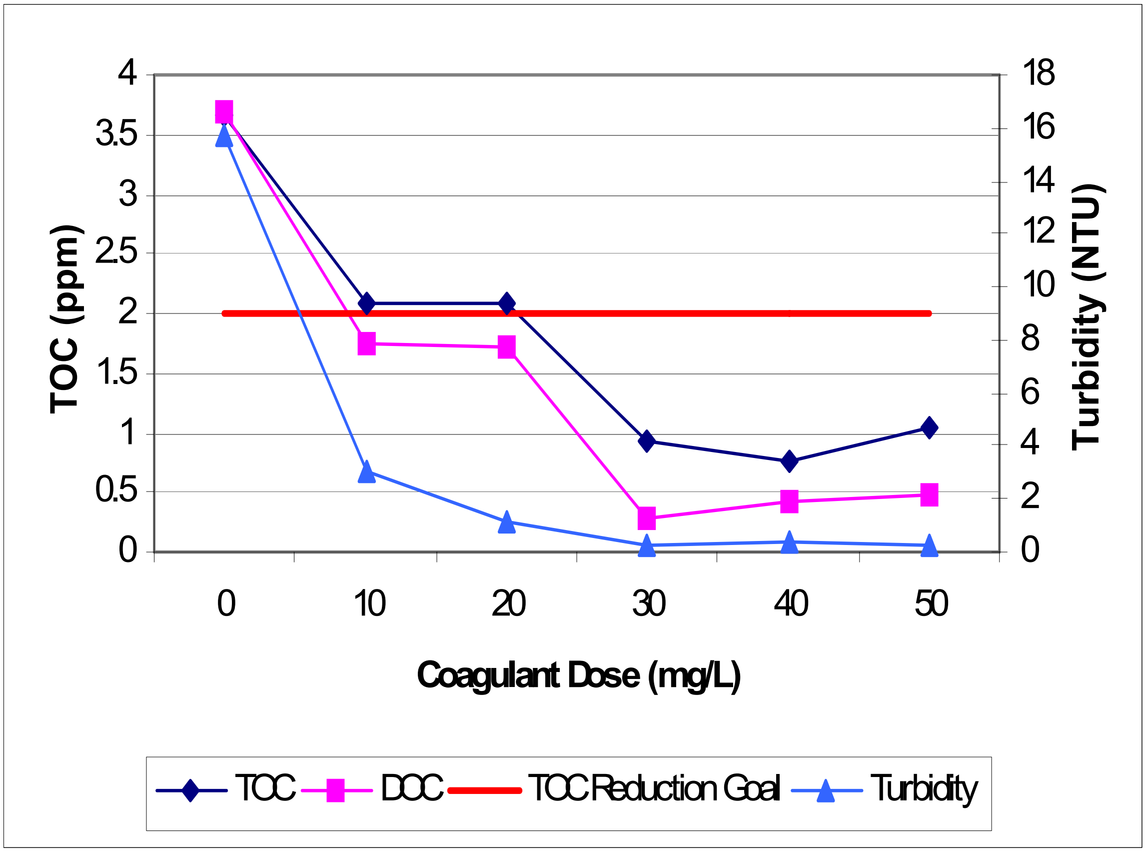


Figure 4.21 - Typical plot for SI-AA, Fall 2002

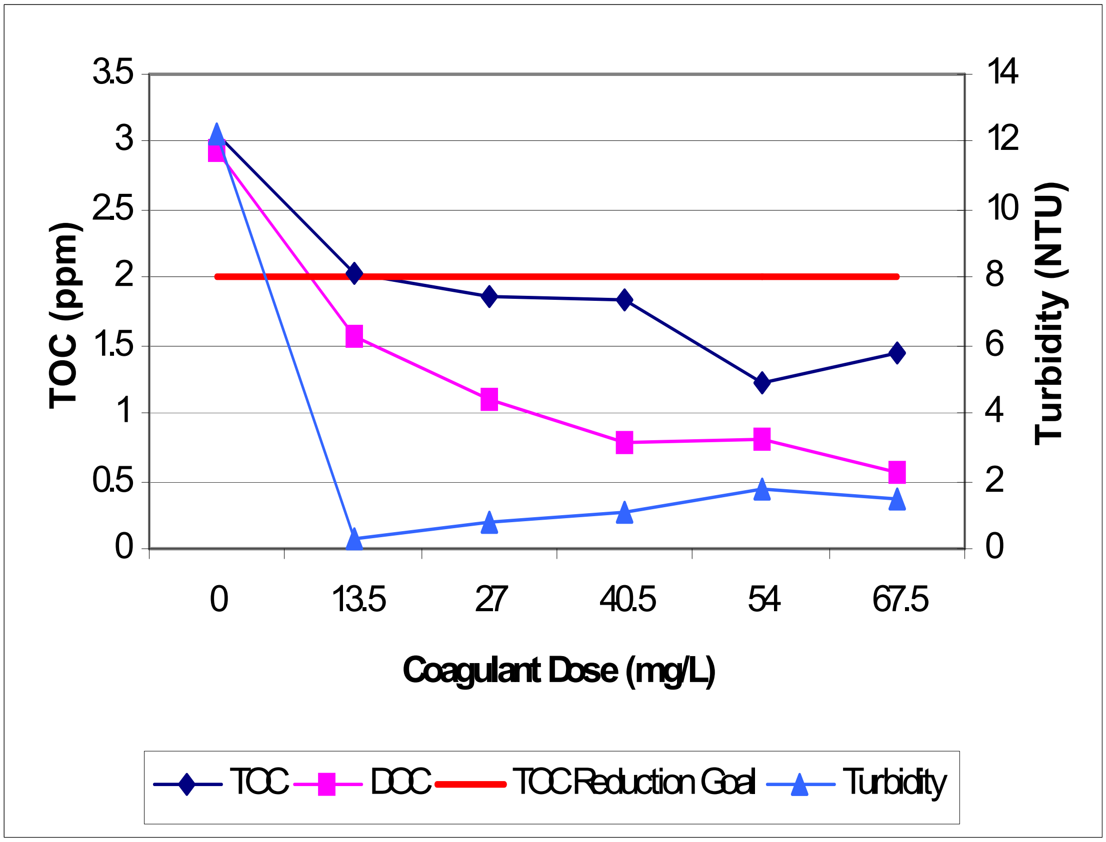


Figure 4.22 - Typical plot for SI-ACH, Fall 2002

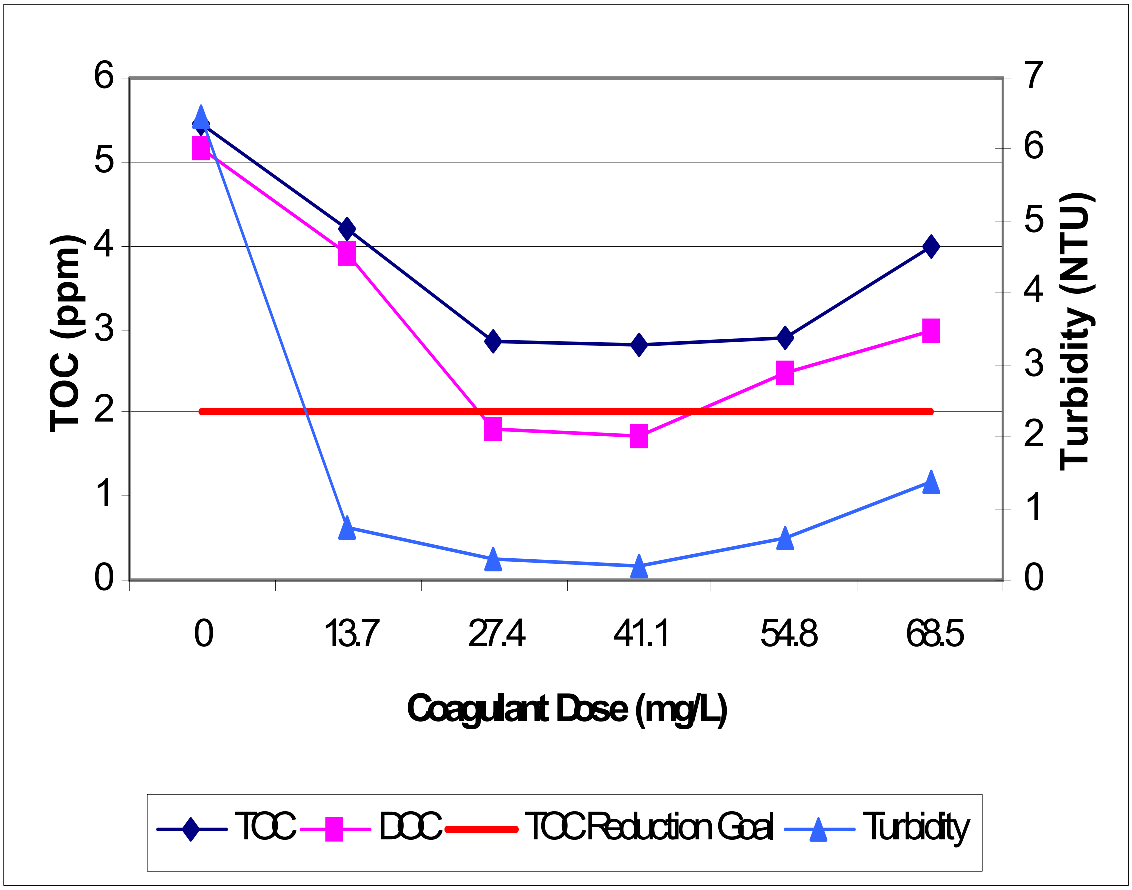


Figure 4.23 - Typical plot for SI-AC, Fall 2002

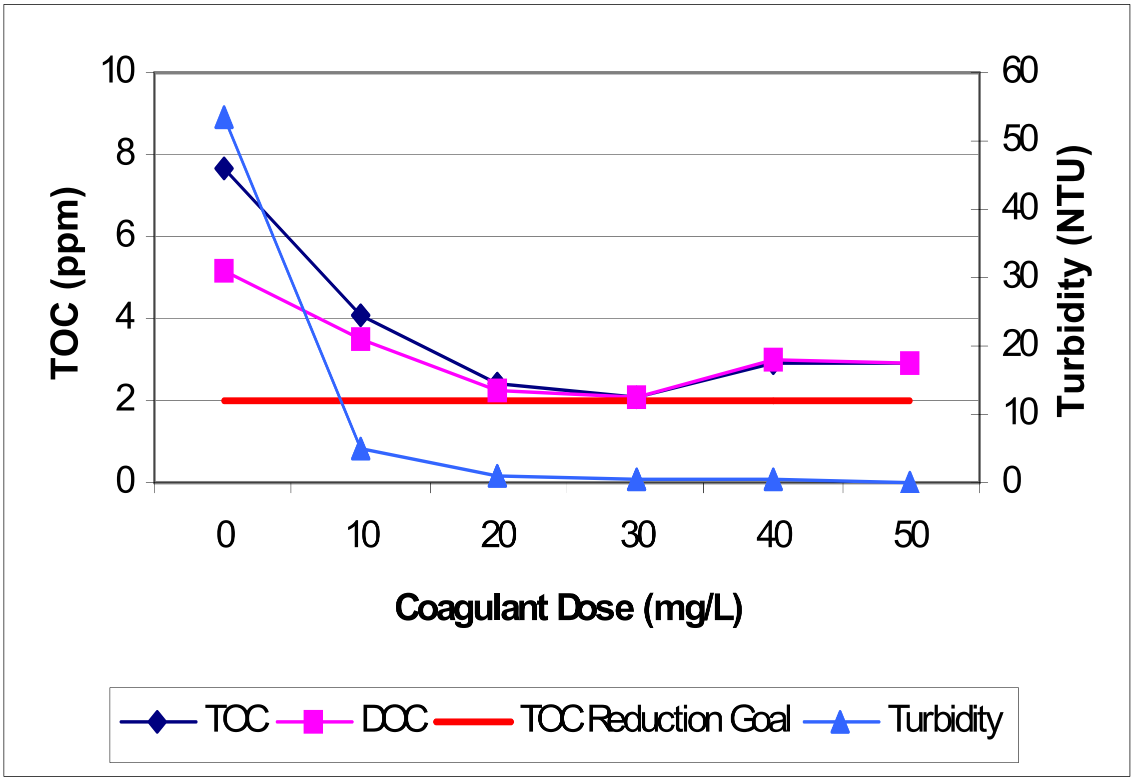


Figure 4.24 - Typical plot for Alum, Spring 2003

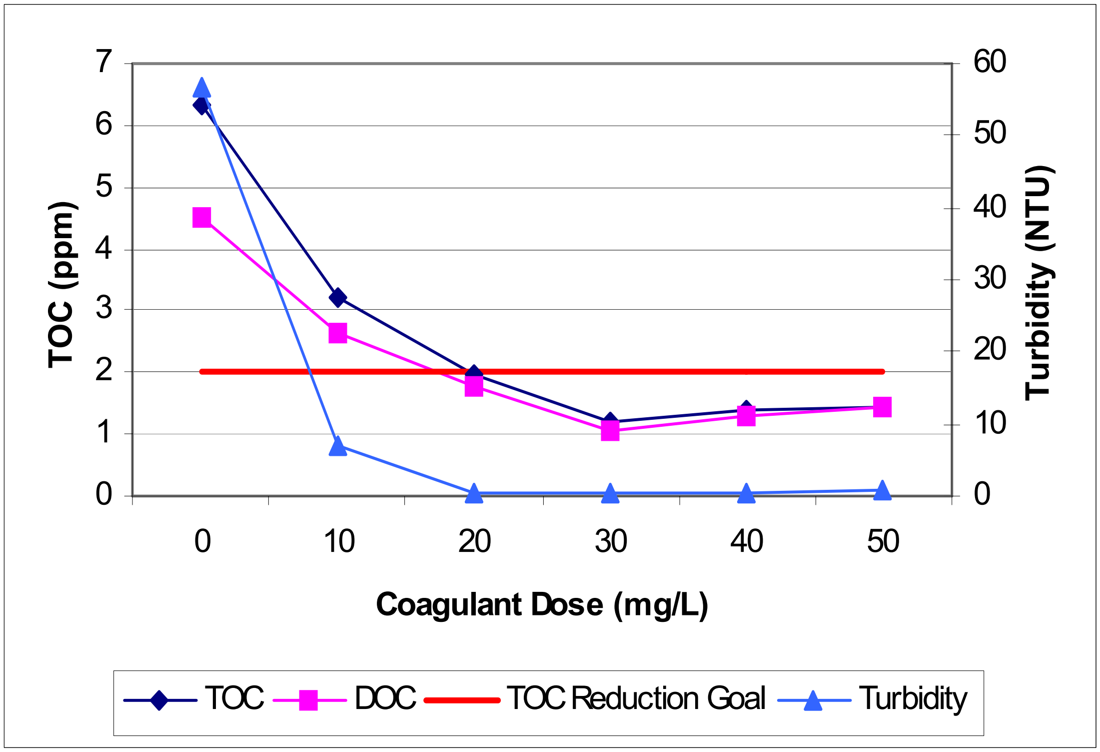


Figure 4.25 - Typical plot for SI-AA, Spring 2003

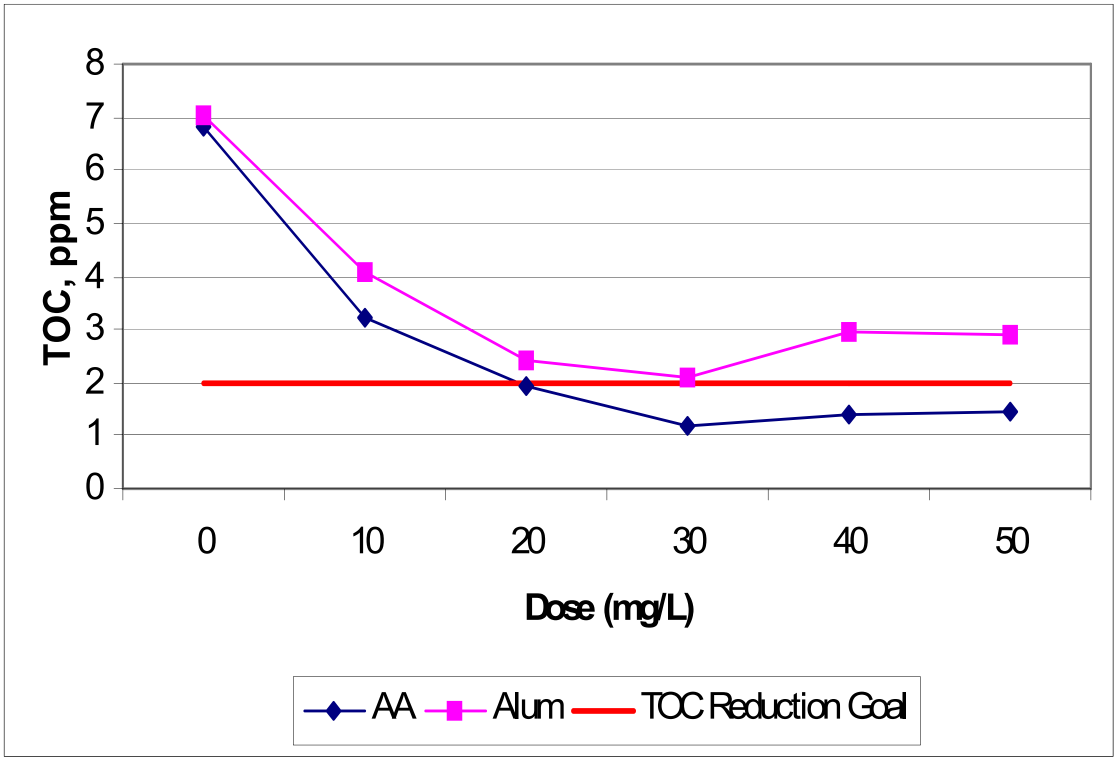


Figure 4.26 - Comparison of SI-AA to Alum at Above Average Initial TOC

CHAPTER V

Engineering Significance

5.1 Economic Comparison

It was determined that an economic comparison of the five best performing coagulants be made as compared to the original alum from Tupelo. For 2001, Tupelo used 718 tons of alum at a price of \$88,283. Tupelo also spent \$19,458 on lime for pH adjustment. These numbers were used as a basis for comparison to the coagulants being considered as replacements. It was determined that alum cost \$122.96 per ton, or \$0.06 per pound. At this point, prices were requested from Kemiron and Southern Ionics for the five top coagulants. Kemiron reported prices of \$0.32 per pound of PAX-XL31, \$0.31 per pound of PAX-4505, and \$0.30 per pound of PAX-XL37. Southern Ionics gave prices of \$0.18 per pound of SI-ACH and \$0.03 per pound of SI-AA. All values given were based on bulk shipments to the Tupelo area.

The next task was to determine the minimum effective dose for the five coagulants and alum to account for differences in dosing amounts. Alum was taken as a baseline at 40 mg/L, which was found to be the average dose that sufficiently reduced TOC to acceptable levels. This was done by analyzing the data acquired in the laboratory and finding the point at which the coagulant sufficiently reduced TOC to acceptable levels under normal water conditions. The SI-AA and SI-ACH were found to be around 30 mg/L, PAX-XL31 and 4505 at 25 mg/L, and PAX-XL37 at 35 mg/L. Taking into account differences in specific gravity, estimates were made for the pounds of product needed each year for each coagulant. These numbers can be found in Table 5.1.

From these estimates, a yearly cost estimate was made for each coagulant, taking into account the cost of lime for coagulants that require pH adjustment. The cost estimates were compared to the current annual cost of coagulant and lime at the Tupelo plant. The results of this evaluation are shown in Table 5.2. The percent change in costs is shown in Figure 5.1. The PAX products, XL31, XL37, and 4505, increase costs 200%, 250%, and 150%, respectively. SI-ACH increased costs 90%, but SI-AA achieved a cost savings of 60%.

The cost of the three PAX products far outweighed their benefits, especially when compared to the well-performing and relatively cost effective SI-AA and SI-ACH coagulants. However, SI-ACH was still a considerable increase in costs from the original alum. The SI-AA actually reduced costs and performed acceptably as far as reducing TOC and turbidity. SI-AA was determined to provide a cost savings of nearly 60% in materials costs as compared to the original alum. This cost savings was found to be nearly $50,000 per year. The SI-AA provides compliance with the EPA’s DBPR, but capital investment in new coagulant implementing equipment could possibly be needed due to the slightly more corrosive nature of SI-AA as compared to their initial alum. However, most water systems across the country expect to spend significant money not only on equipment, but continuous increases in coagulant costs due to the impending EPA regulations (Singer, 1995).

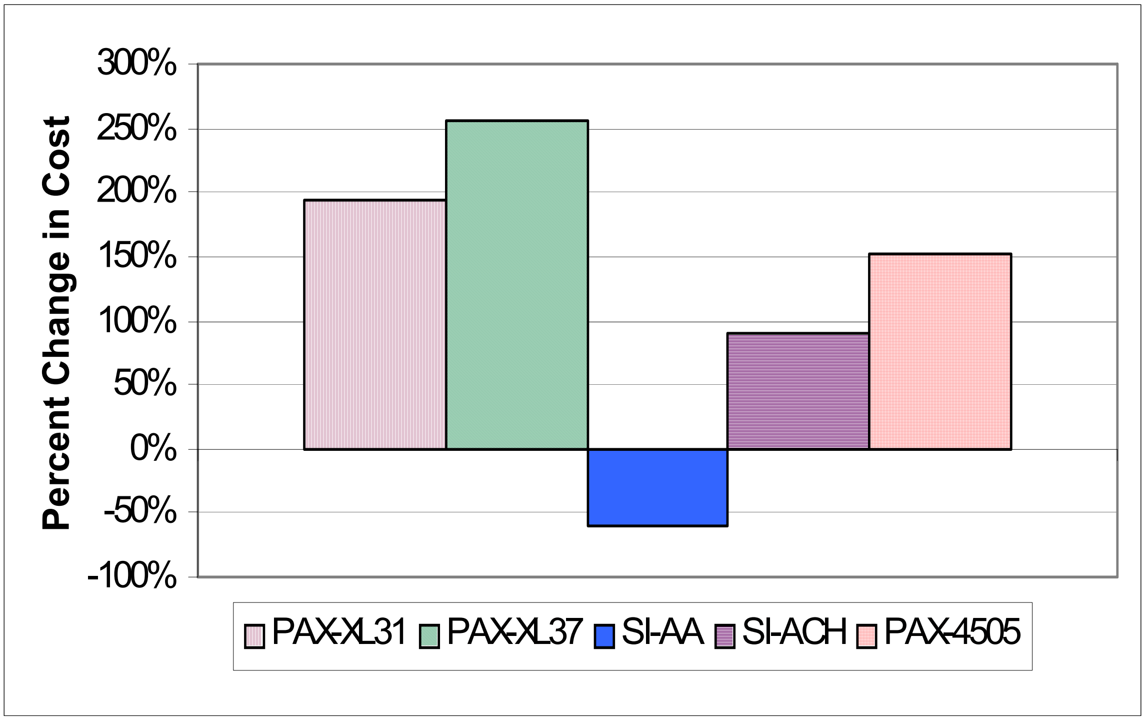


Figure 5.1 - Change in Coagulant Cost as Compared to Alum

Table 5.1 - Estimated Pounds of Coagulant Per Year Needed for Treatment

