A COMPARISON OF ALUMINUM AND IRON-BASED COAGULANTS FOR TREATMENT OF SURFACE WATER IN SARASOTA COUNTY, FLORIDA

by

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B.S.C.E., B.S.Env.E., University of Central Florida, 2011

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Civil, Environmental, and Construction Engineering
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Fall Term
2012

ABSTRACT

In this research, five different coagulants were evaluated to determine their effectiveness at removing turbidity, color and dissolved organic carbon (DOC) from a surface water in Sarasota County, Florida. Bench-scale jar tests that simulated conventional coagulation, flocculation, and sedimentation processes were used. Iron-based coagulants (ferric chloride and ferric sulfate) and aluminum-based coagulants (aluminum sulfate, polyaluminum chloride (PACl) and aluminum chlorohydrate (ACH)) were used to treat a highly organic surface water supply (DOC ranging between 10 and 30 mg/L), known as the Cow Pen Slough, located within central Sarasota County, Florida. Isopleths depicting DOC and color removal efficiencies as a function of both pH and coagulant dose were developed and evaluated.

Ferric chloride and ACH were observed to obtain the highest DOC (85% and 70%, respectively) and color (98% and 97%, respectively) removals at the lowest dose concentrations (120 mg/L and 100 mg/L, respectively). Ferric sulfate was effective at DOC removal but required a higher concentration of coagulant and was the least effective coagulant at removing color. The traditional iron-based coagulants and alum had low turbidity removals and they were often observed to add turbidity to the water. PACl and ACH had similar percent removals for color and turbidity achieving consistent percent removals of 95% and 45%, respectively, but PACl was less effective than ACH at removing organics. Sludge settling curves, dose-sludge production ratios, and settling velocities were determined at optimum DOC removal conditions for each coagulant. Ferric chloride was found to have the highest sludge settling rate but also produced the largest sludge quantities. Total trihalomethane formation potential (THMFP) was measured

for the water treated with ferric chloride and ACH. As with DOC removal, ferric chloride yielded a higher percent reduction with respect to THMFP.

This thesis is dedicated to the Yonge family: Chip, Dana, Tyler and Tatum. Special recognition to my mother who shed tears teaching mathematics to me through middle school.

ACKNOWLEDGMENTS

The study would not have been feasible without the support of a number of individuals who assisted in this research. The author would like to thank Dr. Steven Duranceau for the opportunity to perform this research and for serving as my committee chair. I am tremendously appreciative for his support and vote of confidence in my continued education. Thank you to Dr. David Cooper and Dr. Andrew A. Randall for serving as committee members and donating their time and expertise in reviewing this document. The author wishes to acknowledge the efforts of Ms. Maria Real-Robert, CECE's laboratory coordinator for her assistance. The author would also like to express his appreciation for the unwavering support of Genesis Rios and Paul Biscardi throughout the course of this study. Special thanks to Christopher Boyd and Jayapregasham Tharmapalan for their continuous mentoring, guidance, and physical labors during sampling events. The author is also grateful to the contributions and assistance of UCF students Alyssa Filippi, Nick Webber, Jennifer Roque, Juan Rueda, Marzieh Ghasemi, Shane Clark, Andrea Cumming, and Samantha Jeffrey.

The author would like to express his appreciation to the Sarasota County Government, especially Seton Katz, as well as the Southwest Florida Water Management District. The author is grateful for the support of Carollo Engineers, specifically Dr. Jess Brown, Dr. Sandeep Sethi, Dr. Jennifer Nyfennegger, and Mary Ann Wandling. The author would like to recognize the University of Central Florida for the use of its facilities and the CECE department employees, Stephanie Crouch, Carol Ann Pohl, Pauline Strauss, and Margarida Trim for all their support. Lastly, thanks are in order to General Chemical for providing the coagulants and acknowledgements to

Stephen Robinson, Larry McShane, and Carolyn Wezenter for their expertise and advice in their products. The contents herein do not necessarily reflect the views and policies of the sponsors nor does the mention of trade names or commercial products constitute endorsement or recommendation. Furthermore, the comments and opinions expressed herein may not necessarily reflect the views of the officers, directors, affiliates or agents of Sarasota County Government, the SWFWMD, Carollo, and the University of Central Florida.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

ACH	aluminum chlorohydrate
ACS	American Chemical Society
Alum	aluminum sulfate
am	amorphous
ASTM	American Society for Testing and Materials
cfs	cubic feet per second
CFS	coagulation, flocculation, sedimentation
CPS	Cow Pen Slough
DBP	disinfection byproducts
DT	dry ton
FC	ferric chloride
FS	ferric sulfate
HAA	haloacetic acid
LCL/LWL	lower control limit / lower warning limit
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MF	microfiltration
MG/MGD	million gallons / million gallons per day
NF	nanofiltration
NOM	natural organic matter
NPDOC/DOC	(non-purgeable) / dissolved organic carbon
NRC	National Research Council
NTU	nephelometric turbidity unit
PACl	polyaluminum hydroxychloride
PCU	platinum cobalt units
ppb/ppm	parts per billion / parts per million
RO	reverse osmosis
RPD	relative percent difference
SDWA	Safe Drinking Water Act
SM	standard methods
SMCL	secondary maximum contaminant level
SWFWMD	Southwest Florida Water Management District
TDS	total dissolved solids
THM/FP	trihalomethanes / trihalomethanes formation potential
TOC	total organic carbon
TSS	total suspended solids
UCF	University of Central Florida
UCL/UWL	upper control limit / upper warning limit
UF	ultrafiltration
USEPA/EPA	(United States) / Environmental Protection Agency
USGS	Unites States Geological Survey

1. INTRODUCTION

Historically, Florida has relied on the use of groundwater sources to meet its drinking water demands, accounting for eighty to ninety percent of the water consumed in the state. Between 1994 and 2001 surface water withdrawals consistently accounted for approximately 10% of the public water supply in Florida (Marella, 2005). Since 2001, the percentage of surface water use has increased. This is likely a response to the implementation of additional restrictions on groundwater withdrawals forcing utilities to explore alternative sources of water. One such region experiencing more stringent groundwater regulations is Sarasota County, Florida. However, using surface water as a drinking water source brings new challenges to engineers and utilities due to a variety of factors, including increased water quality variability, organic content and other water contaminants. The research reported in this document was one component of a larger research project funded cooperatively by Sarasota County Government and the Southwest Florida Water Management District (SWFWMD) to perform a treatability analysis that develops, analyzes and integrates treatment alternatives for a new surface water supply.

Project Description

The research presented in the document was conducted by the University of Central Florida (UCF) to assist Carollo Engineers (401 N. Cattleman Rd., Suite 306, Sarasota, FL 34232) with their efforts in the development of the Dona Bay Watershed Management Plan for Sarasota County Government (1001 Sarasota Center Blvd., Sarasota, FL 34240) and the Southwest Florida Water Management District (SWFWMD, 2379 Broad Street, Brooksville, FL 34604-

6899). Sarasota County identified a canal, referred to as the Cow Pen Slough (CPS), as an additional drinking water source.

The primary objective of research conducted by the UCF Civil, Environmental and Construction Engineering (CECE) department was to conduct coagulant selection in support of the overall project by assessing the treatability of turbidity, color and dissolved organic carbon through a bench-scale jar testing evaluation of conventional treatment. Information regarding coagulant dosages, type, optimum pH ranges and percent removals were studied to compare the effectiveness of traditional coagulants with two coagulants less well-established in treating Florida surface water. Additional research parameters included sludge settleability, alkalinity retention and disinfection byproduct formation potential.

2. LITERATURE REVIEW

Surface Water

The term surface water refers to bodies of water open to the atmosphere including estuaries, streams, rivers and lakes. Under the Clean Water Act, Florida has classified surface waters into six water quality classifications. Class one includes proposed and existing drinking water sources and requires the highest level of treatment before the water can be distributed to the public. Common treatment technologies for surface waters include unit processes targeting the removal of turbidity, microbial parameters, organic matter, total dissolved solids (TDS), hardness and taste and odor issues. Conventional treatment methods include the processes of coagulation, flocculation and sedimentation usually followed by filtration and disinfection. Over the past decade, the drinking water treatment industry has become increasingly attracted to membrane technology given its ability to meet more stringent drinking water standards (Van der Bruggen, 2003; Shannon Mark A., 2008). Microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) are classified according to the pore size of the membrane and type of constituents rejected as listed in Table 2-1.

Table 2-1: Pore Size and Rejected Material for Membrane Processes

Membrane Process	Pore Size (μm)	Types of Rejected Materials
Microfiltration	0.1	Particles / Algae / Bacteria / Protozoa
Ultrafiltration	0.01	Colloids / Viruses
Nanofiltration	0.001	Dissolved Organics / Divalent Ions (Mg^{2+}, Ca^{2+})
Reverse Osmosis	Non-porous	Monovalent Species (Na^+, Cl^-)

Drinking Water Regulations

In the 1800s, Dr. John Snow, Dr. Louis Pasteur and Dr. Robert Koch substantially contributed to the understanding of drinking water quality through their studies of water-borne cholera, microscopic organisms and bacteriology. By the late nineteenth century, drinking water quality concerns began to focus on pathogens and microbial contaminants. The U.S. Public Health Service set the first federal standards for drinking water in 1914. By 1962, the standards included regulations for twenty-eight substances and guidelines for public water systems (EPA, Environmental Protection Agency, 1999).

Under President Ford, the Safe Drinking Water Act (SDWA) was established in 1974 by the United States Environmental Protection Agency (USEPA) to protect public health and the quality of ground and surface waters. Under this act the EPA established enforceable primary and recommended secondary standards for drinking water regulations. Primary standards specify maximum contaminant levels (MCLs) affecting public health. Maximum contaminant level goals (MCLGs) are also applied to primary standards but are not enforceable. Secondary maximum contaminant levels (SMCLs) include contaminants of an aesthetic nature such as color, odor, chloride and zinc (Vesilind P. Aarne, 2004). SMCLs are not enforceable but often met by water providers due to the expectations of their customers. Primary and secondary standards are found in Title 40 Part 141 of the Code of Federal Regulations (40CFR141).

Specific Water Contaminants

Disinfection Byproducts

Disinfection has been used to treat drinking water for pathogenic microorganisms in the U.S. since 1908 (EPA, Environmental Protection Agency, 1999). Disinfectants such as chlorine and ozone are highly reactive chemicals, making them efficient for inactivating pathogens. In the mid-seventies however, chemists in Rotterdam discovered that four trihalomethanes were observed to increase following chlorination of a surface water supply (Rook, 1974). In more recent times, ozone and other disinfectants have been shown to react with natural organic matter to form disinfection byproducts (DBPs) (Van Leeuwen, 2000; Kim Mi Hyung, 2005; Edzwald, 2011). Under the Stage One Disinfectants/Disinfection By-Products Rule (DBPR), the EPA has regulated some carcinogenic DBPs such as trihalomethanes (THMs) and haloacetic acids (HAAs) and set MCLGs for controversial DBPs due to their potential carcinogenic effects. DBPs and other contaminants are determined using a risk assessment procedure developed by the National Research Council (NRC) that includes hazard assessment, dose-response, exposure assessment and risk characterization (Allen, 2002). Strategies to maintain DBP rule compliance include either altering the disinfectant or removing the precursor organic matter. Efforts that focus on post-formation treatment are limited to chloroform, a semi-volatile DBP that can under certain conditions be removed by stripping; however, this approach is limiting and does not address non-volatile DBPs.

Natural Organic Matter

Natural organic matter (NOM) refers to complex organic chemicals present in natural waters originating from biological activity, decaying organic matter, excretions from aquatic organisms, and runoff from land (Crittenden, Trussell, Hand, Howe, & Tchobanoglous, 2005). It is of particular concern in drinking water treatment for both its effect on the aesthetic qualities of the water and the fact that NOM serves as a surrogate for DBP precursors. In drinking water treatment, NOM and DBP precursors are often quantified by measuring the total organic carbon (TOC) or dissolved organic carbon (DOC) of the water (Wallace Brian, 2002). Although most ground water has TOC concentrations less than 2 mg/L, surface waters typically range from 1 to 20 mg/L. Swamps and highly colored waters may have TOC concentrations as high as 200 mg/L (Crittenden, Trussell, Hand, Howe, & Tchobanoglous, 2005). The global average for the dissolved organic carbon level in streams is 5.75 mg/L (Kabsch-Korbutowicz, 2006). With respect to enhanced coagulation, the USEPA has set standards on TOC removal under the Stage One DBPR. Table 2-2 provides a listing of the required percent removal of TOC based on source water alkalinity and TOC concentrations.

Table 2-2: Required Percent TOC Removal (EPA, 2012)

Source Water Alkalinity mg/L as $CaCO_3$	**Source Water TOC (mg/L)**		
	> 2.0 - 4.0	> 4.0 - 8.0	> 8.0
0-60	35%	45%	50%
> 60-120	25%	35%	40%
> 120	15%	25%	30%

Treatment technologies for the removal of NOM typically include coagulation, adsorption, oxidation, or membrane filtration. Treatment technologies that use adsorbents such as anion exchange or activated carbon can quickly lose adsorption capacity with high concentrations of NOM. Oxidative processes generally refer to treatment methods that include chemical reactions using ozone, hydrogen peroxide, or ultraviolet (UV) light. These processes have little effect on NOM and turbidity removal and serve rather to disinfect the NOM. Membrane filtration technologies such as MF, UF, NF and RO can effectively remove NOM but fouling of membranes quickly occurs if pretreatment is not implemented. Membrane processes are looking more attractive given their ability to meet regulatory requirements however they often have high operating and capital costs (Shannon Mark A., 2008). A more common treatment method for NOM removal includes the traditional processes of coagulation, flocculation, sedimentation and filtration as seen in Figure 2-1 (Crittenden, Trussell, Hand, Howe, & Tchobanoglous, 2005).

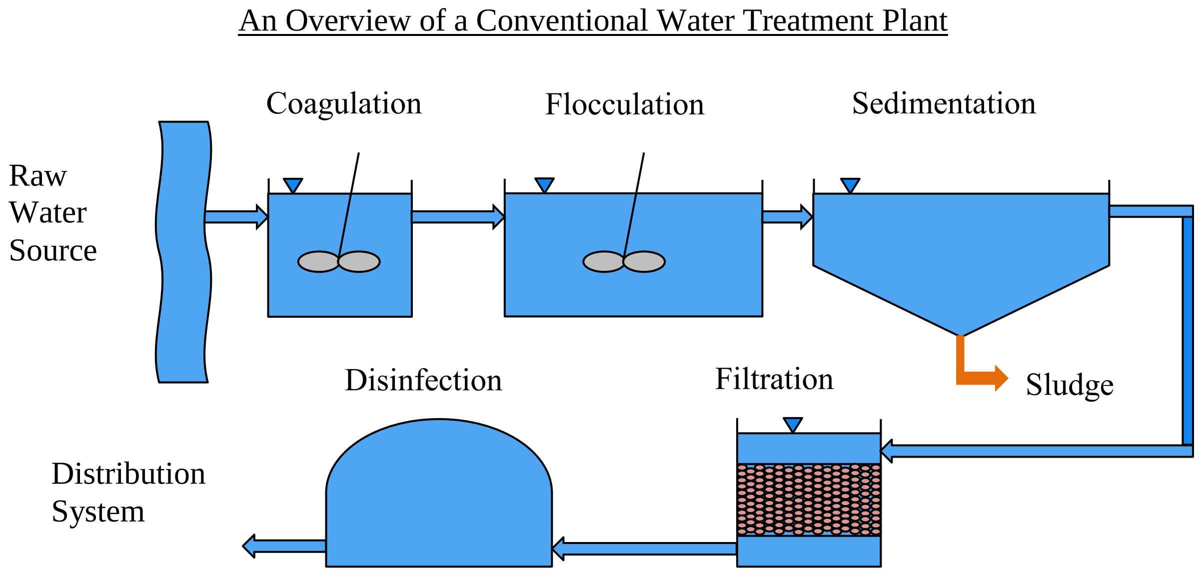


Figure 2-1: Diagram of a Conventional Treatment System

Coagulation/Flocculation

In water treatment, coagulation is the process through which suspended, colloidal and dissolved matter are destabilized by the addition of a chemical (coagulant). Traditional coagulants such as ferric chloride, ferric sulfate and alum hydrolyze rapidly when dispersed in water forming insoluble precipitates and compressing the electrical double layer of the suspended (NOM) particles. The precipitates adsorb to the particles in the water neutralizing their charge, and subsequently allow for interparticle bridging. The concentration of NOM and its composition greatly affect the chemistry of the coagulation process. Flocculation is the process by which the destabilized particles agglomerate and form flocculant particles, or "floc." Velocity gradients and particles undergoing random Browning motion cause particles to collide and attach to other particles, increasing the effectiveness of removing turbidity and dissolved material (Crittenden, Trussell, Hand, Howe, & Tchobanoglous, 2005).

Coagulants

Ferric Chloride & Ferric Sulfate

The primary hydrolyzing ionic coagulants used in water treatment consist of aluminum and iron salts (Edzwald, 2011). Ferric chloride, ferric sulfate, and aluminum sulfate are available commercially in both liquid and solid forms. Typical dosages of ferric chloride range from 5 to 150 mg/L depending on multiple factors including NOM concentrations and raw water quality. Previous studies have found the optimum pH range for iron-based coagulants to be between 5 and 8.5 which is slightly larger than that of aluminum sulfate (Amirtharajah A., 1982). NOM removals of up to eighty percent using iron salts have been achieved at low pH values. However, determination of the optimum pH range and coagulant concentration ultimately depends on the raw water characteristics, and differs for each water source (Kan & Huang, 1998). Furthermore, the use of iron-based coagulants prior to membrane filtration processes is coming into question as more of these integrated processes are employed (Duranceau & Taylor, Chapter 11: Membrane Processes, 2010; Barbot, Moustier, Bottero, & Moulin, 2008; Manzouri & Shon, 2011; Xu, Chellam, & Clifford, 2004). The chemistry associated with the reactions of metal salts in water is complex and can form many species affected by pH and temperature (Sposito, 1996). Simplified solubility diagrams such as in Figure 2-2 have been developed to describe the relationships between metal salt concentrations and pH. Solubility diagrams can help describe the various metal salt species present in the water at varying pH. This information is useful when selecting the type and dosage of coagulants. One observation from solubility diagrams is that iron-based coagulants have a broader pH range, where precipitation is likely to occur, compared to that of aluminum.

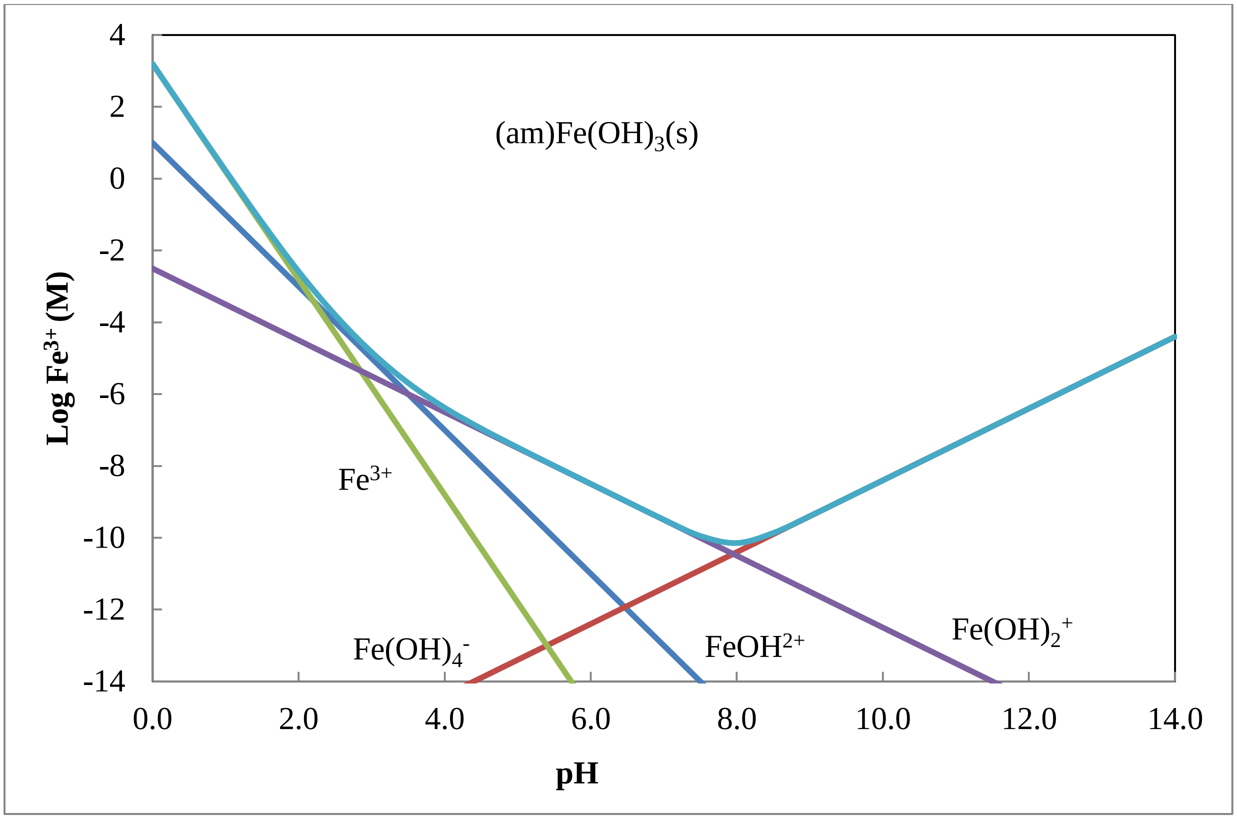


Figure 2-2: Simplified Solubility Diagram for Iron Salts

The solubility of metal salts are described by a number of reactions forming multiple metal species (Ball & Nordstrom, 1991), however the chemical reactions describing the hydrolysis of metal salts are complex and for purposes of coagulation the following equations are adequate. Equations 2-1 and 2-2 provide the overall stoichiometric reactions of ferric and aluminum and show that for every one mole of trivalent metal ion, one mole of amorphous (am) solids and three moles of hydrogen ions are produced (Crittenden, Trussell, Hand, Howe, & Tchobanoglous, 2005). Ferric and aluminum act as acids as they release hydrogen ions and lower the pH of the water.

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_{3,am\downarrow} + 3H^+ \tag{2-1}$$

$$Al^{3+} + 3H_2O \rightarrow Al(OH)_{3,am\downarrow} + 3H^+ \tag{2-2}$$

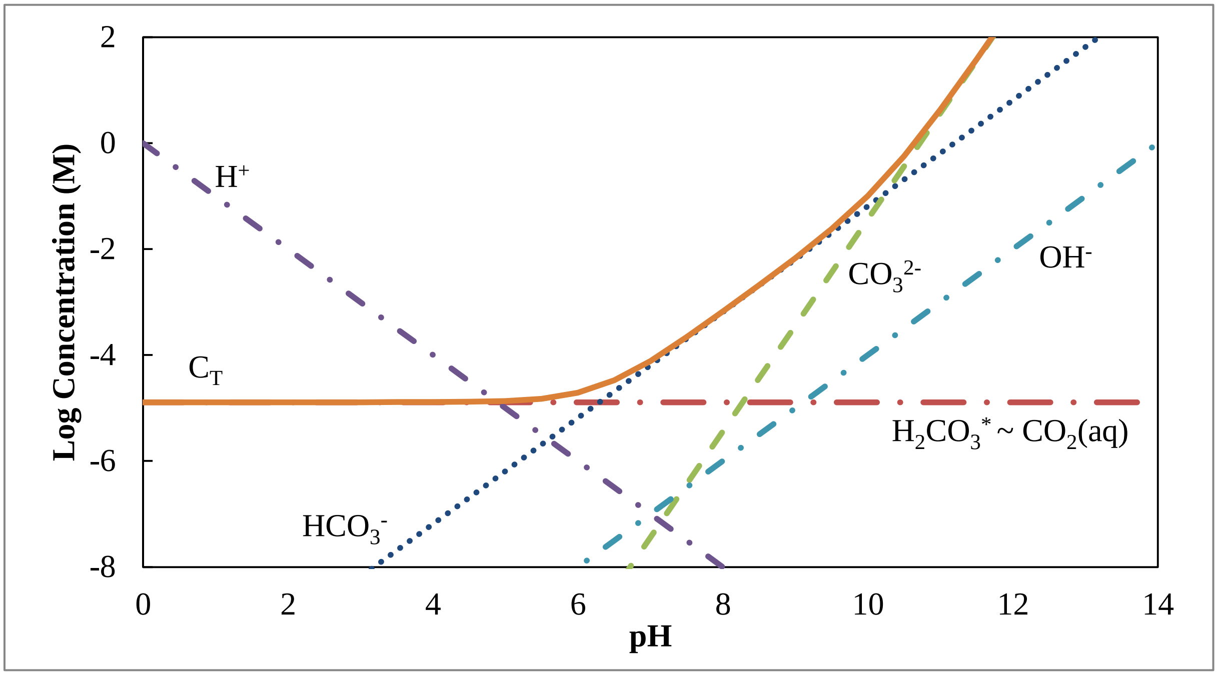


Figure 2-3: Log C-pH Diagram for Carbonate in an Open System

Alkalinity is a measure of water's capacity to neutralize acids. As the pH is lowered, the speciation of carbonate (a major component of alkalinity) shifts on the log C-pH diagram. Once the pH is below 6.37, the predominant form of carbonate shifts to carbonic acid (which does not contribute to alkalinity) as bicarbonate ions gain hydrogen ions (Sawyer, 2003; Jensen, 2003). In an open system, carbon dioxide comes out of solution to equilibrate with the atmosphere as described by Henry's Law. This in effect, decreases the alkalinity which unlike in a closed system cannot be recovered by increasing the pH. As a result, open systems often require the addition of caustic soda, lime, or soda ash to replace the non-recoverable alkalinity. Figure 2-3 illustrates the equilibrium of carbon dioxide in water with the atmosphere. The alkalinity demands of ferric chloride and aluminum sulfate can be calculated using the stoichiometric reactions in Equations 2-3 and 2-4 (Crittenden, Trussell, Hand, Howe, & Tchobanoglous, 2005).

$$FeCl_3 \cdot 6H_2O + 3(HCO_3^-) \rightarrow Fe(OH)_{3,am\downarrow} + 3Cl^- + 6H_2O + 3CO_2 \tag{2-3}$$

$$Al_2(SO_4)_3 \cdot 14H_2O + 6(HCO_3^-) \rightarrow 2Al(OH)_{3,am\downarrow} + 3SO_4^{2-} + 14H_2O + 6CO_2 \tag{2-4}$$

Ferric sulfate behaves much like ferric chloride but is less commonly used in water treatment plants. Typical dosages range from 10 to 250 mg/L (Crittenden, Trussell, Hand, Howe, & Tchobanoglous, 2005). The overall stoichiometric equation for ferric sulfate is provided in Equation 2-5. Coagulation using iron salts, demonstrates higher NOM removals but higher color and turbidity removal is typically attained by using aluminum-based coagulants (Matilainen, 2010).

$$Fe_2(SO_4)_3 \cdot 9H_2O \rightarrow 2Fe(OH)_{3\downarrow} + 6H^+ + 3SO_4^{2-} + 3H_2O \tag{2-5}$$

<u>Aluminum Sulfate</u>

Aluminum sulfate or “alum” is the most common water treatment coagulant in the United States (Crittenden, Trussell, Hand, Howe, & Tchobanoglous, 2005). As alum is added to water the hydrolysis reactions form a number of dissolved monomeric aluminum species and aluminum hydroxide precipitates. A number of scientists have studied the complex reactions for alum in water and have developed theoretical solubility diagrams for aluminum-based coagulants, see Figure 2-4.

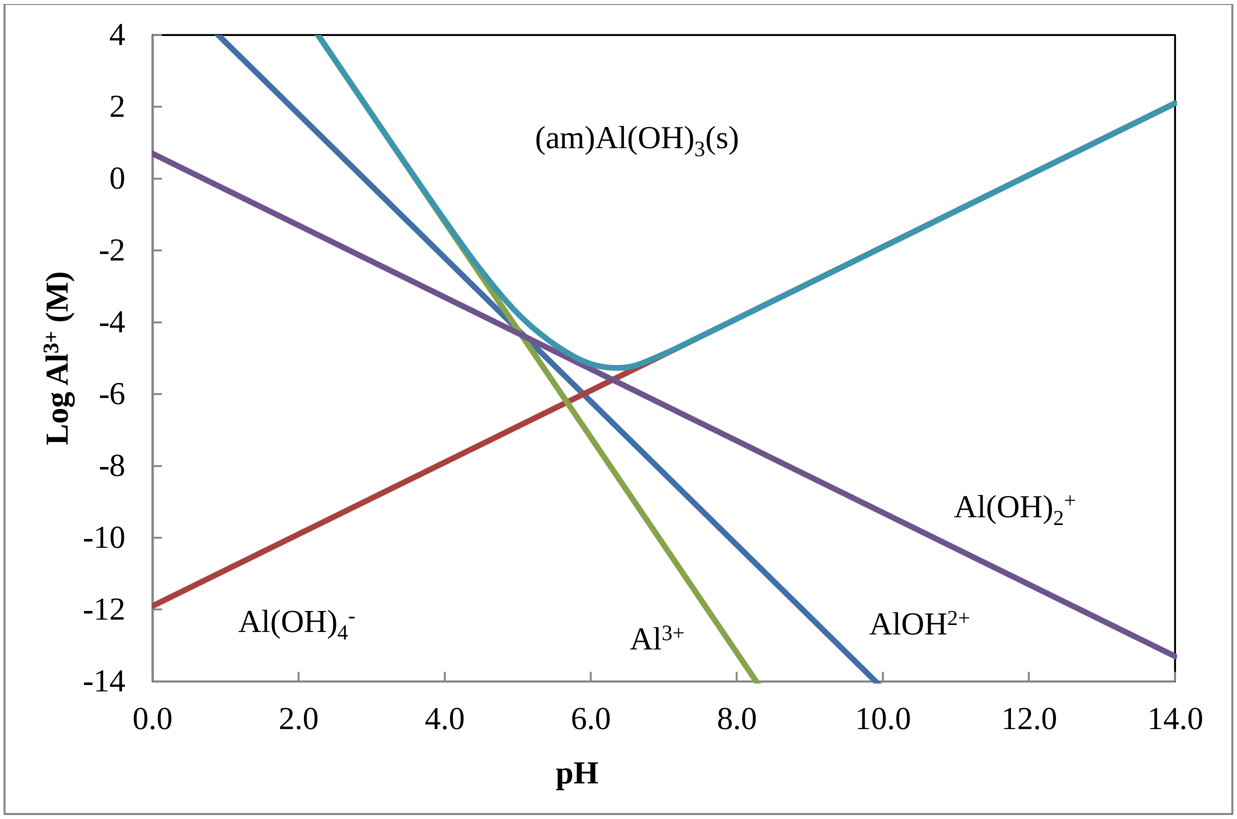


Figure 2-4: Simplified Solubility Diagram for Aluminum Salts

The theoretical effective hydrolyzing pH range for alum is 5.5 to 7.7 with optimal pH values near 6.0. At the optimum pH, the solubility is minimal and the maximum amount of coagulant is converted to solid floc particles. As pH decreases from 6.0, dissolved positively charged aluminum species are formed. As pH increases above 6.0, the concentrations of negatively charged aluminum species increase. Researchers have found the distribution of aluminum species to be greatly affected by pH and temperature (Pernitsky & Edzwald, 2006). The aluminum species present in the water are of concern because of the implications they have with the adsorption of NOM. NOM removals tend to increase at lower pH values where highly charged aluminum species are prevalent. NOM is typically composed of organic compounds with negatively charged functional groups. These groups react with the highly charged aluminum species to form precipitants which can then be settled out of the water. Although NOM removals as high as 70% have been attained at low pH values, the characteristics (charge, molecular weight, pH, etc.) of the NOM will affect the efficiency of the coagulation process. Thus, high NOM removals have been observed at lower pH values and do not necessarily correspond with the pH at which minimum solubility of a coagulant occurs. Equation 2-6 is the overall reaction of alum and water.

$$Al_2(SO_4)_3 \cdot 14H_2O \rightarrow 2Al(OH)_{3\downarrow} + 6H^+ + 3SO_4^{2-} + 8H_2O \tag{2-6}$$

The hydrolysis reactions between water and metal salts produce hydrogen ions which lower the pH and consume alkalinity at a 1:1 equivalent basis. Neutralizing the hydrogen ions with base during manufacturing has led to the development of pre-hydrolyzed coagulants, such as those made with aluminum chloride (Crittenden, Trussell, Hand, Howe, & Tchobanoglous, 2005).