Coagulant Name	Minimum Effective Dose (mg/L)	Specific Gravity (g/mL)	Density (lbs/gal)	Estimated Pounds (M lbs/yr)
Alum	40	1.33	11.1	1.436
PAX-XL31	25	1.35	11.3	0.911
PAX-XL37	35	1.25	10.4	1.181
PAX-4505	25	1.20	10.0	0.810
SI-AA	30	1.30	10.8	1.053
SI-ACH	30	1.30	10.8	1.053

Table 5.2 - Percent Increase in Coagulant Costs as Compared to Alum

Coagulant Name	**Wt. Used (M lbs)**	**Cost (k $)**	**Cost / lb. ($)**	**Lime (k $)**	**Total Cost (k $)**	**% Increase from Alum**
Alum	1.436	88.28	0.06	11.1	99.36	0
PAX-XL31	0.911	291.5	0.32	0.00	291.50	193
PAX-XL37	1.181	354.2	0.30	0.00	354.20	256
SI-AA	1.053	31.58	0.03	8.31	39.89	-60
SI-ACH	1.053	189.5	0.18	0.00	189.50	91
PAX-4505	0.810	251.0	0.31	0.00	251.00	153

CHAPTER VI

Conclusions and Recommendations

The objective of this study was to assist the Northeast Mississippi Water District obtain and maintain compliance with the USEPA's Disifection Byproduct Rule. Nine coagulants were evaluated in this study. Approximately 150 jar tests were run on the water from the Northeast Mississippi Water District, data for which are found in Appendices B through J. Each coagulant was determined to be feasible based on its cost and its effectiveness on treating water of varying initial TOC and turbidity. The following conclusions were drawn based on the data obtained in the laboratory.

- Four coagulants were found to insufficiently remove NOM from the water, therefore leaving TOC levels above 2 ppm.

    1. Alum provided by Tupelo
    2. Eaglebrook's SternPAC
    3. Eaglebrook's FerriClear
    4. Southern Ionics' SI-AC

Alum and SI-AC were very effective at removing turbidity, but failed to meet the 2 ppm standard in TOC concentration under typical conditions. SternPAC and FerriClear reduced neither TOC nor turbidity sufficiently under most of the conditions tested.

- Five coagulants evaluated met the 2 ppm TOC standard.

1. Kemiron's PAX-XL31
2. Kemiron's PAX-XL37
3. Kemiron's PAX-4505
4. Southern Ionics' SI-ACH
5. Southern Ionics' SI-AA

Also, two of the three PAX products, XL37 and 4505, and the SI-ACH do not require the addition of lime for pH adjustment, thus reducing the cost of using them slightly since the cost of lime can be neglected in their cases. All five coagulants performed sufficiently, however there are significant differences in price for the five products. The price per pound of coagulant was as follows:

- PAX-XL31, $0.32
- PAX-XL37, $0.30
- PAX-4505, $0.30

- Alum, \$0.07 (including lime)
- SI-ACH, \$0.18
- SI-AA, \$0.03 (including lime)

SI-AA performed well, reducing TOC levels to below 2 ppm, and costs only \$0.03 per pound. Not only does this coagulant remove NOM to the degree that TOC levels are below 2 ppm, but material costs are reduced by nearly 60%. In addition to the cost savings, since the SI-AA is very similar to the current alum, no changes will need to be made in the water processing system itself in order to prepare for the new coagulant. However, the coagulant storage tank may need to be evaluated for the storage of a corrosive coagulant such as acidified alum.

It is the recommendation of this research that the Southern Ionics Activated Alum be implemented for use in the Northeast Mississippi Water District due to its ability to meet the standards set by the EPA for removal of disinfection byproduct precursors in the form of natural organic matter, as well as the superior water clarification properties it has and its relatively low cost. An evaluation of the current coagulant feed equipment and storage vessels is recommended due to the more acidic nature of the acidified alum coagulant. It is also recommended that in order to be in complete compliance with the EPA regulations, that the Southern Ionics Aluminum Chlorohydrate be kept on hand for major rain events such as a tropical storm.