Polyaluminum Hydroxychloride

Manufacturers refer to pre-hydrolyzed metal salt coagulants with lower basicity values as polyaluminum hydroxychloride or PACl (Edzwald, 2011). Basicity is the degree to which hydrogen ions are pre-neutralized during hydrolysis. It is calculated by Equation 2-7, where [OH]/[M] is the molar ratio of hydroxide bound to the metal ion and Z_M is the charge on the metal species.

$$Basicity\ (\%) = B = 100 \times \frac{[OH]}{[M]Z_M} \tag{2-7}$$

Basicity affects the ratio of polynuclear to mononuclear species present in the solution as well as provides an indication of the alkalinity consumption of the coagulant. PACl has a higher optimum pH value with regards to solubility than alum, which allows it to form precipitates at higher pH values. Furthermore, unlike traditional hydrolyzing metal salts, mixing time and intensity for pre-hydrolyzed coagulants such as PACl are less critical to achieve effective coagulation (Crittenden, Trussell, Hand, Howe, & Tchobanoglous, 2005). Kan and Huang found that the determination of the optimum dosage will not be affected by a 12.5% increase in mixing intensity, supporting a study by Eisenlauer and Horn in 1987. Instead, it was determined that an increase in mixing intensity would cause an increase in floc settling velocities and density (Kan & Huang, 1998).

Aluminum Chlorohydrate

Aluminum chlorohydrate or (ACH) typically refers to aluminum chloride coagulants with the basicity values of approximately eighty-three percent. It has been suggested that the fraction of higher charged aluminum species, such as Al_{13}^{7+}, increases as basicity increases and that it is the primary hydrolysis product in coagulants with basicity greater than seventy percent (Edzwald, 2011). The pH of minimum solubility for ACH is substantially higher than that of alum allowing it to be effective at higher pH values without increasing the dissolved aluminum residuals of the water. This is a concern for meeting aluminum standards in the finished water. Although the active species of pre-hydrolyzed coagulants are not completely understood, they prove to be more effective at low temperatures and produce lower volumes of sludge (Duan Jinming, 2003; Dempsey, Ganho, & O"Melia, 1984).

Sedimentation/Filtration

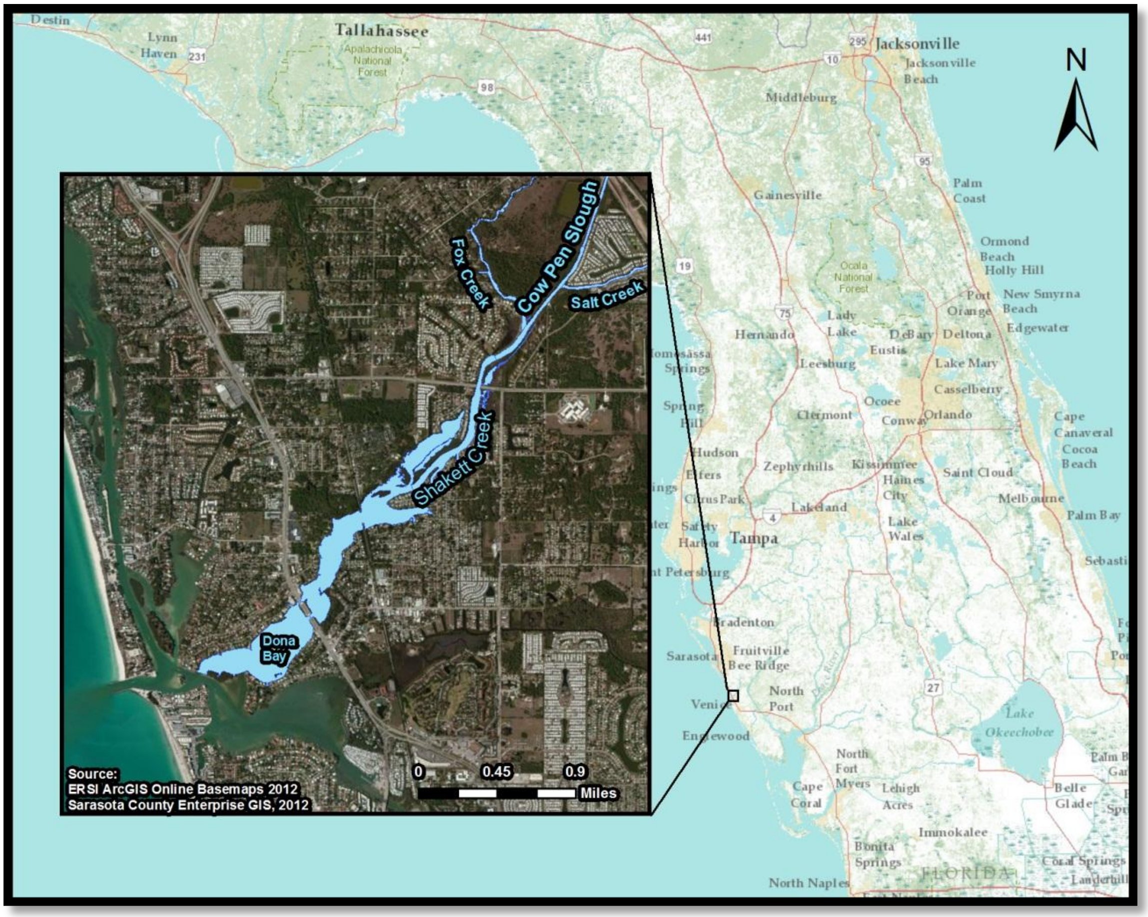
Once the particles have been destabilized by a coagulant and have undergone flocculation, the particles begin to settle. Sedimentation is the process of removing these suspended particles from water by the force of gravity. There are four types of settling. Type I or discrete settling occurs when particles settle independently of the interactions with other particles. Type II or flocculent settling occurs when particles with higher settling velocities overtake those with slower velocities. Type III or zone settling occurs when the drag force of the settling particles affects surrounding particles. Type IV or compression settling is dependent on time and the weight of the solids above the particles undergoing compression (Edzwald, 2011). In some cases, as when settling velocities are low, gas bubbles will be passed through the water to agglomerate with the solids in the process called flotation. In water treatment plants, sedimentation or flotation is followed by some form of filtration. Filtration is a process through which suspended particles are separated from water through porous media (Crittenden, Trussell, Hand, Howe, & Tchobanoglous, 2005). There are pressure driven filtration techniques such as MF, UF, NF and RO as well as conventional granular filtration technologies. Granular filtration involves the use of sand, anthracite, granular activated carbon or some other porous filter media.

3. DESCRIPTION OF RAW WATER

This chapter provides an overview of historical information regarding the hydrological conditions and water quality of the Cow Pen Slough. Data was obtained from the United States Geological Survey (USGS), Sarasota County, National Oceanic and Atmospheric Administration (NOAA) and a treatability study performed by Carollo Engineers in 2011. The historical information has been compiled, organized, and analyzed to provide background information on the source water of this study.

General Overview of the Study Region

The Cow Pen Slough (CPS) is a man-made canal in the Dona Bay watershed located along the western coastal region of Central Florida in Sarasota County. The CPS is one of three main tributaries contributing to Dona Bay. The water in the slough flows south and eventually converges with Fox Creek and Salt Creek before flowing into Shakett Creek and ultimately Dona Bay as seen in Figure 3-1. The CPS was originally constructed in 1966 as a drainage system for flood protection in the Myakka River basin (SWFWMD, 2009).



Source:
ERSI ArcGIS Online Basemaps 2012
Sarasota County Enterprise GIS, 2012

Figure 3-1: Location of Dona Bay and Surrounding Tributaries

Water Resources

Hydrological Data

Historical rainfall and stream flow data for the CPS were obtained from the Sarasota County Water Atlas database. The Sarasota County Water Atlas is a centralized repository containing data from multiple sources of hydrologic information. It includes data from the United States Geological Survey (USGS) gages (station ids: 2299710, 2299700) on the CPS and the County gages CPS-1 and CPS-2. The CPS-1 gage is located at the site of a flood control structure and CPS-2 is located just upstream of the convergence of Shakett Creek and Salt Creek in the CPS canal. The locations of the CPS-1 and CPS-2 gages can be seen in Figure 3-3 as well as the sampling location of the 2011 treatability analysis, CPS-TA. The USGS gage provided data from February 1st, 1963 to June 30th, 1966 and shows flows ranging from 0 to 2,000 cubic feet per second (cfs). CPS-1 and CPS-2 gages have been in operation since 2003 and show similar values in the streamflow, indicating widely variable and flashy flows corresponding to rainfall events. Recent streamflow and rainfall trends were obtained from USGS and the NOAA and can be seen in Figure 3-2.

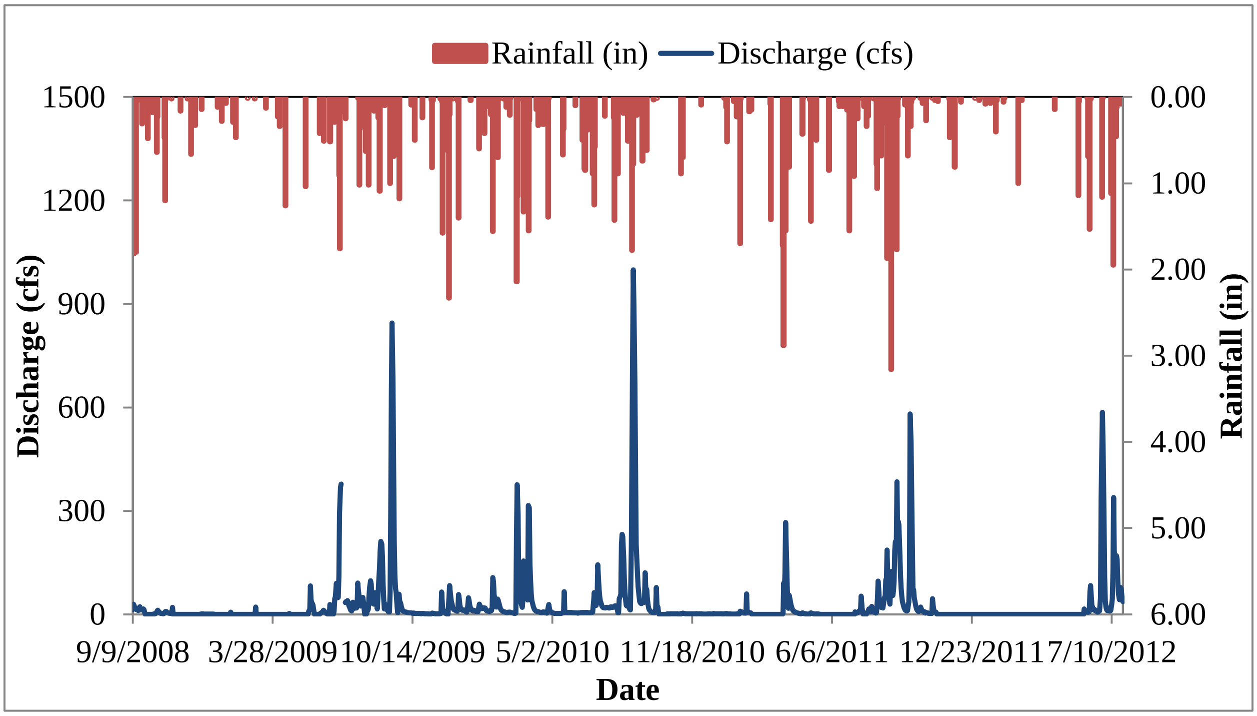
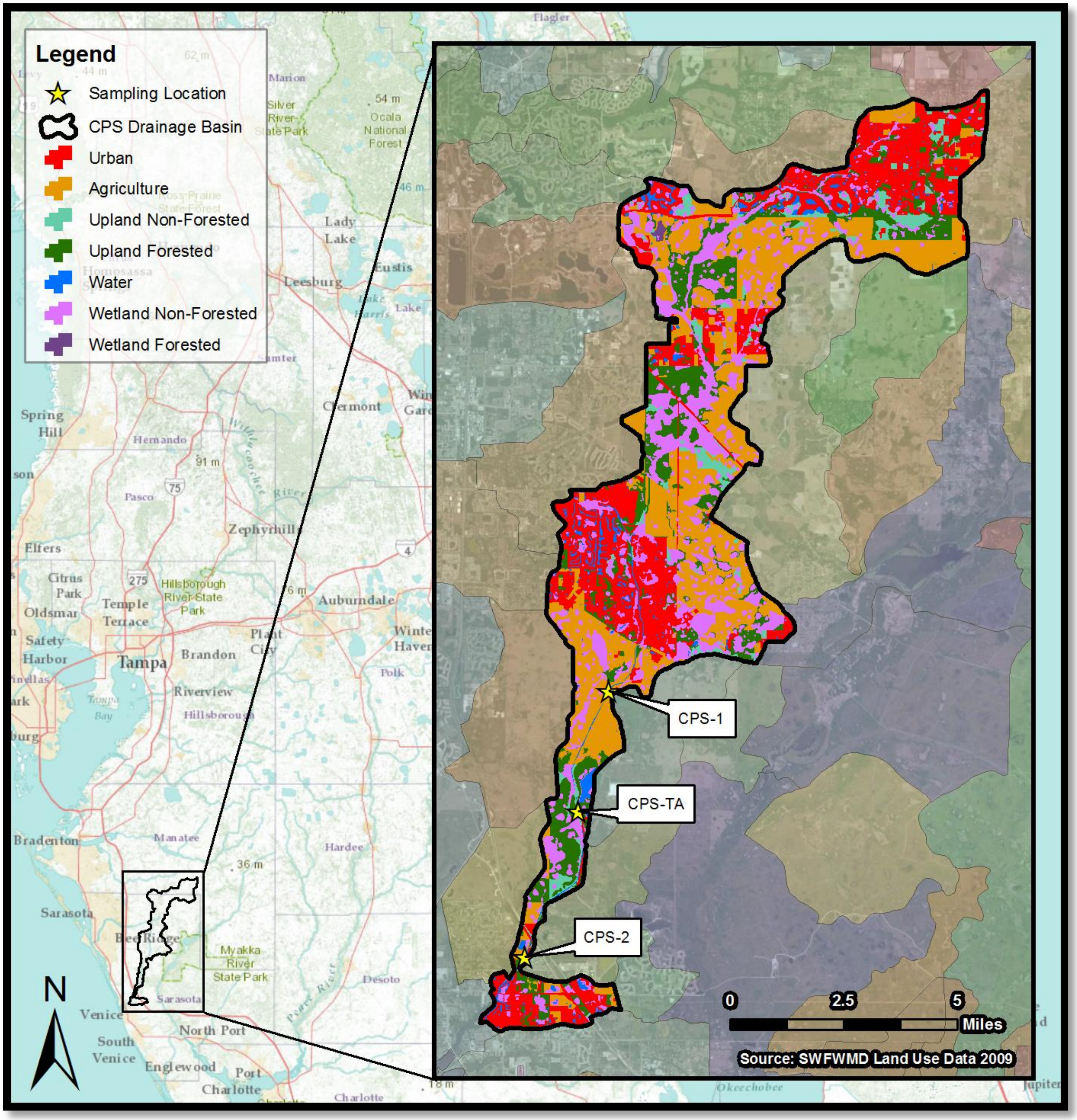


Figure 3-2: Hyetograph / Hydrograph of the Cow Pen Slough



Source: SWFWMD Land Use Data 2009

Figure 3-3: Drainage Basin and Land Use Map

Drainage Basin and Land Use

The size of the CPS drainage basin is approximately 35,380 acres. To characterize the makeup of the area surrounding the CPS, land use data was obtained from SWFWMD and clipped to the extents of the catchment. The land use data for the CPS is categorized into seven classes, according to the Florida Land Use and Cover Classification System (FLUCCS), and is shown in Figure 3-3 and Figure 3-4. Fifty-eight percent of the contributing drainage basin consists of agriculture and urban land indicating a potential source for high nutrient runoff and possibly heavy metals in the water. Table 3-1 provides the acreage of the land use areas by classes.

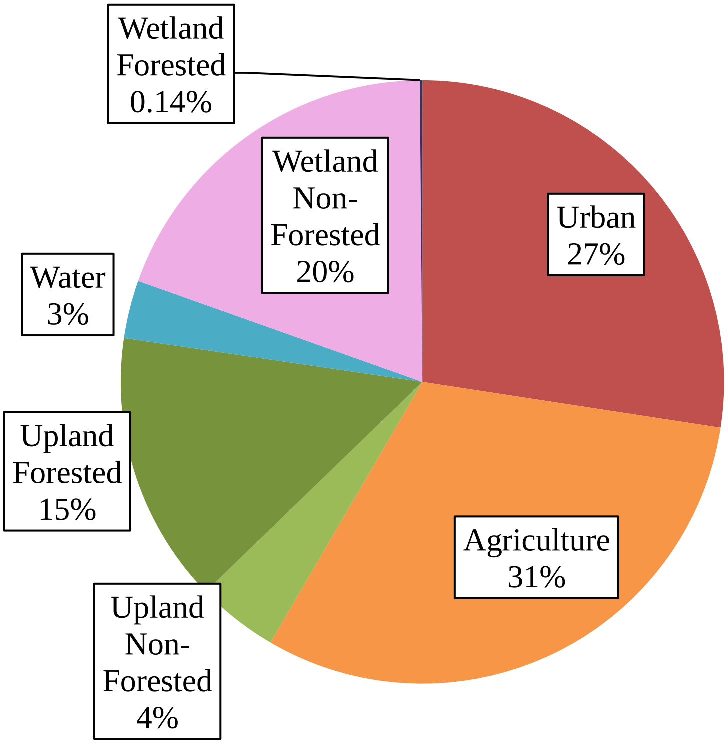


Figure 3-4: Land Use Chart

Table 3-1: Areas of Land Use Classes

Land Use	Area (acres)	% Area
Urban	9,700	27.4%
Agriculture	10,960	30.0%
Upland Non-Forested	1,540	4.4%
Upland Forested	5,150	14.6%
Water	1,100	3.1%
Wetland Non-Forested	6,870	19.4%
Wetland Forested	50	0.14%
Total	35,400	100%

Water Quality

Raw Water Quality

The natural organic content of Florida surface water is typically high, with TOC values often greater than 15 mg/L and true color values as high as 700 platinum cobalt units (PCU). Various water quality data has been collected over the years including an extensive treatability study (Carollo Engineers, Inc., 2012). The water quality in the CPS is representative of typical Florida surface water, containing high amounts of natural organic carbon, color, and suspended solids. The presence of trace levels of organic contaminants were found that included insecticides, herbicides, and petroleum hydrocarbons. Because the majority of the slough is bordered by fertilized agricultural lands, as illustrated in Figure 3-4, it is likely that nutrient runoff from sheet flow over the agricultural lands has occurred during periods of heavy rainfall. Visual observations indicated that leaching of excess nitrates and phosphates from surrounding lands has caused algae blooms and nitrogen concentrations to spike within the slough. Figure 3-5 provides photographs taken during average conditions (featured left) and during a eutrophic event (featured right).

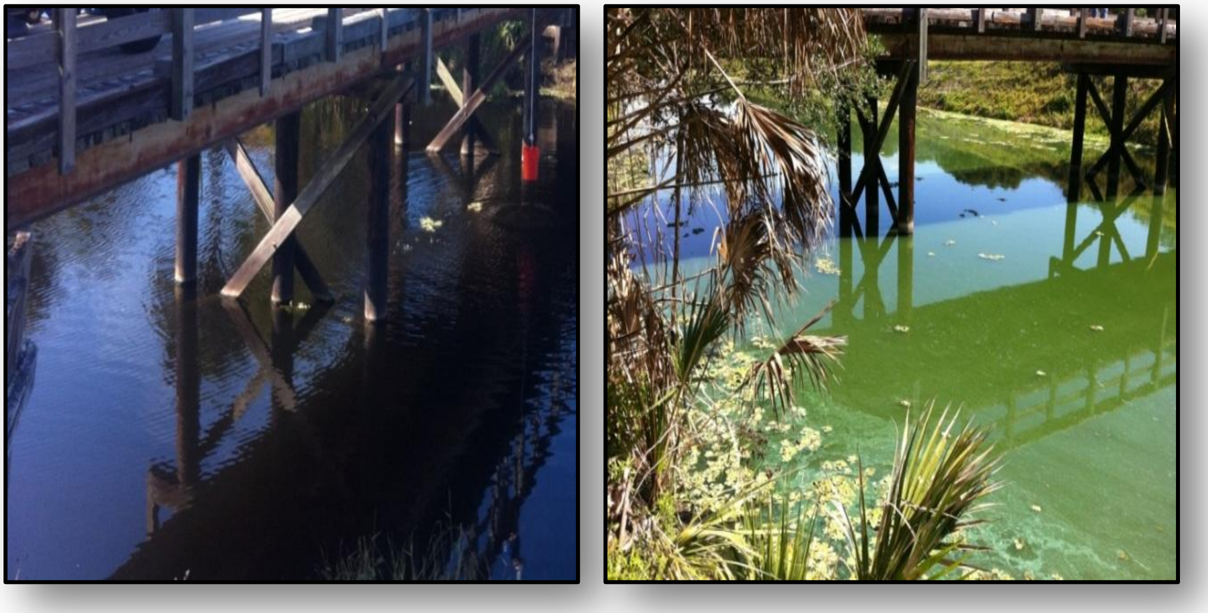


Figure 3-5: Photographic Comparison of the Cow Pen Slough

The parameters shown in Table 3-2 include a partial list of the historical data corresponding to the parameters monitored during this study. A complete list of parameters has been included in Table A-1 in the Appendix. The historical data provided in Table 3-2 was used to develop Figure 3-6 through Figure 3-10 which were used to establish estimates of the water quality parameters prior to conducting laboratory experiments.

Table 3-2: Selected Parameters of Historical Raw Water Quality (1962-2011)

Test	Units	Count	Min	Max	Average	Stdev.
Alkalinity	mg/L as $CaCO_3$	39	10.0	195	106	49.1
Conductivity	µS/cm	439	100	51700	1405	6,024
Color	PCU	256	10.0	453	115	84.9
DOC	mg/L	13	10.4	24.6	15.6	4.50
Iron-total	mg/L	13	0.16	1.66	0.59	0.51
Mn-total	mg/L	13	0.01	0.04	0.02	0.01
pH	s.u.	414	5.80	11.5	7.64	0.66
TDS	mg/L	39	88.0	1000	457	203
Temperature	deg. C	333	9.00	34.4	24.1	4.56
TOC	mg/L	27	10.2	26.0	16.2	4.14
TSS	mg/L	26	1.20	19.4	6.06	4.20
Turbidity	NTU	240	0.40	23.0	2.77	2.28

Review of Historical Data

Figure 3-6 depicts the monthly average pH and temperature values for the CPS. Temperature values vary between 17.5 and 29.0°C and show a seasonal low in the winter months. The monthly averages of pH are between the secondary maximum contaminant levels (SMCL) of 6.5 and 8.5.

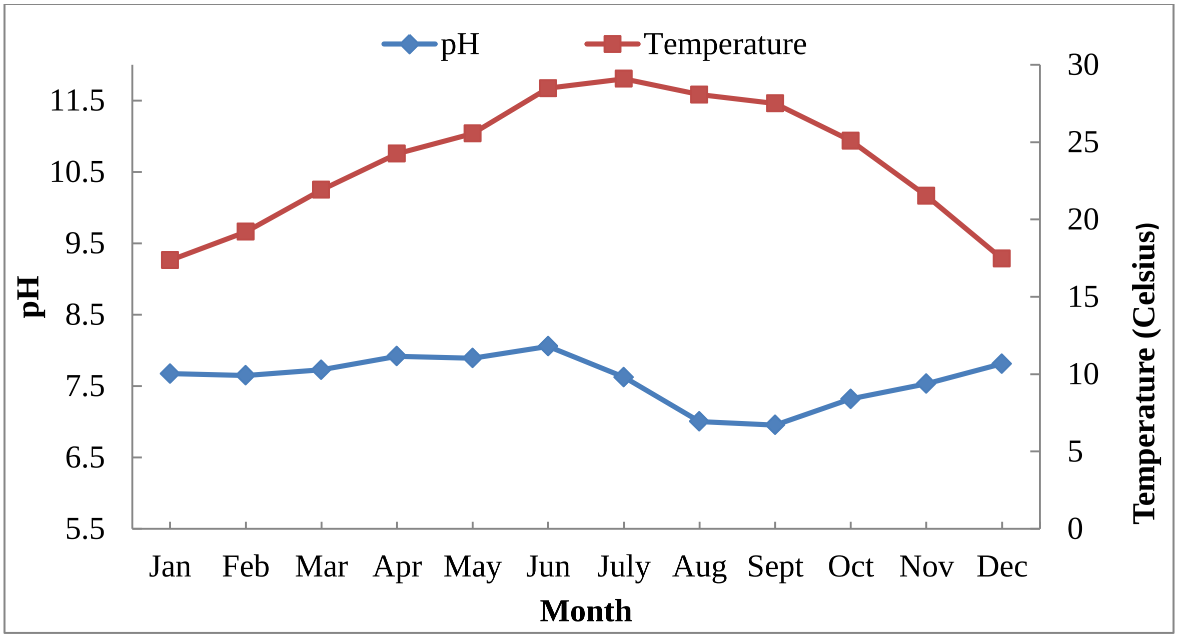


Figure 3-6: Monthly Average Raw Water pH and Temperature

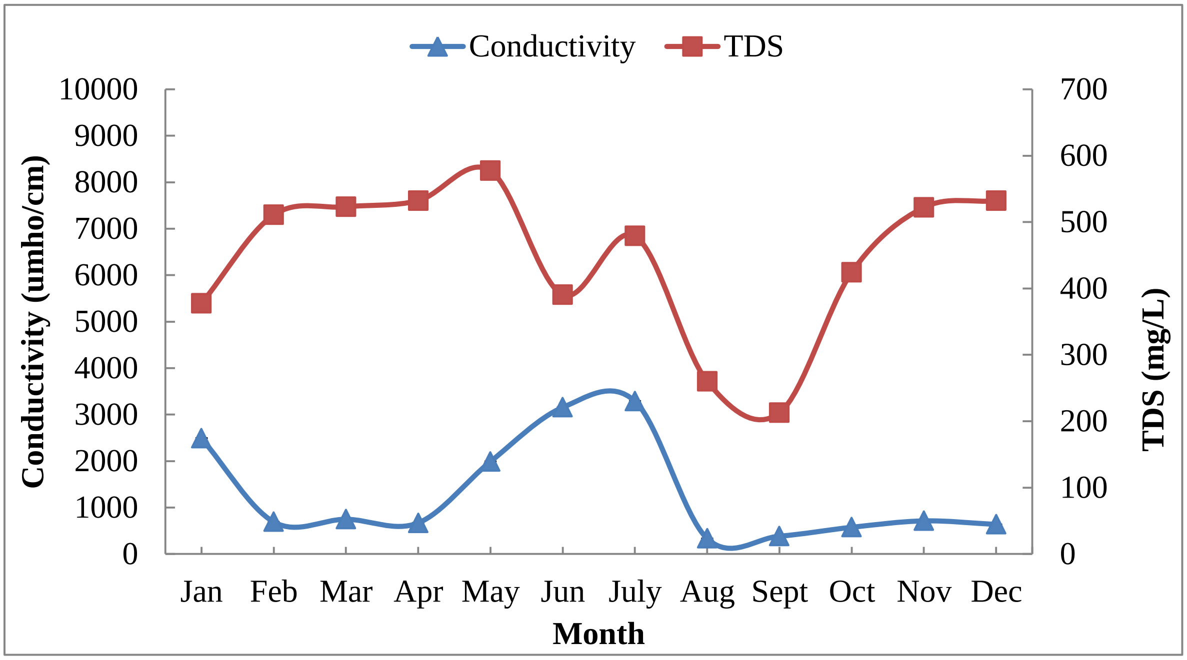


Figure 3-7: Monthly Average Raw Water Conductivity and Total Dissolved Solids

Conductivity and TDS monthly averages are depicted in Figure 3-7. Conductivity is a measure of the ability of water to pass an electrical current. It is affected by the presence of inorganic dissolved solids such as chloride, sulfate, sodium and aluminum. Conductivity measurements can be used to estimate the TDS concentrations of the water by Equation 3-1. This equation can be used to predict most freshwater TDS values with an accuracy of approximately ten percent (Metcalf & Eddy, George Tchobanoglous, Franklin L. Burton, H. David Stensel, 2003).

$$TDS = EC\ (dS/m\ or\ mmho/cm) \times 640 \tag{3-1}$$

It is important to note that Equation 3-1 was not used to estimate the monthly TDS values as shown in Figure 3-7. The trends do not agree exactly because the graph for TDS is created from fewer data points than conductivity and are monthly averages. Figure 3-7 shows that for nearly the first half of the year TDS values are above the SMCL of 500 mg/L. The state of Florida enforces the SMCL for TDS; therefore the months from November to May are of particular concern for treating the CPS to drinking water standards. Treatment methods such as reverse osmosis or ion exchange may need to be considered to reduce TDS levels depending on the nature of dissolved solid particulates. Typical rivers in the United States have conductivity readings from 50 to 1500 µmhos/cm and industrial streams can have readings as high as 10,000 µmhos/cm (EPA, United States Environmental Protection Agency, 2012). The average annual reading for conductivity in the CPS is approximately 1,300 µmhos/cm with a peak value of 3,290 µmhos/cm.