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APPENDIX A

Sample Calculations

Sample Calculations

Equivalent Alum Dosages:

XL37:

XL37 is 10% Al^{3+}
Specific Gravity = 1.25

0.1 * 1.25 = 0.125 g/mL

Alum solution is 3.367% Al^{3+} , with 2 Al^{3+} ions per molecule, so:

0.03367 mM Al^{3+}/L * [(mM Al_2O_3/(2*mM Al^{3+})] * [(102 mg Al_2O_3)/(mM $Al_2O_{3)}$] = 1.717 mg/L

(1.717 mg/L) / (0.125 g/mL) = 13.7 mL/L

Table 6.1 - Alkalinity Sample Calculation

mL acid	Normality	Constant	mL Sample	Alkalinity
1.3	0.094	50000	200	30.55
0.45	0.094	50000	200	10.575

Alkalinity:

Alkalinity = (A * N * 50000) / mL Sample

A = mL acid
N = normality of acid
mL sample = 200 mL

APPENDIX B

Jar Test Raw Data for Alum

Table 7.1 - Raw Jar Test Data for Alum, 6/17/02

Date mixed: 6/17/2002
Date H_2O Received: 6/17/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	5.038	4.51	30.51
Jar 1	4.624	3.037	28.64
Jar 2	3.884	4.16	4.17
Jar 3	3.205	3.542	1.67
Jar 4	3.155	3.479	0.95
Jar 5	3.615	1.504	0.53

	Mixer 2		
	TOC	DOC	Turbidity
Raw	5.039	4.891	30.93
Jar 1	5.62	2.97	21.53
Jar 2	3.678	3.187	7.03
Jar 3	2.829	1.805	1.75
Jar 4	1.233	1.223	0.55
Jar 5	1.63	1.722	0.44

	Average		
Dose	TOC	DOC	Turbidity
0	5.0385	4.7005	30.72
10	5.122	3.0035	25.085
20	3.781	3.6735	5.6
30	3.017	2.6735	1.71
40	2.194	2.351	0.75
50	2.6225	1.613	0.485

Mixer 1:
Initial pH: 6.95 Initial alkalinity: 39.95
Final pH: 6.25 Final alkalinity: 22.33

Mixer 2:
Initial pH: 7.01 Initial alkalinity: 37.6
Final pH: 6.14 Final alkalinity: 19.98

Table 7.2 - Raw Jar Test Data for Alum, 6/24/02

Date mixed: 6/24/2002
Date H_2O Received: 6/24/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	4.145	3.668	29.23
Jar 1	3.423	2.692	5.89
Jar 2	2.356	2.157	1.64
Jar 3	1.878	2.096	0.86
Jar 4	1.079	0.8943	0.32
Jar 5	1.208	1.598	0.24

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.145	3.668	29.23
Jar 1	3.423	2.692	5.89
Jar 2	2.356	2.157	1.64
Jar 3	1.878	2.096	0.86
Jar 4	1.079	0.8943	0.32
Jar 5	1.208	1.598	0.24

	Average		
Dose	TOC	DOC	Turbidity
0	4.145	3.668	29.23
10	3.423	2.692	5.89
20	2.356	2.157	1.64
30	1.878	2.096	0.86
40	1.079	0.8943	0.32
50	1.208	1.598	0.24

Mixer 1:
Initial pH: 7.03 Initial alkalinity: 35.25
Final pH: 6.54 Final alkalinity: 17.63

Mixer 2:
Initial pH: 7.07 Initial alkalinity: 32.9
Final pH: 6.63 Final alkalinity: 18.8

Table 7.3 - Raw Jar Test Data for Alum, 7/1/02

Date mixed: 7/1/2002
Date H_2O Received: 7/1/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.598	4.78	20.34
Jar 1	2.956	3.405	6.13
Jar 2	2.007	2.872	1.91
Jar 3	1.909	2.919	0.73
Jar 4	1.415	2.402	0.47
Jar 5	0.8463	1.87	0.55

Initial pH: 7.09 Initial alkalinity: 35.25
Final pH: 6.64 Final alkalinity: 17.63

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.722	4.245	19.22
Jar 1	2.837	3.399	5.76
Jar 2	1.745	2.407	1.07
Jar 3	1.889	2.448	0.79
Jar 4	1.067	1.83	0.51
Jar 5	1.141	2.178	0.44

Initial pH: 7.05 Initial alkalinity: 34.08
Final pH: 6.61 Final alkalinity: 17.63

	Average		
Dose	TOC	DOC	Turbidity
0	3.66	4.5125	19.78
10	2.8965	3.402	5.945
20	1.876	2.6395	1.49
30	1.899	2.6835	0.76
40	1.241	2.116	0.49
50	0.99365	2.024	0.495

Table 7.4 - Raw Jar Test Data for Alum, 7/17/02

Date mixed: 7/17/2002
Date H_2O Received: 7/17/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	4.07	2.713	63.19
Jar 1	4.954	2.8	28.85
Jar 2	2.194	1.364	4.61
Jar 3	2.742	1.571	1.42
Jar 4	2.203	1.843	0.62
Jar 5	1.554	1.776	0.56

Initial pH: 7.42 Initial alkalinity: 36.425
Final pH: 6.67 Final alkalinity: 19.27

	Mixer 2		
	TOC	DOC	Turbidity
Raw	2.137	1.349	60.46
Jar 1	2.483	1.915	31.71
Jar 2	1.79	1.608	4.5
Jar 3	1.079	1.222	1.57
Jar 4	1.623	0.8614	0.73
Jar 5	1.636	1.105	0.43

Initial pH: 7.23 Initial alkalinity: 34.78
Final pH: 6.61 Final alkalinity: 19.27

	Average		
Dose	TOC	DOC	Turbidity
0	3.1035	2.031	61.825
10	3.7185	2.3575	30.28
20	1.992	1.486	4.555
30	1.9105	1.3965	1.495
40	1.913	1.3522	0.675
50	1.595	1.4405	0.495

Table 7.5 - Raw Jar Test Data for Alum, 7/24/02

Date mixed: 7/24/2002
Date H_2O Received: 7/24/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	4.715	2.69	30.58
Jar 1	2.295	2.201	23.8
Jar 2	2.136	0.424	3.64
Jar 3	1.739	0.8849	0.82
Jar 4	1.85	1.124	0.31
Jar 5	1.561	0.1058	0.21

Initial pH: 7.66 Initial alkalinity: 32.9
Final pH: 5.97 Final alkalinity: 9.4

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.804	2.559	28.03
Jar 1	1.967	1.576	10.18
Jar 2	1.733	1.05	1.33
Jar 3	1.224	0.4282	0.16
Jar 4	1.838	1.246	0.11
Jar 5	1.624	0.9013	0.22

Initial pH: 7.74 Initial alkalinity: 32.9
Final pH: 6.36 Final alkalinity: 9.4

	Average		
Dose	TOC	DOC	Turbidity
0	4.7595	2.6245	29.305
10	2.131	1.8885	16.99
20	1.9345	0.737	2.485
40	1.4815	0.65655	0.49
60	1.844	1.185	0.21
80	1.5925	0.50355	0.215

Table 7.6 - Raw Jar Test Data for Alum, 7/31/02

Date mixed: 7/31/2002
Date H_2O Received: 7/24/2002

Mixer 1 down as of 7/29

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.267	2.401	20.96
Jar 1	3.324	2.131	4.54
Jar 2	1.618	1.023	0.29
Jar 3	1.956	0.8194	0.08
Jar 4	1.271	0.2615	0.19
Jar 5	1.424	0.2295	0.36

Initial pH: 7.18 Initial alkalinity: 30.55
Final pH: 6.21 Final alkalinity: 6.58

	Average		
Dose	TOC	DOC	Turbidity
0	4.267	2.401	20.96
10	3.324	2.131	4.54
30	1.618	1.023	0.29
50	1.956	0.8194	0.08
70	1.271	0.2615	0.19
90	1.424	0.2295	0.36

Table 7.7 - Raw Jar Test Data for Alum, 8/1/02

Date mixed: 8/1/2002
Date H_2O Received: 7/31/2002

Mixer 1 down as of 7/29

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.71	1.417	14.45
Jar 1	1.222	0.7905	0.28
Jar 2	0.5608	0.5052	0.26
Jar 3	0.278	0.2524	0.42
Jar 4	0.2737	0.1624	0.5
Jar 5	0.1202	0.0194	1.76

Initial pH: 7.34 Initial alkalinity: 28.2
Final pH: 5.42 Final alkalinity: 0.94

	Average		
Dose	TOC	DOC	Turbidity
0	3.71	1.417	14.45
20	1.222	0.7905	0.28
40	0.5608	0.5052	0.26
60	0.278	0.2524	0.42
80	0.2737	0.1624	0.5
100	0.1202	0.0194	1.76

Table 7.8 - Raw Jar Test Data for Alum, 8/15/02

Date mixed: 8/15/2002
Date H_2O Received: 8/14/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.563	3.483	10.75
Jar 1	3.058	2.976	2.65
Jar 2	2.782	2.703	0.72
Jar 3	1.708	1.659	0.24
Jar 4	1.335	1.397	0.12
Jar 5	1.123	1.354	0.09

Initial pH: 7.93 Initial alkalinity: 36.66
Final pH: 6.84 Final alkalinity: 19.035

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.255	3.774	12.95
Jar 1	3.485	2.964	4.31
Jar 2	2.612	2.401	0.9
Jar 3	1.868	1.827	0.37
Jar 4	1.472	1.208	0.14
Jar 5	1.545	1.074	0.08

Initial pH: 7.89 Initial alkalinity: 34.075
Final pH: 7.02 Final alkalinity: 17.86

	Average		
Dose	TOC	DOC	Turbidity
0	3.909	3.6285	11.85
10	3.2715	2.97	3.48
20	2.697	2.552	0.81
30	1.788	1.743	0.305
40	1.4035	1.3025	0.13
50	1.334	1.214	0.085

Table 7.9 - Raw Jar Test Data for Alum, 8/22/02

Date mixed: 08/22/02
Date H_2O Received: 08/21/02

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.425	3.226	27.77
Jar 1	2.579	2.516	2.54
Jar 2	1.044	1.145	0.81
Jar 3	0.7416	0.2892	0.29
Jar 4	0.5857	0.4771	0.1
Jar 5	0.5687	0.0943	0.09

Initial pH: 7.51 Initial alkalinity: 35.485
Final pH: 6.62 Final alkalinity: 15.275

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.874	3.166	23.25
Jar 1	1.093	1.022	2.28
Jar 2	1.241	0.5596	0.52
Jar 3	1.018	0.5117	0.13
Jar 4	0.609	0.2867	0.09
Jar 5	0.9058	0.117	0.08

Initial pH: 7.62 Initial alkalinity: 34.78
Final pH: 6.74 Final alkalinity: 13.63

	Average		
Dose	TOC	DOC	Turbidity
0	3.6495	3.196	25.51
10	1.836	1.769	2.41
20	1.1425	0.8523	0.665
30	0.8798	0.40045	0.21
40	0.59735	0.3819	0.095
50	0.73725	0.10565	0.085

Table 7.10 - Raw Jar Test Data for Alum, 9/10/02

Date mixed: 09/10/02
Date H_2O Received: 09/04/02

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.476	3.494	11.4
Jar 1	2.838	2.555	1.65
Jar 2	2.254	1.508	0.56
Jar 3	1.836	1.542	0.26
Jar 4	0.776	0.3471	0.15
Jar 5	1.355	0.8242	0.08

Initial pH: 7.34 Initial alkalinity: 41.595
Final pH: 6.34 Final alkalinity: 23.265

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.542	3.325	11.57
Jar 1	2.612	2.433	1.52
Jar 2	2.602	1.807	0.58
Jar 3	1.872	1.303	0.25
Jar 4	1.671	1.035	0.17
Jar 5	1.072	0.6871	0.2

Initial pH: 7.27 Initial alkalinity: 38.45
Final pH: 6.64 Final alkalinity: 22.595

	Average		
Dose	TOC	DOC	Turbidity
0	3.509	3.4095	11.485
10	2.725	2.494	1.585
20	2.428	1.6575	0.57
30	1.854	1.4225	0.255
40	1.2235	0.69105	0.16
50	1.2135	0.75565	0.14

Table 7.11 - Raw Jar Test Data for Alum, 9/24/02

Date mixed: 9/24/2002
Date H_2O Received: 9/16/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	4.223	4.101	39.65
Jar 1	3.395	3.257	1.36
Jar 2	2.783	2.248	0.34
Jar 3	2.571	2.265	0.14
Jar 4	2.579	1.707	0.14
Jar 5	2.515	1.667	0.11

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.951	4.819	17.43
Jar 1	3.872	3.982	1.19
Jar 2	2.309	1.602	0.51
Jar 3	3.042	2.699	0.33
Jar 4	2.853	1.759	0.2
Jar 5	2.968	2.266	0.09

	Average		
	TOC	DOC	Turbidity
0	4.587	4.46	28.54
10	3.6335	3.6195	1.275
20	2.546	1.925	0.425
30	2.8065	2.482	0.235
40	2.716	1.733	0.17
50	2.7415	1.9665	0.1

Initial pH: 7.71 Initial alkalinity: 36.19
Final pH: 6.86 Final alkalinity: 20.21

Initial pH: 7.68 Initial alkalinity: 36.19
Final pH: 7.03 Final alkalinity: 20.21

Table 7.12 - Raw Jar Test Data for Alum, 10/1/02

Date mixed: 10/1/2002
Date H_2O Received: 9/27/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	12.38	7.26	268.4
Jar 1	6.838	4.316	271.7
Jar 2	7.795	4.067	262.8
Jar 3	4.559	2.989	226.9
Jar 4	5.087	3.994	113.8
Jar 5	3.183	2.338	17.03

	Mixer 2		
	TOC	DOC	Turbidity
Raw	11.16	8.138	292.9
Jar 1	4.701	3.704	285.7
Jar 2	4.278	3.584	275.1
Jar 3	4.713	3.633	201.1
Jar 4	4.426	3.414	137.2
Jar 5	5.552	3.242	10.27

	Average		
	TOC	DOC	Turbidity
0	11.77	7.699	280.65
20	5.7695	4.01	278.7
30	6.0365	3.8255	268.95
40	4.636	3.311	214
50	4.7565	3.704	125.5
60	4.3675	2.79	13.65

Initial pH: 7.41 Initial alkalinity: 41.595
Final pH: 6.7 Final alkalinity: 23.265

Initial pH: 7.56 Initial alkalinity: 40.89
Final pH: 6.75 Final alkalinity: 21.385

Table 7.13 - Raw Jar Test Data for Alum, 10/25/02

Date mixed: 10/25/2002
Date H_2O Received: 10/10/2002

	Mixer 2		
	TOC	DOC	Turbidity
Raw	11.74	11.28	141.3
Jar 1	11.05	11.25	109.3
Jar 2	11.34	10.33	109
Jar 3	10.6	10.24	98.52
Jar 4	4.58	4.158	19.01
Jar 5	4.771	4.717	2.09

	Average		
	TOC	DOC	Turbidity
0	11.74	11.28	141.3
10	11.05	11.25	109.3
20	11.34	10.33	109
30	10.6	10.24	98.52
40	4.58	4.158	19.01
50	4.771	4.717	2.09

Initial pH:	6.6	Initial alkalinity:	47.705
Final pH:	7.28	Final alkalinity:	34.075

Table 7.14 - Raw Jar Test Data for Alum, 11/20/02

Date mixed: 11/20/2002
Date H_2O Received: 10/17/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	10.725	9.012	4.35
Jar 1	8.511	8.348	3.87
Jar 2	4.371	4.215	1.22
Jar 3	3.146	3.051	0.28
Jar 4	3.262	3.015	0.25
Jar 5	2.257	2.126	0.22

Initial pH:	7.73	Initial alkalinity:	25.38
Final pH:	6.51	Final alkalinity:	11.985

	Mixer 2		
	TOC	DOC	Turbidity
Raw	10.14	7.401	3.45
Jar 1	9.308	7.481	3.36
Jar 2	4.749	4.012	0.85
Jar 3	2.637	2.714	0.3
Jar 4	3.441	3.545	0.13
Jar 5	2.454	2.102	0.18

Initial pH:	7.48	Initial alkalinity:	23.97
Final pH:	6.77	Final alkalinity:	13.16

	Average		
	TOC	DOC	Turbidity
0	10.4325	8.2065	3.9
10	8.9095	7.9145	3.615
20	4.56	4.1135	1.035
30	2.8915	2.8825	0.29
40	3.3515	3.28	0.19
50	2.3555	2.114	0.2

Table 7.15 - Raw Jar Test Data for Alum, 12/12/02

Date mixed: 12/12/2003
Date H_2O Received: 12/2/2003

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.144	4.493	9.18
Jar 1	3.137	2.697	1.38
Jar 2	2.304	1.601	0.3
Jar 3	1.562	1.483	0.27
Jar 4	1.181	1.622	0.11
Jar 5	1.371	1.643	0.1