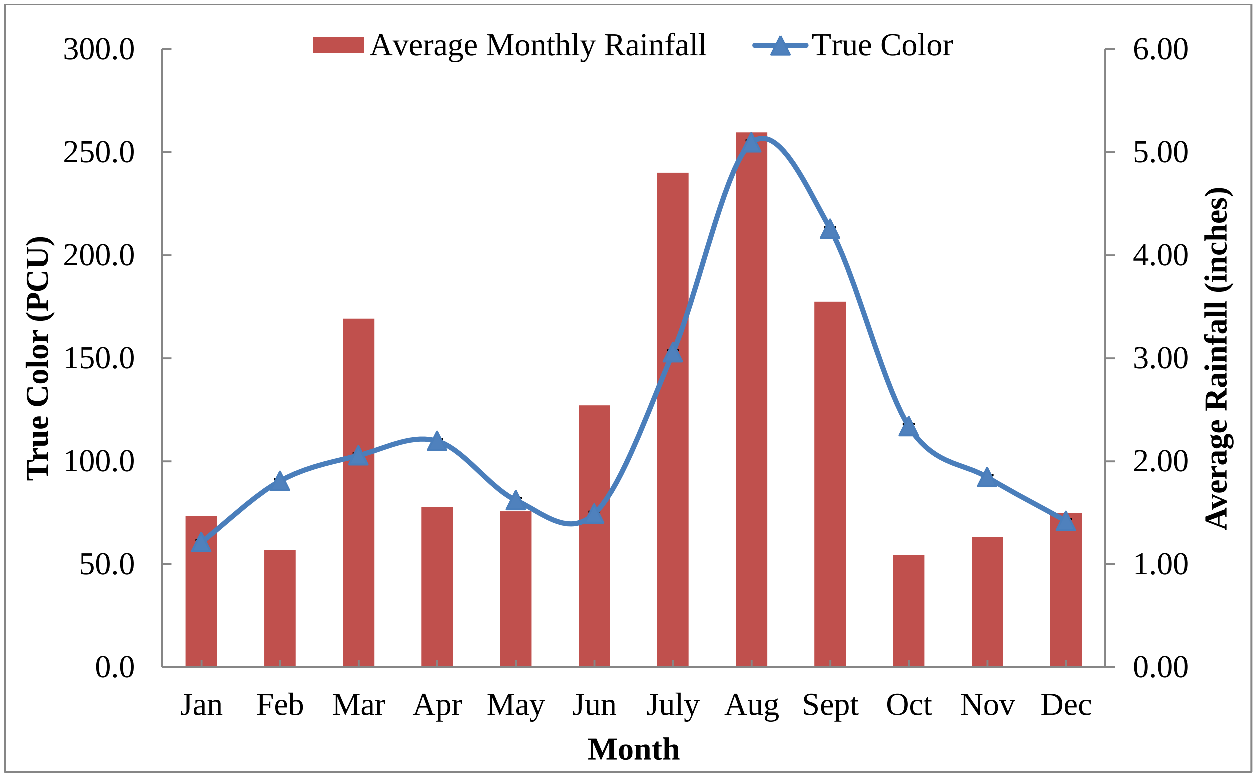


Figure 3-8: Monthly Average Raw Water True Color and Rainfall

One measure of water quality is the aesthetic parameter of color. Color is primarily caused by the presence of natural organic matter (NOM) in the water. There are two classifications of color: apparent and true. Apparent color is caused by suspended particles such as clays, algae, and iron oxides. True color is the measure of color after the sample has been filtered and the turbidity removed. The monthly averages for true color are shown on Figure 3-8 and appear highly correlated to rainfall events. The CPS raw water has true color values ranging from 71 to 254 PCU. In Florida lakes and rivers, true color generally ranges from 5 to 600 PCU (University of Florida, 2004). The SMCL of true color for drinking water standards is 15 PCU (EPA, 2012).

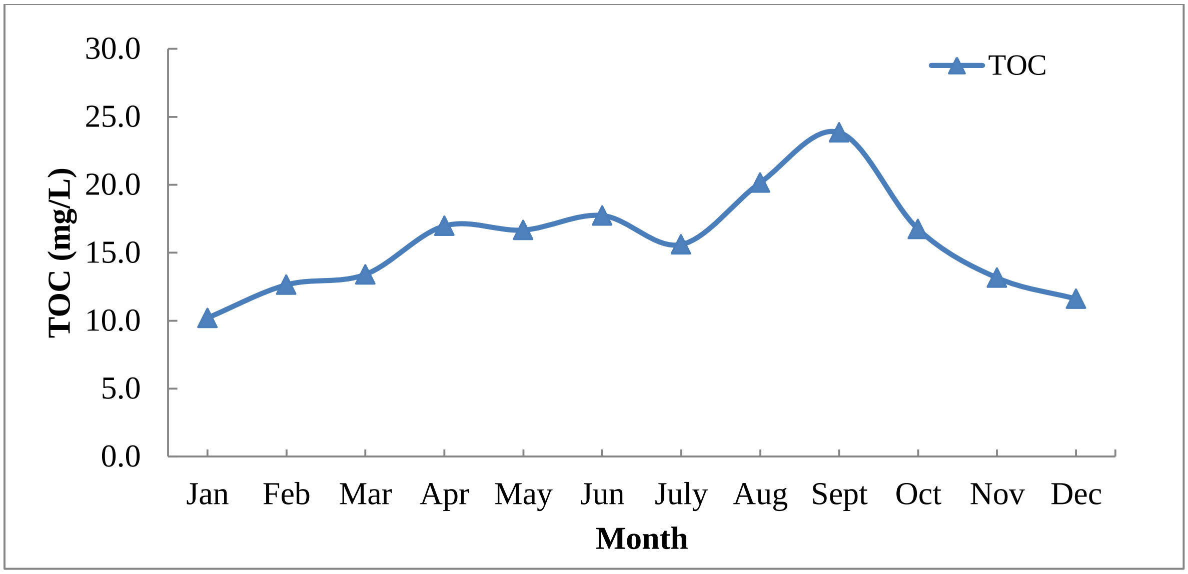


Figure 3-9: Monthly Average Raw Water TOC

The monthly average TOC concentrations are presented in Figure 3-9. The majority of the organic carbon present in the CPS is dissolved and most often the DOC values are within five percent of TOC values. Historical TOC values in the CPS have reached a maximum of 22.9 mg/L. These TOC levels are typical of surface waters in the southwest region of Florida (Lovins, Duranceau, Gonzalez, & Taylor, 2003). Enhanced coagulation has been identified as one of the most effective treatment methods for lowering TOC concentrations and subsequently DBP formation potential.

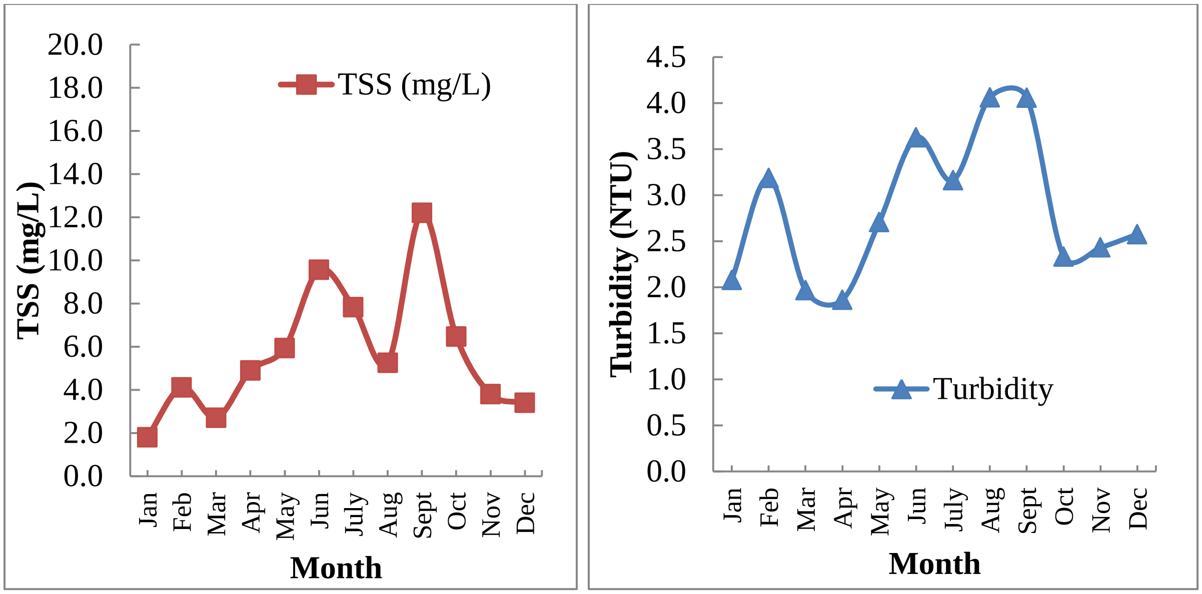


Figure 3-10: Monthly Average Raw Water Total Suspended Solids (TSS) and Turbidity

Turbidity is a measure of the transparency of a fluid and is caused by suspended particles in the water. Typical values for lakes and reservoirs range between 1 and 20 nephelometric turbidity units (NTU) where rivers and streams can range from under 10 to 4,000 NTU (Crittenden, Trussell, Hand, Howe, & Tchobanoglous, 2005). Figure 3-10 shows turbidity and total suspended solids (TSS) in the CPS peaks in September and the summer months where storms often cause increase flows and runoff, with values increasing from 1.86 to 4.06 NTU. Daily readings have shown more variability with values ranging from 0.40 to 23.0 NTU. The EPA specifies that turbidity in treated drinking water may never exceed 1 NTU, and must not exceed 0.3 NTU in ninety-five percent of daily collected samples in any given month. Turbidity is addressed by some form of filtration or in high turbidity water, conventional treatment may be required.

Treated Water Quality Goals

Based on the historical data presented in the previous section, water quality goals were established by Carollo Engineers to meet regulatory standards and compatibility with Sarasota County's existing distribution system. The treatment goal for parameters with a MCL or SMCL regulatory limit was set at eighty percent of the corresponding value in most cases. The parameters of hardness, pH, corrosivity, and disinfection by-products were designed to meet the existing distribution system water quality. Table 3-3 provides a list of parameters and corresponding water quality treatment goals.

Six overall treatment objectives were identified by Carollo Engineers in order to achieve the treatment goals for the CPS and meet drinking water standards. The overall objectives include treatment goals for total solids, natural organics, total dissolved solids (TDS), hardness, hydrogen sulfide (H_2S), synthetic organic compounds (SOCs), methyl-isoborneal (MIB), geosmin, iron, manganese, and included disinfection evaluations (Carollo Engineers, Inc., 2012). Iron and manganese control will be used to achieve odor and color treatment goals. Some form of stripping or aeration will be implemented to address odor concerns cause by hydrogen sulfide. Solids and organics removal will be implemented to treat the turbidity, TOC, and color issues. This study specifically assessed the treatability of turbidity, color, and DOC through conventional treatment technologies.

Table 3-3: Treated Water Quality Goals (Carollo Engineers, Inc., 2012)

Parameter	Units	Regulatory Standards			Treatment Goal
		MCL	SMCL	MCLG	
TDS	mg/L	-	500	-	≤ 400
Sulfate	mg/L	-	250	-	≤ 200
Chloride	mg/L	-	250	-	≤ 200
Iron	mg/L	-	0.3	-	≤ 0.24
Manganese	mg/L	-	0.05	-	≤ 0.04
Turbidity	NTU	See Note 3			See Note 3
Cryptosporidium	#/L	See Note 4			See Note 4
Giardia	#/L	See Note 4			≥ 3 log removal/inact
Viruses	#/mL	See Note 4			≥ 4 log removal/inact
TOC	mg/L	See Note 5			See Note 5
Color	CU	-	15	-	≤ 12
Odor	TON	-	3	-	≤ 1(6)
MIB	ng/L	-	-	-	≤ 8(6)
Geosmin	ng/L	-	-	-	≤ 8(6)
Nitrate-N	mg/L	10	-	10	8
Hydrogen Sulfide	mg/L	-	-	-	Non-detectable
Corrosivity	-	Non-corrosive			See Note 7
Hardness	mg/L as $CaCO_3$	-	-	-	See Note 7
pH	s.u.	-	6.5 – 8.5	-	See Note 7

Notes:
MCL = maximum contaminant limit; SMCL = secondary MCL; MCLG = MCL goal.
1. Treated water implies finished water (after any post-treatment and/or blending).
2. Key parameters of concern are specifically listed in this table. Unless specified otherwise, treated water quality goal for regulated parameters shall be 80% of respective MCLs (SMCLs).
3. Treatment technique is required. Turbidity may never exceed 1 NTU, and must not exceed 0.3 NTU in 95 percent of daily samples in any given month.
4. Treatment technique is required. For cryptosporidium, additional treatment requirement if any depends on treatment bin and is selected from microbial toolbox.
5. Treatment technique is required. Requirement depends on source water TOC and alkalinity levels.
6. Detection limits: Odor = 1 TON; MIB = 5 ng/L; geosmin = 3 ng/L.
7. Goal shall be to maintain compatibility with existing distribution system quality/corrosion strategy.

4. MATERIALS & METHODS

This chapter describes the experimental plan, tests, methods, materials, and procedures used to conduct this study. A brief description of the purpose of the study is provided in the experimental plan. Water quality parameters and their measurement methods are included in the test methods and materials section of this chapter. Descriptions of the cleaning, sampling, storing, and testing procedures are described as well. Continuous laboratory quality control was implemented throughout this study and a summary of data analysis and control procedures including accuracy and precision are reviewed in this chapter.

Experimental Plan

The following methodology was developed to determine the effectiveness of five coagulants for the removal of turbidity, color, and dissolved organic carbon. Jar testing is considered to be an acceptable and economical method for simulating full scale coagulation, flocculation, and sedimentation (CFS) processes and was chosen to determine the effectiveness of each coagulant (Amirtharajah A., 1982; Edzwald, 2011). The primary goal of this research was to compare the effectiveness of traditional coagulants with two coagulants less commonly used in treating Florida surface water. For the purpose of this study, effectiveness was evaluated based on the removal efficiency of non-purgeable dissolved organic carbon (NPDOC herein after referred to as DOC) and color using Equation 4-1. Other indirect costs related to the effective pH ranges and coagulant doses were taken into account in the determination of coagulant effectiveness.

$$Removal\ Efficiency\ (\%) = \frac{C_{initial} - C_{treated}}{C_{initial}} \times 100\% \tag{4-1}$$

$C_{inital} = raw\ water\ NPDOC\ concentration\ \left(\frac{mg}{L}\right) or\ true\ color\ (PCU)$

$C_{treated} = NPDOC\ concentration\ \left(\frac{mg}{L}\right) or\ true\ color\ (PCU)\ \ after\ CFS\ treatment$

Organic content was measured in terms of DOC which assumes filtration will be implemented after the sedimentation process, and is defined as the fraction of organic carbon remaining which has the potential to act as a DPB precursor. The removal efficiency of CFS (herein after referring to the combination of the coagulation, flocculation, and sedimentation processes) is a function of many parameters including mixing intensity, mixing times, chemical addition, pH, temperature, etc. Variables such as mixing intensity and mixing times were held constant and did not change over the duration of the study. Coagulant concentrations ranged from 80 mg/L to 240 mg/L and were increased in increments of 20 mg/L for each coagulant. The established testing range for pH was 4.0 to 8.0 and pH was targeted in increments of 0.5 pH units. By varying pH and coagulant concentrations, optimum removals were determined for a wide range of concentrations and pH values. Graphical relationships between pH, coagulant concentration, and the resulting removals were developed to determine the optimum ranges for CFS for each coagulant. In addition to determining these optimum operating conditions, raw water samples were analyzed to test for additional water quality parameters for quality control. Furthermore, settling curves were developed for each of the coagulants to characterize the differences in sludge settling behavior.

Tests, Methods, and Materials

Water Quality Tests and Methods

Table 4-1 provides a list of water quality parameters monitored during the study. These parameters included TSS, TDS, conductivity, alkalinity, and select anions and metals tests and were used to compare recent water quality parameters with historical data. This data served as a quality control in the methodical procedures conducted throughout this research. The data from tests not directly related to jar testing were used to further characterize the overall treatability of the CPS. Constituents were measured using the procedures outlined in the *Standard Methods for the Examination of Water and Wastewater* (Eaton, Clesceri, Rice, & Greenberg, 2005).

Table 4-1: List of Methods and Equipment for Water Quality Analyses

Test	Location Tested	Standard Method (SM) Reference Number & Instrument Description	Method Detection Level
Barium	UCF Lab	SM: 3120 B. Inductively Coupled Plasma (ICP) Method/Inductively Coupled Plasma Spectrometer	0.002 mg/L
Calcium	UCF Lab	SM: 3120 B. Inductively Coupled Plasma (ICP) Method/Inductively Coupled Plasma Spectrometer	0.01 mg/L
Chlorine, Free	UCF Lab	SM: 4500-Cl G. DPD Colorimetric Method/HACH Spectrophotometer DR5000	0.02 mg/L
Chloride	UCF Lab	SM: 4500 Cl^- B. Argentometric Method	1.0 mg/L
		SM: 4110 B. Ion Chromatography (IC) with Chemical Suppression of Eluent Conductivity	0.1 mg/L
Conductivity	Field	SM: 2510 B. Laboratory/HQ40d Portable pH, Conductivity and Temperature Meter	0.01 µS/cm
Color (True)	UCF Lab	SM: 2120C. Spectrophotometric – Single-wavelength/HACH Spectrophotometer DR5000	0.005 abs
Iron	UCF Lab	SM: 3120 B. Inductively Coupled Plasma (ICP) Method/Inductively Coupled Plasma Spectrometer	0.01 mg/L
Magnesium	UCF Lab	SM: 3120 B. Inductively Coupled Plasma (ICP) Method/Inductively Coupled Plasma Spectrometer	0.03 mg/L

Test	Location Tested	Standard Method (SM) Reference Number & Instrument Description	Method Detection Level
Manganese	UCF Lab	SM: 3120 B. Inductively Coupled Plasma (ICP) Method/Inductively Coupled Plasma Spectrometer	0.02 mg/L
pH	Field/Lab	SM: 4500-H+ B. Electrometric Method/ HQ40d Portable pH, Conductivity and Temperature Meter	0.01 pH Units
Potassium	UCF Lab	SM: 3120 B. Inductively Coupled Plasma (ICP) Method/Inductively Coupled Plasma Spectrometer	0.1 mg/L
Silica	UCF Lab	SM: 3120 B. Inductively Coupled Plasma (ICP) Method/Inductively Coupled Plasma Spectrometer	0.02 mg/L
Sodium	UCF Lab	SM: 3120 B. Inductively Coupled Plasma (ICP) Method/Inductively Coupled Plasma Spectrometer	0.03 mg/L
Strontium	UCF Lab	SM: 3120 B. Inductively Coupled Plasma (ICP) Method/Inductively Coupled Plasma Spectrometer	0.0005 mg/L
Sulfate	UCF Lab	SM: 4500 SO_4^{2-} E. Turbidimetric Method/HACH Spectrophotometer DR5000	1.0 mg/L
Sulfate	UCF Lab	SM: 4110 B. Ion Chromatography (IC) with Chemical Suppression of Eluent Conductivity	0.018 mg/L
Temperature	Field/Lab	SM: 2550 B. Laboratory Method/ HQ40d Portable pH, Conductivity and Temperature Meter	0.01 °C
THMFP	UCF Lab	SM: 6232 B. Liquid-Liquid Extraction Gas Chromatographic Method	0.1 µg/L
Total Alkalinity	UCF Lab	SM: 2320 B. Titration Method	5 mg/L as $CaCO_3$
TSS and TDS	UCF Lab	SM: 2540 C. Total Dissolved Solids Dried at 180^{o}C, SM: 2540 D. Total Suspended Solids Dried at 103-105^{o}C	2.5 mg/L
TOC and DOC	UCF Lab	SM: 5310 C. Persulfate-Ultraviolet Oxidation Method/Tekmarr-Dohrmann Phoenix 8000: The UV-Persulfate TOC Analyzer	0.1 mg/L
Turbidity	Field/Lab	SM: 2130 B. Nephelometric Method/Hach 2100q Portable Turbidimeter	0.01 NTU

Jar Testing Equipment

A six paddle programmable jar tester was used to conduct this study. It included six stainless-steel, 1” x 3” paddles spaced six inches apart. The paddles were adjusted to the maximum depth of nine inches during each experiment. Six two-liter square acrylic B-KER2® testing jars, equipped with sampling ports were used to contain the water samples. Square jars were used in this study because it has been shown they effectively transfer mixing energy into the water (EPA, Environmental Protection Agency, 1999). The jar tester also included a fluorescent lamp to observe floc formation. The jar testing equipment is shown in Figure 4-1.

Figure 4-1: Phipps and Bird PB 900 Jar Tester

Chemicals and Reagents

Table 4-2 includes descriptions for the chemicals used throughout this study. Five iron and aluminum-based liquid coagulants were provided by General Chemical for testing in this study. Hach turbidity solution standards were used to calibrate the turbidimeter. The color standards listed in Table 4-2 were diluted from a 500 PCU stock solution and used to develop standard curves for each jar testing experiment. American Chemical Society (ACS) grade chemicals for pH adjustment, DOC analysis, and pH buffer solutions were ordered through various vendors and dilutions were made as necessary for analyses following the methods listed in Table 4-1.

Table 4-2: Description of Chemicals Used for Jar Testing & Additional Analysis

Chemical	Description
Aluminum Chlorohydrate (ACH) Hyper$^+$Ion® 1090	Coagulant, SG = 1.35, Dry Weight = 45.6% Basicity = 80% (min.)
Aluminum Sulfate (Alum)	Coagulant, SG = 1.34, Dry Weight = 48.5%
Color Standards	5, 10, 50, 100, 200, and 500 Platinum Cobalt Units
DPD Free Chlorine Reagent	Powder Pillows – used for chlorine residual analysis
Ferric Chloride (FC)	Coagulant, SG = 1.41, Dry Weight = 40%
Ferric Sulfate (FS)	Coagulant, SG = 1.59, Dry Weight = 60%
Hexane	ACS Grade – used for THM analysis
pH Buffer Solutions	4, 7, and 10 pH buffer solutions
Phosphoric Acid	ACS Grade – 85% Vol/Vol used for DOC analysis
Polyaluminum Hydroxychloride (PACl) Hyper$^+$Ion® 1750	Coagulant, SG = 1.32, Dry Weight = 50% Basicity = 45% - 55%
Potassium Hydrogen Phthalate (KHP)	ACS Grade – used for DOC analysis and spikes
Nitric Acid	ACS Grade – 60% Vol/Vol used for metals analysis
Sodium Carbonate	ACS Grade – solid, used for alkalinity analysis
Sodium Hydroxide	ACS Grade – solid, 97.8% used for pH adjustment
Sodium Hypochlorite	ACS Grade – used for free chlorine analysis
Sodium Persulfate	ACS Grade – solid, 98+% used for DOC analysis
Sodium Sulfite	ACS Grade – used for free chlorine analysis
Sulfuric Acid	ACS Grade – 36 Normal used for pH adjustment
THM Calibration Standards	1, 5, 10, 20, 50, 100, 200, and 400 ppb standards
Turbidity Standards	0.1, 10, 20, 100, 200, and 800 NTU standards

Procedures

Cleaning Procedures

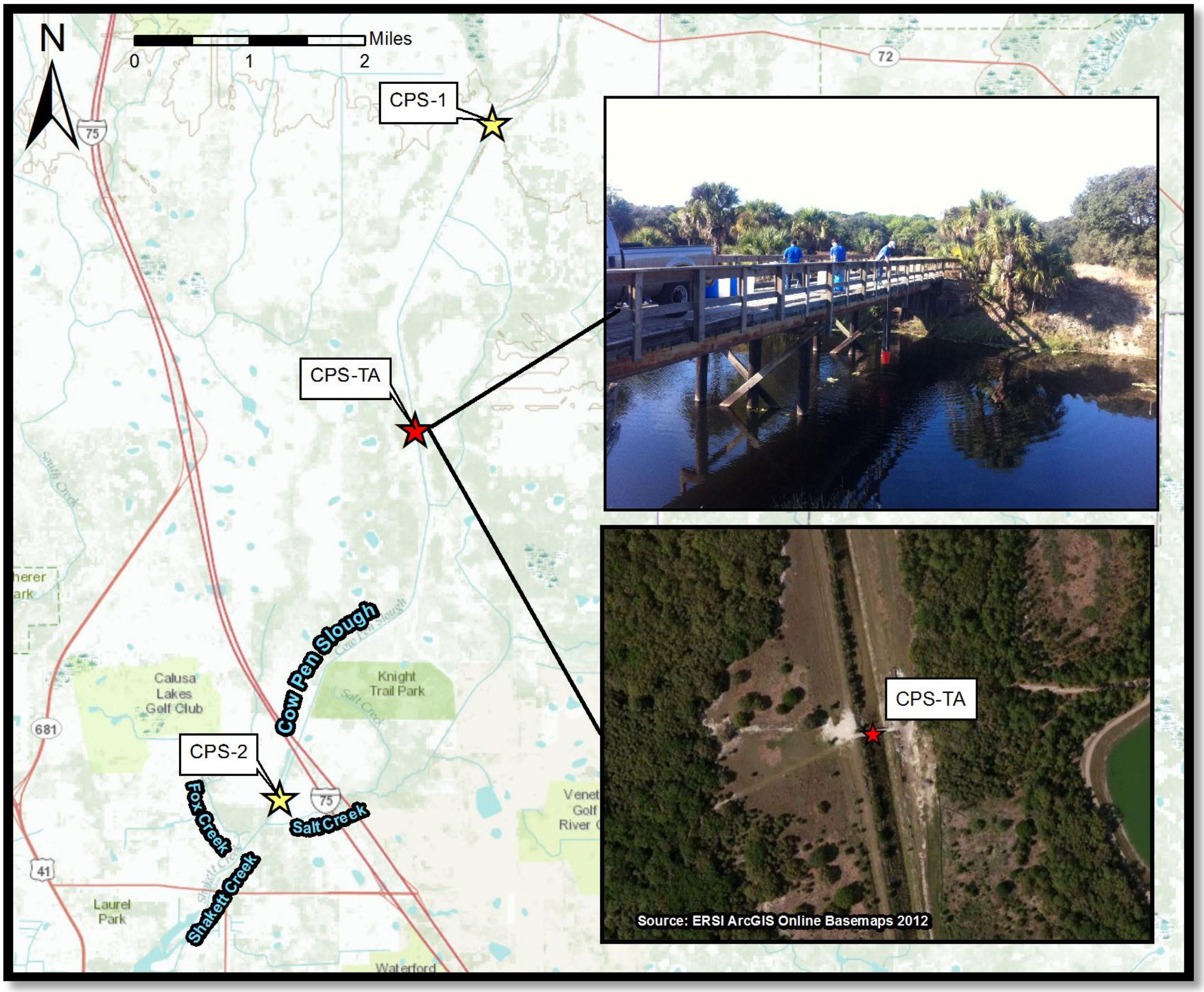
To prevent contamination, sampling containers were cleaned in accordance with the procedures listed in Table 4-3**.** The cleaning procedures, analysis, and/or parameter for each type of sample container are listed in order they were conducted. For example, water samples tested for alkalinity, color, etc., were stored in amber bottles that were previously cleaned by following steps 2 through 7 then steps 9 and 10.

Table 4-3: Cleaning Procedures

<table>
<tr><th>Sample Container</th><th>Cleaning Procedure #</th><th>Analysis/Parameter</th></tr>
<tr><td>15 Gallon Drums</td><td>1</td><td>Sample Storage for Jar Tests</td></tr>
<tr><td>5 Gallon Bucket</td><td>1</td><td>Sample Storage for Lab Tests</td></tr>
<tr><td>35 mL and 1 L Amber Bottles</td><td>2-7, 9-10</td><td>Alkalinity, Color, Inorganics, Metals, pH, Solids, Turbidity</td></tr>
<tr><td>40 mL Glass Vials</td><td>2-6, 8-9</td><td>NPDOC</td></tr>
<tr><td>2 L Square Beaker Jars</td><td>3-4</td><td>Jar Tests</td></tr>
<tr><td colspan="3">1. Rinse inside with sample water.
2. Remove outside labels with tap water and scrub brush.
3. Wash inside with tap water and laboratory detergent.
4. Rinse inside three times with tap water.
5. Rinse inside with ACS grade 1:1 HCl.
6. Rinse inside three times with deionized water.
7. Cover lid with aluminum foil and puncture foil to allow moisture to escape.
8. Air dry and wrap with aluminum foil.
9. Bake for at least two hours at 400°C, and cool to room temperature.
10. Cover lid with aluminum foil.</td></tr>
</table>

Sampling and Storage Procedures

The CPS sampling site was a wooden bridge located between flood control structures, CPS-1 and CPS-2. It has been identified as CPS-TA (Treatability Analysis) and can be seen on Figure 4-2. The GPS coordinates are Latitude 27º11’46”N, Longitude 82º24’25”W, and the SWFWMD Site Identifier (SID) is 771032.



Source: ERSI ArcGIS Online Basemaps 2012

Figure 4-2: Cow Pen Slough Sampling Location Map

Raw water samples were collected from sampling station CPS-TA by repeatedly lowering five-gallon buckets from the bridge into the slough. Raw samples were transferred into fifteen-gallon drums for transportation and storage. Field parameters were measured on site during sampling and one-liter amber sample bottles were filled from each drum. The field sampling matrix is provided in Table 4-4 and includes information on the parameters tested in the field and the calibration procedures for each instrument. The one-liter amber bottles were used for lab analysis including the parameters of alkalinity, select metals and inorganics, total suspended solids and total dissolved solids. The handling and storage preservation techniques are provided in Table 4-5 as per EPA requirements.

Table 4-4: Field Sampling Matrix

Test	Instrument	Calibration Procedures
Conductivity	HQ40d Portable pH, Conductivity and Temperature Meter	Rinse probe 3 times with 0.01 M KCl, with probe in standard KCl solution adjust meter to read 1412 µmho/cm
pH	HQ40d Portable pH, Conductivity and Temperature Meter	Commercial pH calibration buffers, pH 4, 7, 10. Calibrated prior to analyzing a batch of samples using 3 point calibration with standard buffers
Temperature	HQ40d Portable pH, Conductivity and Temperature Meter	Calibrated against NIST-certified thermometer
Turbidity	Hach 2100q Portable Turbidimeter	Use known standards provided by Hach for unit NTU calibration

Table 4-5: Preservation and Holding Requirements (EPA, 1992)

Test	Preservation Technique	Holding Time	
		Recommended	Regulatory
Alkalinity	Refrigerate at 4°C	24 hours	14 days
Anions (Cl^-, SO_4^{2-})	Refrigerate at 4°C	28 days	28 days
Color (True)	Analyze immediately	Immediately	48 hours
Metals	Add HNO_3 to pH < 2	28 days	6 months

Test	Preservation Technique	Holding Time	
		Recommended	Regulatory
NPDOC	Analyze immediately; or refrigerate at 4^oC and in the dark, $pH < 2$ with HCl	7 days	28 days
pH	Analyze immediately	Immediately	0.25 hours
THMs	Analyze immediately; or refrigerate at 4^oC and in the dark	7 days	14 days
Total Dissolved and Suspended Solids	Refrigerate at 4^oC in resistant-glass bottles and store in the dark	24 hours	7 days
Turbidity	Analyze immediately; or refrigerate at 4^oC and store in the dark	24 hours	48 hours

Coagulants were stored in a cool dry, well ventilated cabinet as specified in the material safety data sheets (MSDSs). Twenty-four hours before jar testing, sample drums were taken out of refrigeration to allow raw water samples to reach room temperature. One-liter amber bottles were allowed ample time to reach room temperature before alkalinity and solids analyses were conducted. Anions and metals samples were prepared following the method provided in Table 4-1 and preserved in accordance with Table 4-5.

Preliminary Procedures

Prior to conducting jar tests, titrations curves were developed on the raw water to determine the appropriate volume and normality of pH-adjustment chemicals, necessary to obtain the target pH values for each coagulant dose. Due to the variability of the source water, it was necessary to conduct titrations after many of the sampling events. In addition to the variability in pH of the source water, many coagulants also affect pH making it difficult to achieve a target pH during jar testing. Figure 4-3 illustrates the effect of varying the coagulant dose on pH for each coagulant. Titrations were performed by added the coagulant dose to 100 mL of raw sample water, and titrating with either sodium hydroxide (NaOH) or sulfuric acid (H_2SO_4) to the desired pH endpoint. This process was repeated for each coagulant at multiple doses. After determining the appropriate caustic or acid dosages for each coagulant dose, coagulant concentrations were varied and interference from varying pH and temperature values were minimized.

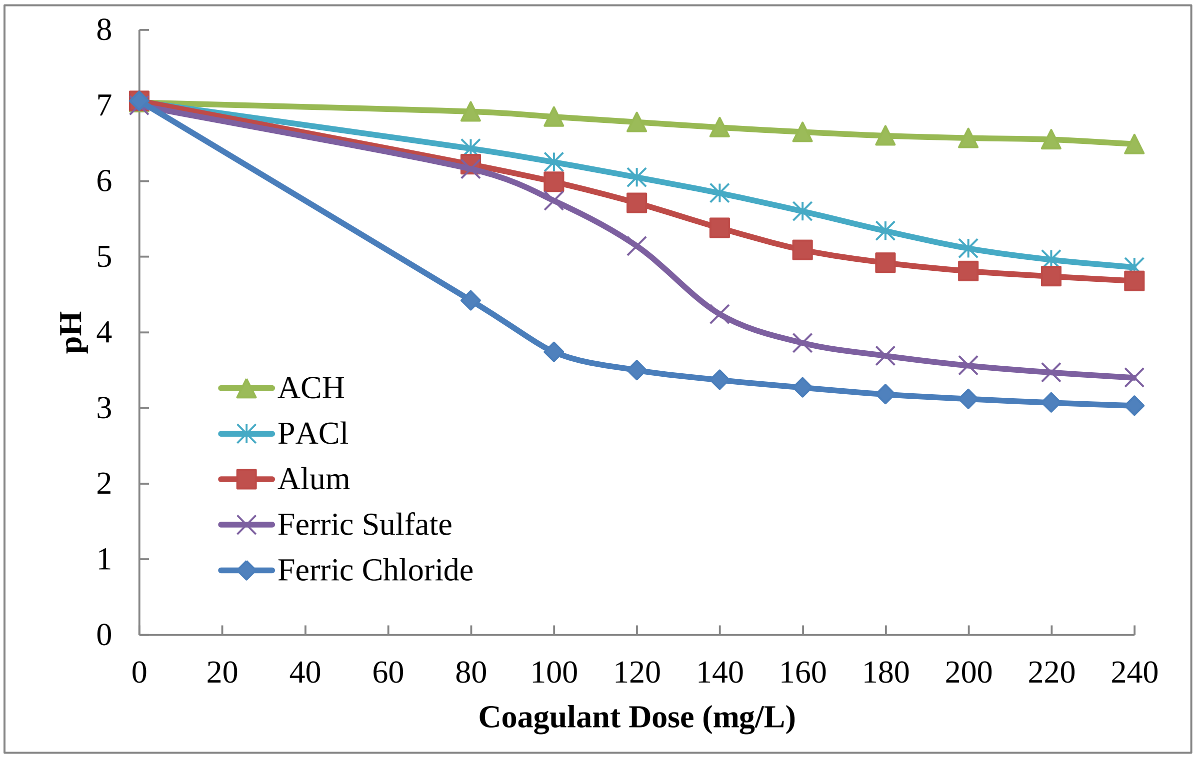


Figure 4-3: Relationships between Coagulant Doses and pH

Jar Testing Procedure

The two-liter square beakers, commonly referred to as jars, were cleaned following the procedure specified in Table 4-3. The jars were filled with two-liters of mixed raw sample water. The jar testing equipment was programmed using the ASTM International standard jar testing sequence of 120 revolutions per minute (RPM) for 1 minute (min), 50 RPM for 20 min, 0 RPM for 15 min, simulating a coagulation time of 1 min, a flocculation time of 20 min, and a settling time of 15 min (ASTM, 2003). The proper volume of coagulant and corresponding caustic or acid volume was measured and delivered onto septas using a pipette. To minimize variation among coagulated samples and obtain equal reaction times, the septas were simultaneously emptied into the jars as the jar testing sequence was initiated. Jars were placed such that the paddle shafts were in the middle of the water vortex during test runs to achieve optimal mixing conditions. During the flocculation stage of jar testing, the pH and temperature were recorded. At the end of the settling period 450 mL of each settled sample was collected and tested for turbidity.

After the values for turbidity were recorded, 250 mL from each settled sample was filtered using a 0.45 µm pore membrane. Each membrane was primed by filtering a small amount of the settled sample, rinsing out the vacuum flask with the filtered sample and proceeding by filtering the remaining volume of sample. Glass vials were filled for each filtered sample for DOC analysis. DOC vials were either analyzed immediately or preserved in accordance with SM: 5310C described in Table 4-5. Acid preservation was not implemented to maintain the validity of inorganic carbon content. Reagents utilized by the TOC analyzer were made twenty-four hours before testing to minimize background interference. Approximately, 100 mL of each filtered sample was adjusted to a pH of 7 with 0.01 N NaOH or H_2SO_4. Color was measured according to SM: 2120C on the pH-adjusted, filtered sample having a minimum detection limit of 5 PCU.

Sludge Settling Procedure

Batch sludge settling was performed following a similar method to that found in research conducted on the Peace River (Lovins, Duranceau, Gonzalez, & Taylor, 2003). The sludge settling assessment was performed after determining the optimum coagulation parameters for each coagulant. Jar tests were dosed and conducted as described in the previous section under the optimum conditions. However, immediately following the flocculation sequence, water from each jar was carefully transferred into one-liter graduated cylinders, inverted once, and allowed to settle. The inversion step was performed to re-suspend floc particles and minimize interference from transferring the water. The sludge interface height was recorded over time and used to compare the settling time of the solids and settling velocities for each coagulant. Figure 4-4 illustrates the sludge settling for ferric chloride over time.

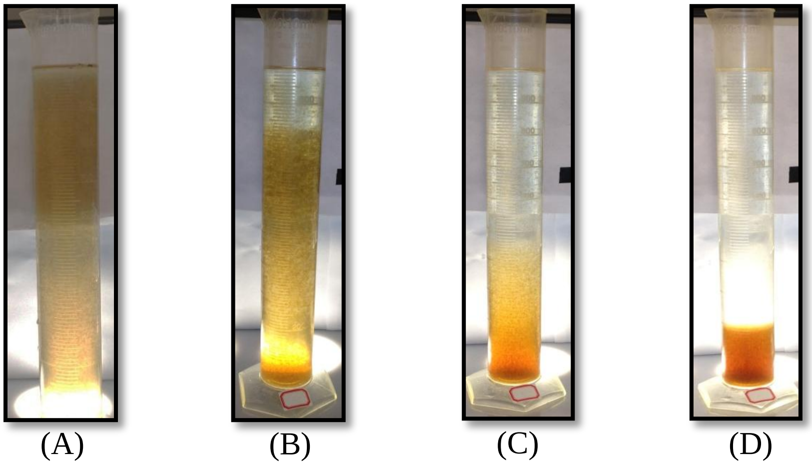

(A) (B) (C) (D)

Figure 4-4: Sludge Settling After: (A) 0 min (B) 5 min (C) 12 min (D) 23 min

Total Trihalomethane Formation Potential Procedure

Total trihalomethane formation potential (THMFP) was measured for the raw water and the water treated using the two most efficient coagulant chemicals with regards to DOC, turbidity, and color removal. The water samples were dosed with a standardized hypochlorite solution to yield a residual chlorine level between 2 to 3 mg/L for treated water samples and a residual of 4 mg/L for the raw water samples. Chlorinated samples were stored in sealed 35 mL amber bottles, incubated for four days, and then quenched with sodium sulfite. Samples were stored at 4°C for a maximum time of fourteen days prior to analysis via a gas chromatograph. THM standard solutions were prepared from an ACS grade stock solution. Ten milliliters of each sample were dosed with 2 mL of hexane and analyzed with an Agilent 6890 Gas Chromatograph with a micro electron capture detector.

Field and Laboratory Quality Control

Extensive field and laboratory quality control measures were implemented throughout this study. Duplicate measurements were taken to assess the consistency of the precision of the analytical instrumentation. Duplicates for field measurements were taken every six samples. During the bench scale testing, duplicates were prepared for each jar test run as well as for each metal and anion analyses. To assess the consistency of the accuracy of the TOC analyzer, one out of every five samples was spiked with 1 mL of 200 ppm TOC solution created monthly for DOC analysis. Quality control requirements for field data were followed according to the analytical methods listed in the Laboratory Quality Assurance Procedures for the UCF Environmental Systems Engineering Institute (ESEI) housed within the Civil, Environmental, and Construction Engineering (CECE) department (Real-Robert, 2011). Quality control measures for laboratory data collection were performed according to the *Standard Methods for the Examination of Water and Wastewater* (Eaton, Clesceri, Rice, & Greenberg, 2005) and the USEPA’s *Handbook of Analytical Quality Control in Water and Wastewater Laboratories*.

Accuracy

Percent recovery for each spiked sample processed through the TOC analyzer, was calculated using Equation 4-2. The percent recovery of each spike was plotted on an accuracy chart to assess the consistency of the TOC analyzer accuracy.

$$\%\ Recovery = \frac{C_{sample+spike} - C_{sample}}{C_{spike}} \times 100\% \qquad (4\text{-}2)$$

$C_{sample+spike} = the\ concentration\ of\ the\ spiked\ sample\ (mg/L)$

$C_{sample} = the\ concentration\ of\ the\ sample (mg/L)$

$C_{spike} = the\ concentration\ of\ the\ spike\ (mg/L)$

Upper and lower control limits (UCL & LCL) for accuracy charts were defined to be plus or minus three standard deviations from the mean and were calculated using Equation 4-3 (Eaton, Clesceri, Rice, & Greenberg, 2005). Upper and lower warning limits (UWL & LWL) were defined to be plus or minus two standard deviations from the mean and were calculated using Equation 4-4.

$$UCL = \mu + 3s\ and\ LCL = \mu - 3s \qquad (4\text{-}3)$$

$$UWL = \mu + 2s\ and\ LWL = \mu - 2s \qquad (4\text{-}4)$$

$\mu = the\ mean\ of\ the\ percent\ recovery\ values$

$s = the\ standard\ deviation\ of\ the\ percent\ recovery\ values$

The relative percent difference (RPD) was calculated using Equation 4-5. RPD was used in replicate and duplicate analyses and was considered acceptable if the RPD was within the range 90%-110%. Outliers were identified as values falling outside three times the standard deviations from the mean and were reviewed and removed when appropriate.

$$RPD = \frac{S-D}{(S+D)/2} \times 100\% \qquad (4\text{-}5)$$

$S = sample\ result\ (mg/L)$

$D = duplicate\ sample\ result\ (mg/L)$

Precision

The industrial statistic was calculated using Equation 4-6 to create control charts for the precision of turbidity, DOC, and color analyses. Control charts are a statistical, graphical method to monitor process variation due to either assignable causes or random variation (Mendenhall & Sincich, 2007).

$$I = \frac{|\mathrm{S-D}|}{(S+D)} \qquad (4\text{-}6)$$

$S = sample\ result\ (mg/L)$

$D = duplicate\ sample\ result\ (mg/L)$

Upper control limits (UCL) for precision charts were defined to be the average I-value plus three standard deviations and were calculated using Equation 4-7. Upper warning limits (UWL) for precision charts were defined as the average I-value plus two standard deviations of the industrial statistic values and were calculated using Equation 4-8 (Environmental Monitoring and Support Laboratory, U.S. EPA: Office of Research and Devlopment, 1979).

$$UCL = I_{avg} + 3s \tag{4-7}$$

$$UWL = I_{avg} + 2s \tag{4-8}$$

$I_{avg} = the\ average\ of\ the\ industrial\ statistic\ values$

$s = the\ standard\ deviation\ of\ the\ industrial\ statistic\ values$

If a point fell above the UCL or below the LCL the data corresponding to the run of the duplicate sample was considered a control violation. Data measurements violating the LCL or UCL were repeated if possible or the data was removed from the results. If any two points were successively exceeding the warning limits the data was considered to be a control violation. Control violations were checked by analyzing another sample and corrected for bias or disregarded.

5. RESULTS & DISCUSSIONS

The data obtained from over 750 jar tests conducted throughout the study have been provided in Appendix B. The results have been presented in this chapter using graphical representations called isopleths shown in Figure 5-1 through Figure 5-7. The isopleths were used to determine the optimum pH and coagulant concentration ranges required to achieve the maximum DOC percent removal. Settling evaluations were performed for each coagulant using the optimum conditions established from the completed isopleths. Supplemental water quality parameters, including metal and anion analyses, were monitored in this research and have been compared to historical data for quality control and treatability of the Cow Pen Slough water.

Coagulant Performance

Coagulant performance variations were determined graphically using isopleths. These diagrams consist of contour lines of constant percent removal plotted against pH (x-axis) and coagulant concentration (y-axis). Contour lines were developed to depict the percent removals of DOC and color. Turbidity removal was not analyzed graphically but numerically because of the sporadic nature of the test. Additionally, for the purposes of this study, DOC removal was prioritized higher than turbidity removal and thus was the basis for the selection of the optimized coagulant conditions. Due to the variability in raw water quality over time it is necessary to consider the water quality at the particular date of sampling. The sampled raw water contained DOC concentrations ranging from 10 mg/L to 30 mg/L and color units ranging from 28 PCU to 275 PCU. It was observed that iron-based coagulants were less effective for removing turbidity, oftentimes adding to the turbidity of the water, whereas aluminum-based coagulants specifically PACl and ACH proved effective at decreasing settled water turbidity.

Ferric Chloride

The maximum percent DOC removal obtained using ferric chloride was 89%, yielding a treated water DOC concentration of 2.90 mg/L. Consistent DOC removals of 80% were observed in the ferric chloride concentration range of 100 to 240 mg/L. This broad variation in ferric chloride concentration suggests that there is a low correlation between coagulant dose and the removal efficiency in the range of tested doses. Consistent DOC removals of 80% were observed within the pH range of 4.0 to 5.0. This narrow range of pH suggests a higher correlation between pH and DOC removal efficiency. In general, Figure 5-1 shows that removal efficiency decreases as ferric chloride concentration decreases and pH increases. In fact, three distinct zones are apparent in Figure 5-1. At pH values greater than five, the gradient becomes more oriented in the vertical direction, showing more variability between percent removal and ferric chloride dosages. A decreasing trend of percent removal is apparent as the pH increases from 5.0 to 7.0 and also as the ferric chloride concentration decreases from 160 to 80 mg/L. A third region is seen at pH values above six where ferric chloride dosages are over 160 mg/L. DOC removal seems to become less affected by pH and more a function of ferric chloride concentration. Color removal appears correlated to the DOC removals achieving higher removals at lower pH values (Figure 5-2). Final color readings varied between 21 PCU and less than 5 PCU with an average value of 8 PCU achieving the goal listed in Table 3-3.

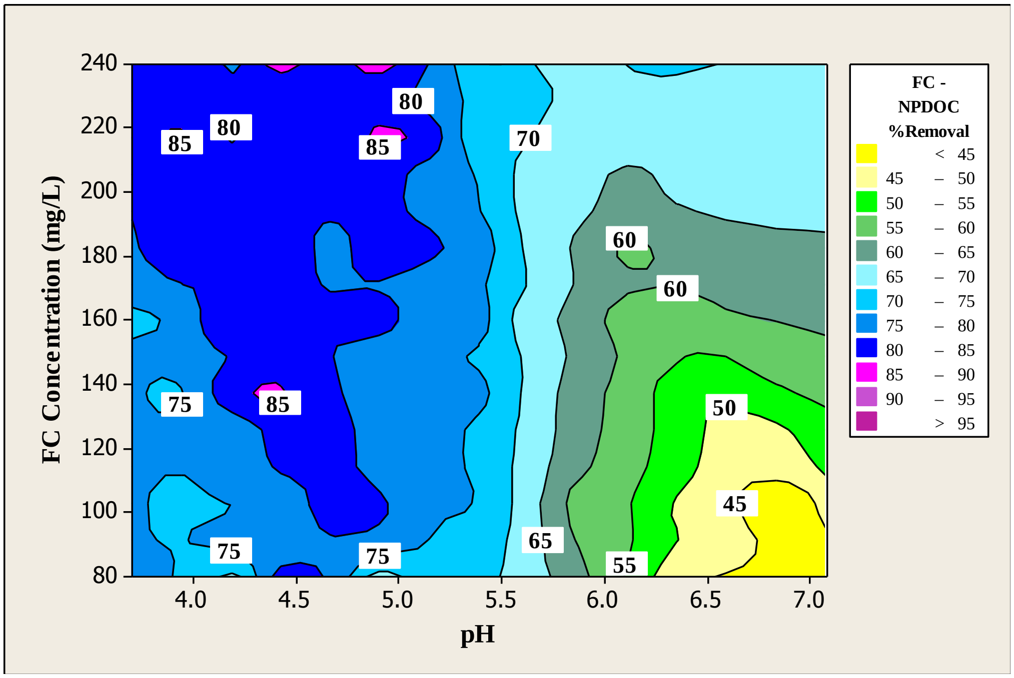


Figure 5-1: Percent DOC Removal Versus Ferric Chloride (FC) Concentration and pH

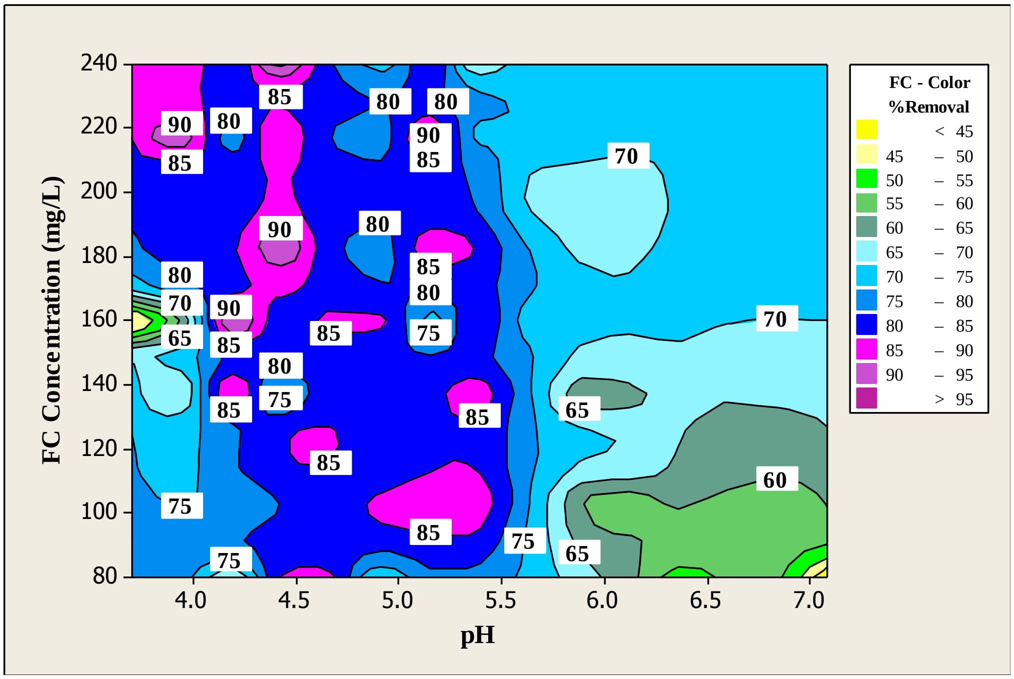


Figure 5-2: Percent Color Removal Versus Ferric Chloride (FC) Concentration and pH

Ferric Sulfate

Figure 5-3 shows little change in DOC removal efficiency between pH values of 3.5 and 5.5. DOC percent removals between 60% and 65% were achieved at concentrations as low as 80 mg/L. Doubling the dosage to 160 mg/L was required to reach the maximum DOC percent removal of 71%. Ferric sulfate does show a similar correlation to that of ferric chloride at pH values above 5.5, in that increasing the pH, caused a decrease in DOC removals. However, unlike ferric chloride, at pH values above 6.5, increasing the ferric sulfate dosages did not produce a significant response in DOC removals. Only a ten percent increase in DOC removal was achieved by raising the pH above 6.5. The maximum DOC removal was 71% and resulted in a final DOC concentration of approximately 3.5 mg/L. The required coagulant concentration of ferric sulfate is 50% higher and removed nearly 15% less DOC than that of ferric chloride. Ferric sulfate was also less effective for color treatment as only 16% of the samples achieved the MCLG of 12 PCU.

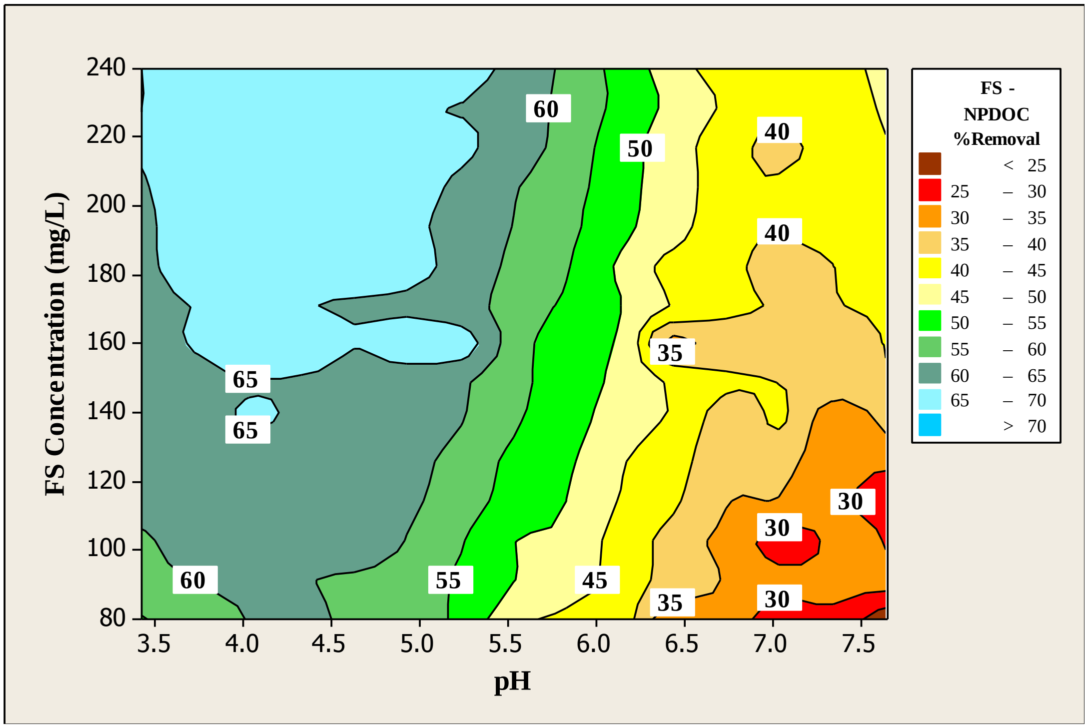


Figure 5-3: Percent DOC Removal Versus Ferric Sulfate (FS) Concentration and pH

Aluminum Sulfate

The isopleth plot for aluminum sulfate shown in Figure 5-4 correlates well with the ferric sulfate results, even though the optimum pH and coagulant ranges are more constrained. Only at a pH range of 4.5 to 5.5 and by dosing alum to a concentration of 180 mg/L was a 55% removal of DOC observed. At 55% removal, final DOC values ranged from 5.5 to 7.5 mg/L. At pH values higher than 6.5, increasing the alum concentration had little effect on DOC percent removals, yielding the lowest DOC removals relative to the other coagulants. However, on average, alum was 82% efficient at removing color yielding 95% of the values below 12 PCU.

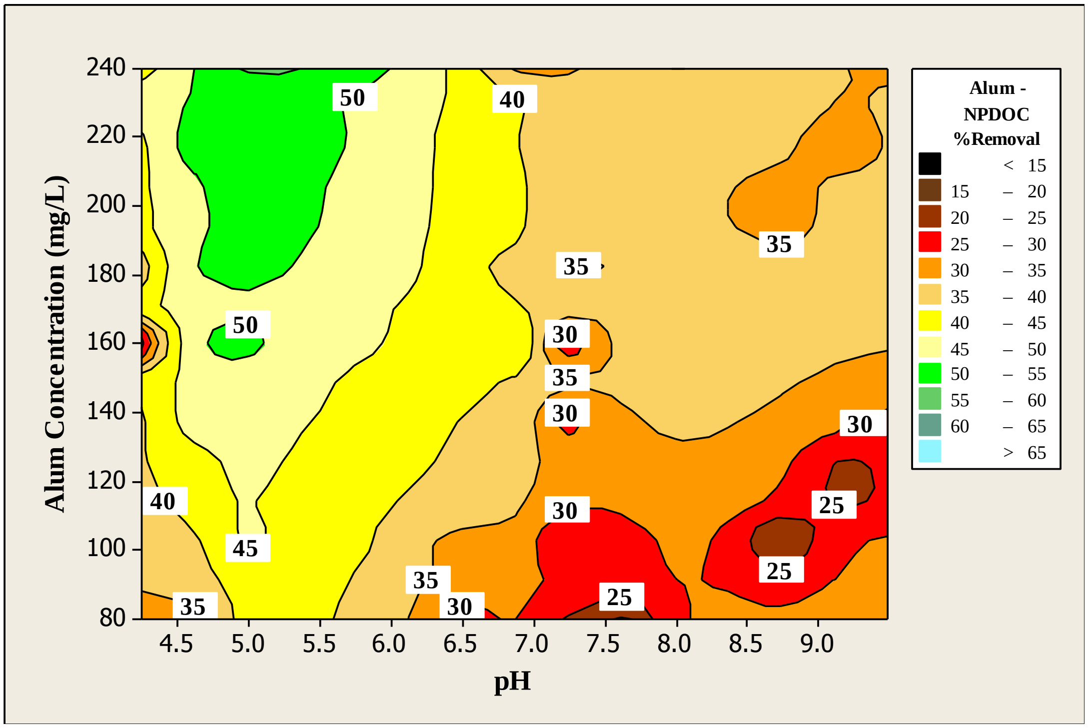


Figure 5-4: Percent DOC Removal Versus Alum Concentration and pH

Polyaluminum Hydroxychloride

Figure 5-5 illustrates the performance of PACl on percent DOC removal versus pH and PACl concentration. PACl achieved similar DOC removals to alum ranging from the lower sixties to the lower twenties but with a less constrained effective pH range of 4.0 to 5.5. Percent DOC removals in the lower fifties were observed at PACl concentrations of 100 mg/L, with a maximum DOC removal of 61% at 240 mg/L. Raw water DOC values were 16 mg/L for the jar tests conducted using PACl. Treated DOC values were observed as low as 5.29 mg/L. Color removal was relatively high as compared to the other coagulants, with an average value of 71%. Turbidity removals ranged from 30% to 60% in the pH range of 4.0 and 5.5.