	Mixer 2		
	TOC	DOC	Turbidity
Raw	5.512	2.827	5.41
Jar 1	4.082	3.083	1.11
Jar 2	1.8553	1.899	0.26
Jar 3	1.746	1.386	0.21
Jar 4	1.982	1.571	0.13
Jar 5	2.454	1.481	0.11

	Average		
	TOC	DOC	Turbidity
0	4.328	3.66	7.295
10	3.6095	2.89	1.245
20	2.07965	1.75	0.28
30	1.654	1.4345	0.24
40	1.5815	1.5965	0.12
50	1.9125	1.562	0.105

Initial pH: 7.56 Initial alkalinity: 42.77
Final pH: 6.76 Final alkalinity: 24.44

Initial pH: 7.45 Initial alkalinity: 36.895
Final pH: 6.8 Final alkalinity: 20.445

Table 7.16 - Raw Jar Test Data for Alum, 2/24/03

Date mixed: 2/24/2003
Date H_2O Received: 1/8/2003

	Mixer 1		
	TOC	DOC	Turbidity
Raw	6.579	3.927	50.37
Jar 1	4.116	3.367	4.94
Jar 2	2.332	2.126	1.49
Jar 3	2.005	2.016	0.75
Jar 4	3.181	3.091	0.29
Jar 5	2.668	2.125	0.2

	Mixer 2		
	TOC	DOC	Turbidity
Raw	8.68	6.457	56.44
Jar 1	4.024	3.567	5.29
Jar 2	2.546	2.322	0.24
Jar 3	2.226	2.114	0.13
Jar 4	2.678	2.846	0.26
Jar 5	3.156	3.634	0.13

	Average		
	TOC	DOC	Turbidity
0	7.6295	5.192	53.405
10	4.07	3.467	5.115
20	2.439	2.224	0.865
30	2.1155	2.065	0.44
40	2.9295	2.9685	0.275
50	2.912	2.8795	0.165

Initial pH: 7.23 Initial alkalinity: 30.67
Final pH: 6.12 Final alkalinity: 15.54

Initial pH: 7.29 Initial alkalinity: 29.87
Final pH: 6.16 Final alkalinity: 12.24

APPENDIX C

Jar Test Raw Data for PAX-XL31

Table 8.1 - Raw Jar Test Data for PAX-XL31, 6/18/02

Date mixed: 6/18/2002
Date H_2O Received: 6/17/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.806	2.814	24.55
Jar 1	2.495	2.273	0.76
Jar 2	1.773	3.069	0.83
Jar 3	1.829	1.772	4.86
Jar 4	2.688	1.406	24.71
Jar 5	3.585	2.719	27.62

	Mixer 2		
	TOC	DOC	Turbidity
Raw	5.243	5.1	24.28
Jar 1	2.936	3.149	0.84
Jar 2	2.104	2.484	0.51
Jar 3	0.6612	1.202	8.93
Jar 4	2.397	1.219	27.01
Jar 5	2.75	1.303	27.4

	Average		
	TOC	DOC	Turbidity
0	4.5245	3.957	24.415
13.9	2.7155	2.711	0.8
27.8	1.9385	2.7765	0.67
41.7	1.2451	1.487	6.895
55.6	2.5425	1.3125	25.86
69.5	3.1675	2.011	27.51

Mixer 1:
Initial pH: 6.95 Initial alkalinity: 38.78
Final pH: 6.49 Final alkalinity: 17.63

Mixer 2:
Initial pH: 6.97 Initial alkalinity: 35.25
Final pH: 6.49 Final alkalinity: 18.8

Table 8.2 - Raw Jar Test Data for PAX-XL31, 6/26/02

Date mixed: 6/26/2002
Date H_2O Received: 6/24/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.727	2.882	22.85
Jar 1	0.4089	0.7226	0.46
Jar 2	1.43	1.152	2.1
Jar 3	1.19	0.1022	7.9
Jar 4	0.8266	0.5665	13.35
Jar 5	1.54	0.7892	15.83

	Mixer 2		
	TOC	DOC	Turbidity
Raw	2.666	2.773	20.07
Jar 1	1.22	1.468	0.57
Jar 2	0.6875	0.6901	1.96
Jar 3	0.8506	1.085	13.4
Jar 4	0.6766	1.035	17.59
Jar 5	1.851	0.5095	17.96

	Average		
	TOC	DOC	Turbidity
0	3.1965	2.8275	21.46
13.9	0.81445	1.0953	0.515
27.8	1.05875	0.92105	2.03
41.7	1.0203	0.5936	10.65
55.6	0.7516	0.80075	15.47
69.5	1.6955	0.64935	16.895

Mixer 1:
Initial pH: 7.27 Initial alkalinity: 32.9
Final pH: 6.37 Final alkalinity: 14.1

Mixer 2:
Initial pH: 7.31 Initial alkalinity: 34.08
Final pH: 6.33 Final alkalinity: 14.1

Table 8.3 - Raw Jar Test Data for PAX-XL31, 7/2/02

Date mixed: 7/2/2002
Date H_2O Received: 7/1/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.403	4.503	13.45
Jar 1	3.09	4.214	0.58
Jar 2	0.8205	4.409	2.9
Jar 3	0.7868	1.936	14.38
Jar 4	2.051	0.9783	14.72
Jar 5	2.277	1.443	15.5

Initial pH: 7.12 Initial alkalinity: 35.49
Final pH: 6.41 Final alkalinity: 12.93

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.212	5.063	13.36
Jar 1	1.883	4.278	0.56
Jar 2	0.8045	2.007	5.86
Jar 3	0.7495	2.043	12.88
Jar 4	2.054	1.653	14.94
Jar 5	2.514	1.513	14.7

Initial pH: 7.13 Initial alkalinity: 34.08
Final pH: 5.92 Final alkalinity: 14.1

	Average		
	TOC	DOC	Turbidity
0	3.3075	4.783	13.405
13.9	2.4865	4.246	0.57
27.8	0.8125	3.208	4.38
41.7	0.76815	1.9895	13.63
55.6	2.0525	1.31565	14.83
69.5	2.3955	1.478	15.1

Table 8.4 - Raw Jar Test Data for PAX-XL31, 7/11/02

Date mixed: 7/11/2002
Date H_2O Received: 7/10/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.516	2.898	15.37
Jar 1	0.9012	0.8278	0.57
Jar 2	0.7874	0.5572	2.86
Jar 3	1.824	0.2145	9.58
Jar 4	1.457	0.5478	14.91
Jar 5	2.133	1.41	16.95

Initial pH: 7.33 Initial alkalinity: 32.9
Final pH: 6.48 Final alkalinity: 10.575

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.468	2.858	17.13
Jar 1	3.181	0.5486	0.57
Jar 2	0.5252	0.2551	2.82
Jar 3	1.197	0.5372	10.62
Jar 4	1.129	0.8075	16.71
Jar 5	2.779	0.601	16.37

Initial pH: 7.14 Initial alkalinity: 30.55
Final pH: 6.3 Final alkalinity: 10.575

	Average		
	TOC	DOC	Turbidity
0	3.492	2.878	16.25
13.9	2.0411	0.6882	0.57
27.8	0.6563	0.40615	2.84
41.7	1.5105	0.37585	10.1
55.6	1.293	0.67765	15.81
69.5	2.456	1.0055	16.66

Table 8.5 - Raw Jar Test Data for PAX-XL31, 7/25/02

Date mixed: 7/25/2002
Date H_2O Received: 7/24/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	2.984	2.902	14.71
Jar 1	3.975	1.507	1.27
Jar 2	3.228	2.778	0.6
Jar 3	4.073	2.512	2.9
Jar 4	3.835	1.539	16.79
Jar 5	3.105	3.272	19.59

Initial pH: 7.34 Initial alkalinity: 28.2
Final pH: 6.4 Final alkalinity: 9.635

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.571	2.204	15.8
Jar 1	1.158	0.6714	1.24
Jar 2	1.004	0.5736	0.5
Jar 3	3.495	1.233	3.59
Jar 4	4.062	1.98	16.64
Jar 5	4.16	2.908	19.7

Initial pH: 7.39 Initial alkalinity: 28.2
Final pH: 6.27 Final alkalinity: 10.575

	Average		
	TOC	DOC	Turbidity
0	3.7775	2.553	15.255
6.95	2.5665	1.0892	1.255
13.9	2.116	1.6758	0.55
27.8	3.784	1.8725	3.245
41.7	3.9485	1.7595	16.715
69.5	3.6325	3.09	19.645

Table 8.6 - Raw Jar Test Data for PAX-XL31, 8/2/02

Date mixed: 8/2/2002
Date H_2O Received: 7/31/2002

Mixer 1 down as of 7/29

	Mixer 2		
	TOC	DOC	Turbidity
Raw	2.246	1.186	16.28
Jar 1	1.083	0.6627	1.24
Jar 2	0.4643	0.2486	0.46
Jar 3	0.6736	0.0154	2.21
Jar 4	1.298	1.256	5.25
Jar 5	1.958	0.4535	10.39

Initial pH: 7.16 Initial alkalinity: 26.32
Final pH: 6.11 Final alkalinity: 8.93

	Average		
	TOC	DOC	Turbidity
0	2.246	1.186	16.28
6.95	1.083	0.6627	1.24
13.9	0.4643	0.2486	0.46
27.8	0.6736	0.0154	2.21
41.7	1.298	1.256	5.25
69.5	1.958	0.4535	10.39

Table 8.7 - Raw Jar Test Data for PAX-XL31, 8/16/02

Date mixed: 8/16/2002
Date H_2O Received: 8/14/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.61	3.339	9.87
Jar 1	2.36	1.933	0.63
Jar 2	1.55	0.9729	0.65
Jar 3	0.9409	0.4171	0.27
Jar 4	1.162	1.044	0.97
Jar 5	1.157	0.8503	1.93

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.908	3.457	9.63
Jar 1	3.259	2.73	0.49
Jar 2	2.973	0.8649	0.5
Jar 3	2.085	0.9193	0.32
Jar 4	1.56	0.9985	0.42
Jar 5	1.467	0.4678	2.99

	Average		
	TOC	DOC	Turbidity
0	3.759	3.398	9.75
6.95	2.8095	2.3315	0.56
13.9	2.2615	0.9189	0.575
27.8	1.51295	0.6682	0.295
41.7	1.361	1.02125	0.695
69.5	1.312	0.65905	2.46

Initial pH: 7.81 Initial alkalinity: 33.135
Final pH: 6.71 Final alkalinity: 15.98

Initial pH: 7.76 Initial alkalinity: 32.43
Final pH: 6.92 Final alkalinity: 15.98

Table 8.8 - Raw Jar Test Data for PAX-XL31, 8/23/02

Date mixed: 8/23/2002
Date H_2O Received: 8/21/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.696	2.861	5.85
Jar 1	3.18	2.787	0.57
Jar 2	2.754	2.274	0.13
Jar 3	2.28	1.536	0.06
Jar 4	1.88	1.364	0.01
Jar 5	0.1605	0.0898	0.51

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.243	3.341	5.78
Jar 1	2.869	2.069	0.71
Jar 2	2.615	1.623	0.24
Jar 3	0.6352	0.5862	0.09
Jar 4	2.095	1.593	0.04
Jar 5	0.7166	0.2079	0.64

	Average		
	TOC	DOC	Turbidity
0	3.9695	3.101	5.815
6.95	3.0245	2.428	0.64
13.9	2.6845	1.9485	0.185
27.8	1.4576	1.0611	0.075
41.7	1.9875	1.4785	0.025
69.5	0.43855	0.14885	0.575

Initial pH: 7.81 Initial alkalinity: 32.9
Final pH: 6.94 Final alkalinity: 16.45

Initial pH: 7.87 Initial alkalinity: 32.43
Final pH: 6.99 Final alkalinity: 16.235

Table 8.9 - Raw Jar Test Data for PAX-XL31, 10/15/02

Date mixed: 10/15/2002
Date H_2O Received: 9/27/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	10.82	9.408	205.2
Jar 1	8.219	8.113	131.6
Jar 2	5.191	4.354	4.48
Jar 3	4.973	3.743	0.95
Jar 4	4.774	4.232	4.44
Jar 5	2.888	3.411	5.18

	Mixer 2		
	TOC	DOC	Turbidity
Raw	11.36	9.833	202.3
Jar 1	7.688	9.359	122.7
Jar 2	4.804	5.606	3.4
Jar 3	4.015	5.055	1.42
Jar 4	2.984	2.825	2.26
Jar 5	2.059	1.954	3.45

	Average		
	TOC	DOC	Turbidity
0	11.09	9.6205	203.75
13.9	7.9535	8.736	127.15
27.8	4.9975	4.98	3.94
41.7	4.494	4.399	1.185
55.6	3.879	3.5285	3.35
69.5	2.4735	2.6825	4.315

Mixer 1:
Initial pH: 7.6 Initial alkalinity: 39.95
Final pH: 6.9 Final alkalinity: 19.505

Mixer 2:
Initial pH: 7.51 Initial alkalinity: 44.18
Final pH: 6.77 Final alkalinity: 22.795

Table 8.10 - Raw Jar Test Data for PAX-XL31, 10/29/02

Date mixed: 10/29/2002
Date H_2O Received: 10/10/2002

	Mixer 2		
	TOC	DOC	Turbidity
Raw	15.15	13.86	129.4
Jar 1	1.661	6.392	106.2
Jar 2	6.676	6.124	6.93
Jar 3	3.871	3.468	0.41
Jar 4	2.852	2.134	0.25
Jar 5	4.162	3.947	0.11

	Average		
	TOC	DOC	Turbidity
0	15.15	13.86	129.4
13.9	1.661	6.392	106.2
27.8	6.676	6.124	6.93
41.7	3.871	3.468	0.41
55.6	2.852	2.134	0.25
69.5	4.162	3.947	0.11

Initial pH: 7.6 Initial alkalinity: 50.995
Final pH: 7.09 Final alkalinity: 36.19

APPENDIX D

Jar Test Raw Data for PAX-XL37

Table 9.1 - Raw Jar Test Data for PAX-XL37, 6/19/02

Date mixed: 6/19/2002
Date H_2O Received: 6/17/2002

*No lime is used with PAX-XL37

	Mixer 1		
	TOC	DOC	Turbidity
Raw	5.204	3.228	22.62
Jar 1	5.085	3.078	1.4
Jar 2	4.486	2.164	0.76
Jar 3	3.347	2.057	0.64
Jar 4	2.698	3.186	1.16
Jar 5	3.399	2.651	3.62

Initial pH: 7.11 Initial alkalinity: 39.95
Final pH: 6.97 Final alkalinity: 30.55

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.867	4.17	22.6
Jar 1	3.501	3.099	1.32
Jar 2	4.552	2.221	0.51
Jar 3	2.505	1.283	0.78
Jar 4	3.342	1.206	1.4
Jar 5	2.312	2.469	3.44