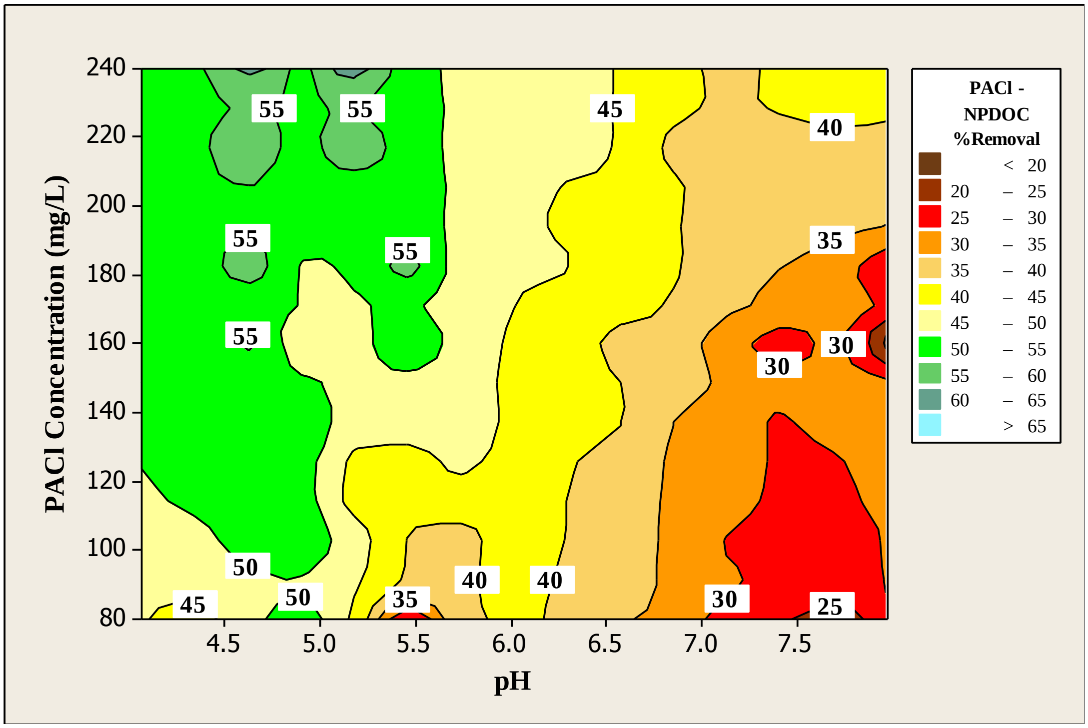


Figure 5-5: Percent DOC Removal Versus PACl Concentration and pH

Aluminum Chlorohydrate

Aluminum chlorohydrate achieved consistent DOC removals in the upper-sixties within a pH range of 6.0 to 7.0. Figure 5-6 suggests a strong correlation between pH and DOC percent removal with ACH concentration having a minimal effect on overall DOC removal. Removals from 60% to 70% were observed at nearly neutral pH and ACH dosages of 80 mg/L. The raw water DOC concentration within these ranges was 30 mg/L. Maximum percent DOC removals were observed in the lower eighties, with treated DOC readings ranging between 5 and 6 mg/L. ACH effectively removed color, with 33% of the samples showing color values under 5 PCU and 80% of the values achieving the MCLG of ≤12 PCU. Figure 5-7 depicts the percent removal for color, showing an 80% color removal for a pH range of 6.0 to 8.0, independent of the ACH concentration range. ACH achieved an average turbidity removal of 46% within this pH range.

Optimum conditions for the highest DOC percent removals illustrated in the isopleths have been listed in Table 5-1. Alkalinity was monitored, at optimum conditions, before and after coagulation to determine the alkalinity consumption of each coagulant. Iron-based coagulants were found to have the highest amount of alkalinity consumption with percent alkalinity reductions greater than 90%. Alum and PACl have substantial effects on alkalinity with percent reductions of 77% and 86%. ACH had a 34% alkalinity reduction at optimum conditions.

Table 5-1: Summary of Observations

Coagulant	Optimum pH Range	Optimum Concentration Range	DOC Percent Removal
Ferric Chloride	4.5 – 5.0	100 – 120 mg/L	80% – 85%
Ferric Sulfate	4.0 – 4.5	160 – 180 mg/L	65% – 70%
Alum	5.0 – 5.5	180 – 200 mg/L	50% – 55%
PACl	4.5 – 5.0	100 – 120 mg/L	50% – 55%
ACH	6.5 – 7.0	80 – 100 mg/L	60% – 70%

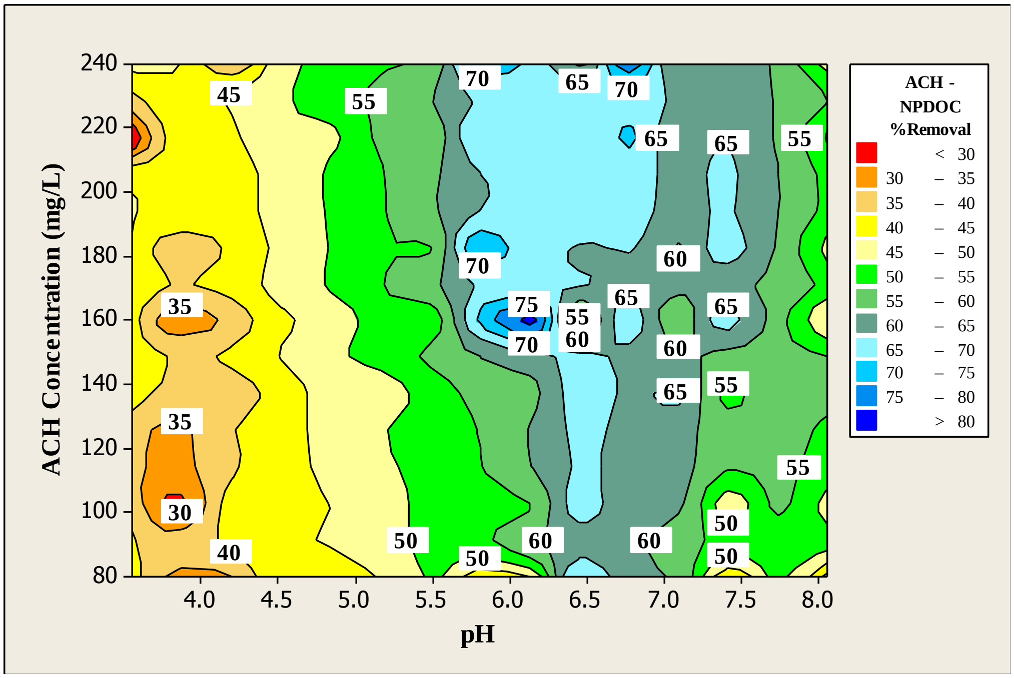


Figure 5-6: Percent DOC Removal Versus ACH Concentration and pH

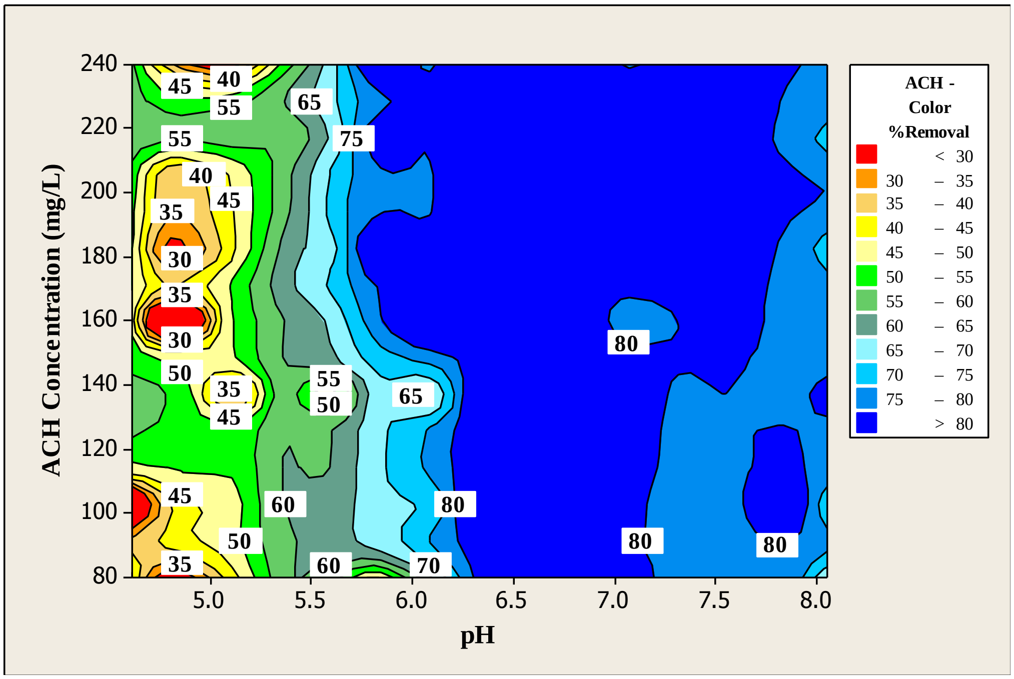


Figure 5-7: Percent Color Removal Versus ACH Concentration and pH

Settling Evaluations

The sludge settling observations of ferric chloride, ACH, and PACl are provided in Figure 5-8. Three types of settling can be observed for each coagulant. Ferric chloride experienced zone settling for the first nine minutes as seen from the linear region of the curve. Ferric chloride also appeared to experience the most rapid settling. Transition settling seemed to occur between the heights of five and ten millimeters for each coagulant. After eighteen minutes each coagulant began to experience compression settling and maintained a height of five millimeters. Distinct interface heights were not apparent for ferric sulfate and alum. The flocs for these coagulants appeared to settle discretely, and a sludge blanket was not observable on water from the CPS.

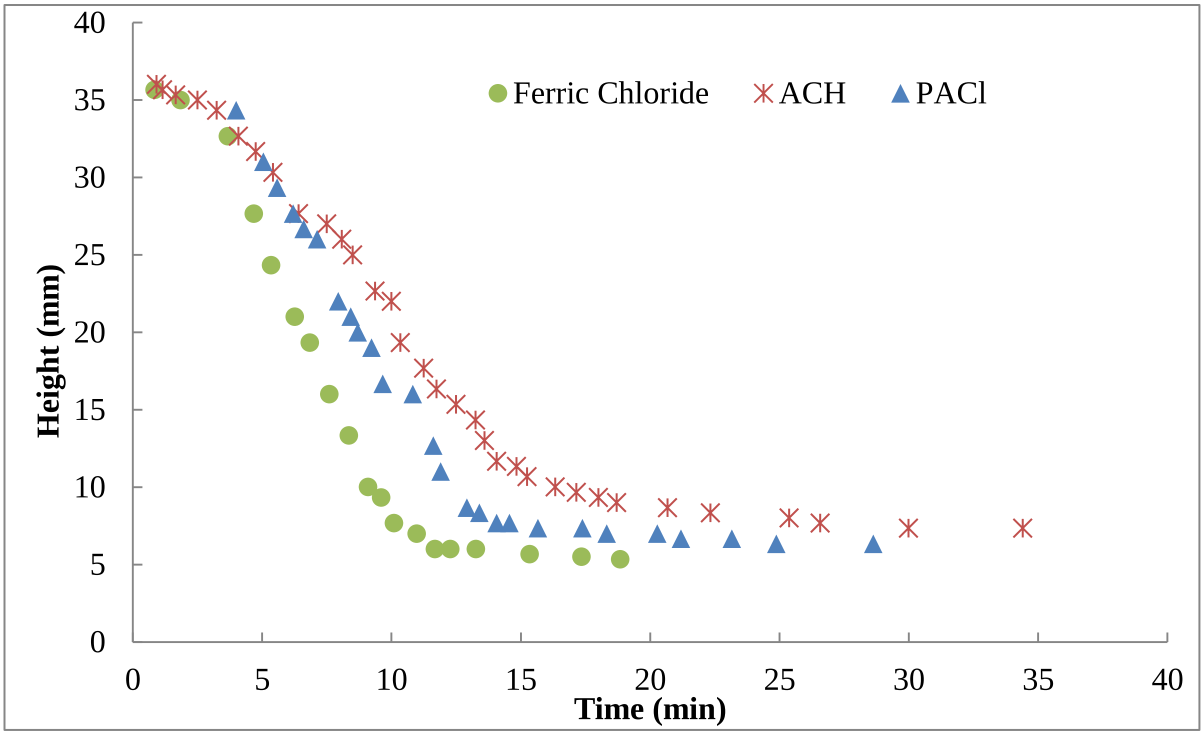


Figure 5-8: Sludge Settling Curves

Table 5-2 presents a qualitative assessment of the amount of sludge (dry basis) produced at the coagulant dose that achieved the highest DOC removal for each coagulant tested. This analysis indicated that there is a penalty on sludge production for more efficient DOC removal. Larger quantities of sludge were generated for the coagulants that achieved more effective DOC removals.

Table 5-2: Dose-Sludge Production Ratios at Optimum DOC Removal

Coagulant	Coagulant Dose (mg/L)	Total Sludge (mg)	DOC Removal (%, typical)	Coagulant-Sludge Ratio (mg coagulant/ mg sludge)	Sludge Settling Velocity (mm/min)
Ferric Chloride	120	489	82	0.49	3.85
Ferric Sulfate	180	456	67	0.79	1.65
Alum	200	441	52	0.91	1.39
PACl	120	452	53	0.53	2.85
ACH	100	454	65	0.44	2.13

Comparison Results

Table 5-3 compares the values from historical data (NOAA, 2012; SWFWMD, 2012; Sarasota County, 2012; USGS, 2012) to the values obtained during the course of this study. Many of the 2012 values fell within the ranges of the historical data taken over the years 1963-2011. More recent data collected in 2012 indicated that DOC, sodium, strontium, TOC, and TSS had increased over time. This was not surprising as there were less than 30 historical samples taken for carbon and metals analyses. The maximum values for TSS corresponded to a eutrophic event shown previously in Figure 3-5 (right featured photograph). Because the historical data makes no mention of eutrophic events that cause increases in algae concentrations, it is possible that in the past samples were not taken for TSS during such occurrences.

Table 5-3: Comparison of Raw Water Quality

Test	Units	Historical Data (1963-2011)*		Yonge (2012)	
		Min	**Max**	**Min**	**Max**
Alkalinity-total	mg/L as $CaCO_3$	10.0	195	167	173
Barium	mg/L	0.013	0.023	0.024	0.026
Calcium	mg/L	7.20	192.0	80.92	89.7
Chloride	mg/L	11.0	75.0	52.0	64.9
Conductivity	µS/cm	100	51700	354	967
Color	PCU	10.0	453	30.0	280
DOC	mg/L	10.4	24.6	11.0	*30.2*
Iron-total	mg/L	0.16	1.66	0.071	0.205
Magnesium	mg/L	6.65	52.5	19.0	30.3
Mn-total	mg/L	0.01	0.04	0.004	0.015
pH	s.u.	5.80	11.5	6.34	7.89
Potassium	mg/L	0.20	8.60	2.52	5.72
Silica-total	mg/L	0.41	11.0	0.24	10.9
Sodium	mg/L	6.10	43.5	36.5	*61.5*
Strontium	mg/L	0.64	1.11	0.92	*1.32*
Sulfate	mg/L	15.0	526	116	154
TDS	mg/L	88.0	1,000	471	525
Temperature	°C	9.00	34.4	18.1	31.2
TOC	mg/L	10.2	26.0	11.3	*30.1*
TSS	mg/L	1.20	19.4	1.50	*27.8*
Turbidity	NTU	0.40	23.0	1.39	11.4

*****Note: Historical data was obtained from NOAA, Sarasota County, SWFMD, and USGS.

Selected raw water quality parameters including alkalinity, TSS, and DOC were monitored throughout this study due to their applicability in coagulation performance. Raw water alkalinity and TOC concentrations were found to increase as high as 170 mg/L as $CaCO_3$ and 30 mg/L, respectively. Based on the requirements of the Stage One DBPR, as highlighted in Table 2-2, treatment is to meet the thirty percent TOC removal criteria. Metals analysis showed iron and manganese concentrations below the treatment goal listed in Table 3-3 suggesting water color is mainly affected by the presence of NOM. Additional metal analysis indicates the water in the Cow Pen Slough is hard, having a total hardness above 150 mg/L as $CaCO_3$.

Total Trihalomethane Formation Potential

Table 5-4 lists the average total THM concentration in the raw and treated water of the CPS; the four species of interest included chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$) dibromochloromethane ($CHBr_2Cl$) and bromoform ($CHBr_3$). Concentrations were determined by comparison to the standards listed in Table 4-2 with coefficients of determination (R^2) greater than 99.8%. Water tested for THMFP treated with ACH was found to have a higher residual post-CFS chlorine demand relative to water treated with ferric chloride. Water treated with ACH had a chlorine demand of ten percent less than the average raw water demand. Chlorine residuals for each sample were within the targeted ranges after the four day incubation period. Note that dilutions of 1:10 were made for raw samples in order to be analyzed within the range of the standard curve. However, the average raw water concentration of dibromochloromethane is reported to have a concentration less than ten because the reading was below the detection limit after being diluted. Bromoform concentrations were not detected in the samples analyzed, and do not appear to contribute significantly to total THMs. Total THMs for samples treated with ferric chloride were significantly less than samples treated with ACH.

Table 5-4: Comparison of THMFP Pre and Post-CFS

Sample	Cl_2 Dose (mg/L)	Cl_2 Residual (mg/L)	Average % Chlorine Demand	$CHCl_3$ (ppb)	$CHBrCl_2$ (ppb)	$CHBr_2Cl$ (ppb)	$CHBr_3$ (ppb)	Total THMs (ppb)
FC	9.50	2.03	79%	98.1	38.9	6.23	<1	143
ACH	20.0	2.78	86%	355	59.1	5.55	<1	419
Raw	90.0	4.00	96%	1980	73.7	<10	<10	>2070

Statistical Analysis

Control charts were constructed by plotting the I-statistic values over time in a sequence plot to determine if variations in the data existed due to identifiable causes or random variation. The control charts for precision and accuracy are provided in Figure 5-9 and Figure 5-10. There was one I-statistic value violating the UCL on the DOC control chart. This value corresponded to a duplicate value with a relative percent difference greater than ten. The value was substantially larger than the expected value based on previous data and did not follow obvious trends displayed by corresponding data. This error was most likely due to human error in labeling or use of contaminated glassware. Therefore, the values obtained from this particular jar test were not used for creating the isopleths. Furthermore, it is unlikely the error was due to the DOC analyzer because values for additional duplicate pairs tested within the DOC sample run did not violate the control limits. This value was also apparent in the control chart for accuracy as seen in Figure 5-10. No other control or warning limit violations were detected in the DOC control charts.

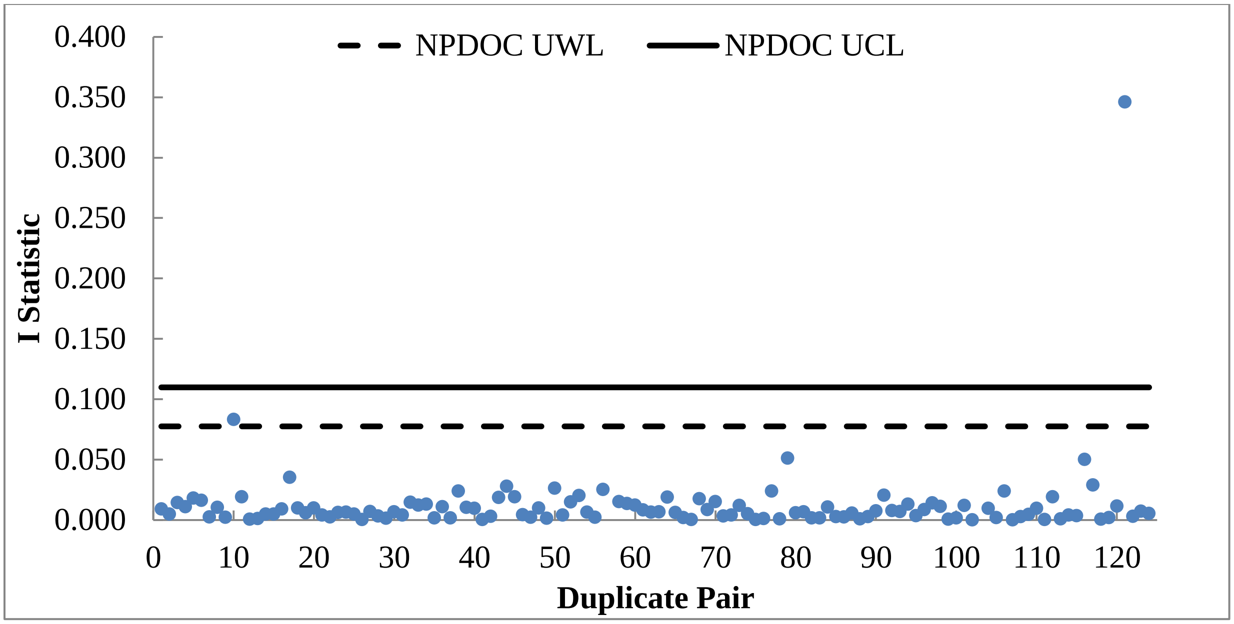


Figure 5-9: Control Chart for DOC Precision

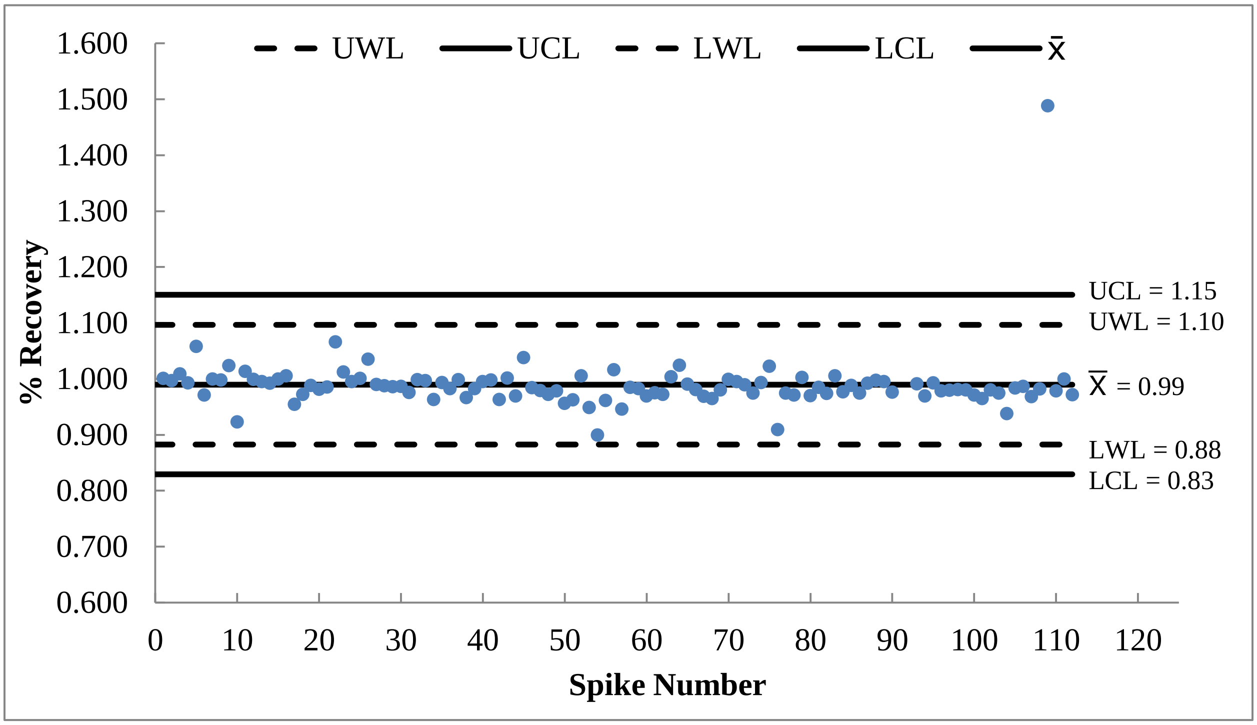


Figure 5-10: Control Chart for DOC Accuracy

The control charts for the precision of color and turbidity are included in Figure 5-11 and Figure 5-12. There are two control violations for color and one control violation for turbidity. Two points violate the upper warning limit for the control chart for color and four points violate the upper warning limit for that of turbidity but none are consecutive and therefore the accuracy of the data was considered to be valid. There was no evidence in the data to suggest a possible reason for the control violations for turbidity and color other than human operation error. The method of analysis calls for the glassware to be wiped before measuring the values for turbidity and absorbance. Error is likely to come from the insufficient preparation of sample prior to measurement. Nonetheless, the data corresponding to the turbidity and color violations were dismissed from isopleth analysis. Less than one percent of the data qualified as outliers and were removed for various reasons, such as broken vials and/or contamination of samples. Control charts for turbidity and color accuracy were not implemented in this study due to the complexity of preparing spike samples for these parameters.

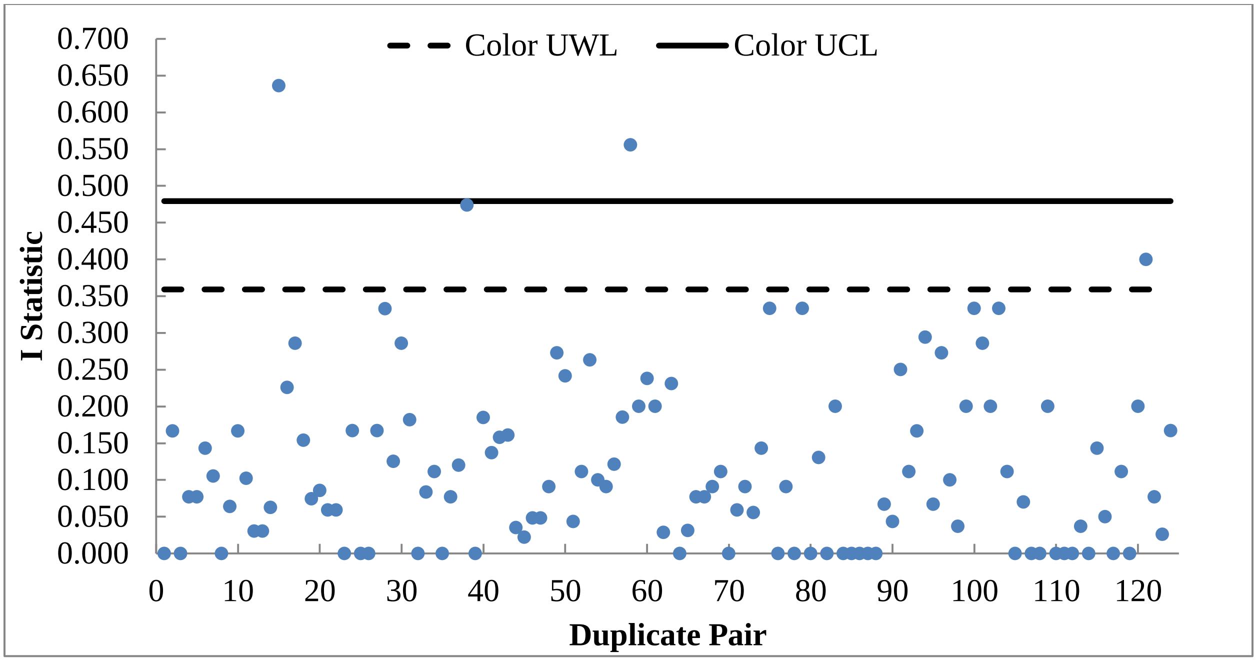


Figure 5-11: Precision Chart for Color

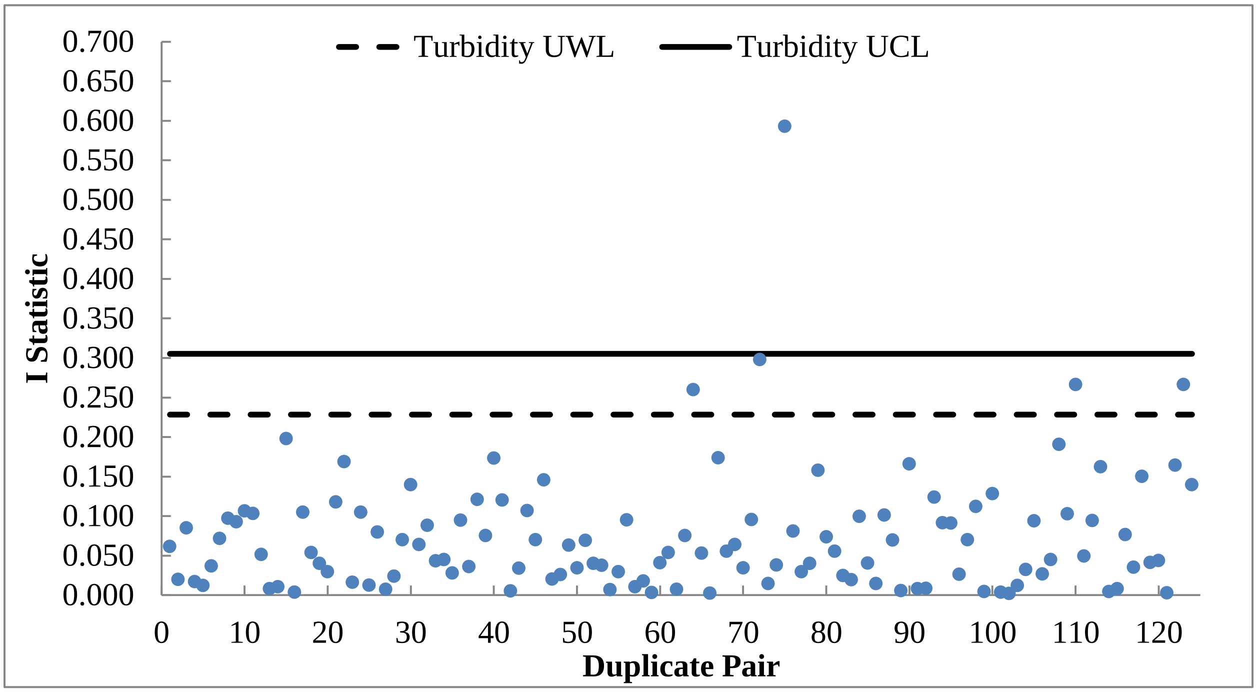


Figure 5-12: Precision Chart for Turbidity

The variability of values that exists in the data set and as portrayed in the precision control charts can be explained by a number of interferences. Human error in conducting the experiment contributed to the variability of the data. The erratic behavior of some of the statistics can also be explained by the variability in the source water. Surface water is highly affected by rain events and data greatly varies between seasons. This study was conducted over a year and therefore limited seasonal patterns were observed despite the collection of historical data.