Initial pH: 7.04 Initial alkalinity: 37.6
Final pH: 6.87 Final alkalinity: 30.55

	Average		
Dose	TOC	DOC	Turbidity
0	5.0355	3.699	22.61
13.9	4.293	3.0885	1.36
27.8	4.519	2.1925	0.635
41.7	2.926	1.67	0.71
55.6	3.02	2.196	1.28
69.5	2.8555	2.56	3.53

Table 9.2 - Raw Jar Test Data for PAX-XL37, 6/25/02

Date mixed: 6/25/2002
Date H_2O Received: 6/24/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.304	3.068	24.58
Jar 1	1.728	2.192	0.79
Jar 2	1.764	2.225	0.34
Jar 3	1.186	1.342	0.56
Jar 4	1.354	1.605	1.76
Jar 5	1.17	1.841	3.81

Initial pH: 7.31 Initial alkalinity: 35.25
Final pH: 6.88 Final alkalinity: 25.85

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.476	4.145	27.53
Jar 1	1.255	1.712	0.97
Jar 2	1.801	1.568	0.48
Jar 3	1.164	1.906	0.64
Jar 4	1.167	1.602	1.97
Jar 5	1.149	1.559	3.55

Initial pH: 7.27 Initial alkalinity: 34.08
Final pH: 6.94 Final alkalinity: 24.68

	Average		
Dose	TOC	DOC	Turbidity
0	3.39	3.6065	26.055
13.9	1.4915	1.952	0.88
27.8	1.7825	1.8965	0.41
41.7	1.175	1.624	0.6
55.6	1.2605	1.6035	1.865
69.5	1.1595	1.7	3.68

Table 9.3 - Raw Jar Test Data for PAX-XL37, 7/3/02

Date mixed: 7/3/2002
Date H_2O Received: 7/1/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	1.443	1.705	14.22
Jar 1	1.332	0.9848	0.7
Jar 2	1.722	1.159	0.46
Jar 3	1.744	1.616	1.05
Jar 4	0.3819	0.4154	3.68
Jar 5	0.9678	0.2802	9.46

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.544	3.174	14.54
Jar 1	1.074	1.091	0.68
Jar 2	1.375	1.169	0.47
Jar 3	0.3888	0.7022	0.91
Jar 4	0.5212	0.1612	2.52
Jar 5	1.822	0.3365	5.13

	Average		
Dose	TOC	DOC	Turbidity
0	2.4935	2.4395	14.38
13.9	1.203	1.0379	0.69
27.8	1.5485	1.164	0.465
41.7	1.0664	1.1591	0.98
55.6	0.45155	0.2883	3.1
69.5	1.3949	0.30835	7.295

Initial pH:	7.38	Initial alkalinity:	34.08	Initial pH:	7.26	Initial alkalinity:	34.08
Final pH:	7.04	Final alkalinity:	25.38	Final pH:	7.04	Final alkalinity:	25.62

Table 9.4 - Raw Jar Test Data for PAX-XL37, 7/12/02

Date mixed: 7/12/2002
Date H_2O Received: 7/10/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.454	3.325	12.3
Jar 1	1.808	0.6742	0.7
Jar 2	0.9522	0.8534	0.4
Jar 3	0.8615	0.6557	0.98
Jar 4	1.636	1.283	3.89
Jar 5	2.09	1.187	8.9

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.286	3.864	14.25
Jar 1	1.249	0.6496	0.7
Jar 2	1.033	0.68	0.32
Jar 3	1.115	0.9562	1.27
Jar 4	1.636	1.64	4.04
Jar 5	2.127	1.779	8.21

	Average		
Dose	TOC	DOC	Turbidity
0	3.87	3.5945	13.275
13.9	1.5285	0.6619	0.7
27.8	0.9926	0.7667	0.36
41.7	0.98825	0.80595	1.125
55.6	1.636	1.4615	3.965
69.5	2.1085	1.483	8.555

Initial pH:	7.25	Initial alkalinity:	38.775	Initial pH:	7.49	Initial alkalinity:	38.775
Final pH:	6.8	Final alkalinity:	27.495	Final pH:	6.97	Final alkalinity:	27.495

Table 9.5 - Raw Jar Test Data for PAX-XL37, 7/26/02

Date mixed: 7/26/2002
Date H_2O Received: 7/24/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	2.11	1.667	36.64
Jar 1	2.24	1.746	3.03
Jar 2	3.094	1.279	1.21
Jar 3	1.883	1.498	0.26
Jar 4	0.7905	0.429	0.63
Jar 5	1.622	1.385	9.16

	Mixer 2		
	TOC	DOC	Turbidity
Raw	1.995	1.246	13.32
Jar 1	1.444	0.6826	1.75
Jar 2	1.308	1.041	0.6
Jar 3	2.21	1.631	0.36
Jar 4	1.507	1.319	1.06
Jar 5	1.2	0.3514	10.44

	Average		
Dose	TOC	DOC	Turbidity
0	2.0525	1.4565	24.98
6.95	1.842	1.2143	2.39
13.9	2.201	1.16	0.905
27.8	2.0465	1.5645	0.31
41.7	1.14875	0.874	0.845
69.5	1.411	0.8682	9.8

Mixer 1:
Initial pH: 7.1 Initial alkalinity: 28.435
Final pH: 6.8 Final alkalinity: 22.325

Mixer 2:
Initial pH: 7.17 Initial alkalinity: 28.2
Final pH: 6.85 Final alkalinity: 21.15

Table 9.6 - Raw Jar Test Data for PAX-XL37, 8/5/02

Date mixed: 8/5/2002
Date H_2O Received: 7/31/2002

Mixer 1 running again as of 8/5

	Mixer 1		
	TOC	DOC	Turbidity
Raw	2.988	1.883	6.65
Jar 1	2.461	1.781	1.06
Jar 2	1.871	1.528	0.37
Jar 3	1.494	1.332	0.22
Jar 4	1.556	1.33	0.8
Jar 5	1.485	0.9202	3.65

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.051	2.123	5.51
Jar 1	2.48	2.356	0.84
Jar 2	1.587	1.411	0.26
Jar 3	1.418	1.162	0.2
Jar 4	1.233	0.9025	1.01
Jar 5	1.422	0.5729	4.9

	Average		
Dose	TOC	DOC	Turbidity
0	3.0195	2.003	6.08
6.95	2.4705	2.0685	0.95
13.9	1.729	1.4695	0.315
27.8	1.456	1.247	0.21
41.7	1.3945	1.11625	0.905
69.5	1.4535	0.74655	4.275

Mixer 1:
Initial pH: 7.65 Initial alkalinity: 30.08
Final pH: 7.09 Final alkalinity: 22.795

Mixer 2:
Initial pH: 7.6 Initial alkalinity: 29.14
Final pH: 7.03 Final alkalinity: 17.39

Table 9.7 - Raw Jar Test Data for PAX-XL37, 8/13/02

Date mixed: 8/13/2002
Date H_2O Received: 8/8/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.419	3.11	9.38
Jar 1	1.706	1.473	1.22
Jar 2	1.539	1.505	0.43
Jar 3	1.89	1.71	0.44
Jar 4	1.512	1.601	0.47
Jar 5	1.005	0.8519	1.21

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.054	3.159	9.18
Jar 1	2.769	2.757	1.24
Jar 2	2.405	2.353	0.59
Jar 3	1.638	1.525	0.2
Jar 4	1.671	1.446	0.26
Jar 5	1.532	1.291	0.8

	Average		
Dose	TOC	DOC	Turbidity
0	3.7365	3.1345	9.28
6.95	2.2375	2.115	1.23
13.9	1.972	1.929	0.51
27.8	1.764	1.6175	0.32
41.7	1.5915	1.5235	0.365
69.5	1.2685	1.07145	1.005

Initial pH: 8.03 Initial alkalinity: 31.02
Final pH: 7.29 Final alkalinity: 22.09

Initial pH: 8.04 Initial alkalinity: 32.195
Final pH: 7.27 Final alkalinity: 21.62

Table 9.8 - Raw Jar Test Data for PAX-XL37, 8/19/02

Date mixed: 8/19/2002
Date H_2O Received: 8/14/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	4.127	3.927	3.81
Jar 1	3.274	2.878	0.64
Jar 2	2.892	2.616	0.38
Jar 3	2.392	2.374	0.15
Jar 4	2.24	2.309	0.07
Jar 5	1.474	1.46	0.23

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.917	4.533	3.75
Jar 1	3.956	3.343	0.54
Jar 2	3.325	2.891	0.09
Jar 3	3.016	2.675	0.01
Jar 4	2.619	2.28	0.04
Jar 5	2.037	1.74	0.24

	Average		
Dose	TOC	DOC	Turbidity
0	4.522	4.23	3.78
6.95	3.615	3.1105	0.59
13.9	3.1085	2.7535	0.235
27.8	2.704	2.5245	0.08
41.7	2.4295	2.2945	0.055
69.5	1.7555	1.6	0.235

Initial pH: 8 Initial alkalinity: 35.72
Final pH: 7.29 Final alkalinity: 26.79

Initial pH: 8.03 Initial alkalinity: 37.835
Final pH: 7.37 Final alkalinity: 25.38

Table 9.9 - Raw Jar Test Data for PAX-XL37, 8/26/02

Date mixed: 8/26/2002
Date H_2O Received: 8/21/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	4.127	3.409	8.32
Jar 1	2.728	2.452	1.05
Jar 2	3.305	3.349	0.34
Jar 3	2.21	2.316	0.12
Jar 4	2.525	2.634	0.02
Jar 5	1.778	1.839	0.1

Initial pH: 8.07 Initial alkalinity: 37.6
Final pH: 7.24 Final alkalinity: 28.435

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.43	3.819	8.23
Jar 1	3.426	3.383	1.02
Jar 2	2.882	2.776	0.65
Jar 3	2.698	2.222	0.16
Jar 4	2.86	2.381	0.03
Jar 5	1.937	1.866	0.19

Initial pH: 7.97 Initial alkalinity: 37.13
Final pH: 7.27 Final alkalinity: 27.73

	Average		
Dose	TOC	DOC	Turbidity
0	4.2785	3.614	8.275
6.95	3.077	2.9175	1.035
13.9	3.0935	3.0625	0.495
27.8	2.454	2.269	0.14
41.7	2.6925	2.5075	0.025
69.5	1.8575	1.8525	0.145

Table 9.10 - Raw Jar Test Data for PAX-XL37, 9/3/02

Date mixed: 9/3/2002
Date H_2O Received: 8/28/2002

*Dilution on day of test began

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.134	1.976	31.87
Jar 1	3.12	2.693	1.65
Jar 2	2.555	2.229	0.65
Jar 3	2.391	2.023	0.28
Jar 4	2.011	1.06	0.34
Jar 5	2.055	1.253	2.12

Initial pH: 7.78 Initial alkalinity: 35.485
Final pH: 6.72 Final alkalinity: 28.67

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.758	3.67	21.22
Jar 1	3.385	2.924	1.51
Jar 2	2.111	1.483	0.81
Jar 3	2.472	2.055	0.71
Jar 4	1.981	1.487	0.33
Jar 5	1.275	0.6764	1.27

Initial pH: 7.77 Initial alkalinity: 35.72
Final pH: 6.87 Final alkalinity: 28.2

	Average		
Dose	TOC	DOC	Turbidity
0	3.446	2.823	26.545
6.95	3.2525	2.8085	1.58
13.9	2.333	1.856	0.73
27.8	2.4315	2.039	0.495
41.7	1.996	1.2735	0.335
69.5	1.665	0.9647	1.695

Table 9.11 - Raw Jar Test Data for PAX-XL37, 9/11/02

Date mixed: 9/11/2002
Date H_2O Received: 9/4/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.736	2.812	11.19
Jar 1	1.852	1.806	1.36
Jar 2	1.586	1.233	0.53
Jar 3	1.896	1.926	0.22
Jar 4	2.051	1.526	0.38
Jar 5	1.712	1.218	1.4

Initial pH: 7.52 Initial alkalinity: 31.96
Final pH: 6.89 Final alkalinity: 20.68

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.752	3.073	12.52
Jar 1	1.67	1.091	1.33
Jar 2	1.14	0.7971	0.88
Jar 3	1.027	0.8654	0.25
Jar 4	0.5362	0.5714	0.56
Jar 5	1.618	1.207	1.03

Initial pH: 7.5 Initial alkalinity: 30.08
Final pH: 6.88 Final alkalinity: 20.445

	Average		
	TOC	DOC	Turbidity
0	3.744	2.9425	11.855
6.95	1.761	1.4485	1.345
13.9	1.363	1.01505	0.705
27.8	1.4615	1.3957	0.235
41.7	1.2936	1.0487	0.47
69.5	1.665	1.2125	1.215

Table 9.12 - Raw Jar Test Data for PAX-XL37, 10/2/02

Date mixed: 10/2/2002
Date H_2O Received: 9/27/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	12.38	8.087	281.7
Jar 1	6.47	5.351	80.55
Jar 2	4.373	4.343	7.81
Jar 3	3.287	3.386	1.56
Jar 4	3.75	3.734	1.09
Jar 5	3.533	3.481	0.44

Initial pH: 7.53 Initial alkalinity: 42.065
Final pH: 7.03 Final alkalinity: 34.31

	Mixer 2		
	TOC	DOC	Turbidity
Raw	11.37	8.288	278.1
Jar 1	5.976	6.064	67.51
Jar 2	4.998	4.752	9.04
Jar 3	3.182	2.655	2
Jar 4	3.769	3.549	1.49
Jar 5	3.325	3.105	0.77

Initial pH: 7.51 Initial alkalinity: 40.89
Final pH: 6.94 Final alkalinity: 34.78

	Average		
	TOC	DOC	Turbidity
0	11.875	8.1875	279.9
27.8	6.223	5.7075	74.03
41.7	4.6855	4.5475	8.425
55.6	3.2345	3.0205	1.78
69.5	3.7595	3.6415	1.29
83.4	3.429	3.293	0.605

Table 9.13 - Raw Jar Test Data for PAX-XL37, 10/8/02

Date mixed: 10/8/2002
Date H_2O Received: 9/27/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	13.64	8.407	254.1
Jar 1	9.184	5.845	198.6
Jar 2	6.766	5.294	80.69
Jar 3	4.179	1.904	7.06
Jar 4	4.831	3.265	3.62
Jar 5	3.848	4.076	0.49

	Mixer 2		
	TOC	DOC	Turbidity
Raw	10.5	7.99	243.9
Jar 1	9.726	6.886	180
Jar 2	3.02	3.226	54.71
Jar 3	5.528	2.922	4.52
Jar 4	3.632	2.203	1.13
Jar 5	1.855	1.755	0.87