6. CONCLUSIONS & RECOMMENDATIONS

Raw Water Quality Observations

The water quality data collected during this study indicate that the surface water of the Cow Pen Slough (CPS) would be more difficult to treat than average Florida surface water. Organic content in the Cow Pen Slough was found to be generally high, with DOC values averaging above the typical surface water range of 1 to 20 mg/L. Oftentimes the DOC concentration was fifty percent higher than representative Florida surface water, reaching concentrations over 30 mg/L. Raw turbidity concentrations over 5 NTU were consistently observed with turbidity spikes as high as 23 NTU. Additionally, field observations revealed that the apparent color of the water was dark. True color values in the CPS ranged from 30 to 280 PCU reflecting characteristics of swamp-like waters. At least one instance of an algae bloom was observed.

The poor water quality of the CPS may be attributed to the surrounding land use and variable environmental conditions. The CPS was originally designed as a drainage system for flood protection and consequentially contains high amounts of debris, vegetation, suspended solids, color, and organic content. The CPS catchment mainly consists of land classified as agricultural, urban, and non-forested wetland. The occurrences of algae blooms in the CPS suggest agricultural and urban runoff has significantly impacted the water quality of the slough.

Bench-Scale Jar Testing Evaluation

From the bench-scale jar testing evaluation, treatment with each coagulant studied achieved the USEPA requirement of thirty percent TOC removal. However, the MCLGs and MCLs for turbidity removal were not attainable with the use of the combined processes of coagulation flocculation and sedimentation (CFS). For example the lowest turbidity achieved after the settling period of the jar tests was 0.49 NTU and the MCLG for turbidity was 0.3 NTU. Therefore, traditional filtration techniques or membrane filtration may need to be supplemented to meet EPA regulations. The maximum turbidity removal seemed to be more correlated to the pH ranges for minimum solubility for each coagulant unlike DOC removal which were more efficient at lower pH values. The results of the jar testing evaluation indicated that ferric chloride and ACH were the most effective coagulants at DOC and color removal at the lowest dose concentrations. Ferric sulfate was effective at DOC removal but required a higher concentration of coagulant and was the least effective coagulant at removing color. The traditional iron-based coagulants and alum had low turbidity removals and they were often observed to add turbidity to the water. PACl and ACH had similar percent removals for color and settled water turbidity achieving consistent percent removals of ninety-five percent and forty-five percent, but PACl was less effective than ACH at removing organics. Alum was the least effective at removing organics and was the second least effective coagulant for removing color. Figure 6-1 outlines the relationships between each coagulant and the attainable percent removals of DOC, color, and turbidity determined through the jar testing evaluation.

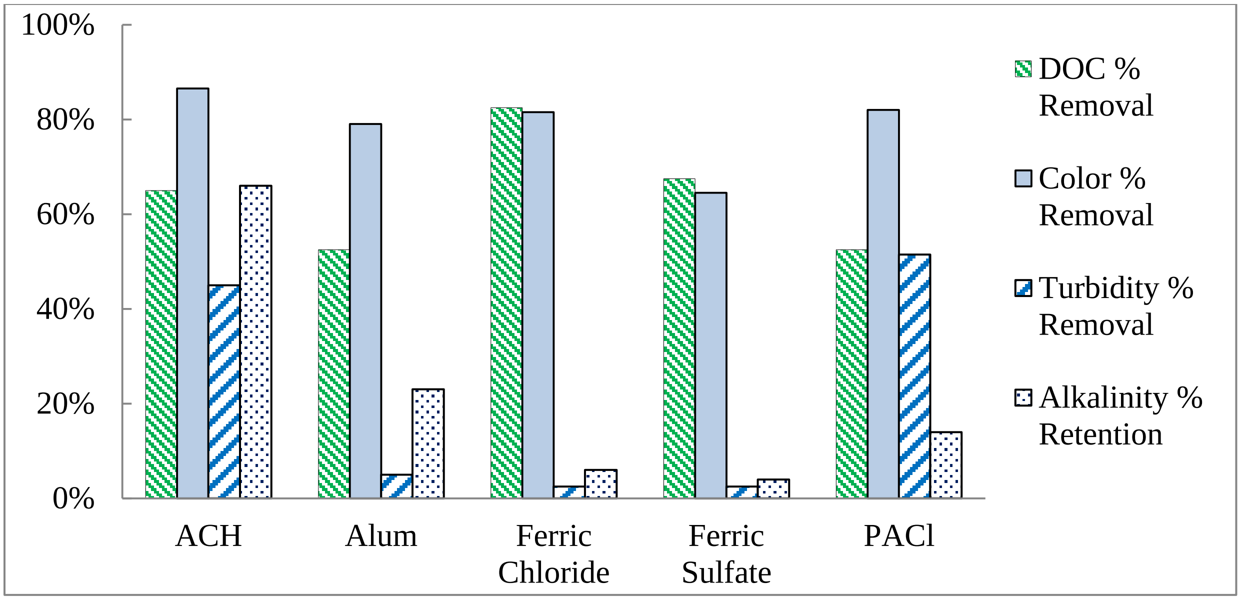


Figure 6-1: Coagulant Comparison Chart

The alkalinity percent retention for each coagulant at optimum conditions is also included in Figure 6-1. This study of nontraditional coagulant performance revealed that ACH was more efficient at removing DOC, color and turbidity under the conditions tested in this evaluation than the other coagulants evaluated for the CPS.

<u>Sludge Settling and Coagulant-Sludge Ratios</u>

Of the coagulants tested, ferric chloride was found to have the most rapid sludge settling. The coagulants with the least effective settling times were alum and ferric sulfate under the conditions tested in this study. However, the more effective coagulants in terms of settling also produced the highest quantities of sludge. This apparent trade-off also was reflected when DOC removal effectiveness was considered. That is, the more effective coagulant for DOC removal produced the greatest amount of settleable sludge.

Total Trihalomethane Formation Potential

Ferric chloride showed, on average, a thirteen percent increase in percent THMFP reduction, relative to ACH, which is likely related to the higher percent DOC removals as seen in Table 6-1. Significant percent reductions of THMFPs were achieved using ferric chloride and ACH resulting in THMFPs of 143 ppb and 419 ppb respectively. However, the THMFP concentrations remained significantly above the USEPA maximum contaminant level of 80 ppb for total trihalomethanes. Additional research is needed to further validate these conclusions regarding the coagulant's effect on disinfectant byproduct formation but this data implies additional treatment methods will need to be implemented to meet USEPA requirements.

Table 6-1: Reductions of Trihalomethanes Formation Potential

Sample	Average % DOC Removal	Average % THMFP Reduction
FC	82%	93%
ACH	65%	80%

Coagulant Cost and Performance

During the evaluation of the coagulants, considerations were made concerning potential ancillary costs and trade-offs associated with each particular coagulant. Figure 6-2 shows the relationships between coagulant costs at varying dosages relative to each other. PACl was shown to have the highest cost relative to the other four coagulants, while ferric sulfate was shown to have the least cost. Note that indirect costs as well as costs for shipping, storage, and freight were not taken into consideration for the development of Figure 6-2.

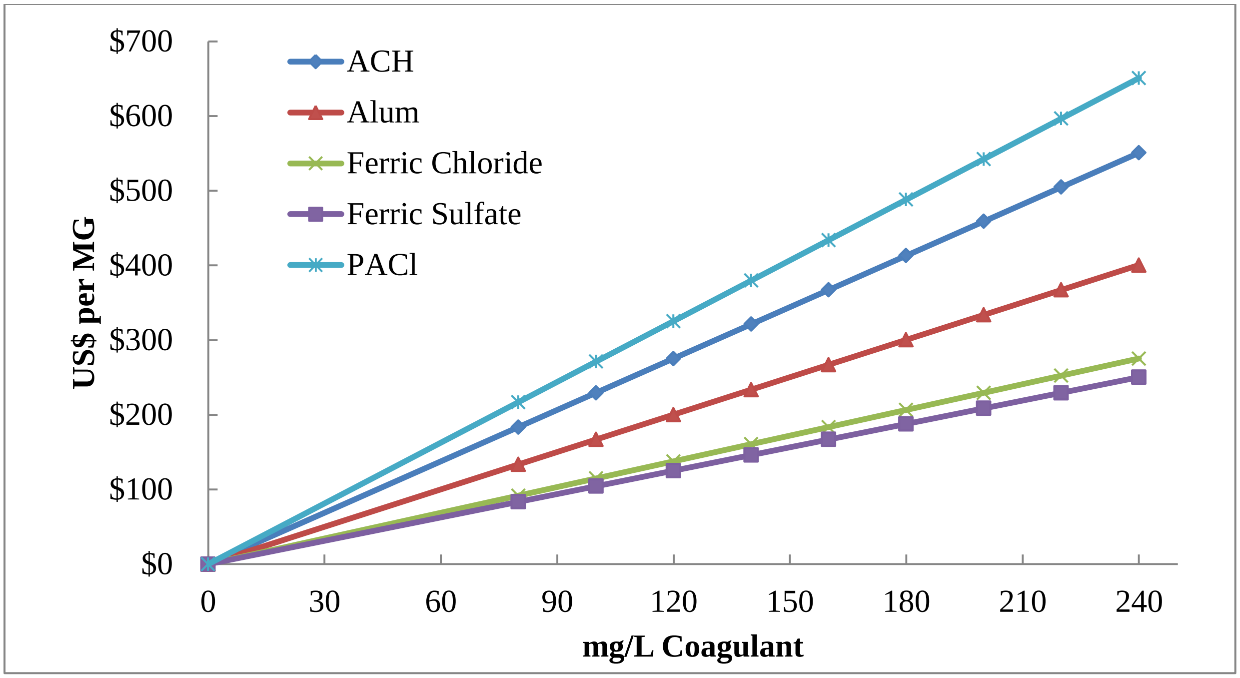


Figure 6-2: Coagulant Cost Estimations

Although ferric chloride achieved the highest DOC removals, it required a pH of approximately 4.75. At this low pH alkalinity recovery would likely be necessary post-CFS adding an additional cost. ACH resulted in greater alkalinity retention than the traditional coagulants and PACl which required low pH values for optimum DOC removals, and resulted in alkalinity reductions greater than seventy-seven percent, and as high as ninety-six percent, for that of iron-based coagulants. The corrosive effects of low pH water on plant infrastructure, upstream of alkalinity recovery should be assessed when considering ferric chloride as a coagulant. Optimum results for coagulation using ACH required an approximately neutral pH which in turn only decreased the alkalinity of the water by thirty-four percent. Furthermore, chemical costs could be reduced since pre-CFS pH adjustment would be minimal. Table 6-2 provides a summary of the advantages and disadvantages associated with each coagulant.

Table 6-2: Summary of Findings

Parameters	ACH	Alum	Ferric Chloride	Ferric Sulfate	PACl
Coagulant Dosage (mg/L)	80 – 100	180 – 200	100 – 120	160 – 180	100 – 120
DOC % Removal (filtered)	60 – 70	50 – 55	80 – 85	65 – 70	50 – 55
Color % Removal (filtered)	76 – 97	75 – 83	65 – 98	48 – 81	68 – 96
Turbidity % Removal (settled water)	40 – 50	< 10	< 5	< 5	40 – 63
Average % Alkalinity Retention	66	23	6	4	14
Sludge Settling Time (min)	≈17	> 27	≈13	>20	≈15
Sludge Settling Velocity (mm/min)	2.13	1.39	3.85	1.65	2.85
Coagulant-Sludge Ratio (mg coagulant/mg sludge)	0.44	0.91	0.49	0.79	0.53
Coagulant Cost ($/dry ton)	500 – 600	300 – 500	250 – 300	200 – 300	600 – 700
Coagulant Cost ($/MG)	184 – 229	300 – 334	115 – 138	167 – 188	271 – 325

Recommendations for Additional Research

This study on nontraditional coagulant performance revealed that ACH was the most efficient at removing DOC, color and turbidity in highly organic Florida surface waters. Extensive cost analysis is recommended to determine which coagulants would be most economical for the treatment of the CPS. This qualitative assessment would suggest that when compared to ferric chloride, ACH, despite its higher chemical cost and slightly lower percent DOC removal levels, could be considered as a viable coagulant for treatment of the CPS. This is due to its overall performance relative to color and turbidity removal and the benefits related to corrosion control. However, conventional treatment with ACH and ferric chloride did not meet EPA MCL levels as regulated for THMs under the Stage One DBPR; therefore membrane filtration may need to be considered. Furthermore, should a membrane filtration process be employed instead of conventional filtration, to meet EPA regulations, iron-based coagulants should be scrutinized prior to selection. Furthermore, pilot testing would be required to determine the necessary measures needed to meet drinking water standards. With these data a detailed economic analysis could be performed to further validate the conclusions of this study.

APPENDIX A: RAW WATER QUALITY

Table A-1: Historical Raw Water Quality (1962-2011)

Parameter	Units	Count	Minimum	Maximum	Average	Stdev.
Alkalinity-total	mg/L	39	10.0	195	106	49.1
Ammonia, as N	mg/L	198	0.00	0.29	0.01	0.03
Arsenic-total	mg/L	12	0.00	1.83	0.21	0.55
Bicarbonate Alk.	mg/L	13	31.5	166	118	41.2
BOD5	mg/L	76	0.00	8.00	2.27	1.69
Bromide	mg/L	9	0.11	0.24	0.14	0.04
Calcium	mg/L	41	7.20	192	81.3	38.1
CarbAlk	mg/L	13	66.0	195	152	32.2
Cd	µg/L	2	0.01	0.03	0.02	0.02
Chla	µg/L	19	5.89	46.2	19.3	10.4
ChlaC	µg/L	24	4.81	58.0	21.5	14.8
Chlb	µg/L	10	0.00	8.09	4.17	2.50
Chlc	µg/L	10	0.00	4.04	1.31	1.38
Chloride	mg/L	53	11.0	75.0	44.4	16.9
Color	PCU	256	10.0	453	115.1	84.9
Color Apparent	PCU	14	20.0	300	84.3	72.4
Conductivity	umhocm	439	100	51,700	1,400	6,020
Cu	µg/L	3	0.00	20.0	6.68	11.5
Depth	ft.	14	1.31	3.28	2.18	0.65
DO	mg/L	313	0.20	18.4	7.22	3.20
DO Percent	%	299	2.38	227.2	84.4	37.8
DOC	mg/L	13	10.4	24.6	15.6	4.50
Ecoccus_100ml	cfu/100mL	1	120	120	120	-
Ecoli_100ml	cfu/100mL	1	230	230	230	-
F	mg/L	14	0.26	0.68	0.51	0.13
Fecal coliform	CFU/100mL	272	0.00	8,000	180	663
FecalStrep_100ml	#/100mL	223	0.00	87,000	1,360	7,530
Geosmin	ng/L	4	4.60	340	91.8	166
Hardness	mg/L CaCO3	54	29.0	986	314	189
HPC	#/mL	12	85.0	50,000	6,080	14,300
Iron-total	mg/L	13	0.16	1.66	0.59	0.51
Magnesium	mg/L	29	6.65	52.50	23.4	9.45
MIB	ng/L	3	26.0	36.00	32.3	5.51
Mn-total	mg/L	13	0.01	0.04	0.02	0.01
Nitrate	mg/L	9	0.01	1.52	0.20	0.50
Nitrite-N	mg/L	3	0.00	0.01	0.00	0.00
NO2	µg/L	89	0.00	38.00	8.98	9.93
NOx	µg/L	103	0.00	2,210	65.5	220
Odor	TON	3	2.00	32.0	12.0	17.3

Parameter	Units	Count	Minimum	Maximum	Average	Stdev.
Orthophosphate	mg/L	145	0.00	25.0	0.87	2.54
Pb	µg/L	2	0.01	0.01	0.01	0.00
pH	s.u.	414	5.80	11.5	7.64	0.66
Pheo	µg/L	24	0.00	8.11	2.48	2.20
Phosphorous-total	µg/L	94	0.00	2,300	249	280
Potassium	mg/L	26	0.20	8.60	3.22	2.67
Salinity	ppt	175	0.00	34.0	0.73	4.21
Secchi	ft.	17	0.98	6.56	2.62	1.60
Silica-total	mg/L	13	0.41	11.0	5.68	3.12
Sodium	mg/L	26	6.10	43.5	27.1	12.1
Sulfate	mg/L	49	15.0	526	135	102
SUVA	L/mg*m	13	2.13	4.21	3.14	0.74
TDS	mg/L	39	88.0	1,000	457	203
Temperature	Celsius	333	9.00	34.4	24.1	4.56
TKN	mg/L	186	0.00	8.40	1.22	0.67
TN	µg/L	102	150	8,400	1,340	827
TOC	mg/L	27	10.2	26.0	16.2	4.14
Total coliform	#/100mL	12	12.0	12,500	1,163	3,570
Total Sulfide	mg/L	2	0.03	0.03	0.03	0.00
TSS	mg/L	26	1.20	19.4	6.06	4.20
Turbidity	NTU	240	0.40	23.0	2.77	2.28
UV-254	1/cm	13	0.26	0.97	0.51	0.25
Zn	µg/L	2	0.01	0.01	0.01	0.00

Table A-2: Raw Water Quality (2012)

Parameter	Units	Count	Minimum	Maximum	Average	Stdev.
Alkalinity-total	mg/L as $CaCO_3$	46	36.4	184	124	56.4
Barium	mg/L	12	0.02	0.03	0.02	0.00
Calcium	mg/L	12	80.9	90.0	85.5	3.10
Chloride	mg/L	10	76.7	94.6	85.1	6.91
Color	PCU	62	25.8	285	69.3	87.6
Conductivity	µS/cm	45	354	967	774	230
DOC	mg/L	62	11.0	30.2	16.8	8.60
Iron-total	mg/L	12	0.02	0.20	0.07	0.07
Magnesium	mg/L	12	19.0	30.3	34.8	4.60
Mn-total	mg/L	12	ND	0.01	0.00	0.01
pH	s.u.	45	6.34	7.89	7.28	0.49
Potassium	mg/L	12	2.52	5.72	4.47	1.16
Silica-total	mg/L	12	0.24	10.9	2.68	3.88
Sodium	mg/L	12	36.5	61.5	52.9	8.20
Strontium	mg/L	12	0.92	1.32	1.15	0.15
Sulfate	mg/L	10	186	205	194	5.79
TDS	mg/L	23	220	525	385	135
Temperature	°C	45	18.1	31.2	24.2	4.94
TOC	mg/L	35	11.3	30.1	15.9	7.15
TSS	mg/L	23	1.50	27.8	12.2	9.51
Turbidity	NTU	45	1.39	23.	4.54	3.28

APPENDIX B: ISOPLETH DATA

Table B-1: Dissolve Organic Carbon (DOC) Isopleth Data

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	Turbidity (NTU)		DOC (mg/L)		DOC % Removal
				I(1)	F(2)	I(3)	F(4)	
ACH	80	4.03	21.9	1.36	5.46	11.0	8.19	25.7%
ACH	80	4.90	21.7	1.47	4.25	12.1	7.41	38.9%
ACH	80	4.99	22.1	1.58	3.73	11.9	7.03	41.0%
ACH	80	5.77	21.9	1.17	3.67	11.3	6.70	40.6%
ACH	80	6.13	19.9	0.87	2.43	12.2	6.72	45.0%
ACH	80	6.46	20.5	0.89	1.56	12.7	6.99	44.9%
ACH	80	6.48	16.9	5.59	3.45	30.0	8.34	72.2%
ACH	80	6.58	19.6	4.52	2.63	28.5	8.89	68.8%
ACH	80	7.04	20.8	4.58	2.01	29.2	8.51	70.9%
ACH	80	7.14	20.9	0.88	1.45	12.4	7.09	42.9%
ACH	80	7.43	20.1	0.96	1.62	12.3	7.40	40.0%
ACH	80	7.70	22.5	4.57	1.74	29.6	14.56	50.9%
ACH	80	8.00	17.9	1.00	1.74	12.1	7.77	35.7%
ACH	100	3.85	22.0	1.36	6.80	11.0	8.17	26.0%
ACH	100	4.61	22.1	1.58	4.20	11.9	7.32	38.6%
ACH	100	4.98	21.7	1.47	4.06	12.1	6.72	44.5%
ACH	100	4.99	21.7	1.47	5.76	12.1	6.85	43.4%
ACH	100	5.70	21.9	1.17	3.03	11.3	6.11	45.8%
ACH	100	6.09	19.9	0.87	2.80	12.2	6.31	48.3%
ACH	100	6.13	19.8	0.87	2.21	12.2	6.36	47.9%
ACH	100	6.41	16.9	5.59	3.17	30.0	6.96	76.8%
ACH	100	6.47	17.1	5.59	2.58	30.0	7.02	76.6%
ACH	100	6.50	20.6	0.89	1.55	12.7	6.59	48.1%
ACH	100	6.51	20.6	0.89	1.60	12.7	6.51	48.7%
ACH	100	6.59	19.6	4.52	2.03	28.5	6.88	75.8%
ACH	100	6.59	19.7	4.52	2.24	28.5	6.89	75.8%
ACH	100	7.03	20.8	0.88	1.41	12.4	6.60	46.9%
ACH	100	7.04	20.9	4.58	2.11	29.2	6.96	76.2%
ACH	100	7.37	20.1	0.96	1.40	12.3	6.88	44.2%
ACH	100	7.39	20.2	0.96	1.38	12.3	6.98	43.4%
ACH	100	7.85	22.5	4.57	1.31	29.6	11.95	59.7%
ACH	100	7.94	22.1	4.57	2.26	29.6	11.78	60.3%
ACH	100	8.03	17.9	1.00	1.95	12.1	7.41	38.7%
ACH	120	3.76	22.0	1.36	4.72	11.0	8.36	24.2%
ACH	120	4.00	22.0	1.36	5.85	11.0	7.90	28.3%
ACH	120	4.44	22.0	1.58	4.73	11.9	7.31	38.6%
ACH	120	4.54	22.1	1.58	4.78	11.9	7.27	39.0%

Coagulant	**Concentration (mg/L)**	**pH**	**Temp. ˚C**	**Turbidity (NTU)**		**DOC (mg/L)**		**DOC % Removal**
				$I^{(1)}$	**$F^{(2)}$**	**$I^{(3)}$**	**$F^{(4)}$**	
ACH	120	5.06	21.7	1.47	3.45	12.1	6.61	45.5%
ACH	120	5.61	22.0	1.17	4.40	11.3	5.97	47.0%
ACH	120	5.63	22.0	1.17	5.90	11.3	5.92	47.5%
ACH	120	6.12	19.8	0.87	2.73	12.2	6.12	50.0%
ACH	120	6.45	17.1	5.59	2.46	30.0	6.41	78.7%
ACH	120	6.47	20.6	0.89	1.44	12.7	6.16	51.5%
ACH	120	6.58	19.7	4.52	1.80	28.5	6.22	78.2%
ACH	120	6.98	20.8	0.88	1.22	12.4	6.38	48.6%
ACH	120	6.99	20.8	0.88	1.19	12.4	6.45	48.1%
ACH	120	7.01	20.8	4.58	1.93	29.2	6.28	78.5%
ACH	120	7.02	20.8	4.58	1.90	29.2	6.32	78.4%
ACH	120	7.32	20.2	0.96	1.10	12.3	6.71	45.5%
ACH	120	7.97	22.6	4.57	1.23	29.6	10.63	64.1%
ACH	120	8.02	17.9	1.00	1.84	12.1	7.07	41.5%
ACH	120	8.02	18.0	1.00	1.60	12.1	7.08	41.4%
ACH	140	4.06	22.0	1.36	4.00	11.0	7.81	29.2%
ACH	140	4.53	22.0	1.58	4.27	11.9	7.13	40.1%
ACH	140	5.12	21.7	1.47	4.49	12.1	6.97	42.4%
ACH	140	5.62	22.0	1.17	3.90	11.3	6.00	46.8%
ACH	140	6.11	19.8	0.87	2.42	12.2	6.06	50.4%
ACH	140	6.26	21.7	5.11	1.73	30.0	5.91	80.3%
ACH	140	6.45	17.0	5.59	2.49	30.0	6.06	79.8%
ACH	140	6.46	20.6	0.89	1.33	12.7	5.92	53.4%
ACH	140	6.58	19.7	4.52	1.74	28.5	5.84	79.5%
ACH	140	6.96	20.8	0.88	0.94	12.4	6.22	49.9%
ACH	140	7.02	20.9	4.58	1.60	29.2	5.90	79.8%
ACH	140	7.32	20.2	0.96	1.05	12.3	6.52	47.1%
ACH	140	8.00	18.0	1.00	1.35	12.1	6.80	43.7%
ACH	140	8.05	22.6	4.57	0.76	29.6	10.04	66.1%
ACH	160	3.97	22.0	1.36	3.85	11.0	8.03	27.2%
ACH	160	4.08	21.9	1.36	4.43	11.0	7.72	30.0%
ACH	160	4.39	21.9	1.58	3.58	11.9	6.92	41.9%
ACH	160	4.51	22.0	1.58	3.83	11.9	6.67	44.0%
ACH	160	4.89	21.9	1.47	3.95	12.1	6.62	45.4%
ACH	160	5.46	22.1	1.17	2.69	11.3	5.45	51.7%
ACH	160	5.50	22.2	1.17	2.80	11.3	5.47	51.5%
ACH	160	5.72	20.9	5.11	2.37	30.0	5.67	81.1%
ACH	160	5.98	20.0	0.87	2.62	12.2	5.93	51.5%
ACH	160	6.13	19.0	5.59	2.24	30.0	5.67	81.1%

Coagulant	**Concentration (mg/L)**	**pH**	**Temp. ˚C**	**Turbidity (NTU)**		**DOC (mg/L)**		**DOC % Removal**
				I(1)	**F(2)**	**I(3)**	**F(4)**	
ACH	160	6.26	21.0	4.58	1.41	29.2	5.94	79.7%
ACH	160	6.45	20.7	0.89	1.18	12.7	5.79	54.4%
ACH	160	6.65	21.1	4.58	1.21	29.2	6.57	77.5%
ACH	160	6.98	20.1	4.52	2.03	28.5	5.69	80.0%
ACH	160	6.99	20.3	0.96	1.30	12.3	6.04	51.0%
ACH	160	7.16	20.9	0.88	1.07	12.4	6.27	49.5%
ACH	160	7.19	20.8	0.88	0.91	12.4	6.28	49.4%
ACH	160	7.46	22.6	4.57	0.86	29.6	8.93	69.9%
ACH	160	8.01	18.4	1.00	1.08	12.1	6.63	45.1%
ACH	160	8.03	18.5	1.00	1.43	12.1	6.71	44.4%
ACH	180	4.02	22.0	1.36	5.34	11.0	8.01	27.4%
ACH	180	4.46	21.9	1.58	5.01	11.9	6.60	44.6%
ACH	180	4.95	21.9	1.47	4.71	12.1	6.35	47.6%
ACH	180	5.48	22.2	1.17	3.13	11.3	5.54	50.9%
ACH	180	5.84	20.9	5.11	2.26	30.0	5.53	81.6%
ACH	180	5.87	20.9	5.11	2.28	30.0	5.57	81.4%
ACH	180	5.99	19.9	0.87	1.97	12.2	5.78	52.7%
ACH	180	6.24	19.0	5.59	2.42	30.0	5.50	81.7%
ACH	180	6.42	21.1	4.58	1.25	29.2	5.75	80.3%
ACH	180	6.44	20.6	0.89	1.53	12.7	5.58	56.1%
ACH	180	6.47	20.7	0.89	1.24	12.7	5.65	55.5%
ACH	180	6.95	20.3	4.52	1.75	28.5	5.50	80.7%
ACH	180	7.01	20.4	0.96	0.99	12.3	5.85	52.5%
ACH	180	7.19	20.9	0.88	0.91	12.4	6.40	48.4%
ACH	180	7.40	22.5	4.57	0.81	29.6	8.07	72.8%
ACH	180	8.02	18.4	1.00	1.55	12.1	6.67	44.8%
ACH	200	4.10	22.0	1.36	3.76	11.0	7.43	32.6%
ACH	200	4.39	22.0	1.58	3.67	11.9	6.84	42.6%
ACH	200	4.86	21.9	1.47	5.22	12.1	6.30	48.0%
ACH	200	4.96	21.8	1.47	4.10	12.1	6.30	48.0%
ACH	200	5.36	22.3	1.17	2.85	11.3	5.26	53.3%
ACH	200	5.91	20.9	5.11	1.53	30.0	5.43	81.9%
ACH	200	5.99	20.0	0.87	2.46	12.2	5.71	53.3%
ACH	200	6.00	20.1	0.87	1.75	12.2	5.74	53.0%
ACH	200	6.26	19.1	5.59	4.14	30.0	5.29	82.4%
ACH	200	6.32	19.1	5.59	2.40	30.0	5.40	82.0%
ACH	200	6.43	20.7	0.89	1.23	12.7	5.59	56.0%
ACH	200	6.48	21.0	4.58	1.15	29.2	6.03	79.3%
ACH	200	6.79	20.3	4.52	1.59	28.5	5.48	80.7%