	Average		
	TOC	DOC	Turbidity
0	12.07	8.1985	249
13.9	9.455	6.3655	189.3
27.8	4.893	4.26	67.7
41.7	4.8535	2.413	5.79
55.6	4.2315	2.734	2.375
69.5	2.8515	2.9155	0.68

Mixer 1:
Initial pH: 7.6 Initial alkalinity: 41.595
Final pH: 7.15 Final alkalinity: 35.25

Mixer 2:
Initial pH: 7.57 Initial alkalinity: 41.83
Final pH: 6.88 Final alkalinity: 26.555

Table 9.14 - Raw Jar Test Data for PAX-XL37, 10/21/02

Date mixed: 10/21/2002
Date H_2O Received: 10/10/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	7.827	6.325	219.4
Jar 1	7.204	7.115	89.25
Jar 2	5.893	5.746	21.6
Jar 3	8.339	7.994	2.91
Jar 4	4.027	3.485	0.7
Jar 5	4.03	4.011	1.98

	Mixer 2		
	TOC	DOC	Turbidity
Raw	12.04	9.873	193.2
Jar 1	6.112	5.946	93.94
Jar 2	6.059	5.486	36.87
Jar 3	5.273	4.987	2.89
Jar 4	4.284	4.113	0.86
Jar 5	3.369	3.124	0.68

	Average		
	TOC	DOC	Turbidity
0	9.9335	8.099	206.3
13.9	6.658	6.5305	91.595
27.8	5.976	5.616	29.235
41.7	6.806	6.4905	2.9
55.6	4.1555	3.799	0.78
69.5	3.6995	3.5675	1.33

Mixer 1:
Initial pH: 7.54 Initial alkalinity: 48.175
Final pH: 7.09 Final alkalinity: 39.48

Mixer 2:
Initial pH: 7.44 Initial alkalinity: 48.175
Final pH: 7.09 Final alkalinity: 39.245

Table 9.15 - Raw Jar Test Data for PAX-XL37, 11/26/02

Date mixed: 11/26/2002
Date H_2O Received: 10/17/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	8.749	7.999	13.08
Jar 1	5.737	4.186	1.95
Jar 2	4.126	3.184	0.18
Jar 3	2.85	2.699	0.01
Jar 4	1.747	1.547	0.01
Jar 5	1.946	1.842	0.01

Initial pH: 7.7 Initial alkalinity: 35.72
Final pH: 7.04 Final alkalinity: 23.03

	Mixer 2		
	TOC	DOC	Turbidity
Raw	8.777	7.424	8.32
Jar 1	4.433	4.213	1.39
Jar 2	2.19	1.948	0.06
Jar 3	2.091	1.984	0.01
Jar 4	1.863	1.745	0.2
Jar 5	3.96	2.961	0.22

Initial pH: 7.89 Initial alkalinity: 33.37
Final pH: 7.17 Final alkalinity: 24.91

	Average		
	TOC	DOC	Turbidity
0	7.257	5.805	10.7
13.9	6.216	6.481	1.67
27.8	3.158	2.566	0.12
41.7	2.4705	2.3415	0.01
55.6	1.805	1.646	0.105
69.5	2.953	2.4015	0.115

APPENDIX E

Jar Test Raw Data for PAX-4505

Table 10.1 - Raw Jar Test Data for PAX-4505, 6/20/02

Date mixed: 6/20/2002

Date H_2O Received: 6/17/2002

*No lime is used with PAX-4505

	Mixer 1		
	TOC	DOC	Turbidity
Raw	5.234	4.029	22.86
Jar 1	3.71	3.752	2.73
Jar 2	2.673	3.215	0.75
Jar 3	1.372	3.132	0.87
Jar 4	2.211	1.123	6.39
Jar 5	3.206	0.6815	21.96

Initial pH: 7.73 Initial alkalinity: 38.78

Final pH: 6.46 Final alkalinity: 12.93

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.592	6.506	21.73
Jar 1	2.87	2.993	3.25
Jar 2	1.515	2.908	0.96
Jar 3	3.98	1.084	0.91
Jar 4	2.29	1.853	5.54
Jar 5	5.391	0.902	22.84

Initial pH: 7.54 Initial alkalinity: 37.6

Final pH: 6.32 Final alkalinity: 11.75

	Average		
Dose	TOC	DOC	Turbidity
0	4.413	5.2675	22.295
13.9	3.29	3.3725	2.99
27.8	2.094	3.0615	0.855
41.7	2.676	2.108	0.89
55.6	2.2505	1.488	5.965
69.5	4.2985	0.79175	22.4

Table 10.2 - Raw Jar Test Data for PAX-4505, 6/27/02

Date mixed: 6/27/2002

Date H_2O Received: 6/24/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.104	2.883	24.71
Jar 1	2.492	2.097	1.49
Jar 2	1.379	1.12	0.7
Jar 3	0.5614	0.6442	2.16
Jar 4	0.5383	0.5558	15.35
Jar 5	1.653	1.683	20.81

Initial pH: 7.37 Initial alkalinity: 38.78

Final pH: 6.31 Final alkalinity: 8.23

	Mixer 2		
	TOC	DOC	Turbidity
Raw	1.279	1.649	26.27
Jar 1	1.046	2.572	1.9
Jar 2	0.4902	0.8133	0.53
Jar 3	1.3	0.06825	1.78
Jar 4	0.8638	1.383	15.14
Jar 5	1.003	0.388	20.42

Initial pH: 7.36 Initial alkalinity: 32.9

Final pH: 6.32 Final alkalinity: 8.23

	Average		
Dose	TOC	DOC	Turbidity
0	2.1915	2.266	25.49
13.9	1.769	2.3345	1.695
27.8	0.9346	0.96665	0.615
41.7	0.9307	0.356225	1.97
55.6	0.70105	0.9694	15.245
69.5	1.328	1.0355	20.615

Table 10.3 - Raw Jar Test Data for PAX-4505, 7/8/02

Date mixed: 7/8/2002
Date H_2O Received: 7/1/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.667	4.824	8.3
Jar 1	2.87	4.223	1.03
Jar 2	1.76	3.105	0.35
Jar 3	1.055	2.328	0.58
Jar 4	0.621	1.729	3.17
Jar 5	2.032	1.382	10.36

Initial pH: 7.05 Initial alkalinity: 41.13
Final pH: 6.23 Final alkalinity: 9.4

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.13	4.436	15.04
Jar 1	2.635	4.036	0.99
Jar 2	0.7637	2.117	0.38
Jar 3	2.717	3.303	0.41
Jar 4	0.7598	1.595	4.12
Jar 5	1.374	1.708	15.22

Initial pH: 7.18 Initial alkalinity: 37.6
Final pH: 6.35 Final alkalinity: 9.4

	Average		
Dose	TOC	DOC	Turbidity
0	3.8985	4.63	11.67
13.9	2.7525	4.1295	1.01
27.8	1.26185	2.611	0.365
41.7	1.886	2.8155	0.495
55.6	0.6904	1.662	3.645
69.5	1.703	1.545	12.79

Table 10.4 - Raw Jar Test Data for PAX-4505, 7/15/02

Date mixed: 7/15/2002
Date H_2O Received: 7/10/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	2.152	1.538	11.4
Jar 1	1.23	0.833	1.18
Jar 2	0.9904	0.3563	0.52
Jar 3	1.367	0.7527	2.96
Jar 4	1.295	0.7368	13.28
Jar 5	1.908	1.778	14.01

Initial pH: 7.41 Initial alkalinity: 32.9
Final pH: 6.1 Final alkalinity: 6.58

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.453	1.418	10.67
Jar 1	1.479	1.533	0.92
Jar 2	1.579	0.3714	0.55
Jar 3	2.066	0.7686	3.44
Jar 4	1.825	1.192	11.86
Jar 5	2.796	1.23	13.22

Initial pH: 7.46 Initial alkalinity: 32.43
Final pH: 6.12 Final alkalinity: 6.58

	Average		
Dose	TOC	DOC	Turbidity
0	2.8025	1.478	11.035
13.9	1.3545	1.183	1.05
27.8	1.2847	0.36385	0.535
41.7	1.7165	0.76065	3.2
55.6	1.56	0.9644	12.57
69.5	2.352	1.504	13.615

Table 10.5 - Raw Jar Test Data for PAX-4505, 7/22/02

Date mixed: 7/22/2002
Date H_2O Received: 7/17/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	5.11	2.089	33.9
Jar 1	3.744	2.24	2.8
Jar 2	1.555	0.8794	0.76
Jar 3	1.213	1.033	0.41
Jar 4	1.427	0.9866	2.26
Jar 5	1.554	1.118	21.2

Initial pH: 7.39 Initial alkalinity: 36.895
Final pH: 6.3 Final alkalinity: 11.985

	Mixer 2		
	TOC	DOC	Turbidity
Raw	5.574	2.034	29.39
Jar 1	2.401	2.4	2.5
Jar 2	1.83	1.37	0.59
Jar 3	1.158	0.9288	0.54
Jar 4	1.363	1.298	2.17
Jar 5	1.012	1.013	24.41

Initial pH: 7.24 Initial alkalinity: 35.25
Final pH: 6.35 Final alkalinity: 11.75

	Average		
Dose	TOC	DOC	Turbidity
0	5.342	2.0615	31.645
13.9	3.0725	2.32	2.65
27.8	1.6925	1.1247	0.675
41.7	1.1855	0.9809	0.475
55.6	1.395	1.1423	2.215
69.5	1.283	1.0655	22.805

Table 10.6 - Raw Jar Test Data for PAX-4505, 7/29/02

Date mixed: 7/29/2002
Date H_2O Received: 7/24/2002

Mixer 1 down as of 7/29

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.712	1.601	28.35
Jar 1	2.502	1.479	7.08
Jar 2	1.534	0.975	0.4
Jar 3	1.33	1.11	0.52
Jar 4	1.88	1.267	3.58
Jar 5	2.617	1.044	17.6

Initial pH: 7.25 Initial alkalinity: 30.55
Final pH: 6.16 Final alkalinity: 7.05

	Average		
Dose	TOC	DOC	Turbidity
0	4.712	1.601	28.35
13.9	2.502	1.479	7.08
27.8	1.534	0.975	0.4
41.7	1.33	1.11	0.52
55.6	1.88	1.267	3.58
69.5	2.617	1.044	17.6

Table 10.7 - Raw Jar Test Data for PAX-4505, 8/6/02

Date mixed: 8/6/2002
Date H_2O Received: 7/31/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	2.788	1.911	6.03
Jar 1	1.482	0.7281	0.53
Jar 2	1.421	0.4645	0.31
Jar 3	2.6	0.7959	4.47
Jar 4	1.766	1.227	9.33
Jar 5	4.324	1.929	9.51

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.472	0.9699	9.95
Jar 1	1.929	1.488	0.45
Jar 2	1.155	0.7424	0.32
Jar 3	0.3697	0.382	2.31
Jar 4	0.9146	0.9255	10.24
Jar 5	2.233	1.994	10.45

	Average		
Dose	TOC	DOC	Turbidity
0	3.13	1.44045	7.99
13.9	1.7055	1.10805	0.49
27.8	1.288	0.60345	0.315
41.7	1.48485	0.58895	3.39
55.6	1.3403	1.07625	9.785
69.5	3.2785	1.9615	9.98

Initial pH: 7.43 Initial alkalinity: 22.56
Final pH: 5.83 Final alkalinity: 2.35

Initial pH: 7.39 Initial alkalinity: 25.38
Final pH: 5.71 Final alkalinity: 1.88

Table 10.8 - Raw Jar Test Data for PAX-4505, 8/14/02

Date mixed: 8/14/2002
Date H_2O Received: 8/8/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.481	3.164	9.34
Jar 1	1.416	1.12	0.81
Jar 2	1.365	1.314	0.29
Jar 3	0.6815	0.5141	0.55
Jar 4	1.142	0.6182	5.46
Jar 5	2.26	0.5764	9.42

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.607	3.206	8.66
Jar 1	2.338	2.012	0.95
Jar 2	1.456	1.218	0.3
Jar 3	0.9979	0.7948	0.45
Jar 4	0.9196	0.4286	2.08
Jar 5	0.7647	0.7806	7.11

	Average		
Dose	TOC	DOC	Turbidity
0	3.544	3.185	9
13.9	1.877	1.566	0.88
27.8	1.4105	1.266	0.295
41.7	0.8397	0.65445	0.5
55.6	1.0308	0.5234	3.77
69.5	1.51235	0.6785	8.265

Initial pH: 7.81 Initial alkalinity: 31.725
Final pH: 6.04 Final alkalinity: 7.285

Initial pH: 7.79 Initial alkalinity: 30.55
Final pH: 6.38 Final alkalinity: 7.99

Table 10.9 - Raw Jar Test Data for PAX-4505, 8/20/02

Date mixed: 8/20/2002
Date H_2O Received: 8/14/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.425	3.144	9.37
Jar 1	3.009	3.061	2.46
Jar 2	1.677	1.444	0.73
Jar 3	1.813	1.653	0.17
Jar 4	1.125	0.7018	0.65
Jar 5	1.902	0.9275	9.73

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.761	3.37	8.8
Jar 1	2.179	1.84	1.99
Jar 2	1.755	1.331	0.41
Jar 3	2.049	1.377	0.15
Jar 4	1.343	0.8525	0.32
Jar 5	1.257	0.9071	10.65

	Average		
Dose	TOC	DOC	Turbidity
0	3.593	3.257	9.085
6.95	2.594	2.4505	2.225
13.9	1.716	1.3875	0.57
27.8	1.931	1.515	0.16
41.7	1.234	0.77715	0.485
69.5	1.5795	0.9173	10.19

Initial pH:	7.5	Initial alkalinity:	34.075	Initial pH:	7.48	Initial alkalinity:	32.43
Final pH:	6.21	Final alkalinity:	10.34	Final pH:	6.03	Final alkalinity:	8.46

Table 10.10 - Raw Jar Test Data for PAX-4505, 8/28/02

Date mixed: 8/28/2002
Date H_2O Received: 8/21/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.045	1.878	30.05
Jar 1	3.932	2.203	3.44
Jar 2	2.138	2.072	1.17
Jar 3	1.458	1.075	0.47
Jar 4	0.7629	0.4178	0.33
Jar 5	1.259	0.9202	10.19

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.151	3.852	51.44
Jar 1	3.225	2.995	3.2
Jar 2	2.5	2.377	1.4
Jar 3	0.7728	0.2293	0.3
Jar 4	1.552	1.355	0.26
Jar 5	1.2	0.5275	9.01

	Average		
Dose	TOC	DOC	Turbidity
0	3.598	2.865	40.745
6.95	3.5785	2.599	3.32
13.9	2.319	2.2245	1.285
27.8	1.1154	0.65215	0.385
41.7	1.15745	0.8864	0.295
69.5	1.2295	0.72385	9.6

Initial pH:	7.58	Initial alkalinity:	33.37	Initial pH:	7.52	Initial alkalinity:	32.195
Final pH:	6.24	Final alkalinity:	9.4	Final pH:	6.41	Final alkalinity:	8.93

Table 10.11 - Raw Jar Test Data for PAX-4505, 9/5/02

Date mixed: 9/5/2002
Date H_2O Received: 8/28/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.24	3.301	14.02
Jar 1	1.046	0.7371	2.03
Jar 2	2.02	1.208	0.52
Jar 3	1.441	0.2309	0.4
Jar 4	0.7631	0.7995	3.57
Jar 5	1.952	1.769	17.01

Initial pH: 7.81 Initial alkalinity: 35.485
Final pH: 6.11 Final alkalinity: 7.05

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.296	3.314	14.19
Jar 1	1.995	1.289	1.77
Jar 2	1.468	1.216	0.44
Jar 3	2.134	1.465	1.14
Jar 4	1.299	0.8672	4.99
Jar 5	1.933	1.763	16.22

Initial pH: 7.76 Initial alkalinity: 31.02
Final pH: 6.42 Final alkalinity: 7.05

	Average		
	TOC	DOC	Turbidity
0	3.268	3.3075	14.105
6.95	1.5205	1.01305	1.9
13.9	1.744	1.212	0.48
27.8	1.7875	0.84795	0.77
41.7	1.03105	0.83335	4.28
69.5	1.9425	1.766	16.615

Table 10.12 - Raw Jar Test Data for PAX-4505, 9/12/02

Date mixed: 9/12/2002
Date H_2O Received: 9/4/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	4.083	3.831	8.65
Jar 1	2.04	1.321	1.6
Jar 2	1.002	1.002	0.37
Jar 3	0.5264	0.3478	0.4
Jar 4	0.9936	0.8936	0.33
Jar 5	1.47	1.139	11.49

Initial pH: 7.83 Initial alkalinity: 30.08
Final pH: 6.38 Final alkalinity: 7.285

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.954	3.228	10.54
Jar 1	1.155	0.8402	2
Jar 2	1.137	0.7223	0.76
Jar 3	0.8021	0.4552	0.26
Jar 4	0.7316	0.6312	0.36
Jar 5	0.9223	1.093	11.6

Initial pH: 7.76 Initial alkalinity: 31.02
Final pH: 6.67 Final alkalinity: 6.815

	Average		
	TOC	DOC	Turbidity
0	4.0185	3.5295	9.595
6.95	1.5975	1.0806	1.8
13.9	1.0695	0.86215	0.565
27.8	0.66425	0.4015	0.33
41.7	0.8626	0.7624	0.345
69.5	1.19615	1.116	11.545

Table 10.13 - Raw Jar Test Data for PAX-4505, 9/27/02

Date mixed: 9/27/2002
Date H_2O Received: 9/16/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.351	3.001	10.31
Jar 1	2.506	2.528	1.32
Jar 2	2.575	1.679	0.32
Jar 3	1.002	0.5546	0.38
Jar 4	1.396	0.7951	0.49
Jar 5	1.773	1.396	6.12

Initial pH: 7.57 Initial alkalinity: 30.08
Final pH: 6.03 Final alkalinity: 8.93

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.349	3.156	8.37
Jar 1	2.381	2.513	1.19
Jar 2	2.232	1.71	0.81
Jar 3	1.222	0.5573	0.16
Jar 4	1.665	0.764	0.62
Jar 5	1.658	1.231	6.48

Initial pH: 7.67 Initial alkalinity: 32.9
Final pH: 6.43 Final alkalinity: 8.46

	Average		
	TOC	DOC	Turbidity
0	3.35	3.0785	9.34
6.95	2.4435	2.5205	1.255
13.9	2.4035	1.6945	0.565
27.8	1.112	0.55595	0.27
41.7	1.5305	0.77955	0.555
69.5	1.7155	1.3135	6.3

Table 10.14 - Raw Jar Test Data for PAX-4505, 10/4/02

Date mixed: 10/4/2002
Date H_2O Received: 9/27/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	12.79	7.993	305.5
Jar 1	11.92	6.771	259.9
Jar 2	5.965	3.317	241.8
Jar 3	7.677	4.744	202
Jar 4	8.188	5.339	122.6
Jar 5	3.101	3.391	3.04

Initial pH: 7.45 Initial alkalinity: 42.3
Final pH: 6.61 Final alkalinity: 19.74

	Mixer 2		
	TOC	DOC	Turbidity
Raw	11.19	7.67	288.9
Jar 1	11.6	7.005	241.8
Jar 2	8.588	6.604	231.5
Jar 3	8.235	5.01	196.1
Jar 4	6.549	4.57	126.9
Jar 5	2.221	1.624	1.79

Initial pH: 7.51 Initial alkalinity: 41.125
Final pH: 6.63 Final alkalinity: 18.33

	Average		
	TOC	DOC	Turbidity
0	11.99	7.8315	297.2
6.95	11.76	6.888	250.85
13.9	7.2765	4.9605	236.65
27.8	7.956	4.877	199.05
41.7	7.3685	4.9545	124.75
69.5	2.661	2.5075	2.415

Table 10.15 - Raw Jar Test Data for PAX-4505, 12/3/02

Date mixed: 12/3/2002
Date H_2O Received: 10/17/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	8.095	6.47	5.79
Jar 1	5.725	4.156	6.02
Jar 2	4.191	3.112	0.42
Jar 3	3.235	2.876	0.14
Jar 4	2.52	2.641	0.41
Jar 5	1.941	1.534	2.55

Initial pH: 7.86 Initial alkalinity: 31.725
Final pH: 6.34 Final alkalinity: 7.285

	Mixer 2		
	TOC	DOC	Turbidity
Raw	7.787	6.102	3.51
Jar 1	7.229	5.441	3.76
Jar 2	3.92	2.948	0.43
Jar 3	3.155	2.468	0.12
Jar 4	2.422	2.049	0.31
Jar 5	1.969	1.439	2.15

Initial pH: 7.84 Initial alkalinity: 30.08
Final pH: 6.55 Final alkalinity: 7.05

	Average		
	TOC	DOC	Turbidity
0	7.941	6.286	4.65
13.9	6.477	4.7985	4.89
27.8	4.0555	3.03	0.425
41.7	3.195	2.672	0.13
55.6	2.471	2.345	0.36
69.5	1.955	1.4865	2.35

APPENDIX F

Jar Test Raw Data for SternPAC

Table 11.1 - Raw Jar Test Data for SternPAC, 8/7/02

Date mixed: 8/7/2002
Date H_2O Received: 7/31/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.258	1.225	11.61
Jar 1	2.619	0.9732	11.35
Jar 2	3.193	1.166	10.17
Jar 3	3.031	1.244	8.82
Jar 4	2.687	0.9807	4.04
Jar 5	3.147	1.662	2.53

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.578	1.281	10.03
Jar 1	3.506	1.341	9.18
Jar 2	2.273	1.476	8.58
Jar 3	3.123	1.209	6.85
Jar 4	3.034	1.243	3.86
Jar 5	2.84	1.298	2.29

	Average		
Dose	TOC	DOC	Turbidity
0	3.418	1.253	10.82
3.65	3.0625	1.1571	10.265
7.3	2.733	1.321	9.375
10.95	3.077	1.2265	7.835
14.6	2.8605	1.11185	3.95
18.25	2.9935	1.48	2.41

Mixer 1:
Initial pH: 7.65 Initial alkalinity: 25.38
Final pH: 7.28 Final alkalinity: 21.385

Mixer 2:
Initial pH: 7.73 Initial alkalinity: 23.97
Final pH: 7.41 Final alkalinity: 20.445

Table 11.2 - Raw Jar Test Data for SternPAC, 8/9/02

Date mixed: 8/9/2002
Date H_2O Received: 8/8/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.168	2.25	8.78
Jar 1	2.919	2.64	7.19
Jar 2	2.828	2.32	3.18
Jar 3	3.001	2.225	1.44
Jar 4	2.19	2.28	0.84
Jar 5	2.204	1.596	0.67

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.278	2.689	9.78
Jar 1	4.017	2.663	8.53
Jar 2	3.639	2.264	4.02
Jar 3	3.379	2.513	1.83
Jar 4	2.957	2.279	1.15
Jar 5	2.658	2.288	1.05

	Average		
Dose	TOC	DOC	Turbidity
0	3.723	2.4695	9.28
7.3	3.468	2.6515	7.86
14.6	3.2335	2.292	3.6
21.9	3.19	2.369	1.635
29.2	2.5735	2.2795	0.995
36.5	2.431	1.942	0.86

Mixer 1:
Initial pH: 7.91 Initial alkalinity: 33.84
Final pH: 7.57 Final alkalinity: 28.905

Mixer 2:
Initial pH: 8.03 Initial alkalinity: 32.9
Final pH: 7.37 Final alkalinity: 30.08

Table 11.3 - Raw Jar Test Data for SternPAC, 8/21/02

Date mixed: 8/21/2002
Date H_2O Received: 8/14/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.113	3.157	13.16
Jar 1	3.111	2.873	11.87
Jar 2	3.381	3.357	5.21
Jar 3	2.46	2.529	1.32
Jar 4	1.833	1.324	0.47
Jar 5	1.103	0.326	0.16

Initial pH: 7.52 Initial alkalinity: 34.545
Final pH: 6.96 Final alkalinity: 26.79

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.086	3.775	12.98
Jar 1	3.162	3.135	11.05
Jar 2	3.22	2.855	4.97
Jar 3	2.579	1.049	1.35
Jar 4	2.176	1.302	0.49
Jar 5	2.266	0.8207	0.27

Initial pH: 7.61 Initial alkalinity: 35.485
Final pH: 6.94 Final alkalinity: 26.32

	Average		
Dose	TOC	DOC	Turbidity
0	3.5995	3.466	13.07
3.65	3.1365	3.004	11.46
10.95	3.3005	3.106	5.09
23.7	2.5195	1.789	1.335
32.85	2.0045	1.313	0.48
43.8	1.6845	0.57335	0.215

APPENDIX G

Jar Test Raw Data for SI-AA

Table 12.1 - Raw Jar Test Data for SI-AA, 9/26/02

Date mixed: 9/6/2002
Date H_2O Received: 8/28/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.409	3.487	18.84
Jar 1	2.788	2.414	3.28
Jar 2	2.198	1.578	0.8
Jar 3	0.8671	0.3665	0.3
Jar 4	0.7201	0.4948	0.27
Jar 5	0.8792	0.3222	0.33

Initial pH: 7.73 Initial alkalinity: 30.55
Final pH: 6.16 Final alkalinity: 8.46

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.911	3.869	12.66
Jar 1	1.404	1.074	2.89
Jar 2	1.968	1.84	1.404
Jar 3	1.015	0.1706	0.1706
Jar 4	0.8215	0.3659	0.3659
Jar 5	1.204	0.6426	0.27

Initial pH: 7.67 Initial alkalinity: 31.255
Final pH: 6.32 Final alkalinity: 9.87

	Average		
Dose	TOC	DOC	Turbidity
0	3.66	3.678	15.75
10	2.096	1.744	3.085
20	2.083	1.709	1.102
30	0.94105	0.26855	0.2353
40	0.7708	0.43035	0.31795
50	1.0416	0.4824	0.3

Table 12.2 - Raw Jar Test Data for SI-AA, 2/28/03

Date mixed: 2/28/2003
Date H_2O Received: 1/8/2003

	Mixer 1		
	TOC	DOC	Turbidity
Raw	6.642	4.595	61.03
Jar 1	3.126	2.542	6.93
Jar 2	1.897	1.776	0.086
Jar 3	1.246	1.089	0.28
Jar 4	1.349	1.297	0.25
Jar 5	1.397	1.334	1.44

Initial pH: 7.56 Initial alkalinity: 29.28
Final pH: 6.2 Final alkalinity: 10.16

	Mixer 2		
	TOC	DOC	Turbidity
Raw	5.987	4.426	52.19
Jar 1	3.264	2.687	7.34
Jar 2	1.997	1.764	0.52
Jar 3	1.124	0.987	0.2
Jar 4	1.398	1.324	0.21
Jar 5	1.495	1.524	0.38

Initial pH: 7.69 Initial alkalinity: 30.55
Final pH: 6.53 Final alkalinity: 9.87

	Average		
Dose	TOC	DOC	Turbidity
0	6.3145	4.5105	56.61
13.9	3.195	2.6145	7.135
27.8	1.947	1.77	0.303
41.7	1.185	1.038	0.24
55.6	1.3735	1.3105	0.23
69.5	1.446	1.429	0.91

APPENDIX H

Jar Test Raw Data for SI-ACH

Table 13.1 - Raw Jar Test Data for SI-ACH, 9/18/02

Date mixed: 9/18/2002
Date H_2O Received: 9/4/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.272	2.973	14.97
Jar 1	2.369	1.87	0.3
Jar 2	2.189	1.305	1.06
Jar 3	1.972	0.912	0.68
Jar 4	1.14	1.023	1.24
Jar 5	1.728	0.4987	1.14

Initial pH: 7.61 Initial alkalinity: 25.85
Final pH: 7.01 Final alkalinity: 21.385

	Mixer 2		
	TOC	DOC	Turbidity
Raw	2.864	2.877	9.56
Jar 1	1.694	1.248	0.27
Jar 2	1.541	0.9016	0.5
Jar 3	1.716	0.6529	1.44
Jar 4	1.308	0.5828	2.24
Jar 5	1.149	0.6078	1.78

Initial pH: 7.59 Initial alkalinity: 25.38
Final pH: 7 Final alkalinity: 21.62

	Average		
Dose	TOC	DOC	Turbidity
0	3.068	2.925	12.265
13.5	2.0315	1.559	0.285
27	1.865	1.1033	0.78
40.5	1.844	0.78245	1.06
54	1.224	0.8029	1.74
67.5	1.4385	0.55325	1.46

Table 13.2 - Raw Jar Test Data for SI-ACH, 10/3/02

Date mixed: 10/3/2002
Date H_2O Received: 9/27/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	13.96	8.099	348.5
Jar 1	3.316	3.235	1.84
Jar 2	2.048	1.639	2.39
Jar 3	1.244	1.084	0.99
Jar 4	1.759	1.137	3.27
Jar 5	1.748	1.488	7.4

Initial pH: 7.54 Initial alkalinity: 45.12
Final pH: 7.11 Final alkalinity: 34.78

	Mixer 2		
	TOC	DOC	Turbidity
Raw	11.13	7.99	320.9
Jar 1	2.083	1.538	1.06
Jar 2	1.817	2.018	0.66
Jar 3	1.427	1.224	1.55
Jar 4	1.414	0.9258	5.08
Jar 5	2.66	1.688	7.12

Initial pH: 7.47 Initial alkalinity: 42.065
Final pH: 6.95 Final alkalinity: 34.075