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	Turbidity (NTU)		DOC (mg/L)		DOC % Removal
				I$^{(1)}$	F$^{(2)}$	I$^{(3)}$	F$^{(4)}$	
ACH	200	6.92	20.2	4.52	1.92	28.5	5.27	81.5%
ACH	200	7.00	20.5	0.96	0.93	12.3	5.70	53.7%
ACH	200	7.02	20.5	0.96	0.89	12.3	5.74	53.4%
ACH	200	7.15	19.4	0.87	0.82	12.2	6.16	49.6%
ACH	200	7.31	22.5	4.57	0.94	29.6	7.58	74.4%
ACH	200	7.33	22.6	4.57	0.71	29.6	7.66	74.2%
ACH	200	8.00	18.4	1.00	0.87	12.1	6.57	45.6%
ACH	220	3.55	22.0	1.36	3.70	11.0	8.55	22.5%
ACH	220	4.24	22.0	1.58	2.75	11.9	6.82	42.8%
ACH	220	4.82	21.8	1.47	6.48	12.1	6.36	47.5%
ACH	220	5.45	22.2	1.17	3.10	11.3	5.18	54.1%
ACH	220	5.88	20.9	5.11	2.59	30.0	5.36	82.1%
ACH	220	5.97	19.9	0.87	2.61	12.2	5.66	53.7%
ACH	220	6.27	19.1	5.59	6.05	30.0	5.20	82.7%
ACH	220	6.38	20.7	0.89	1.03	12.7	5.54	56.3%
ACH	220	6.55	21.1	4.58	1.11	29.2	5.54	81.0%
ACH	220	6.88	20.2	4.52	2.26	28.5	5.17	81.8%
ACH	220	7.01	20.5	0.96	0.85	12.3	5.57	54.8%
ACH	220	7.20	19.3	0.87	0.92	12.2	6.04	50.6%
ACH	220	7.27	22.6	4.57	0.66	29.6	7.27	75.5%
ACH	220	8.00	18.4	1.00	1.14	12.1	6.57	45.6%
ACH	240	4.19	22.0	1.36	3.60	11.0	7.15	35.2%
ACH	240	4.22	22.0	1.58	3.27	11.9	6.89	42.1%
ACH	240	5.00	21.8	1.47	5.00	12.1	6.08	49.8%
ACH	240	5.41	22.1	1.17	3.70	11.3	5.15	54.3%
ACH	240	5.87	20.9	5.11	3.27	30.0	5.24	82.5%
ACH	240	5.96	20.0	0.87	2.42	12.2	5.57	54.4%
ACH	240	6.27	19.1	5.59	3.58	30.0	5.06	83.1%
ACH	240	6.41	20.7	0.89	1.48	12.7	5.46	57.0%
ACH	240	6.60	21.1	4.58	1.35	29.2	5.36	81.7%
ACH	240	6.82	20.2	4.52	3.05	28.5	5.04	82.3%
ACH	240	7.00	20.5	0.96	0.95	12.3	5.53	55.1%
ACH	240	7.19	19.3	0.87	1.09	12.2	5.95	51.3%
ACH	240	7.21	22.5	4.57	0.82	29.6	6.99	76.4%
ACH	240	8.01	18.4	1.00	1.03	12.1	6.41	47.0%
Alum	80	4.38	21.5	1.12	1.55	12.1	9.30	22.8%
Alum	80	4.49	22.0	2.84	2.61	15.8	11.91	24.5%
Alum	80	4.56	22.2	2.99	3.10	15.9	10.90	31.5%
Alum	80	4.70	16.9	1.13	8.10	11.6	7.74	33.4%

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	Turbidity (NTU)		DOC (mg/L)		DOC % Removal
				I(1)	F(2)	I(3)	F(4)	
Alum	80	4.82	16.8	1.20	7.76	11.7	6.74	42.7%
Alum	80	4.86	20.6	2.90	4.15	15.7	9.24	41.3%
Alum	80	4.87	20.6	2.90	4.12	15.7	9.02	42.6%
Alum	80	5.14	15.6	1.35	5.74	11.9	6.63	44.4%
Alum	80	5.66	22.4	4.08	2.04	16.3	9.81	39.7%
Alum	80	6.50	20.1	1.25	3.73	11.8	8.60	27.2%
Alum	80	6.55	19.8	1.02	3.90	12.3	8.80	28.2%
Alum	80	6.60	19.8	1.02	3.29	12.3	9.06	26.1%
Alum	80	6.70	22.0	3.20	1.71	15.9	11.38	28.5%
Alum	80	6.86	21.0	1.11	2.85	11.3	7.94	30.0%
Alum	80	7.40	20.7	1.17	1.61	12.3	10.12	17.5%
Alum	80	7.51	19.9	1.04	1.77	11.7	9.79	16.3%
Alum	100	4.41	21.5	1.12	1.98	12.1	8.75	27.4%
Alum	100	4.42	21.6	1.12	3.37	12.1	8.42	30.1%
Alum	100	4.44	21.9	2.84	4.68	15.8	10.67	32.4%
Alum	100	4.46	22.1	2.84	5.65	15.8	10.62	32.7%
Alum	100	4.53	22.3	2.99	4.89	15.9	9.66	39.3%
Alum	100	4.61	17.4	1.13	7.64	11.6	6.87	40.8%
Alum	100	4.66	17.4	1.13	7.53	11.6	6.79	41.5%
Alum	100	4.79	16.8	1.20	6.62	11.7	6.46	45.0%
Alum	100	4.82	16.8	1.20	6.10	11.7	6.30	46.4%
Alum	100	4.92	20.6	2.90	2.85	15.7	8.34	47.0%
Alum	100	5.05	15.7	1.35	6.10	11.9	6.11	48.7%
Alum	100	5.09	15.7	1.35	5.89	11.9	6.30	47.1%
Alum	100	5.55	22.5	4.08	2.27	16.3	9.33	42.6%
Alum	100	5.63	22.5	4.08	2.25	16.3	9.35	42.5%
Alum	100	6.30	20.1	1.25	4.76	11.8	7.73	34.5%
Alum	100	6.40	20.2	1.25	4.21	11.8	7.88	33.3%
Alum	100	6.45	22.0	3.20	1.53	15.9	10.74	32.6%
Alum	100	6.56	22.0	3.20	2.25	15.9	10.79	32.2%
Alum	100	6.68	21.1	1.11	3.11	11.3	7.35	35.2%
Alum	100	6.75	19.9	1.02	3.25	12.3	8.31	32.2%
Alum	100	7.33	20.6	1.17	1.50	12.3	9.78	20.3%
Alum	100	7.38	20.6	1.17	1.30	12.3	9.73	20.7%
Alum	100	8.68	19.0	1.04	1.58	11.7	9.60	18.0%
Alum	120	4.35	21.6	1.12	3.49	12.1	8.60	28.6%
Alum	120	4.45	22.1	2.84	5.22	15.8	10.01	36.6%
Alum	120	4.56	22.2	2.99	3.40	15.9	9.25	41.9%
Alum	120	4.57	22.3	2.99	3.32	15.9	8.65	45.6%

Coagulant	**Concentration (mg/L)**	**pH**	**Temp. ˚C**	**Turbidity (NTU)**		**DOC (mg/L)**		**DOC % Removal**
				I(1)	**F(2)**	**I(3)**	**F(4)**	
Alum	120	4.65	17.0	1.13	7.80	11.6	6.40	44.9%
Alum	120	4.88	20.8	2.90	2.60	15.7	7.88	49.9%
Alum	120	4.93	16.8	1.20	5.70	11.7	5.87	50.0%
Alum	120	5.11	15.7	1.35	6.10	11.9	6.04	49.4%
Alum	120	5.61	22.5	4.08	1.84	16.3	8.99	44.7%
Alum	120	6.31	20.1	1.25	3.76	11.8	7.20	39.1%
Alum	120	6.35	19.8	1.02	4.33	12.3	6.67	45.6%
Alum	120	6.46	20.8	1.11	3.65	11.3	7.27	35.9%
Alum	120	6.46	22.0	3.20	2.00	15.9	10.00	37.2%
Alum	120	6.57	21.0	1.11	3.74	11.3	7.02	38.2%
Alum	120	7.37	20.6	1.17	1.01	12.3	9.45	23.0%
Alum	120	9.21	19.9	1.04	9.30	11.7	9.18	21.6%
Alum	120	9.23	20.0	1.04	11.2	11.7	9.14	21.9%
Alum	140	4.34	21.6	1.12	4.26	12.1	8.39	30.4%
Alum	140	4.40	22.0	2.84	4.09	15.8	9.08	42.5%
Alum	140	4.63	16.9	1.13	6.85	11.6	6.00	48.3%
Alum	140	4.74	22.2	2.99	2.61	15.9	7.86	50.6%
Alum	140	4.81	20.7	2.90	2.66	15.7	7.66	51.3%
Alum	140	4.83	16.8	1.20	7.00	11.7	5.74	51.1%
Alum	140	5.08	15.8	1.35	7.14	11.9	5.89	50.6%
Alum	140	5.63	22.5	4.08	1.78	16.3	8.91	45.2%
Alum	140	6.25	20.2	1.25	4.23	11.8	6.91	41.5%
Alum	140	6.35	19.8	1.02	3.69	12.3	7.54	38.5%
Alum	140	6.35	22.0	3.20	1.81	15.9	9.40	41.0%
Alum	140	6.48	20.9	1.11	4.23	11.3	6.87	39.4%
Alum	140	7.29	20.7	1.17	1.04	12.3	9.20	25.0%
Alum	140	9.48	19.9	1.04	5.03	11.7	8.35	28.7%
Alum	160	4.24	22.1	2.84	3.55	15.8	12.01	23.9%
Alum	160	4.35	21.6	1.12	4.23	12.1	7.67	36.3%
Alum	160	4.45	22.1	2.99	3.16	15.9	7.61	52.2%
Alum	160	4.53	22.1	2.99	3.37	15.9	7.75	51.3%
Alum	160	4.62	17.4	1.13	7.09	11.6	5.98	48.5%
Alum	160	4.82	17.2	1.20	7.20	11.7	5.59	52.4%
Alum	160	4.85	21.0	2.90	2.43	15.7	7.36	53.2%
Alum	160	5.07	16.2	1.35	6.86	11.9	5.64	52.7%
Alum	160	5.55	22.0	3.20	2.29	15.9	7.92	50.3%
Alum	160	5.97	19.8	1.02	4.21	12.3	6.64	45.9%
Alum	160	6.05	22.2	4.08	1.75	16.3	9.24	43.2%
Alum	160	6.09	19.5	1.25	4.28	11.8	6.86	41.9%

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	Turbidity (NTU)		DOC (mg/L)		DOC % Removal
				$I^{(1)}$	$F^{(2)}$	$I^{(3)}$	$F^{(4)}$	
Alum	160	6.11	20.5	1.11	4.66	11.3	6.33	44.2%
Alum	160	6.39	20.4	1.11	4.33	11.3	6.53	42.4%
Alum	160	6.89	20.0	1.25	2.39	11.8	6.53	44.8%
Alum	160	7.14	20.0	1.25	1.83	11.8	7.70	34.8%
Alum	160	7.28	20.7	1.17	1.44	12.3	9.12	25.7%
Alum	180	4.27	22.0	2.84	4.14	15.8	11.02	30.2%
Alum	180	4.33	21.6	1.12	4.67	12.1	7.83	35.1%
Alum	180	4.56	22.1	2.99	2.93	15.9	7.66	51.9%
Alum	180	4.59	17.2	1.13	6.93	11.6	6.12	47.3%
Alum	180	4.66	21.1	2.90	2.81	15.7	7.21	54.2%
Alum	180	4.81	21.0	2.90	2.80	15.7	7.21	54.2%
Alum	180	4.83	17.1	1.20	8.12	11.7	5.46	53.5%
Alum	180	5.06	16.0	1.35	8.50	11.9	5.44	54.4%
Alum	180	5.48	22.0	3.20	2.47	15.9	7.63	52.1%
Alum	180	6.01	22.2	4.08	2.40	16.3	8.68	46.6%
Alum	180	6.02	19.8	1.02	4.65	12.3	6.47	47.2%
Alum	180	6.04	19.9	1.02	4.81	12.3	6.33	48.4%
Alum	180	6.05	19.8	1.25	4.31	11.8	6.56	44.5%
Alum	180	6.35	20.4	1.11	1.38	11.3	7.30	35.7%
Alum	180	6.91	20.0	1.25	0.96	11.8	7.37	37.6%
Alum	180	7.39	20.7	1.17	1.03	12.3	8.81	28.2%
Alum	200	4.30	21.9	2.84	5.30	15.8	9.90	37.3%
Alum	200	4.31	22.1	2.84	5.59	15.8	9.44	40.2%
Alum	200	4.32	21.6	1.12	5.78	12.1	7.27	39.6%
Alum	200	4.32	21.3	1.12	5.20	12.1	7.36	38.9%
Alum	200	4.54	17.3	1.13	8.00	11.6	5.85	49.6%
Alum	200	4.57	22.1	2.99	2.71	15.9	7.55	52.5%
Alum	200	4.64	17.2	1.13	6.88	11.6	5.97	48.6%
Alum	200	4.82	17.1	1.20	7.84	11.7	5.33	54.6%
Alum	200	4.87	21.2	2.90	2.62	15.7	7.15	54.6%
Alum	200	4.88	16.9	1.20	8.73	11.7	5.42	53.9%
Alum	200	5.02	15.9	1.35	10.1	11.9	5.34	55.2%
Alum	200	5.15	15.9	1.35	10.0	11.9	5.48	54.0%
Alum	200	5.40	22.1	3.20	2.24	15.9	7.39	53.6%
Alum	200	5.43	22.1	3.20	2.45	15.9	7.39	53.6%
Alum	200	5.92	22.2	4.08	2.55	16.3	8.34	48.7%
Alum	200	5.93	22.3	4.08	1.97	16.3	8.37	48.5%
Alum	200	5.96	19.9	1.25	5.03	11.8	6.23	47.3%
Alum	200	5.97	19.8	1.02	4.25	12.3	6.07	50.5%

Coagulant	**Concentration (mg/L)**	**pH**	**Temp. ˚C**	**Turbidity (NTU)**		**DOC (mg/L)**		**DOC % Removal**
				I(1)	**F(2)**	**I(3)**	**F(4)**	
Alum	200	5.98	19.8	1.25	5.23	11.8	6.28	46.8%
Alum	200	6.54	20.4	1.11	1.40	11.3	7.45	34.4%
Alum	200	7.33	20.6	1.17	1.07	12.3	8.65	29.5%
Alum	200	7.33	20.7	1.17	1.30	12.3	8.49	30.7%
Alum	200	8.60	20.0	1.25	1.08	11.8	8.41	28.8%
Alum	220	4.30	21.5	1.12	6.33	12.1	7.20	40.3%
Alum	220	4.30	22.0	2.84	5.26	15.8	9.66	38.8%
Alum	220	4.56	22.1	2.99	2.49	15.9	7.21	54.7%
Alum	220	4.60	17.3	1.13	7.51	11.6	5.76	50.4%
Alum	220	4.82	21.1	2.90	2.40	15.7	7.00	55.5%
Alum	220	4.85	17.1	1.20	8.63	11.7	5.29	55.0%
Alum	220	5.10	15.9	1.35	10.1	11.9	5.35	55.1%
Alum	220	5.36	22.0	3.20	1.88	15.9	7.23	54.6%
Alum	220	5.87	22.2	4.08	2.28	16.3	8.14	49.9%
Alum	220	5.89	19.8	1.25	4.27	11.8	6.15	47.9%
Alum	220	5.90	19.9	1.02	4.65	12.3	5.86	52.2%
Alum	220	6.63	20.5	1.11	0.99	11.3	7.29	35.8%
Alum	220	7.35	20.7	1.17	1.07	12.3	8.42	31.3%
Alum	220	9.10	20.0	1.25	5.44	11.8	8.10	31.4%
Alum	240	4.26	21.6	1.12	7.63	12.1	6.92	42.5%
Alum	240	4.29	21.9	2.84	4.21	15.8	9.10	42.4%
Alum	240	4.57	22.1	2.99	2.93	15.9	7.13	55.2%
Alum	240	4.61	17.3	1.13	8.07	11.6	5.79	50.1%
Alum	240	4.91	17.0	1.20	9.06	11.7	5.18	55.9%
Alum	240	4.93	21.1	2.90	2.53	15.7	6.91	56.1%
Alum	240	5.04	16.0	1.35	9.56	11.9	5.25	56.0%
Alum	240	5.31	22.1	3.20	2.18	15.9	7.06	55.7%
Alum	240	5.76	22.3	4.08	2.18	16.3	7.85	51.7%
Alum	240	5.84	19.9	1.02	5.93	12.3	5.64	54.0%
Alum	240	5.85	19.9	1.25	4.93	11.8	5.95	49.7%
Alum	240	6.78	20.4	1.11	1.12	11.3	7.60	33.1%
Alum	240	7.28	20.7	1.17	0.95	12.3	8.12	33.8%
Alum	240	9.35	19.9	1.25	10.0	11.8	7.88	33.3%
FC	80	4.20	20.3	1.44	6.67	11.6	3.61	69.0%
FC	80	4.50	20.1	1.32	4.90	26.9	3.53	86.9%
FC	80	4.50	21.6	3.81	3.79	29.6	5.34	82.0%
FC	80	4.54	20.3	3.94	3.36	30.2	5.43	82.0%
FC	80	4.92	19.3	1.30	5.80	11.4	3.63	68.3%
FC	80	5.27	20.6	2.85	4.73	30.1	8.37	72.2%

Coagulant	**Concentration (mg/L)**	**pH**	**Temp. ˚C**	**Turbidity (NTU)**		**DOC (mg/L)**		**DOC % Removal**
				I$^{(1)}$	**F**$^{(2)}$	**I**$^{(3)}$	**F**$^{(4)}$	
FC	80	6.34	20.0	0.98	3.15	11.7	6.23	46.6%
FC	80	6.47	19.6	0.86	3.02	12.3	7.65	37.8%
FC	80	6.47	19.7	0.86	2.77	12.3	7.47	39.3%
FC	80	7.07	20.6	0.95	1.94	12.1	8.09	33.3%
FC	80	7.08	20.9	0.68	1.75	11.6	7.94	31.6%
FC	100	4.05	20.4	1.44	6.62	11.6	3.28	71.7%
FC	100	4.16	20.3	1.44	6.65	11.6	3.30	71.6%
FC	100	4.27	20.5	3.94	3.57	30.2	4.76	84.2%
FC	100	4.49	19.4	1.30	6.02	11.4	3.19	72.2%
FC	100	4.53	19.3	1.30	6.34	11.4	3.25	71.6%
FC	100	4.71	21.6	3.81	3.50	29.6	4.98	83.2%
FC	100	4.72	20.2	1.32	5.55	26.9	3.49	87.0%
FC	100	4.73	20.3	1.32	6.20	26.9	3.62	86.6%
FC	100	4.80	21.6	3.81	3.80	29.6	5.00	83.1%
FC	100	5.27	20.7	2.85	3.26	30.1	7.32	75.7%
FC	100	5.28	20.8	2.85	3.04	30.1	6.91	77.1%
FC	100	6.00	20.2	0.98	3.75	11.7	5.37	53.9%
FC	100	6.01	20.1	0.98	3.30	11.7	5.33	54.3%
FC	100	6.47	19.8	0.86	2.00	12.3	7.01	43.0%
FC	100	6.77	20.7	0.95	1.89	12.1	7.34	39.5%
FC	100	6.77	21.0	0.68	2.17	11.6	7.14	38.5%
FC	100	6.80	20.9	0.68	2.02	11.6	7.12	38.7%
FC	120	3.95	20.3	1.30	7.32	11.4	3.08	73.1%
FC	120	4.18	19.3	1.30	7.05	11.4	3.06	73.3%
FC	120	4.36	20.5	3.94	2.73	30.2	4.54	85.0%
FC	120	4.56	20.3	1.32	4.40	26.9	3.32	87.7%
FC	120	4.65	21.6	3.81	2.88	29.6	4.70	84.1%
FC	120	5.29	20.7	2.85	2.60	30.1	6.47	78.5%
FC	120	6.06	20.2	0.98	1.96	11.7	4.98	57.3%
FC	120	6.30	19.8	0.86	2.35	12.3	6.12	50.3%
FC	120	6.60	20.8	0.95	2.22	12.1	6.74	44.4%
FC	120	6.61	21.0	0.68	1.90	11.6	6.57	43.4%
FC	120	6.75	20.7	0.95	2.10	12.1	6.77	44.3%
FC	140	3.96	19.3	1.30	7.57	11.4	3.03	73.5%
FC	140	4.01	20.2	1.30	6.02	11.4	2.92	74.5%
FC	140	4.20	20.5	3.94	2.50	30.2	4.26	85.9%
FC	140	4.43	20.3	1.32	5.14	26.9	3.21	88.1%
FC	140	4.50	21.6	3.81	3.04	29.6	4.21	85.8%
FC	140	5.31	20.8	2.85	2.06	30.1	6.03	80.0%

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	Turbidity (NTU)		DOC (mg/L)		DOC % Removal
				I$^{(1)}$	F$^{(2)}$	I$^{(3)}$	F$^{(4)}$	
FC	140	5.98	20.2	0.98	2.18	11.7	4.67	59.9%
FC	140	6.28	19.8	0.86	2.20	12.3	5.98	51.4%
FC	140	6.47	20.9	0.68	2.15	11.6	6.07	47.7%
FC	140	6.48	20.7	0.95	1.72	12.1	6.19	49.0%
FC	160	3.70	19.6	1.30	7.36	11.4	3.02	73.6%
FC	160	3.87	20.2	1.44	5.00	11.6	2.88	75.2%
FC	160	4.14	21.2	3.94	2.64	30.2	4.27	85.8%
FC	160	4.81	21.6	3.81	2.52	29.6	4.20	85.8%
FC	160	5.10	20.5	1.32	3.49	26.9	3.37	87.5%
FC	160	5.19	20.7	0.95	5.00	12.1	3.37	72.2%
FC	160	5.21	21.9	0.68	4.35	11.6	3.51	69.8%
FC	160	5.25	20.7	0.95	4.30	12.1	3.45	71.6%
FC	160	5.30	21.4	2.85	2.60	30.1	5.08	83.1%
FC	160	5.72	20.3	0.98	2.80	11.7	4.24	63.7%
FC	160	6.03	20.9	0.86	1.65	12.3	5.30	56.9%
FC	160	6.23	20.8	0.95	1.96	12.1	5.82	52.0%
FC	160	6.25	20.8	0.95	2.37	12.1	5.70	53.1%
FC	180	3.92	20.1	1.44	4.96	11.6	2.71	76.7%
FC	180	3.93	20.1	1.44	7.04	11.6	2.71	76.7%
FC	180	3.93	20.5	3.94	2.70	30.2	4.21	86.1%
FC	180	3.96	20.8	3.94	3.76	30.2	4.18	86.1%
FC	180	4.39	21.6	3.81	3.00	29.6	3.90	86.8%
FC	180	4.52	21.6	3.81	2.75	29.6	3.99	86.5%
FC	180	4.72	21.9	0.68	5.15	11.6	3.04	73.8%
FC	180	4.93	20.4	1.32	5.25	26.9	3.06	88.7%
FC	180	4.95	20.4	1.32	4.62	26.9	3.11	88.5%
FC	180	4.96	20.7	0.95	4.50	12.1	3.13	74.2%
FC	180	4.96	19.5	1.30	4.80	11.4	2.79	75.6%
FC	180	4.99	19.5	1.30	4.23	11.4	2.79	75.7%
FC	180	5.22	20.8	2.85	2.07	30.1	4.77	84.2%
FC	180	5.26	21.2	2.85	2.80	30.1	4.77	84.2%
FC	180	5.73	20.3	0.98	2.45	11.7	3.86	66.9%
FC	180	5.98	20.9	0.86	2.46	12.3	4.98	59.5%
FC	180	6.03	20.9	0.86	2.25	12.3	5.12	58.4%
FC	180	6.16	20.8	0.95	1.75	12.1	5.35	56.0%
FC	200	3.94	20.1	1.44	5.30	11.6	2.62	77.5%
FC	200	3.97	20.7	3.94	2.87	30.2	4.03	86.6%
FC	200	4.34	20.1	0.68	5.01	11.6	2.74	76.4%
FC	200	4.54	21.6	3.81	2.43	29.6	3.78	87.2%

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	Turbidity (NTU)		DOC (mg/L)		DOC % Removal
				I(1)	F(2)	I(3)	F(4)	
FC	200	4.73	19.5	1.30	3.94	11.4	2.56	77.6%
FC	200	4.87	20.4	1.32	4.45	26.9	3.04	88.7%
FC	200	5.30	21.0	2.85	2.20	30.1	4.86	83.9%
FC	200	5.57	20.3	0.98	2.48	11.7	3.67	68.5%
FC	200	5.57	20.3	0.98	2.96	11.7	3.78	67.6%
FC	200	5.59	22.1	0.68	2.97	11.6	3.90	66.4%
FC	200	5.70	21.9	0.68	2.33	11.6	4.09	64.8%
FC	200	5.92	21.0	0.86	1.84	12.3	4.50	63.5%
FC	200	6.07	20.8	0.95	1.53	12.1	4.99	58.9%
FC	220	3.58	20.0	0.68	5.73	11.6	2.96	74.5%
FC	220	3.92	20.6	3.94	1.94	30.2	3.93	87.0%
FC	220	4.21	20.1	1.44	4.49	11.6	2.43	79.1%
FC	220	4.49	21.7	3.81	2.72	29.6	3.62	87.8%
FC	220	4.60	19.5	1.30	3.65	11.4	2.57	77.6%
FC	220	4.91	20.4	1.32	3.70	26.9	2.96	89.0%
FC	220	5.12	20.9	2.85	1.95	30.1	4.29	85.8%
FC	220	5.48	20.3	0.98	1.85	11.7	3.58	69.3%
FC	220	5.50	20.8	0.95	2.80	12.1	3.46	71.5%
FC	220	5.54	22.1	0.68	2.80	11.6	3.66	68.5%
FC	220	5.83	21.0	0.86	1.69	12.3	4.14	66.4%
FC	240	3.33	19.9	0.68	8.53	11.6	3.33	71.3%
FC	240	3.84	20.6	3.94	1.82	30.2	3.92	87.0%
FC	240	4.17	20.2	1.44	4.02	11.6	2.40	79.4%
FC	240	4.40	21.7	3.81	2.13	29.6	3.62	87.8%
FC	240	4.51	19.4	1.30	3.39	11.4	2.50	78.2%
FC	240	4.86	20.4	1.32	3.70	26.9	2.90	89.2%
FC	240	5.26	20.9	2.85	1.73	30.1	4.39	85.4%
FC	240	5.35	22.0	0.68	2.25	11.6	3.34	71.3%
FC	240	5.40	20.3	0.98	2.15	11.7	3.42	70.7%
FC	240	5.76	21.0	0.86	2.05	12.3	3.85	68.7%
FC	240	5.80	20.8	0.95	2.00	12.1	4.22	65.3%
FS	80	3.48	20.9	3.33	2.73	16.0	7.39	53.7%
FS	80	3.78	20.0	3.40	3.77	16.0	6.65	58.5%
FS	80	3.92	19.9	1.53	4.37	11.0	4.34	60.7%
FS	80	4.29	19.3	1.45	4.64	11.6	4.30	62.8%
FS	80	4.65	21.9	4.37	4.16	16.2	6.88	57.6%
FS	80	4.92	19.9	1.63	5.45	11.6	4.79	58.8%
FS	80	5.63	21.8	1.01	4.24	12.0	6.60	45.1%
FS	80	5.87	18.9	1.18	4.58	11.6	6.58	43.2%

Coagulant	**Concentration (mg/L)**	**pH**	**Temp. ˚C**	**Turbidity (NTU)**		**DOC (mg/L)**		**DOC % Removal**
				I(1)	**F(2)**	**I(3)**	**F(4)**	
FS	80	6.45	20.8	1.03	3.61	12.5	8.66	30.6%
FS	80	6.45	20.9	3.87	3.35	16.0	10.93	31.7%
FS	80	6.50	20.8	1.03	4.44	12.5	9.00	27.8%
FS	80	6.96	21.1	1.03	3.60	12.0	9.01	24.9%
FS	80	7.18	20.1	1.20	2.98	12.4	9.64	22.3%
FS	80	7.65	22.0	3.54	1.76	12.4	9.87	20.3%
FS	100	3.42	20.9	3.33	7.05	16.0	6.54	59.0%
FS	100	3.84	20.2	3.40	2.90	16.0	5.97	62.7%
FS	100	4.05	19.9	1.53	5.07	11.0	3.95	64.3%
FS	100	4.62	19.3	1.45	4.87	11.6	4.10	64.5%
FS	100	4.72	22.1	4.37	2.77	16.2	6.62	59.2%
FS	100	4.94	20.0	1.63	4.97	11.6	4.60	60.5%
FS	100	5.59	21.8	1.01	4.97	12.0	5.91	50.8%
FS	100	5.62	21.8	1.01	6.13	12.0	6.35	47.2%
FS	100	5.77	19.0	1.18	3.79	11.6	5.92	48.8%
FS	100	6.29	21.0	3.87	3.42	16.0	9.99	37.6%
FS	100	6.55	20.8	1.03	3.42	12.5	8.26	33.8%
FS	100	6.84	19.4	1.03	3.30	12.0	8.60	28.3%
FS	100	7.07	20.1	1.20	4.03	12.4	9.26	25.3%
FS	100	7.11	20.3	1.20	2.70	12.4	9.17	26.1%
FS	100	7.52	22.0	3.54	2.77	12.4	9.36	24.4%
FS	120	3.52	20.9	3.33	4.60	16.0	6.18	61.3%
FS	120	3.53	20.9	3.33	4.00	16.0	6.01	62.4%
FS	120	3.87	20.1	3.40	3.27	16.0	5.63	64.9%
FS	120	3.88	20.2	3.40	2.55	16.0	5.55	65.3%
FS	120	4.27	19.8	1.53	5.15	11.0	3.80	65.6%
FS	120	4.32	19.8	1.53	5.22	11.0	3.75	66.0%
FS	120	4.57	19.5	1.45	5.76	11.6	3.82	66.9%
FS	120	4.72	19.4	1.45	6.24	11.6	3.94	65.9%
FS	120	4.83	22.1	4.37	3.24	16.2	5.98	63.1%
FS	120	4.90	22.1	4.37	3.19	16.2	6.23	61.6%
FS	120	5.02	20.0	1.63	5.38	11.6	4.32	62.9%
FS	120	5.08	20.0	1.63	5.76	11.6	4.55	60.9%
FS	120	5.60	21.8	1.01	4.23	12.0	5.55	53.8%
FS	120	5.63	19.0	1.18	5.87	11.6	5.39	53.5%
FS	120	5.67	19.0	1.18	4.85	11.6	5.67	51.1%
FS	120	6.09	20.9	3.87	2.70	16.0	9.06	43.4%
FS	120	6.19	21.0	3.87	3.24	16.0	9.13	43.0%
FS	120	6.46	20.8	1.03	3.35	12.5	7.54	39.6%

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	Turbidity (NTU)		DOC (mg/L)		DOC % Removal
				$I^{(1)}$	$F^{(2)}$	$I^{(3)}$	$F^{(4)}$	
FS	120	6.70	19.5	1.03	3.12	12.0	8.29	30.9%
FS	120	6.75	19.3	1.03	3.17	12.0	8.32	30.7%
FS	120	7.30	20.1	1.20	2.58	12.4	9.32	24.9%
FS	120	7.57	22.0	3.54	3.27	12.4	9.27	25.2%
FS	120	7.61	22.0	3.54	3.02	12.4	9.16	26.1%
FS	140	3.45	20.9	3.33	4.23	16.0	5.90	63.1%
FS	140	4.15	20.0	1.53	5.54	11.0	3.55	67.9%
FS	140	4.16	20.1	3.40	2.31	16.0	5.21	67.5%
FS	140	4.82	19.4	1.45	4.82	11.6	3.64	68.5%
FS	140	5.00	22.1	4.37	2.01	16.2	6.08	62.5%
FS	140	5.12	20.0	1.63	5.24	11.6	4.21	63.8%
FS	140	5.60	21.7	1.01	5.38	12.0	5.21	56.6%
FS	140	5.65	19.0	1.18	5.03	11.6	5.34	53.9%
FS	140	6.08	21.0	3.87	2.53	16.0	8.52	46.8%
FS	140	6.33	20.9	1.03	2.13	12.5	6.93	44.4%
FS	140	6.76	19.2	1.03	3.40	12.0	8.33	30.6%
FS	140	6.87	20.3	1.20	2.61	12.4	6.39	48.5%
FS	140	7.35	22.0	3.54	3.32	12.4	8.74	29.4%
FS	160	3.63	21.2	3.33	3.03	16.0	5.55	65.2%
FS	160	3.63	21.2	3.33	2.42	16.0	5.43	66.0%
FS	160	3.99	19.5	1.18	6.32	11.6	3.65	68.4%
FS	160	4.27	18.9	1.53	7.01	11.0	3.36	69.5%
FS	160	4.46	19.3	1.53	6.61	11.0	3.38	69.4%
FS	160	4.92	20.4	3.40	2.32	16.0	5.32	66.8%
FS	160	4.96	19.8	1.45	5.29	11.6	3.56	69.2%
FS	160	4.97	19.7	1.45	5.70	11.6	3.71	67.9%
FS	160	5.02	20.2	3.40	2.36	16.0	5.40	66.3%
FS	160	5.18	19.3	1.63	6.03	11.6	3.78	67.6%
FS	160	5.23	19.6	1.63	5.25	11.6	3.81	67.3%
FS	160	5.56	21.6	1.01	5.30	12.0	5.06	57.9%
FS	160	5.75	20.9	3.33	2.81	16.0	7.62	52.3%
FS	160	5.77	21.4	3.87	2.04	16.0	7.61	52.5%
FS	160	5.77	20.8	3.33	2.96	16.0	7.75	51.5%
FS	160	5.83	21.3	3.87	2.45	16.0	7.81	51.2%
FS	160	5.97	21.1	1.03	3.06	12.5	6.19	50.4%
FS	160	6.46	20.1	1.03	2.40	12.0	7.97	33.6%
FS	160	6.64	20.1	1.03	2.35	12.0	7.89	34.2%
FS	160	6.85	20.6	1.20	2.37	12.4	8.34	32.8%
FS	160	7.19	21.7	3.54	2.96	12.4	8.21	33.7%

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	Turbidity (NTU)		DOC (mg/L)		DOC % Removal
				I$^{(1)}$	F$^{(2)}$	I$^{(3)}$	F$^{(4)}$	
FS	160	7.25	21.7	3.54	3.14	12.4	8.37	32.4%
FS	180	3.76	21.0	3.33	1.80	16.0	5.19	67.5%
FS	180	4.04	19.6	1.18	7.85	11.6	3.50	69.8%
FS	180	4.59	18.9	1.53	6.05	11.0	3.33	69.9%
FS	180	4.97	20.0	3.40	2.42	16.0	5.20	67.6%
FS	180	5.04	19.7	1.45	5.95	11.6	3.60	68.9%
FS	180	5.31	19.3	1.63	5.62	11.6	3.91	66.4%
FS	180	5.56	21.6	1.01	4.34	12.0	4.89	59.3%
FS	180	5.65	20.8	3.33	2.77	16.0	6.65	58.4%
FS	180	5.70	21.3	3.87	2.18	16.0	7.03	56.1%
FS	180	6.12	21.0	1.03	3.59	12.5	6.41	48.6%
FS	180	6.14	21.1	1.03	3.24	12.5	6.41	48.6%
FS	180	6.56	20.1	1.03	2.92	12.0	7.92	34.0%
FS	180	6.92	20.6	1.20	2.45	12.4	8.10	34.7%
FS	180	7.18	21.7	3.54	2.29	12.4	8.09	34.7%
FS	200	3.69	21.2	3.33	1.74	16.0	5.14	67.8%
FS	200	4.10	19.6	1.18	6.09	11.6	3.42	70.5%
FS	200	4.63	18.8	1.53	5.63	11.0	3.23	70.8%
FS	200	5.00	20.0	3.40	2.15	16.0	5.06	68.4%
FS	200	5.03	19.6	1.45	6.30	11.6	3.45	70.1%
FS	200	5.29	19.3	1.63	5.73	11.6	3.75	67.8%
FS	200	5.54	21.0	3.33	1.78	16.0	6.05	62.1%
FS	200	5.62	21.3	3.87	2.70	16.0	6.52	59.3%
FS	200	5.80	21.5	1.01	4.76	12.0	5.22	56.6%
FS	200	5.81	21.5	1.01	5.30	12.0	5.32	55.7%
FS	200	6.19	21.0	1.03	2.40	12.5	6.42	48.6%
FS	200	6.62	20.2	1.03	2.32	12.0	7.49	37.6%
FS	200	6.92	20.7	1.20	2.73	12.4	7.79	37.3%
FS	200	6.93	20.7	1.20	2.71	12.4	7.64	38.4%
FS	200	7.12	21.7	3.54	2.34	12.4	7.84	36.7%
FS	220	3.65	21.1	3.33	1.60	16.0	5.06	68.3%
FS	220	4.18	19.6	1.18	7.62	11.6	3.34	71.2%
FS	220	4.65	19.0	1.53	4.78	11.0	3.24	70.6%
FS	220	5.13	19.6	1.45	4.96	11.6	3.47	70.0%
FS	220	5.16	19.9	3.40	2.22	16.0	5.22	67.4%
FS	220	5.34	19.3	1.63	5.44	11.6	3.71	68.1%
FS	220	5.48	20.8	3.33	2.43	16.0	5.86	63.3%
FS	220	5.50	21.3	3.87	1.90	16.0	5.93	62.9%
FS	220	5.70	21.6	1.01	4.66	12.0	4.85	59.6%

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	Turbidity (NTU)		DOC (mg/L)		DOC % Removal
				I(1)	F(2)	I(3)	F(4)	
FS	220	6.14	21.1	1.03	2.35	12.5	6.05	51.5%
FS	220	6.62	20.1	1.03	1.28	12.0	7.43	38.1%
FS	220	6.99	20.6	1.20	2.11	12.4	7.95	35.9%
FS	220	7.15	21.7	3.54	2.08	12.4	7.67	38.0%
FS	240	3.74	21.2	3.33	2.44	16.0	4.88	69.5%
FS	240	4.24	19.5	1.18	6.63	11.6	3.34	71.2%
FS	240	4.79	18.9	1.53	6.44	11.0	3.28	70.3%
FS	240	5.15	19.6	1.45	5.70	11.6	3.42	70.4%
FS	240	5.28	19.3	1.63	6.34	11.6	3.61	69.0%
FS	240	5.33	20.8	3.33	2.41	16.0	5.32	66.7%
FS	240	5.40	21.3	3.87	2.28	16.0	5.59	65.1%
FS	240	5.44	19.9	3.40	1.92	16.0	5.62	64.9%
FS	240	5.59	21.5	1.01	4.55	12.0	4.58	61.9%
FS	240	6.12	21.0	1.03	2.20	12.5	5.84	53.2%
FS	240	6.62	20.1	1.03	2.02	12.0	7.25	39.6%
FS	240	6.88	20.7	1.20	2.64	12.4	7.31	41.1%
FS	240	7.14	21.7	3.54	2.43	12.4	7.65	38.2%
PACl	80	4.42	20.1	2.57	1.12	15.5	9.09	41.3%
PACl	80	4.45	19.7	2.99	1.31	15.8	9.16	42.0%
PACl	80	4.68	22.2	3.36	1.16	15.8	7.86	50.2%
PACl	80	4.95	21.5	1.46	2.19	12.5	5.93	52.5%
PACl	80	5.45	22.9	4.34	1.88	15.8	11.82	25.2%
PACl	80	6.12	18.4	3.15	1.43	16.1	9.56	40.8%
PACl	80	6.78	19.2	4.20	1.55	16.0	10.92	31.6%
PACl	80	6.80	20.5	2.38	1.05	15.6	10.16	34.9%
PACl	80	7.22	20.7	4.01	1.33	15.9	11.87	25.3%
PACl	80	7.51	21.3	1.58	1.10	12.0	9.18	23.4%
PACl	80	7.64	22.2	3.76	1.15	15.7	12.33	21.4%
PACl	100	4.47	20.2	2.57	1.33	15.5	8.05	48.1%
PACl	100	4.51	19.7	2.99	2.55	15.8	7.98	49.5%
PACl	100	4.70	22.3	3.36	1.46	15.8	7.19	54.4%
PACl	100	4.76	22.3	3.36	1.26	15.8	7.11	55.0%
PACl	100	4.96	21.5	1.46	2.25	12.5	5.54	55.6%
PACl	100	4.96	21.4	1.46	4.16	12.5	5.59	55.3%
PACl	100	5.65	22.9	4.34	1.85	15.8	11.97	24.3%
PACl	100	5.83	18.5	3.15	1.18	16.1	8.68	46.2%
PACl	100	5.96	18.5	3.15	1.44	16.1	8.86	45.1%
PACl	100	6.38	20.4	2.38	1.05	15.6	9.35	40.1%
PACl	100	6.45	20.5	2.38	1.02	15.6	9.30	40.4%

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	Turbidity (NTU)		DOC (mg/L)		DOC % Removal
				I(1)	F(2)	I(3)	F(4)	
PACl	100	6.63	19.2	4.20	1.34	16.0	10.13	36.6%
PACl	100	7.04	20.7	4.01	1.08	15.9	11.32	28.7%
PACl	100	7.10	20.7	4.01	1.27	15.9	11.30	28.9%
PACl	100	7.48	21.3	1.58	0.87	12.0	8.96	25.2%
PACl	100	7.59	22.2	3.76	0.96	15.7	12.10	22.8%
PACl	120	4.42	20.2	2.57	1.61	15.5	7.67	50.5%
PACl	120	4.42	20.1	2.57	2.25	15.5	7.55	51.3%
PACl	120	4.54	19.6	2.99	1.77	15.8	7.53	52.3%
PACl	120	4.56	19.6	2.99	1.54	15.8	7.51	52.4%
PACl	120	4.81	22.3	3.36	1.23	15.8	6.77	57.1%
PACl	120	5.03	21.5	1.46	2.33	12.5	5.44	56.4%
PACl	120	5.24	22.9	4.34	1.68	15.8	10.39	34.2%
PACl	120	5.31	22.9	4.34	1.60	15.8	10.36	34.5%
PACl	120	5.83	18.5	3.15	1.24	16.1	8.16	49.5%
PACl	120	6.46	19.4	4.20	1.14	16.0	9.58	40.0%
PACl	120	6.55	19.3	4.20	1.23	16.0	9.67	39.4%
PACl	120	6.91	20.6	2.38	0.89	15.6	10.71	31.3%
PACl	120	7.03	20.7	4.01	0.98	15.9	10.83	31.8%
PACl	120	7.35	21.3	1.58	0.88	12.0	8.63	28.0%
PACl	120	7.36	21.3	1.58	0.82	12.0	8.37	30.2%
PACl	120	7.51	22.2	3.76	0.93	15.7	11.74	25.2%
PACl	120	7.53	22.1	3.76	0.86	15.7	11.71	25.3%
PACl	140	4.45	20.1	2.57	1.65	15.5	7.33	52.7%
PACl	140	4.58	19.7	2.99	1.61	15.8	7.15	54.7%
PACl	140	4.84	22.3	3.36	1.29	15.8	6.59	58.2%
PACl	140	5.07	21.5	1.46	2.50	12.5	5.29	57.6%
PACl	140	5.25	22.9	4.34	1.72	15.8	9.56	39.5%
PACl	140	5.60	18.5	3.15	1.50	16.1	7.21	55.3%
PACl	140	6.46	19.2	4.20	1.04	16.0	9.04	43.4%
PACl	140	6.82	20.5	2.38	0.73	15.6	10.23	34.4%
PACl	140	6.96	20.7	4.01	0.90	15.9	10.45	34.2%
PACl	140	7.33	21.3	1.58	0.71	12.0	8.40	29.9%
PACl	140	7.47	22.1	3.76	0.84	15.7	11.42	27.2%
PACl	160	4.12	22.4	3.36	1.38	15.8	7.68	51.4%
PACl	160	4.30	21.5	1.46	2.65	12.5	5.82	53.3%
PACl	160	4.48	20.0	2.99	1.82	15.8	6.83	56.8%
PACl	160	4.55	19.9	2.99	1.80	15.8	6.79	57.0%
PACl	160	4.98	20.4	3.15	1.60	16.1	8.91	44.8%
PACl	160	5.06	20.1	3.15	1.54	16.1	8.88	45.0%

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	Turbidity (NTU)		DOC (mg/L)		DOC % Removal
				I(1)	F(2)	I(3)	F(4)	
PACl	160	5.51	18.9	3.15	1.25	16.1	7.12	55.9%
PACl	160	6.21	22.4	4.01	0.93	15.9	8.82	44.5%
PACl	160	6.30	20.6	4.20	-	16.0	9.07	43.2%
PACl	160	6.35	20.6	4.20	-	16.0	9.08	43.1%
PACl	160	6.54	19.7	2.38	0.88	15.6	9.68	38.0%
PACl	160	7.16	21.3	1.58	0.60	12.0	8.10	32.4%
PACl	160	7.20	21.3	1.58	0.73	12.0	8.15	32.0%
PACl	180	4.14	22.4	3.36	0.87	15.8	7.96	49.6%
PACl	180	4.33	21.4	1.46	2.30	12.5	5.75	53.9%
PACl	180	4.59	20.0	2.99	1.83	15.8	6.48	58.9%
PACl	180	5.00	20.2	3.15	1.50	16.1	8.49	47.4%
PACl	180	5.41	18.9	3.15	1.74	16.1	6.53	59.5%
PACl	180	6.17	22.5	4.01	0.70	15.9	8.47	46.7%
PACl	180	6.29	20.5	4.20	-	16.0	8.69	45.6%
PACl	180	6.49	19.8	2.38	0.95	15.6	8.84	43.4%
PACl	180	6.54	20.0	2.38	0.78	15.6	8.93	42.7%
PACl	180	7.25	21.3	1.58	0.71	12.0	8.10	32.4%
PACl	200	4.06	22.3	3.36	1.62	15.8	7.61	51.8%
PACl	200	4.13	22.3	3.36	1.81	15.8	7.51	52.4%
PACl	200	4.30	21.4	1.46	2.81	12.5	5.71	54.3%
PACl	200	4.31	21.4	1.46	2.73	12.5	5.57	55.4%
PACl	200	4.55	20.1	2.99	2.06	15.8	6.34	59.8%
PACl	200	4.89	20.2	3.15	1.64	16.1	7.99	50.5%
PACl	200	5.38	18.8	3.15	1.81	16.1	6.51	59.7%
PACl	200	5.38	18.8	3.15	1.67	16.1	6.55	59.4%
PACl	200	6.27	20.5	4.20	-	16.0	8.29	48.1%
PACl	200	6.32	22.5	4.01	0.94	15.9	9.03	43.2%
PACl	200	6.39	22.5	4.01	0.89	15.9	9.47	40.4%
PACl	200	6.43	20.0	2.38	0.61	15.6	8.45	45.8%
PACl	200	7.18	21.4	1.58	0.61	12.0	7.85	34.5%
PACl	220	4.12	22.3	3.36	1.42	15.8	7.39	53.2%
PACl	220	4.26	21.4	1.46	2.31	12.5	5.74	54.0%
PACl	220	4.64	20.1	2.99	2.09	15.8	6.10	61.4%
PACl	220	4.88	20.2	3.15	1.48	16.1	7.70	52.3%
PACl	220	5.23	18.9	3.15	1.49	16.1	6.21	61.5%
PACl	220	6.22	20.5	4.20	-	16.0	7.92	50.4%
PACl	220	6.24	22.5	4.01	0.65	15.9	8.44	46.9%
PACl	220	6.36	19.9	2.38	0.71	15.6	8.16	47.7%
PACl	220	7.12	21.4	1.58	0.54	12.0	7.70	35.8%

Coagulant	**Concentration (mg/L)**	**pH**	**Temp. ˚C**	**Turbidity (NTU)**		**DOC (mg/L)**		**DOC % Removal**
				I[1]	**F[2]**	**I[3]**	**F[4]**	
PACl	240	4.11	22.4	3.36	1.32	15.8	7.38	53.2%
PACl	240	4.25	21.4	1.46	3.61	12.5	5.74	54.0%
PACl	240	4.60	20.0	2.99	2.44	15.8	6.07	61.6%
PACl	240	4.80	20.2	3.15	1.44	16.1	7.60	52.9%
PACl	240	5.15	18.9	3.15	1.71	16.1	6.00	62.8%
PACl	240	6.19	20.6	4.20	-	16.0	7.79	51.2%
PACl	240	6.29	19.9	2.38	0.70	15.6	7.80	50.0%
PACl	240	6.31	22.6	4.01	0.67	15.9	9.14	42.4%
PACl	240	7.04	21.3	1.58	0.49	12.0	7.53	37.1%

Notes: I = initial F = final

1. The settled water turbidity reading of the raw water sample.
2. The turbidity reading of the water sample immediately after the end of the settling period of the jar testing sequence.
3. The DOC concentration of the raw water sample.
4. The DOC concentration of the filtered water sample after the end of the settling period of the jar testing sequence.

Table B-2: Color Isopleth Data

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	True Color (abs)		True Color (PCU)	
				I$^{(1)}$	F$^{(2)}$	I$^{(3)}$	F$^{(4)}$
ACH	80	4.90	21.7	0.023	0.018	34.9	27.6
ACH	80	4.99	22.1	0.021	0.013	32.0	20.3
ACH	80	5.77	21.9	0.023	0.015	34.9	23.3
ACH	80	6.13	19.9	0.026	0.010	31.2	7.86
ACH	80	6.45	21.6	0.201	0.015	284	14.8
ACH	80	6.48	16.9	0.192	0.007	282	12.0
ACH	80	6.58	19.6	0.181	0.011	266	17.9
ACH	80	7.04	20.8	0.195	0.021	275	23.5
ACH	80	7.70	22.5	0.195	0.031	285	46.5
ACH	80	8.00	17.9	0.024	0.009	28.3	6.40
ACH	100	4.61	22.1	0.021	0.019	32.0	29.1
ACH	100	4.98	21.7	0.023	0.016	34.9	24.7
ACH	100	4.99	21.7	0.023	0.011	34.9	17.4
ACH	100	5.70	21.9	0.023	0.010	34.9	16.0
ACH	100	6.09	19.9	0.026	0.009	31.2	6.40
ACH	100	6.24	21.7	0.201	0.014	284	13.4
ACH	100	6.39	21.7	0.201	0.013	284	11.9
ACH	100	6.41	16.9	0.192	0.003	282	6.21
ACH	100	6.59	19.6	0.181	0.005	266	9.12
ACH	100	6.59	19.7	0.181	0.005	266	9.12
ACH	100	7.04	20.9	0.195	0.018	275	19.2
ACH	100	7.85	22.5	0.195	0.020	285	30.5
ACH	100	7.94	22.1	0.195	0.019	285	29.1
ACH	100	8.03	17.9	0.024	0.009	28.3	6.40
ACH	120	5.06	21.7	0.023	0.013	34.9	20.3
ACH	120	5.61	22.0	0.023	0.010	34.9	16.0
ACH	120	5.63	22.0	0.023	0.011	34.9	17.4
ACH	120	6.32	21.7	0.201	0.012	284	10.5
ACH	120	6.58	19.7	0.181	0.003	266	6.21
ACH	120	7.01	20.8	0.195	0.015	275	14.8
ACH	120	7.02	20.8	0.195	0.020	275	22.1
ACH	120	7.97	22.6	0.195	0.013	285	20.3
ACH	120	8.02	18.0	0.024	0.009	28.3	6.40
ACH	140	5.12	21.7	0.023	0.017	34.9	26.2
ACH	140	5.62	22.0	0.023	0.014	34.9	21.8
ACH	140	6.11	19.8	0.026	0.012	31.2	10.8
ACH	140	6.26	21.7	0.201	0.013	284	11.9

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	True Color (abs)		True Color (PCU)	
				I(1)	F(2)	I(3)	F(4)
ACH	140	7.02	20.9	0.195	0.014	275	13.4
ACH	140	8.00	18.0	0.024	0.009	28.3	6.40
ACH	140	8.05	22.6	0.195	0.011	285	17.4
ACH	160	4.89	21.9	0.023	0.021	34.9	32.0
ACH	160	5.46	22.1	0.023	0.010	34.9	16.0
ACH	160	5.50	22.2	0.023	0.011	34.9	17.4
ACH	160	5.72	20.9	0.201	0.011	284	9.03
ACH	160	6.26	21.0	0.195	0.019	275	20.6
ACH	160	6.65	21.1	0.195	0.021	275	23.5
ACH	160	7.46	22.6	0.195	0.009	285	14.5
ACH	160	8.01	18.4	0.024	0.009	28.3	6.40
ACH	180	4.95	21.9	0.023	0.021	34.9	32.0
ACH	180	5.48	22.2	0.023	0.011	34.9	17.4
ACH	180	5.84	20.9	0.201	0.012	284	10.5
ACH	180	5.87	20.9	0.201	0.012	284	10.5
ACH	180	6.42	21.1	0.195	0.020	275	22.1
ACH	180	6.95	20.3	0.181	0.003	266	6.21
ACH	180	7.40	22.5	0.195	0.007	285	11.6
ACH	200	4.96	21.8	0.023	0.022	34.9	33.4
ACH	200	5.36	22.3	0.023	0.012	34.9	18.9
ACH	200	5.91	20.9	0.201	0.012	284	10.5
ACH	200	5.99	20.0	0.026	0.009	31.2	6.40
ACH	200	6.48	21.0	0.195	0.016	275	16.3
ACH	200	7.31	22.5	0.195	0.007	285	11.6
ACH	200	7.33	22.6	0.195	0.005	285	8.71
ACH	220	5.45	22.2	0.023	0.013	34.9	20.3
ACH	220	5.88	20.9	0.201	0.013	284	11.9
ACH	220	6.55	21.1	0.195	0.016	275	16.3
ACH	220	7.27	22.6	0.195	0.006	285	10.2
ACH	240	5.00	21.8	0.023	0.021	34.9	32.0
ACH	240	5.41	22.1	0.023	0.012	34.9	18.9
ACH	240	5.87	20.9	0.201	0.013	284	11.9
ACH	240	5.96	20.0	0.026	0.009	31.2	6.40
ACH	240	6.60	21.1	0.195	0.018	275	19.2
ACH	240	7.21	22.5	0.195	0.005	285	8.71
FC	80	4.20	20.3	0.020	0.007	28.9	9.93
FC	80	4.50	20.1	0.021	0.006	30.4	8.47
FC	80	4.50	21.6	0.186	0.005	272	9.54
FC	80	4.54	20.3	0.189	0.005	277	9.54

Coagulant	**Concentration (mg/L)**	**pH**	**Temp. ˚C**	**True Color (abs)**		**True Color (PCU)**	
				I(1)	**F(2)**	**I(3)**	**F(4)**
FC	80	4.92	19.3	0.020	0.006	25.8	5.38
FC	80	6.34	20.0	0.023	0.011	30.2	12.7
FC	80	6.47	19.6	0.025	0.011	33.1	12.7
FC	80	6.47	19.7	0.025	0.013	33.1	15.6
FC	80	7.07	20.6	0.024	0.011	31.6	12.7
FC	80	7.08	20.9	0.026	0.016	34.6	20.0
FC	100	4.05	20.4	0.020	0.006	28.9	8.47
FC	100	4.16	20.3	0.020	0.007	28.9	9.93
FC	100	4.27	20.5	0.189	0.003	277	6.64
FC	100	4.31	20.5	0.189	0.007	277	12.5
FC	100	4.49	19.4	0.020	0.006	25.8	5.38
FC	100	4.71	21.6	0.186	0.004	272	8.09
FC	100	4.72	20.2	0.021	0.005	30.4	7.01
FC	100	4.73	20.3	0.021	0.006	30.4	8.47
FC	100	4.80	21.6	0.186	0.004	272	8.09
FC	100	5.27	20.7	0.190	0.012	272	18.2
FC	100	5.28	20.8	0.190	0.012	272	18.2
FC	100	6.00	20.2	0.023	0.009	30.2	9.76
FC	100	6.01	20.1	0.023	0.013	30.2	15.6
FC	100	6.47	19.8	0.025	0.011	33.1	12.7
FC	100	6.77	20.7	0.024	0.010	31.6	11.2
FC	100	6.77	21.0	0.026	0.014	34.6	17.1
FC	100	6.80	20.9	0.026	0.011	34.6	12.7
FC	120	3.95	20.3	0.020	0.007	25.8	9.93
FC	120	4.36	20.5	0.189	0.004	277	8.09
FC	120	4.56	20.3	0.021	0.006	30.4	8.47
FC	120	4.65	21.6	0.186	0.003	272	6.64
FC	120	5.29	20.7	0.190	0.010	272	15.4
FC	120	6.06	20.2	0.023	0.006	30.2	5.38
FC	120	6.30	19.8	0.025	0.009	33.1	9.76
FC	120	6.60	20.8	0.024	0.010	31.6	11.2
FC	120	6.61	21.0	0.026	0.009	34.6	9.76
FC	120	6.75	20.7	0.024	0.010	31.6	11.2
FC	140	3.96	19.3	0.020	0.008	25.8	8.30
FC	140	4.01	20.2	0.020	0.006	25.8	8.47
FC	140	4.20	20.5	0.189	0.003	277	6.64
FC	140	4.43	20.3	0.021	0.008	30.4	11.4
FC	140	4.50	21.6	0.186	0.002	272	5.19
FC	140	5.31	20.8	0.190	0.009	272	13.9

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	True Color (abs)		True Color (PCU)	
				I(1)	F(2)	I(3)	F(4)
FC	140	5.98	20.2	0.023	0.012	30.2	14.1
FC	140	6.28	19.8	0.025	0.008	33.1	8.30
FC	140	6.47	20.9	0.026	0.010	34.6	11.2
FC	140	6.48	20.7	0.024	0.008	31.6	8.30
FC	160	3.70	19.6	0.020	0.011	25.8	12.7
FC	160	3.87	20.2	0.020	0.010	28.9	14.3
FC	160	4.14	21.2	0.189	0.006	277	11.0
FC	160	4.81	21.6	0.186	0.003	272	6.64
FC	160	5.10	20.5	0.021	0.009	30.4	12.9
FC	160	5.30	21.4	0.190	0.007	272	11.1
FC	160	5.72	20.3	0.023	0.007	30.2	6.84
FC	160	6.03	20.9	0.025	0.008	33.1	8.30
FC	160	6.23	20.8	0.024	0.006	31.6	5.38
FC	160	6.25	20.8	0.024	0.007	31.6	6.84
FC	180	3.92	20.1	0.020	0.006	28.9	8.47
FC	180	3.93	20.1	0.020	0.007	28.9	9.93
FC	180	3.93	20.5	0.189	0.007	277	12.5
FC	180	3.96	20.8	0.189	0.006	277	11.0
FC	180	4.39	21.6	0.186	0.003	272	6.64
FC	180	4.52	21.6	0.186	0.002	272	5.19
FC	180	4.72	21.9	0.026	0.006	34.6	5.38
FC	180	4.93	20.4	0.021	0.004	30.4	5.55
FC	180	4.95	20.4	0.021	0.005	30.4	7.01
FC	180	4.96	19.5	0.020	0.007	25.8	6.84
FC	180	5.22	20.8	0.190	0.004	272	6.80
FC	180	5.26	21.2	0.190	0.005	272	8.23
FC	180	5.73	20.3	0.023	0.006	30.2	5.38
FC	180	5.98	20.9	0.025	0.010	33.1	11.2
FC	180	6.03	20.9	0.025	0.008	33.1	8.30
FC	180	6.16	20.8	0.024	0.007	31.6	6.84
FC	200	3.94	20.1	0.020	0.006	28.9	8.47
FC	200	3.97	20.7	0.189	0.010	277	16.8
FC	200	4.54	21.6	0.186	0.005	272	9.54
FC	200	4.87	20.4	0.021	0.004	30.4	5.55
FC	200	5.30	21.0	0.190	0.006	272	9.65
FC	200	5.57	20.3	0.023	0.006	30.2	5.38
FC	200	5.57	20.3	0.023	0.006	30.2	5.38
FC	200	5.59	22.1	0.026	0.014	34.6	17.1
FC	200	5.92	21.0	0.025	0.011	33.1	12.7

Coagulant	Concentration (mg/L)	pH	Temp. ˚C	True Color (abs)		True Color (PCU)	
				I(1)	F(2)	I(3)	F(4)
FC	200	6.07	20.8	0.024	0.009	31.6	9.76
FC	220	3.58	20.0	0.026	0.015	34.6	18.5
FC	220	3.92	20.6	0.189	0.009	277	15.4
FC	220	4.21	20.1	0.020	0.005	28.9	7.01
FC	220	4.49	21.7	0.186	0.002	272	5.19
FC	220	4.91	20.4	0.021	0.005	30.4	7.01
FC	220	5.12	20.9	0.190	0.005	272	8.23
FC	220	5.48	20.3	0.023	0.006	30.2	5.38
FC	220	5.50	20.8	0.024	0.009	31.6	9.76
FC	220	5.83	21.0	0.025	0.006	33.1	5.38
FC	240	3.84	20.6	0.189	0.013	277	21.2
FC	240	4.17	20.2	0.020	0.004	28.9	5.55
FC	240	4.40	21.7	0.186	0.004	272	8.09
FC	240	4.86	20.4	0.021	0.006	30.4	8.47
FC	240	5.26	20.9	0.190	0.005	272	8.23
FC	240	5.35	22.0	0.026	0.007	34.6	6.84
FC	240	5.40	20.3	0.023	0.008	30.2	8.30
FC	240	5.76	21.0	0.025	0.008	33.1	8.30
FC	240	5.80	20.8	0.024	0.006	31.6	5.38

Notes: I = initial F = final
1. The color absorbance of the raw water sample.
2. The color absorbance of the filtered water sample after the jar testing sequence.
3. The true color of the raw water sample.
4. The true color of the filtered water sample after the jar testing sequence.

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