	Average		
Dose	TOC	DOC	Turbidity
0	12.545	8.0445	334.7
27	2.6995	2.3865	1.45
40.5	1.9325	1.8285	1.525
54	1.3355	1.154	1.27
67.5	1.5865	1.0314	4.175
81	2.204	1.588	7.26

Table 13.3 - Raw Jar Test Data for SI-ACH, 11/7/02

Date mixed: 11/7/2002
Date H_2O Received: 10/10/2002

	Mixer 1				Mixer 2			Dose	Average		
	TOC	DOC	Turbidity		TOC	DOC	Turbidity		TOC	DOC	Turbidity
Raw	13.69	14.34	183.3	Raw	13.48	12.74	135.4	0	13.585	13.54	159.35
Jar 1	10.88	9.408	31.79	Jar 1	10.47	9.827	23.63	13.5	10.675	9.6175	27.71
Jar 2	8.345	6.135	1	Jar 2	5.207	5.111	1.03	27	6.776	5.623	1.015
Jar 3	3.674	3.142	1.34	Jar 3	4.261	3.718	0.41	40.5	3.9675	3.43	0.875
Jar 4	4.542	4.124	0.51	Jar 4	4.228	4.101	0.73	54	4.385	4.1125	0.62
Jar 5	4.546	4.442	0.71	Jar 5	4.113	4.012	1.25	67.5	4.3295	4.227	0.98

Initial pH:	7.38	Initial alkalinity:	46.295	Initial pH:	7.4	Initial alkalinity:	43.945
Final pH:	6.97	Final alkalinity:	38.775	Final pH:	6.94	Final alkalinity:	37.6

Table 13.4 - Raw Jar Test Data for SI-ACH, 11/14/02

Date mixed: 11/14/2002
Date H_2O Received: 10/17/2002

	Mixer 1				Mixer 2			Dose	Average		
	TOC	DOC	Turbidity		TOC	DOC	Turbidity		TOC	DOC	Turbidity
Raw	11.37	6.949	4.78	Raw	10.75	8.496	4.43	0	11.06	7.7225	4.605
Jar 1	9.756	7.537	0.82	Jar 1	8.59	7.004	0.62	13.5	9.173	7.2705	0.72
Jar 2	5.215	5.001	1.98	Jar 2	5.437	5.126	0.16	27	5.326	5.0635	1.07
Jar 3	4.472	4.245	0.33	Jar 3	4.863	4.579	2.39	40.5	4.6675	4.412	1.36
Jar 4	4.008	3.487	0.67	Jar 4	6.031	5.911	2.85	54	5.0195	4.699	1.76
Jar 5	4.508	4.224	0.53	Jar 5	3.938	3.874	3.12	67.5	4.223	4.049	1.825

Initial pH:	8.07	Initial alkalinity:	36.19	Initial pH:	7.99	Initial alkalinity:	36.425
Final pH:	7.38	Final alkalinity:	29.14	Final pH:	7.39	Final alkalinity:	28.435

Table 13.5 - Raw Jar Test Data for SI-ACH, 12/11/02

Date mixed: 12/11/2003
Date H_2O Received: 12/2/2003

	Mixer 1		
	TOC	DOC	Turbidity
Raw	5.798	4.578	9.07
Jar 1	2.999	2.458	0.01
Jar 2	0.8142	1.234	0.01
Jar 3	3.821	2.478	0.27
Jar 4	1.036	1.234	0.31
Jar 5	2.732	1.875	0.31

Initial pH: 7.67 Initial alkalinity: 32.9
Final pH: 7.09 Final alkalinity: 23.03

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.448	4.012	9.33
Jar 1	3.066	2.447	0.01
Jar 2	2.637	2.013	0.01
Jar 3	1.091	1.264	0.03
Jar 4	2.162	2.014	0.3
Jar 5	2.248	1.976	0.88

Initial pH: 7.76 Initial alkalinity: 32.43
Final pH: 7.17 Final alkalinity: 24.205

	Average		
Dose	TOC	DOC	Turbidity
0	5.123	4.295	9.2
13.5	3.0325	2.4525	0.01
27	1.7256	1.6235	0.01
40.5	2.456	1.871	0.15
54	1.599	1.624	0.305
67.5	2.49	1.9255	0.595

APPENDIX I

Jar Test Raw Data for SI-AC

Table 14.1 - Raw Jar Test Data for SI-AC, 9/25/02

Date mixed: 9/25/2002
Date H_2O Received: 9/16/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	4.067	3.601	6.35
Jar 1	3.072	2.815	0.78
Jar 2	2.42	1.839	0.26
Jar 3	2.828	1.722	0.21
Jar 4	2.499	2.049	0.38
Jar 5	3.66	2.854	1.32

	Mixer 2		
	TOC	DOC	Turbidity
Raw	6.802	6.727	6.58
Jar 1	5.301	5.028	0.71
Jar 2	3.275	1.748	0.32
Jar 3	2.771	1.746	0.19
Jar 4	3.3	2.913	0.81
Jar 5	4.327	3.135	1.42

	Average		
Dose	TOC	DOC	Turbidity
0	5.4345	5.164	6.465
13.7	4.1865	3.9215	0.745
27.4	2.8475	1.7935	0.29
41.1	2.7995	1.734	0.2
54.8	2.8995	2.481	0.595
68.5	3.9935	2.9945	1.37

Initial pH:	7.38	Initial alkalinity:	31.255	Initial pH:	7.31	Initial alkalinity:	31.02
Final pH:	6.13	Final alkalinity:	9.4	Final pH:	6.35	Final alkalinity:	9.4

Table 14.2 - Raw Jar Test Data for SI-AC, 10/16/02

Date mixed: 10/16/2002
Date H_2O Received: 9/27/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	9.337	5.614	257.7
Jar 1	6.415	5.706	233.2
Jar 2	6.371	6.438	227.1
Jar 3	6.089	5.896	192.7
Jar 4	6.508	6.651	116.7
Jar 5	4.611	4.512	8.42

	Mixer 2		
	TOC	DOC	Turbidity
Raw	12.95	9.709	220.9
Jar 1	5.97	5.088	218.1
Jar 2	7.285	5.858	219.8
Jar 3	5.371	5.456	188.5
Jar 4	5.377	5.284	108.6
Jar 5	4.448	4.218	8.63

	Average		
Dose	TOC	DOC	Turbidity
0	11.1435	7.6615	239.3
13.9	6.1925	5.397	225.65
27.8	6.828	6.148	223.45
41.7	5.73	5.676	190.6
55.6	5.9425	5.9675	112.65
69.5	4.5295	4.365	8.525

Initial pH:	7.47	Initial alkalinity:	41.36	Initial pH:	7.41	Initial alkalinity:	40.89
Final pH:	6.63	Final alkalinity:	22.09	Final pH:	6.7	Final alkalinity:	20.445

APPENDIX J

Jar Test Raw Data for Ferriclear

Table 15.1 - Raw Jar Test Data for Ferriclear, 6/21/02

Ferriclear

Date mixed: 6/21/2002
Date H_2O Received: 6/17/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	5.212	4.424	21.83
Jar 1	5.049	4.093	22.28
Jar 2	3.806	2.745	23.93
Jar 3	4.106	2.928	25.1
Jar 4	2.538	2.187	16.65
Jar 5	0.7341	0.8245	7.65

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.687	4.785	22.01
Jar 1	4.957	3.848	24.3
Jar 2	1.029	1.752	24.48
Jar 3	4.812	3.081	19.74
Jar 4	2.44	1.912	10.03
Jar 5	1.193	0.8581	6.68

	Average		
Dose	TOC	DOC	Turbidity
0	4.9495	4.6045	21.92
16.7	5.003	3.9705	23.29
33.4	2.4175	2.2485	24.205
50.1	4.459	3.0045	22.42
66.8	2.489	2.0495	13.34
83.5	0.96355	0.8413	7.165

Initial pH:	7.14	Initial alkalinity:	41.13
Final pH:	6.73	Final alkalinity:	24.68

Initial pH:	7.11	Initial alkalinity:	39.95
Final pH:	6.76	Final alkalinity:	23.5

Table 15.2 - Raw Jar Test Data for Ferriclear, 6/28/02

Date mixed: 6/28/2002
Date H_2O Received: 6/24/2002

	Mixer 1		
Dose	TOC	DOC	Turbidity
50.1	1.115	1.993	55.25
66.8	2.082	3.061	7.55
83.5	0.4708	2.22	3.08
100.2	0.3544	2.385	1.89
116.9	1.473	2.019	1.09
133.6	0.457	2.501	1.23

	Average		
Dose	TOC	DOC	Turbidity
0	1.115	1.993	55.25
16.7	2.082	3.061	7.55
33.4	0.4708	2.22	3.08
50.1	0.3544	2.385	1.89
66.8	1.473	2.019	1.09
83.5	0.457	2.501	1.23

Initial pH:	7.87	Initial alkalinity:	35.25
Final pH:	6.67	Final alkalinity:	17.63

Table 15.3 - Raw Jar Test Data for Ferriclear, 7/9/02

Date mixed: 7/9/2002
Date H_2O Received: 7/1/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.471	4.169	31.3
Jar 1	0.7726	3.288	19.9
Jar 2	0.8155	2.058	19.02
Jar 3	0.8385	1.915	8.95
Jar 4	0.6443	1.666	3.81
Jar 5	0.603	1.821	2.13

Initial pH: 7.36 Initial alkalinity: 34.78
Final pH: 6.59 Final alkalinity: 19.98

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.234	4.754	11.11
Jar 1	1.026	2.545	11.01
Jar 2	3.7	3.51	12.11
Jar 3	0.5982	1.049	4.69
Jar 4	1.575	2.688	3.52
Jar 5	0.3869	1.907	2.2

Initial pH: 7.35 Initial alkalinity: 33.61
Final pH: 6.67 Final alkalinity: 18.8

	Average		
Dose	TOC	DOC	Turbidity
0	3.8525	4.4615	21.205
16.7	0.8993	2.9165	15.455
33.4	2.25775	2.784	15.565
50.1	0.71835	1.482	6.82
66.8	1.10965	2.177	3.665
83.5	0.49495	1.864	2.165

Table 15.4 - Raw Jar Test Data for Ferriclear, 7/16/02

Date mixed: 7/16/2002
Date H_2O Received: 7/10/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	1.583	1.598	21.32
Jar 1	1.051	1.345	17.27
Jar 2	1.36	0.5943	15.2
Jar 3	1.502	0.9547	15.95
Jar 4	1.295	0.7368	3.74
Jar 5	1.908	1.778	5.58

Initial pH: 7.39 Initial alkalinity: 29.375
Final pH: 6.8 Final alkalinity: 18.095

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.453	1.418	10.1
Jar 1	1.479	1.533	12.52
Jar 2	1.579	0.3714	9.73
Jar 3	2.066	0.7686	5.23
Jar 4	1.825	1.192	2.34
Jar 5	2.796	1.23	1.56

Initial pH: 7.31 Initial alkalinity: 28.2
Final pH: 6.75 Final alkalinity: 16.45

	Average		
Dose	TOC	DOC	Turbidity
0	2.518	1.508	15.71
16.7	1.265	1.439	14.895
33.4	1.4695	0.48285	12.465
50.1	1.784	0.86165	10.59
66.8	1.56	0.9644	3.04
83.5	2.352	1.504	3.57

Table 15.5 - Raw Jar Test Data for Ferriclear, 7/23/02

Date mixed: 7/23/2002
Date H_2O Received: 7/17/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	5.581	2.496	24.48
Jar 1	2.634	2.78	24.13
Jar 2	2.237	1.513	24.03
Jar 3	1.836	1.685	12.08
Jar 4	2.223	1.998	7.67
Jar 5	1.681	1.36	4.06

Initial pH: 7.53 Initial alkalinity: 33.84
Final pH: 6.82 Final alkalinity: 21.62

	Mixer 2		
	TOC	DOC	Turbidity
Raw	5.424	2.86	25.86
Jar 1	2.723	1.877	24.7
Jar 2	1.92	1.727	27.27
Jar 3	4.294	2.399	26.85
Jar 4	1.621	1.111	16.78
Jar 5	1.575	0.8949	5.25

Initial pH: 7.6 Initial alkalinity: 33.84
Final pH: 6.87 Final alkalinity: 22.09

	Average		
Dose	TOC	DOC	Turbidity
0	5.5025	2.678	25.17
16.7	2.6785	2.3285	24.415
33.4	2.0785	1.62	25.65
50.1	3.065	2.042	19.465
66.8	1.922	1.5545	12.225
83.5	1.628	1.12745	4.655

Table 15.6 - Raw Jar Test Data for Ferriclear, 7/30/02

Date mixed: 7/30/2002
Date H_2O Received: 7/24/2002

Mixer 1 down as of 7/29

	Mixer 2		
	TOC	DOC	Turbidity
Raw	3.259	2.492	32.29
Jar 1	4.338	2.229	8.27
Jar 2	1.375	1.211	1.75
Jar 3	0.9924	0.5552	0.83
Jar 4	1.806	0.6668	0.51
Jar 5	2.172	1.022	1.52

Initial pH: 7.27 Initial alkalinity: 31.725
Final pH: 5.97 Final alkalinity: 5.875

	Average		
Dose	TOC	DOC	Turbidity
0	3.259	2.492	32.29
50.1	4.338	2.229	8.27
83.5	1.375	1.211	1.75
116.9	0.9924	0.5552	0.83
150.3	1.806	0.6668	0.51
183.7	2.172	1.022	1.52

Table 15.7 - Raw Jar Test Data for Ferriclear, 8/27/02

Date mixed: 8/27/2002
Date H_2O Received: 8/21/2002

	Mixer 1		
	TOC	DOC	Turbidity
Raw	3.226	3.247	10.33
Jar 1	3.576	3.128	11.78
Jar 2	1.386	0.5673	1.28
Jar 3	0.8808	0.6791	0.42
Jar 4	0.7199	0.7289	0.25
Jar 5	0.6103	0.1487	0.28

Initial pH: 7.65 Initial alkalinity: 33.135
Final pH: 6.36 Final alkalinity: 8.93

	Mixer 2		
	TOC	DOC	Turbidity
Raw	4.179	3.337	9.75
Jar 1	3.373	2.891	11.44
Jar 2	1.131	0.4536	1.23
Jar 3	1.1	0.5016	0.36
Jar 4	0.5913	0.06	0.2
Jar 5	0.83	0.1573	0.45

Initial pH: 7.57 Initial alkalinity: 31.96
Final pH: 6.59 Final alkalinity: 9.635

	Average		
Dose	TOC	DOC	Turbidity
0	3.7025	3.292	10.04
16.7	3.4745	3.0095	11.61
50.1	1.2585	0.51045	1.255
83.5	0.9904	0.59035	0.39
116.9	0.6556	0.39445	0.225
150.3	0.72015	0.153	0.365